UNIVERSITY OF CALIFORNIA
Santa Barbara

**Mitigation of Impaired Stormwater Quality in Los Laureles Canyon,
Tijuana, Mexico**

A Group Project submitted in partial satisfaction of the requirements for the degree of
Master of Environmental Science and Management
for the
Donald Bren School of Environmental Science and Management

by

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March 2008

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We proudly submit this Group Project report for display on the Donald Bren School of Environmental Science and Management web site, such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility in fulfilling the archiving standards set by the Bren School.

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

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ABSTRACT

The Tijuana River Watershed is situated on the border between the United States and Mexico located near San Diego, California and Tijuana, Mexico. During storm events, pollutants originating from both sides of the border are transported through the Tijuana River Estuary and are discharged into the Pacific Ocean, impacting human health and ecosystems in Mexico and the United States. Los Laureles Canyon, located on the outskirts of Tijuana, Mexico, was selected as the focus area for this study as it is representative of twenty-eight transborder canyons facing similar water quality challenges. Using fecal coliform as a proxy for pathogens, a watershed model was employed to quantify pathogen loading and assess the effectiveness of potential sewage management options including the installation of septic systems or sewer lines throughout Los Laureles Canyon. To address stormwater associated pathogen, sediment and refuse issues, a best management practice viability assessment was conducted to identify applicable technologies for mitigation of these constituents. Results from these project analyses suggest that the installation of sewer lines, coupled with stormwater mitigation and control technologies including detention basins, vegetated swales, tire retaining walls, and channel stabilization may effectively reduce the export of pathogens, sediment and refuse from Los Laureles Canyon. Community actions are also important for mitigating pollution originating in Los Laureles Canyon. Governmental and non-governmental stakeholders in the United States and Mexico contributed information and resources vital to the success of this study, and recommendations from this project will be delivered to these stakeholders. Recommendations may be applied to the other twenty-seven canyons in the transborder region, and these recommendations provide a basis for the implementation of a larger watershed-wide mitigation plan.

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EXECUTIVE SUMMARY

The Tijuana River Watershed is a bi-national basin spanning the United States-Mexico border. The main stem of the Tijuana River flows through highly developed landscapes characterized by agriculture, industry, and dense urban centers before entering U.S. territory in southern San Diego County and discharging into the Pacific Ocean. During wet season storms, transborder flows of the Tijuana River are contaminated with sewage, sediment, refuse/debris, nutrients, pesticides, and heavy metals, impacting human and environmental health on both sides of the border. Rapid land use change is further converting remaining undisturbed areas to industrial and urban centers, exacerbating the existing water quality problem. The impaired water quality in the region has raised much public concern, although implementing successful mitigation projects is challenging due to the complex nature of transborder issues.

In southern San Diego County, elevated pathogen concentrations have led to extensive beach advisories and closures each year, with wide-reaching economic implications ranging from suppressed tourism to devalued property and widespread ecological damage. In Mexico, thousands of residents on Tijuana's periphery inhabit unsewered areas where vegetation has been removed to allow for dense development on unstable slopes. Extensive pathogen and sediment loading is believed to be occurring in these unplanned border developments. The San Diego Regional Water Quality Control Board (SDRWQCB) and the project client, the California State Water Resources Control Board (SWRCB) have identified pathogens, sediment, and debris/refuse as the three greatest constituents of concern. California state and U.S. federal funding has been allocated to focus on source identification, control and remediation in U.S. territory, while few quantitative studies have worked to identify priority areas within Mexican territory.

The purpose of this project was to address one aspect of the considerable problem of stormwater contamination within the U.S.-Mexico transborder Tijuana River Watershed. Los Laureles/Goat Canyon (henceforth Los Laureles Canyon) was selected as a case study for our project analysis as it is representative of the twenty-eight transborder canyons along the border and because of its close proximity to the coastal zone. Los Laureles Canyon is densely lined with makeshift dwellings that are largely unsewered and are positioned, often precariously, along the unstable canyon walls. The population in Los Laureles Canyon is above 40,000 residents and continues to grow, exacerbating the pollution problem in the process. The Municipal Planning Institute of Tijuana (IMPlan) developed a Los Laureles Master Plan in 2007 to frame the pollution problems in the canyon and proposes some general recommendations. This project complements the Los Laureles Master Plan as it expands on a possible range of actions that stakeholders may pursue within Los Laureles Canyon.

Through communication with stakeholders three primary constituents of concern were identified; pathogens, sediment and refuse/debris. To address the three contaminants a dual approach was used, separating sewage management and stormwater management.

Sewage management options were evaluated using a watershed model (WARMF) by first identifying the magnitude of pathogen loading in Los Laureles Canyon, and then assessing possible sewage control options. Sewage management options assessed include the installation of

sewer or septic systems throughout Los Laureles Canyon. The model results and analysis suggest that, in order for Los Laureles Canyon to meet the Mexican federal basin water quality objective of fecal coliform concentrations below 1000 MPN/100 mL, Los Laureles Canyon would have to be completely sewered. The economic costs as well as political and social resource requirements of such an endeavor are high, but may be necessary for the long-term control of sewage, especially in the context of a growing population.

Stormwater management options were evaluated through a literature review and survey of stormwater technology users and manufacturers. This analysis led to the selection of structural Best Management Practices (BMPs) that may be most viable for use within Los Laureles Canyon: detention basins, infiltration basins, vegetated swales, terracing, tire-retaining walls, as well as channel and bank stabilization. These technologies can be implemented together as part of 'treatment trains' for effective treatment and control of sediment, pathogens and small debris in a number of locations throughout Los Laureles Canyon.

Sewage and stormwater control requires the efforts and engagement of local communities requiring the expansion of ongoing community actions as well as the development of additional projects. Current projects including the construction of permeable pavement and a small scale sewage treatment system are underway through Engineers without Borders (EWB) and a key project stakeholder, Oscar Romo, with the NOAA Coastal Training Program. Non-structural BMPs, such as native seed planting programs, distribution of an erosion control flyer, refuse collection programs, and the utilization of rainwater collection systems in individual dwellings may provide short term water quality benefits.

Sewage and stormwater management recommendations will be delivered to the project client and U.S. and Mexican stakeholders. Mexican entities receiving these recommendations include the Baja California Watershed Council, the Mexican National Water Commission, the State Public Services of Tijuana, the City of Tijuana, and Mexican local, state and federal environmental protection agencies. U.S. entitties receiving recommendations include the project client, the SWRCB, the U.S. EPA Border Office, the SDRWQCB, and the City of Imperial Beach. Furthermore as part of the International Boundary and Water Commission (IBWC), the information was presented to stakeholders present at the Border 2012 forum in March 2008. Recommendations may be applied to the other twenty-seven canyons in the transborder watershed to mitigate their contribution to this significant transborder pollution problem, and to generate a more effective transborder watershed management approach.

Recommended actions:

Key recommendations to be delivered to stakeholders are summarized below. Some of the actions identified should be implemented immediately, while others are goals for the medium (1-3 years) to long-terms (3-5 years). A detailed description of the recommended plan of action is available in the project report.

Sewage management
1. Collection of additional water quality data
2. Sewering San Bernardo
3. Financial and technical resource identification
4. Canyon-wide sewering
5. Sewage treatment reduction and greywater systems

Stormwater management
1. Installation of a flume to quantify discharge
2. Quantify sediment transport
3. Distribution of residential erosion control flyer
4. Permeable paver project
5. Rainwater collection systems; tire retaining walls and terracing workshops
6. Native seed-start program
7. Community education
8. Pilot stormwater BMP project
9. Implementation and expansion of BMPs
10. Monitoring of BMPs

Watershed management
1. Landuse planning
2. Transborder watershed management

Initiating and implementing the previously mentioned recommendations into a plan of action will require communication and collaboration between governmental and non-governmental agencies, and management of joint resources and projects. This cooperative approach may ensure the most efficient and effective approach is utilized to reduce the transport of pollutants originating in Los Laureles Canyon through the canyon, and will subsequently improve watershed-wide water quality.

EXTERNAL ADVISORS AND PROJECT STAKEHOLDERS

Client
California State Water Resources Control Board (SWRCB)

External Advisors
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Stakeholders
Border Environment Cooperation Commission/Comisión de Cooperación Ecológica Fronteriza
City of Imperial Beach
City of San Diego
City of Tijuana
Comisión Estatal de Servicios Públicos de Tijuana (CESPT)
Comisión Nacional de Agua (CNA)
County of San Diego
El Colegio de la Frontera Norte (COLEF)
Environmental Protection Agency (EPA) Region 9
International Boundary Water Commission (IBWC)
NOAA Coastal Training Program
San Diego Regional Water Quality Control Board (SDRWQCB)
San Diego State University – Department of Geography
Tijuana River National Estuarine Research Reserve (TRNERR)
Wildcoast

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ABBREVIATIONS

BASINS   Better Assessment Science Integrating Point and
        Nonpoint Sources
BMPs   Best Management Practices
CBI   Clean Beaches Initiative Program
CESPT   Comisión Estatal de Servicios Públicos de Tijuana
COLEF   El Colegio de la Frontera Norte
CONAGUA/CNA Comisión Nacional del Agua
CWA   Clean Water Act
DEM   Digital Elevation Model
EPA   Environmental Protection Agency
GIS   Geographic Information System
GPS   Global Positioning System
IBWC   International Boundary Water Commission
IWTP   International Wastewater Treatment Plant
LID   Low-Impact Development
mgd   Million Gallons Per Day
NOAA   National Oceanic Atmospheric Administration
SBOO   South Bay Ocean Outfall
SCERP   Southwest Consortium for Environmental Research & Policy
SDRWQCB   San Diego Regional Water Quality Control Board
SDSU   San Diego State University
SWIA   Southwest Wetlands Interpretive Association
SWRCB   State Water Resources Control Board
TMDL   Total Maximum Daily Load
TRNERR   Tijuana River National Estuarine Research Reserve
WARMF   Watershed Analysis Risk Management Framework
cfs   Cubic Feet per Second
cms   Cubic Meters per Second

1 INTRODUCTION

The Tijuana River Watershed is a bi-national basin spanning the U.S.-Mexico border. The Tijuana River flows through highly developed landscapes characterized by agriculture, industry and dense urbanization on both sides of the border before discharging into the Pacific Ocean. Transborder flows of the Tijuana River are contaminated with sewage, sediment, debris/refuse, nutrients, pesticides and heavy metals particularly during storm events, when there are peak river flows and stormwater runoff. The impaired water quality often impacts human and environmental health on both sides of the border and is the focus of many local, state and federal entities, but mitigation of this water quality is difficult due to the transborder nature of the problem.

The purpose of this Masters Thesis Group Project is to address the problem of stormwater contamination within the Tijuana River Watershed by focusing control and mitigation efforts on a smaller catchment within the larger watershed. The Tijuana River Watershed contains twenty-eight north-draining canyons that contribute contaminated stormwater runoff to mainstem flows of the Tijuana River. Los Laureles/Goat Canyon (henceforth Los Laureles Canyon) within the Tijuana River Watershed was selected for this study because it is representative of the twenty-eight transborder canyons and because of its close proximity to the coastal zone. A Master Plan had already been developed for the canyon in 2007 (Municipal Planning Institute – IMPlan) delineating the extent of current infrastructure and providing insight regarding future plans. A series of small scale projects are currently underway that are managed or supported by community members and NGOs such as Wildcoast, Engineers Without Borders (EWB), and local universities, in concert with NOAA's Coastal Training Program (through Oscar Romo). Focusing on Los Laureles also complements work on the U.S. side of the border by EPA Region 9 which is working to develop a TMDL for the Tijuana River as well as the SWRCB (the project client) that helps local agencies and non-profits in the region develop and implement projects that may protect and restore coastal water quality through the Clean Beaches Initiative (CBI) Program.

The three pollutants of greatest concern in the canyon that were examined for this project were pathogens, sediment, and refuse/debris. In order to address the issue of transborder pollution originating from the canyon, two research questions were developed through consultation with stakeholders:

1. What is the magnitude of the transborder pollution problem in Los Laureles Canyon?

2. How can stakeholders reduce the transport of pathogens, sediments, and refuse through the canyon?

Traditionally, pathogens are controlled and mitigated through sewage management. Therefore the project assessed how different sewage management options would control pathogen transport into and through the canyon. These sewage management options were assessed using fecal coliform as a proxy for pathogens, and a watershed model was then employed to understand the effects of installing different treatment options, such as sewering and septic systems in the canyon, on fecal coliform loading into the waters of Los Laureles Canyon. However, addressing

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pathogen loading through sewage management would not address issues associated with the loading of sediment or refuse/debris. Additionally, sediment can act as a transport mechanism for pathogens that sorb to sediment particles and become mobilized. Therefore it was also necessary to conduct an assessment to determine which stormwater control technologies may be viably implemented within the canyon. By conducting an internet survey of stormwater technology users and manufactures in addition to carrying out a comprehensive literature, we identified Best Management Practices (BMPs) that would be most viable and effective within Los Laureles Canyon. These BMPs included both structural stormwater control technologies as well as community-based actions. These two streams of analysis focusing on sewage and stormwater management guided the formulation of recommendations. These recommendations may be implemented within Los Laureles Canyon and may be applied to other canyons across the watershed experiencing similar stormwater associated pollutant issues to mitigate the overall contribution of each sub-basin to the larger transborder pollution problem.

Working in a bi-national context to conduct analyses and formulate recommendation presented several challenges. First and foremost we encountered a paucity of Mexican data for the canyon limiting the descriptive power of our analyses. Existing data were unpublished and difficult to acquire to the absence of a central location for such data. Additionally, much of the documentation provided for the canyon, such as the Los Laureles Canyon Master Plan, was only available in Spanish and therefore the need for translation of these documents slowed progress. Project milestones were also delayed due to Mexican elections in 2007 forcing us to re-establish and create new relationships with stakeholders at various levels of government. Safety issues involved with visiting the canyon during storm events also made it difficult to collect data or observe stormwater discharge in the canyon.

This report is structured in eight sections: background, methods, Tijuana River Watershed, Los Laureles Canyon, watershed modeling, best management practices, key recommendations, and conclusions.

The background section of this report frames the environmental problem that was identified as the focus of this project. The problem statement describes and summarizes the causes of extensive stormwater pollutant loading as a result of urban development and lack of capacity for treatment of Tijuana River Watershed stormwater. Previous investigations are then highlighted by examining former studies and literature which have focused on watershed contaminants in order to provide a greater breadth of understanding of the environmental problem of pollution in the watershed. The project significance subsequently emphasizes the importance of this project in filling a research need to determine the magnitude of pollutant loading within Los Laureles Canyon, as well as possible control and mitigation options. Finally, the project objectives are described to define the scope of this group project.

The methods section relays the general social and scientific research methodology as well as data sources and collection. The next section then describes the Tijuana River Watershed in terms of its environmental elements and the surrounding landscape and land use. Following this is a summary of Los Laureles Canyon and the pollution problem. A discussion of contaminants, including the transport and fate of pathogens, sediment and refuse is then provided, followed by more detailed methodology of the WARMF model used, and the results of the model analysis.

Following discussion of WARMF model results is a section describing BMP selection which identifies the most viable BMPs for the canyon. Finally, the recommendations section highlights the most appropriate plan for action and distribution of recommendations.

2   BACKGROUND

2.1   Problem Statement

The Tijuana River Watershed encompasses an area of 4,532 km^2, with one-third located in San Diego County, California (CA) and two-thirds in Baja California, Mexico (SDSU, COLEF and SCERP, 2005). The watershed spans the U.S.-Mexico international border and flows from its headwaters between the Laguna and Juarez Mountain Ranges to the Pacific Ocean (Figure 1). The river's main stem flows through a number of major industrial Mexican cities before reaching Tijuana and eventually entering U.S. territory near the San Ysidro International Border Crossing.
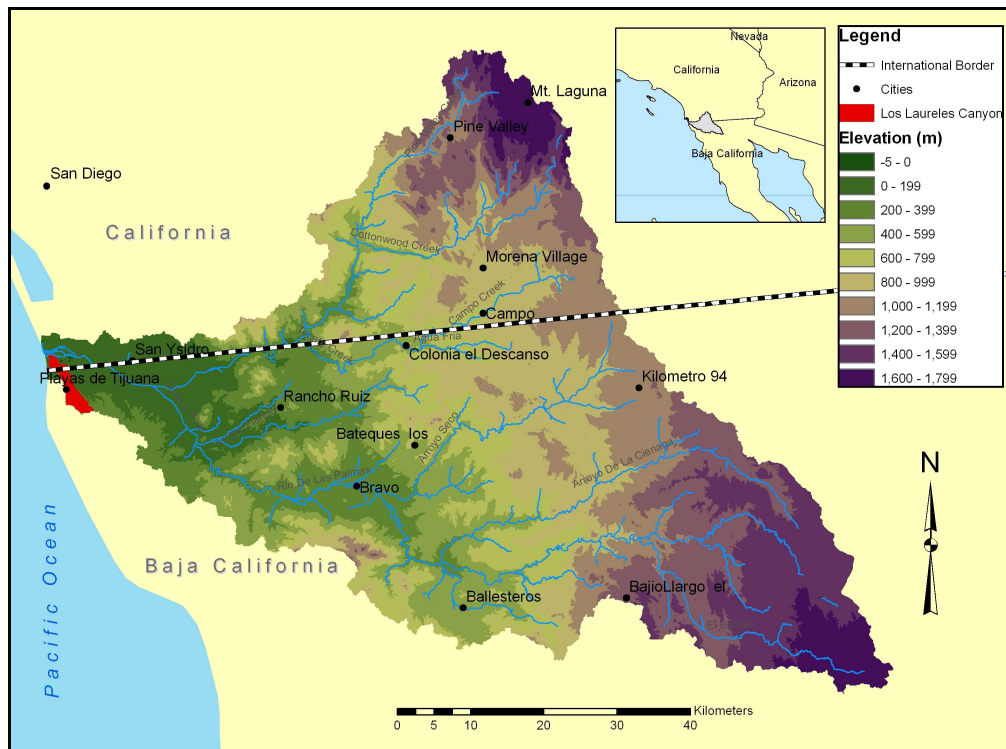
Figure 1. Tijuana River Watershed (Lewis, W., and N. Virgilio, 2008. Data source: SDSU).

Rapid urbanization and population growth in the San Diego-Tijuana transborder region over the last fifteen years have led to significant changes in regional landuse (Pauw, 1995). The implementation of a binational Maquiladora Program to spur border trade in the 1960s, and the geopolitical changes brought about by the North American Free Trade Agreement (NAFTA) in the 1990s, contributed to extensive regional industrialization and subsequent population growth (Pauw, 1995; Ganster *et al*., 2000). The current estimated population of this region is 1.4 million, of which a predominant proportion is migratory workers (SDSU, COLEF and SCERP, 2005). The growing population in the border areas has also resulted in environmental degradation and changes to land cover, such as the removal of native chaparral vegetation due to the growth and expansion of urban areas.

Rapid land use changes, coupled with the absence of stringent environmental regulation and investment in infrastructure, has led to water quality impairments in the lower reaches of the watershed, most notably the densely populated "pueblos" adjacent to the international border between the City of Tijuana and the southernmost U.S. city, Imperial Beach. Low income housing developments are located in unsewered areas on steep, unvegetated slopes and such developments contribute many of the contaminants crossing the border during storm events (Borowiec, 2007). Management of this transborder area to control pollution has proven to be quite difficult. There is very little, if any, planned urban development in the City of Tijuana periphery. In many areas such as Los Laureles Canyon, "squatters" have set up dwellings in communities that are not formally recognized by levels of Mexican Government that are not required to provide residents with infrastructure or public services (Oscar Romo, personal correspondence, October 2008).

Extensive governmental resources and coordinated efforts between U.S and Mexican authorities at federal, state, and local levels on both sides of the border, have yielded progress addressing transborder contamination, but have fallen behind the rate of progression of the problem due to political and legal complications. Actions implemented by the International Boundary Water Commission (IBWC), most notably the development of the South Bay International Wastewater Treatment Plant (IWTP) in Imperial Beach, have improved coastal water quality near the Tijuana River mouth during dry periods. However, during storm events, impaired waters in the Tijuana River exceed the IWTP's capacity for treatment. Untreated stormwaters flow through the river channel into the Tijuana River Estuary and the coastal zone. Additionally, in Los Laureles Canyon stormwater runoff originating from the upper reaches of this sub-watershed flows under the U.S. border and into the estuary, circumventing the Tijuana River and IWTP treatment entirely. These overland flows have led to significant stormwater plumes in the Pacific Ocean containing a myriad of pollutants of concern (Figure 2) which lead to adverse environmental and human health effects. These impacts are highlighted by well publicized U.S. beach closures in San Diego County.

The costs associated with the flow of contaminated waters through the transborder region have been estimated at approximately $2 billion (excluding costs of ecological damage) (SCERP, 2007). Although the contribution of pollutants from Los Laureles Canyon are believed be a small part of the contaminant load associated with adverse economic, political, and ecological impacts, stakeholders identified the canyon as an area of concern due to the absence of treatment infrastructure, the canyon's proximity to the coastal zone and the Tijuana River Estuary and the rate of population expansion into previously unpopulated areas.

Figure 2. Aerial image of Tijuana River and associated sewage plume in Pacific Ocean (Source: phfactor.net)

2.1.1 Water Quality Treatment

In 1965, during the early stages of regional industrialization and subsequent border population growth, the City of San Diego proposed and signed an agreement to treat a portion of Tijuana's sewage in an attempt to reduce environmental degradation and transborder pathogen transport (Pauw, 1995). The renewal of this agreement involved Annex I of the Border Environmental Agreements, which called for the construction of two treatment facilities. The Tijuana government constructed a facility on the Mexican side of the border, Punta Bandera that was to be supported by what is now the IWTP (Figure 2a). In 1987, amendments to the U.S. Clean Water Act (Section 510) provided the EPA and governmental officials with the mandate to take "vigorous steps" to address what was identified as a growing water quality issue in the flows of the Tijuana River (Pauw, 1995). The IWTP became operational in July of 1997 and is funded by the IBWC, City of San Diego, Army Corp of Engineers, and SDRWQCB (Comer, 2007). While it was initially expected that the $239 million earmarked for the project would fund a facility capable of secondary treatment, this goal still has not been met, despite extensive California State and non-governmental legal actions against the IBWC. The IWTP is located on the U.S. side of the border and has the capacity to treat 25 million gallons per day (mgd) of sewage from Tijuana to advanced primary levels. Since 1997, treated water has been discharged through the IWTP South Bay Ocean Outfall (SBOO), approximately 3 miles off the coast of Imperial Beach (Bajagua, LLC, 2007). IWTP capacity is utilized to treat a portion of Tijuana's wastewater to primary treatment levels. While the primary role of the IWTP is to treat sewage from Tijuana, any remaining real time capacity is used to treat water pumped directly from the Tijuana River

channel near the border in an attempt to limit the impacts of impaired dry weather water flow into U.S. territory.
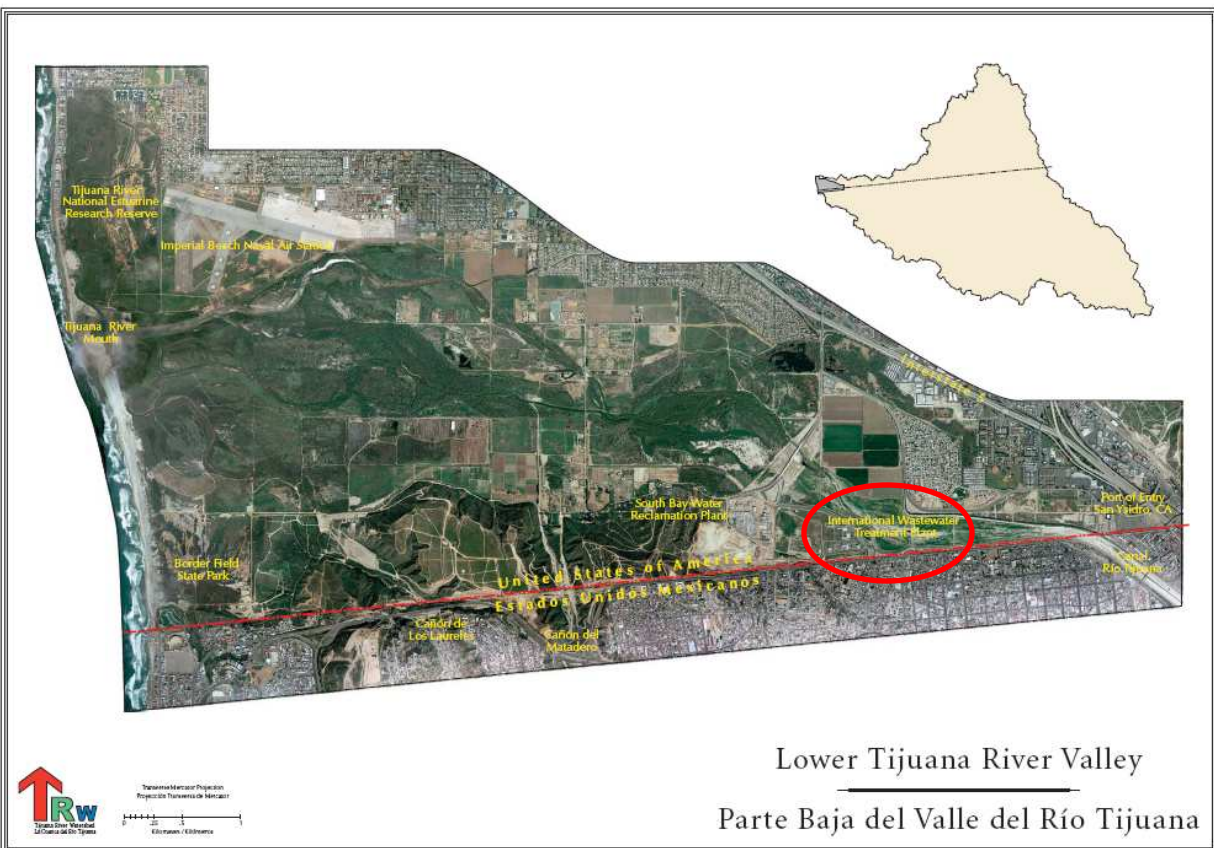

Figure 2a. Location of IWTP (Source: SDSU, COLEF and SCERP, 2005)

The IWTP has been operating in violation of the U.S. Clean Water Act (CWA) since coming online in 1997 by not achieving secondary treatment. Congress intervened in November of 2000 with public law 106-457 mandating that the IBWC contract Bajagua LLC, a private sector water treatment firm, to construct a secondary level treatment facility on the Mexican side of the border (Bajagua, LLC, 2007). Bajagua would treat all IWTP waters as well as an additional 37 mgd of Tijuana's sewer wastewater to secondary levels (Bajagua, LLC, 2007).

A lawsuit brought against the EPA regarding CWA violations was filed in 2002 and subsequently dropped to prevent what was expected to be a protracted legal battle, and would have set a precedent as to whether state governments can bring suit against the federal government for failure to adhere to federal environmental laws. Bajagua, was to be completed by a court-ordered deadline of September 2008, a date which is presently the focus of renegotiation.

Most recently, the IWTP had not yet met secondary treatment standards. A current legal suit led by the SDRWQCB has been bolstered by the 9th Circuit's refusal of the Department of Justice's

request (on behalf of the IBWC) to extend the deadline for the IWTP to come into compliance. The IBWC is still under legal pressure to meet secondary standards by September 2008.

The additional capacity of the planned treatment facility at Bajagua may lead to the treatment of a greater volume of the impaired stormwater crossing the border into the Tijuana River Estuary and coastal zone. However, the uncertain situation of the Bajagua project, and the non-compliance of the IWTP, highlights the urgent need for control and management of sewage and wastewater in the watershed. Even if the IWTP were to stay on-line, the treatment of in-channel stormwater will continue to be limited by the facility's treatment capacity, a volume that will not significantly increase if and when Bajagua becomes operational as Bajagua will not address Los Laureles Canyon stormwater flows. As a result, transborder stormwater runoff containing toxics, heavy metals, debris and refuse, sediments, and pathogens would likely continue to impact water quality in canyon.

2.2   Previous Investigations

Previous investigations of pathogens and other pollutants of concern in the watershed have examined some of transport mechanisms and the associated effects of constituents on the U.S. side of the border. Gersberg *et al.* (1994) determined that pathogens are a major concern in the estuary. Results from this study highlighted "the profound effect that rainfall and runoff have on microbial water quality in the Tijuana River Estuary." The authors also concluded that they expected to continue to see elevated counts of fecal indicator bacteria (fecal coliform) in the Tijuana River following IWTP construction and operation due to the presence of diffuse nonpoint sources within the watershed. When coastal currents flow from south to north during storm events, many southern San Diego County beaches are closed due to high levels of pathogens, which have the potential to cause adverse health effects such as respiratory illness, skin rashes and gastro-intestinal illness (San Diego County Department of Environmental Health, 2006).

The Pacific Ocean and the Tijuana River Estuary act as the sink for many of the pollutants transported across the international border (Figure 3). The contaminants of particular concern for the ocean, according to previous research, are pathogens, sediment, toxic metals and refuse. With regard to pathogens, Gersberg and Brooks (2003) conducted a study to quantify the impacts of Tijuana River flows on water quality in the Pacific Ocean near the mouth of the Tijuana River and Imperial Beach. The study focused on concentrations of the pathogen causing Hepatitis A, which poses a significant threat to human health. Hepatitis A exposure may lead to a viral infection of the liver and can cause nausea, vomiting, diarrhea and fatigue. The study found concentrations of the Hepatitis A virus in six of eight samples sites; four from the Tijuana River and two from Imperial Beach. Ingestion of the contaminated water has been identified as the primary cause of infection. Elevated levels of the Hepatitis A virus and other pathogens have provided the impetus for beach closures near the river mouth and in Imperial Beach. Gersberg *et al.* (2006) conducted a follow up study to evaluate Hepatitis A virus concentrations in the Pacific Ocean near the Tijuana River mouth and in Imperial Beach. Results corroborated findings from the previous study and suggested that elevated concentrations of the Hepatitis A virus remain in the ocean 1-2 days after peak rainfall events.

One recent study on the Mexican side by Orozco-Borbon *et al.* (2006) quantified the bacteriological water quality at Baja California's northwest shoreline where "the combined volume of wastewater discharged to the shoreline is of 40 million gallons per day, which [has] produced a deterioration of the seawater quality" (2006: 1190). This survey was part of a bi-national program in microbiological water quality, with the goal to examine bacteriological water quality near Mexican ocean outfalls, wastewater discharges, and beaches.

Figure 3. Coastal zone near Tijuana River National Estuarine Research Reserve (TRNERR) (Source: R. Keane-Dengel, May 2007).

In addition to assessing levels of pathogens, some studies have attempted to quantify the composition and relative concentrations of the other constituents of concern in flows from the lower Tijuana River Watershed. Gersberg *et al.* (2003) assessed the peak toxicity of stormwater runoff in the Tijuana River by sampling the river at 5-7 hour intervals following a storm event. The authors concluded that peak toxicity occurred 1-2 hours after the event and then decreased in subsequent flows. Riveles and Gersberg (1999) also evaluated the toxicity of the Tijuana River during wet and dry weather periods. Results from this study indicated that river water toxicity was higher during wet periods than during dry periods due to flushing of accumulated pollutants driven by stormwater runoff. This study also incorporated Toxicity Identification Evaluations (TIEs) which identified non-polar organic pollutants, such as detergents, surfactants, petroleum hydrocarbons, and pesticides, as the major constituents contributing to toxicity in river discharge.

The Tijuana River Estuary is believed to be most significantly impacted by impaired transborder waters flowing from the Tijuana River Watershed due to its close proximity to the river mouth, effectively acting as filter or sink for many of the contaminants mobilized during stormwater events. A study conducted by Meyer and Gersberg (1997) determined that heavy metals from the Tijuana River contaminate the estuary. Findings also suggested that toxicity derived from metals may not be as high of a concern as pathogens because sediment associated sulfides can bind to and immobilize many metals. However, a possible critique of this conclusion is that the immobilization of metals is nevertheless dependent on the concentration of sulfides, the requirement of appropriate redox conditions and a timescale for reaching equilibrium. Therefore

toxic metals could still present a problem in the watershed, as they are transported largely by sorbing to sediments throughout the watershed. These findings suggest that incorporating sediment control measures should be an important component of addressing overall stormwater quality. Furthermore, Gersberg's 1997 study determined that during storm events, stormwater runoff from north-draining canyons originating on the Mexican side of the watershed such as Los Laureles, contribute constituents of concern to and lead to significant adverse ecological effects in the estuary. Therefore, these canyons, as previously noted, are also important sources of contaminants that have been shown to affect the coastal zone.

2.3   Project Significance

To date there have been few studies specifically investigating diffuse nonpoint source pollution and associated transport of contaminants on the Mexican side of the watershed (Gersberg, 2006). The marked absence of water quality assessments or data from Tijuana and the city's periphery may limit the bi-national discussion regarding the transborder water quality issue and limit the realized water quality gains derived from California state remedial actions in the lower reaches of the watershed. The project client, the SWRCB, is in the initial stages of funding a pathogen source identification study in Southern San Diego County through their Clean Beaches Program. EPA Region 9 is in the early stages of developing a TMDL for the Tijuana River under the CWA which is a prerequisite for further state or federal action.

This study was developed to function in concert with current SWRCB and SDRWQCB actions and stakeholder goals. Furthermore, in 2007, a Master Plan was completed by the Municipal Planning Institute of Tijuana (IMPlan). This document frames the pollution and development problems within the canyon, and makes broad recommendations for future management of the sub-watershed. This project works within the recommendations of the Master Plan and identifies specific BMPs to complement IMPlan recommendations.

The SWRCB indicated a preference for this research project to examine loading of three specific contaminants: pathogens, sediment and refuse from Los Laureles Canyon. Recommendations provided in this study will provide stakeholders with options to pursue strategies for managing pathogens, sediment, and refuse while addressing the challenges of dense urbanization and rapid landuse change in the urbanized lower reaches Tijuana River Watershed.

2.4   Project Objectives
The purpose of this study was to identify options for controlling sources and mitigating stormwater transport of pathogens, sediment and refuse/debris through Los Laureles Canyon to the TRNERR and the coastal zone.

The project objectives were defined to complement existing work on the U.S. side of the border by the SDRWCB and SWRCB to meet EPA guidelines and standards, and to assist Mexican authorities and stakeholders in selecting viable solutions to reduce the problem of pollutant, most notably pathogen, loading from the north draining canyons within the watershed. A modeling approach was used to analyze the transport and fate of pathogens, one of the constituents of concern, using fecal coliform as a proxy. Stormwater control and mitigation options were also simultaneously analyzed to understand which BMPs are most applicable in Los Laureles

Canyon. This study of Los Laureles Canyon and the subsequent findings and recommendations can be used to inform stormwater control and mitigation actions throughout the other canyons and the greater transborder watershed.

The project objectives were to:

- Interface with stakeholders in the U.S. and Mexico to understand the environmental problem within Los Laureles Canyon
- Identify the pollutants of greatest concern in the canyon for the project analysis
- Model pathogen loading in the canyon:
    - Identify sub-basins within Los Laureles Canyon where the highest pathogen loading occurs
- Assess the effectiveness of sewage management options including:
    - Installation of sanitary sewer infrastructure in one community in Los Laureles Canyon, San Bernardo;
    - Installation of septic systems throughout Los Laureles Canyon and
    - Installation of sanitary sewer infrastructure throughout Los Laureles Canyon.
- Determine stormwater mitigation strategies viable for Los Laureles Canyon sediment and refuse/debris that can be replicated in other similar canyons of the Tijuana River Watershed.
- Deliver recommendations to stakeholders to contribute to and facilitate future discussions or political actions regarding the design, funding and implementation of techniques and technologies to address stormwater pollution control measures on the Mexican side of the Tijuana River Watershed.
- Work with stakeholders in the U.S. and Mexico to facilitate a binational effort to identify effective mitigation strategies for reducing pathogens, sediment, and refuse in the canyon and larger watershed.

3 METHODS

3.1 Approach and Conceptual Model

Figure 4 illustrates a conceptual model of the project approach and analysis and the following is an outline of the general research approach to achieving our project objectives:

- Identify locations of high concentrations of pathogens in Los Laureles Canyon
  - Research common urban sources of pathogens
  - Use existing Tijuana River GIS project data layers (from San Diego State University) for qualitative assessment of land use patterns facilitating pathogen sources
  - Use a Digital Elevation Model (DEM) to qualitatively determine ground surface topography and the relation to pathogen sources and transport
  - Determine the availability of fecal coliform data to use as a proxy for pathogen contamination within Los Laureles Canyon.

- Analyze sewage management options by characterizing fecal coliform loading using the WARMF model
  - Establish suitability of WARMF for modeling pathogen fate and transport during stormwater runoff events, using fecal coliform as a proxy
  - Obtain relevant data for WARMF import, such as meteorological and hydrologic data, from universities, agencies and governments in the U.S. and Mexico
  - Use BASINS 4.0 to delineate sub-basins within Los Laureles Canyon
  - Identify model uncertainties in simulating fate and transport of pathogens and sediment from hydrologically complex regions such as Los Laureles Canyon
  - Use hydrology auto-calibrate within WARMF model to guide alteration of physiographic parameters
  - Run WARMF model for delineated sub-basins in Los Laureles Canyon
  - Assess impact of different sewage management scenarios on simulated fecal coliform concentrations
  - Analyze model results for Los Laureles Canyon and use these results to inform necessary sewage management strategies in the canyon

- Analyze stormwater runoff control and mitigation techniques and technologies
  - Conduct survey of manufacturers and users of stormwater control and mitigation techniques and technologies to determine their applicability to conditions similar to those within Los Laureles Canyon
  - Investigate and assess stormwater mitigation techniques and technologies including costs, maintenance, implementation, and effectiveness in Los Laureles Canyon

- Present recommendations to client and stakeholders for Los Laureles Canyon based on study results

- Combine data from areas with high fecal coliform loading with modeling of transport and fate to determine the most viable mitigation strategies for sewage
- Identify viable BMPs such as stormwater technologies and community actions for Los Laureles based on pathogen, sediment and refuse control, as well as implementation feasibility
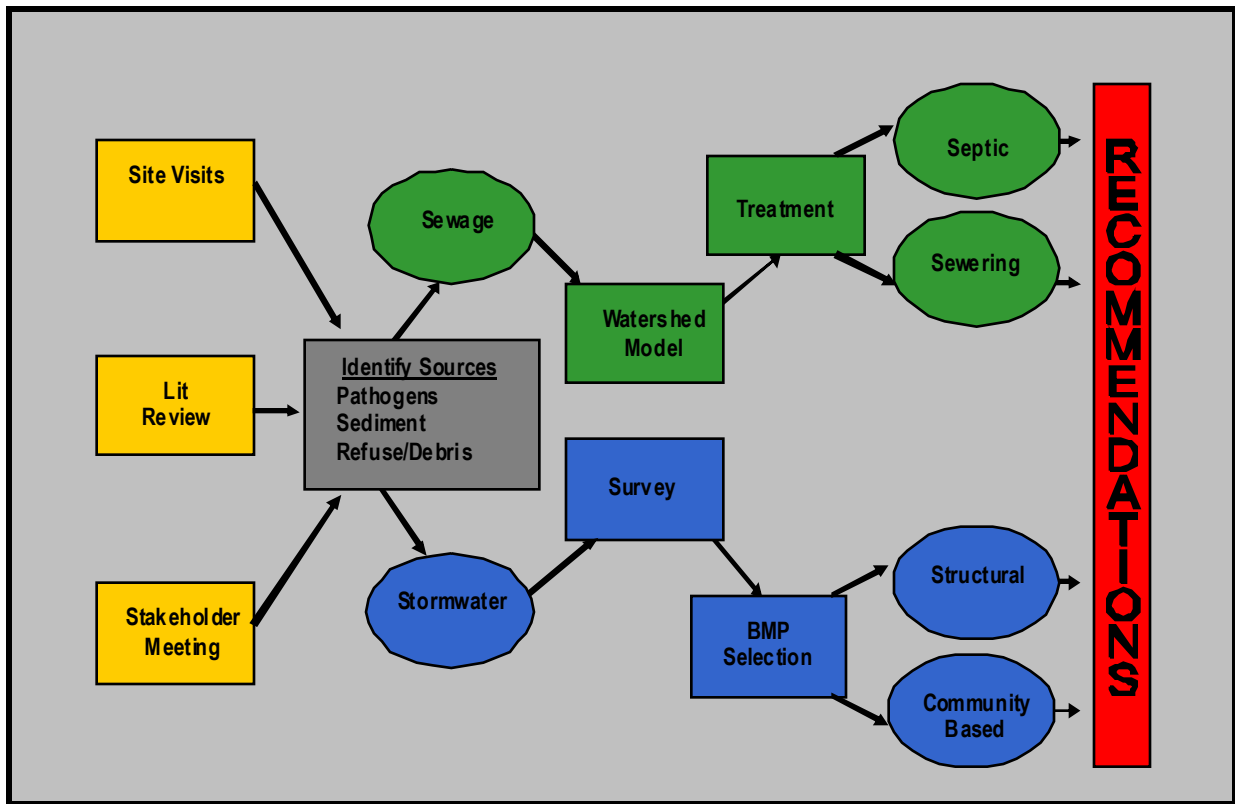- Provide results, model and mitigation options report to the client and key stakeholders.

