ANALYSIS OF ALTERNATIVE WATERSHED MANAGEMENT STRATEGIES FOR THE LAURO CANYON WATERSHED, SANTA BARBARA COUNTY, CALIFORNIA

A Group Project submitted in partial satisfaction of the requirements of the degree

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By

Dana L. Armanino
Jon A.G. Clemens
Chris H. Coburn
Noah P. Molotch
Stephanie A. Oakes
Jill K. Richardson

Advisors:

Jeff Dozier, Ph.D.
John M. Melack, Ph.D.

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Dana L. Armanino

Jon A.G. Clemens

Christopher H. Coburn

Noah P. Molotch

Stephanie A. Oakes

Jill K. Richardson

This Group Project is approved by:

Dean Jeff Dozier

Professor John M. Melack.

ABSTRACT

The objective of this project was to identify the spatial distribution of erosion occurring within the Lauro Canyon Watershed (113 hectares) and to present a set of watershed management options that will minimize the flux of sediment into the Lauro Canyon Reservoir. We estimated sediment loss and runoff volumes for water years 1994-95 and 1995-96 using a GIS model based on the Revised Universal Soil Loss Equation. The modeling results indicate that the open slopes located just above the reservoir (flanking slopes) contribute 19% of the total sediment mobilized in the watershed. Revegetation of the flanking slopes has the potential to reduce sediment mobilization by 444 m^3, an 82% reduction for the flanking slopes accounting for 15% of the sediment mobilized in the entire watershed status quo. Alteration of groundcover in the avocado orchards would result in a 5% and 17% reduction in sediment mobilization in two separate sub-catchments. The peak rainfall event of water year 1994-95 yielded a runoff volume greater than the proposed maximum free storage capacity if the debris basins were expanded. By maintaining at least 50% storage capacity in the debris basins through dewatering during the rainy season and excavation between the rainy seasons, the basins will be able to accommodate most storms in even an extreme year. Given the associated costs and the likelihood that the expanded debris basins would not accommodate the runoff from extreme storm events, structural expansion of the debris basins is not warranted. Watershed management recommendations are to:

(1) Revegetate the open slopes surrounding the reservoir (flanking slopes) at a one-time cost of $371,000.

(2) Dewater the debris basins between storms to maintain an available storage capacity of at least 50% ($21,000 capital cost).

(3) Excavate the sediment from each debris basin such that the sediment does not occupy greater than 50% of the storage capacity at the beginning of each water year ($20,100 annualized cost, assuming average rainfall).

EXECUTIVE SUMMARY

Located in the foothills of the Santa Ynez Mountains, the Lauro Canyon Reservoir is a crucial drinking water storage facility for the residents of southern Santa Barbara County, California. During storm events in 1995 and 1998, the water impounded behind the Lauro Canyon Dam became too turbid for filtration. Subsequently, treatment plant operators were forced to shut off the intake from the reservoir. Taking Lauro Reservoir off-line jeopardizes the overall county water supply and poses a threat to sufficient drinking water supplies during peak demand periods. With its poor soil composition and high erosion potential, the Lauro Canyon Watershed is the most likely source of sediment that causes the high turbidity levels. The objective of this research was to identify the spatial distribution of erosion occurring within the Lauro Canyon Watershed, to determine runoff volumes and to present a set of watershed management options that will minimize the flux of sediment into the reservoir.

To identify slopes most susceptible to erosion, we used a GIS model based on the Revised Universal Soil Loss Equation to obtain sediment loss values (kg ha^{-1}) within the watershed. Using an aerial photograph, a 3 m digital elevation model and a soils map, we obtained model-input values for land use, vegetation type, slope, aspect and soil composition. Using precipitation data from water year 1994/95, an El Niño year that produced record precipitation in Santa Barbara County, we estimated the runoff volume (m^3) reaching each of the three debris basins. We researched management alternatives, including structural adjustments to the reservoir's sediment debris basins and the revegetation of slopes susceptible to sheetwash erosion. Using the model, we evaluated the effectiveness of differing strategies of revegetation and basin enlargement.

Areas in the watershed with sediment loss values one or more standard deviations above the mean sediment yield, in a normal water year (1995/96), were classified as critical. These cells had sediment loss values of 56×10^4 kg ha^{-1} or higher. Sediment modeling results showed that critical areas within the watershed correspond to the flanking slopes adjacent to the reservoir, avocado orchards and areas surrounding residences where slopes are high (34° to 67°) and vegetation has been removed to reduce fire hazard. Most of these critical areas had slopes less than 34°, although a few isolated critical areas in the watershed had slopes from 34° to 67°. The flanking slopes adjacent to the reservoir had sediment loss ranging from 22×10^4 kg ha^{-1} to 8.46×10^6 kg ha^{-1} and slopes ranging from 11° to 34°. Results of model simulations for the two water years showed that a 25% reduction in basin-wide sediment loss could be achieved by revegetating the slopes flanking the reservoir, an area occupying only 18% of the total watershed area. Revegetation or mulching of the sub-canopy of the avocado orchards (5% of the watershed area) would reduce sediment loss by 9%. Given that runoff from the avocado orchards flows into debris basins and the political constraints associated with this alternative, revegetation of these areas was not determined to be a priority at this time.

Water year 1994/95 is considered an extreme rainfall year spawned by El Niño. The four largest storms from this year would overrun any feasibly enlarged debris basin. Yet, if we average runoff volumes for all but the four largest storms of the year (190 m^3, 431 m^3 and 1596 m^3 for the HydroPlant, Boy Scout and Main sub-catchments, respectively) we see that these volumes do not exceed the current debris basin capacities. Therefore, expanded debris basins are not needed to capture this runoff. Given the estimated costs of expanding the debris basins ($700,000 to $1,800,000) and the likelihood that the expanded basins would not accommodate the runoff from extreme storm events, their structural expansion is not warranted. Watershed management recommendations are to:

(1) Revegetate the open slopes surrounding the reservoir (flanking slopes) at a one-time cost of $371,000.

(2) Dewater the debris basins between storms to maintain an available storage capacity of at least 50% ($21,000 capital cost).

(3) Excavate the sediment from each debris basin such that the sediment does not occupy more than 50% of the storage capacity at the beginning of each water year ($20,100 annualized cost, assuming average rainfall).

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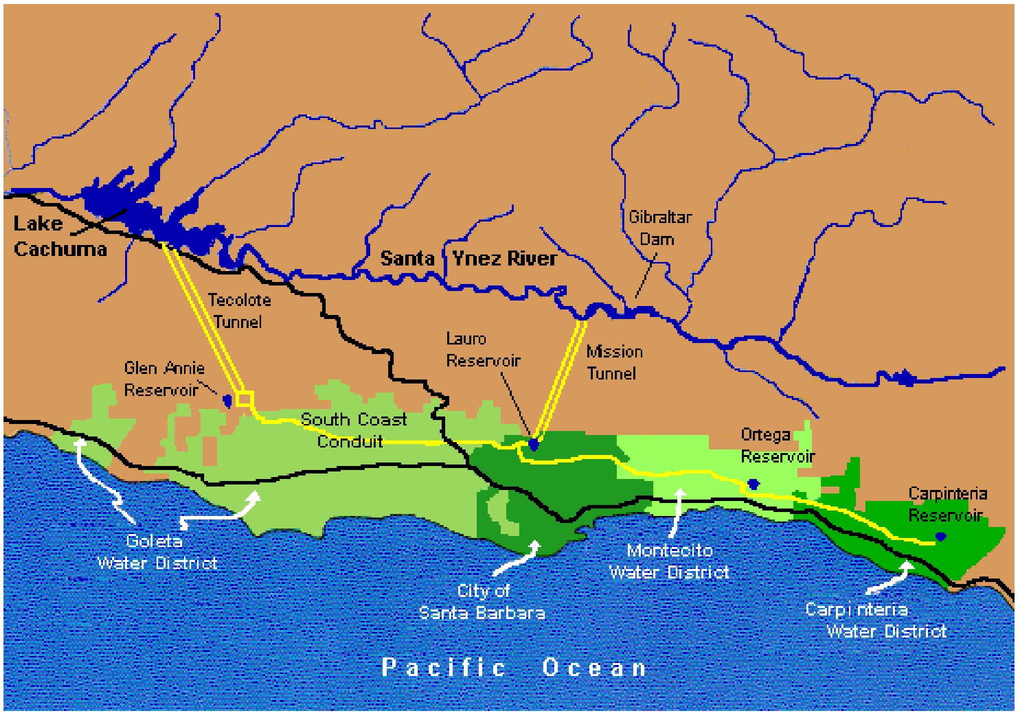
SECTION 1. INTRODUCTION

Nested within the large water supply system of Santa Barbara County, CA is a small reservoir in the coastal foothills called Lauro Canyon Reservoir (see Figure 1.1) (Woodward-Clyde Consultants and CH2M HILL, 1995). In the early 1950s, the U. S. Bureau of Reclamation built Lauro Reservoir to regulate and store water received from both the South Coast Conduit and Gibraltar Reservoir before treatment at Cater Water Treatment Plant (Summers Engineering Inc., 1995).

Figure 1.1 Configuration of Santa Barbara County Water Supply Components



PURPOSE AND NEED OF INVESTIGATION

Lauro Reservoir serves as both a regulatory and storage facility for water from Cachuma Reservoir via the South Coast Conduit and from Gibraltar Reservoir via the Mission Tunnel. The position of Lauro Reservoir in the overall scheme of the Cachuma Project is expected to become more important as water demand increases in the future.

Lauro Reservoir allows the Cachuma Project to meet its objective of maintaining an adequate level of water distribution. The reservoir aids in moderating daily and seasonal fluctuations in peak demands from the city of Santa Barbara (Water and Power Resources Services, 1980). This increases distribution efficiency and reliability to the downstream consumers who depend on water delivered through the South Coast Conduit. With the regulating ability of Lauro Reservoir, water availability is no longer restricted by the limited flow capacity of the South Coast Conduit or the lag time involved with requesting additional water from alternative sources (Thomson; pers. comm., 1999). The necessity for Lauro Reservoir is evident during the summer months when the total peak water demands of the member units (Santa Ynez River Water Conservation District, Goleta Water District, the City of Santa Barbara, Montecito Water District and the Carpinteria Water District) exceed the South Coast Conduit's maximum flow capacity. Under drought conditions, it also maximizes efficiency of distribution by providing an additional backup supply of water (Ahlroth; pers. comm., 1999).

Aside from facilitating operational efforts in meeting fluctuating daily demands, Lauro Reservoir also provides seasonal storage needs and emergency storage for planned and unplanned outages (Ahlroth; pers. comm., 1999). The reservoir temporarily serves as the primary water source for downstream member units during routine maintenance of the South Coast Conduit or the Mission Tunnel. The reservoir is also an important emergency source of water should the Tecolote Tunnel, Mission Tunnel or South Coast Conduit be compromised by events such as geologic disturbance (Almy; pers. comm., 1999).

Water received by Lauro Reservoir is generally of good quality. A typical daily sample is clear with a turbidity measurement of 1 nephelometric turbidity unit (NTU). With normal rains, the turbidity rises to values between 5 and 10 NTU, and several times per year, the turbidity measures over 100 NTU (Thomson; pers. comm., 1999). During a storm in January 1995, a large volume of runoff inundated one of the debris basins and run-off subsequently flowed directly into the reservoir. Following this, Lauro Reservoir was taken off-line because of high turbidity and a positive test for *Giardia* and *Cryptosporidium*. Water samples from the event were extremely turbid, with levels above 4000 NTU (the maximum measurable value). In 1998, similar events occurred causing a maximum turbidity measurement of 324 NTU. Lauro Reservoir was subsequently taken off-line for two months from February 3 until March 10. Cater Water Treatment Plant was able to receive water from Lauro Reservoir after turbidity levels dropped (Thomson; pers. comm., 1999). These events raised awareness of potential water supply issues for the Southern Santa Barbara Coast.

During the summer months, the chance of Lauro being taken off-line for high turbidity levels is negligible. Currently, the system-wide impacts of Lauro going off-line during the winter months are minimal because the peak demand during this period is low enough to be met by the South Coast Conduit (Thomson; pers. comm., 1999). This may not be the case in the future as water demand across the West Coast increases because of population growth. Regardless, a reduction in the efficiency of distribution can result any time Lauro Reservoir goes off-line.

Other water sources such as groundwater and desalinated water are available to lessen the impacts of Lauro going off-line. However, such sources have associated constraints that limit them to function primarily as reserve sources for excessive drought conditions (Woodward-Clyde Consultants and CH2M HILL, 1995). Groundwater supplies are restricted by the possibility of overdraft, slow recharge and the potential for salt-water intrusion. The operational costs of desalination are high and a substantial lead-time is necessary for the Santa Barbara plant to begin supplying water.

Therefore, the Watershed Analysis Group sought to minimize the threat of Lauro Reservoir being taken off-line in the future. In order to do this we set two project objectives,

(1) Identify the spatial distribution of erosion occurring within the Lauro Canyon Watershed.

(2) Present a set of watershed management options that will minimize the flux of sediment into the reservoir.

We decided to focus on sediment flux into the reservoir rather than biological contaminants. Our assumption is that if sediment flux into the reservoir were minimized, biological contaminants that are carried with the sediments would also be minimized.

NOTE ON UNITS

This report presents all measurements and results using SI units. However, many of the equations and models used were derived using English units. In those cases, calculations were performed using the English units and results were then converted into SI units.

Table 1.1 Selected Conversions

Measurement	SI Units	English Equivalents
Volume	1233.5 m^3	1 acre-foot
Flow	1 m^3 min^{-1}	264 gal min^{-1}
	1 m^3 s^{-1}	35.3 cfs
Distance	1 km	0.62 miles
	1 m	3.28 feet
	1 cm	0.39 inches
Area	1 hectare	2.47 acre
Mass	1 kg	0.0011 ton

SECTION 2. BACKGROUND

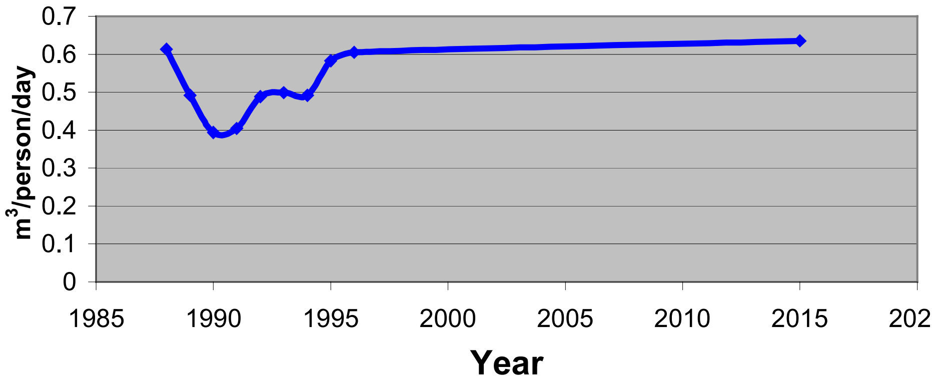
GEOGRAPHIC AND CLIMATIC SETTING

Santa Barbara County is located in an arid coastal plain at approximately 34°N and 120°W along the southwestern coast of California. The average maximum temperature is 21.2°C while the average minimum temperature is 10.5°C. Annual precipitation averages 46 cm yr^{-1}, however in the last 40 years the range spans from 14 to 107 cm yr^{-1}. This pattern periodically leads to drought conditions and a shortage in the available supply of water.

SANTA BARBARA WATER SUPPLY AND DEMANDS

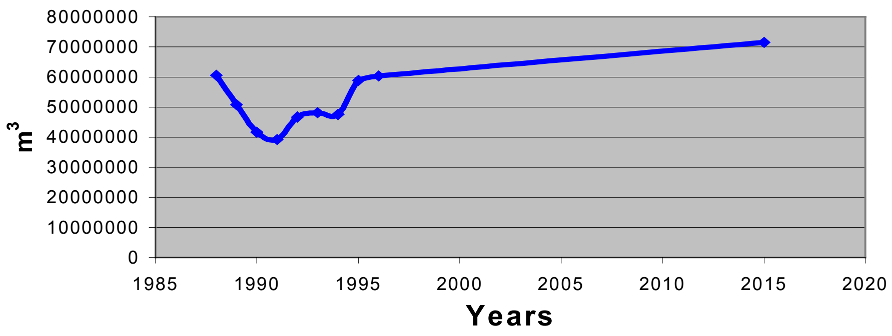
Water demand of the member units has been increasing in both total demand and per capita demand since the end of the most recent drought in 1991. Figure 2.1 shows the decrease in water demand from 1988-1994 during the drought, followed by a gradual, long-term increase in per capita water demand. The graph also includes the projected water use in the year 2015 (Woodward-Clyde Consultants and CH2M HILL, 1995).

Figure 2.1 Average Per Capita Water Use From 1988-1996 and Projected Water Use in 2015



A similar trend is observed in the total water delivered to all the member units for the same period (Figure 2.2). The rate of increase from 1996 to 2015 in projected overall demand is greater than the projected per capita demand. This is a result of the 13% projected increase in population during the same period (Woodward-Clyde Consultants and CH2M HILL, 1995).

Figure 2.2 Water Delivery Totals From 1988-1996 and Projected Totals in 2015 in Southern Santa Barbara County



CACHUMA PROJECT HISTORY AND STRUCTURE

The written history of water on the South Coast predates the establishment of the territory as a part of the United States in 1850. The need to establish a safe and secure supply of water in what is now Santa Barbara County is well documented in this area. The need to establish a consistent supply of reservoirs was recognized as early as 1806 when the first dam and reservoir (estimated to hold 1,900 m^3 of water) were built across Mission Creek (Santa Barbara County Water Agency and Citizens' Committee for Cachuma Water Santa Barbara Calif, 1949).

Construction of the 6 km Mission Tunnel, designed to intercept groundwater seepage and deliver water from Gibraltar Reservoir, commenced in 1904 and was completed in 1912. The tunnel eventually developed an estimated annual seepage of 1.4×10^6 m^3. At this time, the City of Santa Barbara purchased the Santa Barbara Water Company, obtaining water rights to the upper Santa Ynez River basin. Construction of Gibraltar Dam began in 1913 and was completed in 1920 along with the construction of Sheffield Reservoir on the coastal side of the mountains. Gibraltar Dam rose 53 m with an estimated capacity of 17.9×10^6 m^3, providing a safe yield of approximately 6.2×10^6 m^3. The reservoir filled during the winter of 1921-1922. In the years from 1922 to 1925 and 1932 to 1933, it is estimated that 79% of the watershed serving Gibraltar burned leading to future sedimentation problems. In 1936, two debris dams, Mono and Caliente, were built to control sedimentation from tributaries, but by 1941 the capacity of Gibraltar was reduced to 9.9×10^6 m^3. In 1949, Gibraltar Dam was raised by 4 m to mitigate the loss of capacity in the reservoir (Santa Barbara County Water Agency and Citizens' Committee for Cachuma Water Santa Barbara Calif, 1949).

By 1939, it was evident that the various water districts serving the Santa Ynez Valley and the coastal region should organize to facilitate official negotiations concerning water rights. The U. S. Geological Survey was contracted in 1940 to obtain data on surface and groundwater supplies in the region to aid the development of a water program. A countywide plan was deemed necessary in 1941 and the U. S. Bureau of Reclamation was contracted to produce a report aimed at solving the current water supply problems. The initial report, issued in 1944, recommended the eventual construction of seven reservoirs along the Santa Ynez and Santa Maria Rivers. By this time several water districts had been organized - Santa Barbara, Montecito, Carpinteria, Goleta, and eventually Summerland districts serving the coastal region and the Santa Ynez River Water Conservation District serving the Santa Ynez Valley. The Santa Barbara County Water Agency was formed in 1945 as the entity able to enter into contracts with the government to develop water sources and to sell water to member units comprised of the above mentioned water districts (Santa Barbara County Water Agency and Citizens' Committee for Cachuma Water Santa Barbara Calif, 1949).

All required parties tentatively authorized the Cachuma Project in 1948, including the dam, a transport tunnel and a coastal pipeline. Riparian water rights were settled with the Santa Ynez River Water Conservation District and funds were procured through a U. S. Bureau of Reclamation budget request. Subsequently, all parties approved the Master Plan for the Cachuma Project, along with the requisite contracts between the Santa Barbara Water Agency and each member unit. The three main components of the project were the Bradbury Dam and Cachuma Reservoir, the Tecolote Tunnel and The South Coast Conduit (Santa Barbara County Water Agency and Citizens' Committee for Cachuma Water Santa Barbara Calif, 1949).

