UNIVERSITY OF CALIFORNIA
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Evaluation of Rainfall-Runoff Relationships to Develop Stormwater Reduction Approaches for Watersheds in Southern California

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

by Drew Beckwith, Christy Ciarametaro,
Maya Dehner, Mike Rossiter, and
Ruyan Joanne Siew

Faculty Advisor:
John Melack

May 2007

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DREW BECKWITH

CHRISTY CIARAMETARO

MAYA DEHNER

MIKE ROSSITER

RUYAN JOANNE SIEW

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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 four-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:

FACULTY ADVISOR JOHN MELACK, PH.D

DEAN ERNST ULRICH VON WEIZSÄCKER, PH.D

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ABSTRACT

The quantity and quality of stormwater runoff affects the condition of local creeks and the near-shore marine environment. Impervious surfaces, such as roads, roofs, parking lots, and driveways, have the potential to increase stormwater flows and degrade water quality. Our study employed a rainfall-runoff model to examine how the percentage of impervious surfaces affects runoff characteristics in two Santa Barbara catchments, Mission Creek watershed and Atascadero watershed. We investigated techniques for reducing imperviousness, including permeable pavements, and approaches to encourage their use. Our modeling results demonstrated that reducing impervious surfaces would significantly decrease total and peak stormwater flows in both watersheds, during average and El Niño water years; small (0.5-in; 1.27 cm), design (1.2-in; 3.05 cm), and large (5.0-in; 12.7 cm) storms; and all four seasons. Our research showed that pervious concrete can reduce stormwater runoff and improve water quality. A mix of economic, land use planning, and site development strategies can help local water managers to incorporate stormwater reduction techniques. Outcomes-based education and outreach that combines media campaigns with intensive training can build the public and political support required to successfully implement these techniques.

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Contents

EXECUTIVE SUMMARY

Stormwater runoff is a concern for elected officials, land use planners, water managers, community organizations, and residents in California's Santa Barbara area. Most urban stormwater flow originates from impervious surfaces. The imperviousness of developed watersheds located along the Pacific coast in the Santa Barbara area ranges from approximately 20% to 40%. Impervious surfaces in the area consist of 25-50% structural roofs and 50-75% parking lots, driveways, sidewalks, and roads. Replacing these surfaces with permeable materials could positively impact the quantity and quality of local stormwater runoff.

The purpose of this study is to provide local water managers with a scientific analysis of how reducing imperviousness would affect stormwater runoff in two Santa Barbara area watersheds, Mission Creek and Atascadero. The study evaluates and suggests the use of pervious concrete to replace impervious surfaces, highlighting its potential to reduce stormwater volumes and pollutant loads. The study also explores economic incentives, land use planning, site development strategies, and education and outreach programs that could assist local water managers in reducing stormwater runoff.

Impervious surfaces (i.e., roads, parking lots, sidewalks, driveways and roofs) prevent rain from soaking into the ground. Rain runs off impervious surfaces, rapidly flowing into storm drains and local waterways, which leads to greater discharge volumes and higher peak flows. This change in runoff conditions can have significant impacts on storm hydrographs for watersheds with high percentages of impervious cover.

Impervious surfaces collect pollutants from aerial deposition, transportation, and other landscape management practices throughout the year. During major rains, stormwater runoff can mobilize collected pollutants and carry them into storm drains, streams, and the ocean. Stormwater pollution from impervious surfaces potentially threatens freshwater and marine ecosystems. It may also trigger public health warnings, like beach advisories, at popular recreational areas. Beach advisories can have negative economic consequences for communities like Santa Barbara that depend on coastal tourism.

Stormwater management in Southern California is likely to become more challenging as the area becomes more urbanized. Urbanization typically involves the conversion of vegetated surfaces to impervious surfaces. Stormwater management will have to address the stormwater quantity and quality concerns associated with increases in imperviouness.

Conventional stormwater management approaches often employ large infrastructure projects to address stormwater runoff issues. These projects have substantial eco-

nomic, environmental, public safety, political, and practical limitations. A flexible alternative, which tends to be more cost-effective and environmentally friendly, is low impact development (LID). LID is a land planning approach that employs a range of micro-scale techniques to preserve or restore an area's predevelopment hydrologic regime. LID techniques include bioretention cells (i.e., rain gardens), grass swales, rooftop gardens, permeable pavements, and others.

Modeling

Rainfall-runoff models can be used to evaluate the volume and intensity of runoff that results from varying land uses and amounts of rainfall and discharge. Watersheds along the Santa Barbara coastline have a Mediterranean climate, with storms consisting of brief, high-intensity downpours. The hydrologic model used in this project was selected because it was designed specifically for catchments in coastal Southern California and can accurately assess the runoff associated with the type of storms that are prevalent in this climate.

Modeling Results

Both peak and total flows are calculated to steadily decrease as impervious surface area decreases. This trend persisted in both watersheds, Mission Creek and Atascadero, for average and El Niño water years; small (0.5-in; 1.27 cm), design (1.2-in; 3.05 cm), and large (5.0-in; 12.7 cm) storms; and all seasons. Results illustrate that pervious surfaces have the potential to significantly increase infiltration for most storms in the Santa Barbara region, which tend to total less than 1.0-inch (2.54 cm).

Permeable Surfaces

Permeable pavement is a useful stormwater best management practice for reducing total stormwater runoff and reducing stormwater peak flows. Permeable pavements, and pervious concrete in particular, are also effective at reducing stormwater pollutants such as heavy metals and hydrocarbons. In addition to these benefits, pervious concrete provides: stormwater retention, groundwater recharge, reductions in urban heat-island effects, efficient land use, improvements in vehicle safety, and potentially cheaper implementation costs than for more traditional stormwater management practices.

Economic, Land Use Planning, and Site Development Strategies

Economic, land use planning, and site development strategies may be employed to encourage the use of permeable pavement in Santa Barbara. Economic strategies such as stormwater fee and rebate programs and runoff allowance trading schemes are cost-effective approaches that can potentially reduce the amount of impervious surfaces in a watershed and encourage the use of dispersed Best Management Practices (BMPs), e.g., permeable pavements and pervious concrete. Land use planning and site development strategies based on the principles of low-impact development, such as Green Area Ratios, Impervious Overlay Zoning and ‘Country Lanes’, can also provide a systematic framework for the implementation of onsite stormwater runoff reduction controls. Communities in the US, Canada, and Germany have successfully incorporated these strategies in their efforts to reduce stormwater runoff in their watersheds.

Education and Outreach

Education and outreach is an essential component of effective stormwater management. The most successful stormwater education is outcomes-based and focuses on changing or encouraging specific actions within target audiences, while the best stormwater outreach techniques combine media campaigns and intensive training. To reduce stormwater runoff in the Santa Barbara area, education and outreach managers may consider encouraging local decion-makers to implement runoff reduction policy tools and public and private landowners to replace impervious surfaces with permeable pavements.

Conclusions

Our modeling demonstrated that reducing impervious surfaces can significantly decrease stormwater total flow and peak flow. Pervious concrete is an acceptable alternative to traditional pavements that can be used to decrease watershed imperviousness. Local water managers can use a combination of economic, land use planning, and site development strategies to incorporate stormwater reduction techniques. Effective education and outreach can encourage individuals and organizations to use permeable pavement and to implement stormwater runoff reduction policy tools.

INTRODUCTION

Impervious Surfaces

The impacts of impervious surfaces on stormwater runoff, water quality, aquatic habitat, and the urban heat-island affect have been well studied by geographers, environmental planners, biologists, and hydrologists (Arnold 1996; Barnes and Morgan 2001; Brabec et al. 2002). Impervious surfaces inhibit infiltration of rainwater into the ground and provide pathways for rainwater to reach streams. Because no infiltration occurs through impervious surfaces, more rainwater reaches the streams, leading to greater discharge. Furthermore, rainwater reaches the streams more quickly, shortening the time between the peak rainfall intensity and peak discharge (Goudie 1994). Since discharges are greater and lag times are shorter, peak flows in watersheds with high impervious surface cover are greater than those in watersheds with more permeable surface cover.

Streets, parking lots, and other transportation-related structures comprise the bulk of impervious surfaces within a watershed (City of Olympia 1994; Arnold 1996; May et al. 1997). Thus, many impervious surfaces receive and collect pollution, such as heavy metals, grease, and oils. Runoff generated by early-season rains can mobilize and transport these pollutants to streams, as well as other contaminants like nitrogen, phosphorus, and bacteria. These pollutants impact the health of receiving streams as well as the coastal waters into which these streams flow. The peer-reviewed literature suggests that biotic health of a watershed becomes impaired at landscape impervious levels as low as 8-12% (Brabec et al. 2002; Beach 2002).

It is important to draw a distinction between total impervious area and direct or effective impervious area (EIA). Effective impervious area constitutes all impervious areas that are directly connected to stormwater drains. A roof, for instance, may be part of total watershed imperviousness, but if rainwater from that roof flows over a lawn before reaching the street, it is unlikely that the roof is contributing to stormwater runoff. If, however, the roof has downspouts that run through pipes and directly out to the street, then that roof should be considered effective impervious area because it contributes some portion of the total stormwater runoff. Peak storm flows in 100% impervious areas can be 2.5 times greater than in areas of 0% imperviousness, and as much as 8 times greater if those impervious areas are connected via storm drains and sewer networks (Barnes et al. 2001).

Urbanization increases the percentage of impervious surface cover in a watershed. The traditional method of managing stormwater has been to remove runoff as quickly as possible from the area. This practice is gradually being replaced by a new-school of thought suggesting that runoff be treated on-site through the use of stormwater best management practices (BMPs) like permeable pavement and bioswales, or by breaking up EIA with the addition of filter strips. This new methodology is represented by low-impact development (LID). LID is a comprehensive land planning and engineering design approach aimed at "maintaining and enhancing the pre-development hydrologic regime of urban and developing watersheds" (LID Center 2007a). In addition to promoting, progressive, locally-based BMPs, LID encourages a watershed-level approach to managing stormwater, recognizing the upstream impacts on downstream hydrology. The LID approach may also be prove to be more cost effective than traditional stormwater management techniques like straightening and concrete lining of urban streams. In recent studies compiled by the Natural Resources Defense Council, new residential developments using green infrastructure stormwater controls saved $3,500 to $4,500 per lot when compared to new developments with conventional stormwater controls (Kloss and Calarusse 2006).

Mission Creek and Atascadero Creek Watersheds

The watersheds of Mission Creek and Atascadero Creek , located in the southeastern side of Santa Barbara County, have mountainous headwaters in the Santa Ynez mountains and mild sloping coastal plains which ultimately drain into the Pacific Ocean (Figure 1). Both watersheds are characterized by a Mediterranean climate, with mild moist winters and moderately warm, generally rainless summers. Winter rainstorms, which are usually intermittent and intense, provide most of the flow in the drainage network. The average precipitation is 400 mm per year with peak rainfall generally occurring between December and March. ENSO events can influence precipitation in the watersheds considerably, causing large variations in annual precipitation with totals ranging from less than 180 mm to more than 1100 mm in the past 150 years (Santa Barbara Coastal Long Term Ecological Research 2006).

Figure 1: Location of Atascadero and Mission watersheds

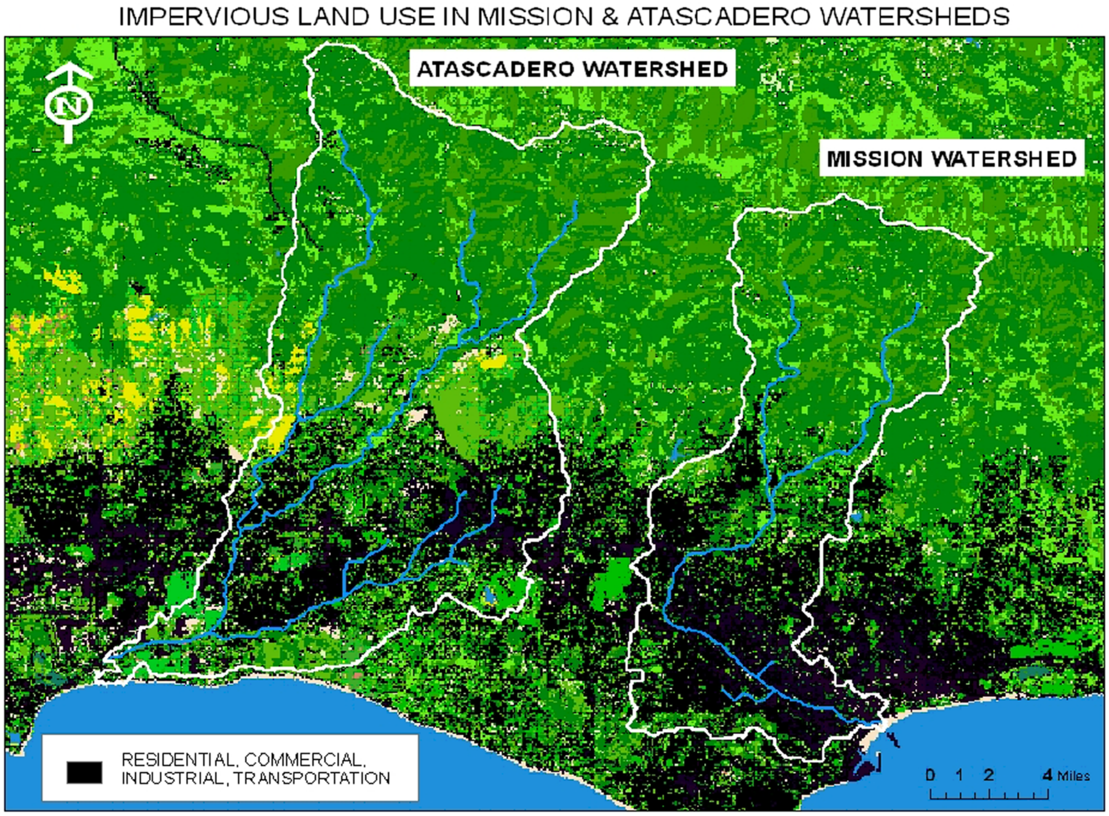


Figure 2: Impervious surfaces in the Atascadero and Mission watersheds (Anderson Level III data)

Mission Creek

Mission Creek drains a watershed area of approximately 30 km^2 [7400 acres] and has an average 100-year peak discharge of 201 m^3/s [7100 cfs] (Questa Engineering Corporation 2005). The river flows from the Santa Ynez mountains through downtown Santa Barbara and ends at the outlet at East Beach that leads into the Pacific Ocean. Elevation in the watershed ranges from 1463 m [4800 ft] to sea-level. The upper portion of the watershed is located within the Los Padres National Forest. The upper section of the watershed, especially the area in the Los Padres National Forest reserve, is relatively steep, with slopes greater than 22°, while the coastal plain in the lower section of the watershed is generally < 6° in gradient.

The upper portion of Mission Creek watershed comprises mostly shrub and brush rangeland, with some outcrops of exposed rock. In the middle portion, there is some mixed rangeland and a small tract of evergreen forest land. There is significant residential development throughout the middle to lower portion of the watershed. Most of the residential development in the upper-middle portion of the watershed consists of single-family houses located on large lots. Development in the downtown area is most intensive, consisting of commercial and residential buildings and facilities. Residential housing density ranges from cottages and duplexes to shopping malls, small hotels, and institutions. There are varying levels of imperviousness ranging from 0.5% in the upper watershed, to 21% in the middle watershed, and 29% (Old Mission) to 49% (Lower Mission) in the lower watershed (City of Santa Barbara Creeks Division 2006d). The highest imperviousness in Mission Creek watershed occurs along the southeastern boundary of the lower watershed, and also in the western boundary of the middle watershed.

Mission Creek suffers from water quality impairments and is included in the EPA's 2002 303 (d) list of impaired waters for pathogen pollution. Bacterial contamination is a principal source of concern. The sources with the greatest potential to contribute to these problems are urban runoff from storm drains, and transient encampments.

Atascadero

Atascadero Creek drains a watershed area of approximately 45 km^2 [11,123 acres] and has an average 100-year peak discharge of 446 m^3/s [15,700 cfs] (Natural Resources Advisory Committee 2004). Land use in Atascadero Creek watershed comprises approximately 38% urban, 51% shrub/brush, and 11% agricultural. Imperviousness ranges from 3% in the upper non-urbanized areas to 46% in the lower urbanized areas (Beighley 2003). Elevation in the watershed ranges from 897 m [2,942 ft] to sea-level.

The upper section of Atascadero watershed is relatively steep, with slopes as high as 35°, while the coastal plain in the lower section of the watershed is generally $< 3°$ in gradient. The uppermost portion of the watershed is located within the Los Padres National Forest. The area immediately below the national forest boundary is dominated by open grassland and chaparral, with relatively little residential development. Land uses change to higher density residential development with some commercial uses in the middle portion of the watershed. In contrast to Mission Creek watershed, where urban development is most intensive in the lowermost portion of the watershed, Atascadero Creek flows through large undeveloped open spaces downstream before entering the Goleta Slough (Natural Resources Advisory Committee 2004). As part of the Flood Control District's maintenance of Atascadero Creek, approximately 0.06 km^2 [15 acres] of riparian vegetation have been planted along lower portions of the creek since 1994 (Santa Barbara County Flood Control District and Water Resources Division 2003).

Project Objectives and Approach

Using a rainfall-runoff model, this project assesses the effects of reducing watershed imperviousness on stormwater runoff. The project evaluates pervious concrete as one method for reducing imperviousness, explaining its volume and pollutant reduction capabilities. The study suggests how local water managers may use economic strategies, land use planning policies, and education and outreach programs to encourage stormwater reduction and permeable pavement installation.

Modeling

Two HEC-HMS models, one calibrated for Atascadero watershed and one calibrated for Mission watershed, were utilized to predict runoff characteristics under a variety of impervious conditions. The models were created and calibrated in 2003 for previous research done on land use changes along the southern California coast (Beighley 2003). The input parameters used in the models were validated to ensure accuracy and the Mission model was altered to include nine subbasins in the lower watershed.

Permeable Pavements, Economic and Land Use Development Strategies, and Education and Outreach

Information for these sections was gathered from published sources including peer-reviewed journal articles; the City and County of Santa Barbara's Stormwater Management Plans; publications from non-profit organizations (e.g., Natural Resources Defense Council); and the websites of relevant government agencies, non-profit organizations, and businesses. For the permeable pavements section, additional information was obtained through interviews with professional engineers and industry representatives.

Research for the pervious pavements section focused on the properties and functionality of pervious concrete with respect to its runoff and pollutant reduction capabilities. Further analysis evaluated the potential for pervious pavement installation at various locations in the Santa Barbara area and addressed relevant concerns and issues to consider before installing this type of stormwater management practice.

For the economic and land use development strategies section, emphasis was placed on incentive mechanisms or programs that aim to mitigate stormwater runoff through reductions in impervious surfaces. Strategies to reduce impervious surfaces in other communities were evaluated and recommended for Santa Barbara based on several considerations: level of success, ease of implementation, and applicability to Santa Barbara. Case studies were also provided to highlight the process of development, implementation, and management of these strategies.

Research for the education and outreach section explored the connection between environmental education and pro-environmental behavior as well as case studies of successful stormwater education and outreach programs in the United States and Australia. This information was used to analyze Santa Barbara's current stormwater education programs and to create an educational plan for reducing stormwater runoff.

MODELING THE EFFECTS OF CHANGING IMPERVIOUS SURFACE PERCENTAGES ON STORMWATER RUNOFF

Introduction

The Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) was used to model how changing the percentage of impervious surfaces in the Atascadero and Mission watersheds will affect stormwater runoff. This section describes how the model was selected, the specific requirements of the model, and the processing of input parameters. Additionally, the validation of our techniques is described and specific parameters of the Atascadero watershed and Mission watershed models are described.

Model Selection

In selecting a model to be used for the project, it was important to match the resources available with the requirements of the project. Many hydrologic models, available from both private and public sources, claim to be able to model watershed runoff. Other modeling programs such as Watershed Analysis Risk Management Framework (WARMF) and Storm Water Management Model (SWMM) have been utilized in many watersheds and were considered in this analysis. HEC-HMS was chosen because of its ability to accurately represent the Santa Barbara area's meteorological and land use conditions.

Watersheds along the Santa Barbara coastline have a Mediterranean climate, with storms consisting of brief rainfall events of high intensity, especially in the mountainous upper watersheds. HEC-HMS can accurately assess the runoff associated with the storms that are prevalent in this particular climate. Unlike many other hydrologic models, which are intended to be run with a daily or hourly precipitation time step, HEC-HMS can accurately model a 15-minute time step.

HEC-HMS models were calibrated for the Atascadero and Mission watersheds prior to this analysis (Beighley et al. 2003). Taking advantage of previous calibration work is preferable to creating an accurate hydrologic model from scratch. The previous modeling analysis for Atascadero watershed focused on the hydrological response to future *increases* in impervious surfaces. This project models the impacts of *reductions* in impervious surfaces.

HEC-HMS System Requirements

Model Version

The US Army Corps of Engineers released HEC-HMS 2.2.2 in May 2003. The HEC-HMS software is continually updated and improved. In January 2007, Version 3.1

superceded Version 2.2.2. The HEC-HMS software is available free to the general public and is easily downloaded from http://www.hec.usace.army.mil. Since Beighley developed his settings in HEC-HMS Version 2.2.2, we are also using Version 2.2.2 in our modeling. Attempts to run the Version 2.2.2 model calibrated by Beighley in the new HEC-HMS Version 3.1 program resulted in inoperable errors.

Hydrologic Processes

On average, about 15% of annual rainfall in coastal southern California watersheds is converted to runoff (Beighley et al. 2005). This means that the watersheds have high soil storage abilities and/or high loss rates to evapotranspiration (Figure 3). Therefore, antecedent soil conditions are important to predicting runoff in these watersheds.

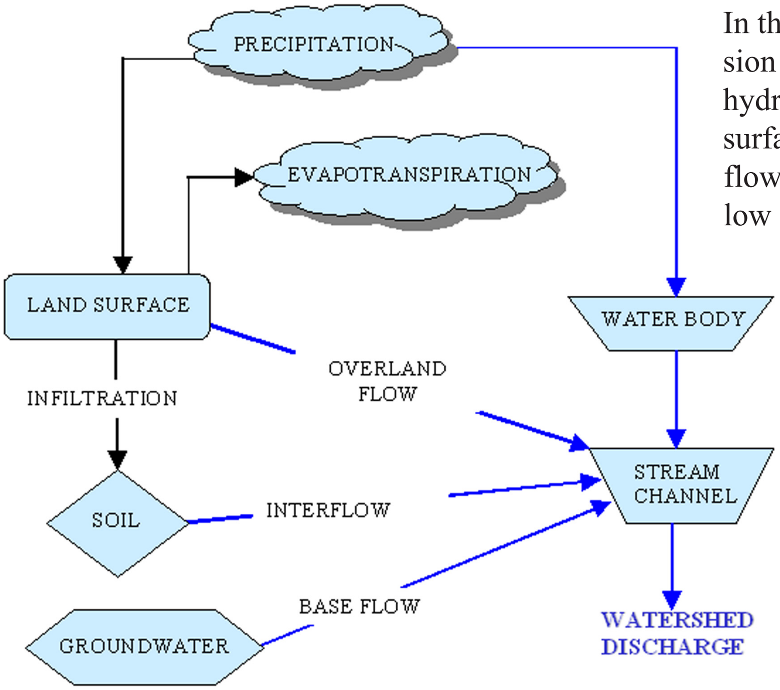


Figure 3: HEC-HMS Watershed Runoff

In the Atascadero and Mission watersheds, the hydrograph is dominated by surface runoff (overland flow) and/or interflow (shallow soil flow) (Beighley et al. 2003). This is shown from the rapid watershed response and hydrograph recession rates. Therefore, changes to impervious surfaces are likely to have a large effect on runoff in Atascadero and Mission watersheds.

In order to most accurately represent local watershed conditions, the following hydrologic processes were selected for routing water through the watersheds:

- Initial deficit constant loss infiltration routing
- Overland and channel flow: kinematic wave routing
- Subsurface flow: exponential recession

Initial deficit constant loss infiltration routing

The initial deficit constant loss infiltration routing is the first modeling process to affect precipitation. A subarea, *i*, has an initial and maximum storage capacity. When precipitation begins, all rainfall not on impervious surfaces goes towards filling the initial deficit (Figure 4). Once the initial storage deficit is satisfied, runoff occurs if the rainfall rate (Pe) exceeds the constant loss rate (I). It is assumed that all rainfall on impervious surfaces results in runoff (Beighley et al. 2003).

