# Agua Hedionda Watershed Modeling and Geomorphic Analysis Report

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# 1 Introduction

The San Diego Regional Water Quality Board (SDRWQCB) has listed Agua Hedionda Creek, Buena Creek, and Agua Hedionda Lagoon as impaired and not supporting designated beneficial uses under the Clean Water Act Section 303(d). Portions of the Agua Hedionda Creek are impaired for total dissolved solids (TDS), manganese, selenium, and sulfates. Buena Creek is listed for DDT, nitrate-nitrite, and phosphate. The lagoon is impaired from excess sediment and bacteria. Though several of the impairments are attributed to unknown sources, the bacterial and sediment-related impairments have been attributed to urban runoff and other nonpoint sources. Monitoring is underway to collect sufficient data to develop TMDLs for these water bodies under a separate project.

To support the development of a Watershed Management Plan (WMP) for the Agua Hedionda watershed, the current analysis provides a preliminary understanding of watershed contributions to existing impairment from sediment and bacteria, an evaluation of the differences between past and future conditions relative to existing conditions, and an assessment of hydromodification impacts to physical integrity of stream channels and habitat. In addition, since the findings of the Agua Hedionda Watershed Water Quality Analysis and Recommendations Report (City of Vista, 2007) suggested an increasing trend in nutrients within the Agua Hedionda watershed, total nitrogen (TN) and total phosphorus (TP) are also evaluated.

The evaluation of hydromodification and pollutant loading is being conducted using a geomorphic analysis, combining field assessment with historic data analysis, and a watershed model that describes hydrology and pollutant loading of TN, TP, sediment, and bacteria (fecal coliform). The analyses support multiple WMP goals and objectives. The goals supported include:

1. Design land use and infrastructure so as to minimize impacts on the watershed
2. Protect, restore and enhance habitat in the watershed
3. Restore watershed functions, including hydrology, water quality, and habitat, using a balanced approach that minimizes negative impacts
4. Support compliance with regional, state, and federal regulatory requirements.

Evaluation of the following indicators under goals 1 and 2 is supported by the modeling analysis: water quality in terms of relative nutrient, upland sediment, and bacteria loading; stream stability; frequency, magnitude, and duration of extreme high flows; and percent imperviousness. The geomorphic analysis supports these indicators as well as those related to restoration and habitat improvement.

Analysis of past, present, and future scenarios is used to guide identification of current areas of degradation and contributors to lagoon impairment as well as potential threats from future development. This can provide important information for identifying key areas where watershed management and improvement projects can be focused.

This report satisfies the Grant Agreement submittal of the "Hydrologic Model and Summary Report" to the State Water Resources Control Board.

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# 2 Model Development

An application of the Loading Simulation Program C++ (LSPC) was developed to address local watershed issues in the Agua Hedionda watershed, building off a San Diego Region application of LSPC for the U.S. Environmental Protection Agency (CARWQCB and USEPA, 2005). LSPC is a continuous watershed model supported by U.S. Environmental Protection Agency (USEPA) and has been used widely throughout Southern California. The model will be used to guide identification of existing areas of elevated pollutant loading and stream channel impacts when combined with information from the stream characterization and geomorphic analysis.

## 2.1 LSPC Model

LSPC is a continuous watershed model developed by the USEPA Region 4, with support of Tetra Tech. The modeling system incorporates Hydrological Simulation Program—FORTRAN (Bicknell et al., 1996) algorithms for simulating hydrology, sediment, and general water quality on land as well as a stream transport model. The LSPC application will be developed to predict flow and represent the build up, wash off, and applicable first order decay processes of nutrients and bacteria as well as sediment generation and transport processes.

Multiple hydrologic components are contained within LSPC including precipitation, interception, evapotranspiration (ET), overland flow, infiltration, interflow, subsurface storage, groundwater flow, and groundwater loss. Figure 2-1 provides a graphical representation of these processes and associated model parameters based on the Stanford Watershed Model. Water introduced into the system is subject to ET and transport through various storage zones eventually flowing to the receiving stream or deep groundwater.

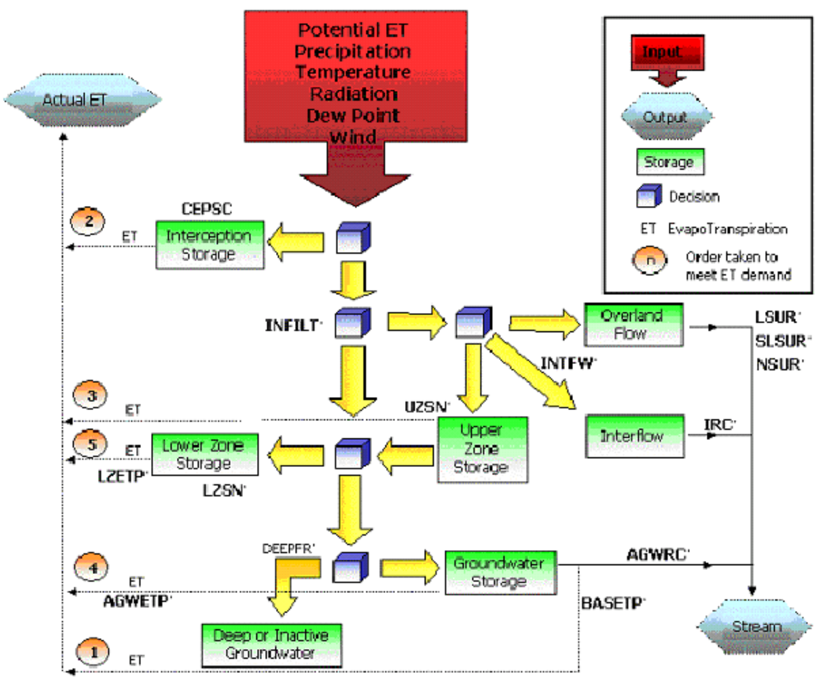


**Figure 2-1. Schematic of LSPC Hydrology Components**

## 2.2 Model Inputs

LSPC is a continuous model that requires inputs of land use by subwatershed, stream channel characteristics, and meteorological data (includes precipitation and evaporation).

### 2.2.1 Subwatersheds and Stream Segments

The subwatershed delineation for Agua Hedionda is derived from a 10 meter resolution digital elevation model (DEM) from the National Elevation Dataset. Boundaries were modified using the municipal storm sewer networks, 2-foot contour topography layers, and aerial images[1]. Accordingly, 29 subwatersheds (not including the "beach" watershed, model ID 999) were delineated with an average size of 1.1 $mi^2$ and covering an area of 31 $mi^2$ (Figure 2-2).

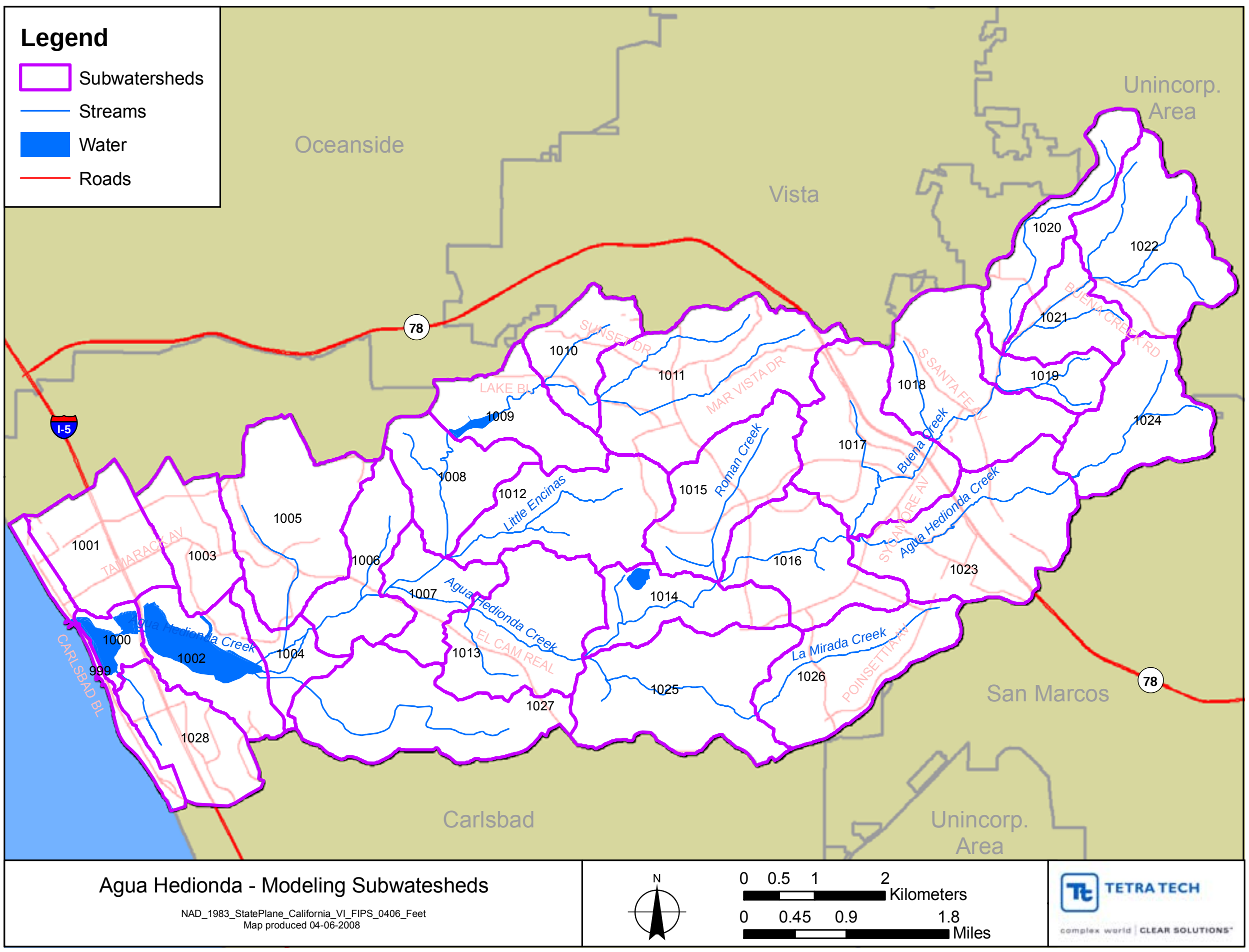


**Figure 2-2. Map of Agua Hedionda Model Subwatersheds**

[1] The City of Vista and Carlsbad are currently developing SWMM modeling of stormwater hydrology. SWMM model subwatersheds (at a finer scale than this project) were provided by Dudek Engineering and Environmental in March 2008. A cursory review of the two boundary sets did not indicate any major discrepancies.