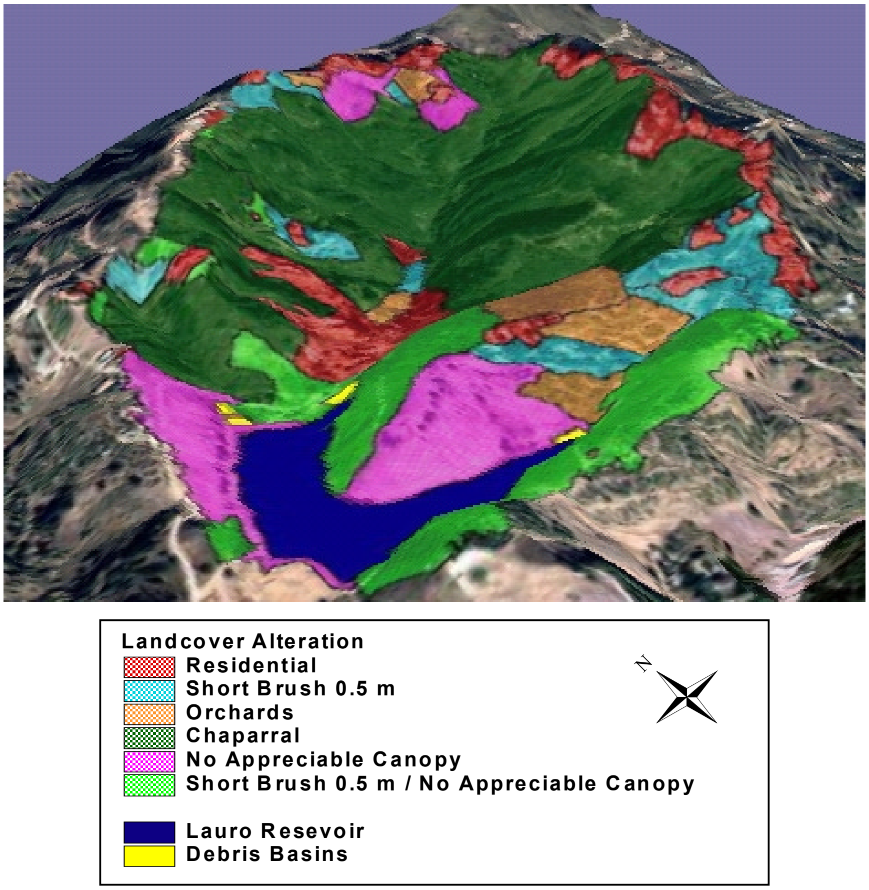
The first phase of construction planned was for the Tecolote Tunnel, a 10.3 km tunnel delivering water from the future Cachuma Reservoir, opposite the mouth of Santa Cruz Creek, to the West Fork of Glen Annie Canyon in Goleta. With a height of 2 m, the tunnel was expected to deliver 2.8 $m^3 s^{-1}$ of water. Eventually the South Coast Conduit, a high-pressure pipeline, was constructed to connect the Tecolote Tunnel to four regulating reservoirs along the coast. The 45 km conduit, with a capacity of 2 $m^3 s^{-1}$, was built to service the Goleta, Montecito, Summerland and Carpinteria Water Districts as well as the City of Santa Barbara (Santa Barbara County Water Agency and Citizens' Committee for Cachuma Water Santa Barbara Calif, 1949).

Gibraltar Dam and Reservoir are still owned and operated by the City of Santa Barbara. The surrounding watershed encompasses 56,000 ha. The Mission Tunnel transfers water held in the Gibraltar Reservoir to Lauro Reservoir. The water is then released to Cater Water Treatment Plant at a rate of $1.5 \times 10^5 m^3 d^{-1}$. After treatment, the water may be utilized by the City of Santa Barbara or released into the South Coast Conduit for delivery to Sheffield Reservoir (City of Santa Barbara), Ortega Reservoir (Montecito Water District) and Carpinteria Reservoir (Carpinteria Water District) (Summers Engineering Inc., 1995).

LAURO CANYON WATERSHED

Lauro Canyon Watershed has a drainage area of 110 ha. The watershed is underlain by the Rincon shale formation. A combination of chaparral and coastal sage scrub are the dominant vegetation in the watershed, although there are 5.7 ha of avocado orchard within the watershed. Nearly 80% of the watershed is privately owned with parcel size varying from 0.8 to 12 ha. There are 20 to 25 homes within the drainage area, but topography and lack of access restricts development of most of the privately held parcels. The watershed is the most impacted by human disturbance in the Cachuma Project water supply system (Summers Engineering Inc., 1995).

Figure 2.3 Land uses within Lauro Canyon Watershed



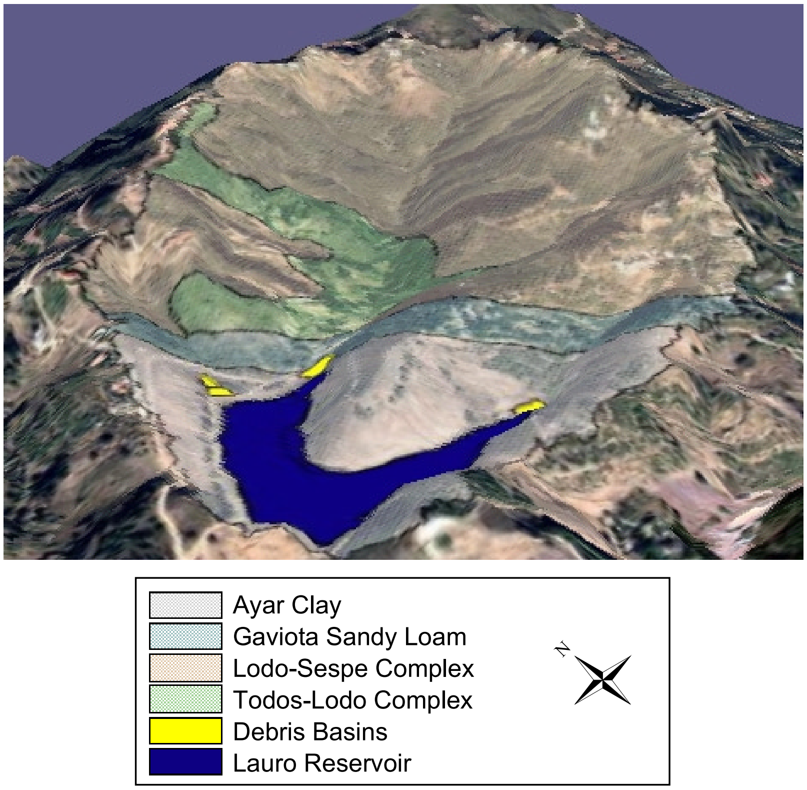
The reservoir has a maximum depth of 25 m and a storage capacity of 7.9×10^5 m^3. The normal surface water elevation is 197 m and the watershed rises steeply to an elevation of 305 m above sea level over the course of approximately 1.6

km. Lauro Reservoir receives an ephemeral stream, Lauro Canyon Creek, which enters from the northwest of the reservoir. Typically, a minor amount of surface runoff occurs on an annual basis from the watershed, but three debris dams located around the reservoir intercept most of this flow. However, during high flow events, the debris basins can be inundated and some local runoff may enter the reservoir.

SOIL TYPES

Data on the underlying soil types consisting of Todos-lodo Complex, Lodo-Sespe Complex, Ayar Clay and Gaviota Sandy loam were downloaded from the SSURGO database (National Cartography and GIS Center, 1995) and are described qualitatively below. This information is directly based on the Soil Survey of Santa Barbara County, CA (USDA, 1981). Much of the original information used to describe soil characteristics is not quantitative. A glossary of applicable terms is provided in Appendix A (page A-1). Figure 2.4 shows the soil types.

Figure 2.4 Soil Types



Ayar Clay: Arnold Series

Ayar clay is a member of the Arnold series soils, which are common in the foothills along the Pacific Ocean. They are somewhat excessively drained soils existing on slopes that vary from 9% to 75% (approximately 5° to 36°). Soils are the product of weathered soft sandstone. Natural vegetation on south facing slopes includes annual grasses, forbs, scattered oak trees and sagebrush, while on the north facing slopes dense brush and oak trees rise above a sparse annual grass and forb understory. Common uses on these soils include urban development, range and orchards or they may be left undisturbed. The watershed specifically contains AhF2 - Ayar clay on 30% to 50% (approximately 16° to 26°) slopes, which are eroded. These soils are rapidly permeable with an available water capacity of 14 to 25 cm. The effective rooting zone is 100 to 150 cm. High erosion hazard is associated with rapid runoff. The soil is specifically used for range and orchards.

Gaviota Sandy Loam: Gaviota Series

Gaviota series soils are somewhat excessively drained soils located on uplands (45 to 450 m in elevation) with slopes from 9 % to 75% (approximately 5° to 36°), however they are, unlike the Arnold series, formed form hard sandstone. Smoother slopes are vegetated with annual grasses, forbs and oak trees, while steep slopes are generally chaparral brush. The specific soil type is GaG – Gaviota sandy loam on 30% to 75% (approximately 16° to 36°) slopes. This narrow band of soil runs parallel to the coastline. These soils have an available water capacity of 2.5 to 8 cm and effective rooting zone of 25 to 50 cm. High erosion hazard is associated with rapid runoff. The soil is generally used only for range.

Lodo-Sespe Complex: Lodo Series

The Lodo series on the foothills of the Santa Ynez Mountains (90 to 610 m in elevation) are also somewhat excessively drained but are formed by the weathering of sandstone or shale bedrock. The slopes range from 30% to 75% (approximately 16° to 36°) and are generally covered with chaparral brush species such as ceonothus and laurel. The available water capacity is 2.5 to 8 cm with an effective rooting zone of 15 to 50 cm. The soil is generally left undeveloped or used as range. The specific soil is LcG – Lodo-Sespe complex on 50% to 70% (approximately 26° to 35°) slopes. The complex is approximately 60% Lodo (high side slopes and ridge tops) and 30% Sespe (low side slopes) with smaller fraction of other soil types. The Lodo portion has very high erosion hazard and very rapid runoff. The Sespe has medium runoff, 12 to 18 cm available water capacity and a moderate erosion hazard.

Todos-Lodo Complex: Todos Series

Todos series are well-drained soils in the uplands (60 to 425 m in elevation) with slopes ranging from 9% to 50 % (approximately 5° to 26°). Soils form from weathered sandstone or shale bedrock. Chaparral brush dominates on steeper slopes with annual grasses, forbs and scattered oak trees inhabiting shallower slopes. Permeability is low. Soils are generally left undeveloped or used as range but lesser slopes may contain orchards and urban development. Specifically the watershed contains TdF2 – Todos-Lodo complex on 30% to 50% (approximately 16° to 26°) slopes, eroded. The complex is approximately 60% Todos (low side slopes) and 30% Lodo (high side slopes and ridge tops). The Todos portion has available water capacity of 15 to 20 cm and a high erosion hazard. The effective rooting zone is 100 to 127 cm. The Lodo portion has very high erosion hazard and very rapid runoff.

VEGETATION

Most of the undeveloped open space of the Lauro Canyon Watershed consists of chaparral and coastal sage shrub (Summers Engineering Inc., 1995). The individual species of plants within the watershed are unknown, as there is no record of a detailed biological inventory performed on the site beyond a sanitary survey performed in 1995. In the 1960s, Boy Scouts planted several pine trees along the reservoir (Rees; pers. comm., 1999). Furthermore, six avocado orchards, totaling 5.7 ha, grow on individual parcels along the creeks and up-slope from the reservoir (Summers Engineering Inc., 1995). The largest orchard is found directly above the southern tongue of the reservoir (see Figure 2.3,page 7). The watershed also has 12.1 hectares of open slopes, primarily along the peninsular region on the northeastern side of the reservoir and on the slopes above the northern tongue of the reservoir (see Figure 2.3, page 7). Moreover, 11 ha of road cuts and residential clearing have left some of the watershed bare of vegetation, especially on the property north of the reservoir where a landowner has cleared the area (Rees; pers. comm., 1999) (Figure 2.5).

Figure 2.5 Cleared Area North of Reservoir

DEBRIS BASINS

Lauro Reservoir's Current Debris Basin Design

According to the Cachuma Operations and Maintenance Board (COMB), who is responsible for managing the reservoir, the problem of reservoir contamination from watershed runoff was never considered in the original design plans (Rees; pers. comm., 1999). Subsequent studies also failed to address the sedimentation problems of Lauro Reservoir and did not provide remediation alternatives. As the problem of runoff contamination became apparent, attempts at minimizing its effects came in piecemeal steps that culminated in the rudimentary drainage system that is in operation today (Dunlap; pers. comm., 1999). Three debris basins, with capacities ranging from 1,410 to 2,760 m^3, catch the runoff from the three sub-catchments of the Lauro Canyon Watershed (see Table 2.1). A drainage ditch runs parallel to the northwestern shore, approximately 5 m above the surface of the reservoir. The Main and HydroPlant debris basins are located at the tip of the reservoir's northern tongue, and are responsible for controlling runoff flows from the largest (68.3 ha) and the smallest (6.6 ha) of the sub-catchments, respectively (Figure 4.1, page 30). The third basin, the Boy Scout basin, is situated at the end of the southern tongue of the reservoir, and collects runoff from the mid-sized sub-catchment (11.6 ha) (see Figure 4.1, page 30). These basins were excavated in 1960 by COMB (Rees; pers. comm., 1999). No hydrological surveys of the sub-catchments or specific design plans were ever drafted for these basins.

Table 2.1 Current Debris Basin Capacities

Debris Basin	Volume (m^3)
Hydro-Plant (total)	1,410
Boy Scout	2,050
Main	2,760

All the basins have unlined sides and earthen embankments that have no soil stabilizing accessories (Dunlap; pers. comm., 1999). With the exception of the Main basin, which has a principal spillway, none of the basins have any outlet controls. The only drainage system that is currently in place services only the northern slope and the Main and HydroPlant basins. The drainage ditch is a paved road that does not always route the runoff effectively.

The Boy Scout basin is most susceptible to overflowing. During an average rainfall season, the basin will frequently become inundated with runoff (Dunlap; pers. comm., 1999). Although overspill occurs less often for the Main and HydroPlant basins, these facilities do not have the capacity to contain runoff for a 10-year storm, the standard by which most debris basins are designed (Debo and Reese, 1995). The basins have limited trapping efficiencies because of their physical dimensions and storage capacities. Sediment removal depends on the settling characteristics of the suspended particles and the ratio of basin surface area to watershed discharge (Colorado Department of Highways in cooperation with the U.S. Department of Transportation, 1978). Sediment removal efficiency of a facility can be improved by having a length to width ratio of 2:1. The trapping efficiency of the basins is limited by their small size. Despite their design limitations, the primary reason why the basins have been ineffective lies in the fact that the sediments are mainly comprised of fine silt, which has a very low settling velocity. Effective settlement of fine particles requires a large basin with a large surface area to discharge ratio for removal through physical means (Colorado Department of Highways in cooperation with the U.S. Department of Transportation, 1978).

Current Excavation Practices

COMB has no set schedule for cleaning out the debris basins. Currently the basins are cleaned out *as needed*, usually when they appear to be approximately 75% full of sediment. The time to reach this capacity varies. For example, the drought that occurred in Southern California from 1984 to 1990 deposited little or no sediment in the basins. On the other hand, the intense storms of water year 1994/95 filled the basins in one season (Rees; memo, 2000).

COMB has limited information on the volume of sediment removed from the basins or the associated costs. Until 1993, sediment was removed by contractors who would excavate the amount of sediment they wanted at no cost to COMB. During the 1994/95 and 1997/98 storm seasons, COMB acquired more accurate estimates of volume and cost so they could obtain compensation from FEMA to excavate the basins (see Table 2.2).

Table 2.2 December 1998 Debris Basin Excavation Statistics

Debris Basin	Volume Sediment Excavated (m^3)	Cost of Excavation
Main	2,800	$21,724
Boy Scout	2,800	$22,515
Hydro-Plant	1,200	$10,690

SECTION 3. MANAGEMENT ALTERNATIVES

REVEGETATION STRATEGIES

BENEFITS OF VEGETATION

To reduce sediment mobilization within Lauro Canyon Watershed, we investigated the management alternative of vegetating bare and poorly stabilized slopes. Proper vegetation of hillslopes prevents erosion by absorbing rainfall energy and preventing soil detachment by raindrop splash. Plant root systems restrain soil particles and aboveground vegetation detains sediment carried in runoff by increasing surface roughness and slowing the flow velocity. Vegetation also maintains soil porosity and permeability, delaying the onset of surface runoff (Gray and Sotir, 1996). The main mechanism by which sediment from the surrounding watershed enters Lauro Reservoir is surface erosion. Herbaceous vegetation and grasses are more effective at reducing erosion than woody vegetation because they provide a dense, stable ground cover. Additionally, grass or herbaceous vegetation provides one of the best protections against rain and wind erosion and can decrease soil loss caused by rainfall up to 100-fold (Gray and Sotir, 1996). Deep rooted, woody vegetation is more effective for preventing mass wasting (Sotir, 1998).

SITE ANALYSIS

Before revegetation of the Lauro Canyon Watershed can be implemented, the site must be analyzed (Wilken; pers comm., 2000). Given the time and resource constraints of this project, a comprehensive environmental assessment could not be performed. A site analysis, or biological inventory, entails assessing climatic variables, the native vegetation, the topography, and the physical and chemical properties of the soil.

Climatic variables of an area are important because of their effects on plant growth. Some of these variables include air temperature averages and fluctuations; maximum ground surface temperature, length of growing season, rainfall totals and seasonal distributions, and drought duration and time of year (Gray and Sotir, 1996). While most of this general information can be found in county government records or the National Weather Service, assessment of the microclimate, such as ground surface temperatures, must be obtained through site analysis.

Determining the native vegetation in an area that is undergoing revegetation is critical. Native plants have adapted to slope, aspect, climate, elevation and soil type; they are better adapted to local conditions in the Lauro Canyon Watershed. Use of existing native plants is advantageous because it will allow the transplant of live plants or branch cuttings. The use of native plants encourages natural invasion by the surrounding plant community, which would help ensure sustainability of the transplanted species (Gray and Sotir, 1996).

The various topographic areas of a watershed have different climate and soil conditions. For example, low topographic areas tend to have cooler soil temperatures and greater soil moisture, while higher areas have warmer soils that contain less moisture. Drought-tolerant grasses are better suited for higher drier topographic areas whereas less tolerant trees and shrubs persist in lower wetter topographic areas (Gray and Sotir, 1996). The general soil types within Lauro Canyon have been previously determined by the U.S. Department of Agriculture, Natural Resources Conservation Service (refer to "Figure 2.4", page 8). However, the site analysis must include specific physical and chemical soil properties such as grain size, structure, density, depth to hardpan, water repellency, moisture, pH, nutrient level, water salinity, possible toxic conditions and exchangeable sodium levels (Gray and Sotir, 1996).

Selection of Vegetation

Site analysis identifies plants suitable for erosion control. The California State Department of Conservation Resources Agency suggests that the plants chosen to control erosion must be self-sustaining, require little or no maintenance and not increase the fire hazard to the area (California State Department of Conservation Resources Agency, 1978). Suitable plants may include either species native to the Lauro Canyon Watershed or exotic. The use of exotic plant species is a controversial issue because of the tendency for exotics to spread and out-compete surrounding native vegetation. In some instances, exotic species survive better than the native plants. For example, exotics grow better on highly disturbed slopes or man-made slopes where infertile soils are exposed (Gray and Sotir, 1996). Some exotic species show little or no aggressiveness or colonizing ability. Some species, such as the vetiver grass, are non-flowering, non-seeding and only replicate by vegetative propagation (National Research Council (U.S.) Board on Science and Technology for International Development, 1993). Regardless of species selected, bioengineers have suggested applying a grass seed mix to the site to increase hydraulic stability as well as improve aesthetics. Trees and shrubs could be planted within watershed to enhance appearance (Sotir, 1998).

Revegetation Methods

Revegetating the entire watershed would be time-consuming and costly. Using a computer model (see "Modeling", page 28) to determine critical areas in the Lauro Canyon Watershed, we found that the avocado orchards, the open slopes and the steeper slopes had the highest erosion rates. Steep slopes were found throughout the watershed, particularly in the upper boundaries. These critical areas are relatively inaccessible because of dense groves of chaparral and their location behind residential properties, making access difficult. Therefore, we deemed the steep slopes infeasible for revegetation, but recommended that these slopes receive further and more detailed evaluation in the future (see "Additional Revegetation Opportunities", page 64). We focused our attention on the avocado orchards and the open slopes. Using the land use map (Figure 2.3, page 7), we calculated the area of avocado orchards to be 5.7 ha and the open slopes to be 12.1 ha.

Generation of cost estimates and revegetation scenarios for the open slopes was straightforward because these slopes are within COMB's property. There will be no land acquisition costs, subsidy costs or resistance from property owners to limit the scenarios. However, because the avocado orchards are under private ownership, we developed revegetation scenarios that took into account the increased costs and decreased flexibility encountered when working with private property. We considered removing the trees and revegetating with grasses. Removal of the trees would require either acquiring the land or annually subsidizing the owners for the loss of their avocado trees. Estimations for the cost of acquiring the land within the watershed were derived from the Santa Barbara County Tax Assessor's value of one of the properties ($80,900 ha^{-1}). Given the 5.7 ha of avocado orchards, land acquisition would cost approximately $457,000. The costs of the annual subsidy were roughly derived, as orchard land is usually bought and not leased or rented (Kalijian; pers. comm., 2000). Therefore, we used the local paper to determine an approximate rental rate of houses in the Mission Canyon area (the next canyon over from Lauro Canyon). We estimated that a house on a one-acre lot rent for approximately $5,000 acre^{-1} month^{-1} (Santa Barbara News Press, 3/9/00). We then estimated that without the house, the land would rent for approximately 40%, or $2,000 acre^{-1} month^{-1} ($5,000 ha^{-1} month^{-1}) (Combs; pers. comm., 2000). The annual subsidy would be approximately $342,000 for the 5.7 ha. We found that the above two scenarios were infeasible given the large cost involved and the possible resistance that would be encountered by the orchard owners (Table 3.1).