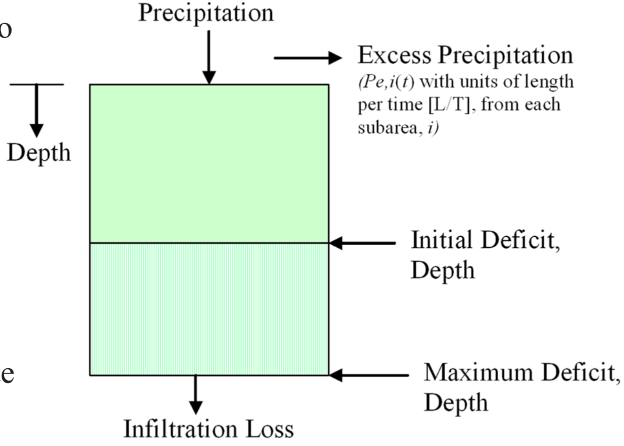


Figure 4: Initial Deficit Constant Loss Infiltration

This routing method requires parameters for the initial deficit (in), constant loss rate (in/hr), and monthly recovery rate (in/day) (adjusted monthly for seasonal influence). These parameters represent the antecedent conditions and physical properties of the watershed soils and land use. HEC-HMS continuously tracks the moisture deficit, computing it as the initial abstraction volume less precipitation volume plus recovery volume during precipitation-free periods. The recovery rate could be estimated as the sum of the evaporation rate and percolation rate (deep groundwater recharge), or some fraction thereof. The recovery rate is adjusted monthly to simulate seasonal effects (USACE 2000).

for Storage = Max Storage AND Precipitation > Constant Loss Rate,
Excess Precipitation Rate = (% Impervious Surfaces)(Precipitation Rate) + (% Pervious Surfaces)(Precipation Rate – Constant Loss Rate)

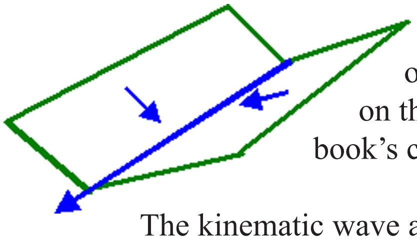
for (Storage < Max Storage OR Storage = Max Storage) AND
Precipitation < Constant Loss Rate,
Excess Precipitation Rate = (%Impervious Surfaces)(Precipitation Rate)

The initial deficit constant loss routing method is appropriate for the Mission and Atascadero watersheds because the initial conditions (i.e., initial storage capacity) and infiltration excess runoff (i.e., surface runoff only during intense rainfall) are dominant factors affecting the storm hydrographs (Beighley et al. 2003). This routing method utilizes a direct input parameter for impervious surface within a given subarea to easily allow changes to impervious surfaces to be modeled.

Overland and channel flow: kinematic wave routing

The kinematic wave method uses the continuity equation and the steady, uniform flow approximation of the momentum equation to transform excess precipitation to flow. The kinematic wave model divides overland flow within a catchment into overland (planar) and channel flow. The plane surface represents the behavior of the overland flow to the channel. The channel flow represents the concentrated flow through channels to the outfall of the watershed.

The kinematic wave method assumes subareas are large planes with a main channel that drains to the subarea outlet. The main channel receives lateral inflow from the overland flow planes (i.e., $Pe,i(t)$), where overland flow is approximated as wide rectangular channel flow. For subareas with upstream inflow, the main channel routes the upstream flow as well as lateral inflow to the subarea outlet. The kinematic wave routing method requires shape, slope, and roughness characteristics for both channel and overland components. To account for urbanization impacts on routing, overland and channel characteristics are modified to reflect altered land use conditions (Beighley 2003).



At a cross section, the system would resemble an open book, with the water running parallel to the text on the page and then into the channel that follows the book's center binding.

The kinematic wave approach determines when flow, or the "wave" of water from a specific subbasin area, arrives at downstream reaches. Flow speed is estimated with Manning's equation:

$$V = (k\ h^{2/3}\ s^{1/2})\ /n$$

where V is flow speed (m/s or ft/s); h is flow depth (m or ft); s is slope (m/m or ft/ft); n is Manning's roughness coefficient (unitless); and k is a unit-conversion factor (1.0 for SI units; 1.486 for English units).

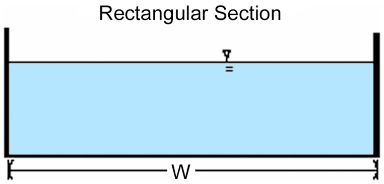
Manning's roughness coefficient, n, represents all surface complications (including spatial variability and flow paths) that delay flow. Flow is estimated by the discharge equation below:

$$Q = aA^m$$

where Q is discharge; A is cross-sectional area; and a and m are parameters related to flow geometry and surface roughness (given for overland flow and channel flow below).

for <u>overland flow</u>: $a = (1.486S^{1/2})/N$ and $m = 5/3$

where N is an overland flow roughness factor (not the same as Manning's n).



for channel flow: $a = (1.486S^{1/2}W^{-2/3})/n$ and $m = 5/3$. where W is width (US ACOE 2000).

The kinematic wave routing method was used because of the steepness of the slopes in the Atascadero and Mission watersheds. Slope and roughness are the two main parameters used in this routing approach.

Subsurface flow: Exponential Recession

The exponential recession approach was used for two types of subsurface flow in the Atascadero and Mission watersheds: steep shallow soil flow and ground water flow. Baseflow is the sustained runoff of prior precipitation that was stored temporarily in the watershed, plus the delayed subsurface runoff from the current storm (Figure 5). The threshold flow value and the exponential decay constant are the main parameters used to determine subsurface flow by exponential recession:

$$Q_t = Q_0 k_t$$

where Q_t is the baseflow at any time t; Q_0 is the initial baseflow (at time zero); and k is an exponential decay constant (the ratio of the baseflow at time t to the baseflow one day earlier).

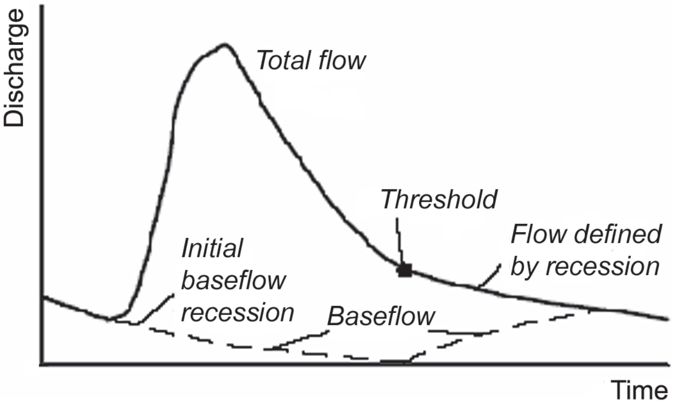


Figure 5: Exponential Recession Subsurface Flow (USACOE 2000)

After the peak of the direct runoff, a user-specified threshold flow defines the time at which the recession model defines the total flow. The threshold factor identifies the flow on the recession limb of the response hydrograph where flow is defined by the recession model (i.e., where subsurface flow shifts from recession to increasing).

Model Modules

HEC-HMS is a mathematical, lumped parameter, deterministic model. A mathematical model uses equations that represent the response of a hydrologic system component to a change in hydrometeorological conditions. A lumped parameter model is one where spatial variations of characteristics and processes are averaged. HEC-HMS is a deterministic model because it does not incorporate random variation into its predictions. Additionally, the model assumes a dendritic pattern of streams with tributaries that branch to form a tree-like pattern.

A HEC-HMS model requires data to be entered via three different "modules":

- Meteorologic: evapotranspiration and rainfall
- Basin: impervious percentages, baseflow, infiltration, etc.
- Control: time frame for specific run

Meteorologic Module

The meteorologic module is used to specify the amount and location of precipitation falling on a watershed. It also accounts for precipitation that does not result in runoff by incorporating evapotranspiration. For precipitation, HEC-HMS allows the user to choose a historical storm or to have the software create a synthetic 'design' storm to model. The user-specified hyetograph method was chosen for the precipitation method. The evapotranspiration method uses monthly average values, along with an ET coefficient. The potential ET rate for each month is computed as the product of the monthly value and the ET coefficient.

The precipitation gauge weights and evapotranspiration amounts were not changed from the values established by Beighley et al. (2003). In addition to using historical precipitation amounts, the precipitation amounts were changed to allow for a "design" storm in the group project analysis.

Basin Module

The basin module is where the majority of information is stored. It is where hydrologic elements are created, connected into a watershed network, and where simulations are controlled. HEC-HMS simulates a real-world watershed by using subbasins, reaches, junctions, and a sink at the outlet of the watershed. The channel and overland flow routing method (kinematic wave), and baseflow routing method (regression) are defined in the basin module.

Subbasin Concept

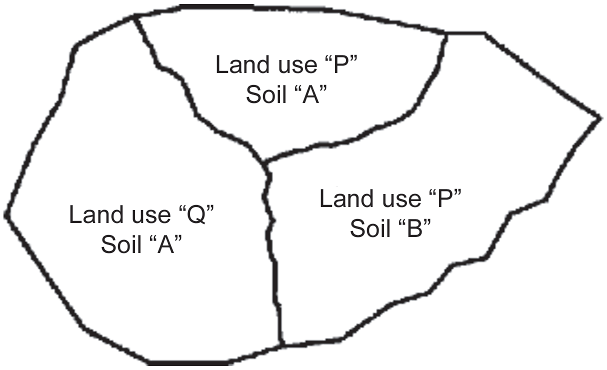


Figure 6: Subbasin Parameters (Olivera 2001)

In HEC-HMS, watersheds are divided into subbasins. The subbasins in the Atascadero and Mission watersheds are about 0.77 square miles [2 km^2] in size. The model uses subbasin data to predict how watersheds will behave. Each subbasin is assumed to be approximately homogenous in terms of key modeling parameters like land use/percent impervious, soil type, slope, and area (Figure 6). Therefore, these parameters are averaged, or ‘lumped’, within a particular subbasin. This process is particularly effective in areas where dominant runoff processes are understood (Beighley et al. 2005). Lumped parameter models are commonly used throughout the United States for design applications (Moglen 2002).

Impervious Percentages

Beighley et al.(2003) used land use characterizations and aerial photography to establish baseline impervious percentage values for the Atascadero and Mission watersheds. Subbasins in the upper areas of the watersheds are typically only 3% impervious, while subbasins in lower areas of the watersheds can reach 45% impervious. It is important to recognize that impervious percentage values are averaged over an entire subbasin. Thus, specific locations within a subbasin may have higher or lower impervious percentages than the subbasin average. Some areas of the lower Atascadero and Mission watersheds, for example, are as much as ~80% impervious.

Control Module

The control module defines the time frame for a specific model run. The starting and ending date and time, as well as the computation time step, are defined in the module.

Model Verification (resolution, scale, sources of error)

Since this project utilized a model created and validated by Beighley et al. in 2003, it was important to ensure that the model is accurate given current (2006-2007) watershed characteristics and that the model is valid for the purpose of analyzing decreases in impervious surfaces. The resolution and scale of available data, as well as sources of error, were evaluated.

The spatial data used in creating input layers or parameters for HEC-HMS include:

- USGS Digital Elevation Models (DEMs) for topography
- Stream and storm drain locations for drainage
- Soil Survey Geographic (SSURGO) Database (NRCS, 1995) for soils
- 1:42,000 scale aerial photographs (1998) classified for land use on Anderson Level III classifications
- Parameter Elevation Regressions on Independent Slopes Model (PRISM) precipitation contours

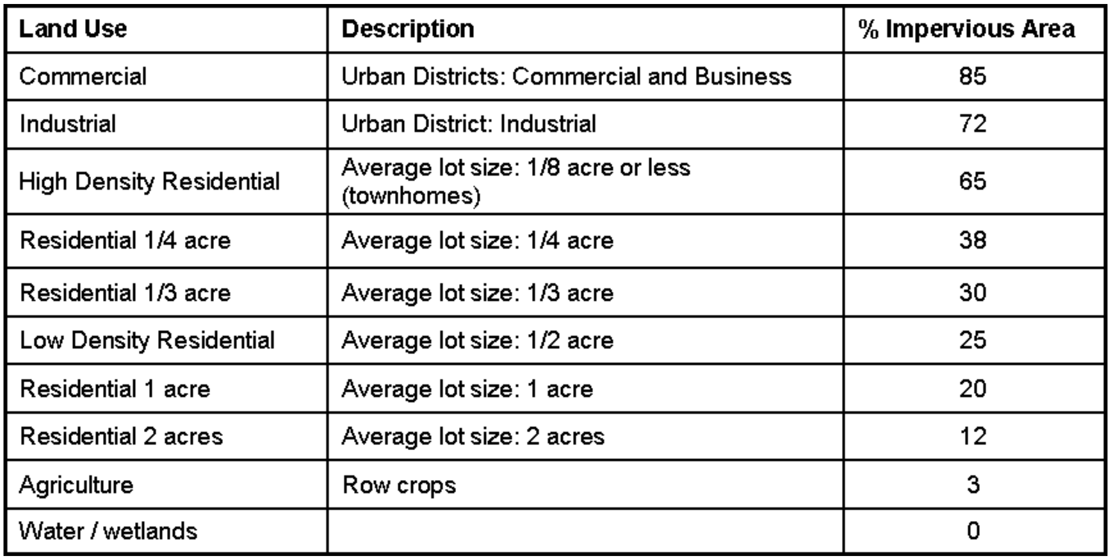
DEMs have a 30-meter by 30-meter grid spatial resolution (approximately a quarter of an acre). For the purposes of calculating slope in a subbasin that is two orders of magnitude larger, this resolution is appropriate.

Errors could arise due to runoff following a drainage pipeline vs. a stream channel in an urban area. Santa Barbara City and County provided the most current data available on stream drainage networks during the summer of 2006. These GIS files were evaluated to ensure that subbasin and reach drainage directions within HEC-HMS are still valid.

The SSURGO soil data, created in 1995 by the US Department of Agriculture's National Resource Conservation Service, is still the most accurate soil data available for the Santa Barbara area. SSURGO soils are classified using field methods and aerial photographs. Soil maps are created at typical scales of 1:15,840, 1:20,000, or 1:24,000 (USDA 1995). The soil data was used to calculate the loss and recovery rate for the kinematic wave routing (USDA 1995).

Anderson Level III land use classifications determined from 1:42,000 scale aerial photography have resolutions of approximately half an acre (Anderson et al. 1972). Additionally, 1:42,000 scale data have an accuracy of approximately 21 meters [70 ft] (Foote 2000). Published USDA tables which relate land use to impervious surfaces allowed the Anderson land use data to be used as the source of impervious surface data (Table 1). The impervious surface/land use data are averaged over a subbasin roughly two orders of magnitude larger than the resolution of the original aerial photography.

The impervious area estimations based on land use assume that all impervious area is connected to a drainage network. Therefore, all roofs on houses are assumed to drain into a connected storm drain network. This may result in an overestimation of imper-



Land Use	Description	% Impervious Area
Commercial	Urban Districts: Commercial and Business	85
Industrial	Urban District: Industrial	72
High Density Residential	Average lot size: 1/8 acre or less (townhomes)	65
Residential 1/4 acre	Average lot size: 1/4 acre	38
Residential 1/3 acre	Average lot size: 1/3 acre	30
Low Density Residential	Average lot size: 1/2 acre	25
Residential 1 acre	Average lot size: 1 acre	20
Residential 2 acres	Average lot size: 2 acres	12
Agriculture	Row crops	3
Water / wetlands		0

Table 1: Impervious Surface Calculations Based on Land Use (USDA 1986)

vious area in the less urban upper watersheds where rainfall from roofs may drain onto yards.

PRISM precipitation contours are created based on a mathematical relationship between rainfall records and elevation contours (Daly 1994). The scale of PRISM data is usually limited by the scale of the DEM used to create it. Since a 30-meter by 30-meter DEM grid is already being used for slope calculations, PRISM estimates do not introduce any new errors due to scale.

The City of Santa Barbara Creeks Restoration Division, in consultation with Questa Engineering, produced a report on impervious surfaces (Questa Engineering Corporation 2005). The procedure used to determine impervious surfaces involved providing 10% increment ranges of impervious surface interpreted from multi-spectral satellite imagery. Based on this averaged approach, the lower urban subbasins of Mission Creek Watershed have an average impervious surface area of 49%. Based on Andersen Level III land use categories, Beighley classified similar areas in Mission Creek Watershed as having an overall impervious surface of 42%. These discrepancies are expected due to the different averaging methodologies.

The slope, soil data, and impervious surface areas were estimated using the best available resolutions and accuracy. These inputs were averaged over a subbasin (approximately 2 km^2) area and used to compare relative changes in runoff from changes to impervious surfaces.

Watershed Parameterization

Atascadero watershed was chosen to model because it is a good example of a southern California watershed with an urbanized area (Figure 1). The watershed also had good gauging data to use for model calibration. Finally, it provided a good example from which to analyze stormwater reduction strategies within Santa Barbara County.

Mission watershed has an urbanized area and good gauging data. Since Mission watershed is located within the City of Santa Barbara, it provided a good framework from which to analyze city stormwater reduction strategies.

The HEC-HMS input values used for both watersheds in the initial deficit constant loss infiltration routing method varied based on soil type and urbanization (Table 2). The minimum values for the maximum deficit parameter occur in the upper watersheds where soils depths are thin. Even though Atascadero watershed has specific areas of high imperviousness, the soils are able to absorb more rainfall in areas with vegetated land cover. As reflected in the higher recovery rates in Atascadero watershed, more evaporation and/or percolation to groundwater occurs in Atascadero watershed than in Mission watershed.

Sub Area Parameters	**Mission**		**Atascadero**	
	Minimum	Maximum	Minimum	Maximum
Max Deficit (in)	1	6	0.5	2
Loss Rate (in/hr)	0.5	1.02	0.5	1.4
Recovery Rate (in/day)	0.3	2	1	3
Imperviousness (%)	**3**	**42**	**3**	**46**

Table 2: Initial Deficit Constant Loss Inputs to HEC-HMS (Beighley et al. 2003)

Sub Area Parameters	**Mission**		**Atascadero**	
	Minimum	Maximum	Minimum	Maximum
Overland Slope (%)	7	35	4	35
Overland Roughness	0.2	0.8	0.45	0.8
Channel Slope (%)	7	25	3	25
Channel Manning's n	0.015	0.05	0.015	0.05

Table 3: Kinematic Wave Routing Inputs to HEC-HMS (Beighley et al. 2003)

The HEC-HMS input values for channel and overland flow varied based on land use and elevation changes (Table 3). The maximum slope areas for both watersheds are in the upper Santa Ynez Mountains. The lowest roughness values for both watersheds can be found in the lower urbanized areas where flow is mainly on impervious surfaces.

Atascadero watershed

The majority of parameters in the Atascadero Watershed HEC-HMS Basin Model did not have to be altered from the values used in Beighley's 2003 model. Impervious surface percentages were changed in order to represent varying levels of impervious surface reductions in the watershed.

Mission watershed

The parameters in the Mission Watershed HEC-HMS Basin Model had to be updated from values used in Beighley's 2003 model to include subbasins in the lower watershed. The new subbasins were concentrated in the urban lower watershed and were therefore given parameter values equal to those of a subbasin in the lower Mission watershed with similar land use, imperviousness, and slope.

Model Validation

Because the HEC-HMS model used for Atascadero watershed was already used in a published paper (Beighley et al. 2003), its parameterization and validation were accepted for this project. The parameterization and validation of the model used for the Mission watershed were completed with the same methods. However, as mentioned previously, the Mission model was altered for this project. Nine subbasins were added to the lower portion of the Mission watershed to include the entire watershed in simulated flows. As such, the Mission model was re-validated to ensure an appropriate error subsequent to the alteration of the model.

The Santa Barbara Coastal Long Term Ecological Research flow gauge *MC00* is located at the outlet of the watershed and is close to the outlet of the model (SBC-LTER 2007). Simulations were run for water years 2002 through 2005 and results were compared to the gauged data (Figure 7).

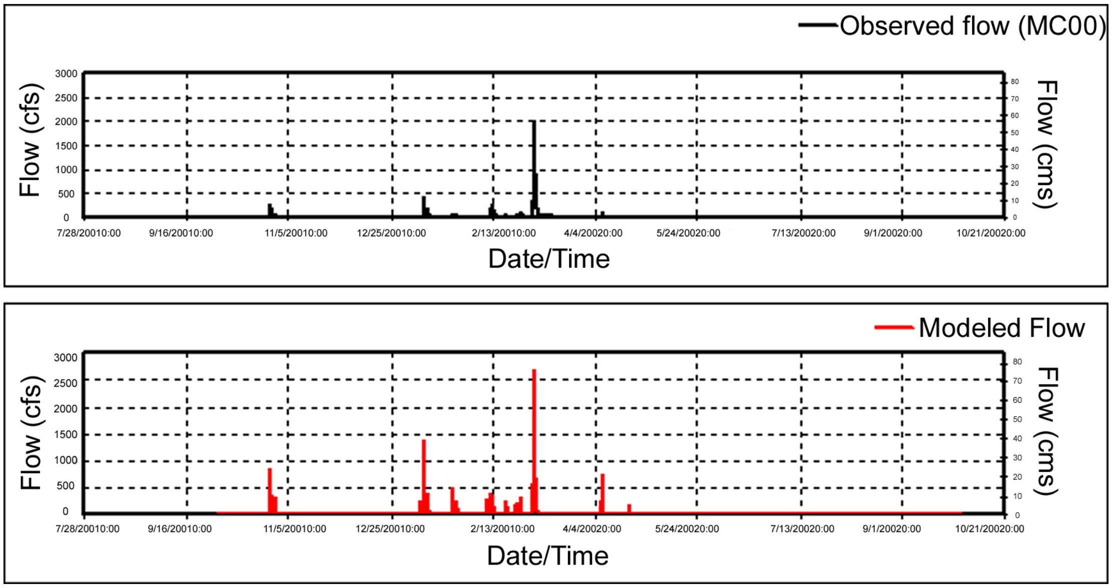


Figure 7. Model validation for Mission watershed

Relative error (RE) was used to determine the model's performance in estimating total runoff :

$$RE = \frac{x_o - x_s}{x_o} \cdot 100\%$$

where x_0 is the observed value measured from the MC00 gauge and x_s is the simulated value.

To determine the model's performance in estimating peak flow, a number of individual storms were evaluated for each water year. The relative errors for peak flows in runoff events that exceeded 200 cfs [5.66m^3/s] were calculated for each water year. The absolute values of these errors were then averaged, yielding an average absolute error for each water year (Table 4).

	Rainfall (in.)	Relative Error (Total Flow)	Average Absolute Error (Peak Flow)
WY2002	9.01	37%	63%
WY2003	24.98	-19%	64%
WY2004	10.7	42%	51%
WY2005	36.94	-72%	48%

Table 4: Model error for total flow and peak flow

The model performed relatively well when compared to other HEC-HMS model validations. Ahmat Nor (2007) tested the performance of calibrated HEC-HMS models for a number of different scenarios in two different catchments where the absolute values of total flow errors ranged between 22-116%. The absolute values of total flow error for our model ranged from 19-72%.

As expected, the model had difficulty in accurately predicting peak flows and often under- or over-estimated its value. The El Niño year (WY2005) was also problematic for the model. Total flows were underestimated by 72% during these extremely wet conditions.

With recognition of their error, it is important to note that our model results are not meant to predict exact runoff values, but rather to illustrate trends that follow a given change in conditions.

A portion of the error experienced in this validation can likely be attributed to errors associated with the precipitation and flow gauges that were used.

Simulated Scenarios

A number of different scenarios were modeled to simulate how a decrease in impervious surfaces might affect the quantity and timing of stormwater runoff in the Mission and Atascadero watersheds. These scenarios varied by water year, storm size, season, and impervious surface coverage (Figure 8).