Figure 4. Conceptual model of methods.

3.2 Stakeholders, relationship-building, and site visits

The key project stakeholders listed in the introduction have been an integral component of this study in terms of data and information acquisition, project guidance, and relationship-building with both U.S. and Mexican contacts. These contributions have been vital from the start of the project and are a significant component of the project methodology. The group project members and advisors met with the client, SWRCB, represented by Bart Christensen, in May 2007 in the border region to discuss the intended scope of the study and some of the key issues of water quality and treatment in the watershed. This meeting was followed by a tour of the middle and lower watershed on both sides of the border, including the Tijuana River on the border, estuary (TRNERR), coastal zone, Smuggler's Gulch, and Los Laureles Canyon. The tour was led by Benjamin Winkler-McCue (Wildcoast) and Oscar Romo (NOAA), both of whom are stakeholders for the project. The visit was integral in providing group project members with site-

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specific information and a vision of the landscape, urban development and the associated environmental problem. It was during this visit that Los Laureles Canyon was chosen as the focus area for the study, given its location in the watershed and its likely contribution to the larger pollution problem (see Los Laureles Canyon section for further details).

In addition to the site visit, group project members hosted a stakeholder meeting (Figure 5) at the Tijuana River National Estuarine Research Reserve (TRNERR) to initiate stakeholder collaboration and relationship-building for this project. The meeting was held on May 4, 2007, and there were seven attendees in addition to the Group Members and Advisors. These attendees were: Bart Christensen (SWRCB); Jeff Crooks (TRNERR); Harry Johnson (SDSU, Department of Geography); Laura Peters (Clean Beaches Program, SWRCB); Oscar Romo (NOAA); Melissa Valdovinas (SDRWQCB); and Mayda Winter (City of Imperial Beach, SWIA).

The meeting provided valuable insights into some of the key transborder pollution issues in the estuary, coastal zones, and river, and was an important networking event with stakeholders and the client. The meeting offered the group the opportunity to bring on Mayda Winter as an external advisor, and to establish an informal working relationship with Oscar Romo.

On October 19, 2007 Oscar Romo set up an appointment for group project members to meet with Benigno Medina Parra from CESPT in Baja California. This meeting was useful in connecting with a Mexican local authority and provided further insight into data availability for assessing fecal coliform concentrations within the watershed. The meeting was carried out largely in Spanish and translated for some group members by Oscar Romo. The CESPT meeting was followed by a site visit to Matadero Canyon, (another transborder canyon with extensive unplanned urban development), and another visit to Los Laureles Canyon. Oscar Romo again led this second site visit and also confirmed his desire to be involved more formally as an external advisor for the project and offered NOAA facilities for use in future stakeholder meetings.

Figure 5. Stakeholder meeting May 4, 2007 (Source N. Virgilio, May 2007).

There will be ongoing stakeholder engagement, such as the distribution of erosion control flyers to local residents as well as delivery of recommendations to the client and stakeholders. Before finalizing this report, the group members plan to organize a final stakeholder meeting to deliver the project results, solicit input, and thank involved parties for their support. The project will also be presented at a StormCon conference in Orlando, Florida in August 2008 and other potential conference opportunities in the future.

3.3 Scientific data

In addition to stakeholder relationship-building, the site visits and meetings held to date have been fundamental in researching and obtaining existing data and information relevant to this project. As stated in the approach, collecting data layers for the watershed and importing data into the WARMF model is an essential component of the project methodology. Table 1 provides information about data used in this study.

Table 1. Data utilized for modeling and BMP selection.

Data Set	Source	Method of Collection	Purpose	Data Uncertainty
GIS Data Layers	San Diego State University Tijuana River Watershed Project (Department of Geography)	Electronic	Creation of watershed maps in ArcGIS for analysis	Secondary data collection, but from a reputable academic source
DEM	San Diego State University Tijuana River Watershed Project (Department of Geography)	Electronic	Creation of elevation maps and for import into WARMF	
Meteorological Daily Time-Series Data (1990-2007) (Precipitation data corroborated by CONAGUA)	NOAA, National Climatic Data Center http://gis.ncdc.noaa.gov/ General Abelardo L. Rodríguez International Airport	Collected electronically by group members	Import into WARMF	Data collection techniques potentially different between U.S. and Mexico
Observed Hydrology Daily Time-Series Data (2000-2007)	USGS National Water Information System	Collected electronically by group members	Import into WARMF	Selected as representative of the hydrology within Los Laureles Canyon
Water Quality Data (Fecal Coliform)	17 data points from Jajan and 1 data point from CESPT over 2005-2007	Electronic and site visit	Comparison to WARMF output for calibration	Dilutions from Jajan data are questionable
Geo-referenced Channel Data (see Appendix 2 for details)	Group Project Members	Collected by members in the field in Los Laureles using GPS and measuring tape	Determination of realized flow through canyon	Measurements were taken at a few select locations in the channel

4 TIJUANA RIVER WATERSHED

4.1 Geography and Geology

Elevations within the Tijuana River Watershed range from sea level in the west to more than 1,944 m and in the northeast and 1,800 m southeast. Much of this area is sharply dissected by eroded canyons and valleys, with steep (>25%) slopes in the border region.

The geological profile of the area is quite varied, due in large part to the region's active tectonic history. Plate subduction across the entire west coast during the Cretaceous Period produced substantial quantities of magma, displacing and uplifting coastal mountain areas. The eastern two-thirds of the watershed consist mainly of Cretaceous Western Peninsular Range Granitics, with smaller patches of Cretaceous Eastern Peninsular Range Granitics and Triassic Metamorphic Clastic Sediments. The western one-third of the Watershed is more diversified, with large sections of Jurassic Metamorphic Volcanics, as well as various Quaternary and Tertiary Period sediments (SDSU, COLEF and SCERP, 2005).

This surfeit of rock types leads to an assortment of soils within the Tijuana River Watershed (Appendix 1, Figure A). U.S. soils in the lower basin consist mainly of Entisols and Inceptisols, while further inland, Alfisols and Mollisols dominate (SDSU, COLEF and SCERP, 2005). Soil maps are quite detailed in the U.S.; however, due to soil survey availability issues, different taxonomic criteria, and differences in scale, it is more difficult to characterize soils on the Mexican side of the border. In order to accommodate these differences, the authors of the SDSU, COLEF and SCERP used an integrated predictive model to match locations of soil types and physical characteristics of the land on both sides of the border, creating a detailed soil map of the watershed (Appendix 1).

4.2 Climate

Temperature and rainfall vary with elevation in the Tijuana River Watershed. Temperatures at lower elevations range from 16-19 degrees Celsius, while high altitude temperatures are somewhat colder, ranging from 9-11 degrees Celsius. Coastal temperatures are generally lower than inland areas, with peak temperatures occurring in July and August and lows between December and February. These temperature variations within the Tijuana River Watershed are shown in data from U.S. cities. Imperial Beach provides may act as proxy for temperatures in the
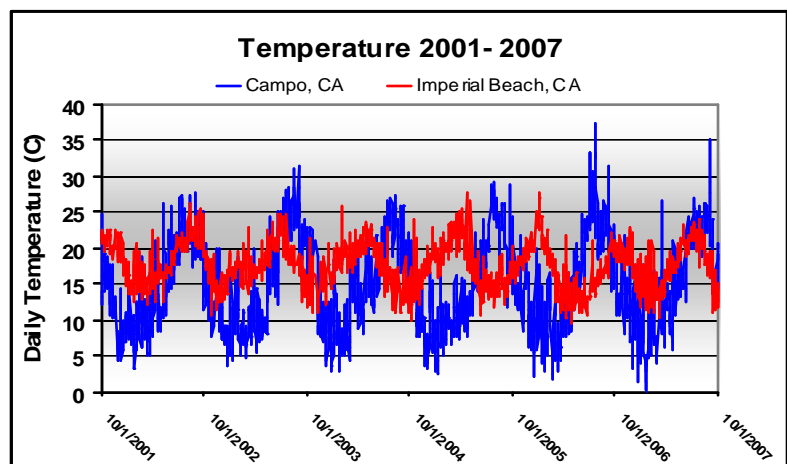

Figure 6: High elevation, inland temperatures (represented by Campo in blue) and low elevation, coastal temperatures (represented by Imperial Beach in red). Temperatures are in degrees Celsius.

coastal areas, and Campo, CA provides a proxy for inland/upland temperatures in the Tijuana River Watershed (Figure 6).

Annual precipitation in the watershed follows a typical Mediterranean seasonal pattern, ranging from 20 cm to 110 cm, with largest quantities falling in the regions just west of the highest peaks. The rainy season occurs between October and March, with a dry season in the summer and early fall. See Figure 7 for an example of low elevation precipitation patterns in the watershed and Figure 8 for an example of high elevation precipitation patterns. There is generally more precipitation in the higher elevations.
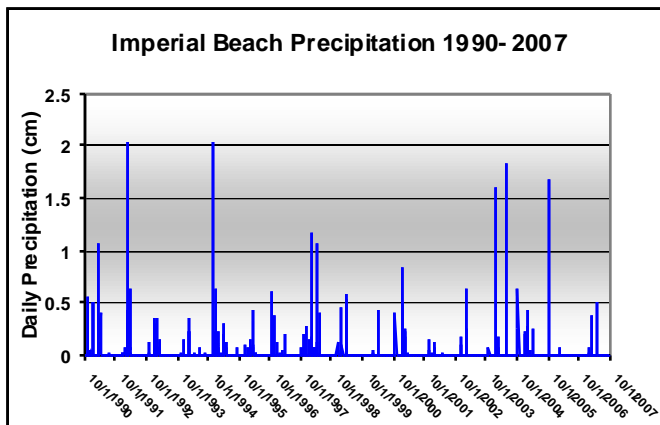

Figure 7: Example of coastal, low elevation precipitation patterns in the watershed. Precipitation is recorded in cm. Imperial Beach, California.
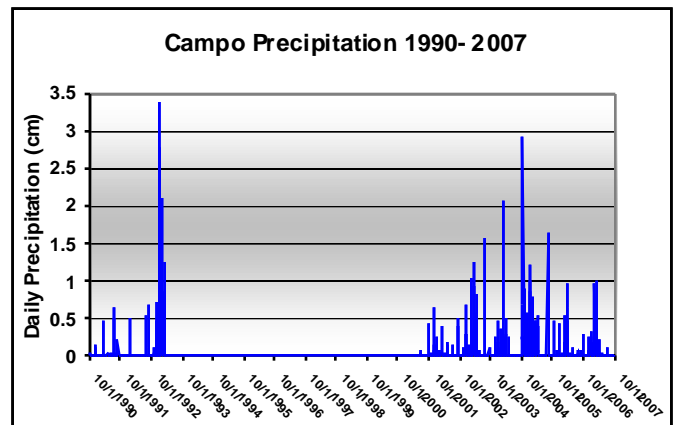**(Source: NOAA Climatic Data Center, 2008)**

Figure 8: Example of inland, high elevation precipitation patterns in the watershed. Note there is a data gap between 1993 and 2001. Precipitation is recorded in cm. Campo, California.
(Source: NOAA Climatic Data Center, 2008)

4.3 Hydrology

The Tijuana River is formed at the intersection of two stream networks; the Pine Creek, Cottonwood Creek, and Campo Creek systems from the north and Arroyo Las Calabazas and Rio Las Palmas from the south. After merging in the city of Tijuana and flowing through a concrete lined channel, the river flwos northwest into the U.S. before discharging into the Pacific Ocean via the Tijuana River Estuary. The semi-arid, Mediterranean climate conditions make streamflow within the watershed intermittent and flashy, closely following precipitation patterns.

4.4 Beneficial Uses/ 303(d) Impairment

Mexico does not have the equivalent of U.S. Clean Water Act derived Beneficial Uses for waterways and associated 303(d) impairments for water bodies. However, the government has established a basin objectives for fecal coliform levels stating that concentrations should not exceed the daily limit of 1000 MPN/100mL (SEMARNAT, 1996). The U.S. currently sets basin objectives for fecal coliform concentration at 400 MPN/100mL which would apply to the one-third of the watershed located within the U.S. (SWRCB, 2008). See Table 2 for the beneficial uses of waters on the U.S. side of the Tijuana River Watershed.

Much of the watershed on the U.S. side does not meet the beneficial use standards (Project Clean Water, 2008). These problems are largely a result of non-point agricultural sources on the U.S.

side of the border and a variety of point and non-point sources on the Mexican side. The main water bodies on the U.S. side of the watershed are the Tijuana River, Cottonwood Creek, Tijuana River Estuary, and the coastal zone. Of these, the Tijuana River is listed as being eutrophic and having high levels of coliform bacteria, organic enrichment/ low dissolved oxygen, pesticides, solids, synthetic organics, trace elements, and trash (Project Clean Water, 2008). Similarly, the Tijuana River Estuary is listed as eutrophic with high levels of coliform bacteria, lead, nickel, pesticides, thallium, and trash. The Pacific Ocean, which is the terminus for much of the Tijuana River stormwater, is listed due to high coliform bacteria levels (Project Clean Water, 2008).

Table 2. Beneficial uses of water bodies on the US side of the Tijuana River Watershed (Source: Project Clean Water, 2008)

Beneficial Uses	Inland Surface Water	Coastal Water	Reservoirs and Lakes	Ground Water
Municipal and Domestic Supply	X		X	X
Agricultural Supply	X		X	X
Industrial Service Supply	X	X	X	X
Industrial Process Supply	X			
Navigation		X		
Commercial and Sport Fishing		X		
Freshwater Replenishment	X		X	
Contact Water Recreation	X	X	X	
Non-Contact Water Recreation	X	X	X	
Biological Habitats of Special Significance		X		
Warm Freshwater Habitat	X		X	
Cold Freshwater Habitat	X		X	
Estuarine Habitat		X		
Wildlife Habitat	X	X	X	
Rare, Threatened, or Endangered	X	X	X	
Marine Habitat		X		
Migration of Aquatic Organisms		X		
Aquaculture		X		
Shellfish Harvesting		X		
Spawning, Reproduction, and/or Early Development		X		

4.5   Vegetative Communities

The varied climate, topography, and geography found in the Tijuana River Watershed also gives rise to a variety of vegetative communities (Appendix 1). The Tijuana River Estuary, located in the Northwest corner of the watershed, is one of the few remaining salt marshes in Southern California and is comprised of Southern Coastal Marsh vegetation. Almost three-quarters of the watershed is made up of coastal sage scrub and chaparral, with species such as California sagebrush, flat-top buckwheat, San Diego sunflower, and black and white sage. Coastal sage scrub is found in low elevation, dry slopes and provides habitat to such endangered species as the California Gnatcatcher. Chaparral is dominant at elevations just above that of Coastal Sage Scrub, covering 56% of the watershed. Due to the dry climate, succulents are also common in the watershed, including velvet cactus, Shaw's agave, and coastal beavertail. Moving west, there are patches of oak woodland, pinyon-juniper woodland, and jeffery pine forest, which provide critical habitat for many species of wildlife. Riparian vegetation is found along the various river and creek segments and also provides refuge for threatened species such as Bell's vireo, willow flycatcher, yellow-breasted chat as well as reptiles, amphibians, mammals and freshwater fish. Most of the riparian habitat south of the border has been seriously degraded or destroyed (SDSU, COLEF and SCERP, 2005).

4.6   Population and Socio-economic Factors

There are 4 million people living in the San Diego- Tijuana region, which makes it the most populous section of the entire U.S. - Mexican border region (Conway, et al., 1998). Table 3 lists population growth in San Diego and Tijuana between 1900 and 2000.

Table 3. Population Growth in San Diego and Tijuana 1900-2000 (Source: Brown, et al., 2002)

Year	Tijuana Population	Annual Growth Rate (%)	San Diego Population	Annual Growth Rate (%)
1900	242		18,000	
1930	11,000		210,000	
1940	22,000	10	289,000	3.8
1950	65,000	19.5	557,000	9.3
1960	166,000	15.58	1,033,000	8.5
1970	341,000	10.5	1,358,000	3.1
1980	462,000	3.5	1,862,000	3.7
1990	747,000	6.2	2,498,000	3.4
2000	1,125,200	5.1	2,896,900	1.6

An estimated 1.4 million people live in the Tijuana River Watershed, with this number expected to double over the next 20 years (SDSU, COLEF and SCERP, 2005). Most of this population is densely concentrated in the western portion of the watershed, in the San Diego communities of Imperial Beach, San Ysidro and Otay Mesa, and the Mexican cities of Tijuana and Tecate. Smaller population centers are located further east, in Potrero, Campo and Pine Valley on the U.S. side of the border, and Nueva Colonia Hindu, Valle de Las Palmas, Carmen Serdan, Vallecitos, Santa Veronica, Neji, and El Hongo on the Mexican side. Population growth in the watershed is greatest on the outskirts of Tijuana and Tecate, due in part to the flux of residents from other areas of the country. It is expected that rapid growth will eventually connect Tijuana and Tecate into one sprawling metropolis (SDSU, COLEF and SCERP, 1995). Because there are available jobs in the Tijuana border region and wages are higher compared to other areas of Mexico, many workers have relocated to this area. One effect of this rapid population growth is that the city of Tijuana has been unable to provide the infrastructure needed to service many

areas, resulting in many places within the Tijuana River Watershed lacking basic plumbing, electricity, paved roads, and sewers (Ganster, et al., 2000; USEPA, 2008).

4.7   Land Use

Although most people living within the boundaries of the Tijuana River Watershed are concentrated in urban centers, these make up only 10% of the actual land use in the watershed (Appendix 1, Figure D). Almost 84% of the watershed is undeveloped and used for low intensity grazing. Agriculture is confined to the central valleys where water is most readily available. Industrial uses in Mexico are concentrated in eastern Tijuana and are largely a due to NAFTA associated industry. On the Mexican side of the border, many of the working poor live in "squatter" communities located in 28 sub-canyons of Mexican territories. These are densely packed enclaves built into the canyon walls with little to no infrastructure. As such, vegetation in these areas is almost non-existent (Oscar Romo, personal correspondence, 2007).

5 LOS LAURELES CANYON

Los Laureles Canyon was chosen as a focus of this study as it is a representative micro-basin among the 28 north draining canyons within the study area, it is in close proximity to the U.S. and that it likely contributes to pollution problems in the Tijuana River Estuary and coastal zone.

> This sub-basin is of particular interest and concern as it flows directly into the Tijuana River National Estuarine Research Reserve (TRNERR) and is a significant source of waste and sediment in the southern end of the Estuary. Over time, this sub-basin has become increasingly developed and degraded, and lacks the basic infrastructure to support this development.

> Regional Workbench Consortium, 2008

5.1 Location

Los Laureles Canyon (Figure 9) is one of twenty-eight sub-basins located in the Tijuana River Watershed. The canyon is 9.5 km in length and is comprised of 17 km^2 situated in the westernmost part of the watershed near the border with the U.S. and three to five kilometers from the coast (Regional Workbench Consortium, 2008). A total of 90% of the sub-basin is located in Mexico, with the remaining 10% as U.S territory (called "Goat Canyon") (Conway, et al., 1998). Directly across the border from Los Laureles Canyon is the southern portion of the TRNERR and the canyon's interface with the coastal zone. From the northern end of the canyon it is possible to see the U.S. coastal zone, the lower part of the TRNERR, and the distant buildings and development of the Cities of Imperial Beach and San Diego.

Figure 9: Aerial view of Los Laureles Canyon and environs highlighted in yellow
**(Source: Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007)**

The main channel, which conveys wet weather flows through the Los Laureles Canyon, drains north into the U.S. Los Laureles Canyon does not flow directly into the Tijuana River though it discharges into TRNERR during storm events. The canyon's transborder nature leads to significant adverse impacts associated with impaired water quality on both Mexican and U.S. populations and ecosystems during storm events.

5.2   Geography, Hydrology and Geology

The Los Laureles Canyon sub-watershed decreases in elevation from south to north draining to the northwest (Figure 10). Elevation ranges from sea level to 310 meters at the highest point. Three upper reach streams converge in the middle reaches of the canyon to form the streams main stem before flows cross the border and reach the TRNERR and Pacific Ocean. During dry weather flow, impaired waters originating in Los Laureles Canyon are captured and pumped to a treatment facility. It is only during storm events that runoff enters the TRNERR (Oscar Romo, personal correspondence, 2007).

Due to a difference in soil classification systems (the U.S. uses the Seventh Approximation classification to define soils, while Mexico uses the United Nations' Food and Agriculture Organization (FAO) classification), it is difficult to distinguish between soils in the northern and southern portions of Los Laureles Canyon (SDSU, COLEF and SCERP, 2005). As many of the soil types described in the Seventh Approximation classification does not align with those found in the FAO classification, mapping of soil cover suggests that the geology in the southern or Mexican portion of the sub-watershed are less diverse though this disparity is likely due to soil sample methodology and data availability (Figure 11). Abbreviations for FAO classifications are defined and described in Table 4.
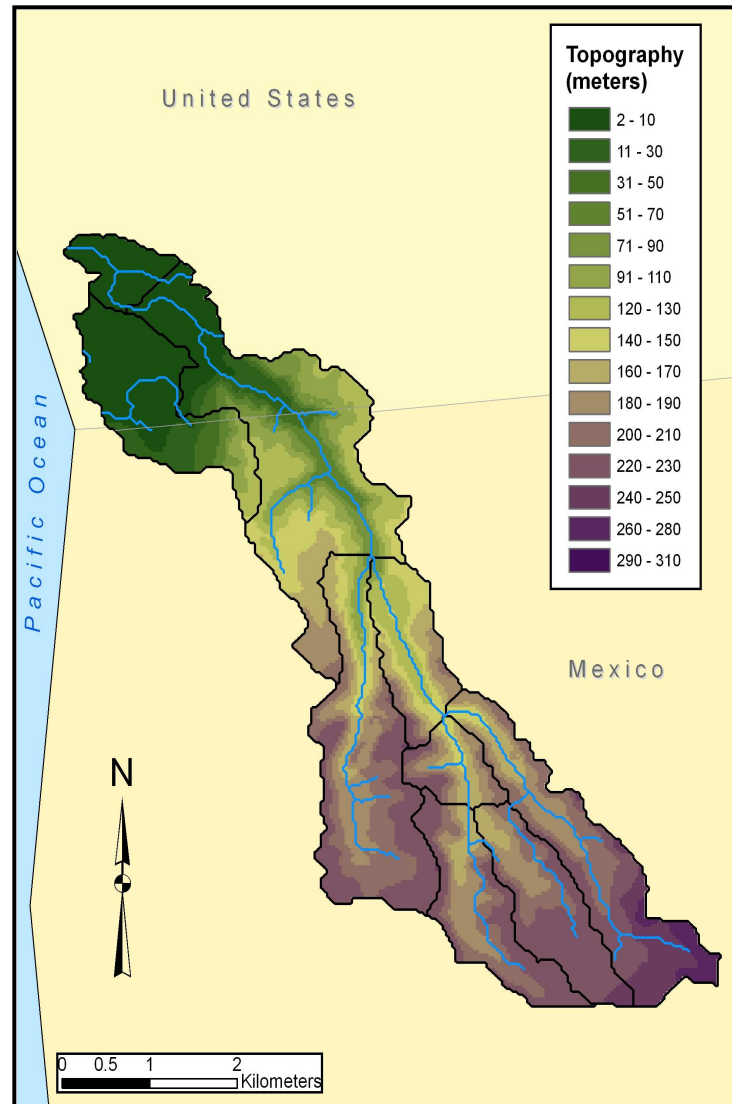
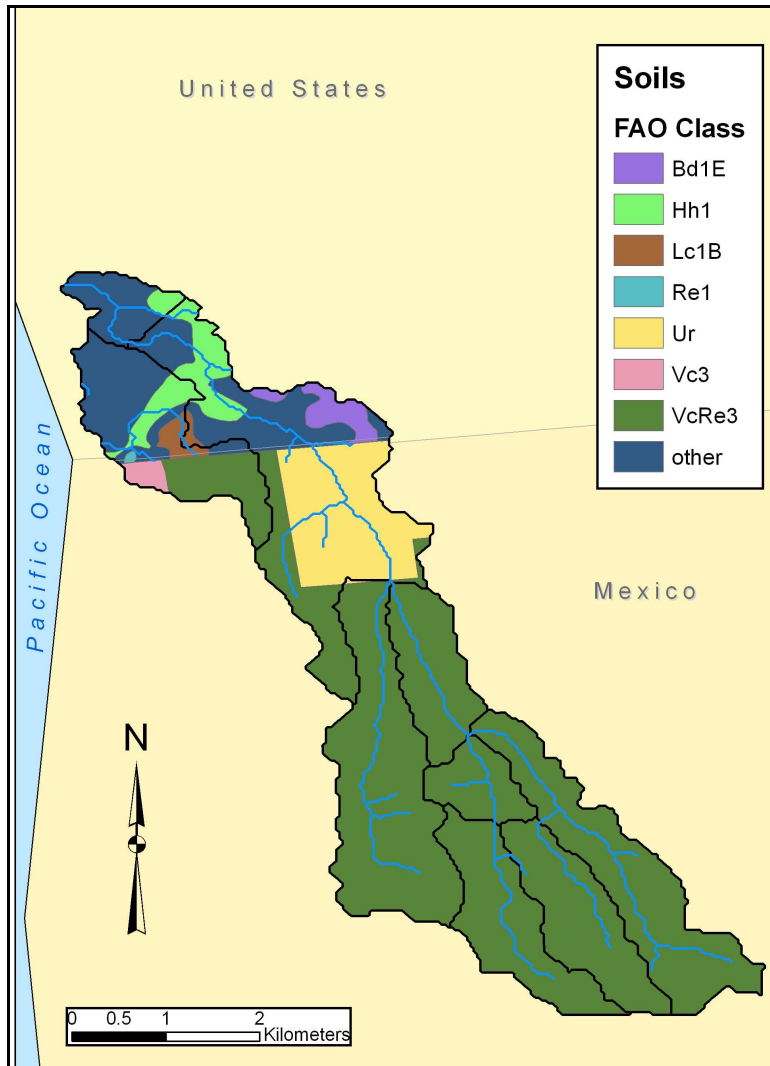**Figure 10: Topography of Los Laureles Canyon (Source: Data Layers from SDSU, Map creation N. Virgilio)**

Figure 11: Soils of Los Laureles Canyon (Source: Data Layers from SDSU, Map creation N. Virgilio).

**Table 4. FAO soil classification key (Source: R.O. Lease, personal correspondence, 2008).**

Abbreviation	Name	Description
Bd1E	cambisol dystric	Like a regosol, but deeper. brown. Incipient soil formation. Slight weathering of parent material. Weak structure. Lack clay + organics. Adequate for agriculture. Second most common soil in world (in acreage).
Hh1	phaeozems haplic	Thick humus (organic)-rich surface layer (topsoil). Great for agriculture. Very permeable, well-aggregated structure. Typically covered with grass or deciduous forest. Mollic A horizon
Lc1B	luvisol chromic	Characterized by leafy, humus (mashed organics) surface layer overlying leached layer. Good for agriculture. Argillic (mudstone) B horizon typically forested. Brown to red.
Re1	regosol eutric	Weakly developed, young, very shallow mineral-rich soil developed on weathering material; sensitive to drought because of high permeability.
Ur	rankers	Shallow soil (topsoil) developed over rock with a chemistry closely related to the rock. Rock is non-calcareous.
Vc3	vertisol chromic	Deep soil that experiences vicious shrink-swell cycles due to high montmorillonite clay, which expands when wet. Typically covered with grass. Impermeable when saturated, but forms cracks when dry.
VcRe3	vertisol chromic	See above
	regosol eutric	See above

5.3 Landuse and Vegetation

Landuse in Los Laureles Canyon significantly differs on either side of the international border. U.S. territory within the canyon is identified as "undeveloped" and "recreational" landuses, while the primary landuses associated with the Mexican side are "developed" and "residential" (Figure 12). In all, 640 ha of the canyon, or 55% of total land, are designated "urban". Due to projected rates of development, Los Laureles Canyon is expected to become completely urbanized in the next 30 years (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007).

High intensity development has occured in the northernmost Mexican and southern sub-basins of Los Laureles Canyon, while areas of relatively undisturbed native vegetation remains in the middle and uppermost sub-basins (Oscar Romo, personal correspondence, 2007). This area supports low intensity grazing for goats and other domestic animals; however, pressure to develop this area is increasing due to regional population growth.

Most of the undeveloped land in the middle and uppermost sub-basins consists of coastal sage scrub, with smaller patches of chaparral and grasslands. (Figures 13, and 14).
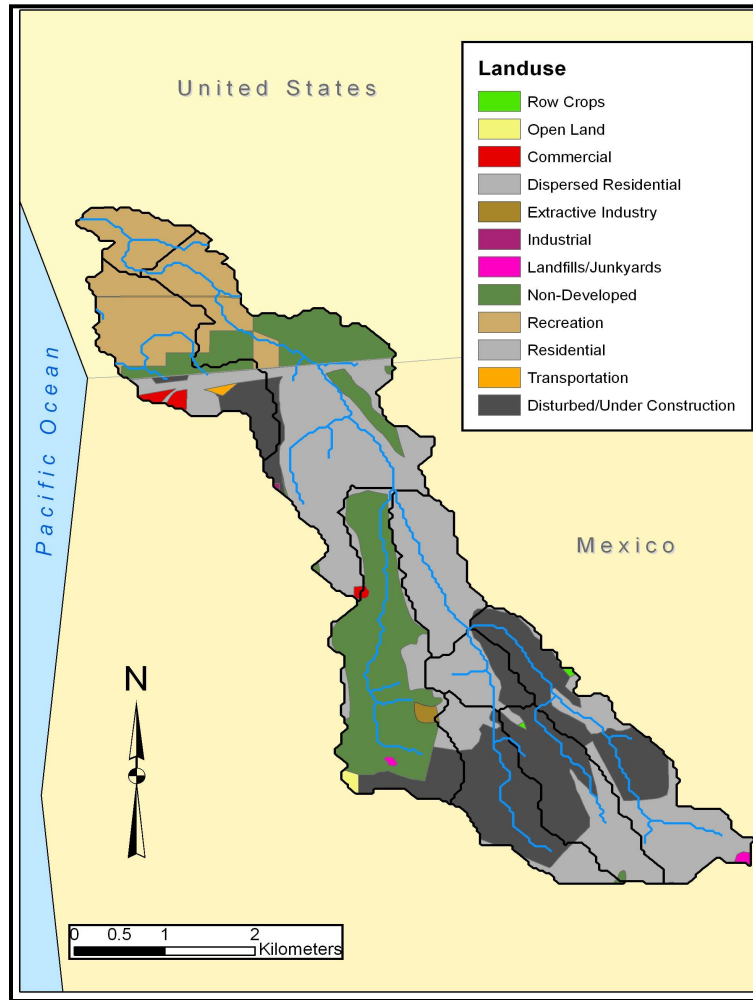
Figure 12. Landuse in Los Laureles Canyon. Note the predominance of development and residential land on the Mexican side of the border. (Source: Data Layers from SDSU, Map creation N. Virgilio)

Figure 13. Middle Los Laureles Canyon is less developed (Source: N. Virgilio – May 2007)

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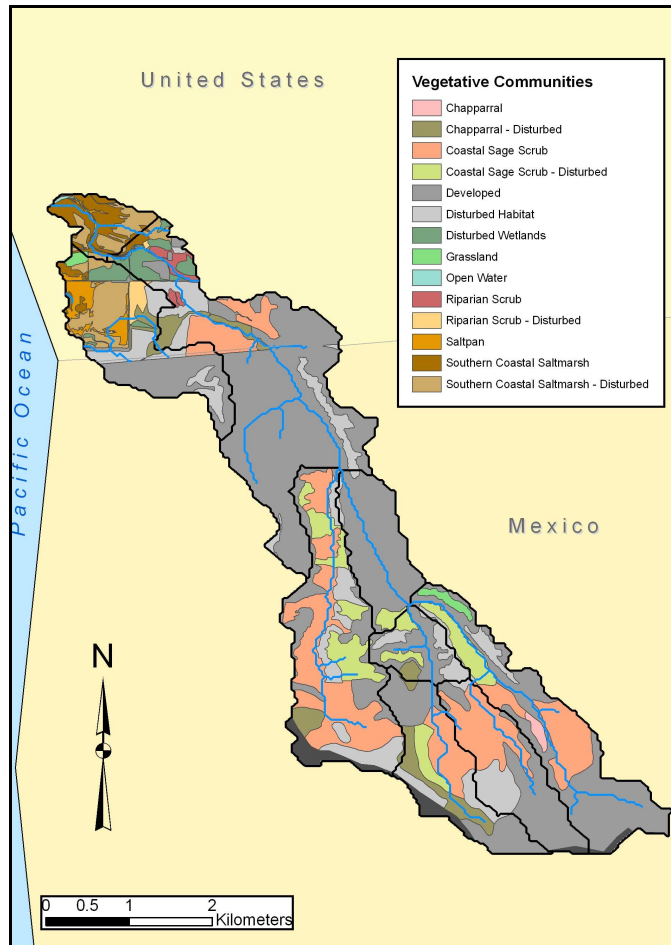
Figure 14. Vegetation in Los Laureles Canyon consists mostly of coastal sage scrub (Source: Data Layers from SDSU, Map creation N. Virgilio)

5.4   Population and Development

The human dimensions of Los Laureles Canyon are characteristic of developments throughout the Tijuana periphery. The population is largely migratory, with an estimated population of 40,000 (Regional Workbench Consortium, 2003). Currently, Los Laureles Canyon is densely packed with dwellings, many of which were illegally sold to inhabitants and erected on steep, unstable slopes (Figures 15 and 16) (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007). The absence of landuse planning or has led to the construction of structures that pose significant personal risk of those

Figure 15. Erosion of canyon walls. (Source: R. Keane-Dengel, May 2007).

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living there (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007). Due to this urban development, very little vegetation remains in Los Laureles Canyon, leaving unstable slopes uncovered and subject to erosion (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007).

Los Laureles Canyon is comprised of a network of steeply sloped ridges and gullies (30% over 35 degrees). These slopes within Los Laureles Canyon make installation of infrastructure difficult due to instability and

Figure 16. Unplanned development on canyon slopes in Los Laureles (Source: R. Keane-Dengel, May 2007).

the risk of canyon wall failure and erosion. The lack of urban planning has also led to deficiencies in the supply of potable water and sewer service (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007).

Population growth is greatest in the outskirts of Tijuana including Los Laureles and stakeholders expect that the Los Laureles Canyon will support more inhabitants in the future (SDSU, COLEF and SCERP, 2005). For this reason, the Los Laureles Master Plan, *Programa Parcial de Mejoramiento Urbano De La Subcuena Los Laureles 2007 – 2015*, was created in 2007 by the Municipal Planning Institute, with the hope of framing the problem and proposing solutions to be implemented over the course of the next 8 years to address environmental pressures associated with expected development (IMPlan and SEDESOL, 2007).

5.5 Los Laureles Canyon Stormwater

Los Laureles Canyon channels vary in dimensions throughout the canyon and continue to be altered by stormwater flows in the wet season. Measurements taken during site visits show that the largest channel width is 38 m, and the narrowest width is 1.8 m across (see Appendix 3). Dry weather flows are currently captured and pumped uphill from the lower channel in Los Laureles Canyon to a wastewater treatment plant located at Punta Bandera located near Playas de Rosarito, in Baja California (Oscar Romo, personal correspondence, 2008). During heavy rains and subsequent stormwater runoff events from December through May, flows exceed channel capacity as volumes associated with these discharges are not completely captured and pumped allowing stormwaters to move downgradient into the TRNERR on the U.S. side of the border.

5.5.1 Constituents of Concern

The three main constituents of concern found in stormwater runoff from Los Laureles Canyon are pathogens, sediment, and refuse/debris.

Pathogens

The term pathogens is used commonly in water quality science to describe microorganisms that cause disease. There are numerous microbes from various genetic origins that are pathogenic, and when testing for pathogens in the environment it is impractical to obtain a quantitative count of each of these groups. By convention, water science practitioners use the term fecal indicator bacteria to indicate the likely presence of pathogens, and when testing for pathogens in the

environment fecal indicator bacteria are the organisms of interest. In this study pathogen dynamics were modeled using fecal coliform as a proxy, but other classes of fecal indicator bacteria could have been used as well if data were available.