Table 3.1 Orchard Removal Associated Costs

	Initial Project Costs	Annual Costs
Land Acquisition	$457,000	$0
Land Easement (subsidy)	$342,000	$342,000

We determined that a more feasible option for the avocado orchards would be to leave the trees intact and stabilize the bare soil. We considered three means of stabilizing the soil, 1) vegetating with grasses, 2) applying mulch to the bare soils and 3) allowing leaf litter to accumulate under the trees.

The first option requires vegetation of the open slopes with short native grasses or exotic grasses that can be mowed (Faber; pers comm., 2000). Short, easily mowed grasses are important because taller grasses and “weeds” can harbor pests such as rats, squirrels, gophers and snails, which damage the leaves and the fruit and spread diseases (Koch, 1983). Clover grass was suggested by a local Santa Barbara avocado grower to stabilize the soil (Giorgi; pers. comm. 2000).

The second option of applying mulch to the bare soil is viable, but would be a temporary stabilizing measure to reduce overland flow until the grasses have reached maturity. In areas lacking good vegetative cover, mulch could be used to stabilize the soil permanently (Faber; pers. comm., 2000). This would require the periodic reapplication of mulch to replace decayed material (Koch 1983). Local farmers have recommended wood chips as mulch because they are not as attractive to pests and they have lower fire hazard potential than some mulch material (Giorgi; pers. comm. 2000).

The third option of allowing litter to build up would slow erosion because mature avocado trees produce a large amount of leaf litter and can create their own mulch layer underneath the trees (Faber; pers. comm., 2000). This can be used in orchards that lie on steeper slopes (Cadwell; pers. comm. 2000). However, like grasses, it must be kept shallow enough to prevent harboring pests. When leaf litter is lacking, the natural tree mulch can be used in conjunction with introduced mulch as described above (Faber; pers. comm., 2000).

SITE PREPARATION

Methods for preparing the soil, seeding, slope stabilization and maintenance of the two sites are found in the *Erosion and Sediment Control Handbook* (California State Department of Conservation Resources Agency, 1978). Soils should be “roughened” to a depth of 5 cm with a raking device to prevent seed loss. However, this practice could destabilize soils on steep slopes.

We determined that the most effective form of seeding for this area would be through hydroseeding, a process of spraying seed, mulch and fertilizer using a pressurized jet of water. This was considered the best method for slopes too difficult to manually seed (Lancaster, 1996).

Protective coverings, such as mulches, wood products and fiber mesh prevent soil erosion while the plants are taking root (California State Department of Conservation Resources Agency, 1978). Given these factors, jute fiber mulch should be considered because it has a medium-high effectiveness in both immediate erosion protection and in establishing vegetation.

The plants chosen for revegetative efforts should require little or no maintenance. Although this is true when the plants have established themselves, while they are taking root, the ground must be kept moist (California State Department of Conservation Resources Agency, 1978). Thus, we concluded a temporary drip irrigation system would be needed to keep the mats and soils moist until the seeds were established.

VEGETATIVE COSTS

This section discusses the estimated costs associated with the revegetation strategies. It must be noted that these costs are preliminary estimates used only to compare relative costs of all the management alternatives. These costs should not be viewed as accurate values on which to base budget allocations for future revegetation endeavors in the Lauro Canyon Watershed.

Project Initiation Costs

In order to calculate the costs for the revegetative methods describe above, we used the most current national construction market cost data (RS Means, 2000) to provide bare material, labor and equipment costs (plus 10% for profit and overhead). The area to which each alternative would be applied was multiplied by the total cost per unit for each method. For instance, the total per unit cost for a slope stabilizer, (jute mesh), was $1.33 m^{-2}. The total area for the open slopes in the watershed was 121,000 m^2 (12.1 ha). Multiplying these two numbers gave the total cost of laying jute on the entire open slope, $161,000. This procedure for calculating costs was used for each of the vegetative methods (soil preparation, seeding, slope stabilization and irrigation) for each of the critical areas (for cost calculations see "Revegetation Alternatives - Cost Estimate Calculations", page B-1).

Operation and Maintenance Costs

As stated previously, the California State Department of Conservation Resources Agency suggests that plants chosen to establish vegetative protection for erosion control must require little or no maintenance. This would be important for the Lauro Canyon Watershed, as its terrain and proximity to residential properties would preclude COMB from periodic maintenance of the vegetation. Beyond the initial maintenance of watering the seedlings until they become established, there should be little or no maintenance required. Therefore, no operation and maintenance costs were considered for the open slopes. However, the avocado orchards would require periodic maintenance such as mowing, applying mulch or monitoring litter accumulation. Total costs for each revegetative management strategy are presented in Table 3.2.

Table 3.2 Total Costs of Revegetation Strategies

Strategy	Total Capital Costs	Annual O&M Costs
Open Slopes Revegetation		
Open Slopes Contained in Sub-Catchment	$58,900	N/A
Open Slopes Flanking the Reservoir	$371,000	N/A
Total	**$430,000**	**N/A**
Avocado Orchards - Ground Cover Alteration Options		
1) Grass	$129,000	$16,800
2) Mulch	$125,000	$125,000
3) Leaf Litter	N/A	$21,500

DEBRIS BASIN ENLARGEMENT

This section describes the criteria and standards that were used in estimating the enlargement of the three debris basins. All of the derived values and measurements are rough approximations. They were used as general guidelines in assessing the projected basin improvements and their associated costs, for the comparison of these alternatives. These values do not represent accurate numerical descriptions to be used in design specifications.

CAPITAL COSTS

Cost Variables and Construction Methods

Unless otherwise specified, all of the material, equipment, labor, overhead and profit that have been used to estimate capital costs are derived from the most current national construction market cost data (R.S. Means, 2000). Various local and non-local construction and engineering firms were consulted for advice on implementing appropriate methods. Construction methods and associated equipment that factored into the costs are listed in Appendix Table C.1.

Expanding the three basins would involve excavation, spoil material hauling and disposal, and wall stabilization. In estimating costs, we assumed that all three basins would use the same equipment, labor and material (Appendix Table C.1). Of the jobs, dewatering and site clearing were only factored into the total costs for enlarging the Main debris basin. Unlike the other basins, the Main debris basin is the only one that maintains a permanent pool of water and would require that it be drained before expansion. The Main basin sits in a natural depression approximately 3 m deep. In its current size, the Main basin occupies less than one half the total area of the depression. Expanding the basin to occupy the entire depression would require the vacant areas in the depression be cleared of debris, shrubs and trees. The site characteristics of the other two basins do not call for such site preparations before expansion.

Enlarging the Main basin requires relocating the current earthen embankment approximately 65 m from its current position. Appendix Table C.2 lists the construction activities and equipment that we incorporated in estimating the costs for a new earthen embankment. These jobs include keying in a trench to increase embankment stability, purchasing and hauling filler material to the site and filling and compacting the embankment. We felt that relocating the embankments of the HydroPlant and Boy Scout basins would be unnecessary because, unlike the Main basin, they are not bounded by a steep hillslope or road that limits expansion to only one direction.

Design Assumptions and Estimates of Expanded Basins

The initial construction cost estimates are based upon the estimated dimensions of the enlarged basins, which we determined from the site constraints and the information regarding the current basin dimensions provided by COMB.

Estimation of the dimensions for the enlarged basins was accomplished by approximating the actual basin dimensions using the aerial image draped over the 3 m DEM (Penfield and Smith Engineers, 1995; Curtis, 1998). From this, a maximum allowable area of expansion was then outlined and measured for each of the basins. Their storage volumes were estimated from the runoff values of the 25-year storm derived from the Rational Method (see "Rational Method Comparison of Runoff Estimates", page 42) and were based on a total peak-flow average duration of one-hour. The basin depths were approximated using the prismoidal formula:

$$V = {}^{1}/_{3} \times [A_1 + (A_1 \times A_2)^{1/2} + A_2] \times D \qquad (3 - 1)$$

Where: V = volume
D = depth
A = area

The surface areas of the basin floors were assumed to be 25% smaller than the surface areas at the embankment crests (Table 3.3) to account for an approximate 1:1 (horizontal to vertical) side slope-factor of the basin walls.

Table 3.3 Current and Enlarged Debris Basin Dimensions

Dimensions	Main		Boy Scout		HydroPlant		
	Current	Enlarged	Current	Enlarged	Current		Enlarged
					Small	Large	Combined
Shape	Triangular	Triangular/ Trapezoidal	Rectangular	Trapezoidal	Rect.	Rect.	Trapezoidal
Length (m)	59.4	125	43.3	43.3	11.0	29.9	40.8
Depth (m)	2.44	6.71	1.83	4.88	1.52	2.44	3.04
Width 1 (m)	38.1	51.8	25.9	85.3	21.3	14.9	21.3
Width 2 (m)	-	-	-	14.3	-	-	14.9
Area 1 (m^2)	-	3,250	-	871	-	-	741
Area 2 (m^2)	-	2,430	-	653	-	-	556
Length:Width ratio	1.6	2.4	1.7	1.7	0.5	2	1.9
Storage capacity (m^3)	2,760	18,700	2,050	3,800	321	1,088	2,053
% Increase in Capacity	-	677	-	185	-	-	146

Area 1 is the surface area of the water at the dam crest.
Area 2 is the surface area of the basin floor.
Storage capacities represent the 25-year storm peak flow for a one-hour duration.

We used the estimated dimensions to approximate the extent of the construction jobs, which were factored into our capital cost assessments of the expanded basins. AAppendix Table C.3 lists the sizes of the activities that have been estimated for each of these construction jobs. The scales of the jobs involved with constructing the embankment for the Main basin are listed separately in Appendix Table C.2.

Cost Estimates

Appendix Table C.4 lists the estimated costs for completing each of the construction jobs that were considered in expanding the basins. The construction jobs listed for the Main basin also include jobs associated with building the embankment. The Quantity column represents the estimated total amount of units for each construction job. The Daily output values for each construction job represents the maximum total number of units that could be completed with the given equipment and crew during an 8-hour workday. The expected completion times for each job are expressed in the Durations column and were calculated by dividing the quantities by the daily outputs. The costs for each job are expressed in terms of per unit costs, hourly costs and daily costs, any of which could be used to estimate the total costs for each job. The last two columns represent the lower and upper bounds for the estimated total costs for each construction job and the overall expansion. Overhead and profit, engineering services, site sample analyses and unavoidable uncertainties in cost estimates can increase the overall expansion costs for each basin. We have accounted for this by adding a 30% margin to the overall expansion costs of each basin.

Enlarging the Main basin to meet the runoff volume from the 25-year design storm (1-hour peak flow duration) would require that it be expanded by 15,900 m^3. The site has approximately 7,700 m^3 of available space and would require an additional 8,200 m^3 of excavated space and the removal of the current embankment to meet the expanded capacity. An extra 1,400 m^3 would have to be excavated to prepare the foundation of the new embankment. 10,800 m^3 of material would have to be excavated at a cost of approximately $33,200. The estimated hauling costs for removing and disposing the excavated material would be $155,600. Disposing the excavated material to a disposal site costs an average of $50 per truckload. The hauling costs could increase to $202,300 if soil swelling and wetness are taken into account. These factors reduce truck carrying capacities and subsequently increase the number of trips per truck. The largest source of cost for the construction of the embankment would come from purchasing and hauling the filler material. We assumed that the excavated soil would inappropriate for use in the embankment construction, given the potential for it to be wet and of poor quality. Therefore, 3,500 m^3 of embankment material would have to be purchased and brought in at a cost of between $92,600 and $101,700. The total costs for building the embankment would vary between $99,400 and $113,300.

Given its low elevation and proximity to the reservoir shoreline, it is possible that below ground infiltration from the reservoir would be a problem, especially since the storage facility calls for a depth of 6.7 m (Table 3.3). If infiltration were a problem, the basin would have to be lined with concrete. At $765 m^{-3}, lining the entire basin with a 30 cm layer of concrete would have a cost of approximately $923,000. Altogether, the total costs expanding the Main basin would be between $573,000 and $1,660,000.

Combining the two existing HydroPlant basins into one large basin and excavating it to a depth of 3 m would enlarge the basin to its targeted volume of 3,833 m^3. The total amount of excavated material would be approximately 644 m^3 and would cost between $11,000 and $14,000 to excavate and haul depending on the degree of soil swelling and wetness. The Boy Scout basin would cost between $30,600 and $38,100 to excavate and haul 1,750 m^3 of spoil to a disposal site. For both basins, the hauling costs are much larger than the excavation costs and represent a significant proportion of the total costs ($9,300-$12,000 for the HydroPlant basin and $28,200 -$32,800 for the Boy Scout basin). At a cost of $27,500, soil stabilization would account for most of the total costs of the HydroPlant basin. The Boy Scout basin would have an estimated cost of $46,100 for stabilizing its walls and would cost about as much as the disposal of the excavated spoil. Both basins are assumed to be high enough above the reservoir to prevent infiltration. As such, we decided that it would not be necessary to line these basins with concrete and that stabilizing their banks would be adequate. The total cost for expanding the HydroPlant basin was estimated to be between $50,400 and $54,000 while the total cost for enlarging the Boy Scout basin was approximated at around $76,700 and $84,200.

Altogether, the costs for expanding all three basins were estimated to fall between $700,000 and $1,800,000 (see Appendix Table C.4).

MAINTENANCE COSTS

The basins should always be inspected for erosion and embankment slumping after each significant rainfall event. Sedimentation and runoff rates ultimately determine the maintenance costs for each basin. However, establishing maximum allowable sediment accumulation levels will also influence their maintenance costs. The estimated maintenance costs serve to support qualitative decisions with respect to choosing management options.

Sediment Removal

The only activities that were considered in determining sediment removal costs dealt with excavating, hauling and disposing the sediments. To simplify our cost analysis, we used the same parameters (i.e., unit costs, equipment used and overhead and profit) that we assumed for estimating the excavation, hauling and disposal costs for expanding the basins (Appendix Table C.4). We also factored soil swelling and wetness into our total excavation costs.

The modeled results for the 1995/96 water year indicates that the Main, HydroPlant and Boy Scout basins would accumulate 630 m^3, 73 m^3 and 121 m^3 of sediment, respectively (see "Sub-Catchment Sediment Loss", page 38). Because 1995/96 was an average rainfall year, we used these values as an average baseline to estimate the average costs of maintaining each of the basins.

The recommended level for sediment removal is normally set at 50% of the maximum design storage capacity of a debris basin. Using this as a threshold, we estimated a 2-year accumulation period for sediments to fill 50% of the Main basin's current maximum storage capacity (1,381 m^3). We further estimated that it would cost $31,400 to remove (Table 3.4). For the current HydroPlant basin, we estimated that it would take 10 years to fill to half of its maximum capacity (705 m^3) and removing it would costs approximately $16,000 (Table 3.4). The amount of time that we estimated for sediments to fill one-half of the Boy Scout basin's current capacity (1,025 m^3) was 8 to 9 years, and its removal costs was estimated at $23,300.

Table 3.4 Sediment Removal Costs Assuming Accumulation to 50% Capacity

	Basin					
	Main		**HydroPlant**		**Boy Scout**	
	Current	**Expanded**	**Current**	**Expanded**	**Current**	**Expanded**
Average Sedimentation Rate (m^3 yr^{-1})	630	630	73	73	121	121
Sediment Volume (m^3)	1,380	9,340	705	1,030	1,025	1,920
Accumulation Time (yr)	2	15	10	14	8-9	16
Removal Cost	$31,400	$212,000	$16,000	$23,400	$23,300	$43,600
Removal Time (d)	1-2	9-10	<1	1-2	1-2	2
Annualized Cost	$15,700	$14,200	$1,600	$1,670	$2,740	$2,730

The costs include excavation, hauling and disposal fees of $50 per truckload and are based on the same conditions and equipment that were considered in estimating the capital costs. The additional hauling costs of soil expansion and water content have also been factored into the costs.

Under the same management practice, we found that the costs for maintaining the enlarged basins increased. At 50% of its maximum storage capacity (9,340 m^3), the costs of removing the sediments was estimated at $212,600 and would require approximately 9 to 10 days to complete. Although the maintenance costs were higher, the accumulation period also increased to approximately 15 years. The same was true for the expanded HydroPlant basin for which we estimated a 50% accumulation period of 14 years (1,030 m^3) and a removal cost of $23,400. The cost for removing a volume of sediment equal to 50% of the maximum capacity of the enlarged Boy Scout basin (1,920 m^3) was estimated at $43,600 and the accumulation period would be 16 years (Table 3.4).

As expected, the costs for maintaining the expanded basins are much higher than the maintenance costs associated with the current basins. However, after annualizing these costs over their respective accumulation times, we found that their annual costs do not vary significantly because the sediment deposition rates are assumed to remain constant.

Another maintenance strategy that would decrease the risk of basin overflow would be to limit sediment accumulation within each of the expanded basins to levels that allow the basins enough free storage to contain runoff from a 10-year design storm. We compared the runoff volumes from the 10-year storm to the storage volumes of each of the expanded basins, which are based on the 25-year design storm. It showed that, for the Main basin, the volume of runoff from a 10-year storm occupies approximately 80% of the basin’s maximum storage (Table 3.5). Therefore, the sediment accumulation limit for the Main basin would be at 20% of its maximum storage (3,740 m^3). It would take an estimated 6 years for the sediment to accumulate to 20% of the Main basin's storage capacity. The total cost for removing the sediments from the Main basin would be $50,700, or $8,400 annualized.

Table 3.5 Maintenance Costs Associated with Sediment Removal Plan based on Containment of 10-year Storm

	Main	HydroPlant	Boy Scout
Runoff volume (m^3)			
10-year storm event (Q_{10})	15,200	1,870	3,330
25-year storm event (Q_{25})	18,700	2,050	3,830
Q_{10}/Q_{25} (approximated)	0.8	0.9	0.9
Sediment removal level	-	-	-
% of maximum storage volume (approximated)	20	10	10
Volume of sediment at removal level (m^3)	3,740	205	383
Average sedimentation rate ($m^3 yr^{-1}$)	630	73	121
Accumulation time (yr)	6	3	3
Removal time (d)	4	<1	<1
Removal cost	$50,700	$4,660	$8,710
Annualized cost	$8,400	$1,550	$2,900

Removal costs include excavation, hauling and disposal costs.
Additional costs due to soil expansion and water content are also factored into removal costs.

For both the HydroPlant and Boy Scout basins, the 10-year design storm runoff volume is 90% of their maximum storage capacities. The accumulation limits for both would be 10% of their maximum capacities (205 m^3 and 383 m^3 respectively). It would take 3 years for the sediments to accumulate to 10% of their storage volumes while the costs for both the HydroPlant and Boy Scout basins would be $4,660 and $8,710, respectively. The annualized maintenance costs for the two smaller basins were similar to those estimated for the two basins with their current capacities.

Dewatering

Seasonal variations in the frequency and intensity of storms necessitate a contingency plan that calls for actively dewatering the basins after receiving flows from events that significantly reduce their free volumes. To maintain their maximum storage volumes, we assumed that the basins should be drained to at least 80% free storage once they have surpassed 50% capacity. Draining the Main and HydroPlant basins would be straightforward because the pumped water could be routed to the existing drainage ditch. However, draining the Boy Scout basin would be more difficult because it lacks a drainage system. To drain the Boy Scout basin would require an outlet that would route the pumped water into San Roque Creek.

To allow for the flexibility required to dewater the debris basins between storm events, a mobile pump should be kept on site. Suspended solids will not have adequate time to settle out between storm events, thus a trash pump with a solids handling capacity of 4 cm and a suction screen to keep out larger particles would be required. The cost of a 16.6 m^3min^{-1} trailer mounted vacuum assisted centrifugal trash pump is about $21,000. This capacity pump would empty the currently designed Main basin in approximately 1.4 hours, assuming the basin was filled to 50% capacity. Under the same conditions, the HydroPlant and Boy Scout basins could be emptied in 0.75 and 1.0 hour, respectively. These pumping times would allow all three basins to be drained in one day and made ready for the next storm. The expanded basins would require slightly longer draining times if they were allowed to fill to 50% capacity. Emptying times would range from 1.0 hour for the HydroPlant basin to 9.3 hours for the Main basin.

SOURCE CONTROLS

In order to control erosion at the source, construction of multiple small basins higher in the watershed was investigated. According to Stahre and Urbonas (1990), storm water runoff can be stored through either downstream controls or source controls. Downstream controls are normally large storage facilities that are located at or near the base of the drainage area, whereas source controls are comprised of many smaller basins located higher up in the drainage system. This type of system may include local percolation, injection or infiltration basins, smaller inlet control basins and on-site detention basins. Some advantages that source control systems commonly have over their downstream counterparts is that they offer a wider range of flexibility in design, can be targeted to a certain area and are generally less expensive to build. Despite these advantages, we decided against including this type of control system as a mitigation alternative. Given the present conditions at Lauro Reservoir, it is highly unlikely that a source control system would have lower construction costs than a downstream control system. The watershed’s steep slopes, rugged terrain and lack of roadways would make construction extremely difficult and costly. Furthermore, seeking approval from the local residents, whose properties include most of the watershed, is another barrier that would cost time and money. The environmental impact such a system would have on the watershed would be greater. Since source control systems normally have multiple basins scattered throughout the watershed, regulating and maintaining such a system would be more difficult and costly than a downstream system that offers a similar level of protection (Stahre and Urbonas, 1990).

IMPROVED DRAINAGE SYSTEM

Another option we considered involves improving the drainage system so that it can effectively route runoff from the basins and the hillsides surrounding Lauro Reservoir. Currently there is no ditch in place to drain the southern hillslope and the Boy Scout basin. Installing such a drainage system would be difficult and costly because that area has a steep slope. Furthermore, the South Coast Conduit outlet is in the direct path of the only feasible flow direction for a drainage system.