Each delineated subwatershed is represented with a single stream segment, originating from the National Hydrography Dataset (NHD) and assumed to be a completely mixed, one-dimensional segment with a trapezoidal cross-section. One exception is Lake Calavera, described below. Once the representative reaches were identified, slopes were calculated based on elevation data (10 m DEM) and stream lengths measured from the original NHD stream coverage. In addition to stream slope and length, mean depths and channel widths are required to route flow and pollutants. Mean stream depth and channel width were estimated using regression curves that relate upstream drainage area to stream dimensions available in the LSPC model setup spreadsheet described in the LSPC manual (USEPA, 2002). An estimated Manning's roughness coefficient of 0.04 was applied to each representative stream reach based on information contained in the Agua Hedionda Flood Plain Delineation Study (SAAD, 2002).

Built in 1940, Lake Calavera is a manmade reservoir owned by the Carlsbad Municipal Water District and operated for the primary purpose of flood control. The lake was represented in the model due to its impact on flow and water quality in the Calavera Creek watershed. Representation in the model was based on information obtained from the City of Carlsbad (personal communication, Dave Ahles, City of Carlsbad, March 18, 2008) and several assumptions on lake operation including:

1. Storage capacity of 480 acre-feet
2. Outflow that assumes the lake is managed to maintain a working volume
3. Draw down between spillway and working volume occurs at the 3-valve rate calculated in the Outlet Pipe Hydraulics spreadsheet received from the City of Carlsbad
4. Spillway with a design flow of 2,300 cfs, which is assumed to occur at the design maximum
5. Weir equation of Q = (mb)*H^1.5.

Two additional impoundments were represented as reaches rather than lakes in the current model. The lake at Squire's Dam is a headwater lake and has little impact on flow relative to the scale of the model. Agua Hedionda lagoon is also represented as a reach because the focus is on loading to the lagoon rather than simulating the lagoon itself.

### 2.2.2 Land Use

Land use data for existing (2007) and future baseline (2030) is based on data obtained from the San Diego Association of Governments (SANDAG). SANDAG GIS coverages were modified using parcel data to allow for a finer resolution of residential categories based on lot size. Future land use was modified based on feedback from municipalities on changes in underdeveloped and undeveloped land use from the existing condition. SANDAG classifications were grouped into a smaller number of categories for the model application (see Table A-1 in Appendix A).

LSPC algorithms require land use in pervious and impervious categories. Impervious assumptions for the Agua Hedionda model are based largely on interpolations of values in SCS (1986)[2]. The land use categories and impervious assumptions for the model are listed in Table 2-1. Figure 2-3 and Figure 2-4 present the land use scenarios for use in the model.

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[2] Tetra Tech explored the use of the MRLC's NLCD impervious cover data for use in determining local impervious estimates. NLCD imperviousness is based on reflectance. In Southern California it appears to count beaches and other sandy areas as impervious surfaces (which they are not). Undeveloped areas of the watershed also have dispersed areas of bare rock. Given the lack of dense vegetative cover, this is also tabulated as imperviousness. This is indeed largely impervious, but is not anthropogenic nor is it connected imperviousness. For these reasons, NLCD appears to overestimate the impervious area in the watershed, particularly for areas that are not developed.

**Table 2-1. Land Use Categories and Impervious Assumptions in the Agua Hedionda Watershed**

| Land Use Category | Lot Size | % Impervious | Source/Assumptions |
|---|---|---|---|
| Heavy Commercial/Transportation | Variable | 85 | SCS (1986) |
| Warehouse/Industrial | Variable | 72 | SCS (1986) |
| Lt. Commercial/Office/Institutional | Variable | 53 | Cappiella and Brown (2001) |
| Multi-Family Residential | Variable | 65 | SCS (1986) |
| High Density Residential | ≤ 0.25 | 51 | SCS (1986) |
| Medium Density Residential | 0.25 - 0.5 ac | 33 | SCS (1986) |
| Low Density Residential | 0.5 - 1 ac | 23 | SCS (1986) |
| Very Low Density Residential | > 1 ac | 12 | SCS (1986) |
| Transitional | Variable | 0 | assume zero |
| Parks/Recreation | Variable | 12 | same as 2 acre lot |
| Open/Recreation | Variable | 0 | assume zero |
| Agriculture | Variable | 0 | assume zero |
| Open | Variable | 0 | assume zero |
| Water | Variable | 0 | assume zero |