Fecal indicator bacteria are identified in the environment by testing for various classes of organisms that are known to live in the gastrointestinal tract of humans and other animals. A visual representation of these various classes of fecal indicator bacteria are shown in Figure 17. Total coliform is a broad class of indicator bacteria that includes all fecal coliform. Fecal coliform is a group that is less inclusive than total coliform but includes all *Escherichia* including *E. Coli*. Specific tests can also be employed to identify only *E.Coli*. Fecal

Figure 17. Classes of bacteria used to indicate the presence of fecal pathogens. (Source: Adapted from Dr. Patricia Holden, 2007)

streptococcus is a separate class of fecal indicator bacteria and includes enterococcus. Enterococcus is a subset of fecal streptococcus that is often discretely sampled.
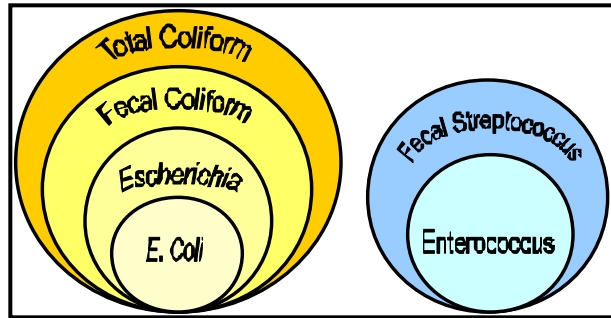
When environmental water quality testing reveals the presence of any of the fecal indicator bacteria described above, it is inferred that fecal material is present in that water sample; because fecal matter contains known pathogens, a water resource science practitioner may assume that pathogens are present in that water sample.

Sediment

The highly erodible soils of Los Laureles Canyon, coupled with the intensity of storm events, lead to high rates of sediment loading in Los Laureles Canyon during the wet season. The canyon's sandy-loam soils are transported through the main channel, and deposit into the U.S. coastal zone. Sedimentation basins have been constructed at the border in an attempt to capture sediment transported through the canyon, but are often filled during the first higher

Figure 18. Sediment settling pond on the U.S. side of the border (Source: R. Keane-Dengel, May 2007).

intensity storm event of the year rendering these basins ineffective in subsequent storms (Figure 18). While sediment itself is pollutant of concern in Los Laureles Canyon and the watershed, it

also acts as a transport mechanism for other contaminants. Pathogens sorb to sediment particles and may be transported downgradient. Heavy metals may also be associated with sediments and can be transported to other parts of Los Laureles Canyon or the coastal zone.

Refuse and Debris

Refuse and debris is ubiquitous throughout Los Laureles and includes tires, plastic bags, paper and plastic waste, food, dead domestic animals (dogs), and various hazardous items (Figure 19). Larger debris such as refrigerators, car parts, and building materials also clog the channel when they are transported downstream during high magnitude storm events (Los Laureles Master Plan, IMPLan Tijuana and

Figure 19. The main channel containing pollutants that are mobilized during wet flows (Source: N. Virgilio. May 2007).

SEDESOL, 2007). There is no central garbage disposal or collection system in the canyon and many residents deposit their household waste within the proximity of their dwellings, or in the canyon's main channel. Additionally, dumping of some industrial wastes may be a significant issue within the canyon though isolating specific point sources for such dumping and quantifying loading may be difficult. CESPT, the local Tijuana authority responsible for public services in the city is responsible for enforcing illegal waste dumping if specific sources can be identified. However, the non-point source nature of refuse dumping makes any actions to control and manage these actions more challenging. Much of this waste, particularly tires, are mobilized during storm events and transported through the canyon to the U.S. side of the border where they are deposited in the coastal zone.

5.6   Current Projects

Los Laureles Canyon, specifically the community of San Bernardo, has already been the site of innovative ad-hoc community projects to address stormwater runoff. An Engineers without Borders (EWB) pilot project, under the guidance of Oscar Romo, is building a wastewater treatment plant in the community. The aim of this project is to manage some of the sewage and wastewater in this specific part of the canyon (Oscar Romo, personal correspondence, 2008). However, supplementary treatment technologies are needed to address wastewater in other parts of the canyon and also to control and mitigate stormwater during particularly heavy precipitation events.

Romo, with the support of NOAA's Coastal Training Program, UCSD and Greeks Gone Green, has started a highly successful permeable paver program. For two years running, the program has enlisted local women to make the pavers. Thus far, over 35,000 pavers have been produced, and the program is set to expand to other parts of the canyon. The pavers are expected to reduce runoff through the canyon and promote infiltration.

A native seed-start program was initiated in spring of 2007 by a group of social workers and community members, with the hope of revegetating many of the bare canyon slopes. Ibera Americana University allowed the use of their facilities to start a plant nursery. However, after the initial planting, most vegetation was destroyed due to unplanned grazing in the area. The program is expected to be initiated again in the spring of 2008.

Most recently, Oscar Romo received funding from NOAA to conduct studies on sedimentation in the canyon. This project will be supported by the NOAA Coastal Training Program, NOAA Southern California Coastal Storm Project, City of Tijuana, SDSU and UCSD researchers. The group plans to bury sensors, historically used to track glacial movement, as well as pressure gauges, to track the movement of sediment in the canyon using wireless technology.

6   WATERSHED MODELING

6.1   Watershed Analysis Risk Management Framework (WARMF)

The Watershed Analysis Risk Management Framework or WARMF model was implemented to simulate the fate and transport of constituents of concern through Los Laureles Canyon. WARMF was developed by Systech Engineering, sponsored by the Electric Power Research Institute (EPRI), and is currently supported by the U.S. EPA's Watershed and Water Quality Monitoring Support Center (EPA ERD, 2007). WARMF is a complex watershed model that has been shown to effectively simulate hydrologic and biogeochemical processes in a number of basins throughout the U.S. and North America, and has been through an extensive peer review process through U.S. EPA (Systech Engineering, 2004; EPA ERD, 2007). WARMF is comprised of a series of modules to allow for watershed-scale modeling efforts and stakeholder involvement to address watershed impairments.

6.1.1   Engineering and Data Modules

The engineering module simulates hydrology as a function of daily runoff and shallow groundwater flow in addition to modeling the fate and transport of constituents through and between each watershed sub-basin (Systech Engineering, 2004). Precipitation data allows the model to estimate the flux of waters into ground and surface waters based on geophysical characteristics impacted by local geology and landuse cover within the watershed. WARMF then simulates the rates of water infiltration, overland flow, and the contribution of constituents of concern from landuses within each watershed sub-basin (Systech Engineering, 2004). Waters and the pollutant loads are routed through the watershed. Pollutant concentrations are simulated by taking into account throughfall, infiltration of waters into the subsurface, soil adsorption, exfiltration, and overland flow (Systech Engineering, 2004). The model incorporates point source contributions to the watershed if any are present in addition to estimated non-point source contribution of constituents of concern from specific landuses (Systech Engineering, 2004). Modeled hydrologic and biogeochemical processes are typically compared or calibrated against observed data which are imported through the data module in order to account for environmental variation and site specific processes.

6.2   Modeling Data Requirements and Uses

Development of a WARMF model to most effectively simulate the processes that determine the hydrology and water quality of flows through Los Laureles Canyon required extensive spatial and time series datasets. A modeling period of October 2000 to October 2007 was selected based upon the availability of time-series data and what was perceived as the limited quantitative value of longer time period based on rate of landuse change within Los Laureles Canyon.

6.2.1   Spatial Datasets

Spatial dataset pre-processing was conducted using ArcGIS 9.2 and BASINS 4.0. Digital elevation model (DEM), Landuse/Landcover, and Streams datasets were acquired from the San Diego State Department of Geography's Tijuana River Watershed Project GIS Clearinghouse. Data were downloaded as ArcInfo Interchange files and converted to raster grids (DEM) or

shapefiles (Landuse/Landcover and Streams) in ArcGIS 9.2. based upon the format of the data. All data were re-projected into Universal Transverse Mercator North American Datum 1983 Zone 11 North to ensure proper orientation when spatial datasets were brought into the watershed model.

Los Laureles Canyon Sub-Watershed delineation was performed in BASINS 4.0 available at no cost through the U.S. EPA Waterscience website. The Tijuana River Watershed 30 m resolution DEM was clipped in ArcGIS 9.2 to focus subsequent processing on the border region in proximity to Tijuana, Mexico. The clipped DEM was used as the base data layer for the watershed delineation process of the Tijuana Region within BASINS 4.0. Automatic watershed delineation was performed by "burning in" the streams data layer into the DEM and allowing the program to delineate the network with a threshold of 4 km^2. Watershed delineation through BASINS 4.0 yielded two spatial files for subsequent use, a polygon layer delineating the spatial extent of catchments and a polyline layer delineating the location of streams.

Los Laureles Canyon was identified among the series of north draining canyons delineated in the border region using spatial reference information collected during site visits. ArcGIS 9.2 was then employed to select the sub-basins and river segments associated with the Los Laureles Canyon Sub-Watershed to guide further pre-processing. Landuse data was then clipped to the extent of the Los Laureles Canyon Sub-Watershed in preparation for model import.

6.2.2 Time Series Datasets

Meteorological data was obtained from the NOAA National Climatic Data Center (NCDC) GIS Portal. The "Surface Data, Global Summary of the Day" provides daily time-series data for select airports around the country as well as limited stations world wide. The closest operating meteorological station to Los Laureles Canyon is currently located at General Abelardo L. Rodríguez International Airport, in Tijuana, Mexico. The airport is approximately 14.5 km due east of the canyon, at an elevation of 149 m. Data was available from March

Table 5. Meteorological data of interest (NOAA NCDC, 2008).

Abbreviation	Significance
YEARMODA	Date: YYYY/MM/DD
PRP	Daily Precipitation
TMAX	Maximum Daily Temperature
TMIN	Minimum Daily Temperature
DEWP	Dewpoint
VISIB	Maximum Daily Visibility
WDSP	Daily Windspeed
SLP	Daily Atmospheric Pressure

22, 1990 to the present. This entire file was downloaded from the NOAA National Climatic Data Center GIS Portal and saved as a text file, which was later converted to an excel file. The data of interest from the General Abelardo L. Rodríguez International Airport are summarized in Table 5.

The dataset was "cleaned" of any irregularities, data gaps and placeholders. Precipitation data placeholders (99.99) were replaced with a "0," wind speed placeholders (999.9) with the average overall wind speed, and atmospheric pressure placeholders (9999.9) with the average overall atmospheric pressure. Single missing data for any category were replaced with the average value of the previous and following day. The data were then prepared for input into WARMF. The date column was formatted as MM/DD/YYYY and precipitation was converted from inches to cm. Maximum temperature, minimum temperature and dew point were converted from Fahrenheit to Celsius, while wind speed was converted from MPH to m/s. Finally, cloud cover

was determined by the algorithm: 1- VISIB/(Max)VISIB. In the following order: PRCP, TMIN, TMAX, CLOUD, DEWP, and WIND, were then entered into the WARMF model. A graph of the data for precipitation and max/min temperature is depicted in Figure 20.
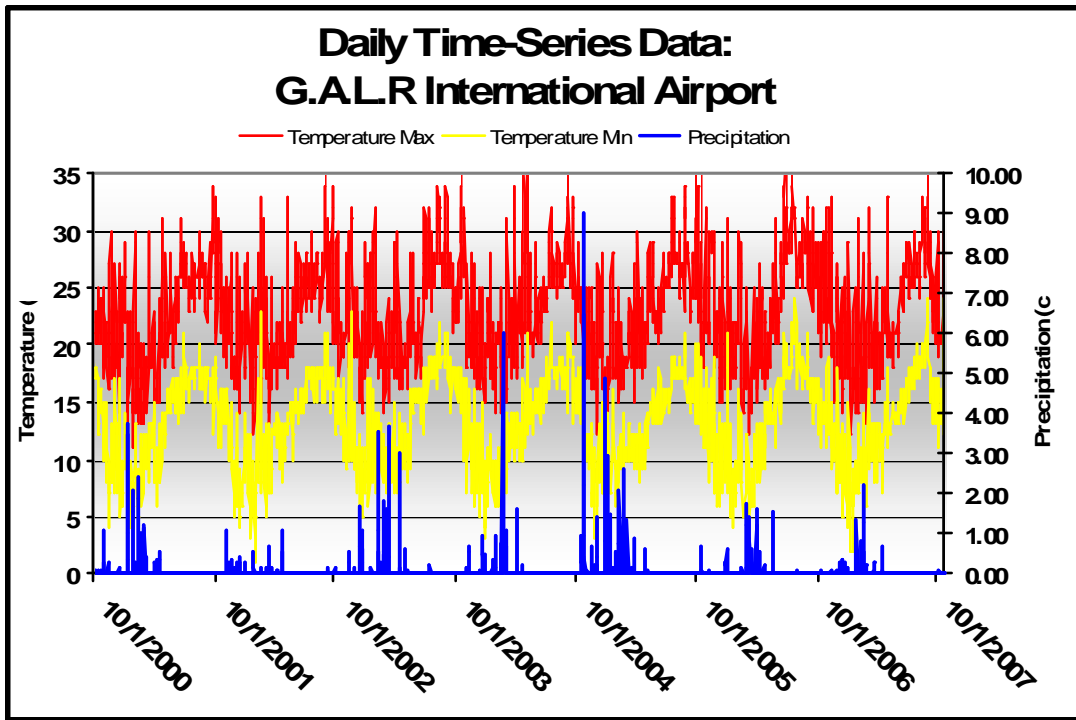

Figure 20. Precipitation, maximum temperature, and minimum temperature for General Abelardo L. Rodríguez International Airport (NOAA NCDC, 2008).

Observed Hydrology data was obtained from the USGS National Water Information System. The "Surface Water Daily Data" provides daily time-series data from gauges located on select rivers and streams around the county. Currently, there are no flow gauges located in Los Laureles Canyon to measure discharge through the canyon. Thus, observed hydrology was measured by proxy from a similar creek. Jamul Creek, approximately 30 km northeast of the canyon, was chosen as a representative for Los Laureles for two reasons: 1) both sub-watersheds are approximately 14 km^2 in area and 9 km in length, and 2) soils in both catchments are dominated by hydrogroup A. A site visit confirmed these similarities, although it was noted that Jamul Creek is more vegetated and less populated in most areas than Los Laureles. For import into WARMF, it was necessary to convert the data from cubic feet per second to cubic meters per second. The hydrograph for Jamul Creek is shown in Figure 21. It is important to note that the wettest year in history, 2004, is included in this time of reference.
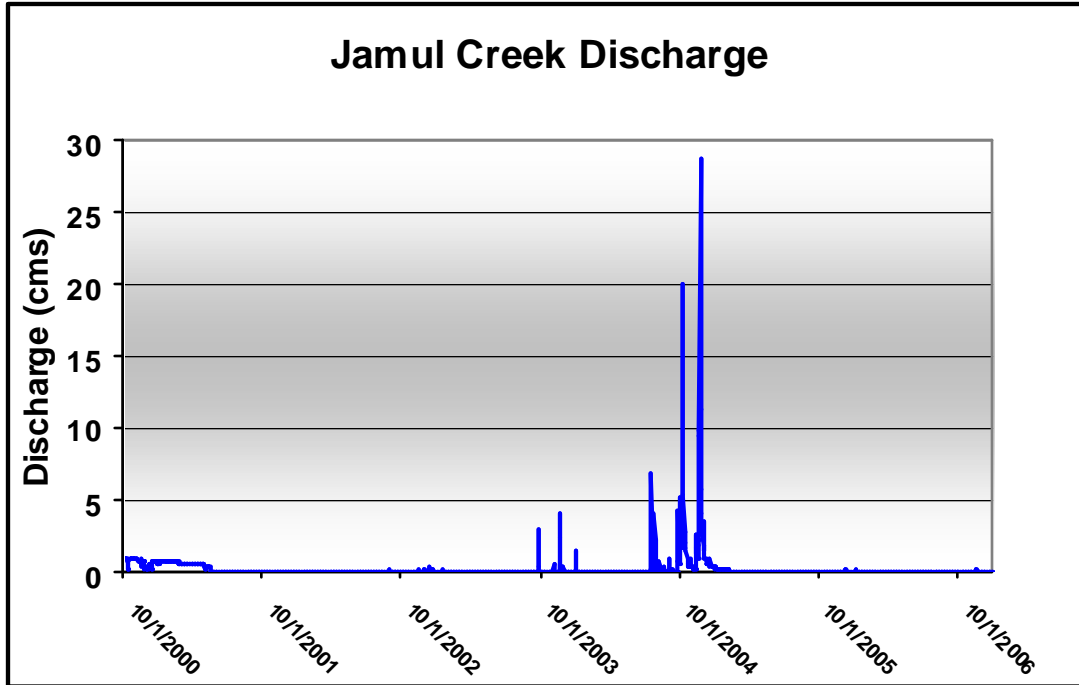
Figure 21. Discharge in Jamul Creek, CA with a conversion coefficient of .4. Note that the wettest year on record, 2004, shows clearly in the hydrograph (USGS, 2008).

Observed fecal coliform data was available through a study completed by Coalición JAJAN as well as efforts by CESPT, and are summarized in Table 6. It is important to note that there is uncertainty associated with the Coalición JAJAN data, as it is apparent that the dilutions required to achieve the appropriate detection range were not completed. The detection limit was 24,192 MPN/100mL, which was consistently exceeded. Realized values for fecal coliform loading are likely significantly higher. This statement is supported by a fecal coliform concentration of greater than 1,000,000,000 MPN/100mL obtained by CEPST in one of the same locations tested by the Coalición JAJAN, presumably due to correct dilution of the sample. All but three samples exceed Mexican fecal coliform basin objectives of 1000 MPN/100mL by varying orders of magnitude.

Table 6. Water quality for Los Laureles Canyon measured in fecal coliform MPN/100mL (Coalición JAJAN and CESPT, 2007)

	Date	Value (NMP/100mL)	Latitude	Longitude
Coalición Jajan				
Cañón de los Laureles #1	11/10/2005	>24,192	32.496	117.084
Cañón de los Laureles #1	09/15/2005	>24,192	32.496	117.084
Cañón de los Laureles #1	06/09/2005	>24,192	32.496	117.084
Cañón de los Laureles #1	05/26/2005	>24,192	32.496	117.084
Cañón de los Laureles #2	09/15/2005	>24,192	32.509	117.084
Cañón de los Laureles #2	06/09/2005	>24,192	32.509	117.084
Cañón de los Laureles #2	05/26/2005	>24,192	32.509	117.084
Cañón de los Laureles #3	04/06/2006	169	32.522	117.091
Cañón de los Laureles #3	06/06/2006	>24,192	32.522	117.091
Cañón de los Laureles #3	03/09/2006	411	32.522	117.091
Cañón de los Laureles #3	05/12/2006	>24,192	32.522	117.091
Cañón de los Laureles #3	03/23/2006	>24,192	32.522	117.091
Cañón de los Laureles #3	05/25/2006	>24,192	32.522	117.091
Cañón de los Laureles #3	04/27/2006	>24,192	32.522	117.091
Cañón de los Laureles #3	09/15/2005	>24,192	32.522	117.091
Cañón de los Laureles #3	06/09/2005	>24,192	32.522	117.091
Cañón de los Laureles #3	05/26/2005	689	32.522	117.091
CESPT				
Cañón de los Laureles #1	08/01/2007	1,000,000,000	32.496	117.084

6.3 WARMF Development

Three spatial datasets were used to develop the WARMF model for Los Laureles Canyon. The two layers developed during watershed delineation and subsequent spatial processing were imported into WARMF as the catchment and river layer shown in Figure 22. Each of the 9 delineated sub-basins within Los Laureles Canyon were separated by a sub-watershed boundary to allow for the manipulation of the sub-basin physical characteristics in subsequent steps of model development.

Watershed landuse/landcover was then imported into WARMF. The spatial distribution of landuse/landcover classes delineated in the dataset acquired from the SDSU TRW Project were site specific and did not align with the more general landuse/landcover class list provided within WARMF. User discretion drawing from
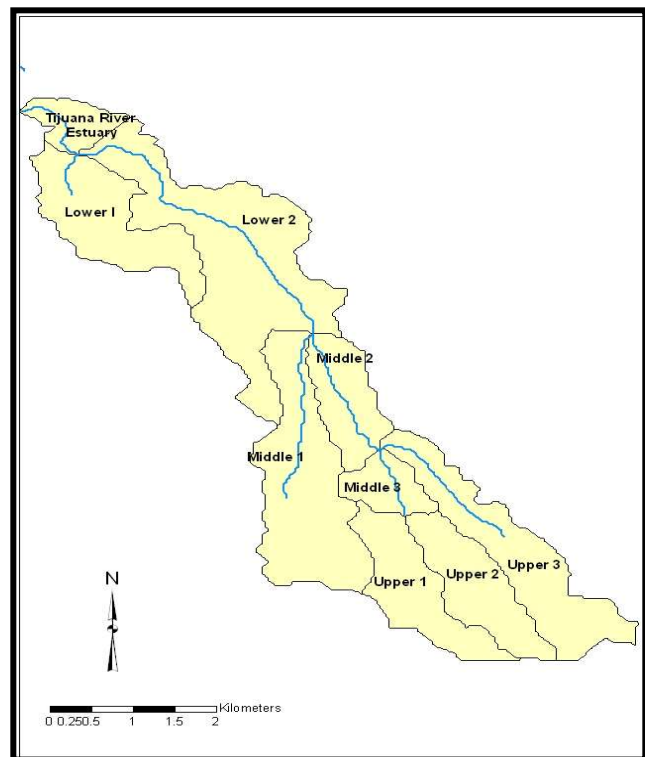
Figure 22. River segment and basin data layers with associated sub-basin names.

observations during site visits was utilized to adapt TRW classifications to WARMF classifications as shown in Table 7.

Following the development of the spatial components of the model, time series data were imported into WARMF. Daily precipitation time series data from the Tijuana General Abelardo Airport were imported into the model and associated with all sub-basins within Los Laureles Canyon. Import of Jamul Creek daily discharge data into WARMF required the development of hypothetical latitude and longitude coordinates for use within Los Laureles Canyon. A qualitative spatial assessment of the location of the USGS Jamul Creek stream gage within the Jamul Creek Watershed showed gage placement in the lower reaches of the creek upstream from a large reservoir. Jamul Creek discharge data were then analogously assigned latitude and longitude values representing an on-stream location in the lower reaches of Los Laureles Canyon in the largest sub-basin on the Mexican side of the border. Time series water quality data were then imported into the WARMF model with geographic reference information.

Table 7. Landuse/Landcover classifications from TRW dataset and associated WARMF classification.

TRW Landuse Classification	WARMF ID	WARMF Classification
Row Crops	5	Cropland/Pastureland
Open Grazeable Land	7	Rangeland
Commercial	13	Commercial/Industrial
Dispersed Residential	12	Residential
Extractive Industry	11	Barren
Industrial	12	Commercial/Industrial
Landfills/Junkyards	11	Barren
Non-Developed	7	Rangeland
Recreation	11	Barren
Residential	12	Residential
Transportation	12	Commercial/Industrial
Disturbed/Under Construction	11	Barren

Default model values for geologic and hydrologic characteristics do not effectively represent the physical parameters influencing stream hydrology within Los Laureles Canyon. WARMF provides an interface for users to specify the constraints of a model hydrologic auto calibration to bring modeled hydrology closer to observed values derived from stream gage data. Three auto calibrations of 1000 iterations each were performed with the Los Laureles Canyon Watershed model. These three sub-basin groups were selected based upon similar slope, soil characteristics and relative levels of development. The first hydrologic auto calibration was run with the three upper sub-basins, the second with the three middle sub-basins, and the third with the three lower sub-basins.

In addition to hydrologic auto calibrations, soil parameters within the Los Laureles Canyon WARMF model were adjusted to represent the predominant soil cover. A series of site visits indicated that soils within the canyon were primarily of the A soil hydrogroup, specifically sandy

loams. Hydrologic characteristics of sandy loam soils incorporated into the model were adapted from Syvitski *et al.* (2000) and Morehed *et al.* (2003) and are shown in Table 8.

Table 8. Soil characteristics of sandy loams soils of Los Laureles Canyon within WARMF model.

Soil Layer	Thickness (cm)	Initial Moisture	Field Capacity	Saturation Moisture	Horiz Cond. (cm/day)	Vertical Cond. (cm/day)	Root Distribution	Density (gcm-3)	Soil Tortuosity
1	15	0.3	0.4	0.5	1500	2500	0.75	1.3	10
2	25	0.2	0.3	0.45	150	250	0.1	1.3	10
3	40	0.22	0.22	0.35	15	25	0.1	1.3	10
4	60	0.35	0.2	0.35	10	10	0.05	1.3	10
5	80	0.35	0.15	0.35	5	5	0	1.3	10

The population of each sub-basin was estimated by assuming equal population density in residential landcover throughout the Los Laureles Canyon and calculating the percent of the total residential area present in each sub-catchment of Los Laurleles Canyon. Population estimates in 2003 were placed at 40,000 individuals. This value was adjusted to 45,000 to account for probable population growth between 2003 and late 2007. The relative percent of basin population for each sub-catchment was used to determine the number of the Canyon's estimated residents were present in each sub-basin. Estimated populations by sub-basin are shown in Table 9.

Table 9. Estimated population by canyon sub-basin based upon landuse cover and sub-basin area.

	Sub-Basin								
Area (sq km)	Canyon	Estuary	Lower I	Lower II	Middle 1	Middle II	Middle III	Upper I	Upper II
	14.74	0.49	1.69	3.69	2.55	0.99	0.57	1.32	1.26
% Total Area	100.00	0.03	0.11	0.25	0.17	0.07	0.04	0.09	0.09
Estimated Residents	40000	0	1919	16378	2796	7031	2769	2334	4333

6.4   Simulation Development

The development of the Los Laureles Canyon Watershed WARMF model focused on most effectively simulating the current hydrologic and biogeochemical force affecting the water quality associated with flows through the catchment. A large component of the analytical value of the WARMF model is derived from the capability of simulating the same processes under differing scenarios. Four scenarios were developed by altering components of the Los Laureles Canyon WARMF model to provide insight into the likely impact of four different sewage management options on basin water quality.

6.4.1   *Baseline Scenario*

The baseline modeling scenario simulates the processes currently impacting the hydrologic and biogeochemical processes within Los Laureles Canyon. This current scenario provides insight into the magnitude of water quality impairment within the catchment as well as the variation of these impairments over time as a response to regional meteorology. The relative contributions of aqueous and suspended constituents from each landuse/landcover were derived from WARMF default values and are shown in Appendix 3 Tables A and B. Sewage management in the developments within Los Laureles Canyon was assumed to be non-existent, based upon the absence of public utility infrastructure, personal correspondence with Oscar Romo indicating existing sewers were non-functional, and site visits showing the presence of blackwater, or untreated waste water, discharged into roads if not into the channel directly.

6.4.2 Sewering San Bernardo Scenario

As stated previously, conversations with staff at the State Public Services of Tijuana or (CESPT) has indicated that the small community of San Bernardo within Los Laureles Canyon may be formally recognized by the Tijuana government and receive public services (see Figure 23). CESPT has indicated that the City of Tijuana hopes to offer sewer service to San Bernardo in 2009 (Medina Parra personal correspondence, 2007). In theory, providing sewer service to a community within Los Laureles Canyon would reduce the volume of untreated water entering the channel. A simulation was developed to quantify the magnitude of the expected reduction in the transport of pollutants of concern into the waters of Los Laureles Canyon as a result of a San Bernardo Sewering project. Parameters reflecting sewage treatment from residential and commercial/industrial landcover in Los Laureles Canyon were altered to reflect public sewage management in the western upper sub-basin of Los Laureles Canyon. Sewage treatment parameter values used for the sewage treatment of this upper sub-basin were adapted from Kirkland 2001 as cited by Weintraud *et al.* 2004 and are shown in Appendix 3.
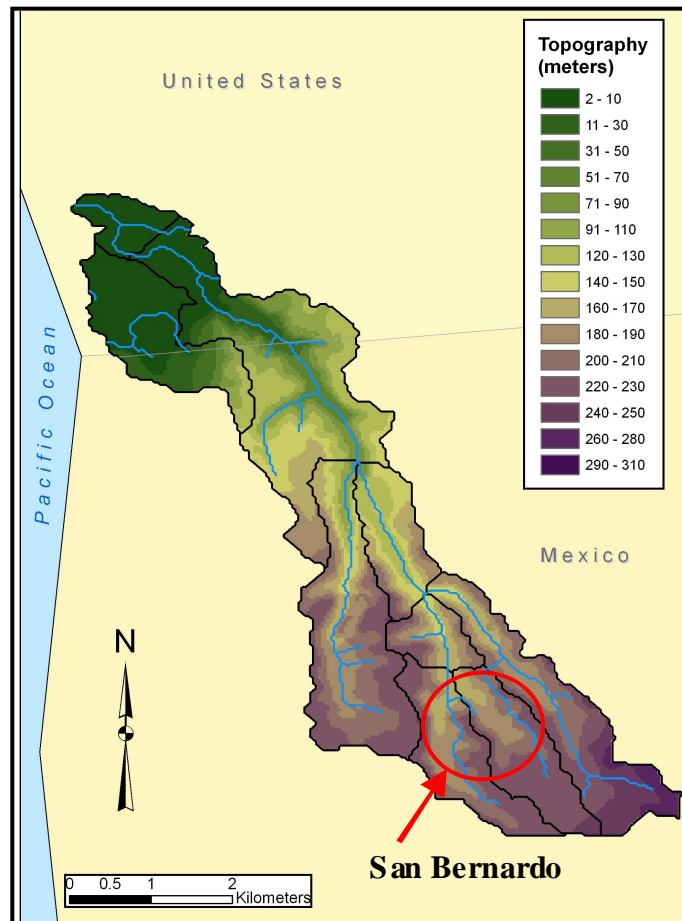

Figure 23. Location of the community of San Bernardo within Los Laureles Canyon.

6.4.3 Los Laureles Septic System Scenario

In addition to simulating current or planned scenarios, WARMF allows the user to develop theoretical scenarios to determine how water quality may be impacted by potential future management or policy actions. Following the completion of the planned San Bernardo Sewering project, a combination of U.S. and Mexican federal and state agencies may establish a fund or provide incentives for the residents of Los Laureles Canyon who occupy land outside of the sewered San Bernardo area to install personal septic systems to treat blackwater. A simulation reflecting this potential policy change was developed where sewage treatment parameters for all sub-basins, with the exception of the sub-basin containing San Bernardo, were altered to reflect well-maintained septic systems. However, due to socioeconomic factors, the simulated penetration of these septic projects was assumed to be 85% leaving 15% of the population that may be unlikely to participate in the program without any sewage treatment infrastructure.

These sewage treatment parameters were again taken from Kirkland 2001 as cited by Weintraud *et al.* 2004 and are included in Appendix 3.

6.4.4   *Los Laureles Sewer System Scenario*

Discussions with stakeholders have indicated that a potential future policy or management response from the state and local governments to the development and associated water quality problem may be to expand the San Bernardo sewering project to encompass all of Los Laureles Canyon residences. Full-coverage sewering was implemented in other north draining canyons within the region, specifically the adjacent Matadero Canyon (Oscar Romo, personal communication, 2007).   A simulation reflecting this sanitary sewer expansion management scenario was achieved by applying the sewage treatment parameters adapted from Kirkland 2001 as cited by Weintraud *et al.* 2004 that were associated with the San Bernardo Canyon sewering project, to all the sub-basins within Los Laureles Canyon. It was assumed that penetration of this policy was 85% due to socioeconomic factors as some residents would not receive or choose to connect their blackwater piping to this sanitary sewer due to cost or physical constraints such as steep canyon walls and easily erodible soils.

6.5   Modeling Results

WARMF outputs provide insight regarding the hydrologic response from Los Laureles Canyon to the region's meteorology and the pollutant loads associated with these flows. The availability of geospatial resources through the SDSU Tijuana River Watershed Project allowed for the development of this model. However, due to the absence of sufficient and reliable data regarding observed hydrology and water quality, a quantitative determination of model performance through statistical methods such as the development of a Nash-Sutcliffe Coefficient of Efficiency was precluded (McCuen, 2006). Subsequent stakeholder actions may yield time-series data for observed hydrology and water quality and allow for future model refinement. The results presented here provide insight into the relative magnitude of the hydrologic and biogeochemical processes affecting water quality within Los Laureles Canyon and can be used to facilitate stakeholder discussions regarding implementation options and identifying associated data needs when allocating resources.

6.5.1   *Hydrology*

Simulated stream discharge derived from WARMF shows a distinct seasonal pattern of flows through Los Laureles Canyon driven by the region's Mediterranean climate. Hydrographs from sub-basins throughout Los Laureles are characterized by periods of little to no discharge in the late spring, summer, and early fall months and comparatively high discharge in the late fall, winter, and early spring months when the region receives precipitation events that drive the stormwater water quality issue.
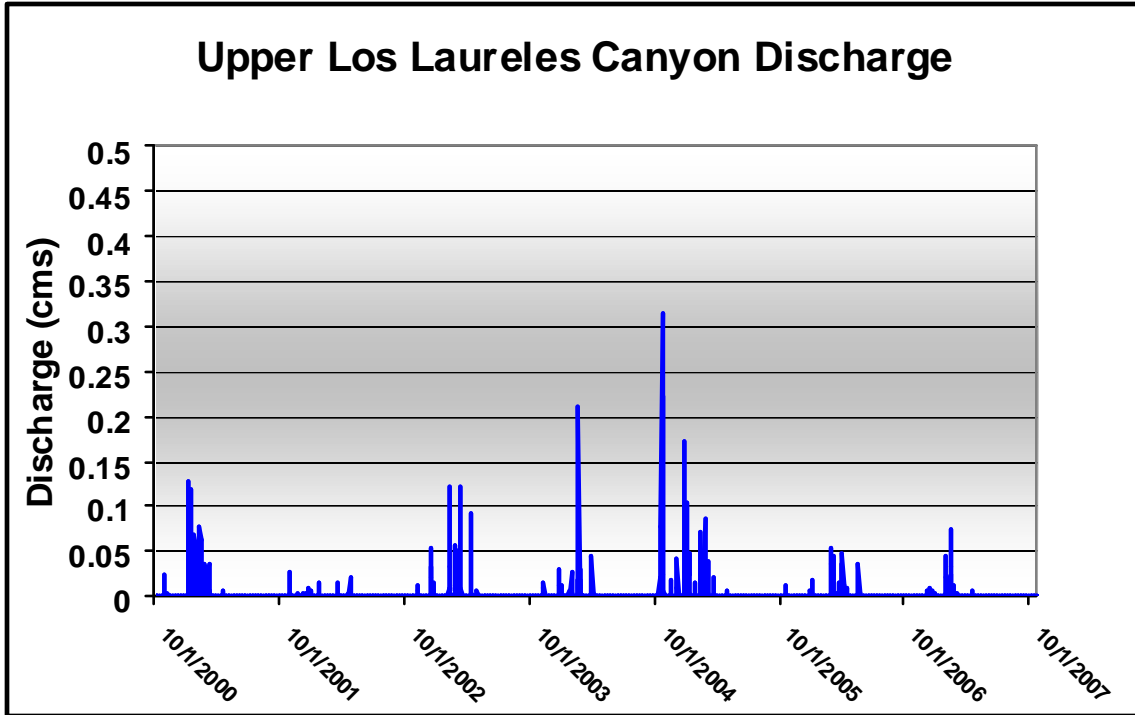
Figure 24. Simulated streamflow or discharge through upper Los Laureles Canyon.
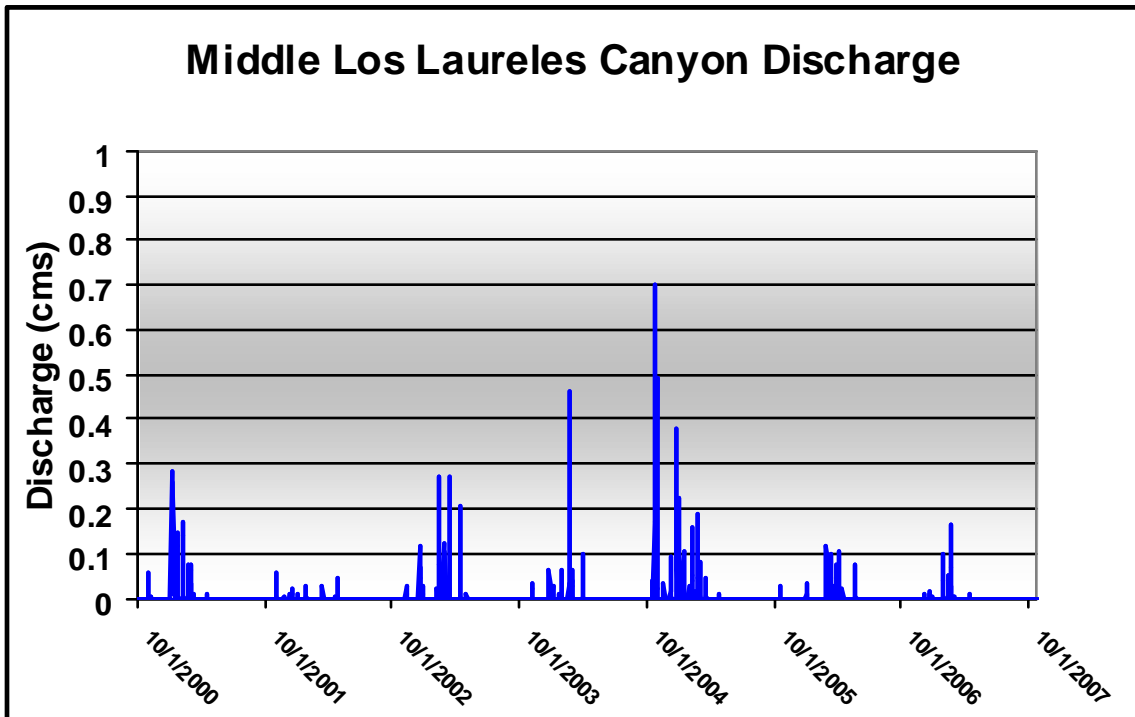

Figure 25. Simulated streamflow or discharge through middle Los Laureles Canyon.
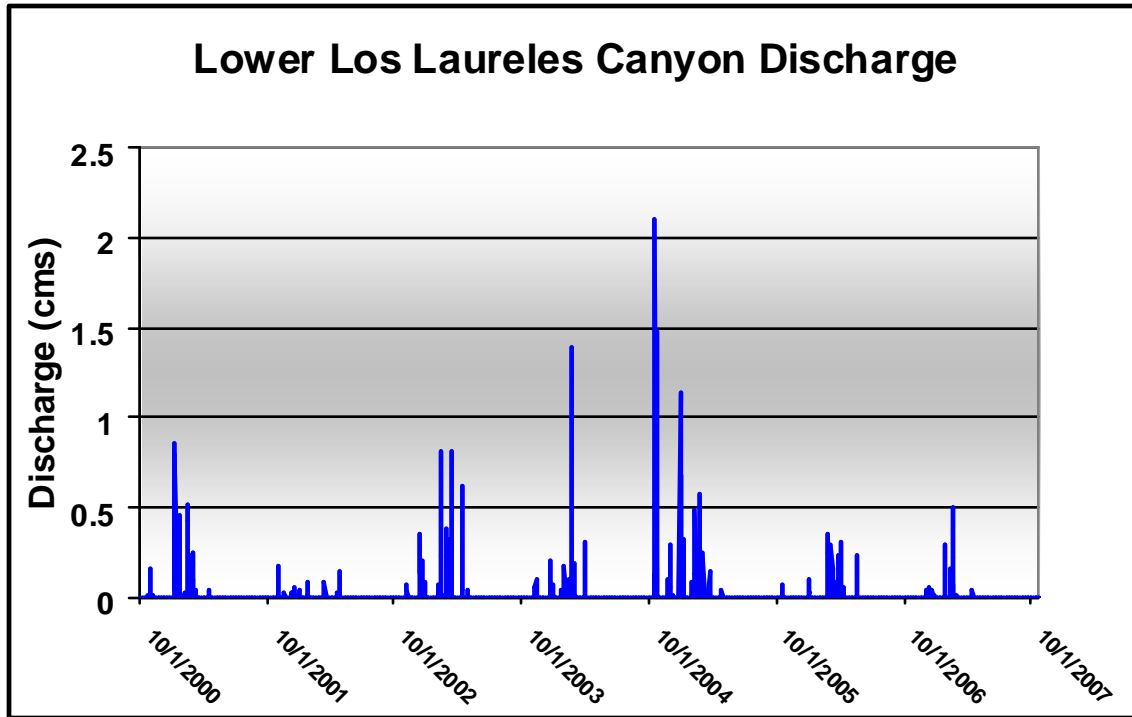
39

Figure 26: Simulated streamflow or discharge through lower Los Laureles Canyon.