The only other alternative would be to install a drainage ditch that could either drain into the adjacent watershed (Mission Creek Watershed) via a tunnel dug into the hillslope or have the runoff drain into San Roque Creek by running a pipeline across Lauro Reservoir. The capital costs alone would make both of these alternatives infeasible. Furthermore, the pipeline would probably require that the runoff be pumped to maintain efficient flow rates and prevent settling.

The drainage system that serves the northern hillslope and the other two basins could be improved. However, the site conditions may require that it be enlarged by a significant amount. As previously mentioned, the ditch is actually a paved road that meanders along the northern hillslope. There is a 1.8 m head elevation difference between the two endpoints and many quiescent areas along the ditch where sediment and runoff are collected. Enlarging the ditch to meet the runoff flows will ultimately require that the hillside be excavated. This complication would increase costs by a significant amount, especially since the hill slope is steep. Given its close proximity to the reservoir shoreline, care would have to be taken to ensure that Lauro Reservoir is not contaminated during construction.

SEPTIC TO SEWER

As part of an initial investigation we looked at converting 22 houses in the Lauro Canyon Watershed convert from septic to sewer system to avoid the risk of bacterial contamination stemming from leaking or faulty septic tanks. Steep slopes and soils subject to poor percolation enhance the risks from these tanks (Flowers and Associates Inc., Camp Dresser & McKee Inc., et al. 1982). These factors enhanced the risk of fecal contamination to the reservoir from potential tank ruptures or over-flow. This option was considered but ruled out because of the amount of lift necessary to construct a sewer line in the area and the associated costs of construction (Rees; memo, 1997). Therefore, Lauro Canyon was placed on the Mission Canyon Septic Tank Maintenance District, County Service Area No. 12 (Langle; memo, 1997), whereby the Santa Barbara County Environmental Health Services monitors tank condition and proper disposal every two years (Marx; pers. comm., 2000).

END OF PIPE ALTERATIONS

End of pipe alterations are made to existing water treatment facilities to improve the ability of the plant to treat water. This alternative was considered as a means to improve the ability of Cater Water Treatment Plant to treat water from Lauro Reservoir during extreme events. This type of alternative is one that is often implemented because it proves to be the most cost-effective option.

Cater Treatment Plant was designed, by James M. Montgomery Consulting Engineers in the early 1960s (Thomson; pers. comm., 1999). It uses a rapid sand filtration system and can treat as much as 1.5×10^5 m^3 d^{-1} of raw water (Thomson; pers. comm., 1999). The untreated water from Lauro Reservoir enters the plant through a conduit beneath the headhouse where alum is added, to promote coagulation and mixed via air flashing. The water is routed into two flocculating basins about10 m wide by 9 m long by 7 m deep. After flocculation, the water flows into two stacked sedimentation basins (approximately 10 m wide by 60 m long by 7 m deep) where the floc particles are allowed to settle. The clarified water is collected by finger launders with V-notch weirs and delivered to four rapid sand filters with filtration rates of approximately 0.11 m^3 min^{-1} m^{-2}. The water is then chlorinated before being delivered to the underground 19,000 m^3 storage reservoir, from where it is distributed for consumption.

Expanding its footprint to include extra flocculating and sedimentation basins can increase the plant's ability to effectively treat highly turbid water (James M. Montgomery Consulting Engineers, 1985). However, the lack of available space is a confounding factor that affects the extent to which the plant can be retrofitted (Perman; pers. comm., 1999). Space is an underlying reason why an end-of-pipe alternative would be an expensive capital venture. Regardless, Cater Water Treatment Plant has contracted Corolla Engineering Consultants to investigate the possible options and their feasibility, for expanding the plant’s capacity and its treatment efficiency. The study is in final stages of completion at this time (Thomson; pers. comm., 1999).

SECTION 4. MODELING

As the investigation of the various management alternatives proceeded, a watershed model was developed to examine the runoff and sediment loss patterns within Lauro Canyon. The model was then used to identify areas with sediment loss above a selected threshold value. Once the critical areas were established, specific revegetation and ground cover alteration scenarios were created and simulated to assess their potential effectiveness in reducing sediment mobilization. After the modeling results and cost information were gathered, all aspects of each potential management alternative were considered in order to identify the most cost effective strategy to minimize the flux of sediment into Lauro Reservoir.

PURPOSE OF MODELING

We analyzed the physical characteristics of Lauro Canyon Watershed to identify characteristics that substantially contribute to the sediment load entering the reservoir during storm events. Topography, soil characteristics, land use and precipitation were the determinant factors that facilitated sediment transport into the reservoir. We concluded that using a model as opposed to fieldwork or experimentation would allow for analysis of a range of conditions.

MODELING METHODS

SCREENING OF MODELS

One of the difficulties in attempting to manage small urban watersheds is the lack of basic data required to evaluate the condition of the watershed and the effect of land use or management alterations. Lauro Canyon Watershed lacks stream flow, soil loss, pollutant loading and nutrient measurements. Given these data limitations, we began to investigate several models with which we could estimate sediment transport and the runoff characteristics of Lauro Canyon Watershed under a variety of conditions.

We first identified Better Assessment Science Integrating Point and Non-point Sources (BASINS) as a model that could analyze the geomorphologic characteristics of the watershed. We contacted EPA-BASINS technical support and determined that we would need daily measured flow data in order to use BASINS. We would also need to calibrate the model with field measurements. Because of the lack of stream gauge data, we decided to abandon using BASINS.

Many models have significant data needs. Realizing this, we sought a model with reduced data requirements. We identified Agricultural Non Point Source Pollution (AGNPS) model. This model requires less data input and models sediment transport on a storm-by-storm basis from individual cells within the watershed via the application of the Universal Soil Loss Equation (USLE). However, we later discovered that the model is poorly documented and the input format requirements are unclear. While AGNPS takes a simple approach to modeling sediment transport and erosion, it is poorly documented and contains numerous functions that lie outside the scope of our project.

RUSLE ARC/INFO MODEL

Most models were too complicated for both our data and our needs, and these models would be generating results that we could not support. We decided to write our own model of sediment transport using the Revised Universal Soil Loss Equation (RUSLE) in a Geographic Information System (GIS) environment. GIS is used to provide spatial data, define input parameters, execute the model and display the results. In order to model soil loss modeling at the watershed scale, one of two approaches may be taken (Cox and Madramootoo, 1998). The first approach requires the establishment of observation plots to determine the variation in soil loss in a heterogeneous environment. This method is expensive and time consuming and was determined to be beyond our capability given the project time frame. The second approach is to simulate soil loss under different land-use scenarios. This requires that model input parameters, derived from field measurements or established literature values, are adequately quantified. GIS allows model-input parameters to be generated from geographic databases. The raster data format allows runoff and erosion to be calculated on a cell-by-cell basis. The GIS environment allowed us to generate qualitative estimates of sediment yield and runoff values, with which we were able to rapidly assess different land use and management alternatives. We developed a GIS based land management tool, as part of a decision support system, for the Lauro Canyon Watershed.

ARC METHODS

We used Arc/Info, Arc/Grid and ArcView to model runoff and erosion potential in Lauro Canyon Watershed. This exercise was based on the University of California, Santa Barbara Geography 251 lab series, from which much of the model development and the subroutines used were drawn.

Data Gathering

We obtained a 3 m DEM from the University of California, Santa Barbara Map, and Imagery Laboratory (MIL). The Department of Geological Sciences, Quaternary Research Laboratory at UCSB published the 3 m DEM, which was created from AutoCad topographic maps with 2 ft contour intervals from maps provided by the Santa Barbara County Flood Control. Because of the small study area, the 3 m DEM served as the main grid for manipulations performed in Arc/Grid. Any errors inherent at this level of spatial resolution were outweighed by the detail necessary to effectively model such a small area. Because the 3 m

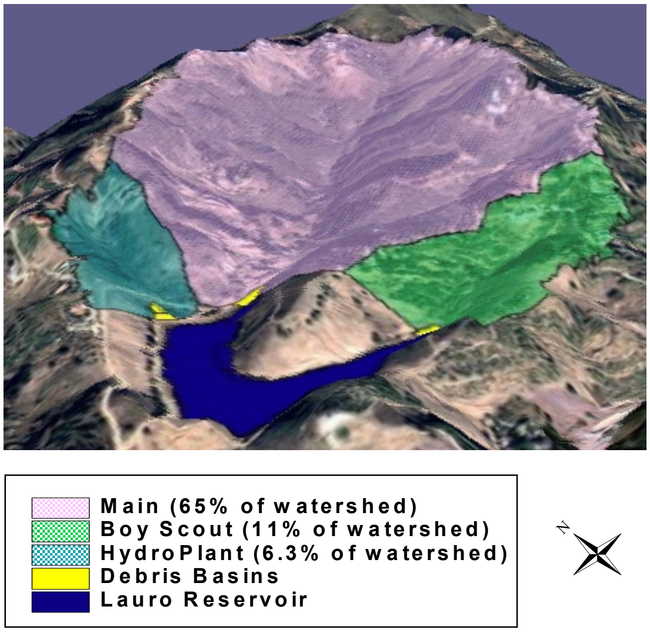
DEM does not cover the entire watershed boundary, we also obtained a 30 m DEM from Watershed Environmental. We also obtained a 1:42,000 orthophoto aerial photograph from the MIL. We acquired rainfall records from the Santa Barbara Flood Control Office, including unpublished data for storm return interval, storm intensity, storm duration and rainfall depth. We obtained 30-min rainfall intensity values for water year 1994/95 from gauge 199 located at the Wood Residence near the Mission. We also received daily rainfall values from the gauge located at Cater Water Treatment Plant.

Arc Analysis

The 3 m DEM did not fill the entire watershed boundary. While only a small portion of the boundary was missing, it was necessary to fill in the missing data with data from the 30 m DEM by merging the two data sets. Where data was present for the 3 m DEM, Arc/Grid maintained the data. However, where data was absent, data from the 30 m DEM was used to complete the grid. Most of the 3 m resolution was maintained, but for the northeastern-most portion of the grid, the data was generated at a 30 m resolution.

To reduce computational time and to minimize data storage, we reduced the merged DEM to the area of the land use grid (a process called clipping). This served to exclude any data from the DEM that lay outside of the watershed boundary. We analyzed the aerial photograph and constructed sub-catchments based upon the watershed's ridgelines, slope and aspect. We identified three sub-catchments, named HydroPlant, Main, and Boy Scout (Figure 4.1).

Figure 4.1 Sub-Catchment Delineation



To discern the contributions of the sub-catchments in the watershed, the merged DEM was clipped to each of the sub-catchment boundaries. All of the following procedures were carried out for each of the sub-catchments and for the entire watershed.

Anomalously low points, or sinks, in the clipped coverage were “filled.” A sink was defined as a pixel with an elevation lower than its 8 surrounding neighbors. The resulting coverage is necessary because the modeling tools assume that water flows continuously across the landscape. Each sink was filled to an elevation equal to its neighbors.

We used the Deterministic-8 Node Algorithm to create a flow direction grid. This algorithm assumes that water will take a single flow path where all runoff accumulated upstream of a given grid cell will drain into only one of its eight surrounding cells. The algorithm directs the flow into the cell with the steepest angle of descent among the eight. Based on the flow network an accumulation grid was created using the flow accumulation command in Arc/Grid (http://earth.agu.org/revegophys/hornbe01/node8.html).

RUSLE MODEL PARAMETERS

The USLE is an empirical model that predicts long-term average annual soil loss developed by Wischmeier and Smith (1965) for use in agricultural applications. The model contains six factors that influence soil loss.

(4 - 1) $A = R \times K \times L \times S \times C \times P$

Where: A = annual soil loss in kg km $^{-2}$
R = rainfall erosivity factor
K = soil erodibility factor
L = hillslope length factor
S = hillslope gradient factor
C = cover and management factor
P = conservation practice factor

This is an empirical equation, so the units for the factors do not determine the units for the output (A), in our case tons acre^{-1}, which we convert to kg ha, $^{-1}$. With 20 years of application, mathematical refinements have been made to the USLE and are consolidated in the RUSLE.

Rainfall Erosivity Factor (R)

Rainfall data were obtained from the Santa Barbara County Rain gauge 199 located at the Wood Residence above the Mission. The erosivity factor (R) was calculated using 30-min rainfall intensity data from water years 1994/95 and 1995/96. The rainfall intensity of each 30-min interval was used in the equation:

(4 - 2) $E = 916 + 331 \log_{10} I$

Where: E = the kinetic energy of each interval in foot-tons acre^{-1} in^{-1} of rainfall
I = rainfall intensity of each interval in hr $^{-1}$

The kinetic energy associated with each 30-min interval was then used in the rainfall erosivity index equation (Dunne and Leopold, 1978):

(4 - 3) $R = [\Sigma \times (E \times I_{30})] / 100$

Where: R = erosivity index in foot-tons acre^{-1}
E = kinetic energy in foot-tons acre^{-1} inch of rainfall^{-1}
I_{30} = amount of rain falling during each interval in inches

Rainfall statistics and resulting erosivity index values for water years 1994/95 and 1995/96 are presented in Table 4.1.

Table 4.1 Rainfall Statistics, Water Years 1994/95 and 1995/96

Water Year	R-Factor	Number of 30-minute Intervals	Total Rainfall for Water Year (cm)	Average Intensity (cm hr^{-1})
1994/95	275	663	99	0.30
1995/96	97	246	38	0.30

Soil Erodibility Factor (K)

The basic definition of soil erodibility is the change in soil per unit of applied external force or energy (rainfall erosivity) (Dunne and Leopold, 1978). The soil-erodibility factor (K) is related to the combined effect of rainfall, runoff, and infiltration and accounts for the effect of soil properties on soil loss during upland storm events. We determined the soil erodibility factor based on the soil texture of the different soil types described previously. K-values were assigned based on Appendix Figure D.1 (Wischmeier and Smith, 1965). We assigned K-values for the four soil types as follows: Gaviota Sandy Loam = 0.25, Ayar Clay = 0.27, Lodo-Sespe Complex = 0.30 and Todos-Lodo Complex = 0.33.

Hillslope Length Factor (L)

The L-factor is the ratio of soil loss by the action of surface water runoff from the field slope length to the soil loss that would occur from a 22 m length under otherwise identical conditions (NRCS web page, 2000). The hillslope length factor (L) accounts for the effect of topography on the erosion rate, which is found to increase with the length of the slope over which water flows. The L factor was determined using Arc/Info subroutine based on the DEM. Using the flow direction grid, the subroutine first created a flow length grid. Based on the flow length grid and the slope grid, the subroutine created the hillslope length factor grid by raising the flow length grid by a power according to the slope value (see Appendix Table D.1 for the Arc/Info script).

Hillslope Gradient Factor (S)

The influence of slope gradient on erosion rates is accounted for by the hillslope gradient factor (S). The values for S were generated using an Arc/Info subroutine based on the clipped DEM. The subroutine first converted the percent slope grid into degree values. The subroutine created a grid by taking the sine of the slope values. The sine value grid was squared and the slope gradient value grid was created as a function of that grid and the slope degree grid (see Appendix Table D.1 for the Arc/Info script).

Cover and Management Factor (C)

The cover management factor (C) assists in accounting for variation in soil erosion rates based on cropping land management practices within the watershed. Standard C-factors were developed for a variety of agricultural land uses however, very little has been done to establish factors that are suitable for California coastal watersheds. Only a small portion of Lauro Canyon Watershed is agricultural, 5% orchards, which presented difficulty in assigning an appropriate crop-management factor.

Using the aerial photograph to create a GIS coverage of vegetation types within the watershed (Figure 2.3, page 7) and values obtained in Dunne and Leopold (1976) (see Appendix Table D.2), we assigned C-values for the different land covers. The C-values were assigned as follows: Chaparral = 0.036, short brush (0.5 m height) = 0.1, short brush mixed with areas with no appreciable canopy = 0.039, orchards = 0.090, residential areas = 0.14 and areas with no appreciable canopy = 0.240. To obtain percent canopy cover estimates for areas representative of the individual vegetation types we used ArcView GIS software to trace polygons around the vegetation canopy. We then summed the area of the canopy polygons for each vegetation type and divided by the total representative area for the vegetation type.

Conservation Practice Factor (P)

The conservation practice factor reflects the effect on erosion of mechanical practices such as ripping, root plowing, contour furrowing and chaining. (Renard et al., 1997). Almost any mechanical practice that disturbs rangeland soil increases infiltration, which reduces runoff to a degree that depends on the nature of the soil. By increasing infiltration, surface runoff decreases, which reduces the amount of sediment mobilized and transported.

The conservation practice factor is often the least reliable of the RUSLE variables and determining appropriate values for P is generally difficult (Renard et al., 1994). Our information regarding all the RUSLE factors came from GIS databases or was generated from aerial photography. Due to time and resource limitations, we used this information within the framework of the Geography 251 lab series, which we took as a guide for the application of the RUSLE in a local watershed. Lacking any field data with respect to the P factor, we consulted the 251 lab for a reference and used the recommended value of 0.5 for a P factor in a local watershed where insufficient information exists.

See Appendix E for a summary of each model-input parameter and its source.

MODELING SCENARIOS

One of the goals of our study was to identify areas that could be revegetated to reduce the amount of sediment entering the reservoir. We felt that the flanking slopes of the reservoir and the avocado orchards were the locations where revegetation would be most effective. To qualitatively assess the effects of revegetation we ran four scenarios that would model the effects of this process. The scenarios were 1) status quo, 2) revegetation of the flaking slopes surrounding the reservoir, 3) alteration of the ground cover of the avocado orchards and 4) returning the entire watershed to natural chaparral. By changing the values for the C-grid, we were able to produce land uses that were more resistant to erosion because of increased land cover.

By running an analysis on a watershed that was completely chaparral, we were able to assess a natural condition of the watershed. We thereby developed a baseline sediment yield, which served as an upper bound for any expected reduction of sediment yield through revegetation. This process was accomplished by applying the RUSLE with four different C-grids that represented the status-quo, revegetation, ground cover alteration, or return to native chaparral. We created a C-value coverage to simulate the effect of revegetation the open slopes with no appreciable canopy, by changing C-values for these areas from 0.240 to 0.003. The management alternatives involving the avocado orchard examined three different approaches for minimizing sediment loss from that area - revegetation with grasses, mulching, and increased leaf litter. Given the sensitivity of our model, all three techniques for ground cover alteration can be captured in one universal C-value. Therefore, we created a third C-value coverage by changing the C-values for the avocado orchards from 0.090 to 0.003. The fourth C-value coverage we created had a uniform C-value of 0.036, simulating an “all natural vegetation” scenario in which the entire watershed is covered by chaparral (Table 4.2).

Table 4.2 C-values for the Four Modeling Scenario Coverages

	Model Scenario			
Land Use	**Status Quo**	**Revegetate Open Slopes**	**Altered Ground Cover in Orchards**	**Natural State**
Residential	0.140	0.140	0.140	0.036
Short Brush 0.5M	0.039	0.039	0.039	0.036
Orchard	0.090	0.090	0.003	0.036
Chaparral	0.036	0.036	0.036	0.036
No Appreciable Canopy	0.240	0.003	0.240	0.036
Shrubs 0.5M No Canopy	0.100	0.100	0.100	0.036

SEDIMENT MOBILIZATION ANALYSIS

To apply the RUSLE, grids were created which represented the integer values for each of the factors. Reclassifying a grid to the appropriate values for each factor using the reclass command created R, L, S, and P factor grids. Because the values for the K and C grids were non-integers, they were converted by multiplying K-values by 100 and C-values by 1000, before reclassification. Duplicate C-grids were created to represent revegetation of the flanking slopes, alteration of the ground cover under the avocado orchards, and a natural watershed that contained only native chaparral.

To calculate sediment displacement per given area within the watershed, we used Arc/Grid and performed map algebra to determine this value, using the equation:

(4 - 4) A = [R-grid x K-Grid x L-Grid x S-Grid x C-Grid x 0.5] / 100,000

Where: A = sediment displacement in kg km^{-2}
0.5 represents the conservation practice factor
100,000 is a conversion factor to obtain appropriate units

We clipped the resulting grid to each sub-catchment boundary and summed the values in the grid to determine the sediment displacement from each sub-catchment (in kg). This was process was repeated for each of the four scenarios for water years 1994/95 and 1995/96.

RUNOFF ANALYSIS

First, a flow direction grid was created in Arc/Grid, using the D-8 model. Based on this flow network an accumulation grid was created using the flow accumulation command in Arc/Grid.