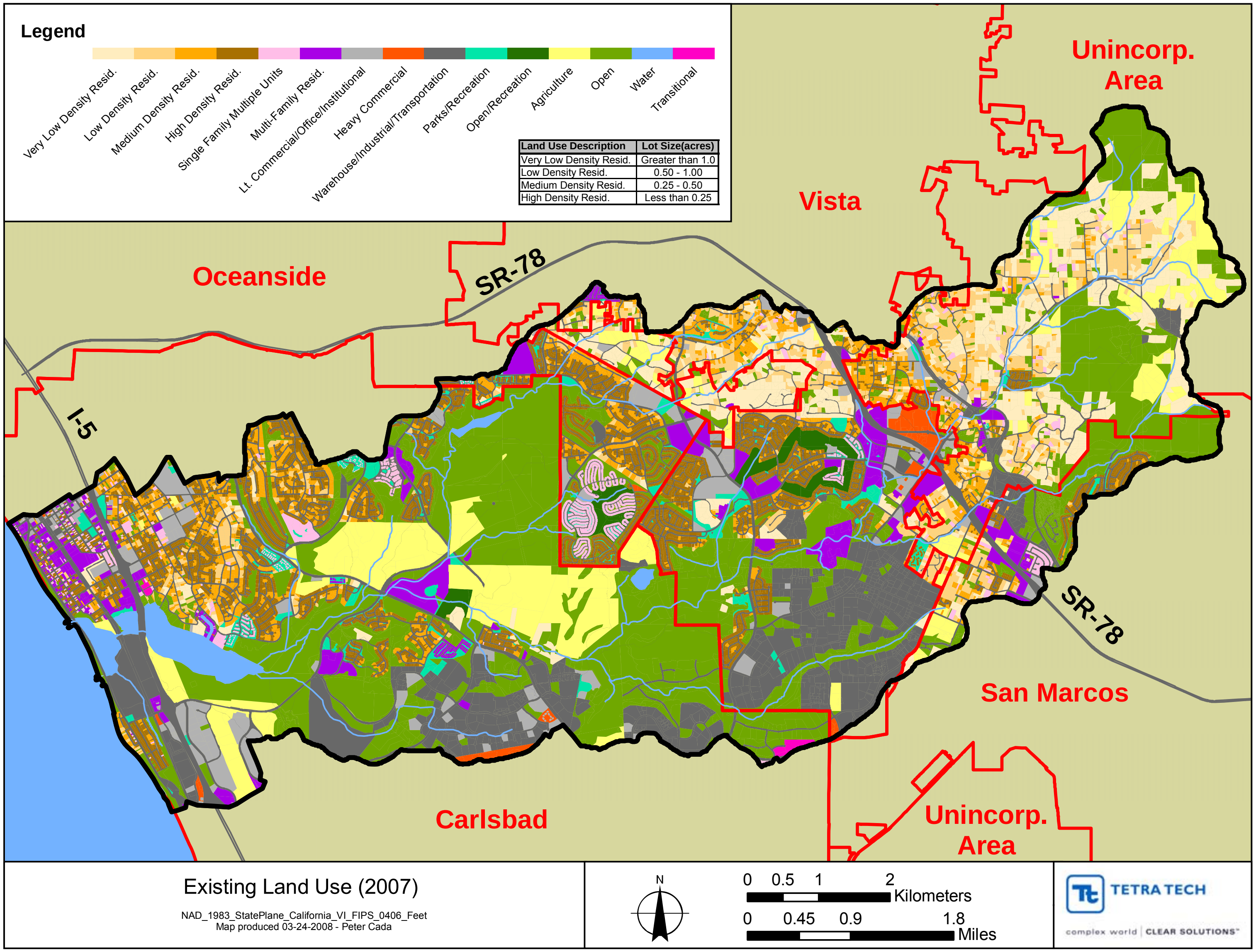


**Figure 2-3. Existing (2007) Land Use in the Agua Hedionda Watershed**

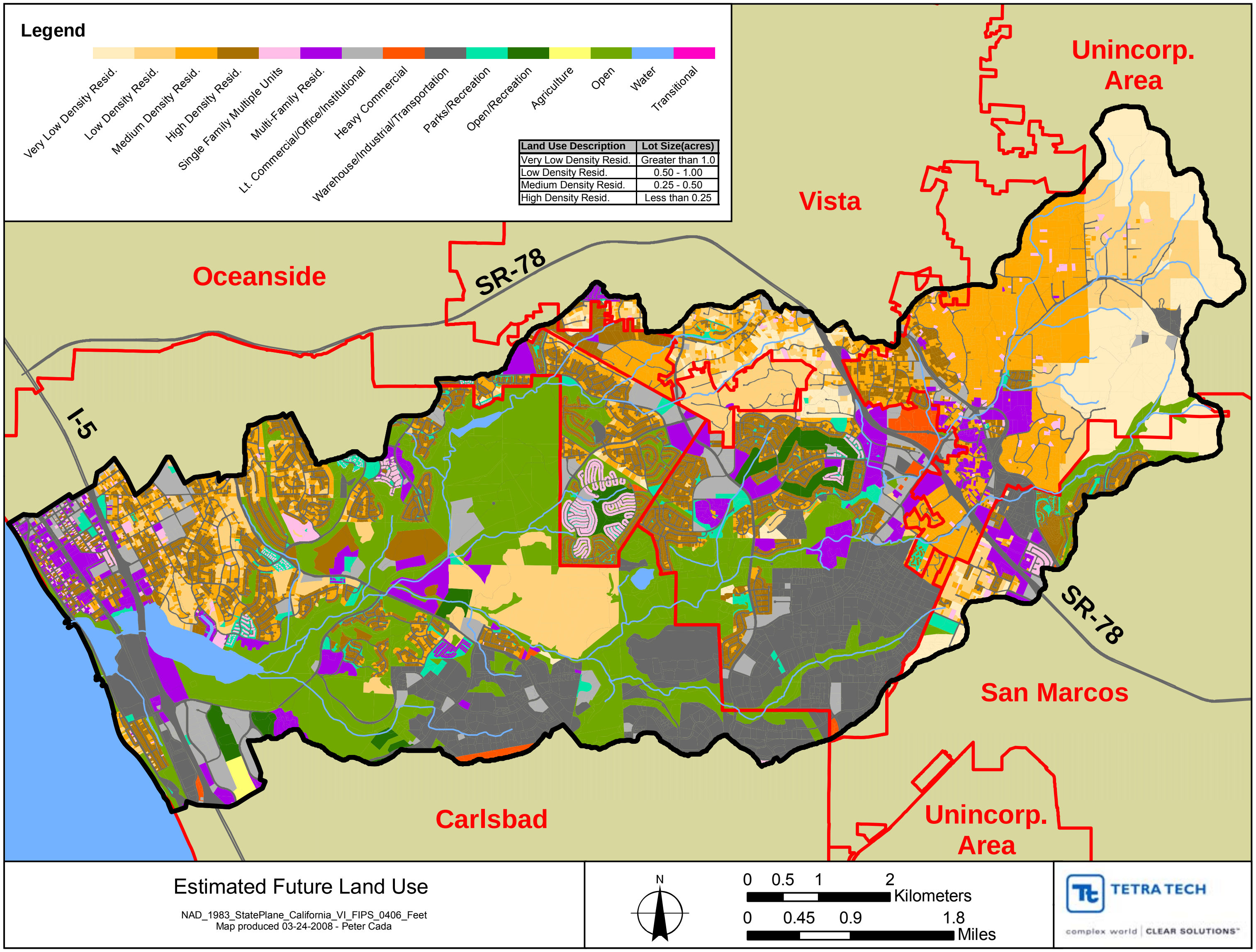


**Figure 2-4. Estimated Future (2030) Land Use in the Agua Hedionda Watershed**

A comparison of land use change between the Existing and Future Scenario shows large decreases in Agriculture and Open Space in the future (Table 2-2). Concurrently, Low Density and Medium Density Residential are expected to increase along with other higher density land uses. Also, more than 13 percent of the watershed is being redeveloped according to the future land use projections due to both specific redevelopment projects (e.g., City of Vista) and increases in density of existing development areas (particularly in the uppermost portions of the watershed).

**Table 2-2. Land Use Change from Existing to Future**

| Land Use Category | Percent Change |
|---|---|
| Heavy Commercial | 333% |
| Medium Density Residential | 123% |
| Low Density Residential | 87% |
| Multi-Family Residential | 45% |
| Open Recreation | 44% |
| Lt. Commercial/Office/Institutional | 27% |
| Warehouse/Industrial/Transportation | 11% |
| Parks/Recreation | 8% |
| High Density Residential | 0% |
| Water | 0% |
| Very Low Density Residential | -11% |
| Open Space | -34% |
| Agriculture | -98% |
| Transitional | -100% |

### 2.2.3 Meteorological Data

Simulation with a continuous model is driven by meteorological data, including rainfall and potential evapotranspiration (amount of water that can be evaporated or transpired by vegetation). Hourly rainfall data were obtained from the National Climatic Data Center (NCDC) station CA6379 at the Oceanside Pumping Plant covering 17 years (January 1, 1990 through December 31, 2006). To augment the NCDC data, hourly rainfall data were also obtained from the California Irrigation Management Information System (CIMIS); and the ALERT (Automatic Local Evaluation in Real-Time) Flood Warning System.

Because rainfall gages are not always in operation and accurately recording data, the resulting dataset may contain various intervals of accumulated, missing, or deleted data. Missing or deleted intervals are periods over which either the rainfall gage malfunctioned or the data records were somehow lost. Accumulated intervals represent cumulative precipitation over several hours, but the exact hourly distribution of the data is unknown. To address the incomplete portions, it is necessary to patch the rainfall data with information from nearby gages. The precipitation record for CA6379 was patched as needed using Tetra Tech’s MetAdapt tool. Since the station is located outside of the watershed and in an area that receives less rainfall than significant portions of the upper Agua Hedionda watershed (the station is located closer to the coast), a multiplier (1.075) was used to account for the increased precipitation that occurs on average across the entire watershed.

Potential evapotranspiration (PET) data were obtained from CIMIS. Data were updated to reflect the appropriate CIMIS evapotranspiration zone. ET data were obtained from CIMIS for seven stations and used to develop hourly ET time series for each of the five ET zones. A GIS coverage of the ET zones developed by CIMIS for the State of California was obtained. Table 2-3 summarizes the CIMIS stations used to assign hourly ET values. The primary stations used to develop a time series were chosen based on proximity to the weather station, matching ET zone, and dates of activity matching the simulation period (1/1/1990 to 12/31/2006). For days where a primary station did not record ET, a secondary station was used to patch the missing dates. A ratio of the average annual ET over the simulation period was used to scale up or down the secondary ET values as needed.

**Table 2-3. Assignment of CIMIS ET Data to Each Weather Station**

| ET Zone | Primary CIMIS Stations | Secondary CIMIS Stations | Weather Stations |
|---|---|---|---|
| 3 | CIMIS66 (1/1/90 to 12/18/01)<br>CIMIS184 (4/19/02 to 12/31/06) | CIMIS49 (1/1/90 to 4/17/02)<br>CIMIS153 (2/1/99 to 12/31/06) | CA6379 |

### 2.2.4 Irrigation

Most of the water supply is imported into the watershed. The representation of landscape irrigation in the model is important for simulating summer hydrology. According to the San Diego County Water Authority (SDCWA), about 50 to 70 percent of water use is for irrigation (personal communication with Carlos Michelon, SDCWA, March 4, 2008). The Model Local Water Efficient Landscape Ordinance (1992) specifies restrictions on irrigation in the watershed. Rulemaking is currently underway to strengthen the 1992 requirements by 2010.

Lawn irrigation is represented in the model as demand based (based on PET). All landscape irrigation water is derived from a source outside of the watershed. An ET adjustment factor, applied to reference evapotranspiration to adjust for plant factors and irrigation efficiency, of 0.8 is used based on the 1992 ordinance.

### 2.2.5 Model Parameters

The initial basis for model parameterization was derived from the following sources:

- Hydrology: San Diego Region TMDL Model (CARWQCB and USEPA, 2005)
- Bacteria: San Diego Region TMDL Model (CARWQCB and USEPA, 2005)
- Nutrients: San Jacinto Model (Santa Ana Watershed Project Authority, 2003)
- Sediment: Local Watershed Properties and SCCWRP Regional Sediment Approach (discussed in Appendix B)

Hydrologic parameters are provided in Appendix C. Some parameters were adjusted during calibration to achieve reasonable loading rates (see Appendix D) by land use class and to improve model fit to data collected in the Agua Hedionda watershed.

## 2.3 Stormwater Requirements

Each regional board operates a stormwater program that issues permits to comply with federal NPDES requirements. Under the Clean Water Act, the federal NPDES stormwater program requires municipal separate storm sewer systems (MS4s) designated by the EPA to meet stormwater runoff control requirements. The SWRCB has issued an MS4 General Permit that applies to all regulated MS4s in the state. To facilitate compliance with the Statewide Small MS4 General Permit, the San Diego Regional Board is one of several regional boards who have issued a regional permit. In addition to the municipal stormwater permit, the regional boards also administer a statewide General Construction Permit, which regulates stormwater discharges from construction sites, and a statewide General Industrial Permit, which regulates stormwater discharges for specific industrial practices.