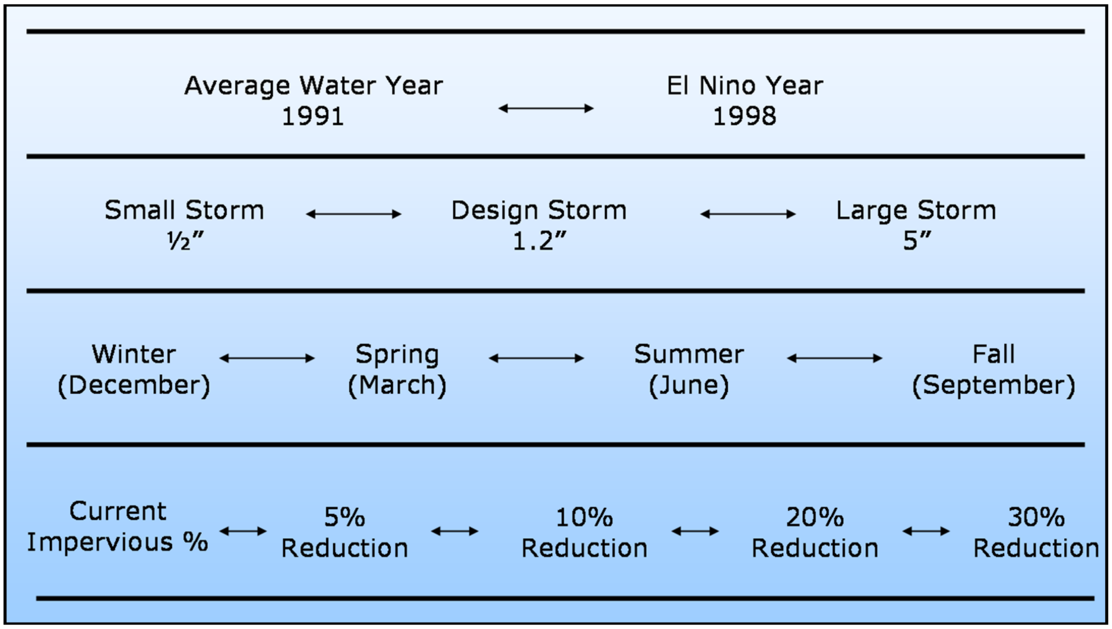


Figure 8: Scenarios entered into HEC-HMS

Alterations of Impervious Surface Coverage

The principal intention of this modeling exercise was to test the hypothesis that changes in impervious surface coverage across the mid- and lower-watershed can alter runoff coming from that watershed. To illustrate these changes, a number of simulations with varying percentages of impervious surface coverage were compared.

One simulated scenario was run with the current impervious surface percentages that were previously identified throughout the Mission (Beighley et al. 2005) and Atascadero (Beighley et al. 2003) watersheds to provide an idea of baseline runoff conditions. The subsequent simulations were run with calculated decreases of impervious surfaces in subbasins throughout the mid- and lower-watersheds.

The upper one-third of both watersheds (two subbasins in Atascadero watershed and four subbasins in Mission watershed) lies in the Los Padres National Forest. Impervious percentages in this portion of the watersheds were given values of 3% based largely on the rock outcroppings prevalent in the Santa Ynez Mountains. Given the inability to convert these areas to pervious surfaces, these were not altered. Impervious areas in the lower two-thirds of the watersheds were decreased by 5%, 10%, 20%, and 30% to demonstrate the potential consequences this may have on runoff.

Modeled results were recorded for each scenario. The log of the flow output began two hours before the start of storm and ended when the hydrograph returned to baseflow conditions (about 36 hours after rainfall had stopped). Results for each scenario include the total storm flow and the peak storm flow that registered at the outlet of the watershed.

Meteorological Conditions

Varying meteorological conditions were examined within the modeling exercise to determine the effect that differing scenarios might have on the pervious surfaces' ability to alleviate stormwater runoff.

Observed rainfall data from the Santa Barbara County Flood Control District (2002) were entered into the model for two different water years and used to recreate the meteorological conditions typically seen along the Santa Barbara Coast.

Data from water year 1991 were used to represent an average water year. The average rainfall for Santa Barbara is 18.22 inches [46.3 cm] and 1991 was a year in which the area received 17.73 inches [45.0 cm] of rainfall. Data from water year 1998 were used to represent a wet year. This was an intense "El Niño" year in which Santa Barbara received 46.97 inches [193.3 cm] of rainfall (Santa Barbara County Flood District 2005).

In addition to differing water years, three different storm sizes were modeled. This was done to demonstrate the effect the intensity of a rainfall event might have on the capability of pervious surfaces to mitigate runoff from that event. The 15-minute time steps for the storms were taken from real data and are therefore assumed to provide an accurate representation of the timing and progression of storm events that occur around Santa Barbara, California (S.B. County Flood Control 2002).

A 0.5-inch storm [1.27 cm] over 2.25 hours was chosen to represent the small storms so characteristic of rainfall events seen in Santa Barbara. This minor storm event is the most common type of rainfall event in the area. Eighty-six percent of daily rainfall events in Santa Barbara total less than one inch [<2.54 cm] (Figure 9).

About 10% of rainfall events in the area total between one and two inches [2.54-5.08 cm] (Figure 9). A 1.2-inch storm [3.05 cm] was chosen to represent an intermediate-sized storm for Santa Barbara. It has additional relevance to this project and the local area. A 1.2-inch storm evenly spread out over a 24 hour period is used to help set rainfall design standards for projects within Santa Barbara County. The runoff simulations from this storm size may become useful for local planners of pervious parking lots. For this project, the duration of the design storm was compressed from 24 hours to 7.75 hours. This observed time-interval and intensity is more representative of Santa Barbara's flashy, Mediterranean climate.

A 5.0-inch storm [12.7 cm] over an 11-hour period was chosen as an example of a large downpour event that can occur in Santa Barbara and was also taken from observed rainfall data. Storms of this size make up only 1% of daily rainfall events in this area (Figure 9), but are the type of events that can cause flash-flooding and produce a substantial amount of runoff.

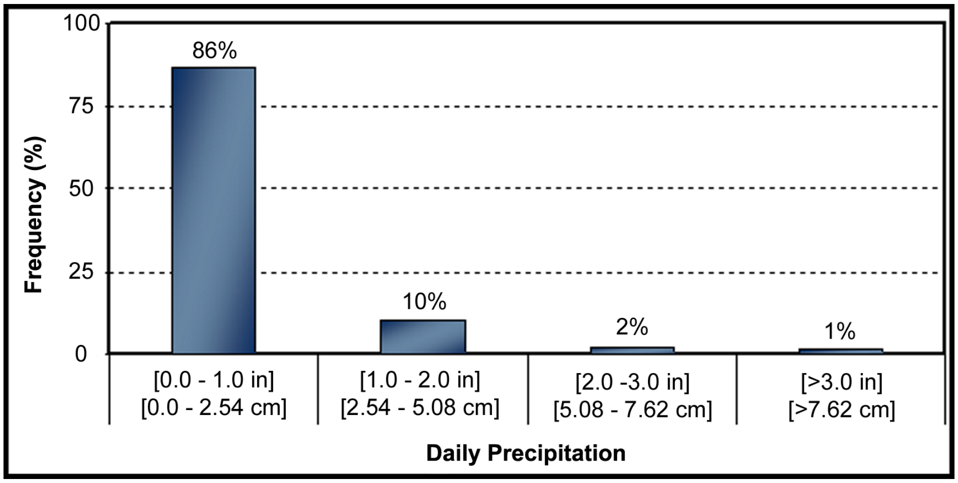


Figure 9: Frequency distribution of daily precipitation totals seen in Santa Barbara, CA from 1941-1995 (LTER 2004)

Seasonal Variations

The different storm sizes were individually added to the observed rainfall data in the winter, spring, summer, and fall. Modeling storms in different seasons indicates how antecedent soil moisture conditions can affect the resulting storm runoff.

The winter storm was added in December and provides a good indication of runoff conditions which might be observed during a first flush event. The spring storm was added in March after a series of winter storms and provides a good indication of runoff conditions which might be observed under more saturated soil conditions. The summer and fall storms were added in June and September, respectively.

Simulated Results

Alterations of Impervious Surface Coverage

In all scenarios, peak discharge varied as a function of impervious surface percentage. Peak flow steadily decreased as impervious surface area decreased. This trend persisted in both watersheds and under all meteorological and seasonal conditions. A representative example of this outcome can be seen after modeling a 1.2-inch winter storm in Atascadero watershed during the 1991 water year (Figure 10).

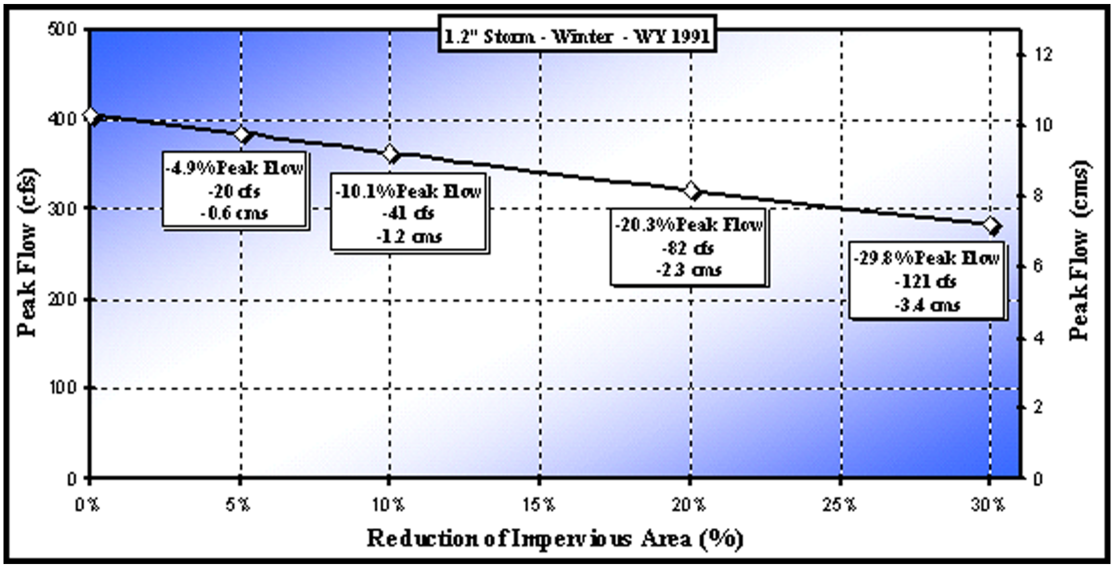


Figure 10: Reduction of impervious surfaces and its effect on peak flow during a 1.2-inch winter storm in Atascadero watershed

Similarly, total flow varied as a function of impervious surface percentage for all scenarios. Total flow steadily decreased as impervious surfaces decreased when modeling a variety of meteorological and seasonal conditions. The trend resulting after modeling a 1.2-inch winter storm in Atascadero watershed during the 1991 water year is illustrated in Figure 11.

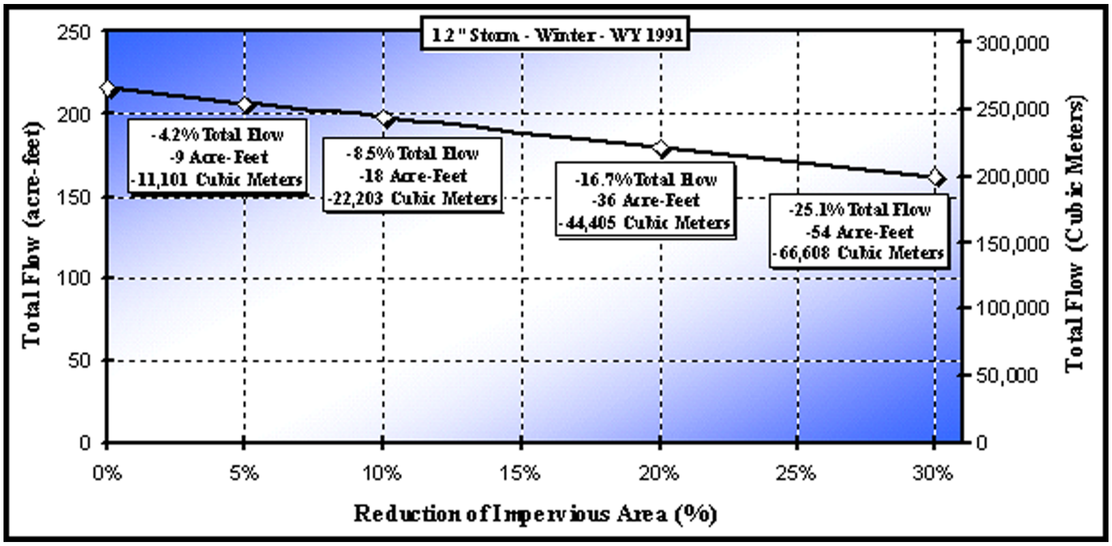


Figure 11: Reduction of impervious surfaces and its effect on total flow during a 1.2-inch winter storm in Atascadero watershed

The series of storm hydrographs in Figure 12 displays the peak flow reduction and shows a flattening of the curve as impervious percentages are reduced throughout the mid- and lower portions of Atascadero watershed.

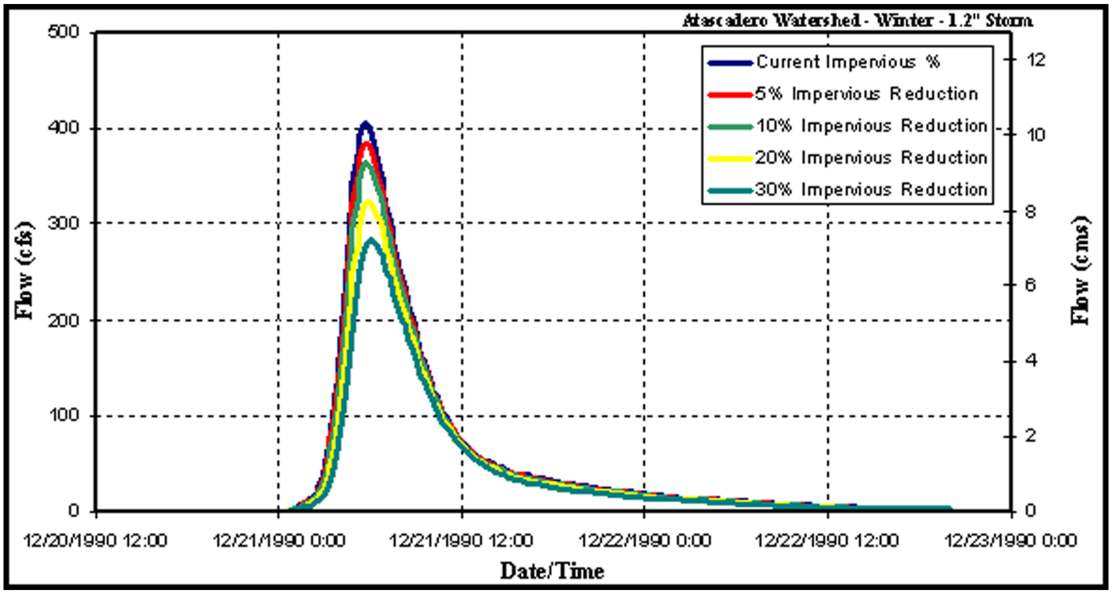


Figure 12: Modeled changes in the storm hydrograph during a 1.2" winter storm (WY1991) as impervious surfaces were decreased throughout Atascadero watershed

Further simulations for both watersheds followed these same runoff trends when water year, storm size, and season were varied. Additional results are available in Appendix I.

Storm Size

The size of the storm influenced how efficiently pervious surfaces alleviate storm runoff. Quantitatively, reduction in peak flows and total runoff increased as the size of the storm increased (Figures 13 and 14).

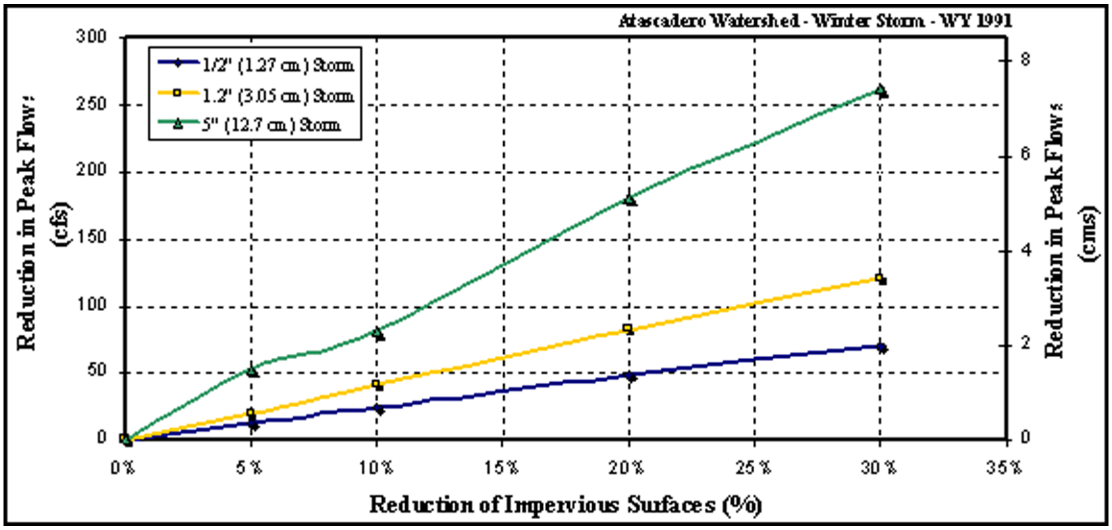


Figure 13: Quantitative reductions in peak runoff flows after 0.5, 1.2, and 5.0 inch winter storm events in Atascadero watershed

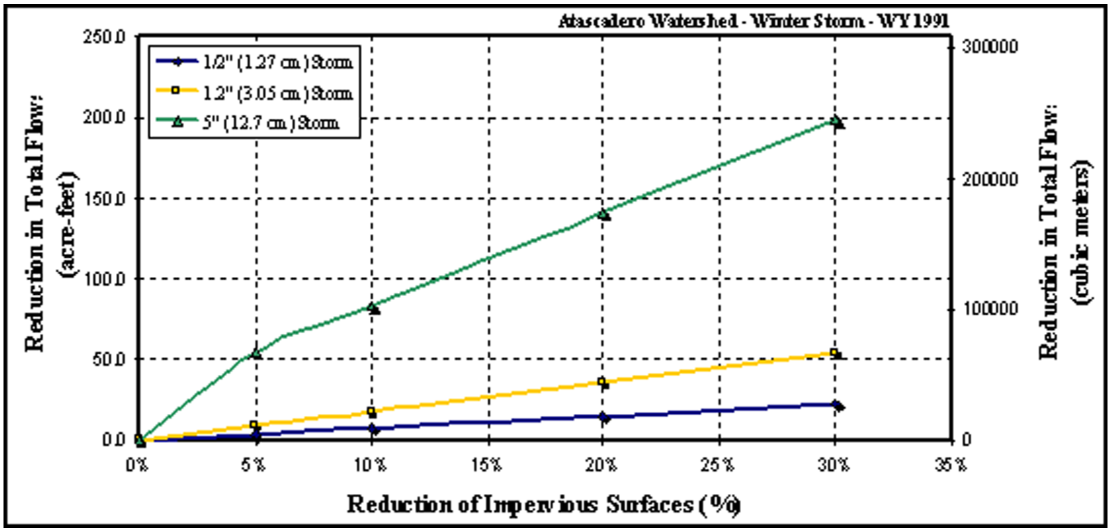


Figure 14: Quantitative reductions in total runoff flows after 0.5, 1.2, and 5.0 inch winter storm events in Atascadero watershed

However, if these results are expressed as *percent* reductions from the baseline conditions, peak flow and total runoff reductions are inversely related to the size of the storm (Figure 15 and Figure 16). Larger storms caused the infiltration efficiency of pervious surfaces to decrease.

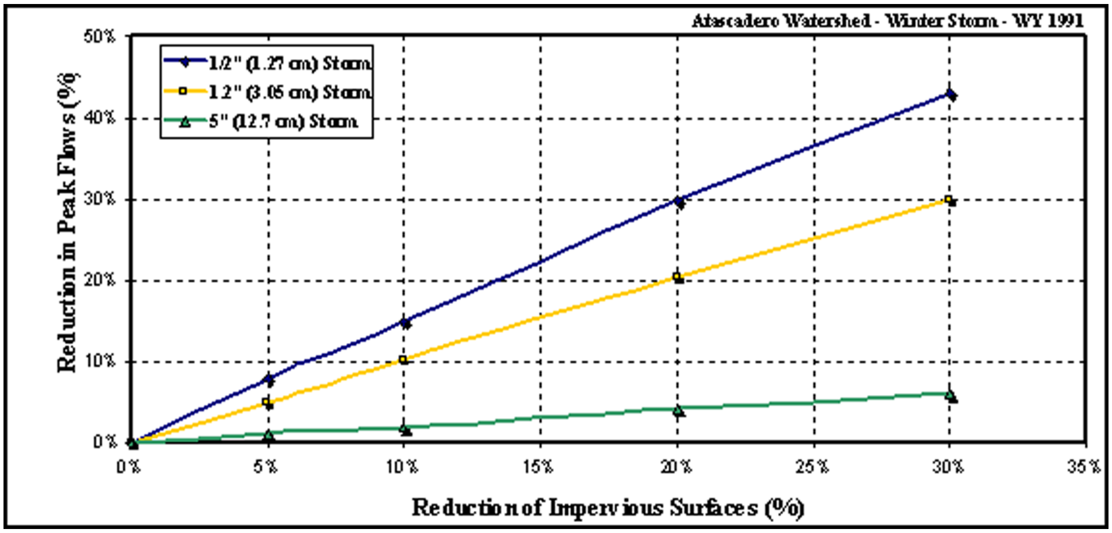


Figure 15: Percent reductions in peak runoff flows after 0.5, 1.2, and 5.0 inch winter storm events in Atascadero watershed

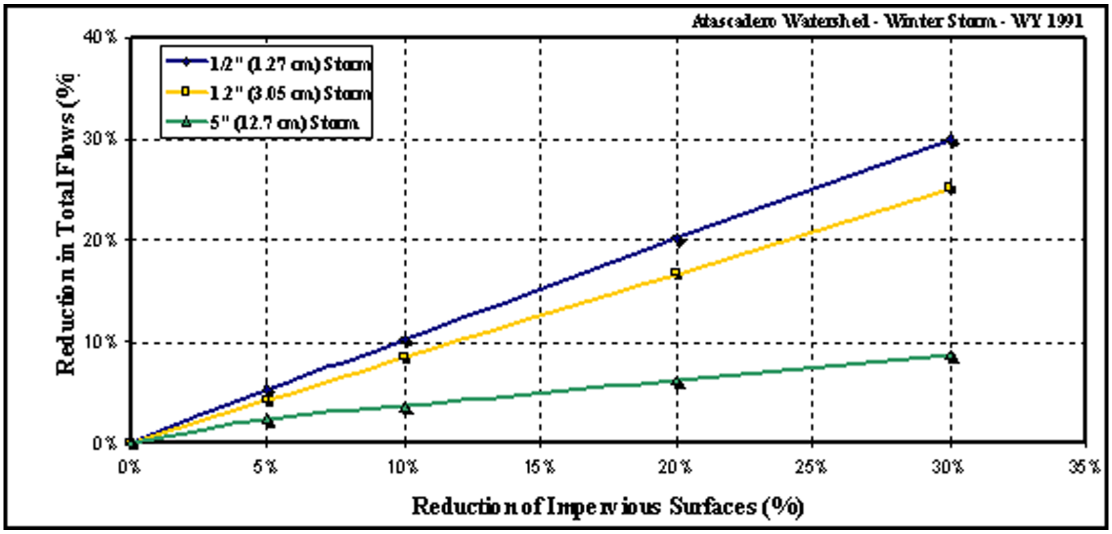


Figure 16: Percent reductions in total runoff flows after 0.5, 1.2, and 5.0 inch winter storm events in Atascadero watershed

Although a 5.0" storm saw reductions in flow when impervious surfaces were reduced, there remained a large quantity of runoff flowing through the basin. These results indicate that pervious surfaces will probably *not* significantly reduce large floods within a watershed. It is likely that even if impervious surfaces are significantly reduced, the storage capacity of soils will be exhausted and creeks will still experience flood stages during extreme storm events.

Pervious surfaces *do*, however, have the potential to significantly increase infiltration for the vast majority of storms in the Santa Barbara region, which total less than 1.0-inch [2.54 cm] (Figure 9). Results demonstrate that a reduction in impervious surfaces can mitigate a particularly high percentage of runoff during a 0.5-inch [1.27 cm] storm.

Mission Watershed vs. Atascadero Watershed

The results from Mission watershed demonstrated the same runoff trends as Atascadero watershed. As more impervious surfaces were removed, peak flows and total runoff continued to decrease under a variety of conditions.

Simulations in Mission watershed were more responsive to changes in impervious surfaces than in Atascadero watershed. Mission exhibited even more dramatic decreases in runoff as impervious surfaces decreased. Mission is a more urbanized watershed and has a greater percentage of its area covered by impervious surfaces. Fifty percent of Mission watershed is considered urban, compared to only 39% of Atascadero watershed (Beighley et al. 2005). Because a greater proportion of Mission watershed's surface area is urban, a decrease in imperviousness is likely to have a greater impact on runoff.

Average Water Year vs. El Niño Water Year

There was a notable difference in total runoff between water year 1991 and water year 1998 in most modeled scenarios. For example, when compared to water year 1991, a 1.2-inch, spring storm in Mission watershed resulted in an increase in total runoff during water year 1998 (Figure 17).