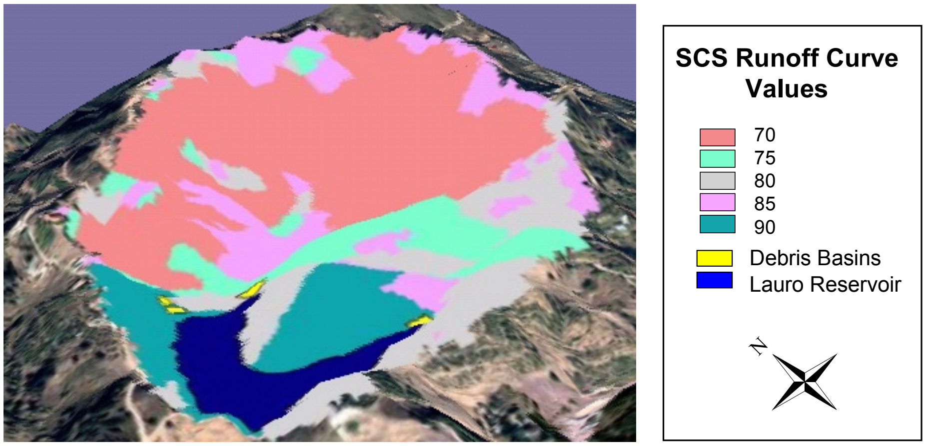
Based on the soil types (Figure 2.4, page 8) and land cover (Figure 2.3, page 7) in the watershed, we created a grid that represents the combined effect of soil properties and land-cover type on runoff. We did this by classifying soils into four groups based on their hydrologic properties as outlined by Dunne and Leopold (1976). We derived soil classification based on the aforementioned soil descriptions (see "Soil Types" above). Classification values are shown in Appendix Table D.3 (Dunne and Leopold, 1978). We assigned the four soil types into the following hydrologic classes: Todos-Lodo Complex = C, Lodo-Sespe Complex = C, Gaviota Sandy Loam = C, and Ayar Clay = D. We converted these soil classification types into a numerical representation and assigned runoff curve numbers (see Table 4.3).

Table 4.3 Runoff Curve Values

Land Cover Type	Soil Type	Runoff Curve Numbers
Residential Areas (0.4 ha, 20% impervious)	C	80
	D	85
Chaparral & Short Brush	C	70
Chaparral	D	75
Avocado Orchard	C	75
	D	85
No Canopy	C	85
	D	90
Short Brush/No Canopy	D	75

We used Arc/Info GIS to assign these values to the watershed coverage. We then combined this coverage with numerical representations of our land classification coverage and created a runoff curve number coverage (Figure 4.2) of the watershed using values outlined in Appendix Table D.4 (Dunne and Leopold, 1978).

Figure 4.2 SCS Runoff Curve Values



In order to generate runoff values to compare with values obtained using the Rational Method, we used rainfall data from the County of Santa Barbara to create coverages that represented storms of a specific duration and return interval. First, using the 30-min rainfall intensity records from gauge 199, we selected an average storm duration of six hours. We used this value to determine rainfall depth at varying return intervals (Stubchaer, 1964). Although an elevation difference of 152 m exists in the watershed, we assumed a universal rainfall surface, and did not account for orographic effects. From these data, we were able to reclassify grids into rainfall surfaces for 10-, 25-, and 50-year storms.

In order to estimate runoff volumes from individual historic storms, we used data from the Cater Water Treatment Plant rain gauge for water year 1994/95. We created a separate grid to represent the rainfall amount of each storm in water year 1994/95 (See Appendix F). To calculate runoff, a subroutine in Arc/Info was utilized. This subroutine used both the rainfall surface and the SCS runoff values grid to calculate the runoff associated with each storm. Runoff was expressed in inches per 3 m by 3 m cell and was then converted to a volume that was accumulated using the flow accumulation command. Thus, any cell within the watershed could be identified with a volume of accumulated runoff in m^3.

SECTION 5. RESULTS

SEDIMENT MOBILIZATION RESULTS

TOTAL WATERSHED SEDIMENT LOSS, 1994/95 AND 1995/96

Using sediment loss estimates for water years 1994/95 and 1995/96 allowed us to illustrate the differences in annual sediment loss between a year with average rainfall and one with rainfall 76% above average. The total modeled sediment loss in kg and m^3 for the four land-cover scenarios are listed in Table 5.1. Percent reduction in sediment loss for both years was 25% for revegetation of the flanking slopes, 5% for ground cover alteration of the orchards and 44% for the returning the watershed to natural vegetation. Modeled sediment loss in 1994/95 exceeded that of 1995/96 by 65% for all four of the land-cover scenarios.

Table 5.1 Total Watershed Sediment Loss in kg and m^3 1994/95 and 1995/96

Land-cover Scenario	kg		m^3	
	1994/95	1995/96	1994/95	1995/96
Status Quo	7.62×10^6	2.69×10^6	2870	1010
Revegetate Flanking Slopes	5.67×10^6	2.00×10^6	2140	755
Ground Cover Alteration - Orchards	7.22×10^6	2.55×10^6	2720	960
Natural Vegetation	4.30×10^6	1.52×10^6	1620	572

SUB-CATCHMENT SEDIMENT LOSS

Sub-catchment sediment loss values for water years 1994/95 and 1995/96 are listed in Table 5.2.

Table 5.2 Sub-Catchment Sediment Loss in m^3 (1994/95 and 1995/96)

Land-cover Scenario	Water Year 1994/95				Water Year 1995/96			
	Hydro -Plant	Boy Scout	Main	Flanking Slopes	Hydro-Plant	Boy Scout	Main	Flanking Slopes
Status Quo	206	342	1790	539	72.7	121	630	190
Revegetation of Flanking Slopes	130	300	1610	95.1	46.7	106	569	33.5
Ground Cover Alteration - Orchards	206	285	1690	539	72.7	100	597	190
Natural Vegetation	113	138	1222	150	39.8	48.8	431	52.8

The percent sediment loss for both water years was the same in each scenario. Sediment loss from the Main sub-catchment was substantially higher than the other areas of the watershed, representing 62% of the total sediment loss for the status quo scenario, 75% for the revegetation of flanking slopes scenario and 75% for the natural vegetation scenario. Percent reductions in sub-catchment sediment loss for each land-cover scenario were the same for both years and are listed in Table 5.3.

Table 5.3 Percent Reduction in Sediment Loss (1994/95 and 1995/96)

Land-cover Scenario	Water Year 1994/95				Water Year 1995/96			
	Hydro-Plant	Boy Scout	Main	Flanking Slopes	Hydro-Plant	Boy Scout	Main	Flanking Slopes
Revegetation of Open Slopes	37	12	10	82	37	12	10	82
Ground Cover Alteration - Orchards	0	17	5	0	0	17	5	0
Natural Vegetation	45	60	32	72	45	60	32	72

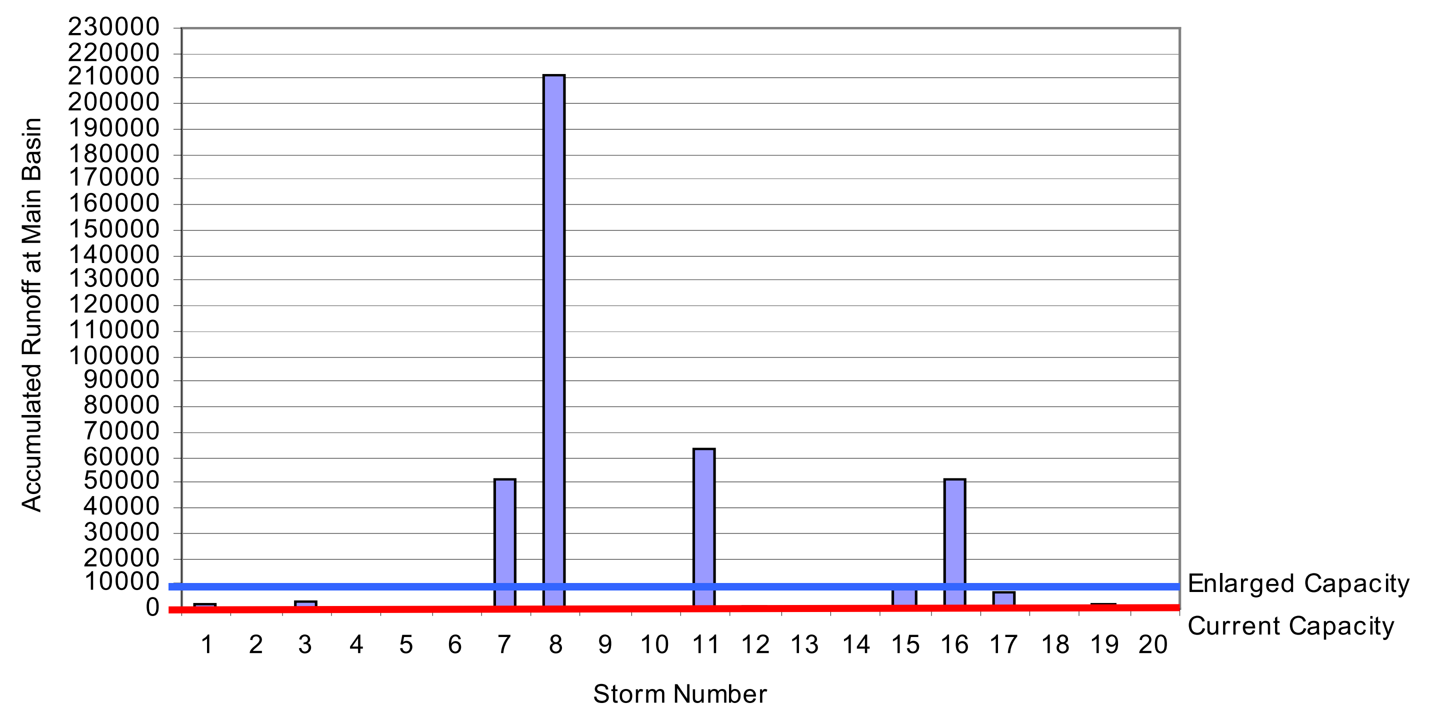
The model predicted the reduction in sediment loss was highest on the slopes that flank the reservoir, with a decrease of 82% for revegetation with erosion controlling grass and a decrease of 72% when modeled with native vegetation. There are no orchards on the flanking slopes to address so there was no reduction in sediment loss for this scenario. Percent reduction in the HydroPlant sub-catchment was 37% for revegetation with grasses and 45% for native vegetation. The HydroPlant sub-catchment also does not contain orchards. Percent reduction in modeled sediment loss for the Boy Scout basin was 12% for revegetation with grasses, 60% for the native vegetation and 17% for orchard ground cover alteration within the sub-catchment. Percent reductions in the Main basin were 10%, 32% and 5% for the revegetation with grasses, native vegetation and orchard alteration scenarios, respectively.

RUNOFF ACCUMULATION RESULTS

The runoff grids created in Arc/Grid were analyzed using ArcView. To determine the volume of runoff entering each of the three debris basins, the cell in the streamline just before the debris basin was identified and its accumulated value was assumed to be the value of the runoff entering the basin (Figure 5.2).

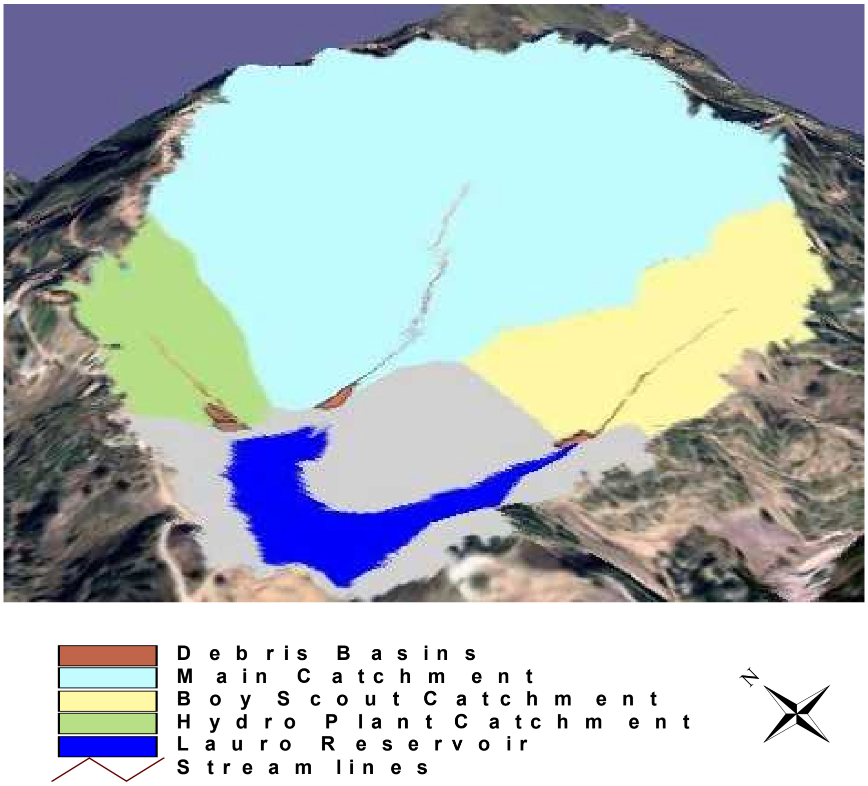
Figure 5.1 shows the accumulated runoff at the Main basin on a per storm basis for the water year 1994/95. This graph shows that the four largest storms in that year would greatly exceed enlarged basin capacity. However, if the remaining storms were averaged, they would not exceed current basin capacity.

Figure 5.1 Model Predicted Per Storm Runoff Volumes (1994/95)



For each storm, an associated runoff for each basin was determined. These values were summed to generate a total runoff for the water year. The total precipitation for water year 1994/95 was 127 cm. The Main basin, with a capacity of 2,760 m^3, had an accumulated runoff of 4.0 x 10^5 m^3. The Boy Scout basin with a capacity of 2,050 m^3 had an accumulated runoff of 7.96 x 10^4 m^3. The HydroPlant basin with a capacity of 1,410 m^3 had an accumulated runoff of 3.32 x 10^4 m^3.

Figure 5.2 Flow Accumulation Stream Lines for Each Sub-Catchment



MODEL VALIDATION

RATIONAL METHOD COMPARISON OF RUNOFF ESTIMATES

Since actual storm runoff volumes were not available for the Lauro Canyon Watershed with which to test the validity of the model predictions, the rational method for estimating runoff from small catchments was used as a comparison (data used in the calculation are presented in Appendix A, page G-1).

Using rainfall intensity data (Stubchaer 1964) and the drainage basin characteristics of each sub-catchment (shown in Appendix Table G.1), a range of possible peak runoff rates were calculated for storms with a return interval of 10-, 25-, and 50-years. The basin characteristics were used to calculate the time of concentration (t_c) (the time required for a drop of water falling on the most hydraulically remote portion of the drainage basin to reach the basin outlet) for each of the sub-catchments using the SCS equation (1972):

(5 - 1) $t_c = L^{1.15} / (3093.16 \times H^{0.38})$

Where: t_c = time of concentration in hrs
L = length of the catchment along the mainstream from the most remote point to the basin outlet in m
H = difference in elevation between the most remote point and the basin outlet in m

The t_c values were used to determine rainfall intensity values (i) for each of the catchments for each interval storm using the County of Santa Barbara Rainfall Intensity-Duration Curves (Stubchaer, 1964). (Appendix Table G.2) The rainfall intensity values were then used in the rational method equation (Dunne and Leopold, 1978):

(5 - 2) $Q = 0.278CiA$

Where: Q = peak rate of runoff in $m^3 s^{-1}$
C = rational runoff coefficient (dimensionless)
i = rainfall intensity in mm hr^{-1}
A = drainage area in km^2

A range of values for C was used for each land coverage type in order to account for possible variations in factors contributing to the coefficient (soil type, surface roughness, vegetation, and topography) within each land use type (Appendix Table G.3). One set of high and low C values for each catchment was then calculated by weighting each land use type's C value by the percentage of the total catchment area the land use type occupied (Appendix Table G.4). The result of these calculations was a range of predicted peak runoff rates in $m^3 s^{-1}$ for the three catchments for each of the three return interval storms.

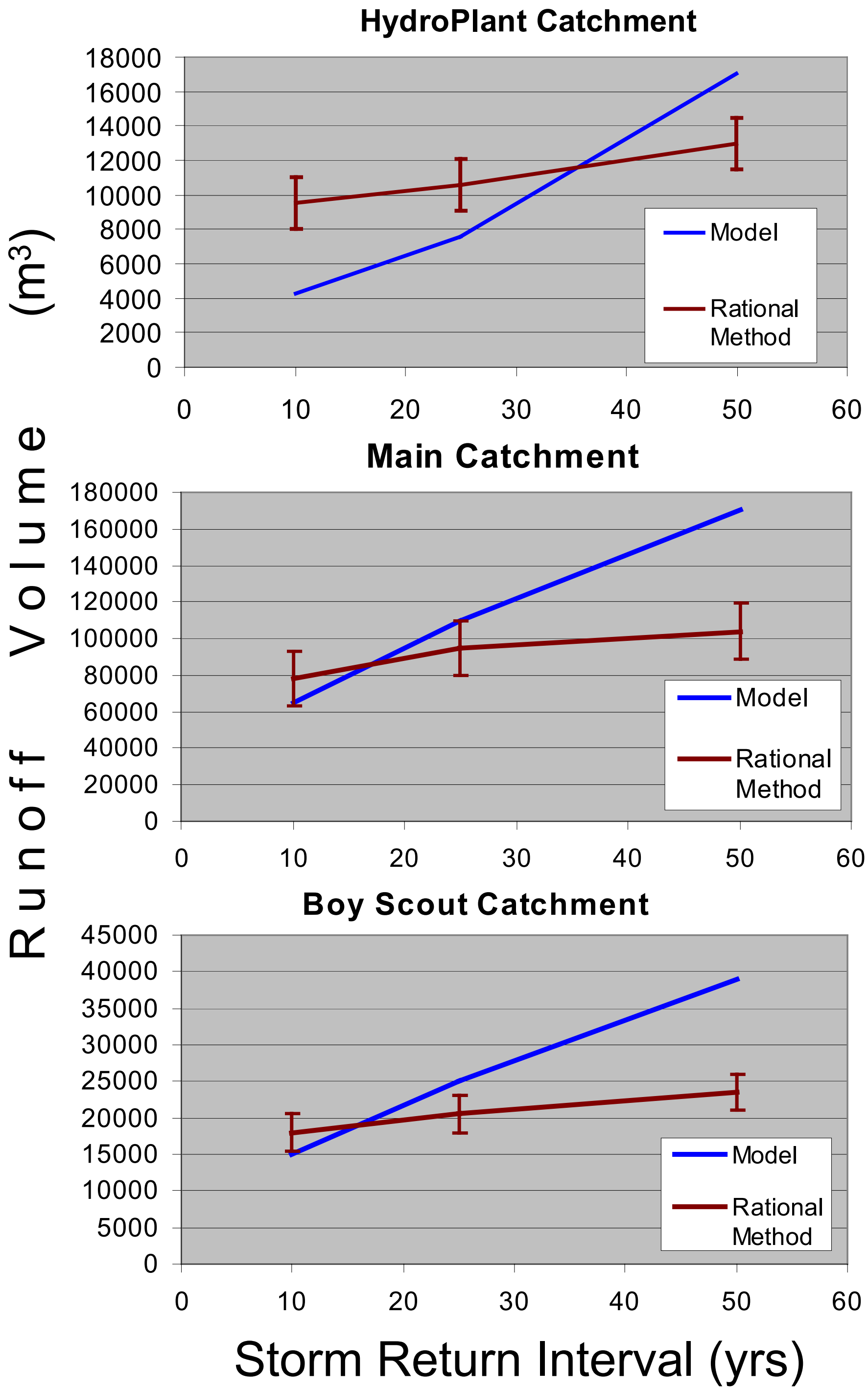
In order to compare the estimated peak runoff values with the accumulated volume of runoff predicted by the model, a storm duration of six hours was selected in order to estimate the volume of water that could accumulate at each of the basin locations during a theoretical storm. The predicted volumes produced by the model and the values estimated using the rational method are presented in Table 5.4.

Table 5.4 Model-Predicted and Rational Method Estimated Runoff Volumes Given a 6-Hour Storm

Catchment	**Storm Return Interval**	**Rational Method (m^3)**			**Model (m^3)**
		C_{low}	**C_{high}**	**Average**	
Hydro-Plant	10-Year	8.00×10^3	1.10×10^4	9.50×10^3	4.30×10^3
	25-Year	9.20×10^3	1.20×10^4	1.06×10^4	7.60×10^3
	50-Year	1.10×10^4	1.50×10^4	1.30×10^4	1.70×10^4
Boy Scout	10-Year	1.60×10^4	2.00×10^4	1.80×10^4	1.50×10^4
	25-Year	1.80×10^4	2.30×10^4	2.05×10^4	2.50×10^4
	50-Year	2.10×10^4	2.60×10^4	2.35×10^4	3.90×10^4
Main	10-Year	6.50×10^4	9.10×10^4	7.80×10^4	6.50×10^4
	25-Year	8.00×10^4	1.10×10^5	9.50×10^4	1.10×10^5
	50-Year	8.80×10^4	1.20×10^5	1.04×10^5	1.70×10^5

The graphs in Figure 5.3 show the model values plotted against the average volume of runoff estimated using the rational method, with the range bars representing the values predicted using the high and low C values.

Figure 5.3 Comparison of Rational and Model Method Predictions



Overall, the model predictions and the rational method estimates roughly agree on the volume of runoff that would be expected from the three return interval storms. Runoff values are within the same order of magnitude for all sub-catchments and storm return intervals. The two methods appear to agree better when used on the smaller storm events, with an average difference of 29% and 22% for the 10- and 25-year return interval storms, respectively (see Table 5.5).