To comply with the federal Clean Water Act Section 402(p) rulemaking and the first statewide general municipal stormwater permit, the Regional Board adopted its first regional stormwater permit by Order 90-42 in 1990. The permit required local governments to initiate urban runoff and stormwater management programs, eliminate illicit discharges, and implement BMPs on existing development. The BMPs that were implemented on existing development tended to be source control BMPs, such as street sweeping. Order 90-42 did not require new development to control and treat stormwater (personal communication, P. Hammer, SWRCB, December 11, 2007).

With Order 2001-01, the SWRCB updated the MS4 permit in 2001 to include stormwater control and treatment requirements for new development, hereafter referred to as the 2001 Order (SD RWQCB, 2001). The Regional Board subsequently updated the permit in January 2007 by issuing Final Order No. R9-2007-0001, hereafter referred to as the 2007 Order (SD RWQCB, 2007). These orders regulate discharges of urban runoff, defined as:

> Urban Runoff – all flows in a storm water conveyance system and consists of the following components: (1) storm water (wet weather flows) and (2) non-storm water illicit discharges (dry weather flows) (SD RWQCB (2007).

The copermittees were required to comply with most of the order's provisions by January 23, 2008. However, due to staff reassignments for fire storm recovery efforts, Copermittees were granted an extension of 60 days for several of the plan updates and the Construction Ordinance update.

The MS4 copermittees within the Agua Hedionda watershed are San Diego County and the cities of Carlsbad, Vista, Oceanside, and San Marcos. Each copermittee must prepare a written account of its plan to comply with the overall 2007 Order and incorporate the permit requirements into their jurisdiction's stormwater requirements. This written account is entitled the Jurisdictional Urban Runoff Management Plan (JURMP). Several other plans are required under the order, including the Standard Urban Stormwater Mitigation Plan (SUSMP), which outlines the structural and nonstructural practices to be used to meet MS4 permit requirements for new development and significant redevelopment and provides guidelines for the selection, design, implementation, and maintenance of those practices. The copermittees were required to update JURMPs and SUSMPs developed under the 2001 Order to comply with the 2007 Order. All jurisdictions in the Agua Hedionda watershed have updated their stormwater plans and requirements. The following sections describe the major requirements of the 2001 Order as well as the additional requirements of the 2007 Order.

Priority Developments

The pollutant discharge requirements outlined in the 2001 and 2007 Orders apply to Priority Developments, whose characteristics are specified in the order and include most new and redevelopment above specific areas or densities. Under the current and future requirements, new development priority developments include, but are not limited to, housing subdivisions of 10 or more dwelling units and commercial and heavy industry developments above one acre. The following developments greater than 5,000 square feet are also considered priority developments: restaurants, retail gasoline outlets, all hillside development, and paved areas that will be used for transportation. Development is considered "hillside" if it is located on erosive soils and on natural soil with slopes equal to or greater than 25 percent. Redevelopment is considered priority development if it creates, adds, or replaces at least 5,000 square feet of impervious surface on an already developed site that falls under the same development and location categories as priority new development.

Priority development includes development discharging stormwater to receiving waters of environmentally sensitive areas (ESAs), including water bodies designated as supporting a RARE beneficial use (supporting rare, threatened or endangered species) and CWA 303(d) impaired water bodies. Agua Hedionda Lagoon qualifies as an ESA since it is designated in the Basin Plan as supporting a RARE beneficial use. Priority development impacting an ESA is defined as:

> All development located within or directly adjacent to or discharging directly to an ESA (where discharges from the development or redevelopment will enter receiving waters within the ESA), which either creates 2,500 square feet of impervious surface on a proposed project site or increases the area of imperviousness of a proposed project site to 10 percent or more of its naturally occurring condition. “Directly adjacent” means situated within 200 feet of the ESA. “Discharging directly to” means outflow from a drainage conveyance system that is composed entirely of flows from the subject development or redevelopment site, and not commingled with flows from adjacent lands (SD RWQCB, 2007).

Pollutants of Concern and Treatment Control BMP Requirements

All priority developments must employ treatment control BMPs under the 2001 and 2007 Orders. The developer must prepare a stormwater management plan that details how stormwater will be managed on the site. The developer must also specify the pollutants of concern. The SUSMP specifies pollutants of concern for general development categories; additional pollutants may be considered if a development will discharge to a 303(d)-listed waterbody.

Next, treatment control BMPs are selected to treat the pollutants of concern for a particular development. Each copermittee’s current SUSMP contains a list of treatment BMPs whose pollutant removal efficiencies are rated according to high, medium, and low pollutant removal. The developer must use a single BMP or treatment train that addresses each pollutant of concern with high or medium pollutant removal. Low ratings are only allowed if a feasibility analysis shows that high to medium BMPs are not feasible. Developers must site BMPs as close as possible to the pollutant source unless shared BMPs are used. Each jurisdiction is required to oversee developer compliance during the project approval and development permitting process.

Hydrology Requirements

The following regional hydrology requirements for priority developments are currently in place and will continue to be in place with the 2007 Order:

> i. Volume-based treatment control BMPs shall be designed to mitigate (infiltrate, filter, or treat) the volume of runoff produced from a 24-hour 85th percentile storm event, as determined from the County of San Diego’s 85th Percentile Precipitation Isopluvial Map; or
>
> ii. Flow-based treatment control BMPs shall be designed to mitigate (infiltrate, filter, or treat) either: a) the maximum flow rate of runoff produced from a rainfall intensity of 0.2 inch of rainfall per hour, for each hour of a storm event; or b) the maximum flow rate of runoff produced by the 85th percentile hourly rainfall intensity (for each hour of a storm event), as determined from the local historical rainfall record, multiplied by a factor of two.

In addition to enforcing the current hydrology requirements, the copermittees must collaborate on the development of a Hydromodification Plan (HMP) by January 2009. The HMP will specify criteria to reduce downstream erosion and protect stream habitat. As the HMP is being developed, the copermittees are required to develop interim criteria by early 2008. The criteria will apply to any development greater than 50 acres that does not drain to a hardened facility (e.g., concrete channel) leading directly to the ocean. The criteria are likely to involve a tool that calculates the required size of a treatment basin based on a site's land use and impervious surface (personal communication, D. Hauser, City of Carlsbad, October 19, 2007).

The permanent HMP criteria will apply to all priority developments and will maintain runoff at or near the pre-development peak flow for a continuous range of storm events (e.g., all events within the 2-yr or less to 10-yr range). The continuous range of storm events would represent the events during which the greatest, cumulative erosion impact or effective work on the channel is likely to occur. This type of requirement has been used in northern California, and a storm event range from one-tenth of the 2-year to the 10-year storm has been applied. Although modeling is required to determine the appropriate range for southern California, a storm event range closer to the 5-year to 15-year storm may be used since rainfall frequency is lower in southern California (personal communication, D. Hauser, City of Carlsbad, October 19, 2007).

Low Impact Development (LID) Requirements

The 2007 Order requires priority development projects to use Low Impact Development (LID) techniques to minimize impervious surface and promote infiltration. Each priority development must be designed to minimize connected impervious areas and direct runoff from impervious surface to pervious areas. The pervious areas must be designed to treat and infiltrate runoff from impervious areas. For priority developments with low traffic areas and appropriate soils, a portion of the impervious surface must be constructed with permeable pavement. In addition to the use of these LID design techniques, developers are required to implement the following LID BMPs where applicable and feasible:

- Conserve natural areas
- Minimize width of streets, parking areas, and walkways
- Minimize impervious footprint
- Minimize soil compaction
- Minimize disturbance to natural drainages

### 2.3.1 BMP Representation in the Model

A large number of BMPs are applicable to the urban lands, and these are typically applied in various combinations, configurations, and sizes depending on the characteristics of the development and site conditions. For this analysis, two BMP categories were defined that represent groups of typical practices with similar functions. This consolidation was necessary to avoid analysis of an unmanageable number of alternatives and relies on defining expected performance in terms of primary function for a group of BMPs. While the performance of individual BMPs or individual storm water quality improvement projects could vary from these estimates, this approach is reasonable for the purpose of estimating average expected load reductions by scenario.

Following a similar approach used in the Lake Tahoe Basin (CARWQCB and NDEP, 2007), BMPs were grouped into two major load reduction elements for the purpose of estimating performance by function—Hydrologic Source Controls (HSCs), and Storm Water Treatment (SWT). Pollutant load reductions can be associated with each of these major elements. These practices are often applied in combinations and their performance is interdependent (e.g., HSC increases SWT effectiveness by reducing runoff volumes).

- HSCs reduce runoff volumes and rates through runoff interception, infiltration, and disconnection of impervious surfaces. HSCs primarily function is to increase infiltration, which routes precipitation or surface runoff to groundwater. Examples may include vegetated swales, biofilters, infiltration basins, permeable pavement, and media filters. Swales were the most common HSC practice in the Agua Hedionda watershed.

- SWTs removes pollutants after they have entered concentrated storm water runoff flow paths. This might include treatment of flows to be infiltrated to groundwater as well as those to be discharged to surface waters. Examples may include extended dry detention, constructed wetlands, wet ponds, and hydrodynamic devices Dry detention basins were the most common SWT practice in the Agua Hedionda watershed.