Discharge through the upper sub-basins, where the drainage area is the smallest, is the lowest with a maximum discharge simulated to be 0.34 cms with an average discharge of 0.002 cms (Figure 24). Sub-basins in the middle and lower sections of Los Laureles Canyon have greater discharges due to runoff from upstream sub-basins integrating with runoff in the middle and lower sub-basins. Simulated discharge from the middle sub-basins within the canyon show a peak discharge of 0.73 cms and with average discharges of 0.05 cms and (Figure 25). The highest discharge through the canyon occurs in the lower sub-basins where flow through the upper and middle reaches of Los Laureles Canyon come together in the concrete channel before flowing under Transpeninsular Highway 1 and into the U.S. Peak discharge in the lower sub-basins is 2.12 cms with an average of 0.15 cms (Figure 26). Simulated hydrology is not influenced in the scenarios developed for differing sewage management options.

6.5.2 Water Quality

Simulated fecal coliform concentrations for the Baseline, San Bernardo Sewer (SB Sewer), Los Laureles Septic (LLSeptic), and Los Laureles Sewer (LLSewer) scenarios over the modeling period are shown in Figures 27 through 29. Fecal coliform concentration figures are shown with a logarithmic y-axis to account for significant temporal variability. Periods of no discharge correspond with periods of no data or the absence of the fecal coliform concentration series. Periods of fecal coliform transport occur in the late fall, winter, and early spring when canyon hydrographs in Figures 24 through 26 show the highest rates of discharge. The Mexican Federal basin water quality objective for fecal coliform concentrations is 1000 MPN/100mL and is shown on the graph (SEMARNAT, 1997). The U.S. fecal coliform objective when these waters flow across the border is 400 MPN/100mL (U.S. EPA ORD, 1986).

Simulated fecal coliform concentrations in the waters flowing through Los Laureles Canyon for the Baseline scenario range from 0 to over 100,000 MPN/100mL in the upper sub-basins and 0 to 1,500,000 MPN/100mL in the middle and lower sub-basins. Modeled results for all reaches of the canyon show periods of significant non-compliance with the Mexican water quality standards and exceedances of three orders of magnitude or more (Figures 27 - 29). Highest fecal coliform concentrations throughout the catchment are simulated to occur in the lower reaches of the watershed as relative fecal coliform loads from upper and middle sub-basins are integrated in waters flowing through the lower reaches of the canyon. Periods of compliance for the baseline scenario are primarily limited to periods when the WARMF model simulated a discharge of 0 cms and therefore no concentration of fecal coliform colonies.

Los Laureles Canyon WARMF model outputs for planned and potential sewage management actions in Los Laureles Canyon are also shown in Figures 27 through 29. San Bernardo Sewer scenario model simulations suggests that providing sewer service to this small upper-basin community will yield a slight reduction in the fecal coliform concentration associated with waters flowing through the upper reaches of the canyon leading to continued periods of significant non-compliance only slightly improving from the Baseline scenario.

Simulation results for the Los Laureles Canyon Septic System scenario show a notable reduction in fecal coliform concentrations leading to periods of compliance with the Mexican basin objective among extended periods of non-compliance throughout the modeling period (Figures 27-29). Fecal coliform concentrations in the upper sub-basins of Los Laureles Canyon for this scenario, as all previous scenarios, were the lowest throughout the Los Laureles. Downstream flows integrated from upper and middle sub-basins are simulated to contain greater concentrations of fecal coliform and experience greater frequency of non-compliance.

WARMF model results for the Los Laureles Canyon Sewer scenario show a significant reduction in fecal coliform concentrations throughout the duration of the modeling period. Fecal coliform concentrations are simulated to vary between 0 and 800 MPN/100 mL remaining below the Mexican basin objective for the duration of the period modeled. In addition this scenario achieved compliance with the U.S. basin objective for all but the most significant periods of discharge associated with the winter of 2007-2008 (Figures 27-29).
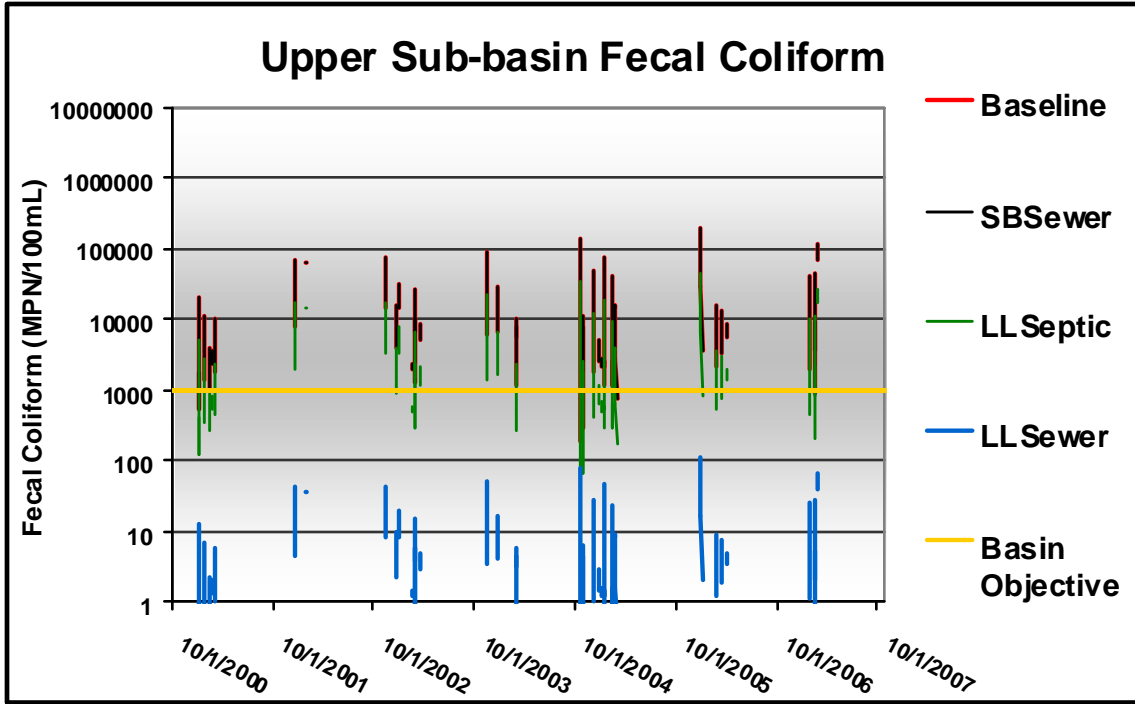
Figure 27: Simulated fecal coliform concentrations through upper Los Laureles Canyon.
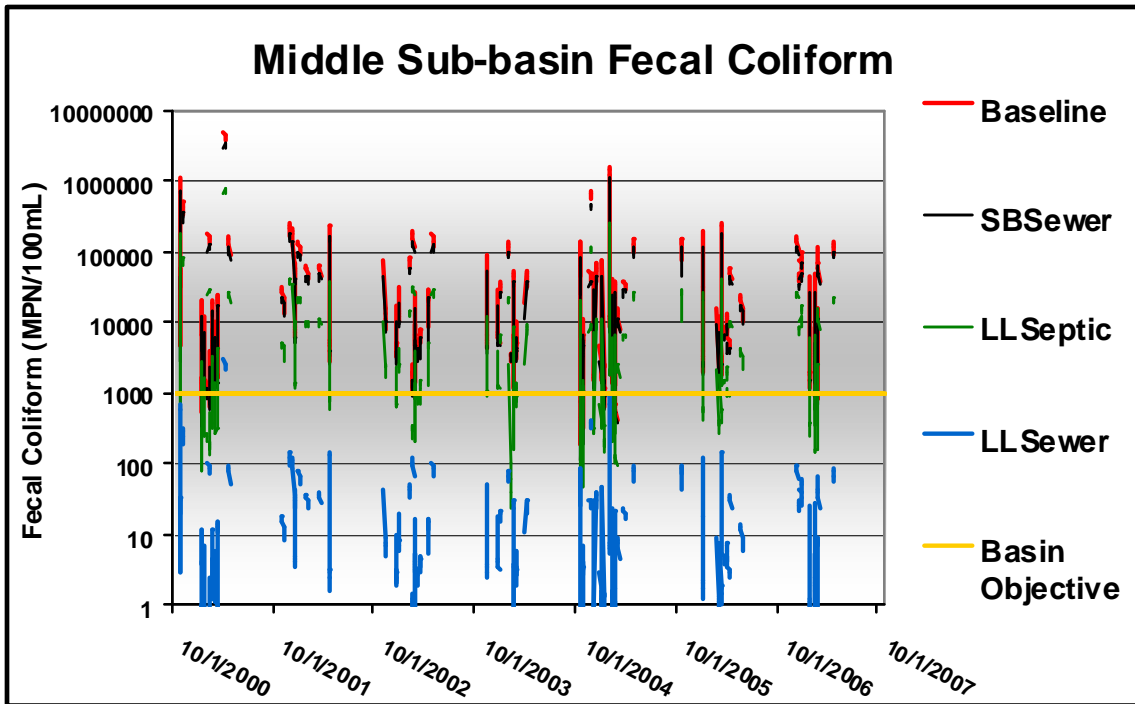

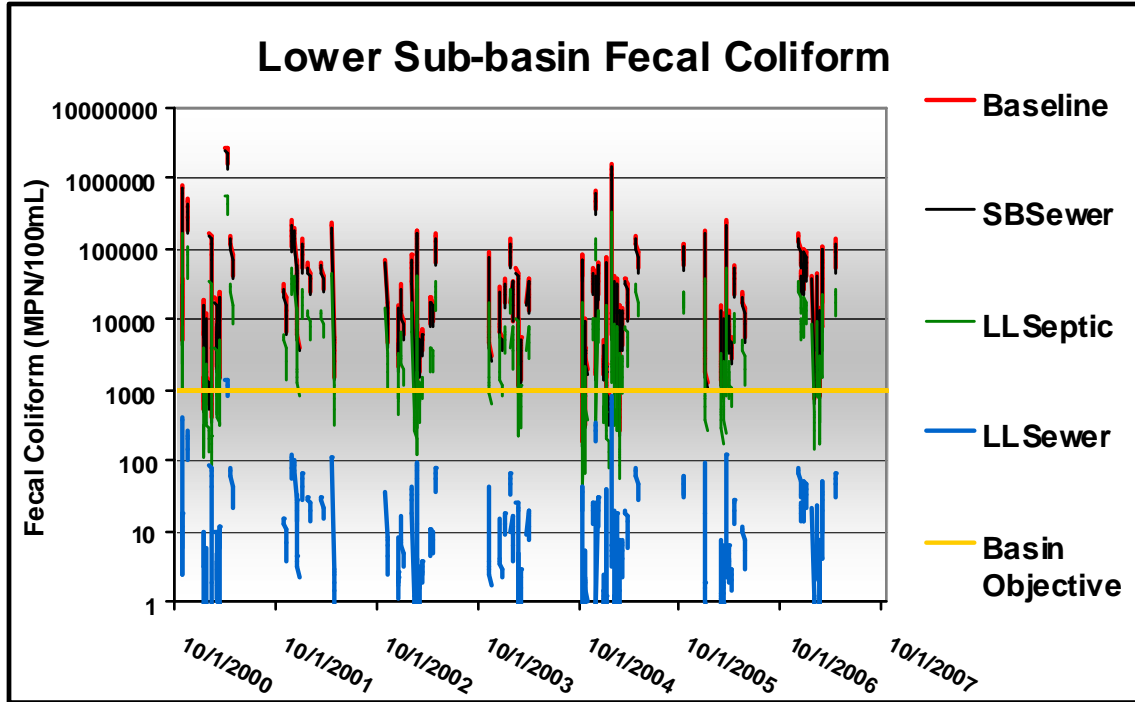**Figure 28: Simulated fecal coliform concentrations through middle Los Laureles Canyon.**

Figure 29: Simulated fecal coliform concentrations through lower Los Laureles Canyon.

6.6   Discussion

Results from WARMF simulations provided insight into the hydrologic regime regulating the transport of pollutants of concern and should be used to guide subsequent discussions and technical endeavors. A number of key points derived from watershed modeling are outlined in the following sections.

6.6.1   *The Hydrologic-Water Quality Relationship*

Simulated hydrographs for sub-basins within Los Laureles Canyon show no discharge throughout much of the year due to the region's Mediterranean climate. In the absence of significant baseflow, the transport of fecal coliform colonies through Los Laureles Canyon is limited during the dry season. Realized low discharge baseflow derived from the direct release of blackwater into the canyon may provide a means of transport during between March and November though the rate and relative distance of effects is limited due to regional geology. The transport of fecal coliform colonies between sub-basins of Los Laureles Canyon and across the border is limited to periods following high intensity, short duration storm events that lead to overland flow and stormwater runoff. Discharge and associated fecal coliform concentrations are shown to be lower in the upper sub-basins of Los Laureles Canyon and increase downstream as flows and their pollutant loads are integrated.

6.6.2   *Basin-Wide Fecal Coliform Loading*

Addressing water quality constituents of concern may involve addressing the pollutants or the mechanism of transport. The process of sewering the community of San Bernardo may effectively de-couple the hydrologic-water quality relationship and reduce loading from the sewered area. WARMF results indicate a reduction in the concentration of fecal coliform flowing through Los Laureles Canyon when comparing the baseline to the San Bernardo Sewer

scenario. However, this reduction is very slight due to the contributions of fecal coliform colonies from untreated blackwater systems associated with communities in other sub-basins throughout the Los Laureles Canyon. WARMF simulates the greatest loading from sub-basins supporting the largest populations though the contribution of fecal coliform from all sub-basins is significant when working to address ambient concentrations (Figure 30).
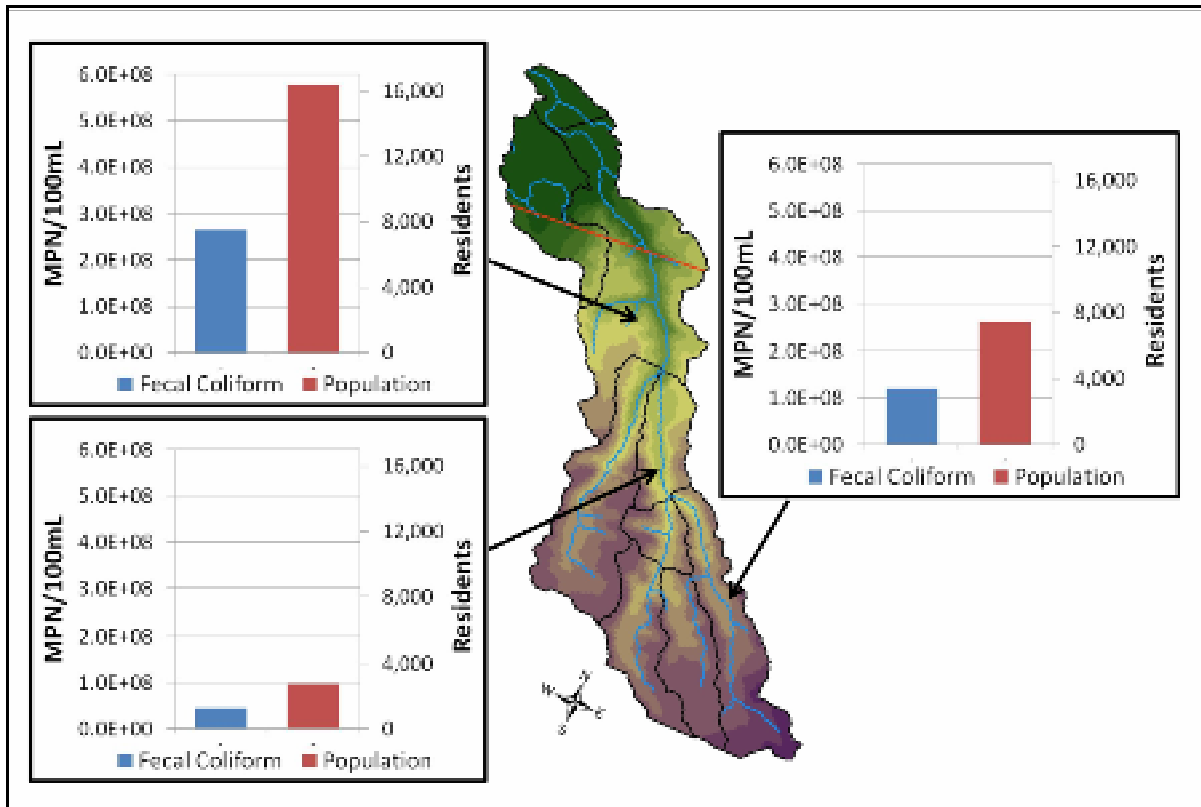

Figure 30: Simulated fecal coliform loading and associated population for three sub-basins within Los Laureles Canyon.

6.6.3 Basin-Wide Sewage Treatment

Simulation outputs indicate that the proposed project to sewer the community of San Bernardo is not going to significantly reduce the loading of fecal coliform through Los Laureles Canyon due to basin-wide contributions. The likely viability of policy or management responses addressing blackwater treatment in communities throughout Los Laureles Canyon were assessed through WARMF simulations. Due to topographic and geologic characteristics, a plan to implement septic systems throughout Los Laureles Canyon are likely to result in a significant reduction in loading though this decrease may not bring concentrations below Mexican basin objectives. Physical constraints may preclude the use of septic systems on developments on steep slopes within the canyons. Additionally, the relative instability of current developments and rates of canyon erosion may provide a strong disincentive for managers or homeowners to make such an investment. Septic system use within Los Laureles Canyon may be encouraged by community groups or all levels of government in stable developments on minor slopes. However, the widespread application of septic systems in Los Laureles Canyon may prove to be infeasible, ineffective, and costly.

WARMF simulations suggest that the expansion of the project to sewer the community of San Bernardo to all communities within Los Laureles Canyon may effectively uncouple the water quality-hydrology relationship and reduce fecal coliform loading. Providing robust infrastructure to convey blackwater to treatment systems and prevent untreated sewage from entering Los Laureles Canyon is expected to bring concentrations below Mexican basin objectives throughout the year. Fecal coliform loading due to the presence of pet waste or homes that have not been connected to sewer systems will remain and may be addressed through future stormwater mitigation actions. The absence of significant coverage of infrastructure, most notably concretized roads or other potential construction impediments, may allow for the construction of a low volume sanitary sewer system to treat the wastewater from community homes.

Historically, sanitary sewer and stormwater sewer systems in developing countries have been combined to reduce piping costs and ease the burden of infrastructure construction (Andoh, 1994). However, combined sewer piping has often been connected to treatment structures that are unable to effectively treat grey water flows derived primarily from stormwaters following storm events. Subsequent overflows of untreated sewage transfer pollutants from sub-basins where stormwaters are collected to areas surrounding the overwhelmed treatment plant. Expenditures avoided by combining stormwater and sanitary sewage piping are often incurred during treatment plant expansion or due to environmental degradation (Andoh, 1994). High rates of stormwater flow through Los Laureles Canyon shown by WARMF through model simulation as well as resident accounts of post-precipitation discharges suggest that combined sewer treatment infrastructure would be required to treat large volumes of impaired waters in short time periods to account for stormwater contributions. Addressing blackwater treatment through sanitary sewer treatment infrastructure is likely to reduce fecal coliform concentrations below basin objectives. Addressing stormwaters flowing through Los Laureles Canyon can be addressed through a series of best management practices outlined in subsequent sections.

6.6.4   Model Uncertainty

WARMF model development was conducted using peer reviewed geospatial datasets and parameter values acquired in the literature of hydrologic and biogeochemical of watershed modeling. Limitations associated with field based water quality data from Coalición JAJAN and CESPT have been discussed in other sections and has led to a more qualitative approach to interpreting the quantitative data provided in model outputs. However, data limitations associated with temporal resolution of precipitation data may have adversely affected the hydrologic performance of the watershed model. Daily precipitation data from General Abelardo Airport in Tijuana were selected for import into the WARMF model due to proximity to Los Laureles Canyon as opposed to hourly precipitation data from San Diego or Imperial Beach. A daily rainfall volume in WARMF is divided by the number of hours in the day and simulated as a constant rate of rainfall throughout the 24 hour period. Precipitation events associated with the Mediterranean climate of southern California and northwest Mexico are characterized by short duration and high intensity (Borowiec, 2007). WARMF hydrology is based upon a water balance model where overland flow is simulated to occur when the water holding capacity of soils, or the field capacity, is exceeded at the modeling timestep. Applying the volume of a typical rainstorm for the region at low intensity over a 24 hour period will allow for greater infiltration into soils allowing for a lesser volume of overland flow.

Discussions with residents of lower Los Laureles Canyon in addition to on site observations have indicated that realized volumes of discharge actually occur at a higher rate than those identified in model simulations. A rough calculation of discharge using Manning's Equation based upon the cross-sectional area of the concretized channel, the associated slope, and the relative roughness of the surface (in this case concrete), provided some insight into the likely magnitude of observed flows through the lower reaches of the canyon (Oregon State University Forestry, 2007).

$$Q=(d^{(2/3)}s^{(1/2)}/n)*A$$

Where:

d = Wetted diameter
s = Slope
n = Roughness coefficient
A = Cross-sectional flow area

Flow through a concretized cross-sectional area (roughness of 0.012) of 16.5 m^2 (1.5 m by 2.5 m) in an area where slope was estimated to be 1° was calculated to be approximately 35 cms (Oregon State University Forestry, 2007). In the absence of stream gage data, discharge over the period of record in Jamul Creek, a catchment characterized by similar physical and meteorological characteristics, was used a proxy for a determination of the likely rate of discharge within Los Laureles Canyon during a mid-magnitude event based upon anecdotal evidence. Jamul Creek discharge data show that the magnitude of flows that can be expected from a 14 km^2 drainage area exceed simulated values and may be closer to the roughly calculated values derived from Manning's Equation (Figure 31).
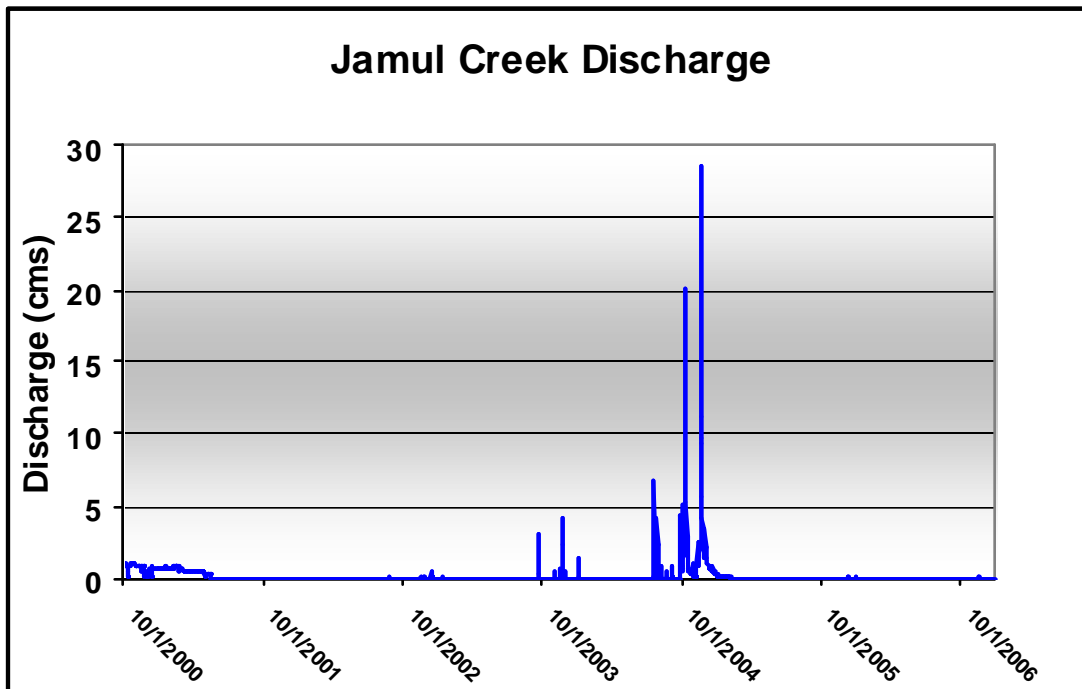

Figure 31: Observed discharge data for Jamul Creek, San Diego County, California (Source: USGS Surface Water Daily, 2007).

The descriptive power of the WARMF model may be enhanced by obtaining hourly time series data to account for the characteristic rainstorms associated with the region. More effectively predicting discharge through Los Laureles Canyon in WARMF is likely to reduce the concentration of pollutants through greater dilution though higher intensity precipitation events may elevate the total loading of pollutants from the relatively undeveloped surfaces of Los Laureles Canyon.

7 BEST MANAGEMENT PRACTICES (BMPs)

7.1 Introduction

Best Management Practices or BMPs, consist of a variety of technologies and techniques designed to treat a number of pollutants of concern including the three primary constituents of concern in Los Laureles Canyon; pathogens, sediment, and debris/refuse. In order to determine BMP viability for Los Laureles Canyon, a comprehensive literature review was completed and a stormwater survey was conducted via the internet. The results of a literature review and stormwater survey provided the required data to conduct a preliminary BMP assessment. The sections below present both structural and non-structural BMPs that may be viable for implementation in Los Laureles Canyon.

7.2 Structural BMPs: Water Quality Control

The sections below provide descriptions, illustrations and schematics of the structural stormwater BMPs selected as viable options for water quality control in Los Laureles Canyon.

7.2.1 Infiltration Basins

Infiltration basins are excavated areas designed for pollutant removal via filtration (Figure 32). Infiltration basins utilize the natural filtering ability of soils to remove pollutants from stormwater runoff (California Stormwater Quality Association, 2003). Properly sited and designed infiltration basins can provide 100% capture of stormwater runoff from small, frequent storms (Urbonas, 1999).

Figure 32. Typical infiltration basin (California Stormwater Quality Association, 2003).

Pollutant removal effectiveness

Infiltration basins are highly effective for treating a number of pollutants including sediment, nutrients, trash, metals, bacteria, organics, as well as oil and grease (California Stormwater

Quality Association, 2003). Correctly sized infiltration basins have been shown to effectively remove 100% of these pollutants. BMP efficiency is often measured by pollutant percent removal, but recent studies have shown that percent removal is not an appropriate metric of BMP efficiency (Wright Water Engineers and Geosyntec Consultants, 2007). The authors present a different measurement approach that focuses on how much the BMP reduces runoff volumes, how much runoff is treated, and the statistical difference between the influent concentration and effluent concentration.

Design considerations

The appropriateness of using infiltration basins for stormwater treatment should be determined by collecting information regarding several site specific factors including soil type, infiltration rate, height of groundwater table, and slope (California Stormwater Quality Association, 2003).

Acceptable soil classes for the use of infiltration basins include soils within the A, B, or C hydrologic groups with soil textures classified as sand, loamy sand, sandy loam, or loam. These soils allow for the necessary infiltration rate of 1.3 cm/hr to ensure each infiltration basin is operating properly. Soils in the D hydrologic group or soils that have high amounts of silts or clays should be avoided (California Stormwater Quality Association, 2003). It is also necessary to ensure a minimum of 1.2 m from the bottom of the infiltration basin to the top of the groundwater table to make certain infiltrated stormwater laden with pollutants does not adversely impact underlying groundwater aquifers (US EPA, 1999). Infiltration basins are most effective when the slope of the basin is less than 15 percent. Low slopes provide adequate stormwater residence time ensuring proper pollutant removal through infiltration (California Stormwater Quality Association, 2003). Infiltration basins are susceptible to clogging in areas with high erosion rates such as Los Laureles Canyon. Therefore, it is necessary to have suitable erosion control techniques (described in Section 7.4) or site pretreatment BMPs designed for sedimentation upgradient from infiltration basin to ensure proper functioning (California Stormwater Quality Association, 2003). Siting infiltration basins outside the channel in areas with flashy high flows may allow for low flow treatment and preserve the integrity of the structure during discharges associated with high magnitude storm events (Barr Engineering Company, 2001). Because infiltration basin functioning depends on many factors, proper design and construction of infiltration basins by expert engineers is vital to ensure proper functioning.

Specifications

Infiltration basin design specifications are site specific and often determined by the structure volume required to capture and treat a desired percentage of annual stormwater runoff. Local, state, or federal governments generally mandate the desired percentage of annual runoff to capture or treat. For instance, the city of San Diego requires the capture and treatment of the amount of stormwater produced from the 85th percentile storm. Based on these calculations and isopluvial maps shown in Figure 33, the 85th percentile storm for Los Laureles Canyon should be approximately 1.4 cm over a 24-hour period (County of San Diego Department of Public Works Flood Control Section, 2003).
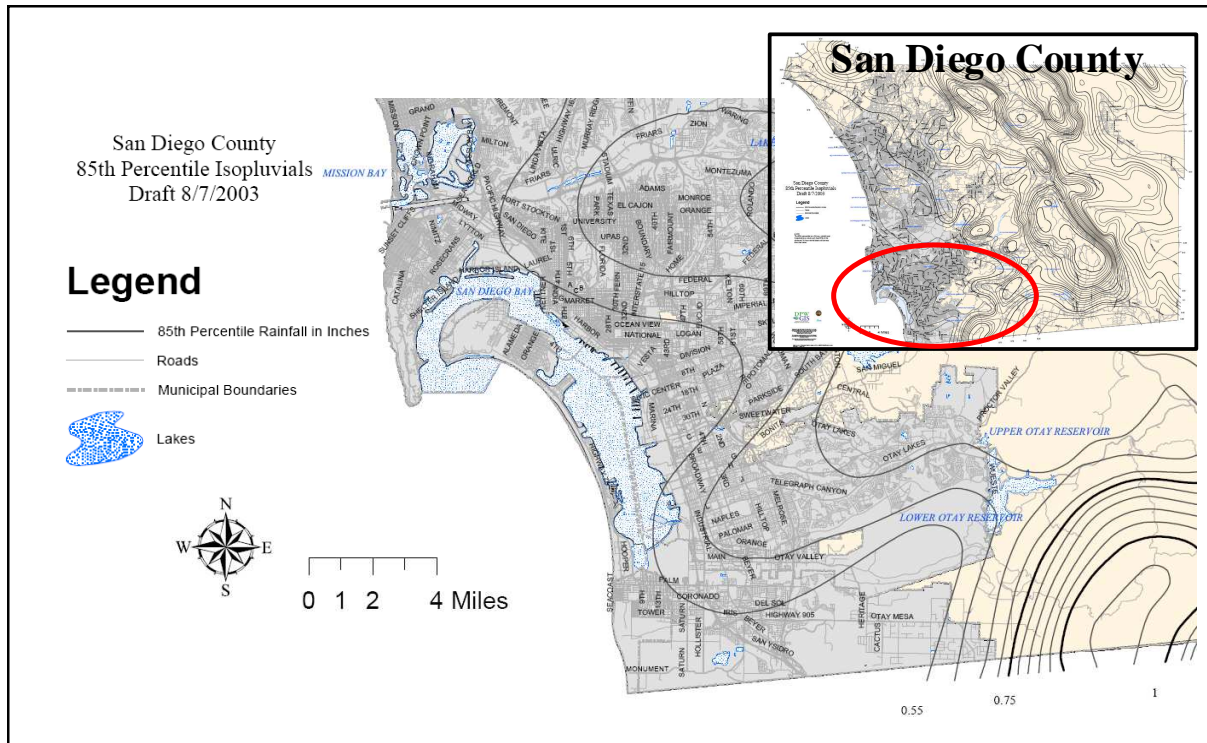
Figure 33. 85th Percentile isopluvial data for San Diego County. (Source: County of San Diego Public Works, 2003).

Infiltration basin volume

There are several methods for calculating the basin volume required for the desired percentage of stormwater runoff treatment. One method presented by the California Stormwater Quality Association (2003) utilizes The Storage, Treatment, Overflow, Runoff Model (STORM) developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers to create curves that relate BMP draw down time, the runoff coefficient of the contributing basin area, and precipitation to determine infiltration basin volume. Drawdown is the amount of time it takes for the stormwater runoff to infiltrate through the basin. The standard drawdown time used in California BMP construction projects is 48 hours. Runoff coefficients represent the percentage of precipitation that is expected to runoff from a given land use type. The runoff coefficient for Los Laureles Canyon is approximately 0.70 due to steep topography, impacted soils, and high population density (County of San Diego Department of Public Works Flood Control Section, 2003). Precipitation data are taken from rain gauges located throughout California.

Required infiltration basin volume can be calculated by multiplying the contributing watershed area with the unit basin storage volume determined by unit basin storage volume charts. Unit basin storage volume charts determine unit basin storage volume located on the x-axis of the chart by relating the desired percentage runoff capture located on the y-axis of the chart to the runoff coefficient for the contributing watershed area represented by four curves. The point of intersection between the line of desired percentage runoff and the runoff coefficient curve determines the unit basin storage volume.

Figure 48 shows the 48-hr drawdown unit basin storage volume chart determined by the STORM model for San Diego County, California.
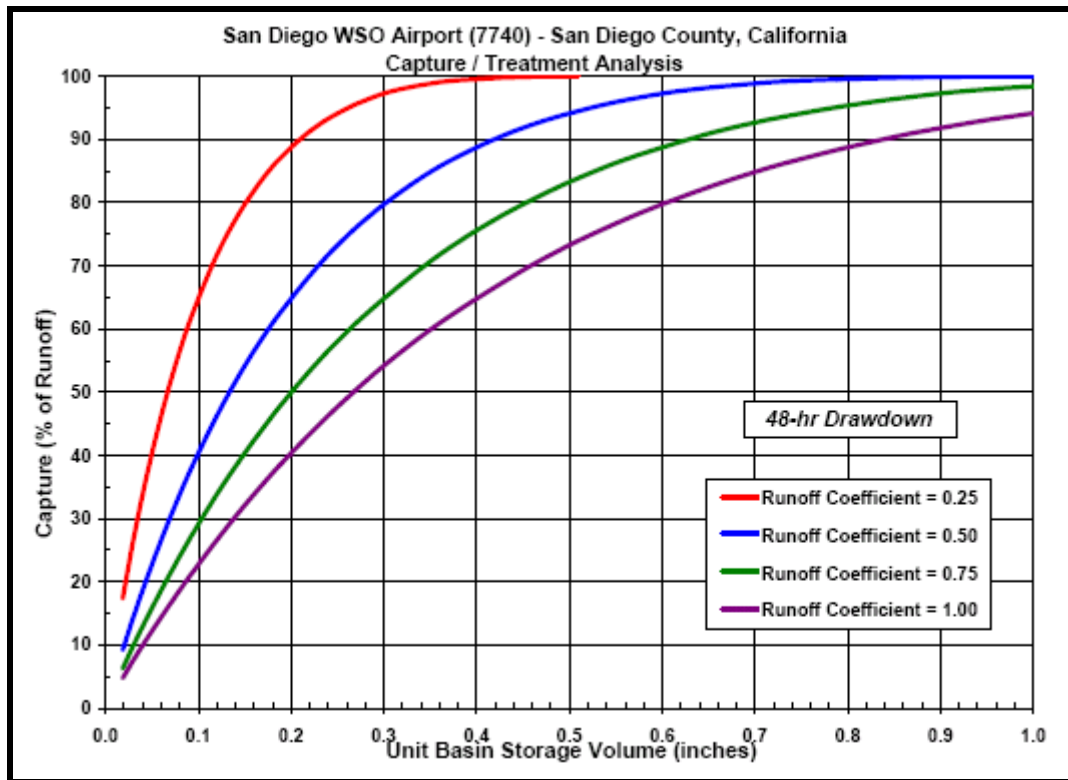

Figure 34. 48-hr drawdown unit basin storage volume chart for San Diego County, California (California Stormwater Quality Association, 2003).

Table 10 lists the estimated stormwater runoff volumes in cubic meters for each sub-basin in Los Laureles Canyon using the STORM unit basin storage volume chart for San Diego County assuming the area of each sub-basin is the contributing area, a runoff coefficient of 0.70, and a desired runoff capture percentage of 85%.

Table 10. Estimated stormwater runoff volumes for each sub-basin in Los Laureles Canyon.

Sub-basin	Area (km^2)	Stormwater Volume (m^3)
Estuary	0.49	6914.45
Lower Los Laureles 1	1.69	23613.21
Lower Los Laureles 2	3.62	50563.44
Middle Los Laureles 1	2.55	35625.04
Middle Los Laureles 2	0.57	7893.89
Middle Los Laureles 3	0.99	13818.19
Upper Los Laureles 1	1.32	18451.30
Upper Los Laureles 2	1.26	17628.60
Upper Los Laureles 3	0.20	2846.07

Infiltration basin area

Infiltration basin areas depend on the stormwater runoff volume, the hydraulic conductivity of the soil and the drawdown time. The following equation adapted from California Stormwater Quality Association, (2003), calculates basin area:

$$A = SRV/kt$$

Where:

A = Basin area (m^2)
SRV = Stormwater Runoff Volume (m^3)
k = 0.5 times the lowest measured hydraulic conductivity (m/hr)
t = Drawdown time (48hr)

Table 11 lists the calculated required BMP area in square meters for treatment of the desired stormwater volume for each sub-basin in Los Laureles Canyon assuming a 0.013 m/hr infiltration rate.

Table 11. Estimated required infiltration basin area for treatment of desired stormwater volume.

Sub-basin	Stormwater Volume (m^3)	Required Infiltration Basin Area (m^2)
Estuary	6900	22000
Lower Los Laureles 1	2400	76000
Lower Los Laureles 2	51000	160000
Middle Los Laureles 1	36000	110000
Middle Los Laureles 2	7900	25000
Middle Los Laureles 3	14000	44000
Upper Los Laureles 1	18000	59000
Upper Los Laureles 2	18000	57000
Upper Los Laureles 3	2800	9100

Implementation and maintenance costs

The main costs associated with infiltration basins are from excavation and construction costs. Limited infrastructure is needed for infiltration basin construction aside from the inlet and outlet structures. Infiltration basin construction costs vary depending on site characteristics, but can be roughly estimated with the following equation (Schueler, 1987):

$$C = 13.9 \, (V / 0.02832)^{0.69}$$

Where:

C = Total Construction Cost ($)
V = Volume of stormwater (m^3)

Table 12 below lists estimated costs in 1995 dollars for infiltration basins sited in each sub-basin of Los Laureles Canyon.