Table 5.5 Absolute Difference Percentages Between Rational Method and Model Predictions

Average By Basin		Average By Storm Interval	
Basin	**Average Difference**	**Interval**	**Average Difference**
HydroPlant	38%	10 Year	29%
Boy Scout	35%	25 Year	22%
Main	32%	50 Year	53%

However, the two methods differed the most when attempting to predict the runoff resulting from the 50-year return interval storm (53% average difference). The model predictions rose faster than the rational methods estimates in all the sub-catchments, with the model predicting a lower runoff volume for the 10-year event and a higher volume for the 50-year event. The average difference in predictions between the rational method and the model for all sub-catchments and all storm events only ranged from 32% to 38%. Discrepancies between the model and the rational method could be a result of the detail with which each method examines the sub-catchments. While the rational method examines each sub-catchment as one unit, the model breaks down the sub-catchments into anywhere from 7,000 to 75,000 pixels.

SIMILAR WATERSHED'S SEDIMENT MOBILIZATION COMPARISONS

After obtaining values for sediment mobilization from the model we converted them to equivalent values for sediment yield, assuming all the sediment was carried into the reservoir, by dividing the net sediment mobilization by the area of the watershed and converting the values to kg ha^{-1}. For values reported as a volume of sediment, the average soil density of 2.65×10^3 kg m^{-3} was used. Calculating these values made it possible to compare our results to sediment yield values for similar watersheds in the Santa Ynez Mountains and other areas of the Transverse Ranges. For comparison, we were able to find several sources of information that were either measured or calculated. We converted all data to kg ha^{-1} to account for the different size of each watershed. The direct comparison of the values in the literature to those obtained by modeling the watershed cannot be used to calibrate the model because they are determined by different methods. However, they do allow us to determine if the values we obtained fall within a reasonable range relative to previously determined sediment yields for similar watersheds in Southern California. Keller et al., (1997) reported annual average sediment production for pre-burn Santa Barbara area watersheds as estimated by Rowe et al., (1949) using the United States Forest Service method based on parameters such as locality, soil type, underlying geology, and slope (see Table 5.6).

Table 5.6 Reported Annual Average Sediment Production for Santa Barbara Drainage Areas

Drainage	Sediment Production Annual Average (kg ha^{-1})
Maria Ygnacio West	2.90 x 10^4
Maria Ygnacio East	1.46 x 10^5
San Antonio	2.01 x 10^4
San Jose	2.38 x 10^4
Atascadero	1.58 x 10^4
Average	**2.43 x 10^4**

Simon, Li and Associates (1984) reported average annual sediment yields for Mission and Rattlesnake Canyons in Santa Barbara, California which when combined gave a value of 8.7 x 10^3 kg ha^{-1} (Table 5.7).

Table 5.7 Sediment Yields from Local Watersheds

Watershed Name	Drainage Area (hectares)	Annual Sediment Yield (kg)	Annual Sediment Yield (kg ha^{-1})
Mission Canyon♣ **Rattlesnake Canyon♣**	2,980*	2.6 x 10^7	8.7 x 10^3
Santa Ynez Mountain♦	90,100	1.8 x 10^9	2.0 x 10^4

* watershed areas combined in analysis
♣Army Corps of Engineers by Simons, Li and Associates, 1984
♦Brent D. Taylor, A.M. ASCE, 1981.

These values were calculated as a weighted average of return event sediment yields and were larger than historical measured yields. This was because the calculations were computed for a worst-case scenario and served as an upper bound for debris basin design. Taylor (1981) reported an actual average annual upland erosion rate for the Santa Ynez Mountains in Santa Barbara, California of

2.0 x 10^4 kg ha^{-1}. Taylor (1981) also reported estimated sediment yields for Cachuma, Gibralter and Matillija reservoirs and Piru Lake (Table 5.8).

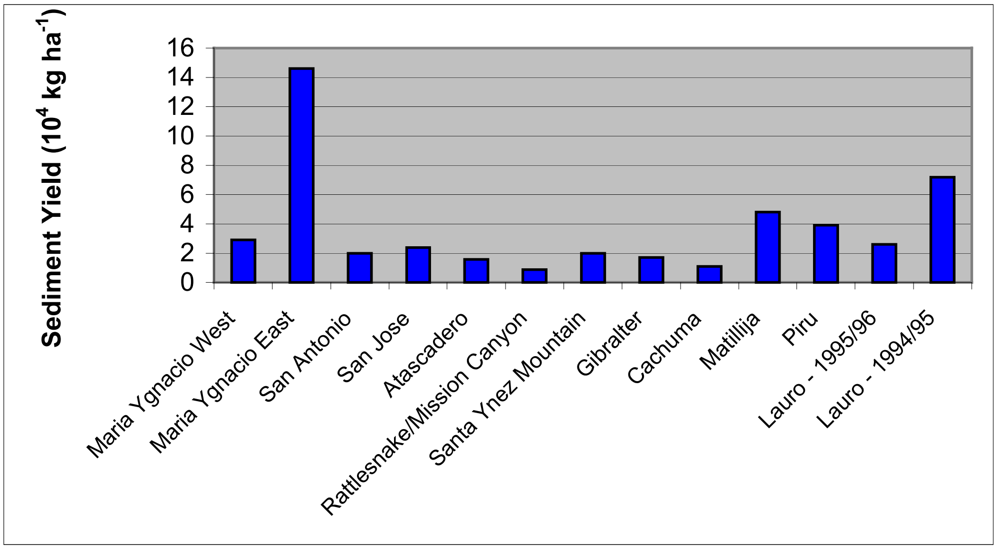
Table 5.8 Sediment Yields for Santa Ynez Mountain Areas

Reservoir Lake	Sediment Yield (kg ha^{-1})
Gibralter	1.7 x 10^4
Cachuma	1.1 x 10^4
Matillija	4.8 x 10^4
Piru	3.9 x 10^4

Estimates were based on long-term sediment delivery data and sediment accumulation measurements. Regression analysis was used to develop a relationship for estimating average annual catchment denudation rates, which were converted into sediment yields. These sediments are estimated to be composed of 80% fines (< 0.06 mm) and 20% sands (0.06 to 2 mm) based on the underlying geology. We assumed sediment trap efficiency to be 100% (Taylor, 1981).

Our model estimated the average sediment yield, based on kg of sediment produced divided by watershed area, for an average rain year (1995/96) to be 2.6 x 10^4 kg ha^{-1} and 7.2 x 10^4 kg ha^{-1} during a year with 76% higher than average rainfall (1994/95). These values fit within the in the range of values reported for watersheds in Santa Barbara, California (Figure 5.4).

Figure 5.4 Sediment Loss Comparisons of Local and Nearby Watersheds



SECTION 6. DISCUSSION OF RESULTS

SEDIMENT MOBILIZATION

The model gave values for sediment loss in kg on a per cell basis as well as an aggregated total sediment loss value in kg. The mean for sediment loss for the status quo scenario 1995/96 was 23 kg per 3m x 3m cell. Using ArcView GIS we were able to determine the sediment loss values for cells that fell –1, 1, 2, and $\geq$ 3 standard deviations from the mean (Table 6.1). The sediment loss values were converted to kg ha $^{-1}$.

Table 6.1 Statistical Results for Status Quo 1994/95

Number of Standard Deviations	Modeled Sediment Loss in 10^4 kg ha $^{-1}$
-1 to 0	-11 to 22
Mean	22
0 to 1	22 to 56
1 to 2	56 to 90
$\geq$ 3	90 to 846

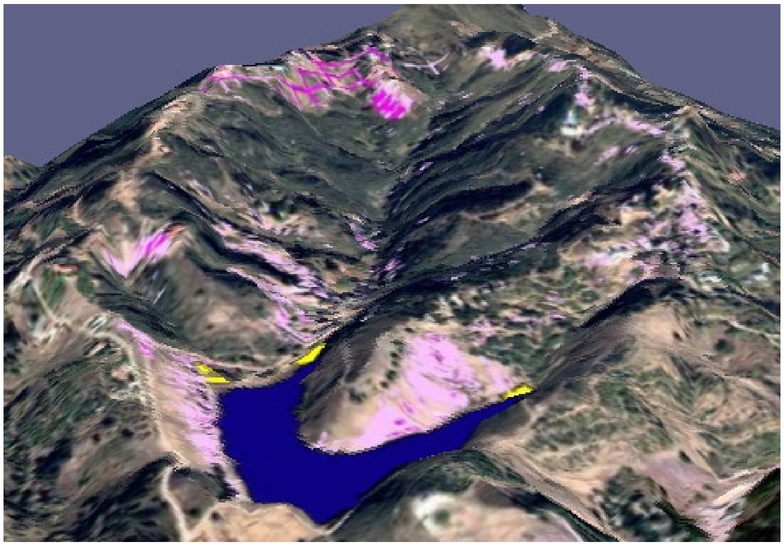
Average annual sediment loss for California ranges from a low of 4.6 x 10^3 kg ha^{-1} to a high of 1.95 x 10^4 kg ha $^{-1}$ (Dunne And Leopold, 1978). Inman and Jenkins (1999) reported annual net sediment yield for the Santa Ynez River of 1.50 x 10^4 kg ha^{-1} for the period 1969 to 1995 based on suspended sediment data from USGS gauging stations. These values do not include sediment trapped behind dams. Simon, Li and Associates (1994) reported sediment yields for the Santa Monica and Franklin Creek watersheds, Carpinteria, California. These values were calculated with the Flaxman method (a relationship derived for watersheds in the western U.S. that uses parameters such as the ratio of precipitation to temperature, percent slope, soil particle size, and peak discharge) and the Modified Universal Soil Loss Equation (an event based version of the USLE). Averaging the results from both watersheds gave values of 3.39 x 10^3 kg ha^{-1} and 4.90 x 10^3 kg ha^{-1} for the Flaxman method and the MUSLE respectively. Neither method accounts for the trapping of sediments behind debris basins.

The mean predicted by our model in a normal water year (1995/96) for individual cells within the study watershed was up to 65 times greater than the range of the average values reported above. This indicates that areas within the watershed are mobilizing sediment at a high rate.

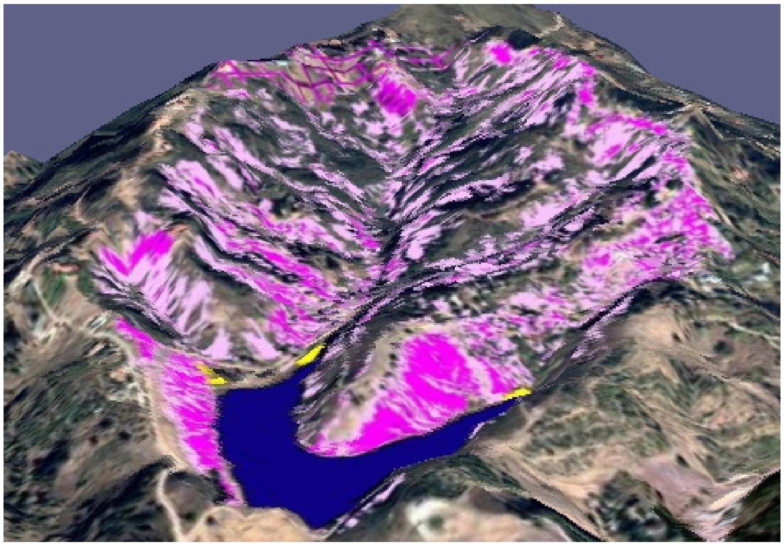
We classified cells with values one standard deviation or greater above the mean sediment yield in a normal water year (1995/1996) as critical areas (Figure 6.1 - A). Thus, critical areas were those that had sediment loss of 56 x 10^4 kg ha^{-1} or higher.

Figure 6.1 Critical Sediment Mobilization Areas - Status Quo

A. 1995/96



B. 1994/95



Sediment Mobilization in kg ha $^{-1}$

- 🟪 6.56×10^4 to 1.81×10^5
- 🟪 1.81×10^5 to 5.24×10^5
- 🟪 5.24×10^5 to 9.87×10^5
- 🟪 9.87×10^5 to 1.41×10^6
- 🟪 1.41×10^6 to 2.80×10^6

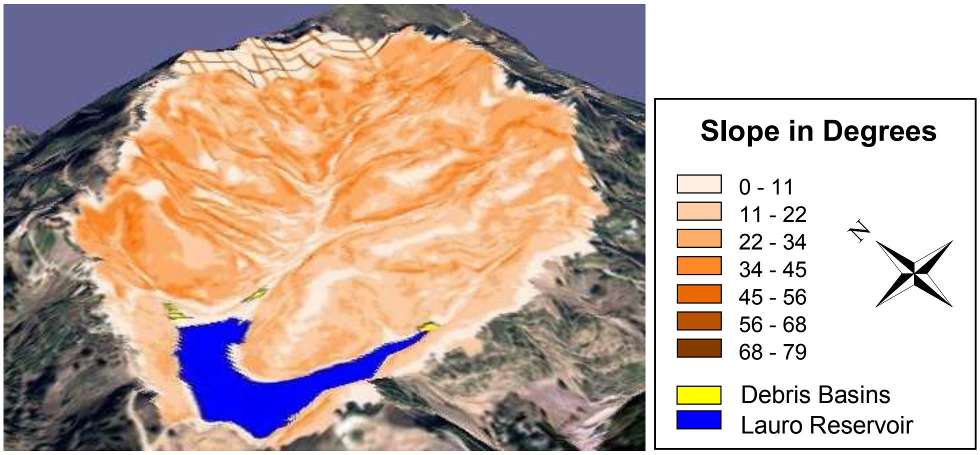
- 🟨 Debris Basins
- 🟦 Lauro Reservoir

N

Sediment mobilization values in the figure are critical values determined by selecting values one or more standard deviation above the mean sediment mobilization value for the Status Quo scenario in a normal water year (1995/96). Darker areas represent the most critical areas in the watershed.

Avocado orchards, areas covered with short brush and areas devoid of canopy cover tended to fall into the critical area category. These areas correspond to the flanking slopes adjacent to the reservoir, avocado orchards in the Boy Scout and Main basins, and areas surrounding residences where slopes are high (34° to 67° (see Figure 6.2) and vegetation has been removed as a preventative measure against fire hazard. Most of these critical areas had slopes ranging from 0° to 34° although a few isolated critical areas in the watershed had slopes from 34° to 67°. The flanking slopes adjacent to the reservoir had sediment loss ranging from 22×10^4 kg ha^{-1} to 8.46×10^6 kg ha^{-1} and slopes ranging from 11° to 34°. These areas were deemed the most critical based on the sediment mobilization rates. These critical areas increased in size and amount of sediment loss for water year 1994/95 (Figure 6.1-B). They are also the easiest to mitigate areas within the watershed because much of the land is controlled by COMB.

Figure 6.2 Lauro Canyon Watershed Slope Values



The percent reduction for each of the sub-catchments is the same for both water years though 1994/95 is an above average rain year and 1995/96 is average (Table 5.3, page 39). This reflects the linear nature of the model. Whether the relationship between sediment yield and rainfall intensity is linear was not clear from the literature. Fraser et al. (1999) observed rainfall intensity and sediment transfer in 22 agricultural sites in southwest England with soils described as “excessively drained” (USDA, 1951) and slopes from 1° to 11°. Plotting mean

Figure 6.3 Mean Rainfall Intensity vs. Mean Sediment Transfer

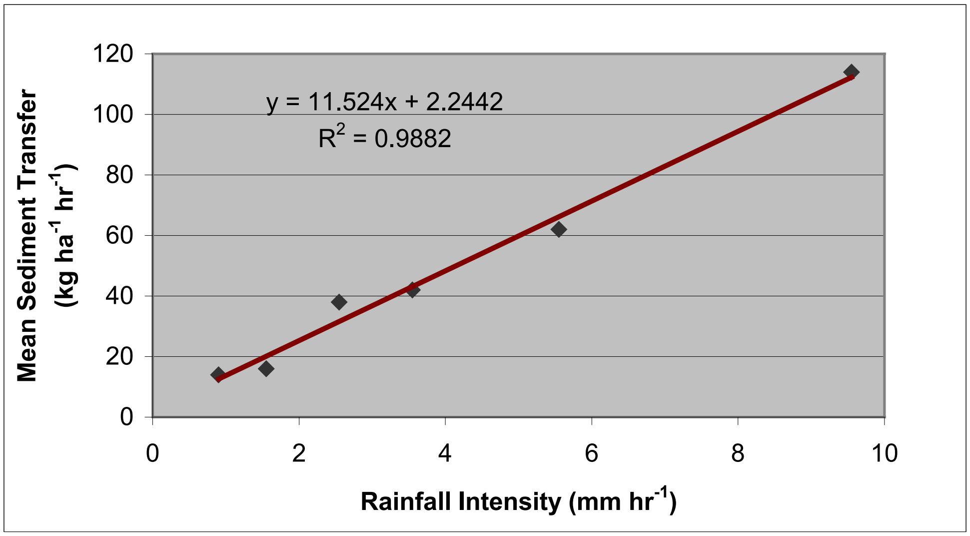
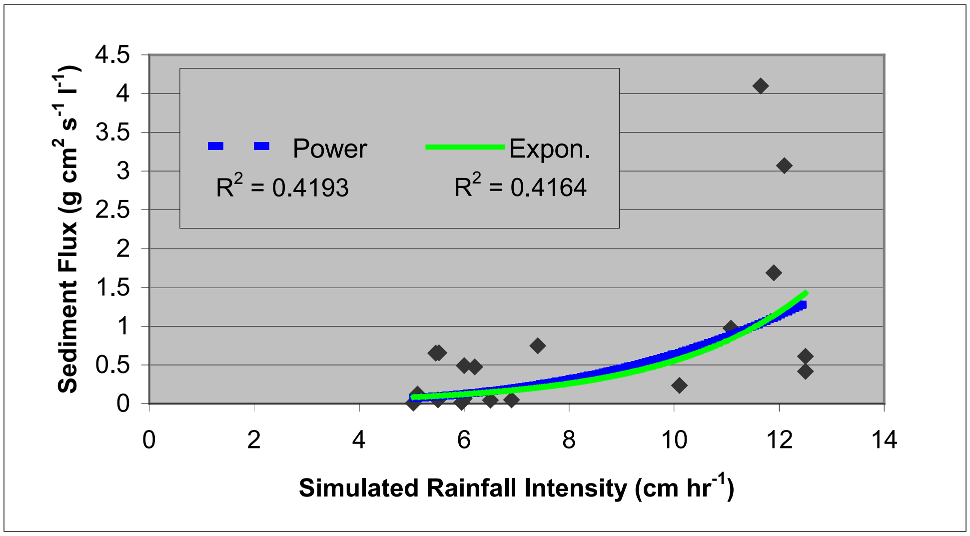


Figure 6.4 Simulated Rainfall Intensity vs. Sediment Flux



rainfall intensity verses mean sediment transport gives a linear relationship with $R^2 = 0.9882$ (Figure 6.3). Their observations were for low intensity rainfall (up to 1 cm hr $^{-1}$) and were measured on fields of mostly winter cereals. Simulated rainfall experiments done by Gabet (unpublished data, 2000) at Sedgwick Reserve in the Santa Ynez Mountains may indicate the relationship is not linear. Measurements were made on plots of varying slope with lightly grazed grass cover. Plotting rainfall intensity verses sediment flux yields an exponential relationship with $R^2 = 0.4164$ and a power relationship with $R^2 = 0.4193$ (Figure 6.4). This indicates that our model may under estimate sediment mobilization, especially at higher intensity rainfall. The ability of our model to quantitatively predict the amount of sediment loss in the watershed precisely is limited. However, the results can be used to qualitatively identify the areas within the watershed where sediment loss is highest and erosion control measures would be most effective.

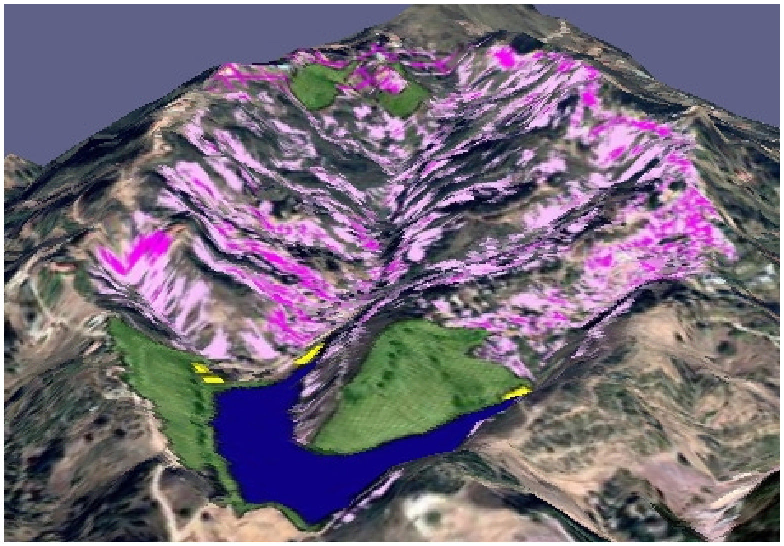
Rather than percent reduction in sediment loss for each scenario, predicted sediment loss volume can be used to discuss the reduction of sediment flux to the debris basins and reservoir. The percent reduction also elucidates the effectiveness of revegetation with grass and orchard groundcover alteration.

The total reduction in the volume of sediment loss by revegetation with erosion controlling grass on the open slopes was 730 m^3 in an extreme water year like 1994/95 (Figure 6.5 - A) and 250 m^3 in an average water year like 1995/96 (Figure 6.5 - B). The model predicts that the greatest percent reduction in sediment loss (82% overall) can be achieved by revegetating the flanking slopes adjacent to the reservoir. For 1994/95, the predicted reduction in the volume of sediment to the reservoir by revegetating the flanking slopes is 440 m^3 or 60% of the total reduction for revegetating open slopes in all proposed areas in the watershed but accounts for only 18% of the total watershed area. For 1995/96, the value predicted is 156 m^3 (also 60% of the total reduction by revegetation with grass). These areas are not the steepest areas of the watershed but when visually inspected were found to be mostly devoid of vegetative cover. Given the unconsolidated nature of the soils, it is not surprising that these areas would provide a sizable reduction in sediment loss when revegetated. More over, the sediment loss from these flanking slopes drains directly into the reservoir. Therefore, revegetation of these areas should be considered.