Atascadero watershed had virtually no difference in runoff between water year 1991 and water year 1998 for the two smaller storms. However, when runoff from the 5.0-inch storm was compared between the two water years, there was a visible difference.

Seasonal Variation

The season in which a storm took place affected the runoff characteristics for that storm. The first flush storm event in the winter produced less runoff than the spring event. Storms that occur earlier in the water year can saturate soils and decrease their infiltration capacity, causing more runoff in the spring. For example, a 1.2-inch, spring storm in Atascadero watershed demonstrated higher volumes of runoff when compared to the same size winter storm (Figure 18).

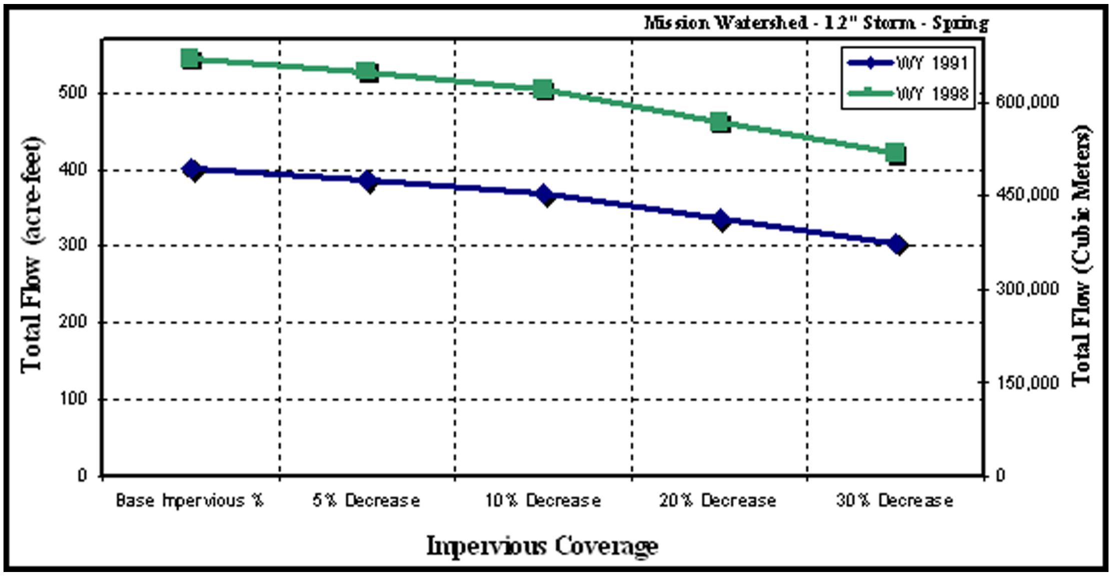


Figure 17: Effect of El Niño year (WY 1998) on total flow after a 1.2-inch, spring storm in Mission watershed

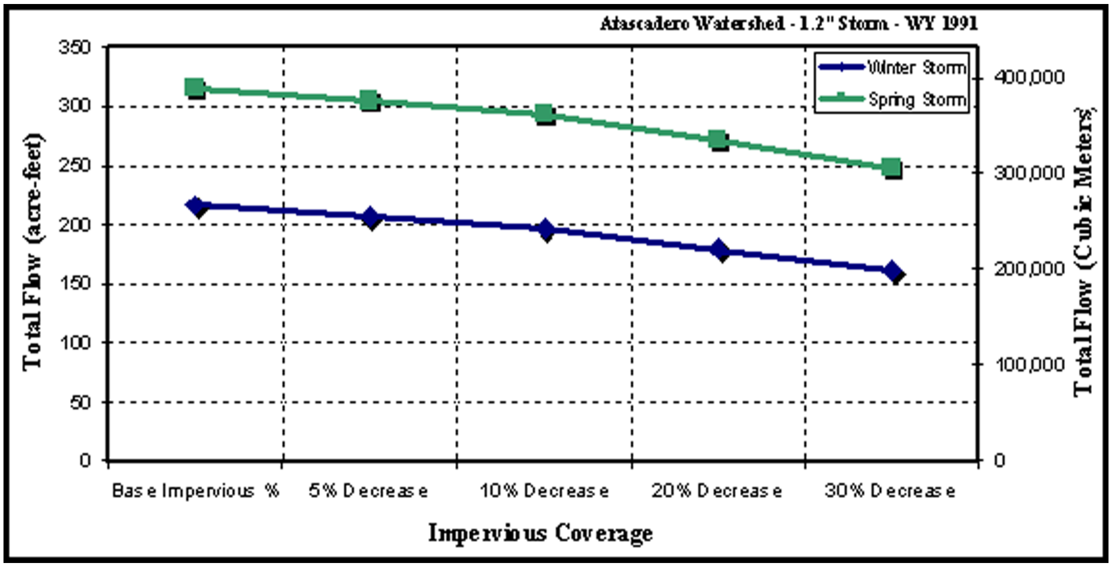


Figure 18: Effects of seasonality on total flow after a 1.2-inch storm in Atascadero watershed during WY 1991

Case Study: Parking Lot Conversion in Atascadero Watershed

Members of Santa Barbara County's Project Clean Water identified a parking lot that has become a potential pilot project for impervious surface conversion. This 16-acre [64,750 m^2] shopping center is located in Atascadero watershed at the corner of Turnpike Road and Hollister Avenue (Figure 19).

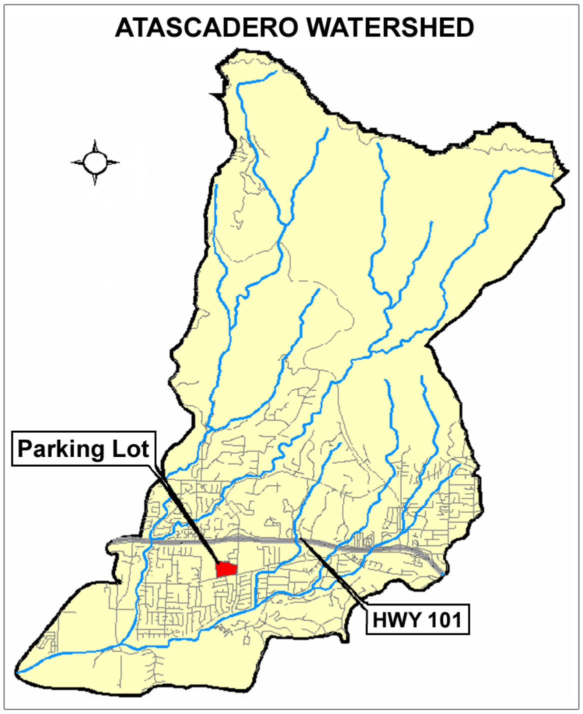


Figure 19: Location of parking lot within Atascadero watershed

The parking lot makes up 0.13% of the area within Atascadero watershed and covers 3.7% of its subbasin in the HEC-HMS model. If this parking lot were to be converted to pervious concrete, the percentage of impervious surfaces within the watershed and within the subbasin would be decreased by these percentages. A number of model runs were conducted to test the potential impact the conversion of this parking lot might have on stormwater runoff. A representative sample of results comes from a modeled 1.2-inch, winter storm during an average water year (Figure 20).

The conversion of one parking lot reduced both total and peak flow by

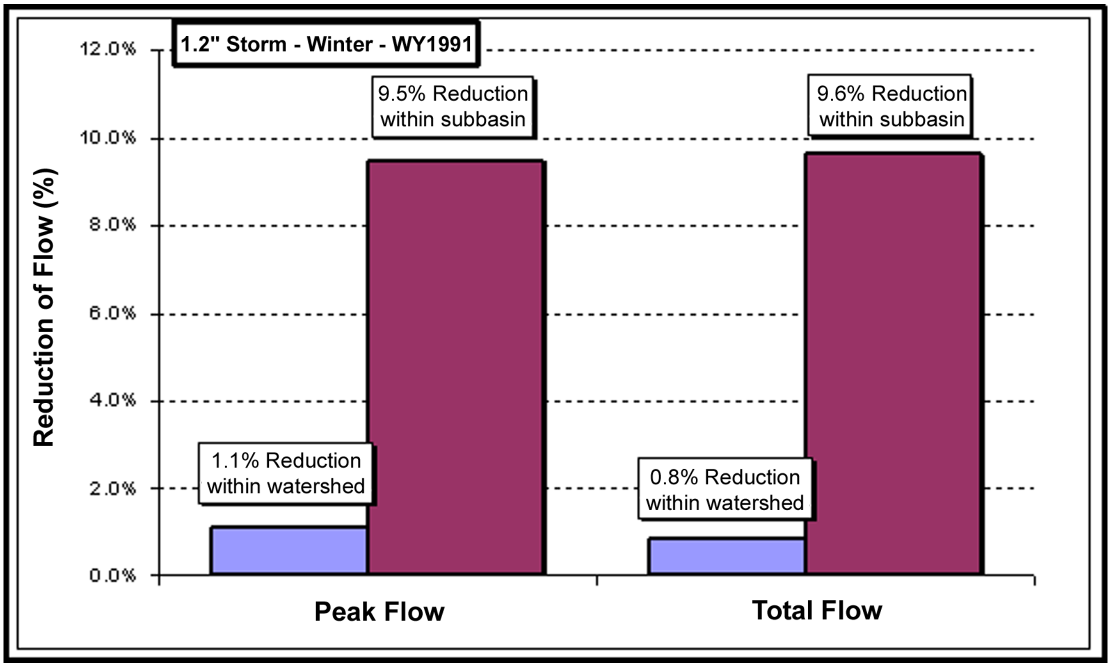


Figure 20: Peak flow and total flow reduction after a 1.2", winter storm in WY1991 as a result of parking lot conversion in Atascadero watershed

about 1% within Atascadero watershed. At a smaller scale, this conversion reduced peak and total flows by almost 10% within its own subbasin.

These results display quite dramatic trends when considering they can be attributed to the conversion of only one parking lot to pervious surface within the 50 km^2 Atascadero watershed. If additional parking lots were to follow, the resulting runoff reduction has the potential to become significant.

Estimating Total Convertible Area

Our modeling indicates how runoff will respond to a reduction in impervious surfaces. The modeled reductions in imperviousness, however, do not specifically consider what types of impervious surfaces exist in the Mission and Atascadero watersheds or whether these surfaces could be converted into permeable alternatives. Neither Anderson Level III land use classifications nor the impervious estimates provided by the Questa Engineering study (Questa 2005) distinguish between types of impervious surfaces.

In order to better understand the types of imperviousness in the Mission and Atascadero watersheds, and to gauge the convertibility of their impervious areas, we analyzed four separate satellite images of the watersheds. In order to understand differences across a watershed and between the two watersheds, we chose one location in the upper and lower sections of both watersheds.

To differentiate the types of impervious area within a ¼ mile by ¼ mile square area [162,000 m^2], we first catalogued the surface area of all roads and parking lots and estimated the surface coverage of sidewalks by multiplying the linear feet of roadway by two. We then estimated roof and driveway coverage by multiplying the total number of buildings in the image with an average roof and driveway area calculated from five representative houses or buildings. The breakdown of impervious areas calculated via our methodology is comparable to total imperviousness as determined by Anderson Level III classification (Figure 21; Table 5).

Driveways, parking lots, and sidewalks could all be replaced with permeable pavements in the near future because they do not endure heavy wear or high traffic loads. Thus, these surfaces were considered “potentially convertible” in our analysis. In the United States, permeable pavement is not yet accepted as a viable alternative for major roadways, so roadways were not considered potentially convertible. Although roofs are traditionally considered impervious surfaces, if they are not directly connected to the storm drain network they may not contribute to overall watershed imperviousness. Nevertheless, the impervious areas in our models that represent roof tops were not considered to be potentially convertible.

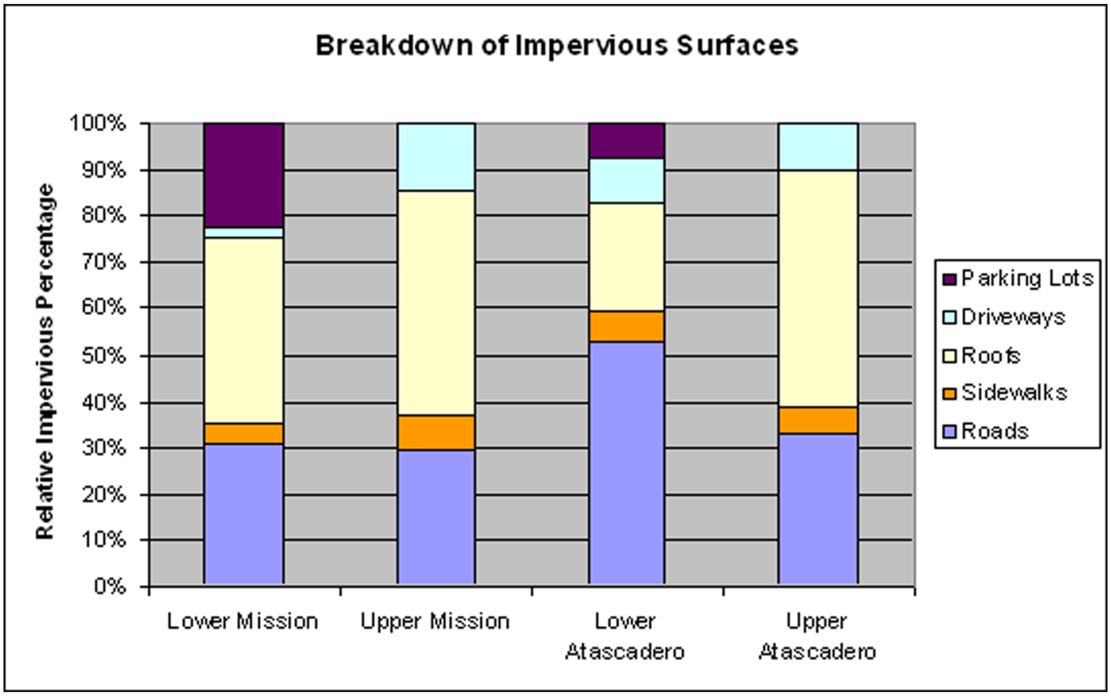


Figure 21: Differentiation of impervious surfaces in the Atascadero and Mission watersheds

	Roads	Side-walks	Roofs	Drive-ways	Parking Lots	Total	Total Imperviousness
Lower Mission	23200	3500	30200	1650	17000	75550	47%
Upper Mission	17484	4512	28810	8454	0	59261	37%
Lower Atascadero	39000	5000	17000	7140	5450	73590	45%
Upper Atascadero	18528	3088	28371	5630	0	55617	34%

Table 5: Estimated impervious areas in a ¼ mile by ¼ mile square area (162,000 m^2). All values in square meters.

Our analysis indicates that the lower watersheds have more convertible impervious area than the upper watersheds (Figure 22). This is largely due to the business- and commercial-related parking lots located in the lower part of the watersheds. The lower Mission watershed has the largest potentially convertible area: 30% of its total impervious area. There are approximately 200,000 square meters of parking lots located throughout Mission watershed (SB City Creeks Division 2006a). Twenty-four percent of impervious areas in the lower Atascadero watershed and 16% of the impervious areas in the upper Atascadero watershed could be converted to permeable alternatives.

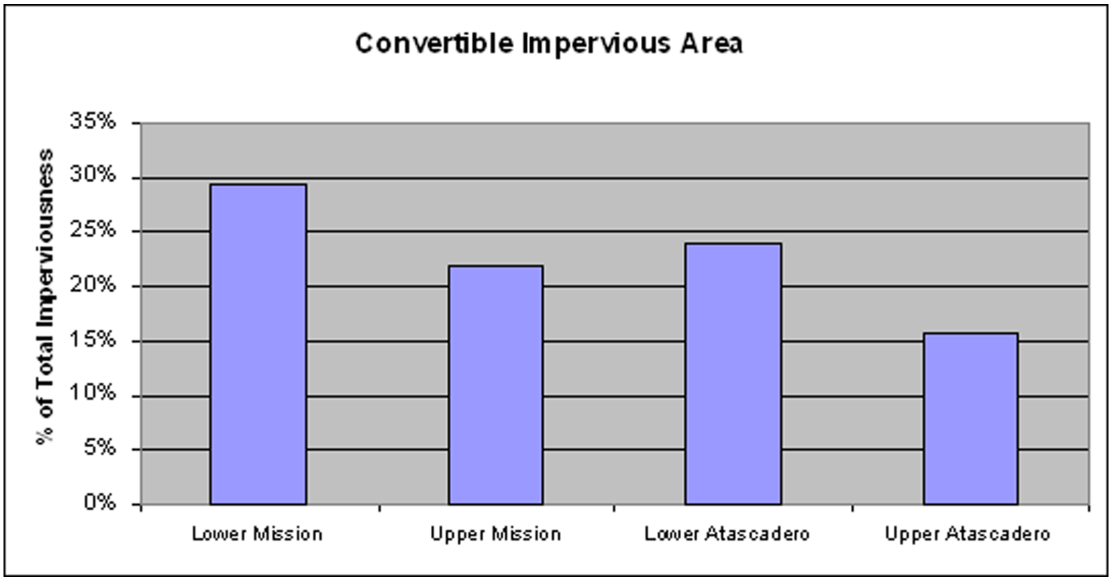


Figure 22: Maximum area of impervious surfaces that could be converted to permeable alternatives

This limited analysis suggests that modeled reductions in impervious area of up to 25% could be possible for Mission watershed. In Atascadero watershed, however, maximum modeled decreases in impervious area of 30% may be impractical. If roads were considered in this analysis, potentially convertible impervious area would significantly increase. On the east coast of the United States, LID developments have used permeable pavement roadways for residential surface streets.

Further comparison between the watersheds would not be appropriate at the level of our analysis. In order to determine the maximum convertible impervious area, a more extended sampling network would be necessary. As an example of a more detailed analysis, the Center for Watershed Protection performed an analysis on the types of impervious surfaces within the Chesapeake Bay Watershed (Cappiella and Brown 2001). A similar, extensive, GIS land-use based approach would be useful in the Santa Barbara area.

PERMEABLE PAVEMENTS

Decreasing impervious area within a watershed can significantly alter the magnitude and timing of storm runoff. Using permeable pavements in place of traditional hardscapes is one alternative to decrease watershed imperviousness. This section will evaluate permeable pavement's ability to decrease the magnitude of storm runoff and to treat stormwater pollution. The section will also describe permeable pavement's ancillary benefits and provide a recommendation for their installation within the watersheds of Santa Barbara County. When possible, this analysis will focus on the properties, functionality, and applicability of pervious concrete in particular.

The effects of permeable pavement installation can be directly evaluated by the HEC-HMS model because permeable pavements turn formerly impervious areas into permeable surfaces. Additionally, because transportation-related surfaces, including parking lots, roads, and driveways, constitute between 50%-60% of the total impervious area within the Atascadero and Mission Creek watersheds, wide spread installation of permeable pavement has the far-reaching ability to alter the total imperviousness of a watershed.

There are multiple types of permeable pavement, including: high-strength plastic grid systems like GravelPave® or Grassroad®, interlocking or jointed pavers such as Ecostone®, flagstones, or bricks, and porous pavements like pervious concrete or porous asphalt. These types of surfaces can be used in place of traditional parking lots, driveways, sidewalks, trails, storage areas, or any other hard surface.

Plastic grid systems, consisting of hollow, interconnected plastic rings, are rolled out in long sheets over the project area (Figure 23). The grid is then filled with decorative gravel, another aggregate, or soil and grass seed, depending on the structural and aesthetic requirements of the project. Plastic systems work well for pedestrian trails, outdoor storage areas, and low-use parking spaces (Invisible Structures 2007). They require occasional refilling/replanting, and thus, are not suitable for high-use automotive traffic. These types of plastic grid systems can be purchased for approximately $1.50 per square foot (City of Santa Monica 2005).

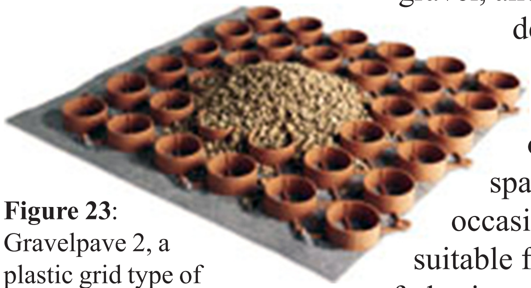


Figure 23: Gravelpave 2, a plastic grid type of permeable pavement

Examples of interlocking and jointed paver systems include bricks jointed with sand, flagstones surrounded by dirt, or manufactured blocks with connecting tabs. Solid paver systems are generally the least permeable of all permeable pavements because water only infiltrates at the joints between the pavers. These pavements create durable surfaces, and in select cases, are structurally stronger than concrete (Barazani 2007). These types of systems are becoming increasingly popular with home-owners interested in aesthetic landscaping, although wide spread use of paver systems is limited because of their high cost. For example, driveways like the one shown in Figure 24 can cost upwards of $15-$20 per square foot to install (Damian 2007).

Figure 24: Decorative use of an interlocking paver system for a residential driveway (Barazani Pavestone)

There are two distinct types of porous pavement, porous asphalt and pervious concrete. Both of these products are similar to their impervious cousins in price, function, and durability. In general, porous asphalt mix is made with less tar and pervious concrete mix is made with less sand compared to the normal varieties. Upon curing, these actions allow interconnected pore spaces to develop within the pavement, making the pavements permeable to water (Figure 25). Pervious concrete has been used in stormwater management for over twenty years in the United States, and for the past seven years in California (Pervious Concrete 2006, Maes 2007a).

Of the various types of permeable pavement, our analysis focused on pervious concrete because:

- it provides a direct connection between decreasing imperviousness in the model and a watershed
- pervious concrete is strong, durable, and well-suited to replace transportation-related surfaces
- the pollutant reduction capabilities of porous concrete have been studied in the peer-reviewed literature
- it looks similar to normal concrete, which may encourage greater acceptance within the community
- there is local interest in installing more pervious concrete in the Santa Barbara area
- there are local contractors who have experience installing pervious concrete

Figure 25: A photo of parking spaces during a heavy Pennsylvania rainstorm. The road to the left of the yellow line is paved with conventional asphalt, while the parking spaces to the right are porous asphalt.

Engineering Properties

Pervious concrete contains Portland cement, uniform graded coarse aggregate, and water. Omitting sand (fines) from the mix and using a consistent size of aggregate causes porous concrete to set with an internal void content of 15-20% (Akers 2004). These internally connected voids are what make the concrete porous, allowing water to easily pass through the pavement (Table 6; Figure 26). Supplementary cementitioius materials (SCMs), like fly ash, are often added to the mix for strength enhancement, coloring, or LEED credits.

A typical mix of pervious concrete contains:

- 2000-2500 pounds per cubic yard (pcy) of coarse aggregate
- 600-700 pcy of cement
- Water to cement ratio of 0.30 lb/lb

Density	1600-2000 kg/m^3
Permeability	3-8 gal/ft^2/min (7200-432000 mm/hr)
Compressive Strength	2500 psi

Table 6: Typical engineering values of pervious concrete (Pervious Pavement 2007)

Figure 26: Pervious concrete: "When it rains, it drains."

If poured to a depth of 3 inches, this mix of concrete will allow internal storage of approximately 1 inch [25 mm] of water. With the increased storage capability provided by the subgrade, pervious concrete systems can easily be designed to hold 3 inches [76 mm] or more of rainwater. Spreadsheet models can be used to determine thickness requirements for the concrete and subgrade by manipulating variables such as rainfall volume, subgrade porosity, and overall system thickness.

Runoff Reduction

Multiple studies have been performed on the runoff reduction capabilities of permeable pavements. These studies can be characterized as in-place field experiments or laboratory experiments. They have tested surface runoff reduction and total runoff reduction. In general, the studies have found that areas covered in permeable pavements are capable of reproducing the natural, pre-development hydrologic regime (Schueler 1987). The following studies, selected for their relevance, clearly illustrate how permeable pavements can significantly reduce stormwater runoff.

Day and Smith (1981) constructed a rainfall simulator to compare the surface runoff quantities of regular concrete and permeable pavements. The researchers varied rainfall intensity and duration (0.91 in/hr - 3.54 in/hr [23 mm/hr - 90 mm/hr]; 30-60 min) in a series of experiments meant to characterize the typical 1-year through 20-year storms in the Washington, D.C., area. The average runoff coefficient of all permeable pavements in their experiments ranged from 0%-0.3%, whereas the runoff coefficient of normal concrete ranged from 60%-95%.