The performance of HSCs for runoff reduction is specified using storage and infiltration parameters on a unit impervious area basis. The total volume of runoff captured by HSCs within a treatment tier will vary by subwatershed in the model, but performance in terms of total runoff volume ( percent capture, or capture ratio) should be relatively uniform. After routing through HSCs, runoff is routed to an SWT. SWT performance is defined by achievable effluent concentrations based on literature for the portion of the runoff treated. Bypassed flows for SWT are assumed to discharge to surface waters at influent concentrations. SWT inputs include storage and infiltration parameters that affect capture ratio.

## 2.3.2 BMP Design

### 2.3.2.1 BMP Designs Based on 2001 Order

In the model, the water quality treatment requirements for priority projects in SDRWQB Order 2001-01 have been applied to the Existing Scenario. For the Future Scenario, priority projects must meet Order 2001-01 plus the 2007 Order. Tetra Tech has assumed that Very Low Density (>1ac) and approximately half of Low Density categories (0.5-1.0 ac) would not be considered priority projects (personal communication, T. Snyder, San Diego County, March 11, 2008).

The treatment requirements can technically be met with either volume-based or flow-based BMPs; a site is not required to have both. The co-permittees under the 2001 Order (San Diego County and the Agua Hedionda watershed communities) are required to develop Standard Urban Stormwater Mitigation Plans (SUSMP) which outline the structural and nonstructural practices to be used to meet the requirements for new development and significant redevelopment and provide guidelines for the selection, design, implementation, and maintenance of those practices.

SUSMP documents from San Diego County, Vista, and Carlsbad were reviewed; the documents are similar, and provide detailed guidance about many aspects of site design and BMP selection, but lack BMP engineering design standards for meeting the hydrology requirements. The California Stormwater Quality Association (2003) (CASQA) has published stormwater BMP handbooks since 1993; the current version was published in 2003. It includes detailed design guidelines for the volume-based and flow-based treatment standards referenced in the 2001 Order. Tetra Tech assumed that BMPs would be designed according to the standards and sizing criteria contained in the 2003 CASQA BMP Handbook.

As discussed in Section 2.3.2.4, the BMPs selected for modeling stormwater management in the Existing Scenario were simplified to the following list:

1. Volume-based BMPs
    a. Extended Detention Basin (TC-22 in the 2003 CASQA BMP Handbook)
2. Flow-based BMPs
    a. Vegetated Swale (TC-30 in the 2003 CASQA BMP Handbook)
    b. Vortex Separator (MP-51 in the 2003 CASQA BMP Handbook)

*Volume-based criteria*

The 2001 Order volume-based criterion corresponds to the Urban Runoff Quality Management Approach described in Section 5.5.1 of the 2003 CASQA BMP Handbook. The approach uses the following formulas for calculating the Runoff Coefficient (C, unitless) and the Maximized Detention Volume ($P_0$, inches):

$$C = 0.858i^3 - 0.78i^2 + 0.774i + 0.04$$

$$P_o = (a \bullet C) \bullet P_6$$

where

i = watershed imperviousness ratio (scaled from 0 to 1)

a = regression constant (1.963 for 48 hour drawdown)

$P_6$ = mean annual runoff-producing rainfall depth (inches)

Using the San Diego County 85th percentile isopluvial map (County of San Diego, 2003a), $P_6$ ranges from about 0.60 to 0.75. A representative value of 0.70 was selected because: a) it is located nearest the zone of most intense expected future development, and b) the same isopluvial line runs near the rain gage north of the watershed used to drive the rainfall input to the LSPC model. Extended detention in LSPC is represented on a unit-area basis, so *i* was set equal to 1 (100 percent impervious). The extended detention basin design calls for a 48-hour drawdown time for water quality treatment, so a value of 1.963 was specified for *a*. $P_o$ was therefore equal to 1.23 inches; *Po* is multiplied by the site area (1 acre of impervious area in this case), with a resulting water quality treatment volume of 4,465 $ft^3$.

The 2003 CASQA BMP Manual also lists the following design criteria:

- Average drawdown time 48 hours. Should completely drain in 72 hours. At least 50 percent should drain within 24 hours.
- No specific peak control; however, the design guidelines state that "For on-line facilities, the principal and emergency spillways must be sized to provide 1.0 foot of freeboard during the 25-year event and to safely pass the 100-year flood." The average storm event depths in the watershed are 4.5 inches for the 25-year event and 5.5 inches for the 100-yr event (County of San Diego. 2003b).
- Side slopes are 3:1 (H:V) or flatter.
- The recommended orifice coefficient is "0.66 for thin materials and 0.80 when the material is thicker than the orifice diameter."

*Flow-based Criteria*

The 2001 Order lists two alternatives for the flow-based requirement - either the maximum flow rate of runoff produced from a rainfall intensity of 0.2 inch of rainfall per hour; or the maximum flow rate of runoff produced by the 85th percentile hourly rainfall intensity, as determined from the local historical rainfall record, multiplied by a factor of two. Both are discussed in Section 5.5.2 of the 2003 CASQA BMP Handbook; each method provides a rainfall intensity, which is then used in the Rational Formula to calculate the BMP Design Flow rate in cfs.

The first method is the Uniform Intensity Approach, which uses the intensity specified in the regulation (0.2 inches per hour). The second method is the California Stormwater BMP Handbook Approach. While the analysis used to support the second approach was robust, the application is simple; one merely chooses the graph of cumulative frequency hourly rainfall intensity for the rain gage closest to the site (San Diego WSO Airport, in this case), finds the cumulative probability from the standard ($85^{th}$), finds the intersection with the graph, and reads the corresponding rainfall intensity (in/hr). The intensity is then multiplied by the factor specified in the regulation (2x). In this application, the rainfall intensity corresponding to the $85^{th}$ percentile probability is 0.1 inches per hour, which results in a design intensity of 0.2 inches per hour. Both methods happen to yield the same result.

The Rational Formula approximates Q (peak flow, cfs) with the following formula:

$$Q = C \bullet I \bullet A$$

where

C = composite runoff coefficient

A = site area (acres)

I = rain intensity, in/hr

Assuming a site is 50 percent impervious (a reasonable average imperviousness for new development), and assuming C = 0.30 for pervious surface and C = 0.95 for impervious surfaces, the composite C is 0.625. LSPC uses a unit impervious area representation of flow-based BMPs; a two-acre site would have one acre of impervious area. Assuming A = 2 in the Rational Formula, Q = (0.625)(2)(0.2) = 0.25 cfs.

Design criteria from the 2003 CASQA BMP Handbook and best professional judgment were used for the design of the Vegetated Swale and Vortex Separator:

- Vegetated Swale
  - supports some infiltration of runoff
  - Water Quality flow rate of 0.25 cfs per acre impervious area
  - Water Quality Minimum residence time of 10 minutes
  - Slope no more than 2.5 percent
  - Manning's n=0.25 for peak of Water Quality storm event
  - Depth not to exceed 4 inches
  - Side slopes not to exceed 3:1 (H:V)
- Hydrodynamic device
  - Outgoing flow equals incoming flow
  - For a unit area (1 acre) of impervious surface, when flow reaches 0.25 cfs, additional flow is routed to a second bypass outlet
  - The device does not support infiltration

#### 2.3.2.2 BMP Designs Based on 2007 Order

The 2007 Order adds a peak flow criterion to the 2001 Order requirements, which remain in place. The Order specifies that the site design will maintain runoff at or near the pre-development peak flow for a continuous range of storm events (e.g., all events within the 2-yr to 10-yr range). The continuous range of storm events would represent the events during which the greatest, cumulative erosion impact is likely to occur. This type of requirement has been used in northern California, and a storm event range of the 2-year to 10-year storm has been applied. Although modeling is required to determine the appropriate range for southern California, a storm event range closer to the 5-year to 15-year storm may be used since rainfall frequency is lower in southern California (D. Hauser, City of Carlsbad, personal communication, October 19, 2007). The extended detention basin was redesigned to accommodate the additional storage volume and discharge needed to meet Order, using the following storm event depths taken from the San Diego County Hydrology Manual (2003b): 5-yr = 3.3 inches, 10-yr = 3.8 inches, assume 15-yr = 4.1 inches.

Each BMP design was translated into a Function Table (F-Table) representing the relationship between volume, stage, area, and discharge for use in the model.

#### 2.3.2.3 BMP Pollutant Efficiency

After routing through HSCs, runoff is routed to an SWT by the model (the HSC and SWT may be physically identical in some cases but are treated as sequential stages by the model). SWT treatment performance is defined by achievable effluent concentrations based on literature for the portion of the runoff treated. Bypassed flows for SWT are assumed to discharge to surface waters at influent concentrations. Table 2-4 presents the effluent concentrations used to represent BMP pollutant efficiency in the model.