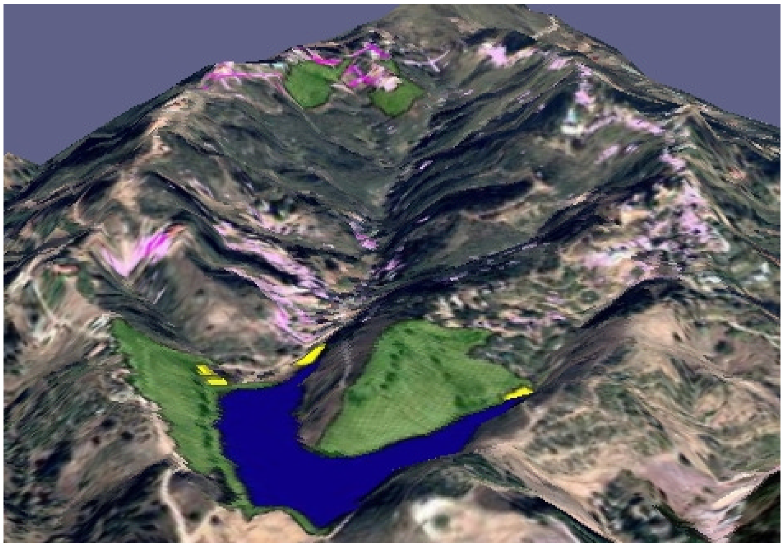
The reductive effects of revegetation of open slopes within the Main debris basin were 177 m^3 (24% of total for revegetation with erosion controlling grass) in 1994/95 and 61 m^3 (24% also) in 1995/96. The sub-catchment drainage area for the Main basin accounts for 65% of the total drainage areas. The predicted volume of sediment flux into the Main debris basin (1790 m^3 in 1994/95) would occupy 65% of its estimated capacity assuming maximum free storage was available initially. Revegetation of slopes in the Main sub-catchment would reduce the sediment flux to 1610 m^3 (1994/95) so it would occupy only 58% of the estimated capacity representing a 7% reduction in the loss of basin capacity. Therefore, the effects of this scenario are not expected to significantly alter the effectiveness of the Main debris basin. These effects are similar in trend but have a smaller magnitude (23% reduced to 21% of estimated basin capacity) in 1995/96. The reduction of sediment flux to the Boy Scout basin by revegetation of open slopes would reduce the loss in the estimated basin capacity from 17% to 15% in 1994/95 and 6% to 5% in 1995/96. The reduction of sediment flux to the HydroPlant basin in this scenario would reduce the loss in estimated basin capacity from 15% to 9% in 1994/95 and from 5% to 3% in 1995/96. Revegetation of open slopes with erosion controlling grasses within the three sub-catchments is not expected to significantly alter the efficacy of the debris basins or the flux of sediment entering the reservoir.

Figure 6.5 Critical Sediment Mobilization Areas - Open Slopes Revegetation

A. 1994/95



B. 1995/96



Sediment Mobilization in kg ha^{-1}

🟪	6.56 x 10^4 to 1.81 x 10^5
🟪	1.81 x 10^5 to 5.24 x 10^5
🟪	5.24 x 10^5 to 9.87 x 10^5
🟪	9.87 x 10^5 to 1.41 x 10^6
🟪	1.41 x 10^6 to 2.80 x 10^6
🟩	Revegetated Open Slopes
🟨	Debris Basins
🟦	Lauro Reservoir

N

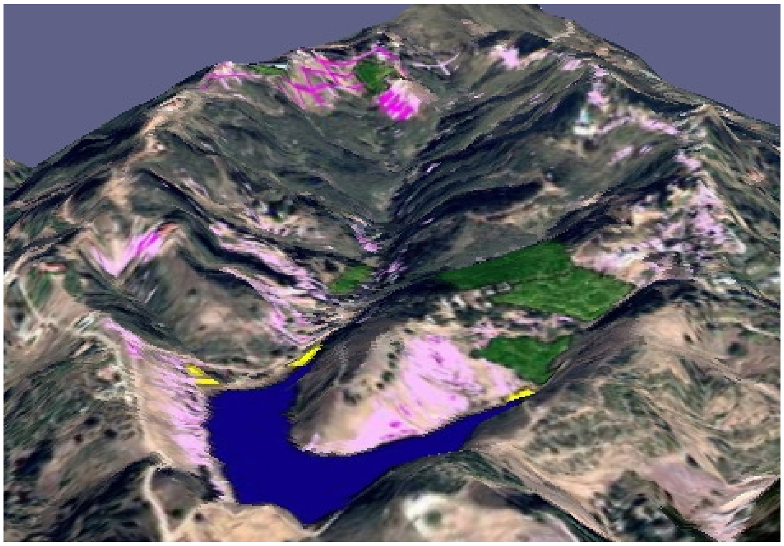
Sediment mobilization values in the figure are critical values determined by selecting values one or more standard deviation above the mean sediment mobilization value for the Status Quo scenario in a normal water year (1995/96). Darker areas represent the most critical areas in the watershed.

Altering the ground cover in the orchards would reduce sediment loss in the entire watershed by 154 m^3 in 1994/95 (Figure 6.6 - A) and by 54 m^3 in 1995/96 (Figure 6.6 - B). This scenario would not affect the sediment loss on the flanking slopes or in the Hydro Plant sub-catchment because there are no orchards in either of these areas. In the Main sub-catchment, altering ground cover within the orchards would reduce sediment loss by 97 m^3 (63% of total reduction by ground cover alteration) in 1994/95 and 33 m^3 (61% of total reduction by ground cover alteration) in 1995/96. In the Boy Scout sub-catchment the reduction was 57 m^3 (37%) in 1994/95 and 21 m^3 (39%) 1995/96. Alteration of ground cover in the orchards would reduce loss in Main basin capacity 4% (1994/95) and 0% (1995/96). Boy Scout capacity loss was reduced by 4% (1994/95) and 1% (1995/96). By itself, alteration of ground cover within the orchards would not have a significant affect on reducing the amount of sediment entering the debris basins. However, alteration of the groundcover in the orchards in conjunction with revegetation of the open and flanking slopes in the watershed would result in an additive effect in minimizing sediment flux to the reservoir.

Figure 6.6 Critical Sediment Mobilization Areas - Orchard Groundcover Alteration

A. 1994/95

B. 1995/96



Sediment Mobilization in kg ha^{-1}

- ▢ 6.56×10^4 to 1.81×10^5
- ■ 1.81×10^5 to 5.24×10^5
- ■ 5.24×10^5 to 9.87×10^5
- ■ 9.87×10^5 to 1.41×10^6
- ■ 1.41×10^6 to 2.80×10^6
- ▨ Orchard Groundcover Alteration
- 🟨 Debris Basins
- 🟦 Lauro Reservoir

N

Sediment mobilization values in the figure are critical values determined by selecting values one or more standard deviation above the mean sediment mobilization value for the Status Quo scenario in a normal water year (1995/96). Darker areas represent the most critical areas in the watershed.

Returning the watershed to native vegetation would virtually eliminate all critical areas in an average water year like 1995/96 (Figure 6.7 - A) but is less effective for an extreme water year such as 1994/95 (Figure 6.7 - B). The natural vegetation scenario was expected to set an upper bound on the amount of sediment reduction achievable in the watershed. This was true for all cases except the revegetation of the flanking slopes area with erosion controlling grass. In this case the all natural vegetation scenario predicted a smaller reduction in sediment loss for the flanking slopes (72%) than if the flanking slopes were revegetated with erosion controlling grass (82% reduction). This was because the C-factor for the chaparral (0.036) is approximately an order of magnitude higher than the C-factor for selected for stabilizing revegetation (0.003) and produces a greater estimated sediment flux.

Figure 6.7 Critical Sediment Mobilization Areas - All Natural

A. 1995/96

B. 1994/95

Sediment Mobilization in kg ha $^{-1}$

- ▢ 6.56×10^4 to 1.81×10^5
- ▢ 1.81×10^5 to 5.24×10^5
- ▢ 5.24×10^5 to 9.87×10^5
- ▢ 9.87×10^5 to 1.41×10^6
- ▢ 1.41×10^6 to 2.80×10^6
- ▨ All Natural Landcover
- 🟨 Debris Basins
- 🟦 Lauro Reservoir

N

Sediment mobilization values in the figure are critical values determined by selecting values one or more standard deviation above the mean sediment mobilization value for the Status Quo scenario in a normal water year (1995/96). Darker areas represent the most critical areas in the watershed.

RUNOFF ACCUMULATION

The results show that for each basin, the total runoff greatly exceeds the current basin capacity (see Appendix C, page C-1). If each basin were expanded according to the basin enlargement management alternative (see Table 3.3), each would be able to collect more runoff, however they would still be unable to collect the total runoff for a year such as 1994/95. While evaporation would remove some water from the basins between storms, there still would be insufficient volume to accommodate all the runoff that would accumulate in a season.

By excluding the four largest storm events of water year 1994/95 (storms 7,8,11 and 16 in Appendix C), and averaging the accumulated runoff from each of the remaining storms of that year, we can determine per average storm accumulated runoff to each debris basin. Table 6.2 shows that for each basin the averaged storm runoff does not exceed the current basin capacity. In fact, the average accumulated runoff volume would only fill the basins to less than 50% of their capacities.

Table 6.2 Current Basin Capacity Compared to Estimated Average Runoff Volume

Debris Basin	Average Accumulated Runoff Volume (m^3)	Current Basin Capacity (m^3)
HydroPlant	190	1,410
Boy Scout	431	2,050
Main	1600	2,760

Sediment concentrations in water can vary greatly. Although it would be difficult to assign a value without conducting field observations, sediment concentrations in the area have been estimated at up to 20% by volume (Simons Li & Associates Inc., 1984). Given a 20% concentration, 7.64×10^4 m^3 of sediment could enter the reservoir in runoff spilling from just the Main basin into the reservoir during an extreme water year such as 1994/95. Considering this value, the goal of preventing sediment from entering the reservoir would not be met by enlarging the basins. Therefore, we must consider the alternatives that will manage runoff accumulated in the basins and decrease sediment mobilization in the watershed.

ASSUMPTIONS AND LIMITATIONS

One of the major limitations to our modeling exercise is the inability to validate the model output using actual observed sediment yield data from the Lauro Canyon Watershed. Yitayew et al. (1999) studied the effectiveness of using ARC/INFO and the RUSLE for estimating erosion in an experimental watershed in southeast Arizona. When comparing estimates of sediment yield for four GIS

RUSLE-based estimates to actual sediment yield data from 1979 to 1989, they found the GIS-based RUSLE tended to underestimate the actual sediment yield. Estimates are good but care must be taken in interpreting results and comparing to actual sediment yields.

Another limitation of the RUSLE is that it is an empirical equation derived from large numbers of experimental sites and therefore should be applied in areas for which it was developed (Dunne and Leopold, 1978). Given that the RUSLE was developed for use in the Mid Western and Eastern United States, its results, when applied in the Mediterranean climate of South-central California, should be interpreted with caution. Another element of caution that must be considered when using an empirical equation is the considerable judgment required in assigning correct values to factors such as vegetation (Gray and Sotir, 1996). This is especially true for this study given that we were unable to gain trespass permission to the majority of the watershed.

Additional limitations in using the RUSLE include the fact that the equation tends to underestimate sediment loss during extreme rainfall events, it only accounts for hillslope erosion and does not consider gully and channel erosion, and it does not account for sediment deposition within the watershed (Gray and Sotir, 1996).

Another key assumption was a uniform rainfall surface within the watershed. Although there is a difference in elevation of approximately 250 m within the watershed, we felt that it was sufficient to apply a uniform rainfall distribution given that there is only one rain gauge in the watershed.

SECTION 7. RECOMMENDATIONS

WATERSHED MANAGEMENT PLAN

Based on the sediment and runoff modeling results and the cost estimates associated with each management alternative, it is the recommendation of the Watershed Analysis Group that the COMB use a combination of revegetative and maintenance efforts to minimize sediment flux into Lauro Reservoir. Improved and enlarged debris basins would achieve a reduction in the sediment flux to the reservoir by increasing the retention volume of each basin and improving their sediment trapping and settling efficiencies. The Main, HydroPlant and Boy Scout basins can be expanded to capacities of 15,940 m^3, 1,750 m^3 and 644 m^3, respectively. For the Main basin, excluding operations and maintenance costs, enlargement costs range from $573,000 to $1,660,000. Considering the enlarged basin would have its capacity exceeded from the four largest storms of water year 1995/96, we felt that this expense was unwarranted. Rather, a combined strategy of revegetation, active basin dewatering, and routine basin excavation would be most effective in managing most of the sediment and runoff produced in almost all but the extreme water years. Therefore, our recommendation for a comprehensive watershed management plan to minimize total sediment into the reservoir includes:

(1) Revegetate the open slopes surrounding the reservoir (flanking slopes) at a one-time cost of $371,000.

(2) Dewater the debris basins between storms to maintain an available storage capacity of at least 50% ($21,000 capital cost).

(3) Excavate the sediment from each debris basin such that the sediment does not occupy greater than 50% of the storage capacity at the beginning of each water year ($20,100 annualized cost, assuming average rainfall).

REVEGETATION

The modeling results indicate that the open slopes located just above the reservoir (flanking slopes) contribute 19% of the total sediment mobilized in the watershed (see Table 5.2). Revegetation of this area would not require major investment of money or effort by COMB, as compared with structural alternatives. The costs associated with revegetating the flanking slopes are considerably less than all other alternatives and since the property is already managed by COMB, there are no anticipated acquisition or permitting difficulties. As shown by the model, this scenario has the potential to reduce sediment mobilization from the flanking slopes by 444 m^3, an 82% reduction for the flanking slopes accounting for 15% of the sediment mobilized in the entire watershed status quo. This represents 60% of the total reduction in sediment mobilization that is predicted if all open slopes in the watershed were revegetated with stabilizing grasses. According to our model, alteration of groundcover in the avocado orchards would result in a 5 and 17% reduction in sediment mobilization from the main and Boy Scout basin sub-catchments respectively. Combined, this accounts for 100% of the reduction in sediment mobilization from altering groundcover in the orchards but is only 5% of the sediment mobilized in the entire watershed for the status quo. This would decrease the sediment mobilized further however, we anticipate resistance from orchard owners because these groundcovers may harbor pests or diseases. This combined with the smaller reduction in sediment mobilization lead us to reject this scenario as a recommended option.

DEBRIS BASIN DEWATERING

As discussed previously, the volume of runoff that can accumulate at each of the debris basins in a larger than average year (like water year 1994/95) will exceed their capacity whether they are expanded or not. Once the basins are compromised, runoff may enter the reservoir directly, carrying sediment with it. If the basins could be kept in a state such that they are ready to receive the next storm's volume of water, the chance of overspill into the reservoir would diminish. Therefore, any management plan should involve the active dewatering of the debris basins between storms as they fill up. The average volume of runoff produced in most of the storms of 1994/95 would not exceed the capacity of the debris basins individually. In fact, the average volume of each storm (excluding the most extreme events) in most cases would not exceed 50% of the storage capacity. Therefore, if COMB were able to pump out each basin once their storage capability had reached 50%, it would allow each basin to more effectively receive and contain the next volume of runoff and hence, sediment.

DEBRIS BASIN EXCAVATION

Sediment build-up from year to year in the basins decreases available storage space for incoming runoff. For that reason, the plan should include a program for sediment excavation such that the storage capacity of each basin at the beginning of each water year should not be less than 50%. By removing sediment accumulation before the rainy season, COMB can avoid the increased costs associated with emergency wet sediment removal in the middle of the season. Not allowing sediment accumulation to exceed 50% of the capacity of each basin also leaves room for runoff storage as discussed above.

USE OF MODEL IN FUTURE

As was demonstrated with our project, data is the limiting factor to performing watershed modeling. Often basic topographical, land use and soil type data is either unavailable or has not been compiled which makes it difficult to perform any type of modeling procedure. This process of accumulating, formatting, and interpreting data from various sources is a time consuming process as much data is inaccessible or not in the proper format. The process of watershed modeling is not without its faults and different models have different levels of reliability and accuracy. However, there is a basic need for baseline data. Our exercise has developed a solid database that can be extended in future research.

We were able to complete preliminary analysis into the critical physical characteristics and processes in Lauro Canyon Watershed. We accumulated a database that includes topography, slope, aspect, flow direction and flow accumulation, land use, land cover, and soil types. Moreover, we have digitally modeled the storm events in water years 1994/95 and 1995/96.

As demand for water use increases in Santa Barbara County, the proper functioning of Lauro Reservoir will gain more and more importance. A natural progression of our work would be an effort to correlate our data and results with field observations. Combining this information would allow more sophisticated models to be implemented in the study of the watershed, which could develop quantitative estimates of sediment, runoff and contaminant transport. With basic software packages and investment into field studies, COMB will be able to utilize the dataset we created to further study the watershed, anticipate the events that precipitate the reservoir going off-line, and meet the increasing demands that will be place on the reservoir.

RECOMMENDATIONS FOR FUTURE RESEARCH

ADDITIONAL REVEGETATION OPPORTUNITIES

Our project identified critical areas of the watershed where sediment mobilization was predicted to be the highest. We modeled management alternatives to control these areas, ignoring other areas that were identified as less critical. Given our limited resources and model resolution we felt that focusing on the most critical areas is supported by the model and is of the most use to COMB. These factors led us to focus on the areas with the highest sediment yields that are most accessible to COMB.

We also felt that the resolution of our model prevented us from accurately discerning if management alternatives involving revegetation would be effective in reducing the total sediment load from these less critical areas. However, by applying management alternatives in these areas, reductions in total sediment load may be possible. A more detailed sediment mobilization and transport analysis should be performed within these areas to determine if they are producing substantial amounts of sediment, and if so, whether management alternatives could be applied that would reduce this sediment loss.

Several of the high sediment producing areas fell within residential boundaries that are devoid of vegetation to provide for wildfire safety around houses. We feel that COMB should investigate methods to revegetate these areas in a way that will reduce sediment mobilization yet continue to provide a fire buffer zone.

WATERSHED DATABASE

One of the difficulties in characterizing the Lauro Canyon Watershed and Lauro Reservoir was the paucity of basic data. There are several recommendations that we can make to COMB for eliminating this problem.

1) In our research, we have modeled the amount of runoff from the Lauro Canyon Watershed. These estimates could not be validated with "truth" data because no previous attempts have been made to gauge or estimate this runoff. We have revealed the importance of runoff estimate accuracy in calculating sediment flux volumes. We recommend that COMB do one of two things to estimate the quantity of runoff from the Lauro Canyon Watershed:
    a) Install stream gauge devices above all of the debris basins to monitor runoff.
    b) Calculate a water balance for the reservoir by compiling the following information:
        i) flow data for water entering Lauro from Mission Tunnel and the South Coast Conduit;
        ii) volume of water inputs from Mission Tunnel and the South Coast Conduit;
        iii) daily total volume of water leaving Lauro and entering Cater;
        iv) daily change in reservoir storage volume.
2) We also modeled the average annual sediment yield for the Lauro Canyon Watershed. These values could not be validated because there has been no attempt to determine the sediment yield from the watershed or concentration of sediment in runoff entering Lauro from Mission Tunnel, the South Coast Conduit, or more importantly from the ephemeral streams that flow into the debris basins during storm events. There are two ways COMB could quantify this.
    a) Measure sediment concentration and turbidity for water entering the debris basins, the reservoir and Cater during storm events. These data can be used to run a regression to develop a relationship between turbidity and sediment concentration. This would allow turbidity data to be

    used to estimate the concentration of sediment entering the reservoir for a given storm.

    b) Determine the current volume of Lauro Reservoir to determine the volume of sediment that has been deposited. This can be done by recording depth and positions in the reservoir with a GPS to produce a bathymetric map of the reservoir. Comparing this volume with the original volume of the reservoir can be used to estimate the amount of sediment that has been deposited in the reservoir. This value can be used to determine a rough volume of sediment that has entered the reservoir on an annual basis and to calibrate the annual sediment deposition values predicted by the model.

3) COMB was unable to provide much data on the amount of sediment that has been removed from the debris basins. Accurately tracking the deposition into the debris basins would facilitate development and refinement of a maintenance schedule for the debris basins.

4) COMB should develop an electronic database that contains the information and data mentioned above and information that has been compiled in this study.

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APPENDICES

Appendix A. GLOSSARY OF SOIL TERMS

The following descriptions are taken directly from the United States Department of Agriculture (USDA) Soil Survey Manual from 1993 or 1951 as noted.

Natural Drainage Classes (USDA, 1993)

Natural drainage class refers to the frequency and duration of wet periods under conditions similar to those under which the soil developed. Alteration of the water regime by man, either through drainage or irrigation, is not a consideration unless the alterations have significantly changed the morphology of the soil. The classes follow:

Somewhat excessively drained. Water is removed from the soil rapidly. Internal free water occurrence commonly is very rare or very deep. The soils are commonly coarse-textured and have high saturated hydraulic conductivity or are very shallow.