Table 12. Estimated infiltration basin costs in 1995 dollars for each sub-basin of Los Laureles Canyon.

Sub-basin	Stormwater Volume (m^3)	Infiltration Basin Costs ($)
Estuary	6900	72,000
Lower Los Laureles 1	2400	35,000
Lower Los Laureles 2	51000	290,000
Middle Los Laureles 1	36000	230,000
Middle Los Laureles 2	7900	80,000
Middle Los Laureles 3	14000	120,000
Upper Los Laureles 1	18000	140,000
Upper Los Laureles 2	18000	140,000
Upper Los Laureles 3	2800	39,000

Regular maintenance is vital for ensuring the longevity of infiltration basins. The most important maintenance activity is the removal of accumulated sediment from inside the basin. Accumulated sediment decreases the infiltration capacity of the basin thereby decreasing stormwater treatment effectiveness. It is also important to remove any accumulated trash or debris in the basin because this type of refuse also affects structure function and decreases the effectiveness. Estimated infiltration basin maintenance costs are 5-10% of total infiltration basin construction costs (California Stormwater Quality Association, 2003). Due to the high volume of refuse found in Los Laureles Canyon, maintenance costs may be higher than estimated for systems installed in areas with more comprehensive waste management.

7.2.2 Dry Detention Basins

Detention basins are excavated areas designed to provide water quality enhancement through the removal of sediments and associated pollutants as well as flood control and erosion control through temporary stormwater storage (Figure 35) (California Stormwater Quality Association, 2003). Detention basins remove sediments and associated pollutants such as bacteria, metals, phosphorus, and nitrogen through the settling of suspended particles from stormwater (US EPA, 2002). Detention basins vary in size and are generally larger for flood control applications than for water quality enhancement

Figure 35. Photo of dry detention basin (Bill Southard, DES Architects

applications. Detention basins sized for flow modification and flood control also provide erosion control by delaying the amount of stormwater flowing through the channel thereby decreasing the erosion potential of the stormwater.

Pollutant removal effectiveness

Detention basins are effective at removing particulate pollutants such as sediment and the associated pollutants sorbed to the sediment including metals, bacteria, organics, as well as oils and grease. Detention basins are highly effective at removing trash and debris from stormwater runoff, but are not as efficient at removing soluble pollutants such as nutrients (California Stormwater Quality Association, 2003).

Design considerations

There are very few siting constraints for detention basins and are widely used in California because they are applicable in almost all types of soils and geology with minor design adjustments for site specific conditions (California Stormwater Quality Association, 2003).

Among the few constraints is that detention basins should be designed so that the bottom of the should not intersect the groundwater table because a permanently wet bottom may become a vector breeding ground (California Stormwater Quality Association, 2003). Designing detention basin outlets to discharge the stormwater volume over a number of hours, usually 48 hours, is important for maintaining proper detention basin function. No more than 50% of the stormwater runoff volume should leave the detention basin within the first 24 hours. Complete drawdown of the stormwater runoff volume should occur in 72 hours (California Stormwater Quality Association, 2003). A minimum length to width ratio of 1.5:1 is also important for detention basin functioning because it provides adequate area to reduce stormwater velocity allowing sedimentation to occur (California Stormwater Quality Association, 2003). Optimal detention basin depths range from .7 to 1.7 meters with an average of 1.2 meters (California Stormwater Quality Association, 2003).

Specifications

Detention basin specifications are site specific and depend primarily on the desired stormwater capture volume, typically 85% of the annual stormwater volume (California Stormwater Quality Association, 2003).

Detention basin volume

Detention basin volume can be calculated using the same method previously presented in the infiltration basin volume section utilizing the unit basin storage volume charts developed using the STORM model. (California Stormwater Quality Association, 2003).

Detention basin area

Calculating detention basin area requires using the equation adapted from the California Stormwater Quality Association, (2003):

$$SRV = D \times SA$$

Where:

SRV = Stormwater Runoff Volume (m^3)
D = Detention basin depth (m)
SA = Surface Area (m^2)

Table 13 lists the estimated required detention basin surface areas in square meters for treatment of the desired stormwater volume for each sub-basin in Los Laureles Canyon.

Table 13. Estimated required detention basin area in square kilometers for each sub-basin of Los Laureles Canyon.

Sub-basin	Stormwater Volume (m³)	Required Detention Basin Area (m²)
Estuary	6900	5800
Lower Los Laureles 1	2400	20000
Lower Los Laureles 2	51000	42000
Middle Los Laureles 1	36000	30000
Middle Los Laureles 2	7900	6600
Middle Los Laureles 3	14000	12000
Upper Los Laureles 1	18000	15000
Upper Los Laureles 2	18000	15000
Upper Los Laureles 3	2800	2400

Implementation and maintenance costs

Construction costs vary considerably due to the site specific nature of detention basin use. One recent study conducted by Brown and Schueler (1997) evaluated detention basin costs and determined costs can be estimated with the following formula:

$$C = 12.4V^{0.76}$$

Where:

C = Total cost ($)
V = Stormwater volume (ft³)

Routine detention basin maintenance consists of sediment, trash, and debris removal. Estimations of annual detention basin maintenance costs are approximately 3-5% of the construction cost (California Stormwater Quality Association, 2003). As with infiltration basins, the presence of high volumes of refuse in Los Laureles Canyon may increase maintenance costs.

Table 14 lists the estimated costs of detention basins for each sub-basin of Los Laureles Canyon.

Table 14. Estimated costs of detention basins for each sub-basin of Los Laureles Canyon.

Sub-basin	Stormwater Volume (ft³)	Detention Basin Costs ($)
Estuary	243671	150,000
Lower Los Laureles 1	84755	69,000
Lower Los Laureles 2	1801048	700,000
Middle Los Laureles 1	1271328	540,000
Middle Los Laureles 2	278986	170,000
Middle Los Laureles 3	494405	260,000
Upper Los Laureles 1	635664	320,000
Upper Los Laureles 2	635664	320,000
Upper Los Laureles 3	98881	78,000

7.2.3 *Vegetated Swales*

Vegetated swales are long, shallow water conveyance channels that are lined with vegetation and are intended to slow water velocity, promote infiltration, and trap pollutants (Figure 36) (U.S. EPA Stormwater Fact Sheet, 1999). Vegetated swales can be used alone or in conjunction with other treatment technologies and have been shown to effectively reduce suspended materials, metals, and some nutrients in stormwaters. This treatment technology is a viable option for treating dry weather flows or small storm events in Los Laureles Canyon because of the low capital cost and associated benefit of reducing erosion in the locations where the swales are placed.

Figure 36. Vegetated swale. Source: Oregon Department of Environmental Quality, 2003 Table B. Los Laureles Canyon sub-sections with the percent coverage of potable water (Source: Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007).

Pollutant removal effectiveness

Limited information regarding the effectiveness of vegetated swales is available, and shows high variation in removal efficiency. The California Stormwater BMP Handbook (2003) compiled percent removal information from eight studies of vegetated swales. The average percent removal efficiency and range of removal efficiencies from those studies is shown in Table 15. These data indicate that vegetated swales are most effective in removing suspended solids and metals, and are less effective in removing nutrients. In the test cases, swales tended to export bacteria suggesting that these structures may cause an unintended effect that would be detrimental in Los Laureles Canyon where fecal coliform levels are already high.

It is important to note that these values may be somewhat misleading because the vegetated swales in the studies provided are likely to be very different in design and influent composition. When analyzing removal efficiencies, the contaminant concentration of the influent is important because removal efficiencies in the 80% to 90% range can still result in unacceptably high contaminant concentrations if the influent is heavily polluted.

Table 15. Percent removal of various storm water constituents by vegetated swales. Average values and ranges were calculated from eight individual studies. (Source: California Stormwater BMP Handbook, 2003).

Constituent	Average Removal Efficiency (%)	Range of Removal Efficiencies (%)
Total Suspended Solids	81	60 to 99
Total Phosphorus	47	8 to 99
Nitrate	39	67 to 99
Metals	66	2 to 99
Bacteria	-46	-25 to -100

Design considerations

The viability of vegetated swales for use in stormwater treatment depends on local soil types, appropriate space, appropriate slope, tributary area, and the ability to establish dense vegetative cover (U.S. EPA U.S. EPA Stormwater Fact Sheet, 1999 and California Stormwater Quality Association, 2003).

The soils of a vegetated swale project should allow for infiltration at a rate of at least 1.3 cm/hour, and care should be taken not to compact the soils during installation (U.S. EPA U.S. EPA Stormwater Fact Sheet, 1999). Adequate infiltration helps to settle out suspended solids and keeps the water level in the swale low. Vegetated swales are best used for treating waters from a relatively small catchment and are generally not used for flows greater than 0.15 cms (U.S. EPA U.S. EPA Stormwater Fact Sheet, 1999). Ideal swale design may include a flat bottom to promote even flow and channel design so that flow does not exceed a depth of four inches (Figure 37). The side slopes of the swale should have a horizontal distance to vertical distance ratio of between 2:1 and 3:1 to prevent erosion (King County, Washington Surface Water Design Manual, 2005).
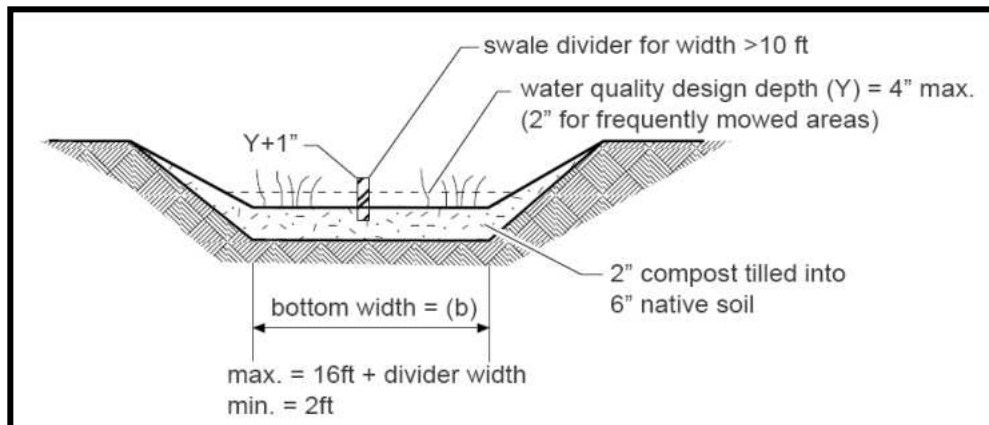
Figure 37. Cross section of a typical vegetated swale (Source: King County, Washington Surface Water Design Manual, 2005).

The lateral slope of a vegetated swale should be carefully designed and should not be so shallow as to allow low flows to stagnate or too steep to convey water so quickly that stormwater contact time is insufficient for physical and biological process to take place. The Surface Water Design Manuel from King County, Washington suggests maintaining a longitudinal slope of between 1% and 6%, as well as installing underdrains or planning for a wet biofiltration system if the slope is 1% or less. Check dams can be inserted at an interval of approximately 17 m to assist in slowing flow and increasing infiltration in locations with greater slopes (California Stormwater Quality Association, 2003).

Landscaping grasses are commonly used in vegetated swales because of their frequent application in manicured areas such as near parking lots or around infrastructure. In Los Laureles Canyon, a mix of drought tolerant native grasses and shrubs may be planted in close proximity to achieve a similar vegetative density as would be found in a grass covered areas. A mix of annual and perennial species should be used to achieve year round coverage. Some species that may be appropriate for swales in Los Laureles include *Bothriochloa barbinodis, Nassella pulchra,*

Bromus carinatus, Bromus grandis, Elymus glaucus, Hordeum brachyantherum, Vulpia microstachys, Leymus condensatus, Atriplex lentiformis, Artemisia californica, Baccharis pilularis, Lupinus albifrons, and *Salix hindsiana* (Calflora, 2008). Irrigation during the dry season may be necessary to establish vegetation in the swales, but the choice of drought tolerant native plants should reduce or eliminate the need for irrigation after the plants are established.

A final consideration for installing vegetated swales in Los Laureles Canyon is the inclusion of a budget for fencing. In the past, residents of Los Laureles Canyon have used vegetated areas to graze domesticated animals such as goats. To help prevent the destruction of vegetation within the swales, all projects should include fencing or other deterrence mechanisms.

Specifications

Unlike design specifications for infiltration and detention basins which are based on the desired treatment volume, vegetated swale sizing is dependant upon flow. Many localities specify particular flows that should be captured by a flow-based BMPs, such as vegetated swales. One common sizing parameter is the hourly flow from an 85th percentile storm. To understand the general size and cost of vegetated swales in Los Laureles Canyon, proxy data from the San Diego Airport was used and indicates that the area receives approximately 1.4 cm of precipitation over a 24 hour period during a 85th percentile storm (County of San Diego Department of Public Works Flood Control Section, 2003).

Vegetated swale flow

Vegetated swales are designed to convey water and therefore their design is dependant on the size of the flow that the swale will treat. The following equation was used for calculating flow from each sub-basin in Los Laureles Canyon:

$$Q = A*I*C$$

Where:

Q = flow (cms)
A = sub-basin area (m^2)
I = rain intensity (m/sec)
C = runoff coefficient (unitless)

The calculated flows in each of the Los Laureles sub-basins are listed in Table 16 and show that the flows range between 0.02 cms to 0.41 cms during 85th percentile storms. As with previous calculations, a runoff coefficient of 0.7 was assumed. As reported earlier, vegetated swales are rarely sited in locations that receive greater than 0.15 cms of flow, and therefore in Lower Los Laureles 1 and 2 and Middle Los Laureles 1, swales should be placed off of the main channel. Even in sub-basins where 85th percentile storms are estimated to be less than 0.15 cms, placing the swales off of the main channel with a diverter, to direct low flows into the swale and bypasses the swale during high flows, would help prevent damage to these BMPs during large storm events.

Table 16. Estimated flow in each Los Laureles sub-basin. Sub-basins highlighted in grey have flows that are too high for vegetated swales and would require placement off-line.

Sub-basin	Area (km^2)	Flow (cms)
Estuary	0.49	0.06
Lower Los Laureles 1	1.69	0.19
Lower Los Laureles 2	3.62	0.41
Middle Los Laureles 1	2.55	0.29
Middle Los Laureles 2	0.57	0.06
Middle Los Laureles 3	0.99	0.11
Upper Los Laureles 1	1.32	0.15
Upper Los Laureles 2	1.26	0.14
Upper Los Laureles 3	0.20	0.02

Vegetated swale area

There are many resources that allow for the detailed calculation of vegetated swale bottom width, swale length, and flow velocity. A selection of these resources include:

- o U.S. EPA's *Stormwater Best Management Practices Design Guide, Volume 2 Vegetative Biofilters* (Clar, Barfield, and O'Connor, 2004).
- o King County, Washington Department of Natural Resources *Surface Water Design Manual* (2005).
- o Denver, Colorado Urban Drainage & Flood Control District *Urban Storm Drainage Criteria Manual Volume 3 – Best Management Practices* (1999).

For the purposes of this assessment, a detailed sizing determination was not conducted as sizes were approximated using the rule of thumb listed by U.S. EPA. The rule states that the total surface area of the vegetated swale should be one percent of the area that drains to the swale (U.S. EPA U.S. EPA Stormwater Fact Sheet, 1999). Using this rule of thumb, the estimated required size of vegetated swales required to effectively treat runoff in each Los Laureles sub-basin are shown in Table 17.

Table 17. Estimated vegetated swale area necessary to treat the flow from each Los Laureles sub-basin.

Sub-basin	Area (km^2)	Swale Area (m^2)
Estuary	0.49	4900
Lower Los Laureles 1	1.69	17000
Lower Los Laureles 2	3.62	36000
Middle Los Laureles 1	2.55	26000
Middle Los Laureles 2	0.57	5700
Middle Los Laureles 3	0.99	9900
Upper Los Laureles 1	1.32	13000
Upper Los Laureles 2	1.26	12600
Upper Los Laureles 3	0.20	2000

It is important to note that the total swale area may be divided among several individual swales within a catchment to achieve the total swale area necessary to treat all targeted flows. Vegetated swales may be sited near the main stream channel to receive waters from the main stem, or they may be placed in smaller tributaries to capture smaller contributing flows.

Implementation and maintenance costs

The costs associated with the construction of vegetated swales includes clearing, excavating, and grading of the site, purchase and installation of plants, and the installation of an irrigation system if necessary (SWRPC, 1991). The California Stormwater BMP Handbook (2003) estimates the implementation cost of vegetated swales at $5.38/m^2 ($0.50/ft^2). The cost estimate for vegetated swales that would treat all of the targeted runoff in each sub-basin is shown in Table 18 and ranges from $26,000 to $194,000 per catchment.

Table 18. Estimated vegetated swale capital cost and annual maintenance cost. (Source: California Stormwater BMP Handbook, 2003.)

Sub-basin	Capital Cost ($)	Annual Maintenance Cost ($)	Annual Maintenance Cost w/ 30% Buffer ($)
Estuary	26,460	662	860
Lower Los Laureles 1	91,800	2,295	2,984
Lower Los Laureles 2	194,400	4,860	6,318
Middle Los Laureles 1	140,400	3,510	4,563
Middle Los Laureles 2	30,780	770	1,000
Middle Los Laureles 3	53,460	1,337	1,737
Upper Los Laureles 1	70,200	1,755	2,282
Upper Los Laureles 2	68,040	1,701	2,211
Upper Los Laureles 3	10,800	270	351

The maintenance of vegetated swales includes trash removal, mowing, and possible replacement of dead vegetation. Many available cost estimates are based largely on the cost of mowing, but swales placed in Los Laureles Canyon would likely use plant species that do not require mowing and would require more extensive trash removal than costs associated with swales in more aesthetically sensitive locations. For the purposes of this assessment, it was assumed that the maintenance cost estimates for mowing can be substituted evenly for maintenance cost estimates of litter removal. Table 18 shows that maintenance costs are estimated to range between $660 and $4,900 per year. The results of the Stormwater Survey indicated that vegetated swale maintenance is often more expensive than anticipated, therefore including a 30% buffer into maintenance cost estimates and subsequent budgets is recommended.

7.3 Stormwater Survey

To better understand the true cost and effectiveness of structural BMPs and their applicability to the unique conditions of Los Laureles Canyon, users of stormwater mitigation technologies were surveyed for information about systems they have installed. The survey, conducted via the internet between the months of September and December 2007, received voluntary responses from structural BMP users across various sectors and geographic locations throughout the U.S. The study was developed to acquire information regarding expected versus actual costs, effectiveness of constituent removal, and situational applicability of structural BMPs from

industry practitioners. Technologies including infiltration basins and trenches, vegetated swales or buffers, porous surfaces, and media filters were highlighted in the survey, while information regarding the effectiveness of other technologies was solicited as well.

The survey was advertised in Stormwater Magazine and through various stormwater practitioner email groups. A total of 163 system-specific responses from BMP users and 26 responses from manufacturers of structural BMPs were received. Survey data analyses were conducted to understand general trends in cost and effectiveness of various stormwater technologies and to specifically identify BMPs that could be implemented effectively and practically in Los Laureles Canyon. Results of media filter effectiveness, cost, and maintenance were not included in these sections as media filters were determined to be unviable for Los Laureles Canyon due to a lack of infrastructure. Media filter results along with a full set of survey questions and analyses can be found in Appendix 5.

7.3.1 BMP Effectiveness

The primary constituents of concern addressed in this study are pathogens, sediments, and refuse/debris. To understand the removal efficiency of these constituents by various BMPs, the following question was posed to survey respondents, "*On a scale of 0-5 Please indicate the removal efficiency for each of the constituents below. (0= the technology does not address this constituent, 5=complete removal.)*" It is important to note that this survey question did not outline any guidance for evaluating removal efficiency and the question allows for only a qualitative analysis of responses.
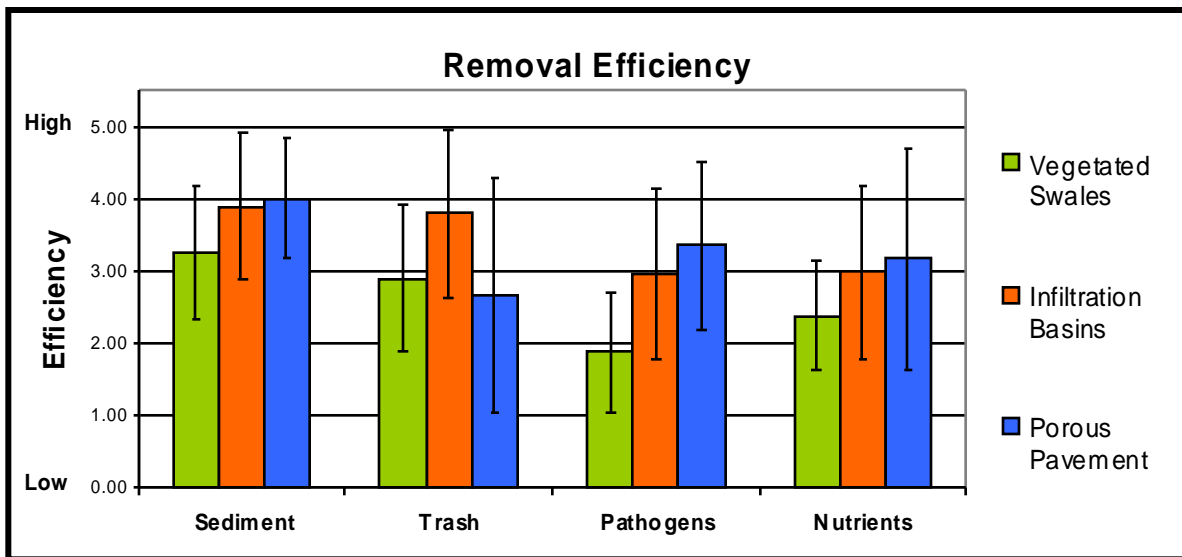

Figure 38. Removal efficiency of sediments, trash, metals, pathogens, and nutrients, rated on a scale of 0 (no removal) to 5 (high removal) for four BMPs. Error bars represent + and – 1 standard deviation.

Summary statistics indicate that none of the three technologies (vegetated swales, infiltration basins, and porous pavement) has shown a consistently high or low removal for sediment, trash, pathogens, and nutrients as reported in existing systems (Figure 38). Therefore none of these three technologies could be initially eliminated or selected for further investigation using this

information alone. These statistics also show that practitioners believe that the three technologies are generally better at removing sediments than pathogens or nutrients.

7.3.2   BMP Cost

Structural BMP implementation cost depends upon the size, location, and the design selected. As opposed to surveying BMP users about their total costs, they were asked about how much the BMP project costs varied from what they had anticipated using the following question, "*For this technology how different were actual capital, installation, and maintenance costs from estimated capital, installation, and maintenance costs?(much less than expected, somewhat less than expected, same as expected, somewhat more than expected, much more than expected, or not sure)."* Responses to this question may help identify if any of the three technologies show a trend of being more expensive than practitioners anticipated.

A summary of responses is shown in Figure 39 and indicate that vegetated swale projects are generally more likely to have capital and installation costs that are similar to what was anticipated, whereas infiltration basins and porous pavement projects have shown more variation in anticipated versus actual costs for capital and installation. These results indicate that vegetated swale projects are more likely to stay on budget for capital and installation than infiltration basin or porous pavement projects.

In the context of the goal of identifying BMPs that would be appropriate and practical for implementation in Los Laurels Canyon, the greatest concern about project costs is that they do not greatly exceed expected costs. Survey results showed that infiltration basins exceeded expected capital costs in 32% of projects surveyed, and exceeded expected installation costs in 49% of projects surveyed. Porous pavement projects also exceeded expected capital costs in 32% of projects and exceeded expected installation costs in 58% of projects, but no porous pavement users reported that these exceedances were much greater than expected. Vegetated swale capital costs exceeded expectations in only 5% of projects and exceeded expected installation costs in 14% of projects with no users reporting that these exceedances were much greater than expected. In light of this information, the recommendation of infiltration basins and porous pavement projects will come with a concomitant recommendation that the planning of these types of projects should anticipate budget exceedances in capital and installation costs.
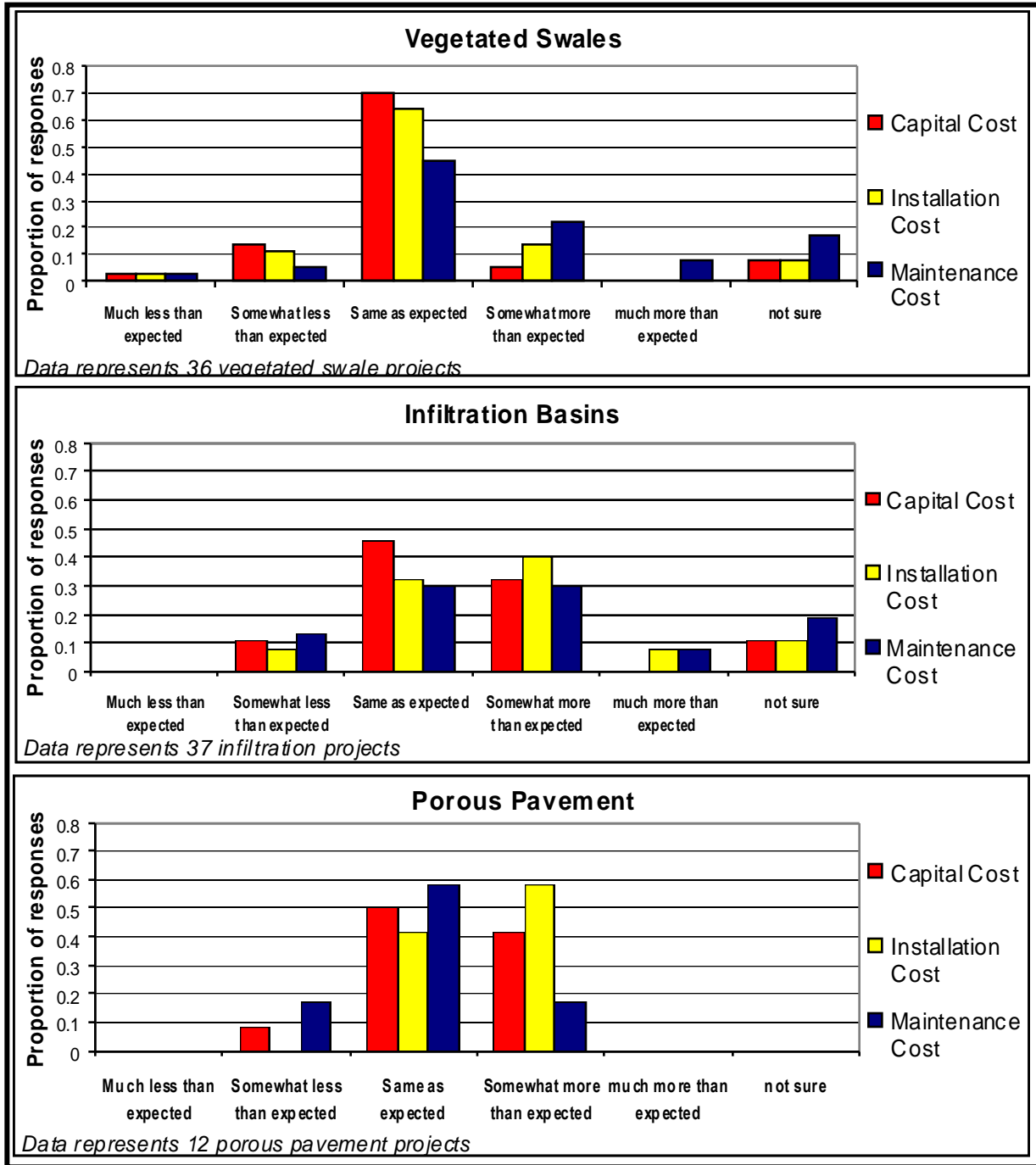
Figure 39. Expected versus actual costs of vegetated swales, infiltration basins, and porous pavement. Projects.

7.3.3 BMP Maintenance

The frequency and cost of BMP maintenance is an important consideration in selecting BMPs. To better understand the frequency of required maintenance for vegetated swales, infiltration basins and porous pavements, survey respondents were asked, "*On average, how frequently do you perform maintenance?(more than once a year, once a month, once every 6 months, once a year, less than once a year)."* A summary graph is shown in Figure 40 and indicates that the most common maintenance interval for all three technologies is every six months or once a year. It is doubtful that any BMP installed in Los Laureles Canyon would be able to be maintained at an interval that is more frequent than once every six months month; because many of the vegetated swale, infiltration basin and porous pavement projects surveyed required less maintenance, they were determined to be viable candidates.

The graphs in Figure 39 reveal information about the expected versus actual cost for maintenance of vegetated swales, infiltration basins, and porous pavement. Vegetated swale maintenance exceeded expected costs in 30% of the projects surveyed, infiltration basins exceeded maintenance costs in 38% of projects, and porous pavement projects exceeded expected maintenance costs in 14% of projects surveyed. This information will be used when making BMP recommendations as a precaution of what budget exceedances have occurred in the past for similar projects so that adequate maintenance budget allowances can be made for projects in Los Laureles Canyon. Specifically, when recommending infiltration basins or vegetated swales a cost buffer should be incorporated into the maintenance budget to allow for unanticipated maintenance costs.
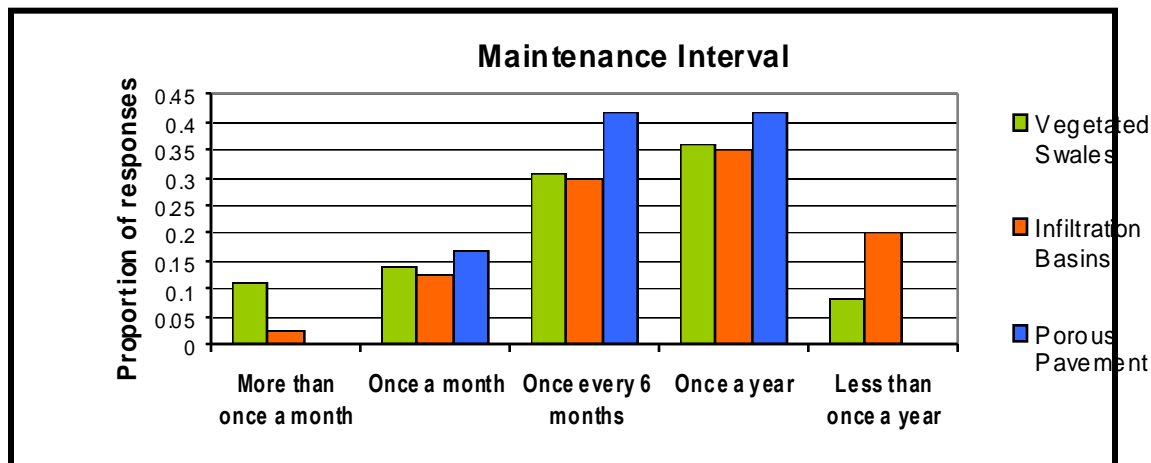

Figure 40. Reported maintenance interval for vegetated swales, infiltration basis, and porous pavements.

7.3.4 Water Quality Control BMPs Discussion

Water quality control BMPs such as infiltration and detention basins are effective at removing a variety of pollutants. Determining the correct size and location of BMPs is vital to ensure proper functioning. The stormwater volumes, required BMP areas, and associated costs presented previously are only estimates calculated using various equations and making several assumptions. Actual stormwater volumes, required BMP areas, and associated costs may vary

widely from the presented values after an in depth analysis by professional engineers is preformed.

The most effective use of both infiltration basins and dry detention basins is to use them in a *treatment train.* This is a process of siting several BMPs in succession allowing for varying processes to reduce pollutant concentrations from stormwater runoff. For Los Laureles Canyon, the use of dry detention basins preceding infiltration basins would allow for sedimentation to occur in the detention basins thereby removing most of the particulate matter and refuse. Stormwater runoff leaving detention basins would then enter infiltration basins where soluble contaminants would be reduced through infiltration of polluted waters. Sedimentation before infiltration is important because it reduces the possibility of the infiltration basin clogging from eroded soil particles.

Vegetated swales are particularly effective in treating contaminated water from a small catchment area. Small swales may be installed to treat dry weather flow from a block of houses, or can be placed offline near the main channel to treat small storm events. Swales may be more effective when installed below detention basins. Much of the sediment and refuse will settle out in detention basins and therefore will not clog the swales.

It is also important to plan for mixed use in the locations where water quality BMPs will be constructed, as these sites would likely be appealing for construction of houses or other structures. Los Laureles Canyon residents will make use of any and all space available. An example incorporating mixed use into a structural water quality control BMP is the construction of a detention basin that can also be used as a soccer field.

7.4 Structural BMPs: Erosion Control

Controlling erosion within Los Laureles Canyon is important because erosion within the canyon is severe and affects human health and safety as well as degrades environmental quality in areas such as the Tijuana River Estuary. High sedimentation rates also decrease the effectiveness of BMPs designed for water quality treatment. Two erosion control options for Los Laureles Canyon include terracing practices and scrap tire retaining structures.

7.4.1 Terracing

Terracing is a viable method currently utilized in Los Laureles Canyon to decrease erosion. Terracing reduces the aspect of slopes which decreases stormwater runoff energy thereby reducing the erosion potential. Terracing practices provide for the interception of surface runoff, facilitation of infiltration and evaporation or the diversion of stormwater runoff toward a protected outlet at a controlled velocity to avoid soil erosion (FAO, 2000). There are many types of terracing practices. Figure 41 shows two common terracing practices, a stepped slope and a terraced slope, both suitable for Los Laureles Canyon.
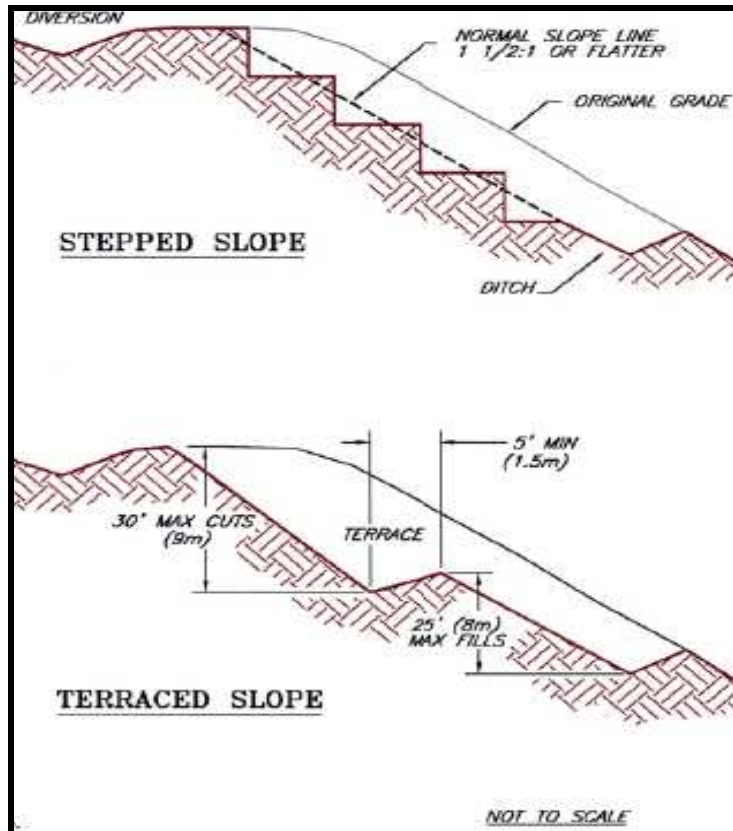
Figure 41. Schematic of stepped and terraced slopes (Source: McCullah, 1994).

Design considerations

Stepped slopes are preferable in areas with a 3:1 horizontal to vertical slope (H:V) ratio while terraced slopes are preferable in areas with flatter slopes. The stair-stepping effect of stepped slopes provides a level area where vegetation can establish and an area that traps soil eroded from above (City of Chattanooga, 2008). Terracing slopes flatter than 3:1 (H:V) allows for a designed drainage channel system located in the middle of the terraces to convey stormwater runoff to the bottom of the slope. It is important to consider using downdrains, riprap, energy dissipaters or other measures at drainage channel intersections to safely control velocities and erosive forces (City of Chattanooga, 2008). Graded areas are not recommended for stepped or terraced slopes because it is difficult to establish vegetation on such surfaces due to reduced water infiltration and the potential for erosion. Rough slope surfaces with uneven soil and rocks encourage water infiltration, speed the establishment of vegetation, and decrease runoff velocity (AMEC, 2006). Stepped slopes are not practical for sandy soils or other soils with low cohesiveness due to a high failure potential (City of Chattanooga, 2008).

Specifications

Stepped slope and terraced slope design specifications are site specific and therefore a licensed professional civil engineer should design terraced slopes and stepped slopes based upon actual site conditions. There are only a few general design specifications for stepped and terraced slopes.

For stepped slopes, the vertical cut distance shall not exceed 0.6 m for soft rock or 1 m for very hard rock and horizontal cut distance shall generally be at least 1.5 times the vertical distance to ensure structural integrity (City of Chattanooga., 2008). It is also important to cut the horizontal bench inwards and groove the slope creating a series of ridges and depressions parallel to the slope to increase runoff capture (City of Chattanooga, 2008).

For terraced slopes the maximum slope height between terraces should be 10 m and terrace widths should be at least 2 m wide. It is also important to design terrace ditches to drain at non-erosive velocities to ensure structural integrity (City of Chattanooga., 2008).

Implementation and maintenance costs

Terracing practices require an initial investment for construction costs including material and labor. Construction costs depend on the size of the structures as well as the slope. A study of agriculture terracing in China found that construction costs of structures on slopes greater than 20° were double that for structures on slopes less than 20° (Kim, 1998). Although these costs do not directly relate to terracing practices intended only for soil erosion, the study shows how implementation costs vary.

Terracing practices also require future investment for the costs associated with scheduled maintenance. Terracing practices in arid areas such as Los Laureles Canyon require maintenance only after significant storm events (ASABE, 2006). Proper maintenance is very important because failing terracing structures often allow for greater erosion; they focus stormwater runoff into a specific area which then increases erosion potential. Total construction and maintenance costs for terracing practices are low compared to other types of erosion control techniques (AMEC, 2006).