Laboratory experiments provide a good foundation for determining the effectiveness of permeable pavements, but how they perform in the field is more important. In Washington State, Brattebo and Booth (2003) performed an evaluation of four permeable pavements installed at a five-year-old experimental parking lot. Their study concluded that surface runoff occurred only during the largest rainstorm of the season, 4.7 inches [121 mm]. Runoff measured only 0.16 inches [4 mm], for a runoff coefficient of 3%. Similar results were obtained by Rankin and Ball (2004) in Australia, where Ecolock pavers were used to replace a road surface. With a 95% confidence level, the authors determined the runoff coefficient from the pavers to be between 2 % and 4%.

Permeable pavements not only reduce the amount of surface runoff from an area, they can also reduce the amount of total runoff. Total runoff includes surface runoff as well as water that flows through the permeable pavement. Pratt et al. (1989) collected sub-surface drainage from a 16-space parking lot constructed with different permeable pavements. Over the course of three storms, total runoff volume was 55%-75% of rainfall volume. This indicates that only 25%-45% of the total rainfall drained completely through the system; the rest of the precipitation was trapped in the pavement itself.

The largest in-situ experiment of pervious concrete was conducted on a car park in the United Kingdom. The car park catchment studied covers 3 acres [12,141 m^2] of land and is underlain with a network of piped drains and an impermeable textile floor. The purpose of the car park's pervious concrete system is to delay stormwater runoff into sewer drains. Over the course of their 13-month experiment, Abbott and Comino-Mateos (2003) recorded peak rainfall intensities of 1.3 inches per hour [33.6 mm/hr] and subsurface runoff peaks of only 0.15 inches per hour [3.9 mm/hr]. The peak runoff flows were also attenuated an average of two hours from the rainfall peak of any given storm. Additionally, the authors documented that only 67% of rainfall became runoff. They suggest leakage through the impermeable membrane, lateral overflow from the system, and seepage into planted areas as possible reasons for reduced runoff volumes, but suggest that storage within the porous concrete and consequent evaporation from the system are the dominant factors in total runoff reduction.

Pollutant Reduction

More studies have been performed on the pollutant reduction capabilities of permeable pavements than on runoff reduction. Because permeable pavements can be substituted for transportation-related uses, the pavements' ability to retain automotive and road-related pollution has been emphasized. Table 7 shows some of these pollutants-of-concern and lists their probable sources, while the following studies document how permeable pavements can significantly reduce stormwater pollution.

Dierkes (1999) built rigs of pervious concrete underlain with four different types of subgrade in order to gauge the pollutant removal effectiveness of the various aggregates. He then performed experiments using rainfall charged with high levels of lead, cadmium, copper, and zinc, measuring the effluent collected from beneath the rigs. His results demonstrate the pollutant retention abilities of pervious concrete (Table 8). Fach and Geiger (2005) performed a similar "charged-water" experiment but tested for differences between four types of permeable pavement. Their experiments found that pervious concrete removed more pollutants (99.4%-99.9% of lead, zinc, and copper) than any other type of permeable pavement.

Pollutant	Potential Source
Sediment	Pavement wear, vehicles, maintenance activities
Nitrogen	Roadside or other fertilizer applications and atmospheric deposition
Phosphorus	Roadside or other fertilizer applications and atmospheric deposition
Lead	Auto exhaust, tire wear, lubricating oil and grease, bearing wear
Zinc	Tire wear, motor oil, grease
Iron	Auto rust, stell highway structures (e.g., guard rails), moving engine parts
Copper	Metal plating, bearing and brush wear, moving engine parts, brake lining wear, fungicides, insecticides, pesticides
Cadmium	Tire wear, insecticide application
Chromium	Metal plating, moving parts, brake lining wear
Nickel	Diesel fuel and petrol exhaust, lubricating oil, metal plating, brush wear, brake lining wear, asphalt paving
Manganese	Moving engine parts, auto exhaust
Sodium / Chloride	Deicing salts
Sulfate	Roadways surfaces, fuels, deicing salts
Hydrocarbons	Spills, leaks, or blow-by of motor lubricants, anti-freeze and hydraulic fluids, asphalt surface leachate
Polychlorinated Biphenyls (PCBs)	PCB catalyst in synthetic tires, spraying of rights-of-way
Polycyclic Aromatic Hydrocarbons (PAH)	asphalt surface leachate

Table 7: Typical pollutant types in stormwater runoff from transportation-related surfaces and potential sources (adapted from Ball et al. 1998)

Field studies show similar results to the laboratory experiments. Two long-term studies on the East Coast of the United States indicate porous pavement removal efficiencies of 82%-95% for sediment, 65% for total phosphorus, and 80%-85% for total nitrogen over a multi-year time frame (Schueler 1987). Similarly, a year-long study at a Florida aquarium shows reductions of 80% for ammonia, 79% for nitrate,

	Lead	Cadmium	Copper	Zinc
Synthetic Rainfall	180 µg/l	30 µg/l	470 µg/l	660 µg/l
Effluent (mean concentration)				
Gravel	< 4 µg/l	0.7 µg/l	18 µg/l	19 µg/l
Basalt	<4 µg/l	0.7 µg/l	16 µg/l	18 µg/l
Limestone	< 4 µg/l	3.2 µg/l	29 µg/l	85 µg/l
Sandstone	< 4 µg/l	10.5 µg/l	51 µg/l	178 µg/l
Retention				
Gravel	98%	98%	96%	97%
Basalt	98%	98%	96%	98%
Limestone	98%	88%	94%	88%
Sandstone	89%	74%	89%	72%

Table 8: Results from Dierkes (1999) study on pollutant reduction capabilities of pervious concrete

and 76% for total phosphorous, when comparing runoff from permeable pavements to runoff from asphalt sections of the parking lot (Rushton 2001). Even porous asphalt reduces suspended solids (64%), lead (79%), zinc (72%), and cadmium (67%) when compared to an imperviously-paved reference catchment of equal size, location, and rainfall patterns (Legret 1999).

Further research illustrates that most of the pollutant mass does not travel through the permeable pavement. Rather, the pollutants either bind directly to the pavement's internal structure or sorb onto larger particles, which become trapped within the pavement. Therefore, it is unlikely that stormwater pollutants will adversely affect groundwater sources or soil quality. In an eight-year-long French study, metal concentrations in soil found under the permeable pavement were equivalent to metal concentrations under the non-permeable comparison catchment (Legret 1999). In Germany, a pervious concrete parking lot study found: no significant increase in heavy metals in the underlying soil; PAH concentrations below detectable limits throughout the depth of the concrete and soil; and hydrocarbons to be undetectable below 20cm depth from surface (Dierkes 2002). These results were reported after the parking lot had been in continual operation for over 15 years.

Newman et al. (2002) suggest that microbial populations in the permeable pavements are responsible for processing the pollutants. These "biofilms" are able to biodegrade motor oils and were resistant to variable road runoff. The authors determined that the highly diverse, indigenous microbial biomass that established itself in the pavement within four years of installation was more effective at degrading oil than commercially-obtained oil degrading microbial mixtures.

The above studies suggest that permeable pavements are capable of removing pollutants over a longer time scale. It is plausible that the pavement will eventually “fill up” and no longer be able to effectively treat pollutants, but it is unclear at what timescale this will occur. Further studies will need to address the longevity of permeable pavement pollutant removal efficiencies.

Little research has been conducted on the ability of any permeable pavement to remove bacterial pollution. An evaluation of porous media filtration used in waste water treatment may describe some analogous processes acting in pervious concrete, and may give reason to believe in its ability to filter bacterial pollution. Bacteria can directly adsorb to porous media, but this is dependent on the flow rate of the contaminated water. Because flow rates are slow in porous concrete, unwanted bacteria may have the potential to adsorb to the internal surfaces of the concrete. Stevik et al. (2004) also suggest that a well-developed biofilm within the media will cause greater removal of bacteria. As these natural biofilms mature, their pathogen removal capabilities will likely increase.

If the environment within the concrete structure is conducive to the development of biofilms and beneficial bacteria, it is possible that pervious concrete may become a source of bacterial pollution. Population of harmful bacteria within the concrete may depend on the input of organic matter, water availability, and their interaction with other pollutants in stormwater runoff. More research is needed to properly evaluate permeable pavement’s ability to remove bacterial pollution.

Other Benefits

Pervious concrete provides many benefits in addition to its pollutant and runoff reduction capabilities. Porous concrete is especially effective at treating first flush stormwater runoff because the pavement reservoir system will be entirely dry before the first storm of the season. This condition allows maximum storage volume capacity and the greatest treatment potential for the most polluted stormwater of the year.

Adoption of permeable pavements allows water that formerly ran off hardscapes to seep into groundwater, recharging local supplies. If the permeable pavement system does not incorporate vegetation, the quantity of ground water recharge via permeable pavements can be greater than in natural environments because of decreased plant transpiration.

Pervious concrete, porous by nature, permits greater air and moisture exchange with the soil. This exchange leads to cooler surface temperatures by allowing convective process to disperse excess heat. Because permeable concrete is light in color, reflecting, rather than absorbing sunlight, it will also have a lower surface temperature than a comparable asphalt-covered area. Additionally, planting trees around pervious concrete requires a smaller planter box because water can infiltrate the concrete in many different areas, thus creating more efficient use of the paved surface and contributing to greater surface shading. These three factors all contribute to decreasing the urban heat-island effect present in many impervious “downtown” areas. Production of ground level ozone increases at higher temperatures, so cooling urban areas with permeable pavement has the potential to create cleaner air quality as well.

Furthermore, porous pavement use is encouraged by the Americans with Disabilities Act (ADA) because of the pavement’s enhanced traction when compared to other traditional hardscapes. The improved traction of pervious concrete, combined with its water permeability, leads to decreased hydroplaning of automobiles, thus making pervious concrete safer to drive on than other hardscapes.

For the developer, pervious concrete has many distinct advantages over other stormwater treatment options. Given today’s regulatory climate and the US EPA’s stormwater NPDES guidelines, most developments are required to mitigate some portion of their stormwater runoff. Using permeable concrete instead of installing a bioswale saves valuable developable land for the property owner, increasing land use efficiency. The light color of concrete requires a third less exterior lighting compared to asphalt surfaces, contributing to short-term capital savings and long-term energy savings (Maes 2007b). There is also some anecdotal evidence that suggests pedestrians feel safer at night crossing a light-colored concrete parking lot compared to an asphalt lot.

Some argue that installing pervious concrete can even be cheaper than building a normal parking lot. Money is saved by decreasing stormwater drain tie-in costs, by not requiring ongoing runoff water quality monitoring, and by recognizing concrete’s 20-30 year potential longevity. Although this cost savings argument is debated by others in the field of stormwater management, these issues should be discussed when comparing all of a developer’s options.

Cost

Pervious concrete is generally more expensive to install than regular concrete because of the need for high quality, uniform aggregate and the addition of supplementary cementitious materials (SCMs). In some cases, installing pervious concrete is cheaper because it requires fewer labor hours. In other cases, it may be more expensive due to the special techniques and equipment used. Total costs for pervious concrete are generally 15%-25% more expensive than normal concrete installation. According to national statistics, pervious concrete costs between $2.50-$6.00 per square foot to install depending on batch size, mix costs, and contractor rates (LID Center 2007c;

University of Rhode Island 2005; USEPA 1999). However, a local contractor in San Luis Obispo suggested rates of $6.00-$9.00 per square foot for full installation (Yates 2007).

Installation and Maintenance

The leading cause of porous concrete system failure is poor installation. Pervious concrete is not installed the same way as normal concrete, so inexperienced workers have the potential to inhibit the concrete's stormwater performance. For this reason, the National Ready Mixed Concrete Association sponsors a certification program for pervious concrete, both at the craftsman and technician levels (NRMCA 2007). An updated list of qualified installers across the US may be accessed from their website: www.nrmca.org.

To provide some understanding of how installation techniques may differ, the following is a brief, non-technical description of how pervious concrete is installed (Pervious Pavement 2007):

- <u>Base and Subgrade</u>: Preparation of the base and subgrade to ensure uniformity and a strong foundation for the concrete is essential. Depth of the aggregate subgrade should be determined based on reservoir storage needs, and can be sized based on conventional stormwater criterion like the 100-year storm.
- <u>Batch Preparation</u>: The mixing and batch preparation for each pour of pervious concrete should be based on local atmospheric and soil conditions as well as available aggregate supply. Traditional concrete mixing equipment is used, but the water content of pervious concrete is substantially lower than normal concrete, so care must be taken to ensure proper water/cement ratios. Excessive water will cause the pores to become filled with paste and lead to diminished permeable properties.
- <u>Transportation</u>: Large aperture concrete trucks should be used for the transportation and pouring of pervious concrete because it is thicker and flows more slowly than traditional concrete. The mix should be delivered and placed within one hour of mixing time.
- <u>Placement</u>: Porous concrete cannot be pumped, so access to the job site should be taken into consideration. Vibratory screeds or other settling devices are used to consolidate the mix into the forms, but care should be taken to not overly compact the mix. Upon placement, consolidation and jointing with a metal roller should take place within 15 minutes.
- <u>Curing</u>: Pervious concrete is not finished with a trowel or other smoothing device because this would clog the surficial pores of the pavement. Instead, the concrete remains at its compacted stage, is wetted with a fogger, and covered with plastic. In order to allow for adequate drying time to ensure proper strength

> and performance, the plastic should be left in place for seven days. At the end of seven days, the pavement is ready for use by automobiles and the general public.

Before the actual installation of pervious concrete, it is important to evaluate the landscape of the project area. Landscape “run on”, or water flowing onto the pavement from nearby surfaces or hill slopes, can be a significant source for pavement-clogging particles. Therefore, it is important not to build pervious concrete surfaces at the bottom of open dirt slopes, under trees with excessive leaf litter, or near other areas of potentially high sediment load.

No significant maintenance is required to keep pervious pavements properly functioning. Studies suggest that vacuum sweeping three to four times per year with a standard sweeper, which both the City and County have available for use, is sufficient to maintain porosity throughout the lifetime of the product (CASQA 2003; LID Center 2007b). Potholes and cracks can be filled with patching mixes, and spot clogging of pervious concrete may be fixed by drilling 0.5-inch holes every few feet. A well installed and maintained surface of pervious concrete should last 20 years or more.

Concerns

There are legitimate concerns regarding the use of pervious concrete. The most significant concern is the potential for clogging of the pavement structure. In one study, two to three years after installation of a permeable pavement, Abbott and Comino (2003) calculated decreases in infiltration rates of 70%-90% of the original rates. However, the parking lot was not maintained during the period and post-infiltration rates varied between 39 inches per hour to 177 inches per hour [1000 mm/hr to 4500 mm/hr], still significantly higher than any likely rainfall intensity. Other studies have concluded that cleaning permeable pavements with a vacuum sweeper can maintain infiltration rates at their original values or restore them to original values (Dierkes et al. 2002).

A study performed on the toxicity of street sweeper waste suggests that heavy metal concentrations in the waste cannot be considered a serious problem (German and Svensson 2002). In Santa Barbara, vacuum waste is sifted and sorted to separate trash and organic debris from dirt, where heavy metals are likely to sorb. The dirt is then used as landfill cover, or dumped directly into the landfill without additional treatment. In general, cities acknowledge that street sweepers clean up pollutants like trash, litter debris, detritus, and toxic materials such as hydrocarbons and heavy metals, but this debris is treated like normal trash.

Another concern surrounding the installation of pervious concrete is the underlying soil’s infiltration capacities. In general, porous pavements perform better on sandy soils than clayey soils. The EPA (1999) suggests that porous pavements be installed on soil types with a field-verified permeability greater than 0.5 inches per hour [13 mm/hr]. If water ponds underneath the pervious concrete and does not drain fast enough through the soil, and rainfall volume is greater than designed specifications, surface runoff could result, defeating the stormwater benefits of the concrete. To analyze part of this issue, Dreelin (2006) performed a field test comparison between asphalt and a permeable pavement overlying a soil with 35%-60% clay content. In his experiment, the porous lot produced 93% less runoff than the asphalt lot, suggesting that permeable pavements perform well even when placed over slow infiltration soils.

When installing a pervious concrete surface, some consideration should be give to where the infiltrated water will flow. If an increase in ground water leads to soil liquefaction at the site or slope instability nearby, an impervious liner should be placed beneath the concrete system to prohibit subsurface water flow. This issue may not be a concern at any one particular location, but it should be addressed during the planning and development stage of the process to account for potential cumulative effects.

The higher initial cost of concrete construction compared to asphalt will also be a substantial hurdle to overcome for pervious concrete applications. Porous concrete may cost approximately four times more than asphalt, but it will last about four times longer. The time-value of money works against higher up-front costs of large initial investments compared to an equal amount of payment but spread out over time. Land owners may be motivated to invest now, taking into account the potential for increased stormwater regulations in the future. It will also be necessary to stress the longevity and durability of the concrete to potential customers.

Local Contractors

The authors conducted an interview with a local contractor in order to establish pervious concrete's current status and future potential in the Santa Barbara area. Rob Yates P.E., a civil engineer at the Wallace Group in San Luis Obispo, is actively promoting pervious concrete for use in non-road related flat work. The civil engineering department of the Wallace Group suggests pervious concrete to developers seeking LEED credits and proactively offers pervious concrete as a stormwater detention or retention BMP that can compete well with other stormwater management systems. The landscape architecture group also recommends pervious concrete as part of a conscious effort in the design community to promote the philosophy of responsible design.

At the current time, pervious concrete makes up a very small percentage of the Wallace Group's work, but they are seeing an upswing in demand due to new EPA stormwater regulations, heavy marketing from the Nation Ready Mix Concrete

Association (NRMCA), and a growing interest in LEED certified buildings. The Wallace Group is currently designing a 20,000 sq ft pervious concrete parking lot in Paso Robles for a developer interested in LEED certification of a new commercial building.

Mr. Yates and a few of his co-workers have attended a pervious concrete training workshop sponsored by the NRMCA. They have spent the past six months refining their concrete mix and have poured multiple test pads to asses each mix's properties. Mr. Yates has had to source the aggregate from outside the normal supply chain and is using a number of SCMs such as fly ash, wetting agents, drying agents, and a bonder to ensure proper concrete performance, but is now confident in the mix.

Smith and Sons, a different pervious concrete contractor in Ventura, was unable to be reached for consultation. These contractors, as well as architects and design firms, represent unique opportunities for promoting pervious concrete as they are often a first point of contact with interested parties. These groups should be educated about the benefits, applicability, and limitations of pervious concrete. If they can become better educated about the product, permeable pavement will gain more widespread prominence.

Local Agencies

Pathogens are the leading cause of water quality impairments for Santa Barbara area waterways. As mentioned earlier, no studies have been performed on permeable pavement's pathogen reduction potential, so pervious concrete's ability to treat this water quality concern is yet undecided. It is unlikely, however, that hardscapes such as parking lots, driveways and roads are a major source of bacterial pollution, so installation of pervious concrete may not result in significant water quality improvements for the waters of concern.

Both the City Creeks Division and Project Clean Water have reported waterway exceedances for heavy metals and hydrocarbons. According to data in the Creek Division's monitoring program update, there were eight exceedances for cadmium, thirty-four for copper, thirteen for zinc, and ten for lead (Creeks Division 2006b). In the County's water quality analysis report, there were nine exceedances for copper and nineteen for zinc (Project Clean Water 2003). Because of pervious concrete's ability to reduce these types of pollutants by 90% or more, adoption of pervious concrete in local watersheds has a high potential to increase water quality.

Furthermore, as demonstrated by our modeling and the researched ability of pervious concrete to reduce runoff, installation of pervious concrete can significantly alter the storm hydrograph. Decreased total flow and decreased peak flows will lead to a more natural, attenuated, pre-development hydrograph. Decreased storm runoff in channels and streams will translate into slower water velocities causing less erosion. Increased groundwater discharge to streams will lead to more perennial stream flows, promote enhanced in-stream and riparian habitat, and naturally treat water quality concerns as the water passes through the soil column.

Recommendations for Local Placement

Many factors should be considered before installing pervious concrete in the Santa Barbara area. Rainfall patterns, soil types, cost, contractor ability, and public perceptions should all be addressed before construction. The combination of these factors make it difficult to generalize where pervious concrete should be installed; rather, it is necessary to perform a detailed analysis at each individual site.

Porous concrete has been tested, and is currently in use, in many other areas of the nation where rainfall patterns differ from those here in southern California. A Mediterranean climate, producing large, infrequent rainstorms typifies the region. This is quite different than lighter, more continuous rainfall patterns typical of the northwest or east coast of America. The majority of rainfall events in this area are less than one inch, however, larger, five-inch rainfall events do occur during El Nino events (LTER 2004). The effects of heavy rainfall on pervious pavement performance has not been well studied. However, based on measured infiltration rates of pervious concrete greater than 280 inches per hour [7200 mm/hr] and flexibility in overall system design, there should be no concerns about pervious concrete's performance in this hydrologic regime.

Soil types and infiltration rates vary widely across the watersheds surrounding Santa Barbara and can be classified according to hydrologic soil group. Hydrologic soil group type A soils have low runoff potential and high infiltration rates even when thoroughly wetted, consisting mostly of sandy grain size. Type B soils are silt/silty-loam soils, which have moderate infiltration rates. Type C soils are sandy clay loam soils and have low infiltration rates. Type D soils are more clayey, with very low infiltration rates and the highest runoff potential. A rule of thumb suggests pervious concrete will function well over hydrologic soil group type A, B, or C soils.

In Mission watershed, this precludes the use of pervious concrete in the highly impervious downtown corridor where the soil is predominantly type D, but allows for its use on the west side of Mission Creek, in areas south of the train tracks, and in a pocket near the intersection of the Mission Canyon and Foothill roads, where soil types are classified as A, B, or C (NRCS 2007). In Atascadero watershed, soil patterns are more complex, but there appear to be many suitable sites for pervious concrete throughout the lower and mid-watershed.

A parcel of land at the north-east intersection of Turnpike and Hollister Avenue is of particular interest for the County of Santa Barbara. The landowner will be replacing the current parking lot soon and may be amenable to incorporating progressive stormwater BMPs, like pervious concrete. It appears that the property is split in half according to hydrologic soil group: the northern area is a type D soil while the southern half is a type B soil . These soil boundaries have been inferred by soil hydrologists with limited field data, so the boundary's true location may not be accurately represented by the map. The soil survey handbook for the region reports infiltration rates greater than 0.5 inches per hour [13 mm/hr], the EPA cutoff value, for both soils (Shipman 1977). This discrepancy highlights the importance of performing individual field analyses at potential sites to asses their suitability for pervious concrete. A localized approach like this could reveal that pervious concrete is more applicable throughout the region than originally indicated.

In the densely urbanized downtown corridor of Mission Creek watershed, permeable pavement could be used over an impermeable liner, much like the UK parking lot discussed in the runoff reduction section. This system would delay runoff to the creeks, decrease total runoff volume, and improve the runoff's water quality. Additionally, there are many parking lots in Mission Creek watershed which represent good candidates for conversion to permeable pavement.

POLICY RECOMMENDATIONS FOR REDUCING STORMWATER RUNOFF

Introduction

Significant efforts have been made in the Storm Water Management Programs of the County and City of Santa Barbara to require the use of both structural and non-structural Best Management Practices (BMPs) in new developments to reduce the incidence of stormwater runoff. Most of the existing policies are aimed at developers and commercial property owners, and are regulatory in nature. In order to address stormwater runoff pollution problems more effectively at a watershed scale, a wider spectrum of the community should be included, such as private homeowners. This section proposes policy strategies that may be used to encourage the use of runoff control BMPs at various levels. The policy strategies are categorized as Economic; Land Use Planning; and Site Development.

Economic Strategies

Stormwater Management Credit Program

The purpose of introducing a stormwater management credit program is to provide incentives for developers, designers, builders, and private property owners to implement better site design and locate new development where effects on runoff generation may be minimized. There are various benefits associated with a credit program. For developers, designers and builders, participation in the credit program can help reduce the costs associated with conventional stormwater storage and conveyance systems that are required in projects to meet stormwater quantity and quality controls. The financial incentives of a stormwater credit program can also encourage private property owners to adopt runoff reduction controls or Best Management Practices (BMPs) on their property. Stormwater credits are usually directly linked to these requirements: 1) groundwater recharge, 2) water quality control, 3) channel protection, and 4) flood control (The Stormwater Manager's Resource Center Manual Builder 2007). There are various ways of designing stormwater management credits, depending on the main goals of the community. In order to ensure effective implementation of a stormwater credit program, communities need to select stormwater runoff sizing criteria and credits that best address their economic, environmental, and social objectives.

This section will provide examples of stormwater management credit programs that focus on environmentally sensitive development or re-development through the reduction of impervious areas.

Example 1: City of Sandy, Oregon

The City of Sandy's stormwater management program targets both residential and non-residential properties. The incentive program is intended to encourage property owners to utilize source control facilities on new development or redevelopment, or to make improvements to existing properties to mitigate stormwater discharges (City of Sandy Stormwater Management Incentive Program 2007).