**Table 2-4. Stormwater Treatment (SWT) Device Effluent Concentrations**

| Pollutant | SWT1<br>Extended Dry Detention Basin | SWT2<br>Hydrodynamic Device | SWT3<br>Extended Dry Detention Basin w/ Peak Flow Control |
|---|---|---|---|
| Sand (mg/L) | 0.4 [2] | 1.1 [1] | 0.4 [2] |
| Silt (mg/L) | 3.7 [2] | 3.3 [1] | 3.7 [2] |
| Clay (mg/L) | 32.9 [2] | No Reduction [1] | 32.9 [2] |
| Total Nitrogen (TN) (mg/L) | 2.4 [4] | 2 [3] | 2.4 [4] |
| Total Phosphorus (TP) (mg/L) | 0.25 [4] | 0.26 [3] | 0.25 [4] |
| Fecal Coliform (#/100mL) | 400 [4] | No Reduction | 400 [4] |

1 Sediment fractions based on 32 mg/L TSS effluent concentration in CASQA BMP Handbook and assumption 89/30/0 percent sand/silt/clay trapping efficiency

2 Sediment fractions based on 37 mg/L TSS concentration from CASQA BMP Handbook and assumption of 98/60/5 percent sand/silt/clay trapping efficiency

3 Estimated from SWT2 to SWT1 ratio from ASCE BMP database and normalized to CASQA SWT1 values

4 CASQA BMP Handbook

#### 2.3.2.4 Existing BMP Treatment

Existing stormwater treatment was determined through a review of SUSMP BMPs[3] and from information provided by the City of Carlsbad on practices implemented prior to 2001 (personal communication, D. Hauser, City of Carlsbad, March 26, 2008). A schematic of BMP representation in the model for the Existing Scenario is shown in Figure 2-5. The percentage of treatment by HSCs and SWTs is based on BMPs for specific development projects that are contained in the annual SUSMP BMP reports.

HSC represents lands that are subject to hydrologic source control, which involves providing opportunity for additional infiltration. HSC1 is a represented as a vegetated swale as this is the most common practice

[3] Only specific SUSMP BMPs for development projects from the City of Vista were readily available. It is assumed that the trends in the type and levels of treatment in City of Vista are consistent with other municipalities in the watershed.

implemented, particularly later in the time frame of 2001 to 2007. HSC1 may also represent biofilters, infiltration trenches and pervious pavement. SWT represents traditional stormwater treatment devices. SWT1 is represented as an extended dry detention pond based on requirements of the 2001 Order. SWT2 represents a variety of devices such as CDS and Vortex. Note that the actual treatment area in the Existing Scenario is less than 2 percent of watershed area, therefore, it represents a small amount of treatment.

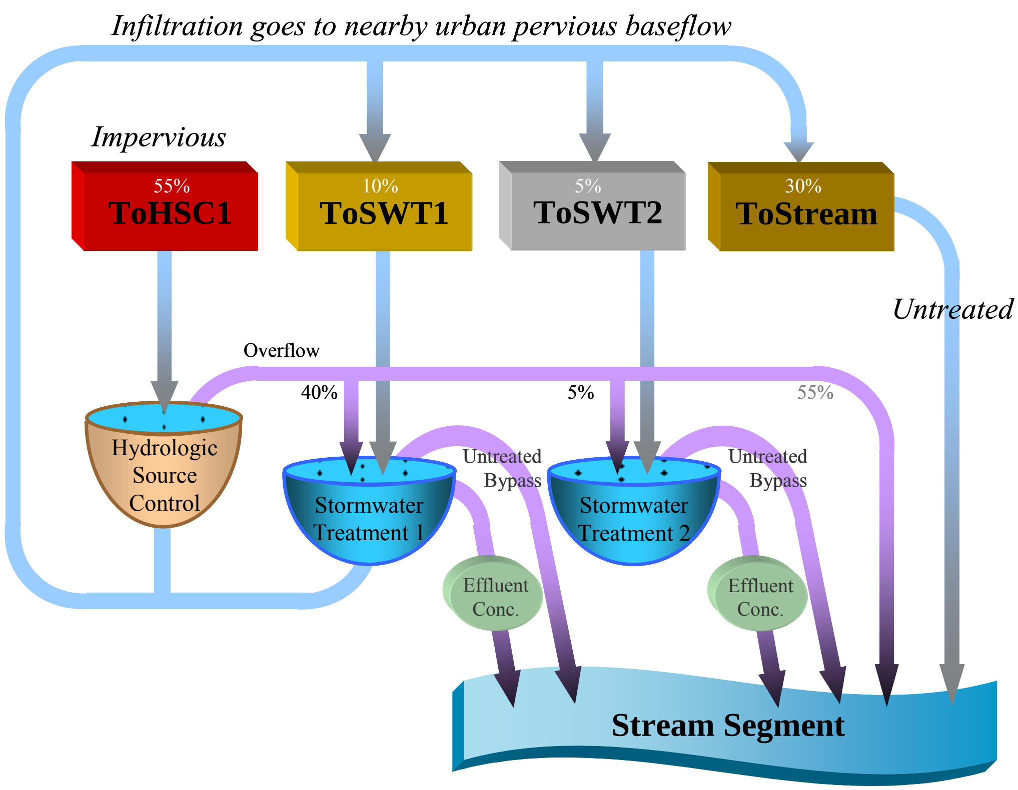


**Figure 2-5. Schematic of BMP Treatment in the Existing Scenario**

Approximately 70 percent of the development occurring between the 2001 Order and 2007 received some level of treatment. Areas not receiving treatment were either not priority projects or received relatively ineffective treatments (e.g., drain inserts used alone). Drain inserts were a common practice in earlier SUSMP projects (e.g., 2002-2003) and appeared to have been phased out to a large extent. While they may have some benefit with respect to trash and course materials, they are relatively ineffective for most pollutants and have no effect on flow. There appeared to be a progression in the SUSMP BMPs with more common implementation of swales and detention toward the latter half of the period.

### 2.3.2.5 Future BMP Treatment

A schematic of BMP treatment implemented in the Future Scenario is shown in Figure 2-6. In this scenario, land developed prior to 2007 is treated the same as in the Existing Scenario except for identified redevelopment areas which receive treatment under the 2007 Order[4]. All future priority projects must meet the 2001 plus the 2007 Order. Accordingly, a portion of the development could be treated via swales and similar devices (HSC1) and varies from 10 percent to 75 percent depending on the levels of imperviousness: higher density projects have a decreased opportunity to use these types of practices. In addition, all priority projects are treated by an SWT: SWT3 in the Future Scenario is designed as extended dry detention with peak control (essentially an enlarged SWT1). Greater than 25 percent of the watershed is treated in the Future Scenario.

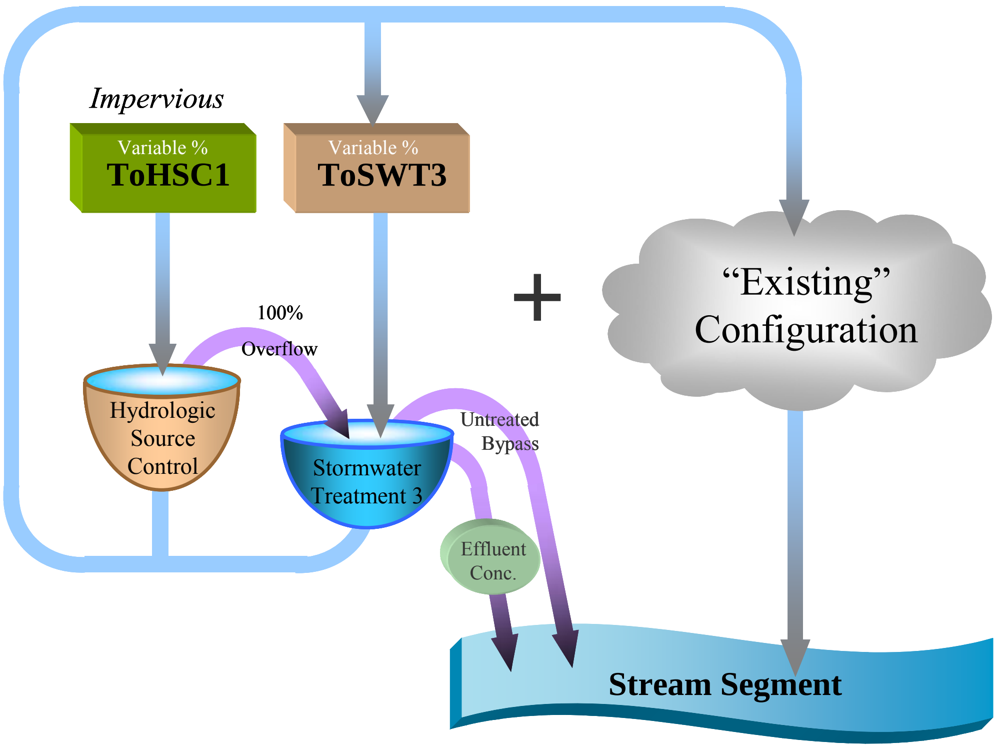


**Figure 2-6. Schematic of BMP Treatment in the Future Scenario**

While the 2007 Order contains an LID requirement, the nature and level of its application is not clear at present. Model testing was conducted to determine the effect of a moderate level of decreased imperviousness and disconnection variable by land use (impervious reductions of 9 percent to 10 percent except for Heavy Commercial at 3.5 percent and Industrial at 4 percent) in addition to the use of vegetated swales (HSC1) which may be considered a type of LID practice. The treatment via HSC1 and SWT3 rendered the model insensitive to these moderate changes in imperviousness. Therefore, this feature was not included in the Future Scenario that receives BMP treatment. Additional LID application will be explored in additional scenarios developed for the WMP.

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[4] The City of Vista provided areas that are planned for redevelopment (>900 acres) and that would require treatment to meet requirements of the 2001 and 2007 Orders. These areas within the watershed are located east of Melrose Rd. and north of San Marcos Rd. In addition, planned increases in residential density can be considered a type of redevelopment for purposes of the model scenarios.