7.4.2   Scrap Tire Retaining Walls

Scrap tires in Los Laureles Canyon are a readily available, light weight, and inexpensive building material capable of providing erosion control. Scrap tires are currently used in Los Laureles Canyon for retaining wall structures, but most of these structures are not properly engineered and therefore subject to failure. Properly engineered and constructed scrap tire retaining structures can provide significant erosion control while maintaining their integrity (Amirkhanian, 1999). Figures 42 and 43 show a schematic profile view and map view of a scrap tire retaining wall respectively.
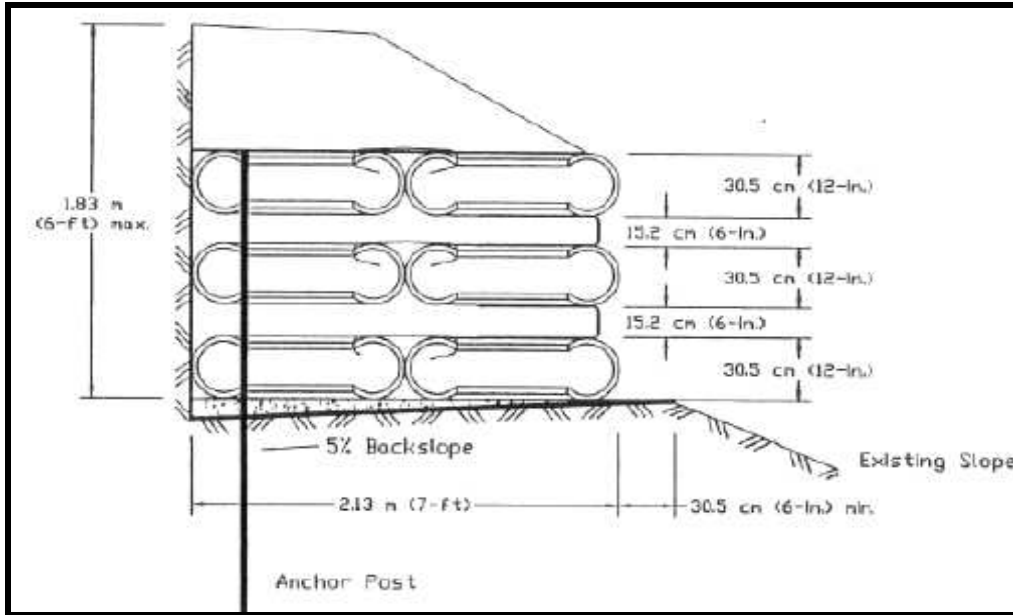
Figure 42. Tire retaining wall profile schematic (Source: Amirkhanian, 1999).
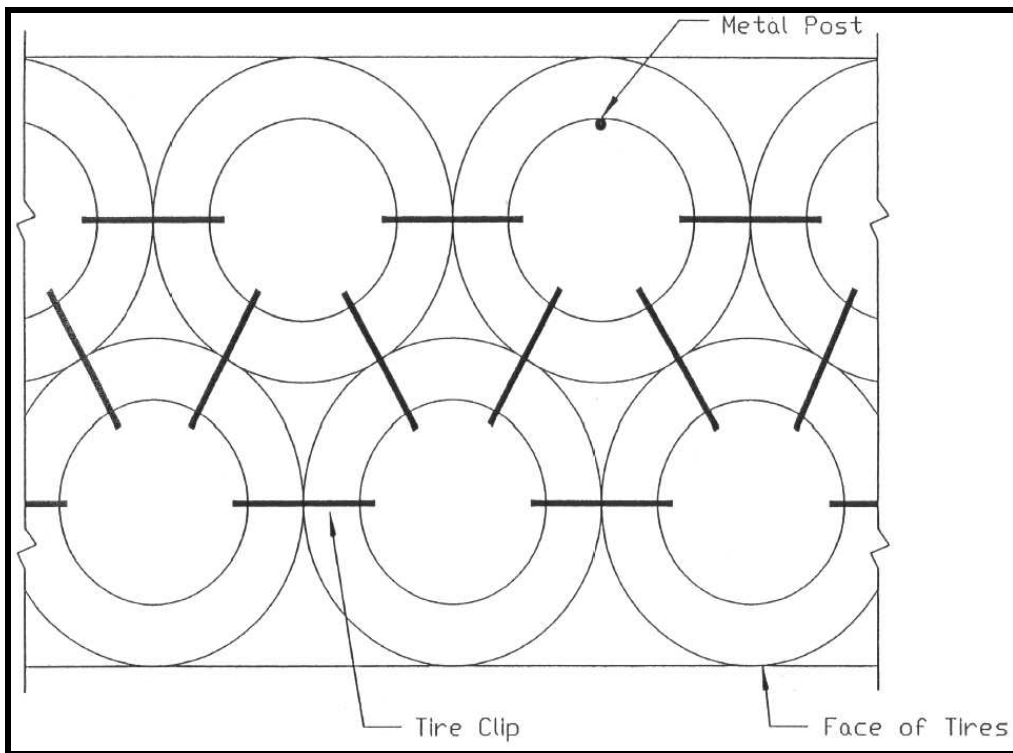

Figure 43. Tire retaining wall profile schematic (Source: Amirkhanian, 1999).

Design considerations

Scrap tire retaining walls do not have many design considerations since they are relatively straightforward to engineer and construct. There are a few important considerations however. One consideration for scrap tire retaining walls concerns the type of back fill used for the wall. It is important to use permeable back fill with a cohesive quality to ensure proper infiltration

while maintaining erosion resistance (Amirkhanian, 1999). Another design consideration is tire size and shape. Uniform tire size and shape allows for easier assembly of the scrap tire retaining wall. Tires with many varying dimensions make it much more difficult to assemble the wall in a manner conducive to proper engineering and construction. It is also important to use tires in relatively good condition so they are able to withstand pressure from stacking (Amirkhanian, 1999). Current tire retaining structures in Los Laureles Canyon generally do not use any type of mechanism to anchor the walls in place. The walls consist of tires laid upon each other and backfilled with loose material from the local area. These types of walls are very unstable and often become part of the stormwater runoff during large precipitation events. Using metal posts and metal tire clips provides stability ensuring the walls can withstand the erosion potential from large precipitation events. It is also important to place the tires above the water table to ensure the tires do not leach materials into the ground water (Amirkhanian, 1999).

Specifications

Scrap tire retaining wall length depends on the location desired for stabilization and can range from as small as a few meters to as large as 30 m. Retaining wall height should not be greater than 2 m to ensure proper stability. Retaining wall width depends primarily on tire size, but should be approximately the width of two tires placed next to each other (Amirkhanian, 1999). Anchor posts should be at least 3.05 m and the metal tire clips should be 1.27 cm in diameter to also ensure proper stability. The base area of the scrap tire retaining wall should have a backslope of approximately 5% and a 1% downslope from one end of the wall to the other (Amirkhanian, 1999). If a geomembrane is used to further protect against soil erosion, the membrane must be smooth, have no tension, and extend from the front edge of the bench to the back of the bench where it shall extend 30 cm up the vertical surface (Amirkhanian, 1999). Adding a geomembrane to the scrap tire retaining wall will increase costs to the project affecting project feasibility for Los Laureles Canyon.

Implementation and maintenance costs

The primary costs of scrap tire retaining walls are construction costs associated with excavating the base area and the labor required for construction. Additional costs may be realized due to maintenance and monitoring. It is important to monitor the scrap tire retaining walls to ensure structural stability. As mentioned previously, improperly constructed tire retaining walls have a high failure rate and often cause more erosion downstream as the tires are mobilized during stormwater events.

Scrap tire retaining walls are considerably less expensive than other types of walls designed for erosion control such as gabion walls, concrete crib walls, or reinforced concrete walls. Table 19 shows the total costs for various retaining wall structures.

Table 19. Cost of varying wall types. Costs calculated assuming a 5% interest rate from 1998-2008 (Adapted from Amirkhanian, 1999).

Wall Type	Cost, 2008 ($/Linear Foot)
Scrap Tire Wall	212
Gabion Wall	438
Concrete Crib Wall	610
Reinforced Concrete Wall	862

7.4.3 Erosion Control Discussion

Erosion control measures such as terracing practices and the use of scrap tire retaining walls are inexpensive, easily constructed and viable for Los Laureles Canyon. Terracing practices like stepped slopes and terraces offer a simply engineered and constructed method that do not require extensive infrastructure or complex structures for erosion control. Similarly, scrap tire retaining walls are simply engineered and constructed structures utilizing locally available materials to provide erosion control. Both erosion control measures require an initial investment and continued funding for routine monitoring and maintenance. The costs associated with proper implementation may not preclude the construction of these BMPS within Los Laureles Canyon.

7.5 Structural BMPs: Channel Stabilization

Large stormwater runoff flows can easily erode parts of the channel creating a hazard to residents within Los Laureles Canyon. High rates of stormwater discharge can also transport large volumes of sediment into the Tijuana River Estuary affecting this sensitive downgradient ecosystem. Stabilizing the channel by decreasing channel stormwater runoff velocities and protecting the channel from erosion may be an important component of improving human health and safety within Los Laureles Canyon as well as providing downstream environmental benefits.

7.5.1 Grade Control and Channel Protection

Grade control is the practice of decreasing the grade or slope of the channel through the use of riprap, concrete, or other solid materials to reduce runoff velocities within the channel. The selection of material and type of grade control depends in part on site specific hydraulic conditions and implementation costs (County of San Diego Department of Public Works Flood Control Section, 2005). Riprap is commonly used for grade control and channel protection as these structures are applicable for varying hydraulic conditions and can be less expensive than structural BMPs utilizing other materials. Figures 44 and 45 show examples of grade control with riprap and channel protection with riprap respectively.

Figure 44. Channel grade control with riprap (Urbonas, 2003).

Figure 45. Riprap used for channel protection (http://www.fs.fed.us)

Design considerations

Two general types of riprap, uniform or graded, can be used for grade control or channel protection structures. Uniform riprap consists of stones nearly all the same size while graded riprap includes a wide mixture of stone sizes. Grade control structures can be constructed with uniform or graded riprap and depends on the type of structure needed for to achieve desired stability. Graded riprap is preferred to uniform riprap in most channel protection applications because it forms a dense, flexible cover (City of North Augusta, 2005). Stabilization structures should be well-graded with 50% riprap by weight larger than the specified design size. Proper slope selection and surface preparation are essential for successful functioning of riprap. It is important to determine the riprap size that will be stable for site conditions and then select the size or sizes that equal or exceed that riprap gradation (City of North Augusta, 2005).

Specifications

The specifications of grade control and channel protection structures are primarily dependent on the type of structure and flow rates. There are many types of grade control and channel protection structures. Selecting the appropriate structure will vary depending on the site-specific conditions in Los Laureles Canyon. Due to the canyon's flashy hydrology, the structures must function over a wide range of flow rates. Therefore, it is important to confirm performance during the maximum design flow as well as during events smaller (County of San Diego Department of Public Works Flood Control Section, 2005).

Table 20 lists the estimated cumulative flows in each sub-basin in Los Laureles Canyon from the 2 year, 6-hour storm that has a magnitude of 2.54 cm as well as the estimated cumulative flow for a 100 yr, 6-hr storm with a magnitude of 5.08 cm assuming 70% runoff (County of San Diego Department of Public Works Flood Control Section, 2003).

Table 20. Cumulative flow for the 2 yr, 6-hr storm and the 100 yr, 6-hr storm for each sub-basin within Los Laureles Canyon.

Sub-basin	Cumulative Flow (cms) 2 yr, 6-hr storm	Cumulative Flow (cms) 100 yr, 6-hr storm
Estuary	0.00	0.00
Lower Los Laureles 1	1.49	2.98
Lower Los Laureles 2	0.54	1.07
Middle Los Laureles 1	2.25	4.50
Middle Los Laureles 2	0.00	0.00
Middle Los Laureles 3	0.00	0.00
Upper Los Laureles 1	1.16	2.32
Upper Los Laureles 2	1.11	2.22
Upper Los Laureles 3	0.00	0.00

The flows presented in the above table are only estimated discharges through Los Laureles Canyon. A further analysis of the actual flows in Los Laureles Canyon must occur before engineering and constructing any grade control or channel protection structures.

Implementation and maintenance costs

Implementation costs vary depending on structure requirements, but follow a general trend that the larger the structure, the more costly it is. There are four classes of riprap based on material size ranging from Class 1 to Class 4 by (City of Knoxville, 2000). The cost of riprap varies depending on location and the type of material selected, but normally as the size of the riprap increases, the more expensive it becomes. For instance, one study determined the approximate cost of riprap to be approximately $21-$54/m^2 depending on size (Nelsen *et al.*, 2007). Even though the costs of riprap vary, riprap is often less expensive than using concrete for grade control or channel protection since concrete costs range from $33-$66 /m^2 (Nelsen *et al.*, 2007). Maintenance costs are generally not very expensive unless the stabilization structures need to be repaired. Routine maintenance costs including inspection of grade control and channel protection structures after major storm events is vital to ensure proper functioning and stability.

7.5.2   Channel Stabilization Discussion

Channel stabilization and grade control practices must occur together to ensure proper protection of the channel and important downstream locations. Grade control decreases stormwater runoff velocities thereby reducing the erosion potential from stormwater runoff flows. Locating grade control and channel protection structures at key locations throughout Los Laureles Canyon can provide the same protective benefits as a concrete channel at a lower cost. Channels in Los Laureles Canyon change rapidly due to human alterations and therefore channel stabilization should be prioritized to prevent further human alteration.

7.6   Non-structural BMPs

Non-structural best management practices include programs and initiatives that do not require the installation of constructed systems that physically address water contamination. Non-structural BMPs may include wide-scale education campaigns focusing on issues such as litter reduction, planning initiatives such as the initiation of land use zoning, and non-governmental actions to improve stormwater quality. For the purposes of this report, the scope of non-structural BMPs explored will be limited to those actions that can be implemented on an individual or community scale, and do not require governmental initiatives.

Many community organizers are currently making great efforts to improve stormwater quality in Los Laureles Canyon. Some of these efforts are highlighted in section 5.6 and are important for improving stormwater quality in Los Laureles Canyon because they can be implemented and replicated faster than projects that require government involvement. Community actions are generally much smaller in scale than governmental projects, but can still provide significant stormwater quality improvements.

7.6.1   Residential Erosion Control

Los Laureles Canyon is being developed at a rapid pace, with residents often settling on steep, erodible slopes. The placement of structures on unstable soils can be dangerous to the residents and can be a source of sediment in the canyon. There are many low-cost and no-cost measures that residents can take to stabilize the area around their homes. A residential erosion control flyer that highlights some of these techniques may be beneficial in educating residents about the dangers of erosion, and will empower them with information about how to control erosion around their homes. A flyer has been drafted and is shown in Appendix 6. This flyer may be modified and distributed throughout the canyon to encourage residents to make changes that will reduce erosion around their homes and in their community.

7.6.2   Permeable Paver Programs

Oscar Romo and community organizers in Los Laureles Canyon have initiated a permeable paver program in which Los Laureles residents construct pavers (bricks) out of local materials and install the pavers on dirt roads that were formerly unpaved. These actions help to stabilize the soils on the roads thereby decreasing erosion and increasing the quality of the road in addition to promoting infiltration following precipitation events. This type of permeable paver program can be replicated in many neighborhoods within Los Laureles Canyon.

7.6.3   Community Workshops

Bringing Los Laureles residents together in community workshops to provide demonstrations of erosion control and water collection techniques may reduce the sediment flux and rate of runoff from residences throughout the canyon. Workshops explaining the proper construction of tire retaining walls, installation of rainwater collection systems, and collection and propagation of native seed can be low-cost and highly effective in empowering residents with the knowledge necessary to make positive changes in their community.

Tire Retaining Wall Workshop

The use of discarded tires in the construction of retaining walls is common throughout Los Laureles (Figure 46). If not properly constructed, tire retaining walls can be unstable and

dangerous. A community workshop focusing on techniques for building a secure tire retaining wall may improve the safety of these structures and help prevent erosion.

Figure 46. Unreinforced tire retaining wall in Los Laureles Canyon. (Source: N. Virgilio, 2007.)

Rainwater Collection Workshop

Rainwater collection systems can be constructed from a variety of materials and can be an effective way to reduce erosion around homes while providing a source of non-potable water. The basic elements of a rainwater collection system are shown in Figure 47. These elements are:

- o Roof-mounted rainwater collection gutters
- o Pipes connecting the gutters to a sealed rainwater collection tank
- o A first flush bypass system
- o A spigot for extracting water from the rainwater collection tank
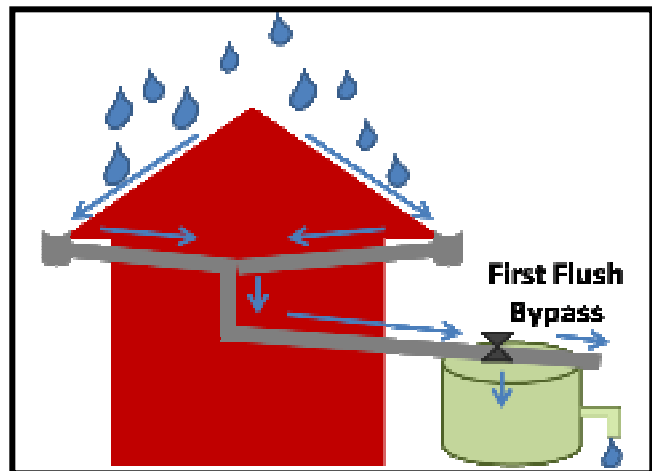
Figure 47. Rainwater collection system. Source, J. Phillips, 2008.

The workshop would be most likely to succeed if community organizers are able to acquire the necessary materials for a rainwater collection system and distribute them to workshop participants at low or no cost.

Native Seed Collection and Propagation
Many of the plants in and around Los Laureles canyon, like the buckwheat shown in Figure 48, produce seeds that can be collected and successfully grown. A native seed collection workshop can teach residents to identify viable seeds, provide techniques for non-destructive collection of seed, provide tips on using reusable materials such as old jugs and bottles for use as nursery pots, and can teach proper water timing and sun exposure. The native plants grown from collected seed can be planted around residents' homes to help stabilize soils and add aesthetic value.

Figure 48. Buckwheat seeds can be collected and grown. (Source: Michael Charters, CalFlora 2003).

7.7 BMP Summary

Stormwater runoff in Los Laureles Canyon contains three priority constituents of concern; pathogens, sediment and refuse/debris. Mitigating the effects of these constituents in canyon stormwater is expected to require the use of structural and non-structural BMPs. Viable structural BMPs for Los Laureles Canyon include both water quality improvement and erosion control measures while non-structural BMPs primarily include erosion control and trash reduction measures. Example structural BMPs for water quality improvement are infiltration basins, detention basins and vegetated swales. Structural BMPs for erosion control include terracing practices, tire retaining walls and channel stabilization. Viable non-structural BMPs for Los Laureles Canyon include replication of existing permeable pavement programs, as well as community workshops demonstrations of tire retaining wall construction, rain-water collection, and native seed start programs.

Combining structural BMPs for erosion control, channel stabilization, and water quality improvement is expected to increase the effectiveness of impaired stormwater quality mitigation efforts within Los Laureles Canyon. It is also important to utilize non-structural BMPs to increase community involvement within the canyon to reduce the sources of sediment from residential property.

Structural BMPs can require significant capital investments. However, when utilized properly, these structures can lead to reductions in stormwater volumes and treat stormwater runoff. The use of structural BMPs for stormwater mitigation is often less expensive than centralized stormwater control measures which can be ineffective at providing stormwater mitigation. Non-structural BMPs can provide important education to community members regarding stormwater runoff and do not require significant capital investments, but do require a significant amount of time and energy to organizing community members. Regardless of the capital investments required for structural BMPs and the investment of time and energy for non-structural BMPs, both types of BMPs can provide significant impacts on the mitigation of impaired stormwater quality.

8   KEY RECOMMENDATIONS

Based on modeling results and BMP selection analyses, we have developed specific recommendations to guide future actions to address stormwater quality issues in Los Laureles Canyon. The recommendations provided require different time horizons, resources, and political commitments. Therefore, we advocate a multi-tiered approach to allow for the continued participation of stakeholders as environmental managers work to address this transborder pollution issue. The current political landscape in Mexico is conducive to governmental actions. For the first time in several years, the same political party, the PAN (the National Action Party), is currently operating at the local, state, and federal governments. Engaging stakeholders in the early years of these administrations may yield opportunities to secure funding or political support for actions within the canyon or the watershed as a whole to address transborder pollution.

The following is a set of recommendations for sewage and stormwater management in the canyon, organized into short, medium and long-term goals in order to provide a systematic approach for implementation. However, these recommendations are mainly a guide to the addressing the most important pollution control issues, and other opportunities and challenges may arise that require attention as part of an iterative implementation process. These recommendations may be applicable to and relevant for several of the other 27 transborder canyons in the region, and as such can be used as part of a watershed-wide mitigation plan.

8.1   Sewage management recommendations

The following recommendations outline a potential plan for actions to guide sewage management in Los Laureles Canyon. Modeling results suggest that in installation of septic systems throughout Los Laureles Canyon are not likely to bring waters into compliance with Mexican basin objectives, however sewering the entire canyon was simulated to lead to compliant concentrations. Short-term recommendations focus on the collection of additional data to better model and analyze the effectiveness of various sewage management options in the future. Medium and longer-term recommendations highlight the need to construct sewering systems within the canyon to control much of the pathogen loading.

Short-term:
The following actions may be taken within the next year to address sewage-derived contaminants in the canyon.

Collection of additional water quality data
These additional data can be used in future modeling efforts using WARMF or another watershed model. One of the critical limitations of the WARMF modeling presented in this study was the lack of suitable fecal coliform data, and additional monitoring will improve the descriptive power of model output. One key caveat is that the collection of such data should be carried out according to a specific set of methodological standards in order to reduce uncertainty and bias. This data collection would help preliminarily calibrate the model output, and may help inform future sewage management actions.

Medium-term:
The following actions may be taken within the next one to three years to continue to address sewage-derived contaminants in the canyon.

Sewering San Bernardo

Modeling analysis determined that sewering the community of San Bernardo will not significantly reduce fecal coliform concentrations as pathogen loading in other parts of the canyon will not be addressed. However, this infrastructure will benefit the local residents of this community, and if effective, may provide a case to support the sewering of the rest of the canyon, which will require significantly more financial resources.

Financial and technical resource identification

The construction of sewer infrastructure in the canyon and the installation of suggested BMPs will require significant financial resources for installation and maintenance. In the short to medium term we recommend that stakeholders work together to pool financial and technical resources and develop financial networks for the long-term options presented in the following section.

Long-term:

In the next three to five years, if financial and technical resources have been secured, a more comprehensive sewage management program may be introduced.

Canyon-wide sewering

In addition to sewering San Bernardo, the rest of Los Laureles Canyon would need to be sewered to completely address the pathogen loading issue and bring concentrations into compliance with Mexican basin objectives. Based on current infrastructure, sewage would be collected and pumped to the Punta Bandera treatment plant. Although this plant is currently at treatment capacity, an additional treatment plant funded by the Japanese Development Bank is expected to come online and begin treating sewage from Tijuana by the end of 2008. The re-routing of sewage to other plants is expected to free-up capacity at the Punta Bandera plant that may be utilized to treat sewage from Los Laureles Canyon.

Sewage treatment reduction and greywater systems

In addition to reducing pathogen loading into the waters of Los Laureles Canyon, grey water reuse and increased water use efficiency may reduce the costs associated with pumping sewage upgradient to Punta Bandera or other treatment plants. Given that Punta Bandera treatment of sewage requires the pumping of Los Laureles sewage over a hill and against gravity, actions to reduce overall sewage blackwater will be less hazardous (and costly). Installing grey water systems in the canyon would be an effective way to manage and reduce wastewater requiring pumping or treatment. Such systems were not explored in detail as part of this project analysis, but the exploration of efficient grey water strategies is suggested for future research and action.

8.2   Stormwater management recommendations

In addition to sewage management, stormwater management is necessary to address sediment and refuse/debris not controlled by sewering. Furthermore, sewage systems may be compromised if stormwater control technologies are not implemented. Therefore the sewage manageemnt and stormwater management recommendations provided by this study are complementary and should be implemented as such. Recommendations for addressing stormwater management are highlighted below, and emphasize the need to collect more data

necessary to more accurately characterize storm flows in the canyon and engineer effective BMPs. Immediate actions also include the creation and expansion of existing community-based projects to mitigate and control stormwater discharge. Medium to long term stormwater management includes BMP pilot project implementation and evaluation and the replecation of successful BMP pilot projects.

Short-term:
Recommendations that may be implemented within the next year focus on collecting and analyzing data to understand the magnitude of canyon stormwater flows which is essential in planning and engineering BMPs.

Installation of a flume
Streamflow data for Los Laureles Canyon was not available for use during modeling and therefore Jamul Creek was used as a proxy for Los Laureles Canyon hydrological data. Installing a flume in Los Laureles Canyon and allocating resources to monitor the stage during storm events will allow for a more accurate assessment of flows within Los Laureles Canyon.

Quantify sediment transport
Measurements of the amount of potentially mobile sediment in Los Laureles Canyon and on the U.S. side of the border may be useful for future modeling of sediment transport and other statistical analyses. Furthermore, in order to determine whether sedimentation BMPs have been effective, it is first necessary to know how much sediment is mobilized during storm events. This will then provide a baseline reference from which to compare future sediment loading following BMP implementation.

Distribution of residential erosion control flyer
A preliminary residential erosion control flyer has been developed during this study and is intended for distribution to residents of Los Laureles Canyon. The flyer should be simplified with additional pircures and translated into Spanish prior to distribution. The flyer suggests low cost or no cost actions that community members can take to reduce erosion around their homes and community. The flyer also may serve as a community engagement tool with the intention that community organizers may modify it to distribute information about small-scale community projects to control both erosion and waste in the canyon.

Permeable pavers project
Oscar Romo is currently working with local Los Laureles community residents on a permeable pavers project where residents construct bricks from local materials and install these pavers in common areas between their homes. We advocate that this project should be expanded in both duration and scope, which may require additional funding and support.

Rainwater collection, tire retaining wall and terracing workshops
These are three low-impact and low-cost actions that can be carried out by individual residents to begin to control some of the unstable slopes and excess runoff in the canyon. By conducting community workshops to inform residents about the best ways to construct sustainable tire retaining walls and how to terrace canyon slopes, these skills may then be transferred to other community members. These workshops also may add value to tires used in retaining walls and

may ultimately reduce the number of tires in the canyon as refuse that make up a large percentage of Los Laureles Canyon waste. A workshop focusing on the construction of a rainwater collection system can provide residents with the knowledge and tools to construct their own collection systems.

Native seed-start program
Vegetation acts to stabilize soils, but has been largely removed from many locations in Los Laureles Canyon which may be causing greater rates of erosion and sedimentation to occur during precipitation events. Developing local native seed-start projects, where community members would collect and grow native vegetation for planting near their homes or in their neighborhoods may educate members about the benefits derived from vegetation and will be the start of a long-term process of stabilizing erodible slopes.

Community education
As part of ongoing engagement and involvement of community members, it is important to conduct informal community education campaigns. By educating community members about how pollution control will benefit their lives and families community members may encourage collective action to reduce improper waste disposal and encourage neighbors to adopt some of the actions recommended in previous sections. The erosion control flyer and the workshops mentioned previously are specific ways in which residents can be involved. Oscar Romo's networks within Los Laureles Canyon communities would be an appropriate place to start building community initiatives and expanding education projects.

Medium-term:
Following community action and projects, the medium term goals in the next one to three years may focus on the most efficient and effective stormwater control and mitigation BMPs for the canyon.

Pilot stormwater BMP projects
To determine the effectiveness of recommended water quality mitigation and control BMPs, we advocate the implementation of a pilot BMP projects. These pilot projects may include the following: vegetated swale installation, reinforced tire retaining wall construction, riprap installation, and infiltration and detention basin construction. These BMPs may be implemented as a treatment train to maximize their cumulative benefits. The initial installation of these BMPs will require that stakeholders secure capital for construction, installation and maintenance costs, although most of the BMPs recommended in this study are relatively low-cost. This pilot program will help to
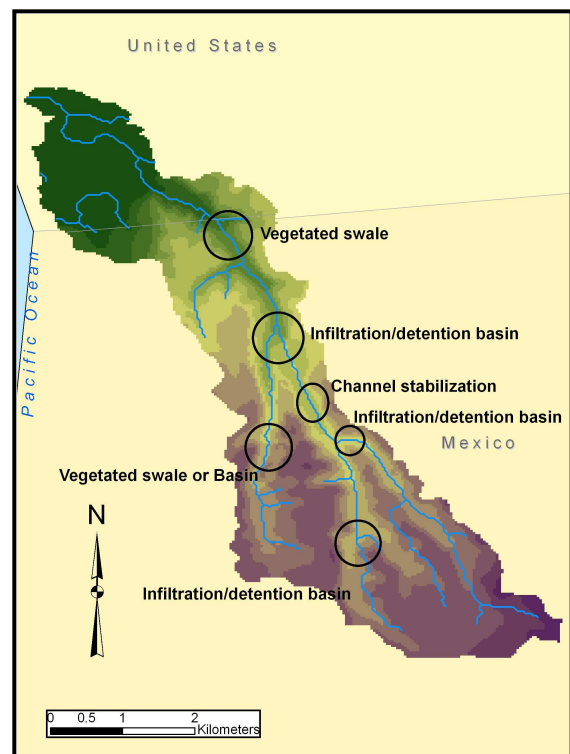
Figure 49. Potential locations for structural BMP pilot projects (Source: Oscar Romo, personal communication, 2008).

identify the relative effectiveness of and resource limitations associated with placing BMPs in Los Laureles and other canyons. Preliminary engineering problems and issues may be addressed before additional BMPs are constructed throughout the canyon. Potential locations for structural BMP pilot projects are shown in Figure 49.

Long-term:
In the next three to five years, if sufficient resources and technologies are available, the BMP pilot program can act as a guide to inform an expand BMP implementation throughout Los Laureles Canyon.

Implementation and expansion of BMPs
If all of Los laurels Canyon is sewered, the issue of stormwater flows and associated mobilization of sediment, debris and other contaminants will still remain. Therefore stormwater mitigation and control BMPs may be an integral component of future stormwater management in Los Laureles Canyon. Information regarding costs and engineering needs garnered from pilot BMP projects may be used to create an implementation and installation plan of the most viable and effective BMPs by using 'treatment trains', or locating BMPs where they will be most efficient in controlling stormwater discharge and pollutants. Much of this information can be taken from the pilot BMP projects.

Monitoring of BMPs
All installed BMPs should be monitored in order to determine effectiveness and value. Taking an adaptive management approach, whereby previously installed projects are evaluated for their effectiveness and successful projects are replicated, may be prudent to ensure the most effective use of resources. A robust monitoring program may facilitate the evaluation of projects.

8.3   Watershed management recommendations

In addition to addressing sewage and stormwater management in Los Laureles Canyon, it is important to also factor in the influence and importance of appropriate and effective landuse planning in the canyon, in the City of Tijuana peripheries, and also across the greater watershed. Doing so will require the collaboration of several levels of government. Currently, the PAN is working at all three levels of government in Mexico, and the opportunity to achieve agreement on pollution control across the Tijuana River Watershed is great. Mexican and U.S. agencies will also have to communicate given the nature of this transborder pollution problem. The following recommendations should therefore be approached as ongoing actions that should be addressed and included early on in the process.

Landuse planning
A long-term socio-political component of the transborder pollution problem is the absence of landuse planning within Los Laureles Canyon and other similar canyons in the Tijuana periphery. With the recent installation of the National Action Party or PAN at the local, state and federal levels, stakeholders may successfully encourage government to engage in more active landuse planning policies for urban management. However, it is important to note that any landuse planning is a tenuous political issue, and would require a large-scale alteration of the current governmental approach to development and urbanization in Tijuana. The rate of regional

growth may bring landuse planning and associated environmental impacts into policy discussions both within Mexico and throughout the transborder region.

Transborder watershed management
In addition to the site-specific recommendations for Los Laureles Canyon, many of these actions can and should be applied to other canyons in the transborder region which are in various stages of urban development. Instead of treating contamination and pollution using end-of-pipe measures, we advocate a focus on addressing source control of pollution in these canyons through community engagement and education, as well as sewage and stormwater control and management. Furthermore, a transborder approach is expected to require working with stakeholders in the U.S. and Mexico. The International Boundary and Water Commission provides the appropriate forum for bi-national watershed planning although the U.S. EPA may provide much of the funding and technical expertise for transborder actions. This approach is likely to require political will and economic commitment from agencies on both sides of the border as stakeholders continue long-term work to address this challenging transborder issue.

9 CONCLUSION

This study recommends specific actions for improving stormwater quality in Los Laureles Canyon: installation of sewage collection infrastructure; construction of structural BMPs to reduce erosion, stabilize the channel, and improve water quality; and non-structural BMPs for engaging the Los Laureles Canyon community in water quality improvement actions. However, the magnitude and geographic extent of this transborder pollution problem may require addressing pollution sources in other canyons within the larger watershed in addition to Los Laureles Canyon to mitigate and control stormwaters adversely affecting human health and ecosystems associated with the coastal zone and the Pacific Ocean. This study's recommendations may help achieve and sustain sewage and stormwater control and management in Los Laureles Canyon, which may benefit Los Laureles Canyon residents and immediate downstream locations on the U.S. side of the border. However, we also recommend the construction of some of the suggested stormwater BMPs, as well as community action, throughout the other transborder canyons as appropriate.

It is imperative that any recommendations delivered to U.S. agencies also are provided to appropriate Mexican governing entities. First, recommendations should be provided to the Baja California Watershed Council, an entity comprised of representatives from all major Mexican government stakeholders. Any recommendations for infrastructure, including structural BMPs, sewers and septic systems, should be provided to the National Water Commission (CAN), as the CNA is responsible for the management of water resources in Mexico. Similarly, the City of Tijuana should be informed of any plans to alter runoff channels, as these structures are owned by the City. City would also be responsible for the maintenance of constructed BMPs. Recommendations regarding non- structural BMPs, specifically education campaigns, should be provided to the local, state and federal environmental protection agencies. Working within existing Mexican governing structures may ensure that recommendations are considered and the viability of implementation is explored.

Despite the complexity of bi-national watershed management, transborder actions guided by stakeholder involvement is likely to be the most effective platform to control and mitigate the transport of pathogens, sediment, and refuse/debris through the Tijuana River Watershed. There are several challenges which will undoubtedly arise in implementing the project recommendations to control sewage and stormwater in Los Laureles Canyon and other transborder canyons. However, there may equally be opportunities for joint collaboration which may reduce overall resource waste, speed up the process of implementation, and strengthen the efficiency of technologies and community actions. In light of urgency of the transborder pollution problem, it is important to immediately take action in putting into motion key recommendations, and to include all involved stakeholders in the process from the start. Doing so will ensure that the watershed management actions suggested here will be both relevant, timely and effective in addressing a significant transborder pollution problem.