The program defines one Equivalent Residential Unit (ERU) as 2,750 square feet of impervious area, or the equivalent impervious area of a typical single-family home site. The monthly stormwater management fee, based on per ERU, is $3.00. Property owners are charged the monthly stormwater management fee multiplied by the number of ERUs that the property is determined to contain. The ERUs are quantified through several ways: ground measurements, blueprints submitted with the building permit application when the property was developed, and aerial photos (City of Sandy Stormwater Management Incentive Program 2007).

The main motivation of the ERU concept is to provide a financial incentive for property owners to reduce or eliminate impervious surfaces on their developments. However, in some cases, total removal of impervious surfaces may not be possible, due to high cost or other practical reasons. The stormwater management credit program offers some flexibility in these situations by providing credits for measures that reduce the effective impervious surface by holding or absorbing stormwater onsite. These mitigation measures include pervious paving, tree plantings within 30 feet of impervious surfaces, eco-roofs, infiltration or flow-through planter boxes, vegetated or grassy swales, vegetated filter strips, infiltration basins, sand filters and soakage trenches.

In the City of Sandy's stormwater management credit program, specifications are provided for each suggested mitigation technique. For instance, pervious pavements may be installed based on the manufacturer's specifications and recommendations; however, when the surfaces are intended to support vehicles, they must be designed by a professional engineer registered in the state of Oregon. In addition, the credit program does not permit the installation of pervious pavement systems on sites that contain high oil and grease concentrations (City of Sandy 2007).

Credits given for the reduction in impervious or effective impervious surfaces are based on the amount of ERUs mitigated (City of Sandy 2007). The maximum allowable credit is one-third of the total number of ERUs, which means that a property owner must have at least three ERUs (8250 sq ft) of impervious surface to qualify for a credit. Additional credits may be given to property owners who completely eliminate impervious surfaces on their property (City of Sandy 2007). Given the low minimum stormwater management fee of $3.00 per ERU per month ($36.00 per ERU per annum), the credit program appears to be targeted towards non-residential property owners, e.g., large, free-standing commercial retail stores, which typically range from 50,000 to 200,000 square feet in floor space. An Excel spreadsheet designed to calculate the amount of credits is publicly available on the City government's website: (see http://www.ci.sandy.or.us/index.asp?Type=B_BASIC&SEC={A9D3CDDE-3BA0-42DE-BE30-4E321A155AA8}).

Example 2: King County, Washington

King County's surface water management fee is based on the average amount of impervious surface on residential properties and the overall amount and parcel size of commercial properties. Residential property owners pay a flat fee of $111 annually, but receive discounts of up to 50% if they implement stormwater flow or quality control Best Management Practices (BMPs) onsite. The fees for commercial property owners are determined on an incremental scale, depending on the area of impervious surfaces, the proportion of impervious area within their parcel, and the extent of effective imperviousness (King County 2007).

There are several discounts offered for runoff mitigation, as well as a cost-sharing and credit program that provides incentives for reducing impervious surface. Programs that address the reduction of impervious surfaces are highlighted below:

> **Pervious Surface Absorption Discount**
> Commercial property owners may obtain up to a 25% discount on their annual stormwater fees if they implement county-approved flow control BMPs and ensure that at least 10% of the impervious areas on their site is mitigated by these BMPs.
>
> **Impervious Surface Cost Share and Credit Program**
> The county has developed a cost-sharing program that provides incentives for commercial properties to convert impervious surfaces or reduce effective imperviousness on their parcels by using native-vegetated landscaping, compost-amended lawns, or grassed, modular-grid pavement. The county will share up to 50% of the costs (a maximum of $20,000) after the conversion project is completed and deemed acceptable by county authorities upon inspection.

Applicability to County and City of Santa Barbara

The County of Santa Barbara has indicated in its Storm Water Management Program (2006) that options are being explored to develop an incentive program to address the problem of polluted runoff in urbanized areas. The county is in the process of researching current technologies to identify potential retrofits for existing development that will reduce storm runoff. Grant opportunities to encourage the implementation of these retrofits are also under consideration.

The draft Storm Water Management Plan of the City of Santa Barbara (2006) does not contain specific references to the development of financial incentive programs aimed at reducing stormwater runoff. However, a funding source for creek restoration and water quality improvement programs was established with the passage of the ballot Measure B in November 2000, which increased the hotel transient occupancy tax (TOT) from 10% to12 %. The funds generated from Measure B are currently channeled to and managed by the Creeks Division in the Parks and Recreation Department.

Many of the strategies highlighted in the examples above may be adapted for Santa Barbara or used as references for developing similar policy tools in Santa Barbara. The success of a storm runoff reduction incentive program is highly dependent on the way it is implemented and managed. Many jurisdictions are creating stormwater utilities to implement and enforce storm water management programs. The main responsibilities of a stormwater utility include: assessment and collection of a user fee dedicated to a stormwater management program (NRDC 2006); verification and distribution of stormwater credits; and establishment of funding programs that address the priority stormwater-related concerns in the community. Alternatively, communities are also obtaining stormwater management funds through the allocation of a portion of their local tax revenue. Santa Barbara County's Project Clean Water and the Creeks Division in the City of Santa Barbara are existing agencies that are well-placed to initiate stormwater management incentive programs, as they have access to the range of information and data required to set up the underlying framework for a stormwater credit or cost-sharing scheme. However, the development of a fee structure and billing system is time-consuming, and is likely to form a large percentage of the start-up costs (Schueler and Holland 2000). Coordination and management of the incentive program is likely to be labor-intensive, requiring personnel for data analysis and management, onsite monitoring, allocation of credits, and enforcement of rules.

A survey of stormwater utilities throughout the U.S. was conducted by Black & Veatch, an environmental engineering consulting firm, between 1995 and1996 (Black & Veatch 1996). The observed trends from the survey could be useful for the County and City of Santa Barbara in analyzing the essential factors needed for effective implementation of a stormwater management credit program. The survey included 97 different utilities from 20 states and produced an index highlighting the main trends among stormwater utilities. The key trends noted from the study are as follows:

- 55% of respondents used impervious cover as a basis for user fees.

- 57% of respondents charged between \$2 - \$4 per month.
- 61% of respondents feel that public information/education is essential to the success of a stormwater utility.
- 35% of respondents included stormwater fees in a water or public utility services bill.
- 57% of respondents allocated credits for private on-site runoff retention/ detention BMPs.
- 82% of respondents indicated that utility revenue from fees was adequate to meet the most urgent stormwater management needs.
- 11% of respondents indicated that utility revenue from fees was adequate to meet all stormwater management needs.
- 54% of respondents regulated non-payment of fees by shutting off water supply or imposing a property lein.

Designing a stormwater management credit program involves (Schueler and Holland 2000):

Definition of the goals of the program

In Santa Barbara, where quality of runoff to the ocean is a main concern, the relationship between reducing stormwater runoff and improving water quality in the watershed would have to be examined to determine the specific goals of the stormwater management program.

Estimation of revenue requirements

Cost estimates should be developed for all aspects of the program. If an independent stormwater utility is to be established, cost estimates for all the functions that it will undertake should be calculated.

Determination of an administrative structure for program management

The scope of activities for the stormwater credit management program need to be established, followed by the identification of agencies that are most appropriate for performing the associated tasks.

Development of a fee structure and billing system

The fee structure would be primarily based on the amount and proportion of impervious cover within a property. Considerations like target sectors should also be factored into the establishment of the fee structure, which could consist of a low minimum fee for single-family properties that do not contribute significantly to runoff and an incremental fee per additional unit of impervious surface for larger non-residential properties that contribute more significantly to runoff. Typically, streets, highways, undeveloped land, rail rights-of-way, and public parks are exempt from fee charges. The agency managing the credit program would also have to determine whether to provide credits for properties that contain structural stormwater treatment facilities onsite.

- **Implementation of a public information program**
  Public participation is essential for the development and implementation of an effective and successful stormwater management credit program. It is critical to involve the community in the development of the fee structure to ensure that the general public will accept the levels of payment, and that the fee structure is perceived as equitable.

Tradable Runoff Allowance Scheme

This market-based tradable allowance mechanism for trading runoff reductions was developed by Thurston et al. (2003) and was applied to the Shepherd Creek watershed, a sub-basin of Mill Creek in Cincinnati, Ohio. It was proposed as a practical and cost-effective method to assign dispersed runoff control throughout urbanized areas (Thurston et al. 2003). The key objective of this scheme is to create an economic incentive for constructing small runoff mitigation BMPs that decrease effective imperviousness onsite, instead of relying on large-scale centralized offsite infrastructure, which is usually much higher in cost. Tradable credit systems are similar to stormwater management fee systems, but may offer more flexibility than fee systems (Thurston et al. 2003).

The analysis by Thurston et al. (2003) was applied to Shepherd Creek, a sub-basin comprising 453 land parcels. In the analysis, it was assumed that a stormwater utility managed surface runoff and determined the ecological limits of streams and sewers in the relevant watersheds. This was done by setting a reference level (e.g., pre-development runoff conditions) for each parcel of land. The stormwater utility would monitor the amount of runoff from each of the parcels to ensure that runoff volume in excess of the reference level is either retained onsite or mitigated with runoff allowance credits traded in a runoff allowance market. The implementation of this scheme creates two cost components for property owners: 1) the cost of constructing and maintaining dispersed BMPs and 2) the opportunity cost of land taken out of other uses. The sum of these costs represents the marginal cost of abating a unit of runoff (Thurston et al. 2003).

The program was initiated by delineating the Shepherd Creek watershed into subwatersheds, and subsequently parcels within those subwatersheds. Using GIS, characteristics of each parcel, including soil type and land use, were analyzed and recorded. Pre- and post-development runoff estimates were modeled using the TR-55 methodology (Urban Hydrology for Small Watersheds) developed by USDA in 1986, based on a design storm of 1.23 inches [3.12 cm]. The amount of excess storm runoff from each parcel was expressed in terms of cubic feet (Thurston et al. 2003). The information on each parcel consisted of a parcel identification number, a land use type classification, a soil type, and the quantity of excess stormwater runoff. In order to develop cost estimates for the tradable runoff credits, a range of existing credit prices was identified, and the average cost of source control BMPs was compared to the cost of centralized runoff treatment systems. A modeling approach was also used to determine property owners' runoff management responsibilities and their responses (Stormwater 2002). Cost functions were developed for the set of possible BMPs from which a property owner could choose for retaining or reducing stormwater runoff.

Findings from the analysis indicated that some small or undeveloped properties have virtually no excess runoff, while large multi-family apartment properties with multiple driveways and rooftops can generate runoff 10 to 17 times higher than the average excess runoff of Shepherd Creek watershed. Conclusions from the applied analysis suggested that a tradable allowance scheme would benefit property owners in a watershed with different abatement costs for each parcel. The analysis also suggested that a dispersed BMP approach would lower the cost per cubic foot of stormwater runoff detection, relative to large-scale centralized (Command-and-Control) systems, thus creating incentives for the construction of small-scale, localized BMPs such as pervious concrete driveways or parking lots. The estimated quantity of stormwater runoff detained by small-scale localized BMPs was close to the quantities detained by large-scale systems. The trading allowance scheme also decreased stormwater runoff in the watershed through refund-driven additional detention practiced by households (Table 9).

Scenario	Cost per cubic foot detained ($/ft^3)	Quantity detained (ft^3)	Allowance detained (ft^3)	Average allowance refund per household ($)	Refund-driven additional detention (ft^3)
Allowances					
$15.00	5.08	119,685	46,275	114.26	6,755
$8.00	4.97	118,111	37,312	95.18	5,380
$5.00	4.59	99,954	114,105	306.73	27,122
$2.50	N/A	0	306,937	0	0
Command and control	5.40	122,755	0	0	0
18-mile tunnel	8.93	122,775+	0	0	0

Table 9: Tradable Runoff Allowance Scenarios (Thurston et al. 2003)

Applicability to County and City of Santa Barbara

Trading of runoff allowances is a relatively new concept, and apart from the pilot application in Shepherd Creek, research is still being conducted on the development of a realistic market-based mechanism (Thurston et al. 2006). The delineation of property rights at the parcel level makes runoff allowance trading a technically feasible arrangement (Thurston et al. 2003); however, existing institutional structures and policy constraints have to be factored into consideration. Certain conditions have to be present before a tradable credits system can be operational (Stormwater 2002). First, there needs to be a targeted level of runoff reduction and detention for each parcel, based on characteristics in individual watersheds. In order for trading to be feasible, the abatement cost (i.e., cost of runoff mitigation or retention) needs to vary among properties. For instance, the opportunity cost of constructing BMPs onsite for a high-density residential development might be higher than that for a single-family land parcel with considerable open space. Hence, there would be an incentive for the high-density residential parcel owner to trade runoff allowances with the single-family residence land parcel owner. There must also be cost reduction opportunities that large, end-of-pipe centralized approaches are unable to provide, compared to localized source-reduction strategies approaches. Second, the regulatory setting should enable parcel owners to share the responsibility for stormwater runoff detention, regardless of their location within the trading area. Trading of credits would occur when a market is created between parcel owners who find it too expensive to construct or implement BMPs, and parcel owners who are able to detain more runoff than they need to due to their low abatement cost.

For a trading system to be feasible in Santa Barbara, the County and City would need to identify or create an agency that would be capable of managing the program. The agency would have to undertake responsibility for the following processes (Thurston et al. 2003):

- Determine the desired or required environmental and flood control targets through a public process
- Model or calculate pre- and post-development runoff quantities at the parcel level – this would involve quantification of existing effective imperviousness of parcels using a combination of ortho-imagery and GIS spatial analysis tools; setting up of pilot test sites to conduct measurements of surface runoff; and finally, simulating existing and potential runoff conditions using a hydrologic modeling software like HEC-HMS
- Distribute the pre-development allowance credits
- Identify the range of appropriate BMPs for parcels in the trading area and provide a list of approved BMP contractors
- Regulate the allowance market to ensure competitiveness
- Manage the buying and selling of allowances and create an allowance bank
- Plan and coordinate investments in centralized facilities

Land Use Planning and Site Development Strategies

Green Area Factor

The “Green Area Factor” focuses on creating green infrastructure on existing public and privately-owned parcels by mandating that a percentage of each parcel utilize green technologies (e.g., rooftop gardens, permeable pavements, green facades) if new development occurs or if retrofitting takes place (Kloss and Calarusse 2006). This concept has been applied in Berlin, Germany, and is seen as a cost effective way of implementing environmental sensitive design as the decentralized approach shifts the responsibility of funding to the property owner (Ahern 2006). One of the main guiding principles of the Green Area Factor approach is that environmental impacts of development must be mitigated onsite. Another guiding principle is that each parcel must contribute to the city’s “green” infrastructure in some way, so that the combined contributions from each parcel generate a cumulative benefit (Ahern 2006).

Land parcels within the city are categorized as residential, mixed use, or commercial/downtown. A Green Area Factor (GAF) or ratio is set for each type of parcel, and the ratios are closely linked to land use zoning plans for the city. The GAF associated with each parcel type is as follows:

- <u>Residential:</u> 60% “green”
- <u>Mixed use:</u> 40% green
- <u>Commercial/Downtown:</u> 30% green

Property owners can choose from a variety of green technologies approved by the city for implementation on their parcel. A weighting system was developed for the different green technologies, based on a combination of various ecologic functions, including the capacity for evapotranspiration; ability to trap airborne particulates; capacity to retain or infiltrate stormwater; potential to maintain or support soil functions; and the creation of habitat for plants or animals (Ahern 2006). The Green Area Factor is calculated by dividing the product of the mitigated area and weighted value of the green technology by the parcel area. A fully impervious surface has a prescribed weight of 0.0, while permeable pavement has a weight of 0.3. The highest weight value, 1.0, refers to surfaces with vegetation that are connected to the underlying soil (Ahern 2006).

<u>Applicability to County and City of Santa Barbara</u>

The Green Area Factor is premised on the implementation of development restrictions on different parcel types; hence, the first consideration associated with the application of this concept in Santa Barbara would be how many land use categories to include. The residential category may need to be further subdivided since high-density areas of downtown Santa Barbara face different conditions and limitations than single-family residences in the middle and mid-upper parts of Mission watershed. The next consideration would be the Green Area Factor or percentage of incorporated 'green' technology for each parcel type. This would require a survey of current building densities and allowable build-out ratios in various land parcels in Santa Barbara, before appropriate and feasible ratios can be derived. The types of green technologies recommended for use need to be evaluated in the context of individual watersheds, depending on the level of urbanization in the watershed. For watersheds that are highly built-up, certain technologies involving the opening up of space for ground-level vegetation may not be practical and widely used. The weight for permeable pavement could be increased in this case to encourage property owners to convert the impervious surfaces on their parcels more easily, and without significant disruption of the structure or layout of the parcel. The effectiveness and success of this concept requires considerable work from the City and County during the initial development process, public education and outreach, as well as the continual evaluation of newly emerging technologies. Another component that can be procedurally intensive and financially costly is the monitoring and administration of the program.

Impervious Overlay Zoning

The objective of impervious overlay zoning is to limit future impervious area by estimating the environmental impacts of potential impervious cover through build-out calculations and setting a maximum amount of impervious area within a given planning area to meet watershed protection goals (EPA 2007). The imperviousness cap then determines the type of development as well as subdivision layout options that can be established within the planning area (EPA 2007). Impervious limits vary from location to location, and are dependent on several factors, including management concerns, existing watershed conditions, zoning structure, etc. Impervious overlay zoning has been applied at different scales, ranging from watershed districts, lake management areas, and residential districts to all districts within a county (Table 10).

Applicability to County and City of Santa Barbara

There is currently no overlay zoning associated with imperviousness in either the County or City of Santa Barbara. However, the Land Use and Development Code of Santa Barbara County (2007) contains an overlay zoning category for Environmentally Sensitive Habitat Area (ESH). Areas near the mouth and other riparian segments of Atascadero Creek are zoned as Environmentally Sensitive Habitat Area-Goleta (ESH-GOL) and/or Riparian Corridor-Goleta (RC-GOL). The ESH overlay zone is applied to areas with rare or especially valuable natural resources or sensitive animal or plant species that are particularly susceptible to the impacts of urban development. The types of development allowed within ESH overlay zones are limited to those that will "provide the maximum feasible protection to sensitive habitat areas" (Santa

Location	**Area of Application**	**Imperviousness Limits**
City of Durham, North Carolina	Development in Watershed Districts is subjected to different limits of impervious areas.	6% to 12% within Urban Growth Areas (UGA) and up to 24% outside UGA.
Sanibel, Florida	All districts.	1% to 35% in residential districts and up to 45% downtown.
High Point, North Carolina	Residential and non-residential development in Lake Management Area.	3% to 15% in development plans, based on the impact of the proposed design, which is rated on a point system.
Prince George's County, Maryland	All districts.	5% in Open Space District to 30% in 6,500-20,000 sq ft residential lots, and up to 30% in developed areas of cluster projects.
Rockford, Illinois	Four residential districts: 1) Estate, 2) 15 units/acre, 3) High density residential 4) Commercial/Retail	40% in Residential Estate up to 85% in Commercial/Retail.
Lake County, Illinois	Different zoning districts from Rural Estate to Urban.	15% to 75% (in areas approved for high density)
Lahontan Region, California	Areas of different capability classes, rated according to erosion hazard, proximity to streams, ability of land to re-vegetate, etc.	1% to 30%

Table 10: Impervious standards in locations that apply Impervious Overlay Zoning (Warbach 1998)

Barbara County Land Use & Development Code, Chapter 35.28.090 2007). The ESH and Riparian Corridor Overlay Zoning, as well as existing stormwater runoff requirements (Santa Barbara County Land Use & Development Code, Chapter 35.30.180 2007), are useful inputs that can help determine the design of an appropriate Impervious Overlay Zoning - for instance, whether it should be based on individual watersheds or land use categories. The amount of allowable imperviousness within the zoning unit will be determined by a combination of factors, such as the existing level of imperviousness; types of land uses; proportion of environmentally sensitive habitat in the area (including proximity to waterways); level of stormwater runoff abatement; and the environmental or water quality objective for that locality.

A preliminary Impervious Overlay Zoning may be introduced into the current land use zoning policies of the County and City of Santa Barbara through the following strategies:

Implementation of maximum parking requirements

The Santa Barbara County Land Use & Development Code (Chapter 35.36, 2007) and the Zoning Ordinance of the City of Santa Barbara (2007) contains minimum parking requirements for specific uses. Imperviousness limits could be set by adding a clause on the upper limit of parking lot provision in the ordinance, that is, the number of parking lots provided in development projects cannot exceed X% (e.g., 10%) above the required minimum. This will prevent the over-provision of parking lots within a development.

Setting of limits on parking lot paving

This mandate would apply to developments that propose to construct additional parking lots in excess of the minimum required number. The ordinance can mandate that the extra lots be constructed with material of lower imperviousness, such as pervious concrete.

Low Impact Site Development - Country Lanes

A “Country Lane” is a length of land containing two narrow bands of hard surface (under vehicle wheel paths) bounded with a structural component able to support vehicles (e.g., permeable pavement, grassgrid, etc.). The main objective of this design is to allow more rain water to percolate through the road surface, thereby reducing storm water runoff. This concept provides an alternative to full width lane paving, which is the default design for driveways in Santa Barbara.

The City of Vancouver, Canada, has implemented Country Lane designs in three different locations since October 2003. The public and other municipalities have shown strong interest for this alternative (City of Vancouver Engineering Services 2007). Examples of the conversion in two of the project sites are shown in Figure 27.

Applicability to County and City of Santa Barbara

This design concept is highly applicable in areas experiencing lower vehicular traffic, such as single-family residential and medium density apartment areas. The Country Lane concept is not new, but it would require considerable promotion in Santa Barbara, through public outreach and education and cost-sharing programs. Relevant agencies in the County or City would have to lead the program and perhaps implement pilot projects as demonstration sites. Demonstration sites would provide a way to evaluate the systems before they are promoted at a larger scale. Implementation of the program would also require a review of existing guidelines on automobile parking and driveway access requirements in the Municipal Codes of the County and City.

Figure 27: Example of Country Lane project in the City of Vancouver (City of Vancouver Engineering Services 2007)

In Vancouver, the construction of Country Lanes is part of an environmental residential lane improvement program led by the Engineering Services Division. The lane improvement program is similar to a cost-sharing program in which property owners are assessed for part of the overall cost of lane construction with the City, contributing the rest of the cost. The amount each property contributes is based upon the assessable length of their property, multiplied by a flat rate. Flate rates are tentatively set as a lump sum cost of $133.12 per foot or an annual cost of $13.71 per foot. Properties pay this amount over 15 years (City of Vancouver Engineering Services 2007). To evaluate the relative benefits of implementing such a program in Santa Barbara, a test project could be constructed to evaluate the average per unit (feet) runoff reduction capability of a Country Lane. This average per unit runoff reduction could then be used to determine if larger-scale conversion would result in a significant decrease in runoff. The economic feasibility of the project could be determined through a cost-benefit analysis.

Conclusions

Incentive-based strategies recommended for the reduction of stormwater runoff in Santa Barbara include a stormwater management credit program or tradable runoff allowance scheme. Land use planning approaches, such as the Green Area Factor and Impervious Overlay Zoning, and site development strategies, such as the City of Vancouver's Country Lanes program, could complement these economic strategies.

Incentive-based strategies require detailed planning and economic feasibility studies to determine if they are financially viable in Santa Barbara. There are currently no stormwater fees imposed on the local community in Santa Barbara. Getting voter approval for implementing a stormwater management fee is expected to be difficult. Proposition 218, implemented by California voters in 1997, requires voter approval (based on one vote per property owner, regardless of acreage or use) for the implementation of stormwater fees. Proposition 218 also requires that fees imposed are fair and equitable (Spray and Hoag 2004).

The development of land use planning strategies is also a data-intensive process, requiring coordination among agencies to supply and produce accurate data. In addition, extensive coordination is needed across departments representing different interests for the determination of impervious overlay zoning units. Land use planning strategies are useful in highlighting spatial differences or characteristics that may affect the cost effectiveness of incentive-based strategies, for instance, environmentally sensitive zones or storm water runoff hotspots that require higher levels of mitigation. A combination of both economic incentive and land use planning and development strategies is recommended to address the multi-faceted issues associated with stormwater runoff problems in Santa Barbara.

STORMWATER EDUCATION AND OUTREACH

This section highlights the importance of including outcomes-based education and outreach in stormwater management efforts in the Santa Barbara area. The section reviews the factors that influence environmental behavior, the elements of effective stormwater education and outreach, and existing stormwater education and outreach programs in the Santa Barbara area. Following an analysis of existing programs, strategies for education and outreach to reduce impervious surfaces in particular are suggested.