Well drained. Water is removed from the soil readily but not rapidly. Internal free water occurrence commonly is deep or very deep; annual duration is not specified. Water is available to plants throughout most of the growing season in humid regions. Wetness does not inhibit growth of roots for significant periods during most growing seasons. The soils are mainly free of the deep to redoximorphic features that are related to wetness.

Runoff (USDA, 1951)

Runoff, sometimes called surface runoff or external soil drainage, refers to the relative rate water is removed by flow over the surface of the soil. This includes water falling as rain as well as water flowing onto the soil from other soils. Where needed for clear descriptions, six classes are recognized based on the relative flow of water from the soil surface as determined by the characteristics of the soil profile, soil slope, climate and cover.

Medium. Surface water flows away at such as rate that a moderate proportion of the water enters the soil profile and free water lies on the surface for only short periods. A large part of the precipitation is absorbed by the soil and used for plant growth, is lost by evaporation, or moves downward into underground channels. With medium runoff, the loss of water over the surface does not reduce seriously the supply available for plant growth. The erosion hazard may be slight to moderate if soils of the class are cultivated.

Rapid. A large portion of the precipitation moves rapidly over the surface of the soil and a small part moves through the surface profile. Surface water runs off nearly as fast as it is added. Soils with rapid runoff are usually moderately steep to steep and have low infiltration capacities. The erosion hazard is commonly moderate to high.

Very Rapid. A very large part of the water moves rapidly over the surface of the soil and a very small part goes through the profile. Surface water runs off as fast as it is added. Soils with very rapid runoff are usually steep or very steep and have low infiltration capacities. The erosion hazard is commonly high or very high.

Erosion Hazard (USDA, 1951).

It is commonly helpful to group soils according to their erodibility or erosion hazard under defined sets of practices. Such a grouping is carried in soil survey reports in tables setting forth the principle characteristics and inferred qualities of the soils. Depending upon the information available and the detail that is significant, soils may be grouped according to erosion hazard into three classes as (1) none to slight, (2) moderate, and (3) high, or into five classes as (1) none, (2) slight, (3) moderate, (4) high, (5) very high.

Meaningful groupings of soils according to erosion hazard are accompanied by descriptions of the sets of soils management practices and cropping systems adapted to them.

Soil Permeability (USDA, 1951)

Soil permeability is that quality of the soil that enables it to transmit water or air. It can be measured quantitatively in terms of rate of flow through a unit cross section of saturated soil in unit time, under specified temperature and hydraulic conditions.

In the absence of precise measurements, soils may be placed into relative permeability classes through studies of structure, texture, porosity, cracking, and other characteristics of the horizons in the soil profile in relation to local use experience.

Sets of relative classes of soil permeability are as follows:

Classification	Possible Rates (in hr^{-1})
Very Slow	< 0.05
Slow	0.05 to 0.20
Moderately Slow	0.20 to 0.80
Moderate	0.80 to 2.50
Moderately Rapid	2.50 to 5.00
Rapid	5.00 to 10.00
Very Rapid	> 10.00

Appendix B. REVEGETATION ALTERNATIVES - COST ESTIMATE CALCULATIONS

Strategy	Initial Project Costs				Operations & Maintenance Costs		
	Stage	O&P Cost* (m^{-2})	Area (m^2)	Total Capital Cost	Unit Cost (m^{-2})	Area (m^2)	Total O&M Costs (yr^{-1})
Open Slopes Revegetation							
Open Slopes Contained in Sub-Catchments	Soil Prep.	$1.72	18,000	$31,000			
	Seeding	$0.51		$9,200			
	Slope Stabilizer	$1.33		$18,000			
	Watering	$0.04		$720			
	Subtotal			**$58,900**			**N/A**
Open Slopes Flanking the Reservoir	Soil Prep.	$1.72	103,000	$177,000			
	Seeding	$0.51		$53,000			
	Slope Stabilizer	$1.33		$137,000			
	Watering	$0.04		$4,100			
	Subtotal			**$371,000**			**N/A**
	Total		**121,000**	**$430,000**			**N/A**
Avocado Orchards - Ground Cover Alteration Options							
1) Grass	Soil Prep.	$1.72	57,000	$98,040			
	Seeding	$0.51		$29,070			
	Watering	$0.04		$2,280			
	Total			**$129,400**	$0.29[†]	57,000	**$16,800**
2) Mulch		$2.19	57,000	**$125,000**	$2.19		**$125,000**
3) Leaf Litter				**N/A**	$0.38[‡]		**$21,500**

Source: RS Means (2000)

* O&P: Overhead and Profit

[†] Annual mowing expense

[‡] Annual cost of maintaining leaf litter to prevent excessive build-up

Appendix C. BASIN ENLARGEMENT ESTIMATES AND CALCULATIONS

Appendix Table C.1 Construction Methods and Associated Equipment Used in Estimating Costs for Enlarging All Three Basins

	Quantity	Equipment & Materials
Site Clearing:		
	1	Chipping machine
	1	F.E. Loader, T.M., 1.9 m^3
	1	Chainsaw, 36 inch
Pump/Dewater:		
	1	Trash pump, 0.9 m^3 min^{-1}
	1	Pump hose, 10.2 cm diameter
	1	Discharge hose, 10.2 cm diameter, 15.2 m length
Excavating		
	1	Crawler mounted, 2.3 m^3 hydraulic excavator
Hauling		
	16	Dump trucks, 7.6 m^3, 1 hour haul cycle
Soil Stabilization		
	1	hydraulic crane, 25 ton
		Rip-rap random, broken stone, machine placed for slope protection 46 cm minimum thickness, not grouted
Concrete Lining		
	1	Gas engine vibrator
	1	Concrete pump
		Cast-in-place cement, 30 cm thickness

Appendix Table C.2 Main Basin Embankment Construction Jobs

Embankment Dimensions:	
	Bank slope: 2.5:1 Height: 3 m Length: 52 m Crest width: 3 m Base width: 18 m
Embankment volume	1,830 m^3
Embankment foundation volume (5 m depth):	1,404 m^3
Total Embankment Volume: (add 10% for settling)	**3,488 m^3 (includes trench volume)**
Trenching:	
Trench volume:	129 m^3 (1m depth throughout embankment length)
Equipment:	1 Tractor loader/backhoe, 0.3 m^3
Hauling:	
Volume hauled:	1,830 m^3 of embankment filler material
Equipment:	10 Dump trucks, 7.6 m^3, 1hr round trip
Filling:	
Volume filled:	1,830 m^3
Equipment:	1 Front end loader, 130 H.P., 1.9 m^3
Compacting:	
Volume compacted:	1,830 m^3
Equipment:	1 Riding vibrating roller, 6 inch lifts, 4 passes

These values are based on the embankment dimensions, which are based on standard design guidelines for earthen embankments

Appendix Table C.3 Estimated Construction Job Size

Construction Job	**Basins**			
	Main		**HydroPlant**	**Boy Scout**
Site Clearing:				
Areas cleared:	Expansion area:	2,970 m^2		
	Embankment footprint:	936 m^2		
Total area cleared:		3,906 m^2		
Pump/Dewater:				
Volume dewatered:		1,380 m^3		
Excavating:				
Areas excavated:	Current embankment:	Height: 3 m Crest Width: 3 m Length: 38 m Slope factor (horizontal:vertical): 2.5:1 Volume: 1,200 m^3		
	Embankment foundation:	Depth: 1.5 m Width: 18 m Length: 52 m Volume: 1,400 m^3		
	Excavated basin volume:	8,220 m^3		
Total volume excavated:		10,800 m^3	644 m^3	1,750 m^3
Hauling:				
Volume hauled:		10,800 m^3	644 m^3	1,750 m^3
		(Soil swelling and wetness not considered)		
Soil Stabilization:				
Area stabilized:		2,440 m^2	451 m^2	756 m^2
		(Includes basin walls and inner slope of embankment)		
Concrete Lining:				
Area lined:		3,960 m^2 at 30 cm thickness		
Volume of concrete:		1,206 m^3		

Jobs are based on the calculated basin volumes and dimensions. These dimensions along with those estimated for the current embankment follow widely accepted design standards.

Appendix Table C.4 Basin Expansion Capital Costs

						Costs				
Basin	**Construction Activity**	**Unit**	**Quantity**	**Daily Output**	**Duration (d)**	**Unit**	**Hourly**	**Daily**	**Total (Low) (Incl. O&P)**	**Total (High) (Adjusted)**
Main	Site Clearing	m^2	3,906	4,047	1	$0.74	$372.30	$2,978	$2,880	$2,880
	Dewatering	m^3	1,380	363	3.8	$0.41	$18.75	$150	$570	$570
	Excavating	m^3	10,800	979	11	$3.07	$375.18	$3,001	$33,200	$33,200
	Hauling	m^3	10,800	979	11	$7.85	$960.00	$7,680	$156,000	$202,300
	Trenching*	m^3	129	115	1.1	$7.44	$106.71	$854	$960	$960
	Filling*	m^3	3,490	459	7.6	$1.07	$61.30	$490	$3,730	$3,730
	Hauling*	m^3	3,490	612	5.7	$7.85	$60.00	$4,800	$92,600	$101,700
	Compacting*	m^3	3,490	1,450	2.4	$0.62	$112.45	$900	$2,160	$6,840
	Soil stabilization	m^2	2,440	44	55	$61.00	$337.89	$2,703	$149,000	--
	Concrete lining[†]	m^3	1,206	--	--	$765.00	--	--	--	$923,000
	Total (30%contingency costs included in Total (High))								**$573,000**	**$1,660,000**
Hydro-Plant	Excavating	m^3	644	979	0.7	$3.07	$375.18	$3,001	$1,980	$1,980
	Hauling	m^3	644	979	0.7	$7.85	$60.00	$7,680	$9,270	$12,040
	Soil Stabilization	m^2	451	44	10	$61.00	$337.89	$2,703	$27,500	$27,500
	Total (30%contingency costs included in Total (High))								**$50,400**	**$54,000**
Boy Scout	Excavating	m^3	1,750	979	3	$3.07	$375.18	$3,001	$5,360	$5,360
	Hauling	m^3	1,750	979	3	$7.85	$60.00	$7,680	$25,200	$32,800
	Soil Stabilization	m^2	756	44	17	$61.00	$337.89	$2,703	$46,100	$46,100
	Total (30%contingency costs included in Total (High))								**$76,700**	**$84,200**
Grand Total									**$700,000**	**$1,800,000**

Costs for each job are represented in per unit, hourly and daily cost.

Daily costs are based on an 8-hour workday.

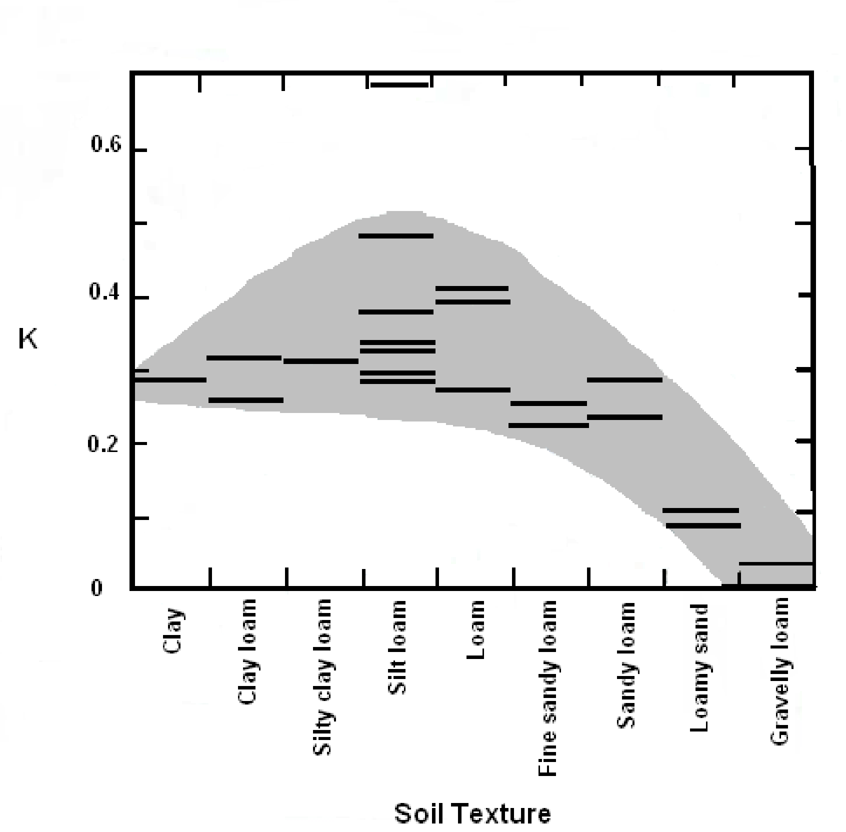
*Construction jobs that are associated with embankment construction.

[†] Concrete lining costs are taken from initial unit cost projections obtained from Summers Engineering Consultants (personal communication).

The total costs for hauling the embankment filler material include their purchasing costs at \$18.70 m^{-3} (based on Proctor Maximum Dry Density of 1810kg m^{-3}.

Appendix D. RESOURCES FOR CALCULATION OF MODEL PARAMETERS

Appendix Figure D.1 Summary of Measured K Values for a Range of Soils



K values are presented for a range of soils in the eastern and central United States. "Each horizontal bar indicates one plot measurement. The shaded area represents the range of the data available so far, apart from a single measurement on silt loam. (Data from Wischmeier and Smith 1965.)" Source: Dunne and Leopold 1978

Appendix Table D.1 ARC/INFO Subroutine to Calculate L and S Factors

Hillslope Length Factor (L)

```
args .flowdir .slope
grid
grid-a = flowlength (%.flowdir%, #, upstream) / 22.13
if (%.slope% < 0.6) l-grid = pow (grid-a, 0.2)
else if (%.slope% >= 0.6 & %.slope% < 1.7) l-grid = pow (grid-a, 0.3)
else if (%.slope% >= 1.7 & %.slope% < 3) l-grid = pow (grid-a, 0.4)
else l-grid = pow (grid-a, 0.5)
endif
quit
kill grid-a
&return
```

Hillslope Gradient Factor (S)

```
&args .slope
&if [null %.slope%] &then
&return &warning Usage: &r s-factor < slope DEG>
&if ^ [exists %.slope% -grid] &then
&return &warning Unable to locate grid %.slope%
grid
grid-a = (%.slope% / deg)
grid-b = sin (grid-a)
grid-c = grid-b * grid-b
s-grid = (65.4 * grid-c) + (4.56 * grid-b) + 0.0654
kill grid-a
kill grid-b
kill grid-c
quit
&return
```

Appendix Table D.2 Cropping-Management Factors (C)

Type of Canopy and Average Fall Height of Water Drops	Canopy Cover (%)	Ground Cover*	Percent Ground Cover					
			0	20	40	60	80	95-100
No appreciable canopy	-	G	.45	.20	.10	.042	.013	.003[†]
		W	.45	.24	.15	.090	.043	.011
Canopy of tall weeds or short brush (0.5 m fall ht)	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
	75	G	.17	.10	.06	.031	.011	.003
Appreciable brush or brushes (2 m fall ht)	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036[‡]	.012	.003
		W	.28	.17	.12	.077	.040	.011
Trees but no appreciable low brush (4 m fall ht)	25	G	.42	.19	.10	.041	.013	.003[♣]
		W	.42	.23	.14	.087	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.083	.041	.011

* G = Cover at surface is grass, grass-like plants, decaying compacted duff, or litter at least 2 inches deep.

W = Cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface, undecayed residue, or both).

[†] Value selected for open slope revegetation

[‡] Value selected for all natural watershed scenario

[♣] Value selected for orchard ground cover alteration

Source: Dunne and Leopold (1978)

Appendix Table D.3 Classification of Soils by their Hydrologic Properties

Classification	Type of Soil
A (low runoff potential)	Soils with high infiltration capacities, even when thoroughly wetted. Chiefly sands and gravels, deep and well drained.
B	Soils with moderate infiltration rates when thoroughly wetted. Moderately deep to deep, moderately well to well drained, with moderately fine to moderately coarse textures.
C	Soils with slow infiltration rates when thoroughly wetted. Usually have a layer that impedes vertical drainage, or have a moderately fine to fine texture.
D (high runoff potential)	Soils with very slow infiltration rates when thoroughly wetted. Chiefly clays with a high swelling potential; soils with a high permanent water table; soils with a clay layer at or near the surface; shallow soils over nearly impervious materials.

Source: Dunne and Leopold (1978)

Appendix Table D.4 Runoff Curve Numbers Chart

Land Use		Hydrologic Soil Group			
		A	B	C	D
Open spaces, lawns, parks, golf courses, cemeteries, etc.					
Good condition: grass cover on 75% or more of the area		39	61	74	80
Fair condition: grass cover on 50% to 75% of the area		49	69	79	84
Commercial and business area (85% impervious)		89	92	94	95
Industrial districts (72% impervious)		81	88	91	93
Residential*					
Average Lot Size	**Average % Impervious**[†]				
1/8 acre or less	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
Paved parking lots, roofs, driveways, etc.[‡]		98	98	98	98
Streets and roads					
Paved with curbs and storm sewers[‡]		98	98	98	98
Gravel		76	85	89	91
Dirt		72	82	87	89

* Curve numbers are computed assuming the runoff from the house and driveway is directed toward the street with a minimum of roof water directed to lawns where additional infiltration could occur.

[†] The remaining pervious areas (lawns) are considered to be in good pasture condition for these curve numbers.

[‡] In some warmer climates of the country a curve number of 95 may be used.

Appendix E. DEFINITION AND SOURCES OF MODEL INPUT PARAMETERS

Model Input	Description	Source
DEM	Digital elevation Model	Map and Imagery Laboratory, UCSB, combined 3 m and 30 m DEM
Watershed Boundary	Delineated boundary	Watershed Environmental
Catchment Boundary	Sub-Catchment boundaries	Delineated From Aerial Photograph
Land use Grid	Delineated Land uses w/in Watershed	Delineated From Aerial Photograph
R-Factor	Rainfall Erosivity Factor	County Gauge 199 Data
K-Factor	Soil Erodibility Factor	SSURGO Soils Data
L-Factor	Hillslope Length Factor	ARC Subroutine
S-Factor	Hillslope Gradient Factor	ARC Subroutine
C-Factor	Cover Management Factor	Delineated From Aerial Photograph
Erosion Grids	Mass of Sediment Mobilized Grids	ARC Subroutine
SCS-Hydro Grid	Soils/Landcover Runoff Grid	Combined Soils and Land Use in ARC
Flow direction	Runoff Flow Direction Grid	ARC Command Flow direction
Flow accumulation	Runoff Flow Accumulation Grid	ARC Command Flow accumulation
Runoff Accumulation Grids	Accumulated Runoff	ARC Subroutine

Appendix F. MODEL PREDICTED ACCUMULATED RUNOFF VOLUMES FOR WATER YEAR 1994/95

Storm Number	Rainfall (cm)	Accumulated Runoff Volume (m^3)		
		HydroPlant	Boy Scout	Main
1	3.18	206	494	1,420
2	1.02	5.14	1.61	3.29
3	3.68	388	740	2,340
4	0.38	0	0	0
5	0.38	0	0	0
6	2.03	58.8	104	266
7	15.1	4860	10400	50,800
8	42.0	14400	39000	211,000
9	1.78	40.4	56	160
10	2.03	58.9	104	266
11	17.4	5990	12700	63,300
12	2.92	163	387	1,050
13	0.33	0	0	0
14	2.92	163	387	1,050
15	6.10	982	2290	9,080
16	15.2	4920	10600	51,500
17	5.20	700	1660	6,220
18	0.76	1.07	0.2	0.02
19	3.56	280	675	2,090
20	0.51	0	0	0
Total Accumulated Runoff:	**126.6**	**33,200**	**79,600**	**400,000**
Current Basin Capacity (m^3):		**1,409**	**2,050**	**2,670**

Appendix G. RATIONAL METHOD CALCULATIONS

Appendix Table G.1 Sub-Catchment Characteristics

Sub-Catchment	Area (hectares)	Height of Most Remote Point (m)	Height of Debris Basin (m)	Distance Between Points (L) (m)
HydroPlant	65.9	277.0	172.0	300.0
Boy Scout	116.3	288.0	172.0	570.0
Main	682.6	314.0	173.0	1050.0

Appendix Table G.2 Time of Concentration (t_c) and Rainfall Intensity Values (i)

Sub-Catchment	Concentration Time (t_c, in min)	Storm Return Interval (Year)	Rainfall Intensity Value (I, in mm hr $^{-1}$)
HydroPlant	2.34	Q_{10}	82.6
		Q_{25}	95.3
		Q_{50}	114.0
Boy Scout	4.72	Q_{10}	76.2
		Q_{25}	88.9
		Q_{50}	102.0
Main	8.84	Q_{10}	66.0
		Q_{25}	81.3
		Q_{50}	88.9

Appendix Table G.3 Runoff Coefficient Values

Land Use Type	C_{low}	C_{high}
Built Areas	0.40	0.50
Shrubs	0.25	0.35
Orchards	0.30	0.40
Chaparral	0.20	0.30
Open Slopes	0.30	0.35
Mixed Grass and Trees	0.30	0.35

Appendix Table G.4 Weighted Runoff Coefficient Values for Each Catchment

Sub-Catchment	Weighted C_{low}	Weighted C_{high}
HydroPlant	0.25	0.33
Boy Scout	0.29	0.37
Main	0.24	0.34