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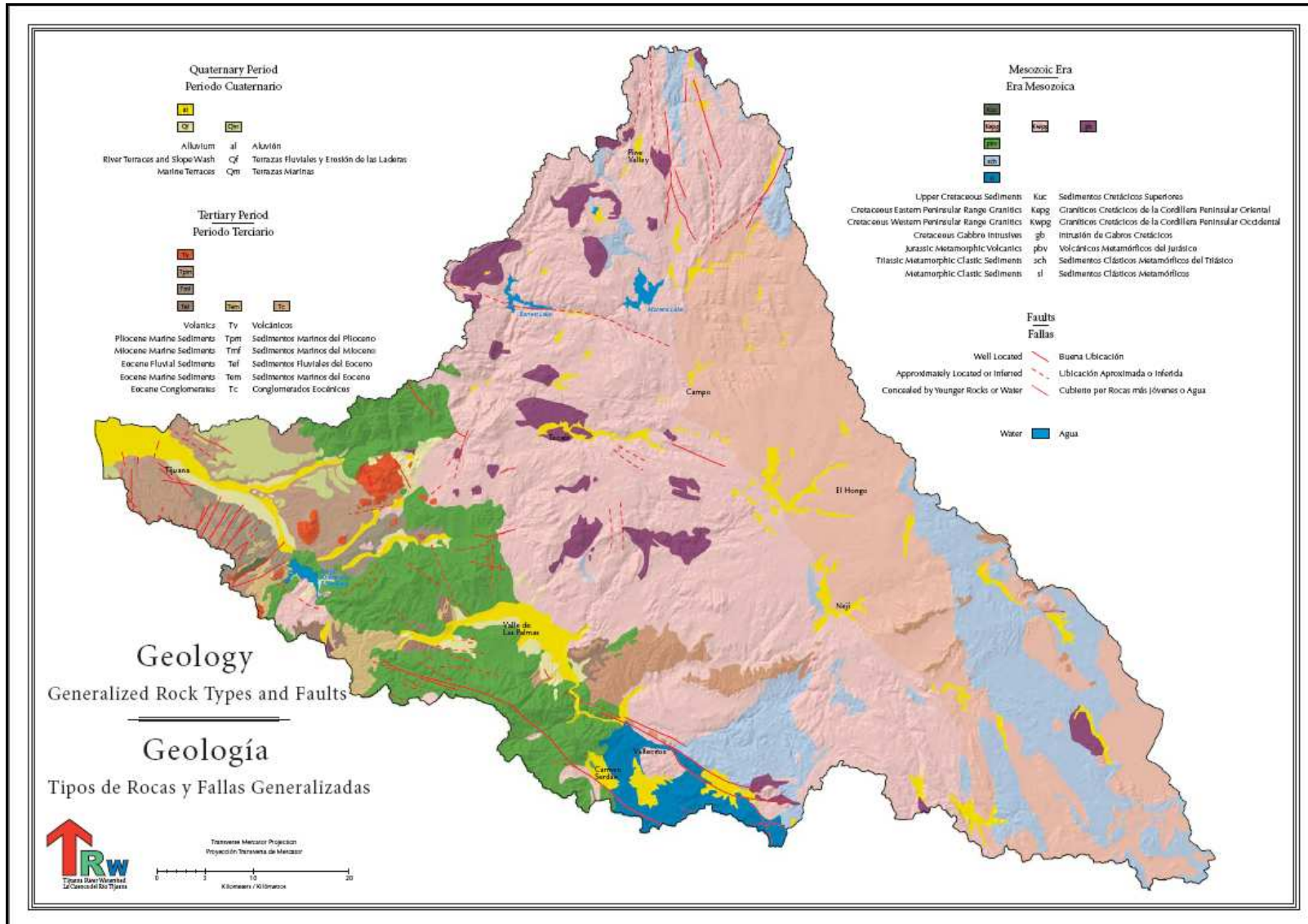
Figure A. Geology of the Tijuana River Watershed. (Source: SDSU, COLEF and SCERP, 2005)

Great Groups
Grandes Grupos

Durixeralfs   Durixeralfs
Haploxeralfs   Haploxeralfs
Natrixeralfs   Natrixeralfs
Paleoxeralfs   Paleoxeralfs
Rhodoxeralfs   Rhodoxeralfs
Durochrepts   Durochrepts
Xerochrepts   Xerochrepts
Xerorthents   Xerorthents
Xerofluvents   Xerofluvents
Torriorthents   Torriorthents
Xeropsamments   Xeropsamments
Haploxerolls   Haploxerolls
Pelloxererts   Pelloxererts
No Data   Ningún Dato

Soils
Integrated Predictive Model, 1997

Suelos
Modelo Integrado Predecible, 1997

Transverse Mercator Projection
Proyección Transversa de Mercator

Kilometers / Kilómetros

Figure B. Soils of the Tijuana River Watershed. (Source: SDSU, COLEF and SCERP, 2005)
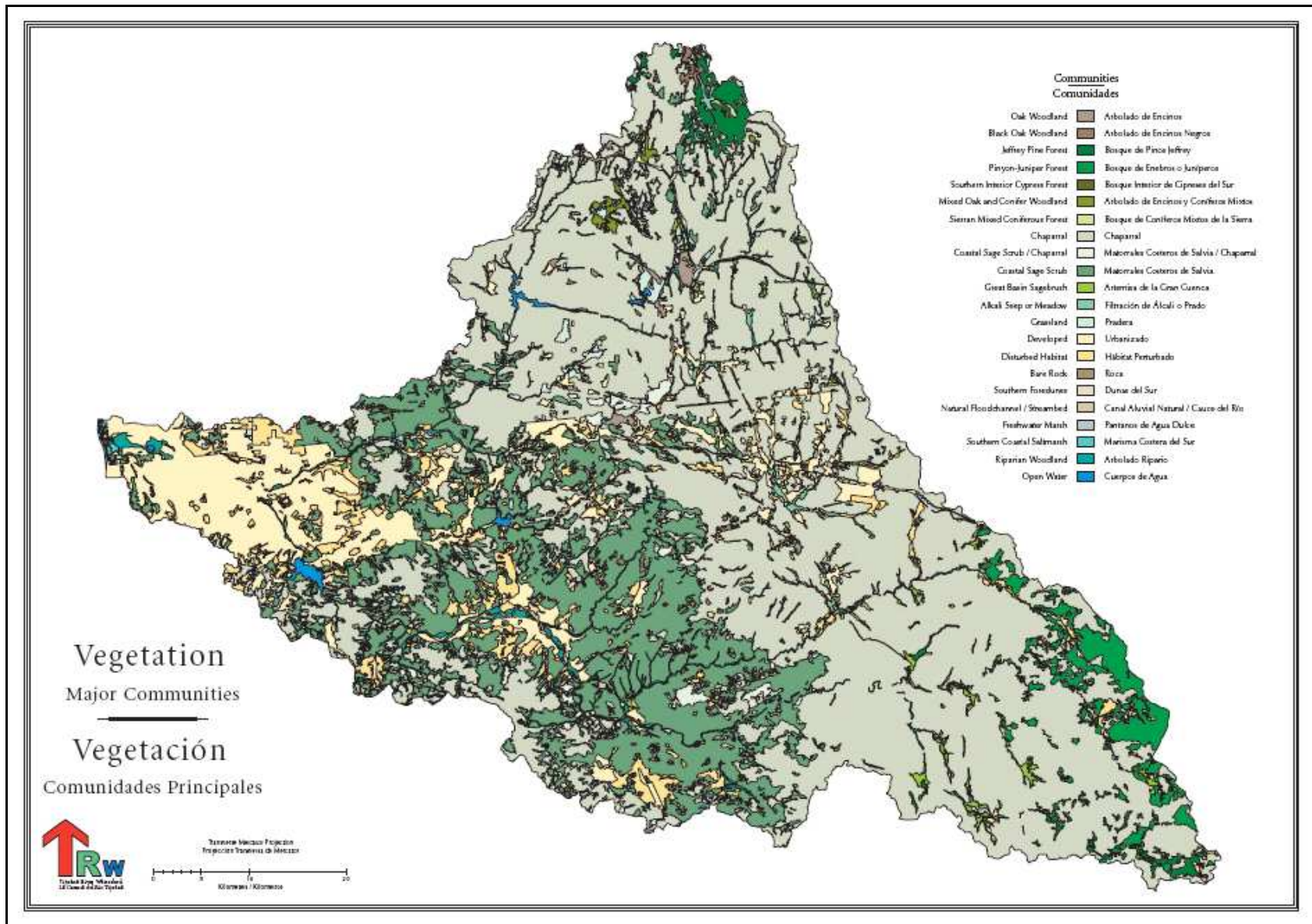
Figure C. Vegetation in the Tijuana River Watershed. (Source: SDSU, COLEF and SCERP, 2005)
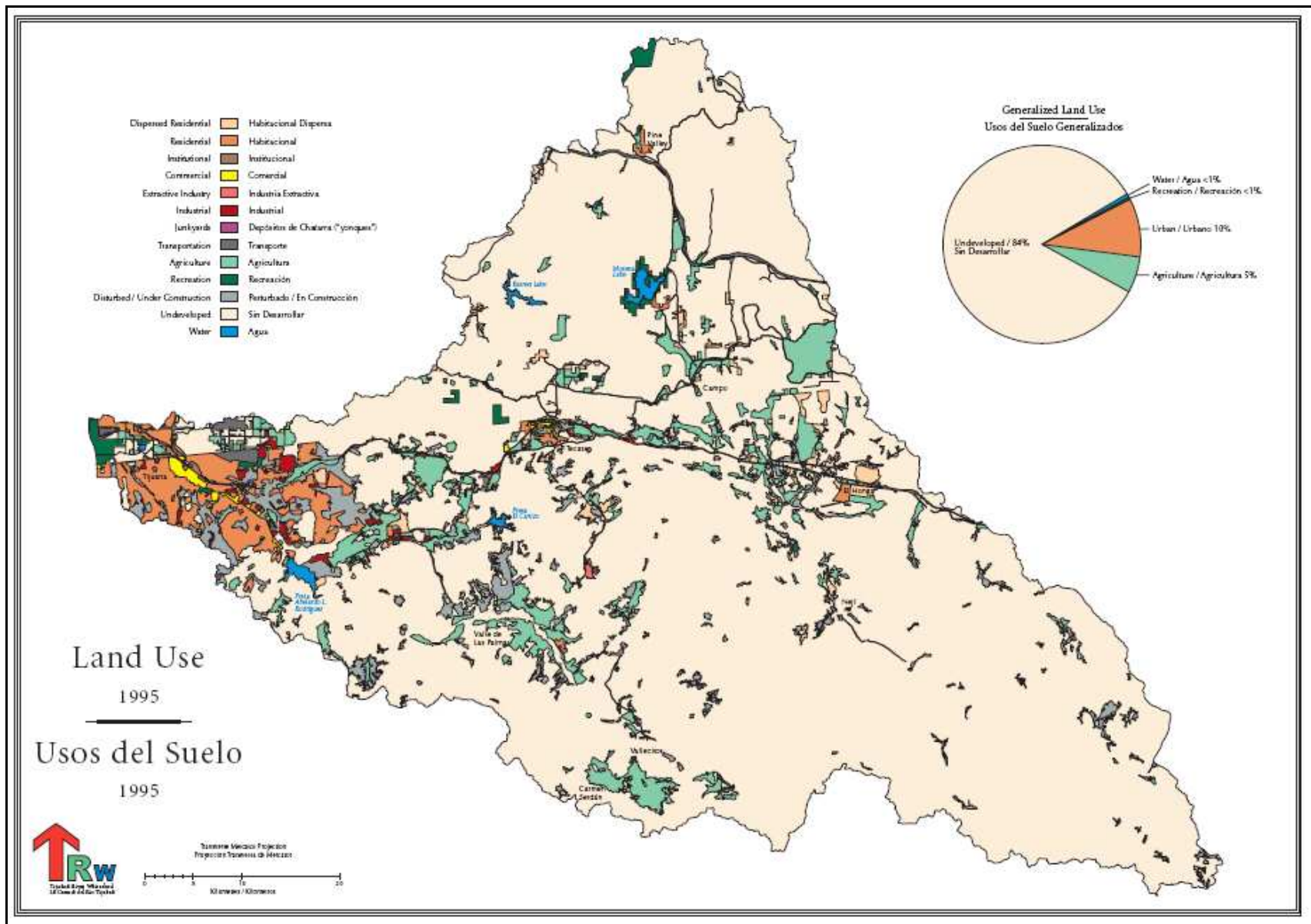
Figure D. Land Use in the Tijuana River Watershed. (Source: SDSU, COLEF and SCERP, 2005)

APPENDIX 2: LOS LAURELES MASTER PLAN

Los Laureles Master Plan

The following section describes the current infrastructure within Los Laureles Canyon and recommendations that have been made by the City of Tijuana for the development of the area, as written in the Los Laureles Master Plan (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007). The Master Plan identifies the main problems present in Los Laureles Canyon as: 1) accelerated and disorganized urban development, 2) removal of native vegetation and subsequent landuse change, 3) intensified erosion and subsequent sedimentation, 4) contamination of natural water sources with solid waste, and 5) high vulnerability of inhabitants of the zone to natural disasters, landslides and floods.

Current Canyon Infrastructure

Although infrastructure is limited in the canyon's steep and unstable slopes, progress been made in providing potable water, sewage treatment infrastructure and roads, to inhabitants of Los Laureles. The city has sub-divided the canyon into 7 distinct sections labeled A-G, running west to east and south to north (Figure A).

Slopes within sub-sections A and B are between 15-35%, while sub-sections C, D, E, F, and G are all greater than 35%. Areas with slopes of 15-35% are considered "conditional" for installation of infrastructure, while >35% is considered "unsuitable" (Table A). Thus, by this definition, very little of the canyon is actually suitable for the construction of sewers, pipes, and roads; with possibilities limited to the higher elevations to the south (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007).

Table A. Physical description of canyon sub-sections (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007)

Canyon Subsection	Average Slope (%)	Area (km2)	Population
A	15-35	2.92	10,381
B	15-35	2.52	10,821
C	35	2.9	3,486
D	35	1.03	6,602
E	35	0.75	5,512
F	35	0.65	5,700
G	35	1.34	5,528
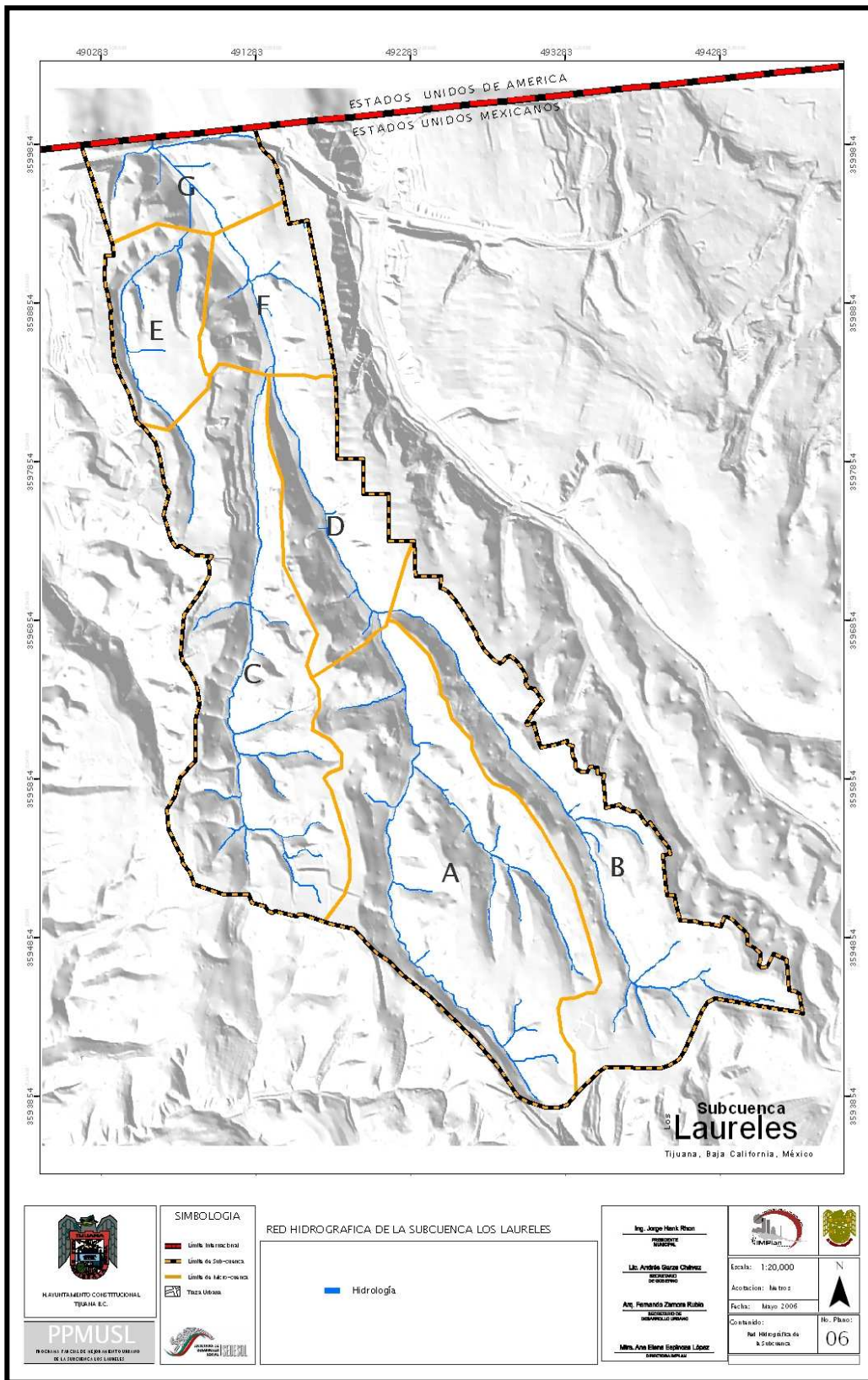
Figure A. Divisions within Los Laureles Canyon by the City of Tijuana (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007)

Water Line Infrastructure

Most Los Laureles Canyon residents have full access to potable water, with the exception inhabitants of sub-sections A and C, where about 50% of homes have been connected to some water supply infrastructure (Table B). These two areas are located in the middle of the sub-watershed, one of the few remaining undeveloped areas. Although a large portion of sub-section A is undeveloped, this largest sub-division supports the second highest population (Table B). A map of water line infrastructure is shown in Figure B.

Table B. Percentage of water line coverage in each section of Los Laureles Canyon (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007)

Canyon Subsection	Coverage of Potable Water (%)
A	58.73
B	80.65
C	45
D	99.39
E	100
F	96.64
G	99.16
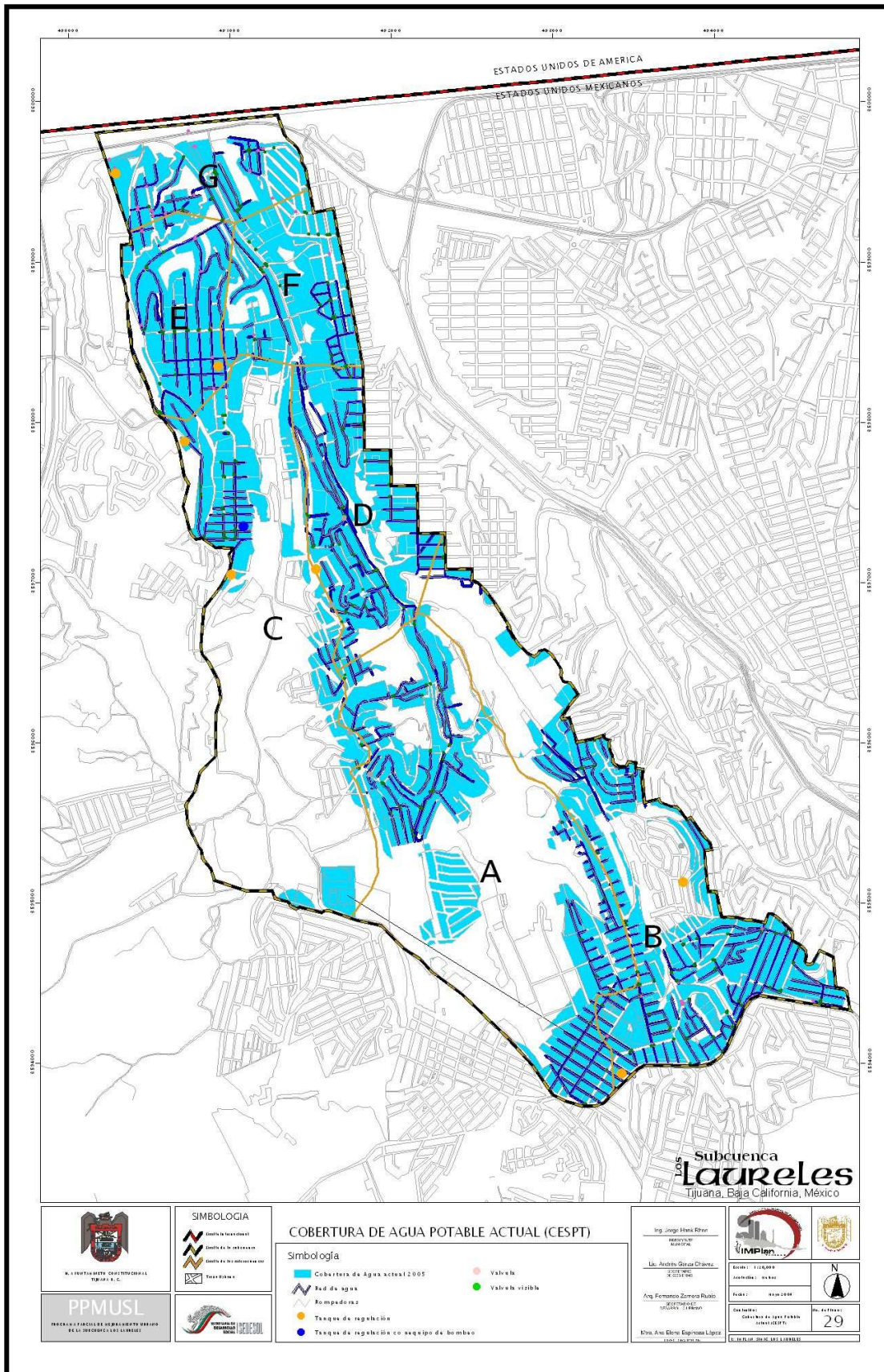
Figure B. Map of water line infrastructure in Los Laureles Canyon (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007)

Sewer Infrastructure

The minimal sewering infrastructure within the Los Laureles Canyon is primarily limited to the lower reaches of the sub-watershed in sub-sections E, F, and G (Table C). However, due to the large volume of sediment traveling downstream from erodible slopes during storm events, these sewer systems have been rendered useless. Plans have been developed to rebuild the systems in a manner that can withstand the risk of sedimentation, and construction is expected to begin within the year (Oscar Romo, personal correspondence, 2008). It is important to note that sub-sections A and B currently have almost no sewer infrastructure (Figure C). The community of San Bernardo, which falls within sub-division A, is slated to be sewered within the next year (Oscar Romo, personal correspondence, 2008)

Table C. Percent coverage of sewer infrastructure in sub-sections of Los Laureles Canyon (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007)

Canyon Subsection	Coverage of Sewering (%)
A	0
B	3.82
C	25.26
D	48.58
E	99.75
F	96.23
G	98.93
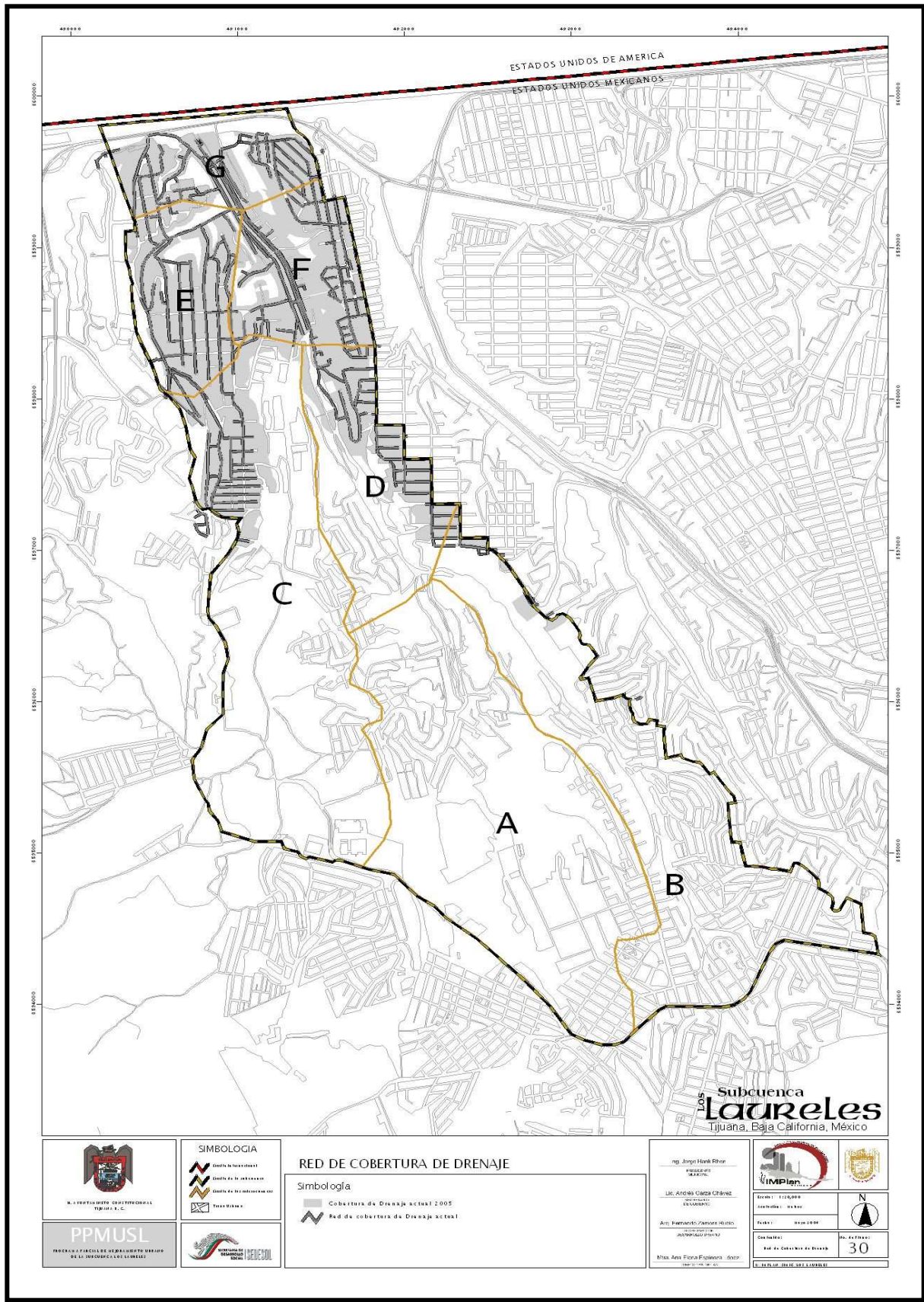
Figure C. Sewering in Los Laureles Canyon. Note the lack of infrastructure in the upper watershed (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007)

Sewer Infrastructure

Most of the paved roads are found in the lower reaches of Los Laureles Canyon (Table D). Roads are frequently washed out during storm events (Oscar Romo, personal correspondence, 2008). The instability of this infrastructure provides an additional challenge to those working to connect certain areas of the canyon to public transportation and the larger city of Tijuana. Figure D depicts the network of roads that weave through the canyon. Most of the roads in the upper watershed are unpaved, while those in the lower watershed are paved.

Table D. Pavement coverage of roads in Los Laureles Canyon (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007)

Canyon Subsection	Coverage of Pavement (%)
A	3.57
B	2.05
C	6.88
D	16.61
E	81.02
F	92.17
G	89.43
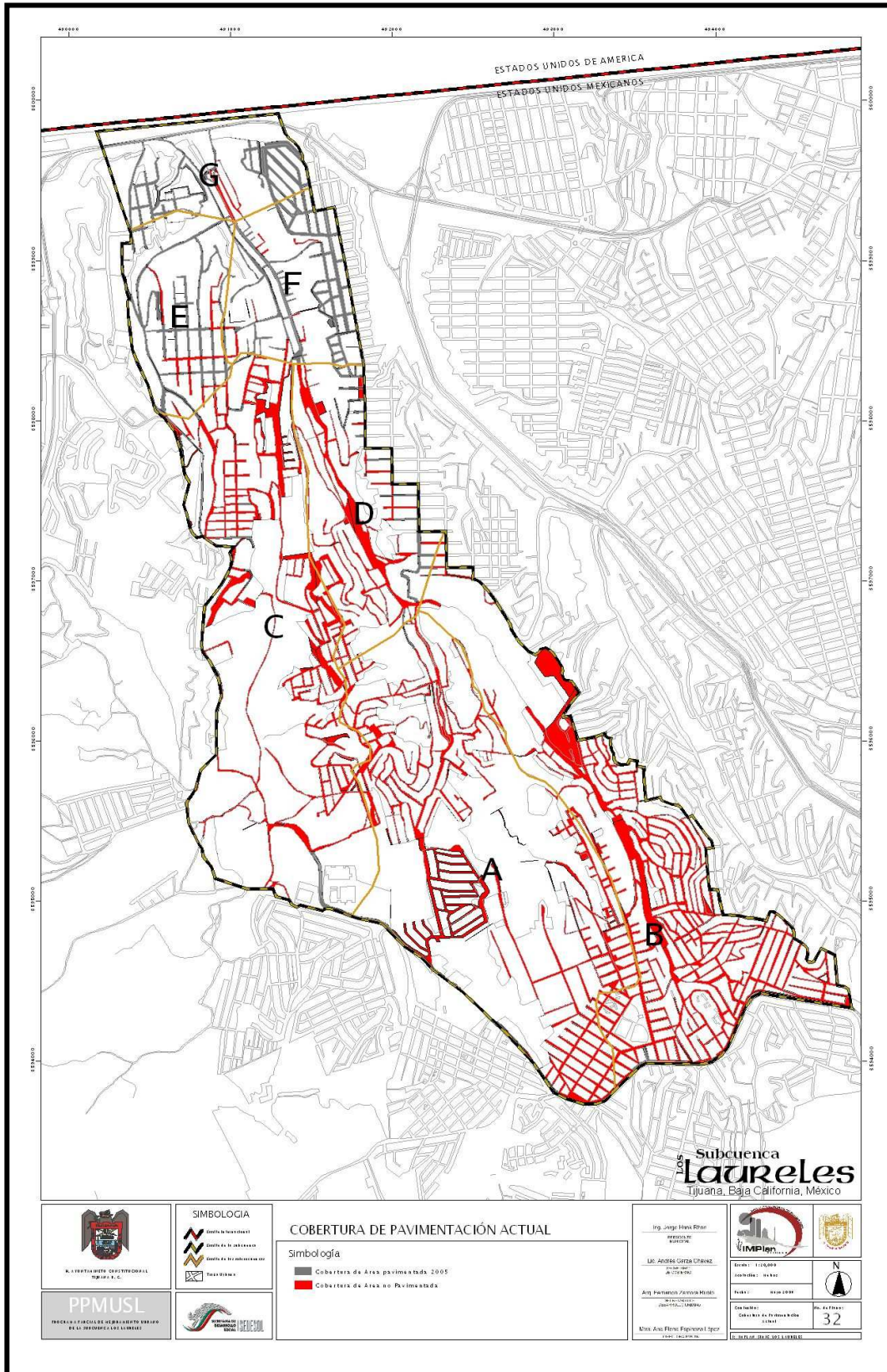
Figure 3. Paved surfaces in Los Laureles Canyon are depicted in gray, while unpaved roads are shown in red (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007)

Future Los Laureles Canyon Infrastructure

The population of Los Laureles Canyon is expected to double to over 95,000 by 2015 (Table E). With the number of inhabitants increasing, associated environmental degradation in the area due to current pollution as well as adverse health impacts are expected to increase. The Los Laureles Master Plan provides an to guide efforts to increase infrastructure in the canyon to accommodate this expanding population by 2015. Specifically, there is a need for sewage lines and paved roads.

Current efforts to provide sewage and paved road infrastructure are concentrated in sub-sections A (north) and B. Proposals for infrastructure construction to be completed by 2010 includes providing sewage service and paved roads to sub-section A (south) and the outskirts of C. By 2015, infrastructure may be provided to the northern portion of sub-section B and southern section of sub-section C (Figure E and F). Higher priority areas are typically those sub-sections that are projected to experience the highest rate of population growth.

Community engagement is necessary for such initiatives to succeed, and any strategy for pollution prevention or mitigation should build upon existing grassroots projects and social networks. Nevertheless, addressing and changing cultural and social attitudes to environmental degradation and pollution in the canyon may require several elements: education, job and tenure security, as well as viable LID and BMP technologies that can be implemented with relative simplicity and minimal cost and infrastructural requirements.

Table E. Projected population growth in canyon sub-sections for the years 2010 and 2015 (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007)

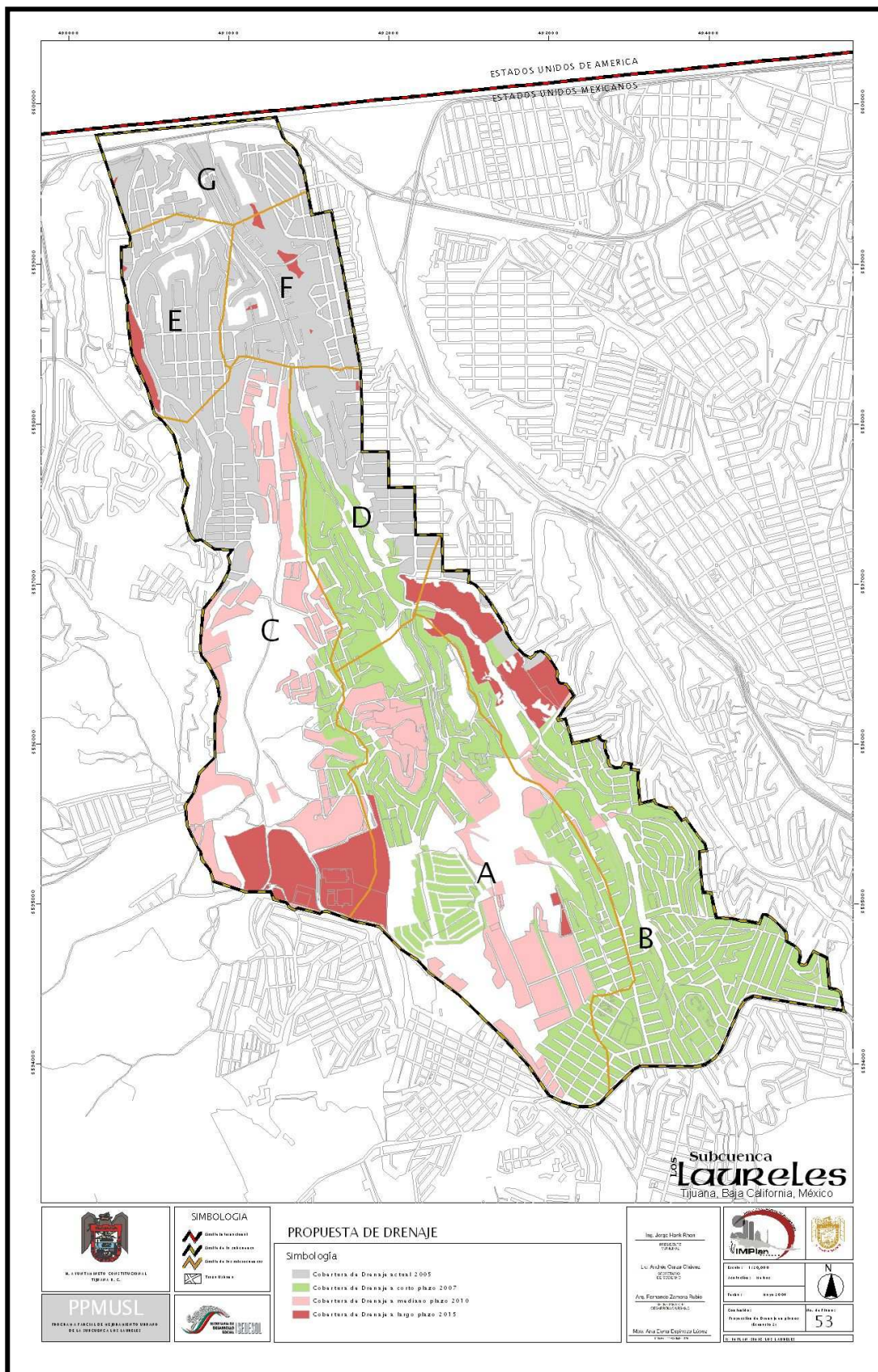| Sub-Section	2010	2015
A	17,101	28,174
B	16,528	25,245
C	4,114	4,855
D	8,567	11,117
E	6,825	8,451
F	6,402	7,189
G	7,748	10,860
TOTAL	67,285	95,891

Figure E. Proposed sewering for Los Laureles Canyon. Added sewer lines by 2007 are represented in green, 2010 light pink, and 2015 maroon (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007)
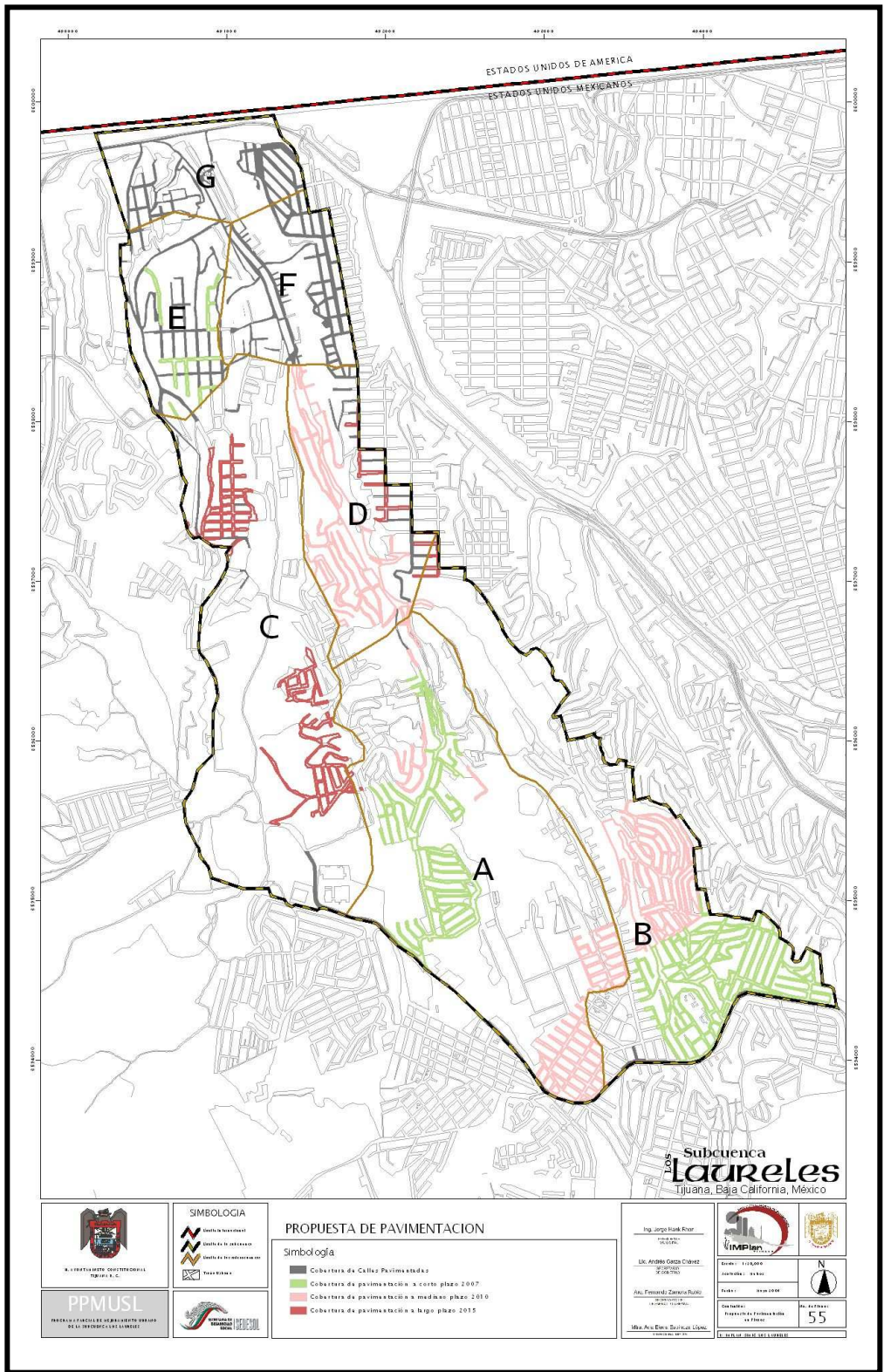
Figure F. Proposed paved roads in Los Laureles Canyon. Green represents 2007, light pink 2010, and maroon 2015 (Los Laureles Master Plan, IMPLan Tijuana and SEDESOL, 2007)

APPENDIX 3: WARMF CONSTITUENT LOADING PARAMETERS

Table A: WARMF sewage treatment parameteriation for fecal coliform modeling

Parameter	Treatment Type		
	No Treat	Septic	Sewer
Calcium	0	0	0
Magnesium	0	0	0
Potassium	0	0	0
Sodium	0	0	0
Sulfate	0	0	0
Nitrate	0.3	0.3	0.1
Chloride	0	0	0
Phosphate	9.8	10	0.1
Alkalinity	0	0	0
Org. Carbon	0	0	0
Inorg. Carbon	0	0	0
Silica	0	0	0
Pesticide 1	0	0	0
Pesticide 2	0	0	0
Pesticide 3	0	0	0
Fecal Coliform	10000000	800	10
BOD	170	18	0.01
Dissolved Oxygen	0	0	0
Carbon Dioxide	0	0	0
BlueGreen	0	0	0
Diatoms	0	0	0
Green Algae	0	0	0
Periphyton	0	0	0
Detritus	0	0	0
Settled Detritus	0	0	0
Clay	0	0	0
Silt	0	0	0
Sand	0	0	0
Sediment Depositio	0	0	0

Table B: Land application rates by landuse for sewage treatment type.

Landuse	Fecal Coliform (1e6/hectare)		
	No Treat	Septic	Sewer
Rangeland	20	0	0
Commercial/Industr	50000	500	15
Residential	50000	1500	30
Barren	100000	0	0

Point	Coordinates				Measurements		Description
	N		W				
	Degree Dec Min	Decimal Degrees	Degree Dec Min	Decimal Degrees	Width (ft)	Depth (ft)	
1	32°29.765	32.49608333	117°05.050	117.0841667	70	9	Sampling Point (Aug 2007). At this point, water was diverted under a road through a ~ 2.5' diameter pipe. Sampling was done at the end of the pipe. The chnnel was a vegitated, soil culvert at this location.
					124	11	
2	32°29.768	32.49613333	117°05.016	117.0836	n/a	n/a	Beginning of the cement channel. Paved road starts around this point.
3	32°29.816	32.49693333	117°05.026	117.0837667	~6	~7	Square concrete channel. Dimensions estimated.
4	32°30.189	32.50315	117°04.934	117.0822333	21	10'6"	Concrete on the bottom and left side (if looking downgradient). No concrete on rt. Side. Dense housing on left side.
5	32°30.560	32.50933333	117°05.074	117.0845667	~30	~8	Vegitated soil culvert.
6	32°30.667	32.51111667	117°05.169	117.08615	~30	~10	Vegitated soil culvert. Likely highly variable at this streatch.
7	32°30.810	32.5135	117°05.274	117.0879	~30	~20	Vegitated soil culvert. Pic #55
8	32°30.857	32.54761667	117°05.289	117.08815	~40	~25	Maquiladora dumping site on right side hill.
9	32°30.241	32.50401667	117°05.460	117.086	n/a	n/a	Potential Sampling Site. Concrete channel begins directly below this site.
10	32°31.410	32.5235	117°05.489	117.0914833	n/a	n/a	"Los Laureles 2" pumping station. Water is pumped to Punte Bundero Treatment Plant
11	32°31.481	32.52468333	117°05.511	117.09185	19	9'6''	Concrete Channel. Minimal sediment #46. Channel bottom is showing signs of wear, re-bar is showing through. Oscar says it could be destroyed by a big event. The channel in this reach was dredged. The sediments were removed and dumped into smugglers gulch (the next canyon over!) >> Need for governmental education on the issues too.
12	32°32.099	32.53498333	117°05.920	117.0986667	n/a	n/a	"los Laureles 1" Pumping station that doesn't actually take in any water from the channel, but helps the other pump convey water to the treatment plant.
13	32°32.132	32.53553333	117°05.929	117.0988167	~20	~8	End of canyon. Goes into a pipe and under the freeway into Goat Canyon at this point.
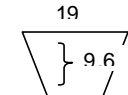
APPENDIX 5: STORMWATER SURVEY QUESTIONS AND RESULTS

Table A. Summary of survey response rates. Only surveys that were fully completed were considered in these analyses.