Environmental Education and Behavior

Early models of environmental education assumed that increasing a person's environmental knowledge and awareness would automatically lead to that person engaging in behaviors that are more beneficial for the environment (Figure 28). Research has showed that this is not the case. It is very difficult to change a person's behavior. Many individuals resist changing their habits, even when doing so would be in their best interest (Kollmuss and Agyeman 2002). Environmental knowledge and awareness are only two of the many factors that influence environmental behavior. To increase the effectiveness of environmental education programs, organizations need to understand and address as many of the factors that influence environmental behavior as possible.

Figure 28. Early models of pro-environmental behavior (Kollmuss & Agyeman 2002)

Kollmuss and Agyeman (2002) surveyed influential and commonly-used analytic frameworks to explain environmental behavior. They found that although no single framework was appropriate for every set of circumstances, each offered valuable insights into what drives environmental behavior. The importance of several demographic, external, and internal factors was highlighted:

Key demographic factors that influence environmental behavior include gender and years of education. Women tend to have less extensive knowledge of environmental issues but to be more emotionally engaged in those issues than men. They also tend to show more concern about environmental destruction. Additionally, women tend to believe less in technological solutions, but to be more willing to change. More years of education are correlated with having more environmental knowledge. However, having more environmental knowledge does not necessarily lead to more pro-environmental behavior (Kollmuss and Agyeman 2002).

Influential external factors include institutional opportunities and barriers, social and cultural factors, and economic factors. If necessary environmental infrastructure, like recycling facilities or public transportation, is lacking or is of inferior quality, direct environmental action becomes impossible and must be replaced with indirect environmental action (i.e., political actions to establish the required infrastructure). An individual's social circle, especially friends, family, and teachers, and, to a lesser extent, the media and political, issue-based, and religious organizations, also influence his or her environmental behavior. Pro-environmental behavior is more likely to occur if the dominant culture supports and encourages a sustainable lifestyle. Although individuals do not always make economically rational decisions, economic factors strongly impact their choices as well. Individuals tend to invest only in items with short payback times; for instance, most people would only buy an energy-efficient appliance if its energy savings offset its higher cost within a short period of time. Economic factors are often intertwined with infrastructural, social, and psychological factors (Kollmuss and Agyeman 2002).

Important internal factors include motivation, values, environmental knowledge, environmental awareness, attitudes, emotional involvement, locus of control, and responsibility and priorities. Motivation, or the reasons for behavior, may be unconscious or conscious. Habits drive a concrete willingness to act, while values and knowledge drive an abstract willingness to act. Environmental values are shaped by a variety of factors. Chalwa's (1998) study of professional American and Norwegian environmentalists revealed that their environmental values were most influenced by: (in order of relevance) experiences in nature, experiences of environmental destruction, values held by family, environmental organizations, values held by role models, and education. Environmental knowledge only explains a small fraction of pro-environmental behavior. A study by Kempton et al. (1995) of strong environmentalists and anti-environmentalists showed that both had low average knowledge about environmental issues. Furthermore, detailed technical knowledge does not seem to promote or increase pro-environmental behavior. Environmental awareness is how well one understands how his or her behavior impacts the environment. There are two components to environmental awareness - one is cognitive, based on knowledge, and the other is affective, based on perception. The cognitive component of environmental awareness can be limited for environmental issues that are intangible or overly complex, or that have non-immediate consequences (Kollmuss and Agyeman 2002).

Attitudes, or enduring judgments and feelings about individuals, objects, and issues, affect how people perceive the costs and benefits of specific behaviors. People tend to undertake pro-environmental behaviors that have the lowest opportunity cost. Those who believe science and technology will ultimately solve all problems are less willing to change their lifestyles for the sake of the environment. Emotional involvement is a person's affective relationship with nature. In general, the stronger one's feelings for nature, the more likely he or she is to take pro-environmental action. On the other hand, if a person with strong feelings for nature is constantly bombarded with information about environmental destruction, emotional defense mechanisms that act as barriers to pro-environmental action can be activated. These include denial, delegation, rational distancing, and apathy and resignation. Reasons why someone may not develop a strong affective relationship with nature in the first place include a lack of environmental knowledge and awareness. The selective perception of environmental information also plays a role - people generally accept information that is consistent with their existing beliefs and analytic frameworks and avoid or do not perceive information that is not. Locus of control is the extent to which a person believes he or she has the ability to create change through his or her behavior. The greater a person's locus of control, the more likely he or she is to take pro-environmental action. People tend to feel most responsible for and to prioritize their own and their family's well-being. They are more motivated to take actions that are in alignment with their personal priorities and are less likely to take actions that contradict their priorities (Kolmuss and Agyeman 2002).

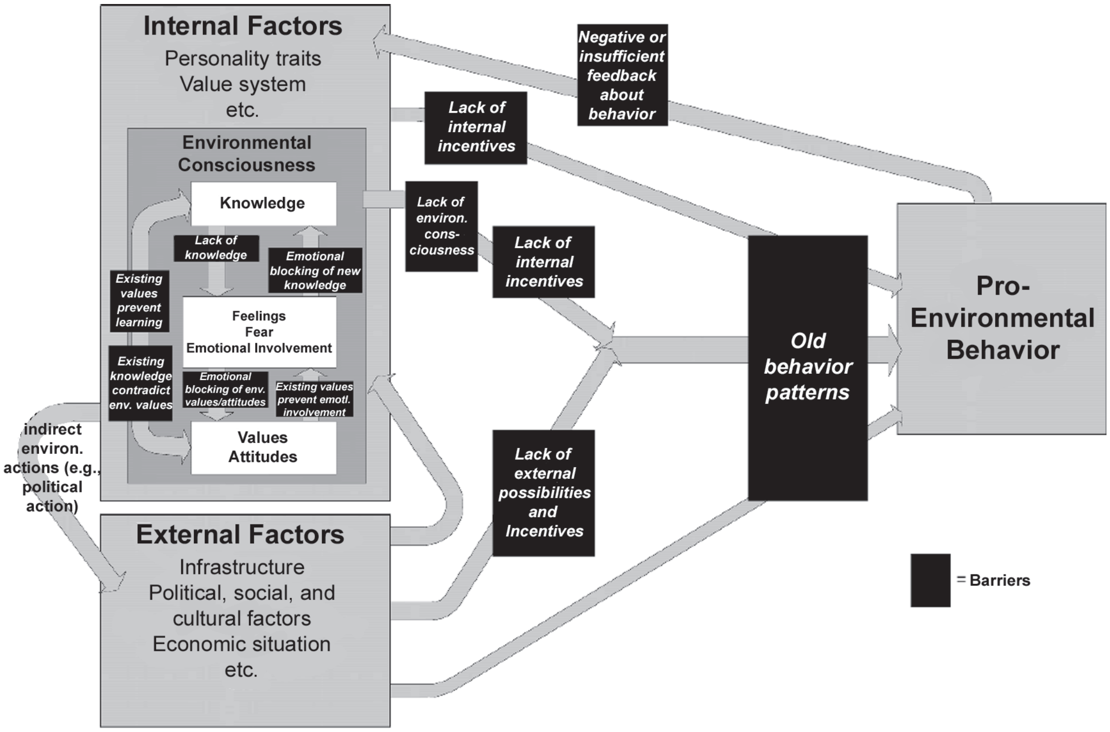


Figure 29. The factors that drive environmental behavior (Kollmuss & Agyeman 2002)

The demographic, external, and internal factors that affect behavior are complex and interrelated. Kollmuss and Agyeman (2002) created a diagram to clarify the relationship between these factors and to show how they might drive environmental behavior (Figure 29). Kollmuss and Agyeman stress that their diagram does not apply to all situations. Nevertheless, it is a useful tool for identifying the factors an educational plan that aims to influence behavior should address.

Effective Stormwater Education

Stormwater education programs have been implemented in communities around the world to enhance stormwater management efforts. The U.S. EPA requires operators of regulated municipal separate storm sewer systems (MS4s) to include public education and outreach in their stormwater management programs (EPA 2005). Effective stormwater education enables local decision makers, elected officials, businesses, and community members to make better stormwater management decisions and to take actions that positively impact the quality and quantity of stormwater. It also helps to ensure public support for and compliance with stormwater management regulations (EPA 2005). Stormwater education is especially important when enforcement of stormwater regulations is inconsistent, when penalties are light, or when audiences are large and widespread (Neiswender and Shepard 2003). Furthermore, it may be the most cost-effective method to achieve stormwater management goals (Swann 2000). Despite its potential benefits, stormwater education is often undervalued, understaffed, and underfunded (Swann 2000).

To ensure that stormwater education programs receive financial and political support, the programs must demonstrate positive results. Although different communities have different goals for their stormwater education programs, in general, program performance is measured in terms of changes in attitudes, awareness, and behavior within target audiences. Program efficiency, sustainability, and adaptability are also important considerations (Neiswender and Shepard 2003).

Neiswender and Shepard (2003) identified seven key elements of successful stormwater education programs. Although these particular elements were drawn from stormwater and urban water quality education programs in Ohio, Wisconsin, and Minnesota that involve or are led by university extension faculty, they are applicable to a wide range of situations. The elements are described below:

- **Using outcomes-based educational principles:** It is more effective to focus on meaningful outcomes, like desired behavior changes, than intermediary goals, like the number of educational products (e.g., brochures) distributed or individuals reached. One approach, which was successfully implemented in Dane County and Fox Valley in Wisconsin, is to identify and prioritize specific desired behaviors based on their potential to impact stormwater management goals. After desired behaviors have been prioritized, strategies that will achieve those behaviors can be developed and prioritized. Outcomes-based educational strategies may employ social marketing concepts such as: a) asking for a commitment from the audience, b) placing specific behavior prompts near behavior, c) communicating the norm, and d) removing barriers to desired behavior.

- **Audience targeting:** Desired behavior changes are carried out by specific groups of people. In Wisconsin, three types of target audiences are identified: a) those who must act (e.g., elected officials, homeowners, businesses, and developers), b) those who must support change (e.g., environmental and community organizations, concerned citizens, and the media), and c) those who are future supporters and actors (e.g., youth and teachers). Important issues like high turnover rates among local officials and decision makers and the presence of non-English speakers in the community should be addressed. Ohio's NEMO (Nonpoint Source Education for Municipal Officials) program includes a process for educating new decision makers as leadership changes occur. Educational materials should be provided in multiple languages and distributed through additional outlets (e.g., specialized newspapers and television channels), if necessary, to ensure that non-English speakers have access to the same information as other community members.

- **Partnering educators with technical expertise:** Stormwater professionals can address technical questions and analyze different stormwater management approaches. Educators should consult them as they are developing their education programs to ensure that they identify the most meaningful outcomes and use the best strategies to achieve those outcomes. Educators can distill complex technical information into forms target audiences can grasp.

- **Incorporating stormwater into natural resources planning processes:** Measures taken to conserve water, protect natural areas, and reduce sprawl often benefit stormwater management efforts. Multi-agency coordination to integrate these goals in planning processes can improve efficiency and reduce duplication.

- **Using public participation effectively:** Public participation is one of the other five components the U.S. EPA requires MS4 operators to include in their stormwater management plans in addition to public education and outreach. Public participation can build support to fund and implement stormwater management programs and help minimize problems that arise when the public is not involved in the early stages of the planning process (Neiswender and Shepard 2003). The Bronte Catchment Citizens' Jury Project in Eastern Sydney, Australia, showed that community participation in stormwater management programs can also be a valuable education tool. The Bronte Project engaged the community, which was broadly defined as everyone who has an impact on water quality in Bronte, including visitors, through community development activities, deliberative decision-making processes, and council program reviews. Pre- and post-project citizen surveys demonstrated a broadening of perspective across community groups and areas, from minority and special interest views to more collective, general interest views, as well as improvements in environmental attitudes, knowledge, and self-reported behavior across the catchment (NSW EPA 2005a).

- **Coordinating multi-jurisdictional efforts to effectively use education resources:** Coordinating educational efforts and messages and pooling educational funds between municipalities can be more cost-effective and efficient than working alone. Other benefits of forming multi-jurisdictional or regional outreach groups include collective creativity and the ability to draw from a wider range of experiences and interests. A few examples of successful regional stormwater education and outreach partnerships include Metro WaterShed Partners in Minneapolis-St.Paul, Minnesota, Ohio's Stormwater Task Force, the collaboration between 19 municipalities in Dane County, Wisconsin, and STORM (STormwater Outreach for Regional Municipalities) in Phoenix, Arizona (Neiswender and Shepard 2003; Worlton and Christensen 2003).

- **Evaluation:** Regularly evaluating a program's success in meeting its desired outcomes enables program coordinators to justify their use of program funds, to continuously improve programs based on the relative success of different strategies, and to adapt programs to changing circumstances. Evaluation should address short-, medium-, and long-term desired outcomes. Stormwater education programs are typically evaluated by comparing the results of citizen surveys distributed before the educational program begins to those of surveys distributed some time after the program is been in effect. The most meaningful surveys tackle desired outcomes directly; for reasons discussed above, a person's attitudes towards broad issues, like water quality, are not good indicators of whether he or she takes specific actions to address those issues, like disposing of his or her pet waste in the trash (Newhouse 1991).

Swann (2000) described the stormwater education outreach techniques that are the most effective at influencing watershed behaviors. His conclusions were based on an analysis of before-and-after citizen surveys conducted in Washington, Oregon, California, Michigan, Wisconsin, Maryland, Florida, and Virginia. The surveys indicated that media campaigns and intensive training have the greatest potential to change watershed behavior, improving selected behaviors in up to 20% of their respective target audiences. Media campaigns broadcast general watershed messages to a large audience through a mix of radio, television, newspapers, direct mail, signs, and\or other channels. Intensive training provides complex information to smaller, more specialized audiences through workshops, consultations, and guidebooks. Because the techniques complement each other, Swann concluded that outreach should include a combination of the two to be most effective. To use media campaigns and intensive training to their best advantage, Swann offered several suggestions, gleaned from the results of the citizen surveys. These suggestions are outlined below:

- Keep messages simple, direct, and, if possible, funny.
- Repeat messages frequently to enhance recall.
- Use multiple media, preferably television, radio, and newspapers.
- Use cable or public television channels instead of community access channels.
- Develop regional media campaigns to overcome limitations imposed by small budgets.
- Use creative approaches to reach specific target audiences (e.g., to reach middle-aged men, broadcast messages during radio sport event broadcasts).
- Provide information in additional languages if there are non-English speakers in your community.
- Make information packets small, attractive, and durable.
- Prioritize reaching audiences who have the greatest potential to impact stormwater in your area.
- Emphasize adult education over youth education.
- Stress the link between specific behaviors and the undesirable effects to which they contribute (e.g., beach closures, fish kills, algal blooms).
- Educate private sector allies.

Business and industry outreach can be a useful component of stormwater education. A number of businesses have the potential to directly impact watershed health and\or to influence their customers' watershed-related behaviors. Swann mentioned lawn care companies, landscape services, and lawn and garden centers as obvious targets (2000). Construction contractors, mobile cleaners, and automotive services also come to mind. Business outreach typically includes some or all of the following: a) site assessments, b) follow-up and distribution of checklists for certification, c) certification, d) distribution of educational materials, and d) promotional activities and publicity. Promotion is especially important because most customers do not choose businesses on the basis of their environmental practices. Customers looking for lawn care companies in the Chesapeake Bay, for example, primarily consider direct mail, word of mouth, and cost (Swann 2000).

The Cooks River Environmental Assessment and Education Project, conducted from July 1999 to August 2000, in New South Wales, Australia, is an example of a stormwater education program that successfully employed business outreach (NSW EPA 2005b). During its ten-month run, the Cooks River project assessed over 1,700 small businesses, developed a set of checklists for assessing different types of businesses, developed a set of industry information resources that can be used throughout

Australia, trained council officers in completing assessments, and developed real case studies that can be used in future training exercises. More importantly, the project improved the way hundreds of small businesses manage their environmental impacts, improved the businesses' compliance with environmental regulations, and raised community awareness about and responsibility for stormwater issues. Based on the Cooks River project, the following recommendations were developed for future business outreach programs: stress the importance of follow-up; encourage small business owners to form working groups; provide professional development opportunities for assessment officers; give assessment officers the power to enforce relevant laws; and, use local newspapers, radio, and\or television to explain your project and to provide regular updates on all aspects of the project.

The most effective stormwater education programs make positive contributions to the ultimate goals of stormwater management, which may include reductions in stormwater pollutant loads, stream channel protection, prevention of increased overbank flooding, safe conveyance of extreme floods, and maintenance of groundwater recharge and quality (CWP 2007). Dietz and Clausen (2004) used a paired watershed approach to assess the impacts of stormwater education on common stormwater pollutant levels in a residential neighborhood near Long Island Sound in Branford, Connecticut. They found that education significantly reduced nitrite and nitrate nitrogen (NO_3-N) but did not affect ammonia nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), total nitrogen (TN [NO_3-N+TKN]), or total phosphorus (TP). Dietz and Clausen hypothesize that education did not reduce ammonia and phosphorus loads because it did not affect contributions for streets and driveways; educational efforts, which consisted of public seminars and home assessments and consultations by trained volunteers, focused on yard and garden care and pet waste management. Because education occurs in combination with other stormwater management practices in most communities, it may be difficult to isolate its effects on measures of these goals from the effects of other management practices.

Stormwater Education in City and County of Santa Barbara

Existing Strategies

The City and County of Santa Barbara have developed public education and outreach programs as part of their stormwater management plans to comply with the U.S. EPA's Phase II rule for small-regulated MS4s. The scope of the programs is five years. The Creeks Restoration and Water Quality Improvement Division of the Parks and Recreation Department is responsible for implementing the City of Santa Barbara's stormwater education and outreach plans (Creeks 2007). The Public Works Director is responsible for implementing the County of Santa Barbara's stormwater education and outreach plans; however, Project Clean Water plays a key role (PCW 2007).

Project Clean Water is a coalition of government agencies, community groups, and individuals established by the County in 1998 to investigate and implement solutions to contamination in local creeks and the ocean. The principal departments involved are the Public Works Department's Water Agency and the Public Health Department's Environmental Health Services. The cities of Santa Barbara County; community groups including the Urban Creeks Council, the Audubon Society, the Surfrider Foundation, Heal the Ocean, CURE, Santa Barbara Channelkeeper, the Coalition of Labor, Agriculture and Business, and the Community Environmental Council (CEC); and other interested community members also participate (PCW 2007).

Want to know more?

Call 1-877-OUR-OCEAN if you see

- illegal dumping
- pollution in a creek
- a clogged storm drain
- a pollutant spill near a gutter, storm drain or creek
- disposal of wastewater into a gutter or storm drain

If you need to dispose of a pollutant:

- Used motor oil, call: Used Oil Hotline - 800-CLEANUP
- Hazardous waste, call: (Paint, paint thinner, garden chemicals, etc.) Community Environmental Council 805-963-0583

For more information on clean water programs

- City of Santa Barbara Creek Restoration & Water Quality Improvement Program: 805-897-2658 www.ci.santa-barbara.ca.us
- Santa Barbara County Project Clean Water: 805-568-3440 www.co.santa-barbara.ca.us/project_cleanwater

A Dog Owner's Duty

Part of a unified community effort to clean up Santa Barbara County's creeks and beaches

PROJECT CLEAN WATER

So what's the problem?

Our ocean and creeks are polluted

Bacteria and other types of pollution have been found in local creeks and the ocean. Ongoing contamination of these waters has resulted in beach and creek closures, and unconfirmed reports of illness from contact with these polluted waters. Remember, everything that flows into a storm drain or creek ends up in the ocean without being treated.

Our community is working to solve this problem

Project Clean Water is a coalition of nonprofit organizations, businesses, government agencies and concerned citizens. All of these groups have these goals: to improve water quality in our creeks and the ocean, to promote public health and to protect the quality of life in Santa Barbara County for everyone.

You can help

By implementing the solutions in this pamphlet, you can take part in protecting and improving the water quality of local creeks and making our beaches safe again.

How would you like to live in a community of over 50,000 residents with no sewer system?

Over 50,000 dogs live in Santa Barbara County, and of course, do not use the toilet.

Pet waste washes into our creeks and oceans if pet owners do not dispose of it properly.

When it rains, or sometimes during irrigation, animal waste left uncovered or stored improperly near creeks and storm drains can flow, untreated, directly to the ocean.

Animal waste contains bacteria, which is detected in oceanwater sampling and can trigger beach advisories.

When the bacterial level in ocean water at the beach gets too high, the beach is posted with warning signs to protect the public.

Solutions...

On a walk

Picking up after your pet ensures that waste will not wash into catch basins that drain to creeks and eventually to the ocean. Also, picking up after your pet on the beach stops the direct flow of waste to the ocean. **Remember, in public parks it is illegal not to pick up your dog's waste.**

- Always carry a plastic bag with you when you take your dog for a walk. Although some parks and beaches provide plastic bags, don't assume you will find a public dispenser.
- Plastic grocery and vegetable bags work well. Place your hand in the bag, pick up the waste. Turn the bag inside out, and then drop it in a trash receptical.
- Commercial "scoopers" can also be purchased to make proper disposal of pet waste even easier. Some are disposable and available with biodegradable, sealable bags. Check pet stores and catalogs.
- Urge your neighborhood or community organization to sponsor a mutt mitt station. Call County Parks (568-2461) or City of Santa Barbara (564-5418) for more information.

Clean up at home

Pet owners have many different ways of cleaning up after their pets at home. Here are a few that are creek- and ocean-friendly:

- Smaller quantities of pet waste can be raked or turned into the soil of lawns or gardens to decompose slowly.
- Larger amounts should be scooped and placed in the trash. One method suggested for this is to place a plastic bag in a 5 gallon trash can with a lid. When you pick up dog droppings in your yard, put them in that trash can, then cover them with a sprinkling of powdered lime (available at building supply stores) and close the lid. Each time you clean up the yard and add droppings to the container, add more lime. When the container is full, tie the bag closed and put it in your regular trash container.
- A more innovative method, which not only disposes of pet waste but also creates fertilizer, is to install a disposal system, commercially available through pet owners' and gardening catalogs. These systems use bacterial and enzymatic cultures. These cultures reduce the waste to a liquid, which is then absorbed into the soil.

Dumping *anything* into a creek, gutter or storm drain is ILLEGAL

Would you believe...?

MYTH #1
Runoff from streets and storm drains is treated at wastewater treatment plants.

FACT Storm drain runoff in Santa Barbara County is not treated and goes directly into our creeks — what goes into the storm drain ends up at the beach. That is why it is important to insure that pollutants such as animal waste, automotive fluids, garbage and chemicals do not end up in storm drains.

MYTH #2
Most creek pollution comes from a few big polluters.

FACT The well-known stories about environmental problems tend to focus on big, recognizable targets such as industrial factories, leaking toxic waste dumps, and oil spills. As a result, people often forget that the majority of water pollution comes from small sources — especially at the household level.

MYTH #3
The impact of one household doesn't really matter.

FACT Although an individual home might contribute only minor amounts of pollution, the combined effect of an entire neighborhood or city is serious.

MYTH #4
Creek contamination and beach postings are usually caused by chemical pollution such as paints, solvents, and motor oils.

FACT Chemical contamination is always a concern. Yet, bacterial contamination from animal waste, litter, leaking septic tanks, garbage, and green waste also threaten creeks, beaches, wildlife and your health. Beach postings are actually triggered by bacterial contamination.

santa barbara's LIVING WATERSHEDS AND OCEAN

what's inside

- Clean Beaches and Water Quality
- State of Our Watersheds
  - Arroyo Burro
  - Mission Creek
  - Sycamore Creek
  - Laguna Creek
- Community Priorities
- How You Can Help
- Benefits of a Healthy Watershed

A COMMUNITY GUIDE TO HEALTHY WATERSHEDS

Figure 30: Educational brochure and guidebook used in Santa Barbara (Creeks 2007; PCW 2007)

In 2002, the City and County of Santa Barbara conducted a public survey and extensive stakeholder interviews to measure residents' level of knowledge about stormwater issues, their level of concern about these issues, and their willingness to change their behavior in response to these issues. The survey and interviews also identified groups within the community who are less knowledgeable about stormwater issues (Creeks 2007; PCW 2007). The results of the survey and interviews were used to craft the City and County's stormwater education and outreach programs.

The City and County of Santa Barbara collaborate and share resources for several aspects of their stormwater education and outreach plans. As a result, their plans are similar. Both education plans use four brochures printed in English and Spanish, including a general brochure for creekside residents, one for dog owners (Figure 30), one for horse owners, and one for gardeners. The County also developed a brochure that promotes sustainable landscaping techniques to protect water quality. The City additionally created a 16-page community guide to healthy watersheds called "Santa Barbara's Living Watersheds and Ocean" (Figure 30). Other printed materials include posters and fliers (Creeks 2007; PCW 2007).