# 2.4 MODEL CALIBRATION

The watershed model used regionally calibrated parameters that required some adjustment for local conditions. Though additional calibration was possible, it was limited due to lack of data.

Approximately one year of stream flow data was available at El Camino Real Bridge beginning in spring 2005. Flow data collected by the San Elijo Lagoon Conservancy (SELC) at El Camino Real Bridge (Model subwatershed 2007). Due to a dredging operation, the stream gage was not operational between March and July 2006. Rating curves for converting stream level to discharge may have been altered; therefore, only data before the dredging were used.

Wet weather observations were also available at this station from 1998 – 2006 (~25 observations). Though this station was co-located with dry weather sample collection, few observations exist. In addition, SWAMP data was included but was limited.

## 2.4.1 Hydrology

Figure 2-7 through Figure 2-10 and Table 2-5 provide graphical and statistical results of model performance for one year at El Camino Real Bridge following a process of parameter adjustment within physically reasonable ranges for the watershed.

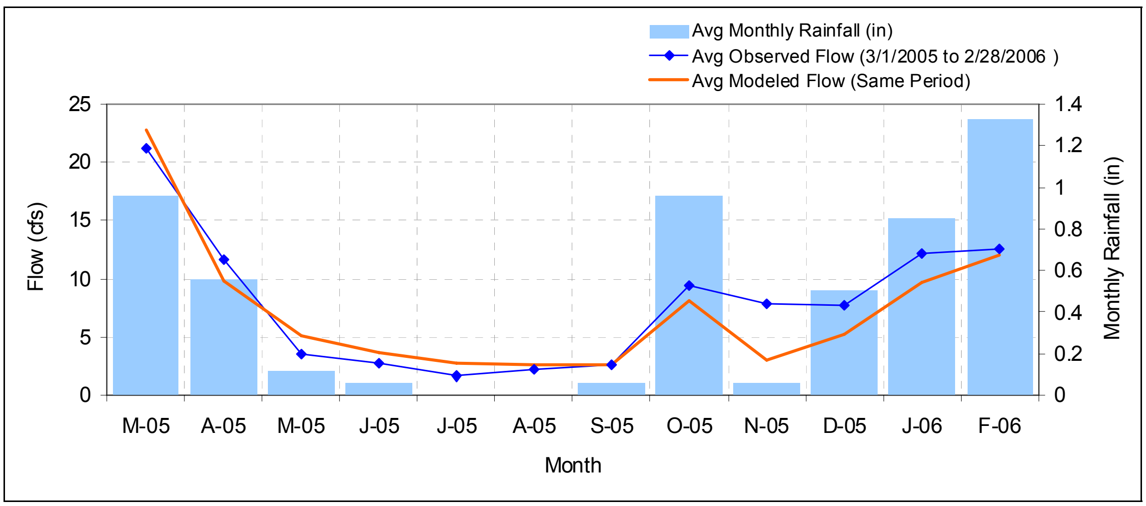


**Figure 2-7. Mean Monthly Flow: Model Outlet 1007 vs. Agua Hedionda Creek at El Camino Real Bridge**

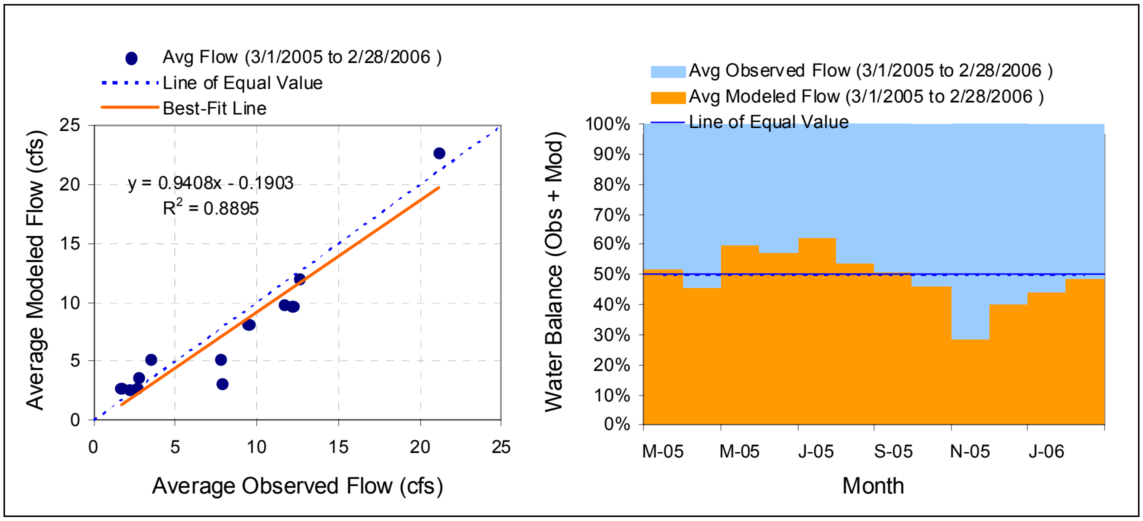


**Figure 2-8. Monthly Flow Regression and Temporal Variation: Model Outlet 1007 vs. Agua Hedionda Creek at El Camino Real Bridge**

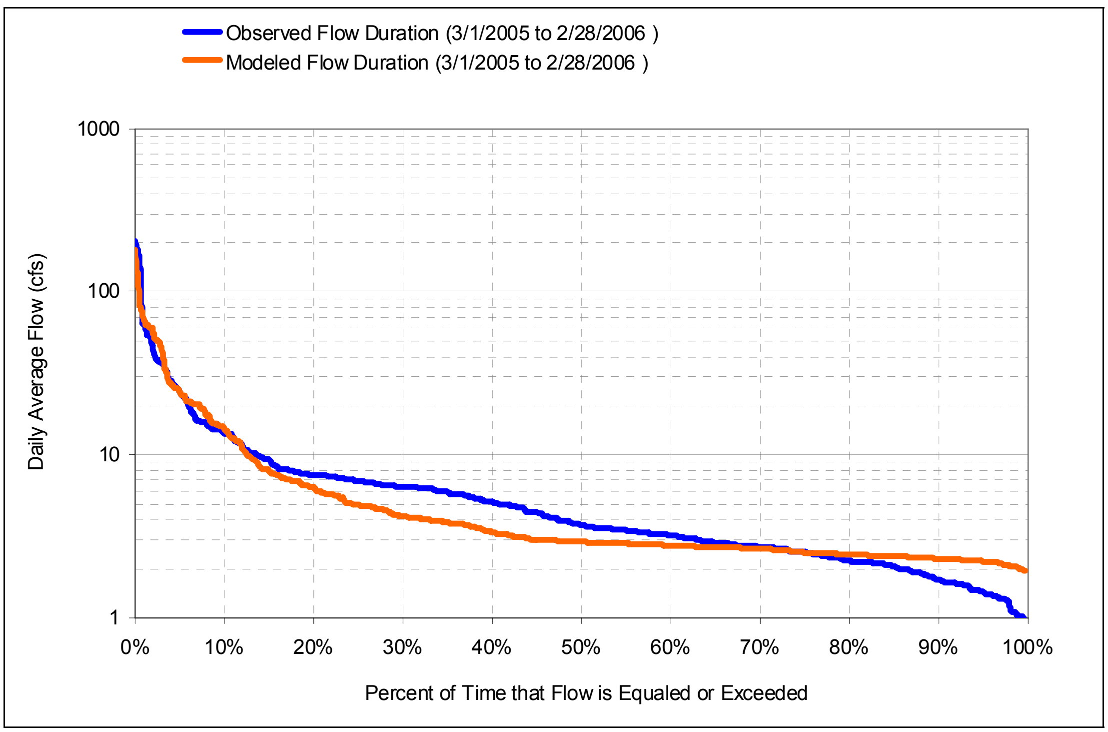


**Figure 2-9. Flow Exceedence: Model Outlet 1007 vs. Agua Hedionda Creek at El Camino Real Bridge**

**Table 2-5. Summary Statistics: Model Outlet 1007 vs. Agua Hedionda Creek at El Camino Real Bridge**

| LSPC Simulated Flow | | Observed Flow Gage | |
|---|---|---|---|
| REACH OUTFLOW FROM SUBBASIN 1007 | | Agua Hedionda Creek at El Camino Real Bridge | |
| 1-Year Analysis Period: 3/1/2005 - 2/28/2006<br>Flow volumes are (inches/year) for upstream drainage area | | Drainage Area (sq-mi): 23 | |
| Total Simulated In-stream Flow: | **4.31** | Total Observed In-stream Flow: | **4.69** |
| | | | |
| Total of simulated highest 10% flows: | **2.33** | Total of Observed highest 10% flows: | **2.38** |
| Total of Simulated lowest 50% flows: | **0.75** | Total of Observed Lowest 50% flows: | **0.73** |
| | | | |
| Simulated Summer Flow Volume (months 7-9): | **0.40** | Observed Summer Flow Volume (7-9): | **0.32** |
| Simulated Fall Flow Volume (months 10-12): | **0.82** | Observed Fall Flow Volume (10-12): | **1.25** |
| Simulated Winter Flow Volume (months 1-3): | **2.17** | Observed Winter Flow Volume (1-3): | **2.25** |
| Simulated Spring Flow Volume (months 4-6): | **0.91** | Observed Spring Flow Volume (4-6): | **0.88** |
| | | | |
| Total Simulated Storm Volume: | **1.23** | Total Observed Storm Volume: | **1.36** |
| Simulated Summer Storm Volume (7-9): | **0.03** | Observed Summer Storm Volume (7-9): | **0.04** |

| *Errors (Simulated-Observed)* | *Error Statistics* | *Recommended Criteria* | | |
|---|---|---|---|---|
| Error in total volume: | -8.24 | 10 | | |
| Error in 50% lowest flows: | 2.60 | 10 | | |
| Error in 10% highest flows: | -2.07 | 15 | | |
| Seasonal volume error - Summer: | 23.33 | 30 | | |
| Seasonal volume error - Fall: | -34.14 | 30 | | |
| Seasonal volume error - Winter: | -3.30 | 30 | | |
| Seasonal volume error - Spring: | 4.28 | 30 | | |
| Error in storm volumes: | -9.90 | 20 | | |
| Error in summer storm volumes: | -40.53 | 50 | | |
| Nash-Sutcliffe Coefficient of Efficiency (-inf to 1): | 0.837 | < 0 poor, 0 = mean, 1 perfect | | |
| Baseline adjusted coefficient E', 0-1 (Garrick): | 0.565 | 0 = poor, 1 = perfect | | |