Category	Technology	Number of Responses
User	Vegetated swales and buffers	43
	Infiltration basins and trenches	55
	Porous surfaces	12
	Media filters	20
	Other	33
Manufacturers	Various	26

Stormwater Technology Users Survey

Introduction

This survey is being conducted by the Donald Bren School of Environmental Science and Management at the University of California at Santa Barbara. A summary of the results will appear in Stormwater Magazine in 2008. All respondents will be provided with a complete report of the survey results as soon as they are available. For questions about the survey please contact Jenny Phillips at jephillips@bren.ucsb.edu.

1. **Technologies** (Questions 2-9 were asked for each of the technologies A-E when the respondent indicated "yes" they were a user of that technology)
A. Have you Used Infiltration Basins and Trenches?
B. Have you used vegetated swales or buffers?
C. Have you used porous pavement?
D. Have you used media filters?
E. Have you used other technologies?

2. Was the technology named above installed to address urban runoff or stormwater from a combined stormwater and sewer systems?
All stormwater technology users responded that they had used the technology for treating stormwater only, with the exception of one infiltration basin user that reported using the system for a combined sewer and stormwater system.

3. What regime best characterizes the climate in the area of use?
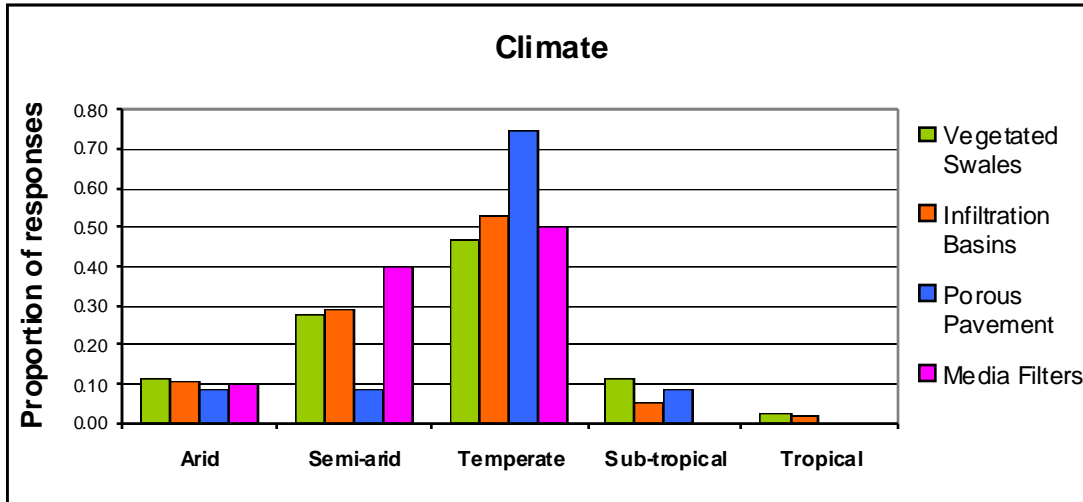
Figure A. Climate in the area where vegetated swales, infiltration basins, porous pavement and media filters were installed.

4. How many systems have you installed in your area? Please specify units (systems, miles, etc.) in the second box.
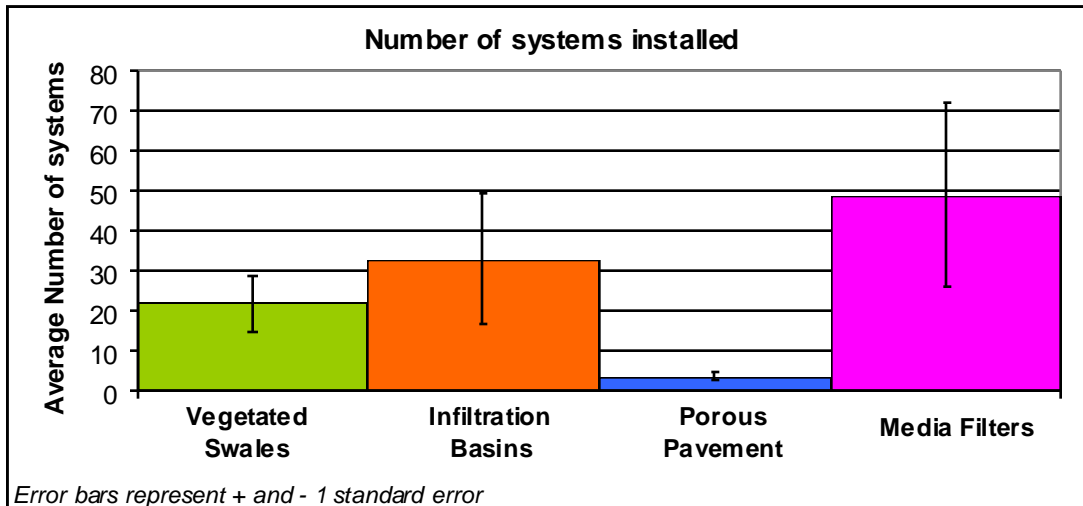
Figure B. Average number of systems installed. Note: system size is not represented in these data, only total number of systems installed by the survey respondent (e.g. a system of 5m² and 5000 m² would each count as one system.)

5. What is the technologies maximum flow interception capability? Please specify units in the second box.
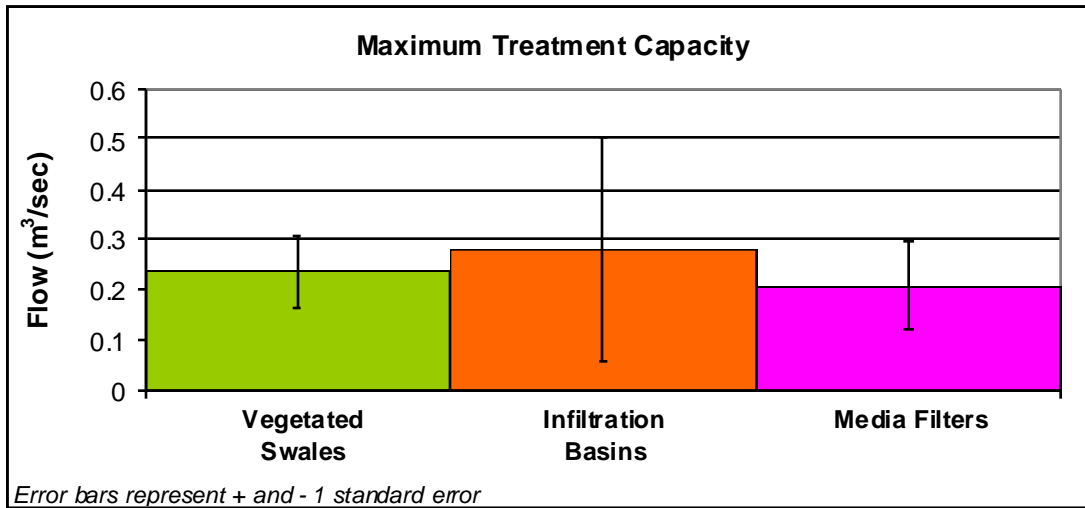
Figure C. Average reported maximum flow intercepted by the technology. Response rate: Vegetated swales n = 12; Infiltration Basins n = 13; Media Filters n = 9.

6. On a scale of 1 to 5 please rate the relative intensity of precipitation, erosion, and development at the site where the technology was installed. 1= minimal; 5= severe.
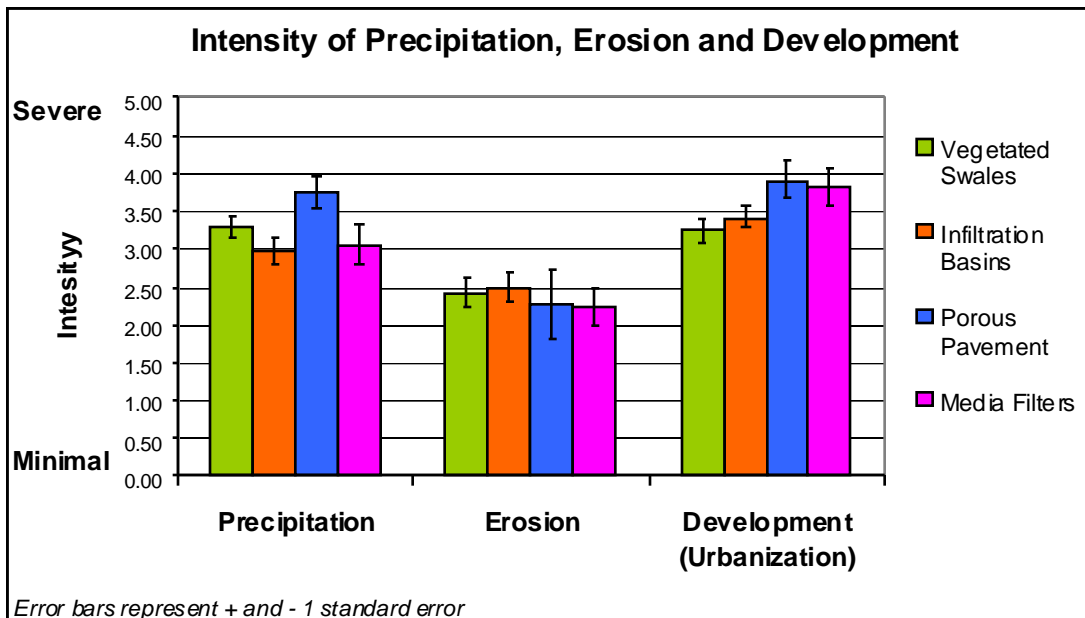
Figure D. Intensity of precipitation, erosion, and development in the location where stormwater technologies were installed.

7. On a scale of 0-5 Please indicate the removal efficiency for each of the constituents below. (0= the technology does not address this constituent, 5=complete removal.)
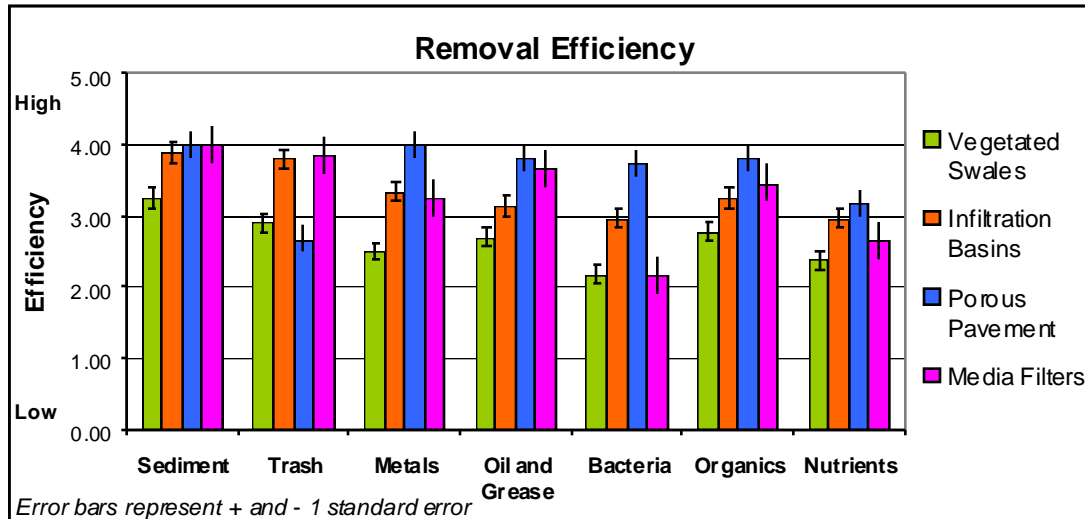
Figure E. Average reported removal efficiencies for seven constituents.

8. For this technology how different were actual capital, installation, and maintenance costs from estimated capital, installation, and maintenance costs?
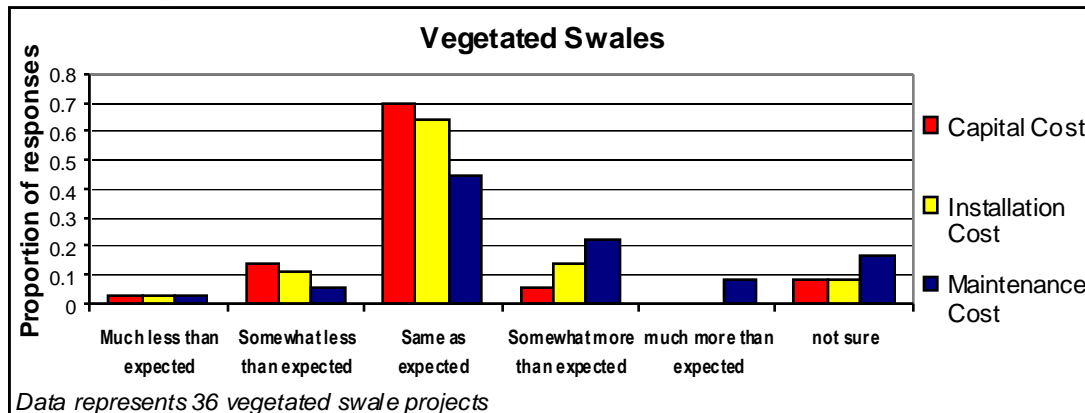
Figure F. Proportion of respondents that reported that vegetated swale capital, installation and maintenance costs were less, the same, or greater than expected.
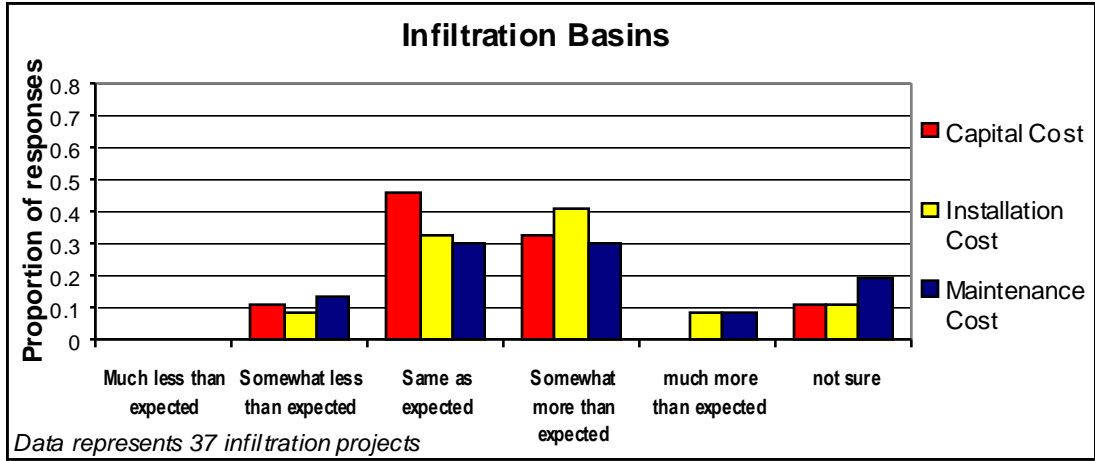
Figure G. Proportion of respondents that reported that infiltration basin and trench capital, installation and maintenance costs were less, the same, or greater than expected.
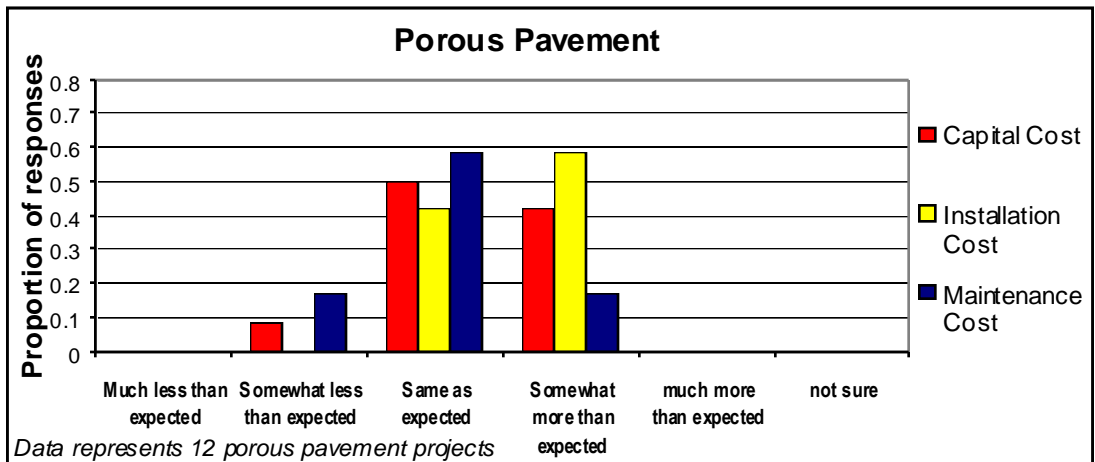
Figure H. Proportion of respondents that reported that porous pavement capital, installation and maintenance costs were less, the same, or greater than expected.
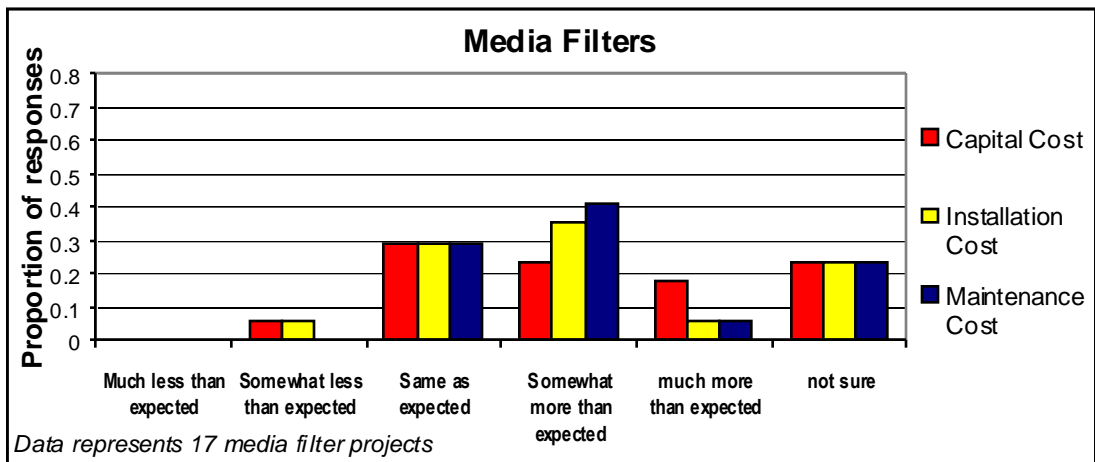
Figure I. Proportion of respondents that reported that media filter capital, installation and maintenance costs were less, the same, or greater than expected.

9. On average, how frequently do you perform maintenance on the technology named above?
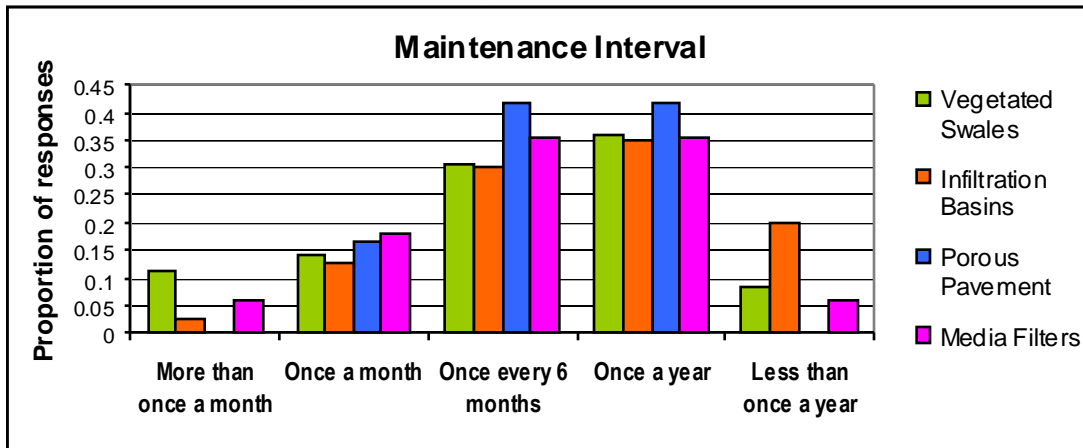
Figure J. Reported maintenance interval.

Stormwater Technology Manufacturer Survey

Introduction

This survey is being conducted by the Donald Bren School of Environmental Science and Management at the University of California at Santa Barbara. A summary of the results will appear in Stormwater Magazine in 2008. All respondents will be provided with a complete report of the survey results as soon as they are available. For questions about the survey please contact Jenny Phillips at jephillips@bren.ucsb.edu.

Technologies

Please complete the following questions for one technology that your company manufacturers. You will be given the opportunity to complete these questions for each stormwater technology that your company manufacturers.

1. Technology Name:

Responses:

Cartridge sand filters	Retention/detention
Clearwater BMP	Safe Drain
CleasnAll	Smart Sponge Technology
Curb inlet Filtration	SST(TM)
DownsTream Defender	Stormceptor 1
drywell	Stormceptor 2
EF Recovery Spill Cleanup Program	Stormceptor 3
Filterra	StormTrap
Filterra Bioretention Systems	The Stormwater Management StormFilter
FM 186-2 Clean and Safe Program	Trencher / plow
Hydrodynamic seperator	Trident CurbScreens
Hydroguard	Turf reinforcement mats
Rain gardens	V2B1

2. Is the technology designed for urban runoff stormwater or combined stormwater and sewer systems?
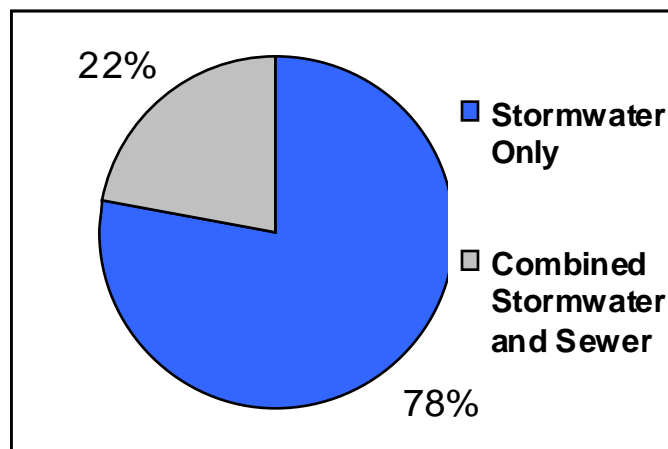

Figure K. Proportion of stormwater technologies that are suitable for stormwater only, or combined stormwater and sewage systems.

110

4. What climate(s) is/are the technology suitable for? (select all that apply)
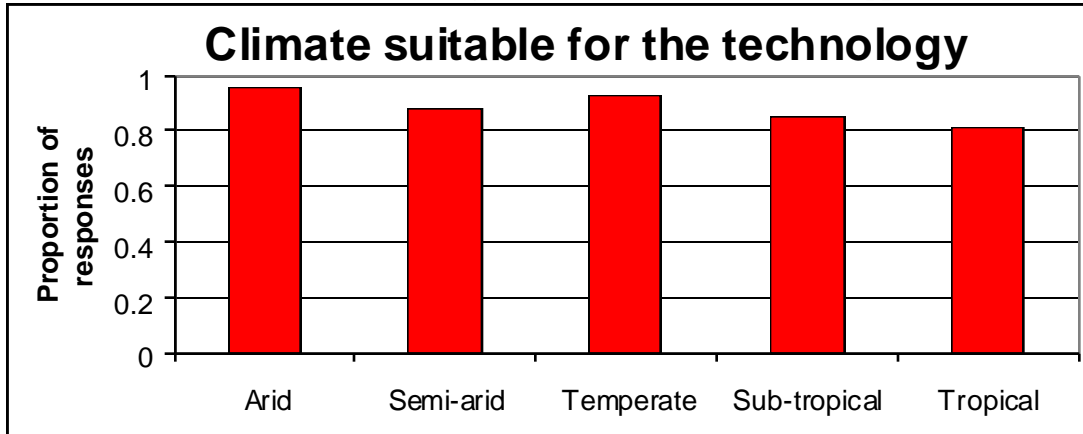
Climate suitable for the technology

Figure K. Proportion of technologies that are suitable for installation in arid, semi-arid, temperate, sub-tropical, and tropical climates.
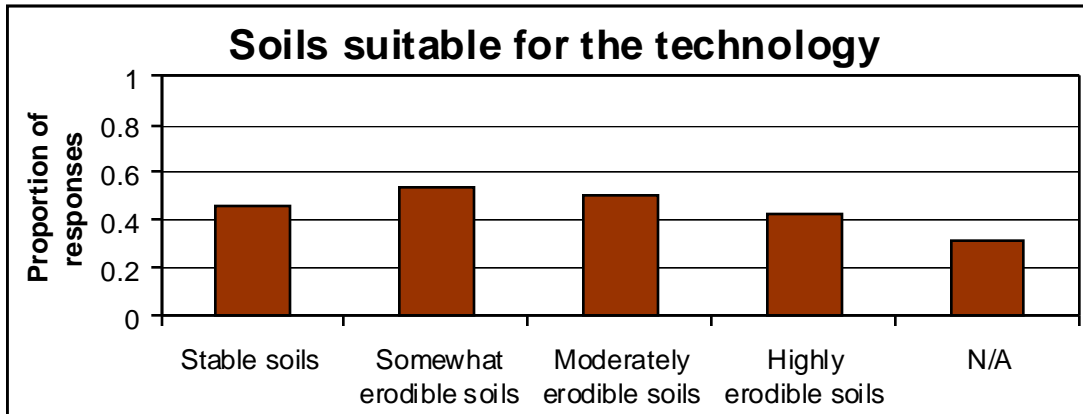
5. What soil type is the technology suitable for?

Soils suitable for the technology

Figure L. Proportion of technologies that are suitable for installation in stable, somewhat stable, moderately stable, or highly erodible soils.

6. What slope is the technology suited for?

Slope suitable for the technology
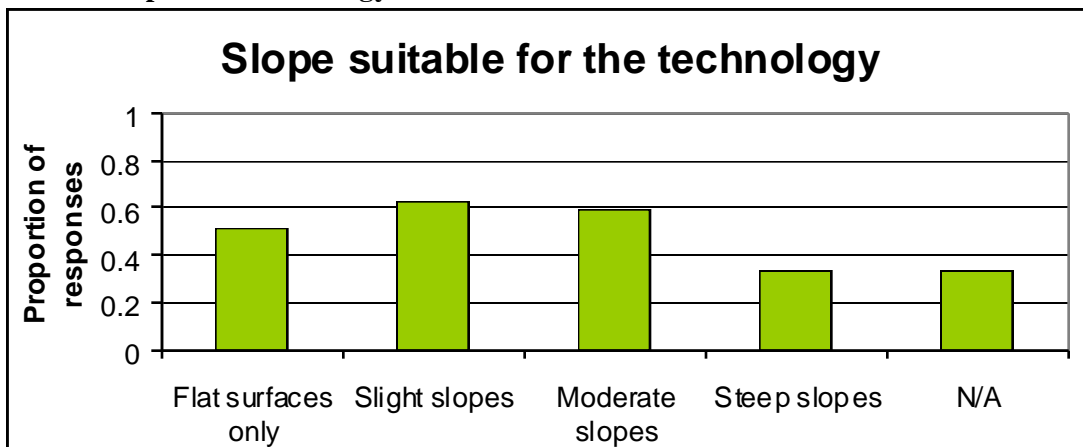
Figure M. Proportion of technologies that are suitable for installation on flat, slight, moderate, or steep slopes.

7. On a scale of 0-5 Please indicate the removal efficiency for each of the constituents below. (0= the technology does not address this constituent, 5=complete removal.)
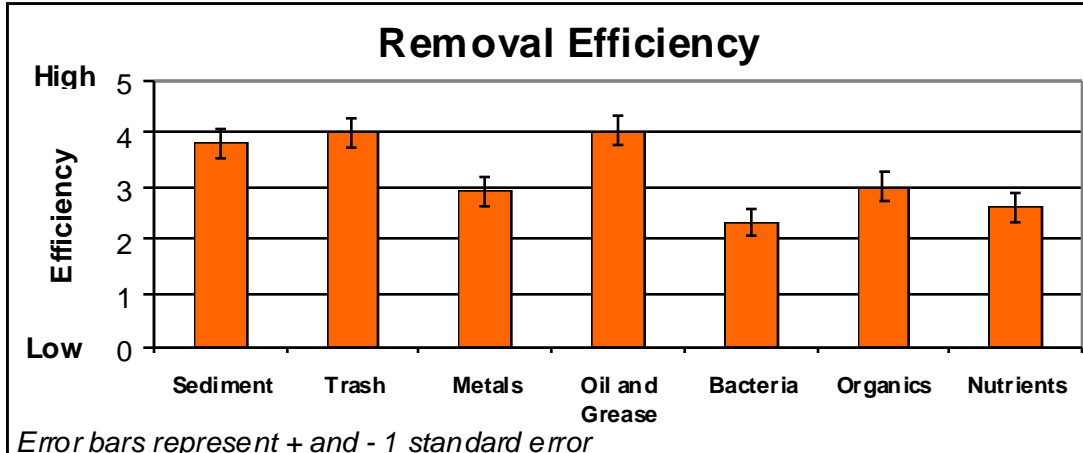

Figure N. Removal efficiency for seven constituents of concern.

8. What maximum flow can this technology handle?
9. What minimum flow does this technology require?
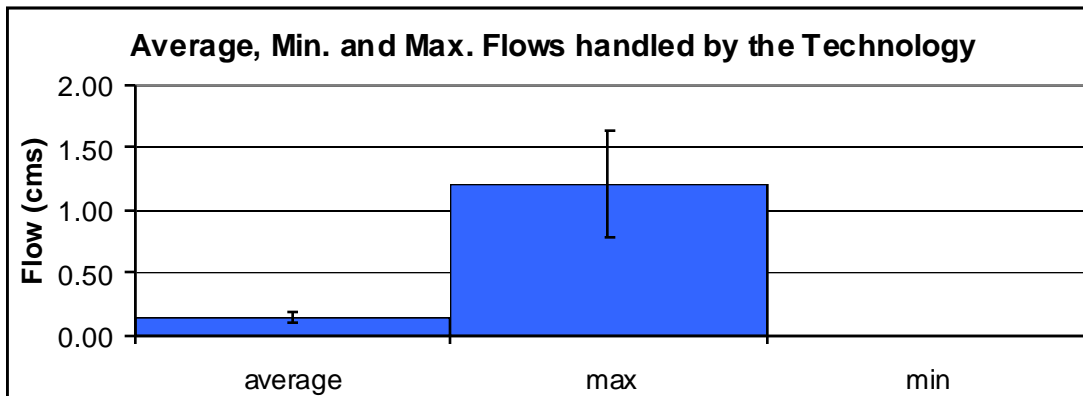**12. What is the flowrate of a typical system (please specify units.)**

Figure O. Average, minimum, and maximum flows intercepted by the technology.

10. Does the technology require external power or other utilities for regular operation?
All respondents except for one stated that the system did not require external utilities.

11. On average, how frequently is the technology expected to require maintenance?
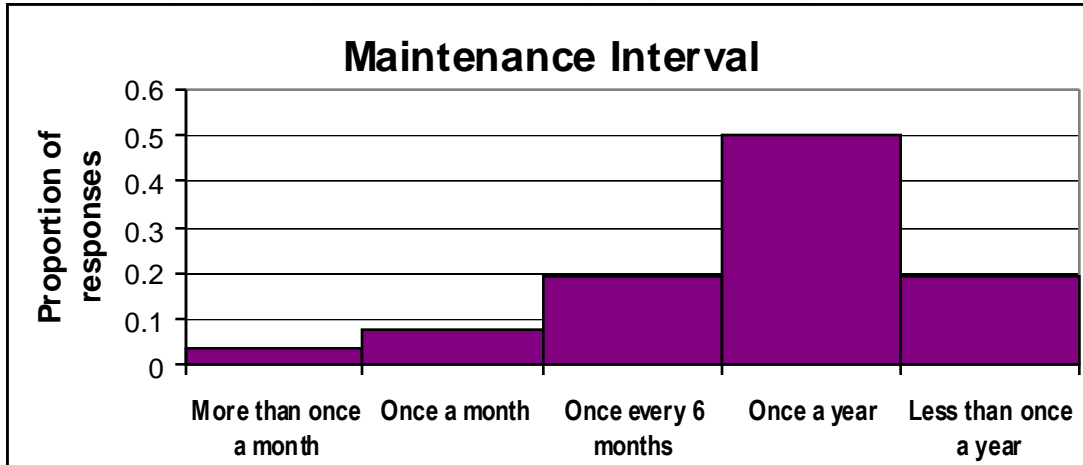
Maintenance Interval

Figure P. Expected maintenance interval.

13. What is the expected annual maintenance cost?

14. For the technology named above, what is the expected capital cost (purchase and installation) cost of the technology?
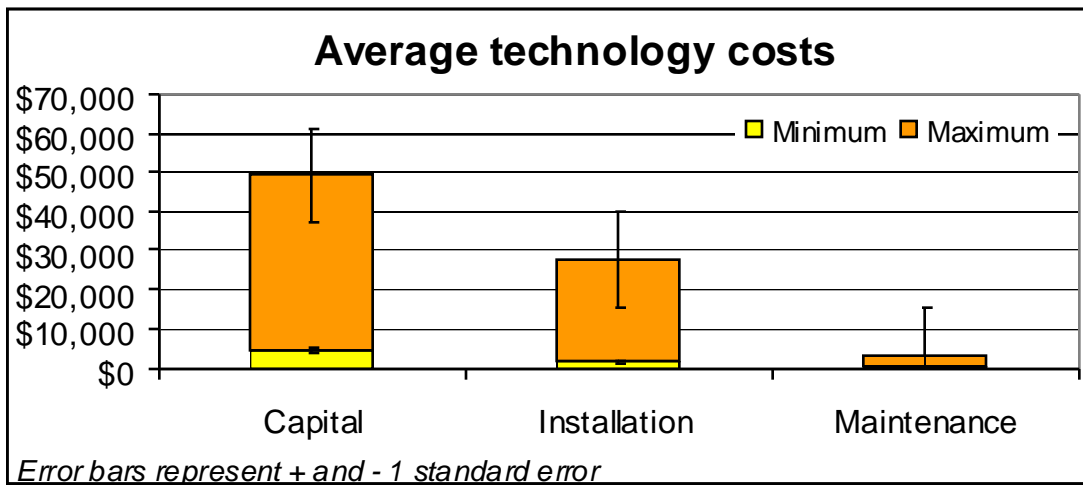
Average technology costs

Error bars represent + and - 1 standard error

Figure Q. Average minimum and maximum technology capital, installation and maintenance costs.

Residential Erosion Control Flyer

What is erosion?

Erosion occurs when flowing water picks up soil and carries it from one place to another. In the canyons of Tijuana, soils are highly sandy and will easily wash away during rain storms. If your home is on a slope, erosion will likely occur on the side(s) facing downhill. The steeper the slope the more erosion can occur.

Why is reducing erosion important?

It is important to identify locations near your home where erosion is likely to occur because continual erosion can make the foundation of your home unstable and dangerous. The climate in Tijuana produces rain storms that can suddenly drop a large amount of water, which may cause homes with unstable foundations to be damaged or destroyed during the coarse of a storm. Reducing erosion around your home can help protect it from damage during a storm and can help keep your family safe.


What can you do to reduce erosion around your home?

1. IDENTIFY EROSION. The first step to reducing erosion around your home is to identify the locations where erosion is likely to occur. Take a walk around the perimeter of your home to identify signs of existing erosion [insert pictures of eroded foundations]. Look for the way that the water will move around the foundation during a rain storm. Water will always flow from uphill to downhill, and during large rain events, and soil will move with the water.

2. MAKE A PLAN. After identifying the locations where erosion is likely to occur, create a plan for slowing down the water that moves around your home, and stabilizing the soil around it. By slowing down the water and stabilizing the soil you will reduce the amount of soil that can be picked up and carried away during a rain storm. There are many different ways to accomplish this, and you can be creative about how you do it. Some options for slowing down the water and stabilizing the soil include:

   a. Placing plants around your home – Plants have roots that extend down into and hold onto the soil. Plants reduce erosion because the water must slow down when it flows around plants and is less able to pick up the soil around plants because the roots are holding onto it. Look for plants that do not require much water and are likely to have large root systems, like bushes or small trees.

   b. Construct a retaining wall – A retaining wall is a structure that is designed to hold the soil in place. Retaining walls are usually built on a slope and can be constructed out of many materials including bricks, tires, wood, or other materials that will stay in place during a rain storm. Retaining walls must be constructed with careful planning in mind and must be strong enough to hold back increasing amounts of soil that may build up during a storm.

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c. <u>Rainwater collection systems</u> – Rainwater collection systems can reduce the amount of water that flows off of your property, which will reducing erosion and provide a source of water for landscaping or other non-consumptive uses.
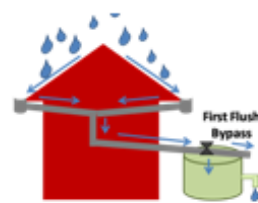
d. <u>Terracing</u> – Creating reinforced terraces can help maintain useable space around your home while protecting your property from erosion. When designing terraces, be careful to ensure that the walls are sturdy and will be able to withstand sediment accumulation.

3. MAINTENANCE. After installing any erosion reduction systems around your home, you must periodically check the system to ensure that it is structurally sound and is producing the desired erosion reduction. Observing the area before and after a storm is a good way to understand the effect of your erosion control measures. After a storm, you may want to make modifications or implement additional erosion control techniques.

What can you do to reduce erosion in your community?

Reducing erosion around your home is a great way to help keep your home safe from being damaged during a rain storm, but areas away from your home are subject to erosion too. Streets and communal areas may become inconvenient or dangerous if they are eroded. [INSERT PICTURES]. Working with your neighbors to reduce erosion in your community will make the area safer for everyone. Some community erosion-control projects include:

- o Paving streets with pavers [highlight existing project]
- o Constructing vegetated swales
- o Direct runoff from homes and other structures into stabilized channels

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