Printed and other educational information is distributed at community events, including Creek Week, Earth Day, Sustainable Landscape fairs, the Steelhead Festival, and other relevant public events. Creek Week is hosted by the Creeks Division and Project Clean Water. Community environmental organizations plan the events for Creek Week. In 2006, these included: a community planting day at San Roque, volunteer water quality monitoring, a guided nature hike at Arroyo Hondo preserve, an oceanfront bird walk, a Mission lagoon clean-up, and a community forum focused on water quality, bacteria, and human health (Creeks 2007; PCW 2007).

The City and County share a stormwater hotline: 1-877-OUR-OCEAN, through which residents can report pollutants being dumped in storm drains and request information about where to dispose of hazardous waste. This hotline is advertised on all printed educational materials. The City advertises two additional phone lines: a Creeks Division information number and a water quality enforcement number (Creeks 2007; PCW 2007).

The City and County of Santa Barbara mark their storm drain catch basins and drop inlets. Their storm drain markers read “No Dumping” in English and Spanish and have a graphic of a fish and water (Figure 31). The City has marked all 2,300 of its storm drains already and has a plan for cleaning and replacing its markers as needed; the County has almost completed marking its storm drains and once it is done it will make plans for systematically replacing them. Signs with creek names that reinforce the connection of creeks to the ocean have also been posted by major tributaries in the City and County of Santa Barbara (Creeks 2007; PCW 2007).

Figure 31: Santa Barbara City (left) and County (right) storm drain markers (Creeks 2007; PCW 2007)

The County of Santa Barbara built and operates the South Coast Watershed Resource Center (WRC) with the CEC. The WRC is located at Arroyo Burro County Beach, a popular site that is often polluted. The center contains bilingual exhibits on watersheds, non-point source pollution, and native plants; a wet lab; a library; a computer research area; and a Chumash tomol (canoe) construction area. The WRC is open to the public and hosts field trips and meetings (PCW 2007).

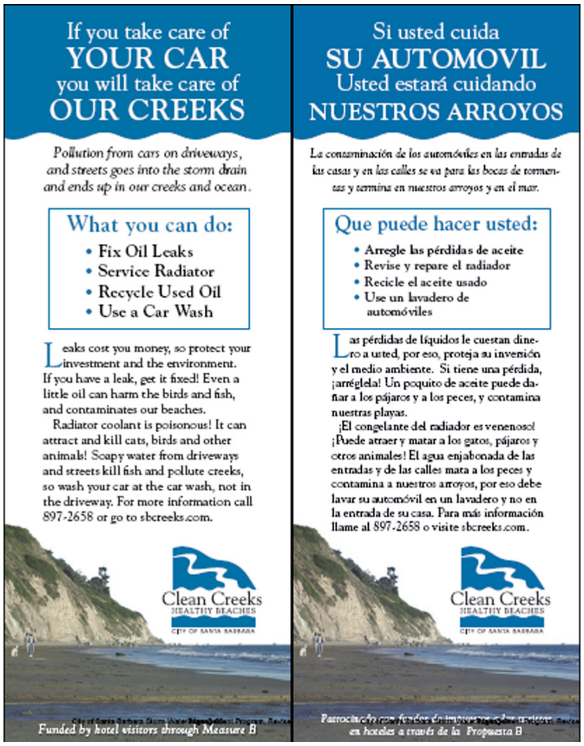
The City and County of Santa Barbara’s stormwater education and outreach plans include a youth education component. In 1999, they collaborated with the CEC to develop a watershed science curriculum for kindergarten through sixth grade students called “Mountains to the Sea”. Annual teacher training was conducted for this curriculum from 2000 to 2004. In 2000, the City added programs for summer camp students, and in 2004, the City expanded its educational materials and targeted more elementary age students. With Art from Scrap, a local organization, the City and County now offer classroom presentations on a variety of water-related topics, tailored for specific age groups. They also offer field trips to the WRC, creek water quality testing, beach clean-ups, and teacher training in the national Project WET (Water Education for Teachers) curriculum. The City offers field trips to Old Mission Creek at Bohnett Park as well, and is currently evaluating opportunities to educate youth through after-school projects. Participation in all youth education offerings is free and voluntary. All educational materials are consistent with the California State educational standards. Programs are evaluated annually through surveys of teachers and presenters and are revised accordingly (Creeks 2007; PCW 2007). The County aims to conduct additional evaluations of students, before and after presentations, to determine whether the presentations are successful. The City estimates that its youth education programs reach approximately 3,000 students per year (Creeks 2007).

The County of Santa Barbara is also involved with the Agua Pura Leadership Institute, which is a joint effort between the UC Cooperative Extension – Santa Barbara County, Project Clean Water, Santa Barbara City College, and local Latino and environmental groups. The goal of the institute is to support youth leaders in improving Latino youth's understanding of local water quality issues and to involve Latino youth in local water protection. Education is conducted through workshops, camp programs, and after-school activities (ERC 2006).

The Creeks Division and Project Clean Water both have websites. These provide information about their programs and explain what individuals and businesses can do to protect water quality. The websites also provides access to relevant reports and studies, additional education materials, and a calendar of events. The Creeks Division's website is updated each quarter and new events are added to its calendar of events on a monthly basis. The websites are advertised through printed educational materials and media campaigns. The County's website is also advertised on a magnet that is distributed at community events. Two hundred and fifty people are subscribed to the Creeks Division's email list and Project Clean Water's website receives over 300 visitors per month (Creeks 2007; PCW 2007).

The City and County of Santa Barbara run a water pollution prevention awareness media campaign together. Five bilingual public service announcements, focusing on garden chemicals, pet waste, motor oil, yard clippings, and car washing, respectively, are broadcast on Univision and Cox cable television stations in Santa Barbara, Goleta, and Santa Maria. Additional public service announcements are broadcast on three English and two Spanish radio stations operated by Clear Channel Communications. The media campaign also includes advertisements that have been installed inside local buses, and others that are shown before films at local theaters. Advertisements printed in local newspapers accompany the Earth Day and Creek Week events (Creeks 2007; PCW 2007).

Business outreach is part of the City and County of Santa Barbara's stormwater education and outreach plans. The primary targets thus far have been restaurants, automotive services, construction contractors, and mobile cleaners. Bilingual educational materials, like fliers and posters, that show how employees and customers can reduce stormwater pollution, have been developed for each business type (Figure 32). Materials are distributed during site visits, often in connection with reported code violations, or through the mail. The City of Santa Barbara has already distributed educational materials to over 700 businesses (Creeks 2007).



If you take care of
YOUR CAR
you will take care of
OUR CREEKS

Pollution from cars on driveways, and streets goes into the storm drain and ends up in our creeks and ocean.

What you can do:

- Fix Oil Leaks
- Service Radiator
- Recycle Used Oil
- Use a Car Wash

Leaks cost you money, so protect your investment and the environment. If you have a leak, get it fixed! Even a little oil can harm the birds and fish, and contaminates our beaches.

Radiator coolant is poisonous! It can attract and kill cats, birds and other animals! Soapy water from driveways and streets kill fish and pollute creeks, so wash your car at the car wash, not in the driveway. For more information call 897-2658 or go to sbcreeks.com.

Funded by hotel visitors through Measure B

Si usted cuida
SU AUTOMOVIL
Usted estará cuidando
NUESTROS ARROYOS

La contaminación de los automóviles en las entradas de las casas y en las calles se va para las bocas de tormentas y termina en nuestros arroyos y en el mar.

Que puede hacer usted:

- Arregle las pérdidas de aceite
- Revise y repare el radiador
- Recicle el aceite usado
- Use un lavadero de automóviles

Las pérdidas de líquidos le cuestan dinero a usted, por eso, proteja su inversión y el medio ambiente. Si tiene una pérdida, ¡arréglela! Un poquito de aceite puede dañar a los pájaros y a los peces, y contamina nuestras playas.

¡El congelante del radiador es venenoso! ¡Puede atraer y matar a los gatos, pájaros y otros animales! El agua enjabonada de las entradas y de las calles mata a los peces y contamina a nuestros arroyos, por eso debe lavar su automóvil en un lavadero y no en la entrada de su casa. Para más información llame al 897-2658 o visite sbcreeks.com.

Patrocinado con fondos de impuestos ... en hoteles a través de la Propuesta B

Figure 32: Bilingual fliers for automotive services to distribute to their customers (Creeks 2007)

Figure 33: City of Santa Barbara Clean Water Certification logo (Creeks 2007)

The City established a Clean Water Business Certification Program in 2004. As of March 2007, eleven automotive services and twelve restaurants had been certified through this program. Checklists outline the steps each business type must take to become Clean Water certified. Businesses that complete these steps receive a certificate signed by the Mayor and advertisements of their certification in the local newspaper. Newly-certified businesses also receive a special window sticker (Figure 33). Clean Water certified businesses are inspected annually to ensure that they remain in compliance with certification requirements (Creeks 2007).

The County of Santa Barbara has a similar certification program for restaurants that take steps to reduce stormwater pollution. Certified restaurants receive a certificate and recognition from the County Board of Supervisors and city councils, as well as advertisements in the newspaper. The County also conducts best management practices training for restaurant managers with the Goleta Sanitary District (PCW 2007).

The County of Santa Barbara runs a Green Gardener Certification Program for landscape maintenance professionals. The program consists of training in methods to reduce resource consumption and limit pollution from landscaped sites. Training is offered twice a year, in Spanish and English, through the Santa Barbara Community College District Continuing Education Division and the Allan Hancock College Noncredit Program. Partners include local water districts and other resource management agencies. Certified gardeners are advertised to the public through the distribution of a list of certified Green Gardeners. Over 500 gardeners have been trained since the program began in 2000. The County aims to survey at least 25 certified gardeners per year after the first year. The program relies on grants for funding (PCW 2007).

The City of Santa Barbara plans to include neighborhood-based outreach in its stormwater education and outreach program in the future. This would consist of educational programming and creek clean-up and restoration activities (Creeks 2007).

The City and County of Santa Barbara's stormwater education and outreach plans contain evaluation components. For each of the practices included in their plans, the City and County set measurable goals. For instance, the City of Santa Barbara's measurable goals for its classroom-based youth education program are to conduct 132 presentations per year and to reach 3,000 youth. Data for each measurable goal will be collected and analyzed in annual reports. Practices or measurable goals may be adjusted on the basis of this analysis. The City notes that every year, before a new budget is adopted, it will review and revise its education and outreach program to ensure the program remains relevant and cost effective. Additionally, the City will hire a consulting firm to conduct a citizen survey in the fourth year of program implementation to determine how successful the program has been in improving awareness about stormwater issues and changing people's behavior. The County will conduct a similar survey in the fifth year of implementation. The County also plans to assess the Green Gardener Certification Program's impacts on water quality in the County by the end of the second year of implementation (Creeks 2007; PCW 2007).

Analysis of Existing Strategies

The City and County of Santa Barbara's stormwater education and outreach plans have several strengths. They work together and partner with local environmental and community groups for specific activities. They use a regional media campaign that broadcasts advertisements on cable television channels. They provide education materials in English and Spanish so that non-English-speaking members of the large local Hispanic community can understand them. They use signs and storm drain markers to visually link storm drains and creeks to the ocean. They attempt to engage businesses in water quality protection. They use attractive printed educational materials that highlight simple steps residents and businesses can take to reduce stormwater pollution. They also include evaluation.

Nevertheless, several parts of their plans could be improved. The measurable goals for their stormwater education and outreach plans are mostly numerical: the number of brochures distributed, events attended, audience members reached, and so on. These goals may be easy to measure, but they are not meaningful indicators of how successful their education programs have been. The surveys that will be conducted at the ends of years 4 (for City) and 5 (for the County) should produce more meaningful results, but it is essential that the surveys be crafted carefully, keeping in mind that increases in broad attitudes towards and awareness of stormwater issues are not necessarily correlated with beneficial stormwater-related behavior changes. Earlier, more frequent surveys might be burdensome, but would be helpful in terms of identifying which practices are the most effective and which need to be improved or discontinued.

Stormwater-related business outreach has gotten off to a good start, but more could be done to promote the business certification program. It is unclear why the City and County do not use the same certification program. Although they might need to use different checklists to assess businesses due to differences in their policies, a common certification program would help to improve customers' familiarity with the program and make it easier to compare Santa Barbara area businesses on the basis of their impacts on stormwater pollution. In the long term, it might be helpful to establish a certification program that encouraged not just water pollution prevention, but other environmentally-friendly practices, like water conservation, energy efficiency, greenhouse gas emissions reductions, and so on. In any case, the City and County should stress the benefits of becoming certified and strongly promote certified businesses so that more businesses join the program.

Ensuring that all impacted communities have the ability to influence and benefit from stormwater-related decision-making processes and programs is also important. Approximately thirty-eight percent of Santa Barbara County's population is Hispanic, and twelve percent of the population lives below the poverty level (U.S. Census Bureau 2005). The differences in public attendance at community watershed planning forums held in the City of Santa Barbara's Arroyo Burro, Mission, and Sycamore watersheds in 2004 suggest the Sycamore watershed community is not as engaged in watershed protection as the communities in other watersheds. Fifty-one and sixty members of the public attended the Arroyo Burro and Mission public forums, respectively, but only ten members of the public attended the Sycamore public forum. Furthermore, no community forum was held for Laguna watershed, which is located between the Mission and Sycamore watersheds (Creeks 2007). Although most of Laguna Creek runs under streets, preventing stormwater pollution and providing public participation opportunities are as important in Laguna watershed as in the other watersheds. To achieve broader-based, more representative community participation and involvement in stormwater management, the City and County of Santa Barbara may want to consider following the example of the Bronte Catchment Citizens' Jury in Australia, which was mentioned previously. They should also recognize that traditional public participation approaches, including public meetings and plans and reports advertised for public comment, often work only for the most vocal, educated, and recognized members of the community. Relying on these approaches alone can lead to polarized results, that emphasize differences and special interests rather than consensus and collaboration (NSW 2005a).

In general, the City and County of Santa Barbara's stormwater education and outreach plans would benefit from placing a greater emphasis on outcomes. Starting with desired outcomes and working backwards, to identify and prioritize specific actions needed to achieve those outcomes and audiences that must take or support those actions, should help the City and County to select the most efficient and effective education and outreach strategies.

Suggested Strategies to Reduce Stormwater Runoff

Existing stormwater education and outreach programs in the City and County of Santa Barbara have primarily focused on reducing stormwater pollution, rather than reducing impervious surfaces. However, this project has demonstrated that reducing impervious surfaces can reduce total and peak stormwater flow. This project has also demonstrated that permeable pavements, which not only reduce stormwater runoff, but also provide additional benefits, are a good alternative for many impervious surfaces. As such, supplementing existing education and outreach programs to address the effects of impervious surfaces on stormwater runoff, the potential benefits of permeable pavements, and the use of policy tools to reduce stormwater runoff is recommended. This would enable local decision makers, elected officials, businesses, and community members to make more effective stormwater management decisions.

The most successful stormwater education and outreach strategies focus on changing or encouraging specific actions within target audiences. To reduce impervious surfaces in the Santa Barbara area, it is recommended that the following actions be prioritized:

1) Local decision-makers implement stormwater runoff reduction policy tools.
2) The City and County of Santa Barbara use permeable alternatives for paved public areas like sidewalks, alleys, lightly-used residential streets, and parking for public buildings.

3) Landowners use permeable alternatives for driveways, patios, and walkways.
4) Businesses use permeable alternatives for parking lots, patios, and uncovered walkways.

The target audiences for education and outreach connected with each action are (according to number above):

1) Local decision-makers, and community members that can influence local decision-makers.
2) The Public Works departments of the City and County of Santa Barbara, and community members that can influence the departments' decisions.
3) Landowners, and members of City and County agencies who can implement policies to influence landowners.
4) Businesses, and officials involved in stormwater-related business certification programs.

Suggested education and outreach strategies, each of which address one or more of the objectives outlined above include:

- Conduct training workshops in runoff reduction policy tools for local decision-makers. Arrange or encourage local decision-makers to attend a conference at which they can exchange ideas with decision-makers who have experience implementing these tools in other communities .
- Build community support for the reduction of impervious surfaces by linking impervious surfaces to their potential negative consequences for creeks and beaches. Likewise, associate permeable pavements with healthy creeks and beaches. This can be accomplished through existing media campaigns, including messages on television and the radio and in newspapers, as well as with signs and posters.
- Develop community capacity to influence decision makers by familiarizing them with local planning processes and advertising opportunities for public participation.
- Provide landowners, businesses, and relevant Public Works officials with practical information about how to install, maintain, and pay for permeable alternatives to impervious surfaces. A list that compiles names and contact information for contractors that install permeable pavements and stores that sell permeable products that can be self-installed should also be distributed. Basic information can be provided through a brochure or flier distributed at community events and through business outreach; however, training workshops that enable more complicated information to be exchanged are recommended.
- Encourage businesses seeking stormwater-related certification to install permeable pavements or otherwise reduce stormwater runoff, where appropriate.

Train officials involved in certification processes about these alternatives so that they can discuss them with businesses during site assessments.

- Evaluate the success of these strategies in achieving their desired outcomes by surveying all community groups, conducting interviews, and holding discussions with the staff involved in implementing the strategies. Revise the strategies accordingly.

Conclusions

This section suggested using outcomes-based education and outreach strategies to reduce impervious surfaces in Santa Barbara. Suggestions were based on research that explored the factors that influence environmental behavior and the stormwater education and outreach techniques that have been the most successful in other communities. The costs of implementing the various strategies were not considered. Furthermore, target audiences were not consulted to determine their specific needs in terms of how educational materials should be phrased and packaged. Despite these limitations, the suggested strategies should provide a useful starting point for educators and outreach coordinators interested in addressing the stormwater runoff concerns associated with impervious surfaces in the Santa Barbara area. Additionally, the model used to develop the strategies (i.e., start with desired outcomes and work backwards) can be used to develop strategies for a wide range of environmental education and outreach needs.

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APPENDIX I

Detailed Modeling Results

Peak Flow (cfs)

Atascadero Watershed

	0.5" Storm																			
	Base Impervious %				5% Decrease				10% Decrease				20% Decrease				30% Decrease			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	162	165	162	162	149	152	149	149	138	141	138	138	114	117	114	114	93	95	92	92
WY 1998	162	165	162	162	149	152	149	149	138	141	138	138	114	117	114	114	93	95	92	92

	1.2" Storm																			
	Base Impervious %				5% Decrease				10% Decrease				20% Decrease				30% Decrease			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	405	409	404	405	385	390	385	384	364	367	363	363	323	328	322	322	284	288	284	284
WY 1998	405	409	404	405	385	390	385	384	364	367	363	363	323	328	322	322	284	288	284	284

	5.0" Storm																			
	Base Impervious %				5% Decrease				10% Decrease				20% Decrease				30% Decrease			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	4376	4375	4379	4377	4323	4344	4326	4329	4295	4297	4297	4296	4195	4188	4193	4192	4113	4111	4119	4119
WY 1998	4384	4376	4376	4376	4343	4324	4328	4330	4298	4294	4296	4296	4195	4190	4193	4192	4122	4119	4119	4119

Atascadero Watershed

Total Flow (acre-feet)

0.5" Storm

	Base Impervious %				5% Decrease				10% Decrease				20% Decrease				30% Decrease			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	74	160	157	161	70	149	146	146	67	137	134	135	59	115	113	113	52	96	93	93
WY 1998	74	160	157	161	70	149	146	146	67	137	134	135	59	115	113	113	52	96	93	93

1.2" Storm

	Base Impervious %				5% Decrease				10% Decrease				20% Decrease				30% Decrease			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	216	315	311	311	207	305	300	300	198	293	289	289	180	271	267	267	162	248	244	245
WY 1998	216	315	311	311	207	305	300	300	198	293	289	289	180	271	267	267	162	248	244	245

5.0" Storm

	Base Impervious %				5% Decrease				10% Decrease				20% Decrease				30% Decrease			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	2261	2264	2262	2262	2231	2235	2234	2234	2203	2205	2203	2203	2145	2147	2146	2145	2087	2090	2088	2088
WY 1998	2262	2427	2427	2427	2233	2399	2399	2398	2203	2368	2368	2369	2145	2311	2311	2311	2087	2254	2253	2253

Mission Watershed

Peak Flow (cfs)

0.5" Storm

	Base Impervious %				5% Decrease				10% Decrease				20% Decrease				30% Decrease			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	474	476	473	473	445	446	443	443	411	414	410	410	338	341	338	338	283	285	283	283
WY 1998	474	474	474	474	441	443	443	442	411	410	410	411	338	338	338	338	283	283	283	283

1.2" Storm

	Base Impervious %				5% Decrease				10% Decrease				20% Decrease				30% Decrease			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	647	651	649	646	608	610	608	608	572	575	572	572	504	506	504	504	434	436	434	434
WY 1998	647	646	646	646	608	608	608	608	573	572	572	572	504	504	504	504	434	434	434	434

5.0" Storm

	Base Impervious %				5% Decrease				10% Decrease				20% Decrease				30% Decrease			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	3365	4485	3305	3377	3287	4405	3231	3300	3232	4313	3179	3251	3079	4206	3154	3153	2948	4077	3024	3024
WY 1998	3365	3469	3469	3469	3289	3385	3381	3381	3232	3331	3328	3328	3078	3167	3168	3168	2948	3026	3024	3024

Total Flow (acre-feet)	Mission Watershed																			
	0.5" Storm																			
	Base Impervious %				5% Decrease				10% Decrease				20% Decrease				30% Decrease			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	125	273	270	274	118	264	261	261	111	253	251	251	96	233	231	231	83	213	211	211
WY 1998	144	301	298	298	137	294	291	291	129	286	283	283	115	272	269	269	101	258	255	255
	1.2" Storm																			
	Base Impervious %				5% Decrease				10% Decrease				20% Decrease				30% Decrease			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	278	402	398	398	264	387	384	384	250	369	366	366	222	336	333	333	194	303	300	300
WY 1998	285	544	545	545	271	528	529	529	257	504	505	505	229	461	462	463	200	420	421	422
	5.0" Storm																			
	Base Impervious %				5% Decrease				10% Decrease				20% Decrease				30% Decrease			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	1637	1885	1685	1667	1597	1840	1646	1627	1560	1805	1614	1591	1472	1695	1619	1619	1390	1614	1564	1535
WY 1998	1638	2220	1877	1862	1599	2175	1828	1817	1561	2132	1793	1781	1473	1802	1695	1691	1391	1734	1605	1592

Peak Flow (cfs)

Atascadero Watershed

	0.5" Storm							
	Base Impervious %				Converted Parking Lot			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	162	165	162	162	162	164	162	162
WY 1998	162	165	162	162	162	164	162	162

	1.2" Storm							
	Base Impervious %				Converted Parking Lot			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	405	409	404	405	400	404	400	400
WY 1998	405	409	404	405	398	400	398	399

	5.0" Storm							
	Base Impervious %				Converted Parking Lot			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	4376	4375	4379	4377	4375	4375	4380	4378
WY 1998	4384	4376	4376	4376	4384	4377	4376	4376

Parking Lot Subbasin

	0.5" Storm							
	Base Impervious %				Converted Parking Lot			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	10	10	10	10	8	8	8	8
WY 1998	10	10	10	10	8	8	8	8

	1.2" Storm							
	Base Impervious %				Converted Parking Lot			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	36	36	36	36	32	32	32	32
WY 1998	36	37	36	36	32	33	32	32

	5.0" Storm							
	Base Impervious %				Converted Parking Lot			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	211	211	211	211	204	204	204	204
WY 1998	211	213	211	211	204	205	204	204

Total Flow (acre-feet)

Atascadero Watershed

0.5" Storm

	Base Impervious %				Converted Parking Lot			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	74	161	160	157	73	159	159	156
WY 1998	74	160	157	157	73	157	156	156

1.2" Storm

	Base Impervious %				Converted Parking Lot			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	216	315	314	314	214	312	311	311
WY 1998	216	315	314	314	214	312	311	311

5.0" Storm

	Base Impervious %				Converted Parking Lot			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	2261	2264	2262	2262	2256	2259	2257	2257
WY 1998	2262	2427	2427	2427	2252	2424	2422	2422

Parking Lot Subbasin

0.5" Storm

	Base Impervious %				Converted Parking Lot			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	7	8	7	7	6	6	6	6
WY 1998	7	9	7	7	6	6	6	6

1.2" Storm

	Base Impervious %				Converted Parking Lot			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	18	19	19	19	16	16	16	16
WY 1998	18	19	19	19	16	16	16	16

5.0" Storm

	Base Impervious %				Converted Parking Lot			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
WY 1991	99	99	99	99	94	94	94	94
WY 1998	104	98	99	99	94	95	94	94