Daily flow follows overall observed trends except for a lack of peak matching for the largest storms during this period (Figure 2-7). Monthly flow patterns are captured though there is noticeable underprediction during fall and early winter (Figure 2-8 and Figure 2-9). Given the absence of local rainfall data in the watershed, this underprediction may result partly from misrepresentation of precipitation forcing data. A comparison of flow duration for observed and simulated flows also shows consistent underprediction of flows between the 20 percent and 60 percent exceedance interval. In addition, there is some overprediction at low flows. Some of the error in low flow simulation may be driven by the uncertainty in the representation of lawn irrigation in the watershed.

Overall summary statistics comparing observed and simulated hydrology for this one year of comparison are within the recommended criteria based on HSPEXP (Lumb et al., 1994) for all metrics except fall volume error (Table 2-5). The error in high and low flow volumes is less than 3 percent. Both storm volume and overall volume error is less than 10 percent.

Caution should be used when extrapolating model performance calibrated based on this one year, a relatively normal rainfall condition, to the entire model simulation period. The calibration did not benefit from multiple years and variable hydrologic conditions for use in adjusting model parameters. Despite these limitations, the resulting hydrologic model provides a useful tool for comparing model scenarios and their relative differences.

Plots of simulated versus observed loads at El Camino Real Bridge for the period of observed data (1998 – 2006) are shown in Figure 2-10, Figure 2-12, Figure 2-14, and Figure 2-16. Since flow data were only available for one year, loads for both simulated and observed flow are calculated using simulated flow. Time series plots of observed and simulated concentrations are provided in Figure 2-11, Figure 2-13, Figure 2-15, and Figure 2-17.

Trends are similar across all variables when comparing simulated and observed loads and concentrations. The overall patterns and magnitudes of pollutant loading are captured. However, the apparent increases in most of the observed variables beginning in about 2003 are not captured well in the model. Further, the lack of dry weather data at this station limits the ability to fit the model in lower flow periods.

The amount of available observed data available limits the ability to calibrate and test the model. However, on average, the model underestimates pollutant concentrations (Table 2-6) as shown in the percent average error statistics (a measure of model accuracy). Model performance appears better for nutrient concentrations relative to fecal coliform and sediment predictions. Modeling of fecal coliform is notoriously wrought with uncertainty given the variability in sources and dynamics of bacterial transport and decay. The model does not take into explicit account illicit discharges and sewer line leaks that may exist. While model simulation of sediment is fair, the discrimination between upland and channel sources may not be well described due to the lack of detailed stream channel morphology data and sediment monitoring in other areas of the watershed.

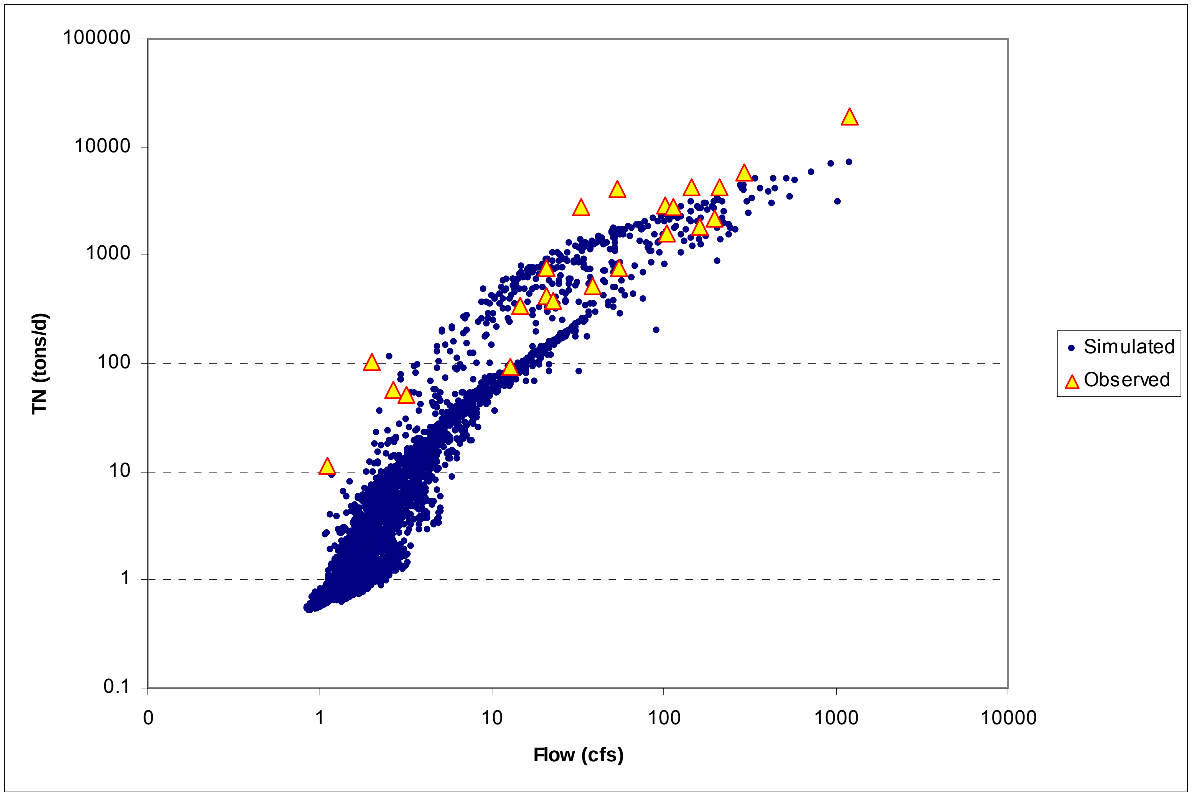


**Figure 2-10. Observed and Simulated TN Loads at Model Subwatershed #1007**

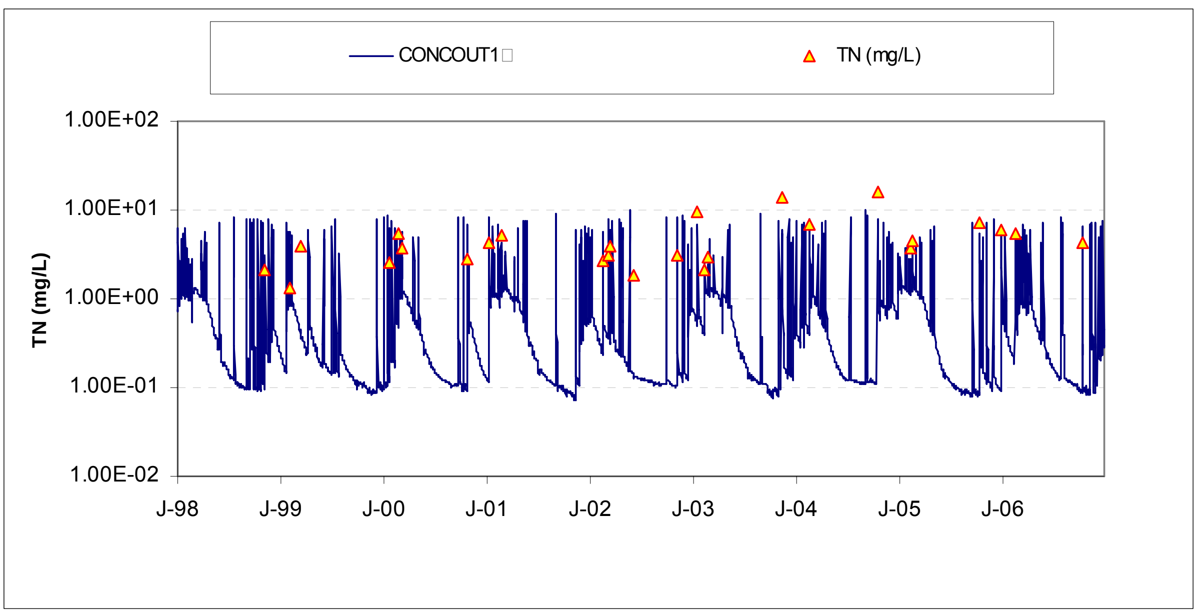


**Figure 2-11. Observed and Simulated TN Concentrations at Model Subwatershed #1007**

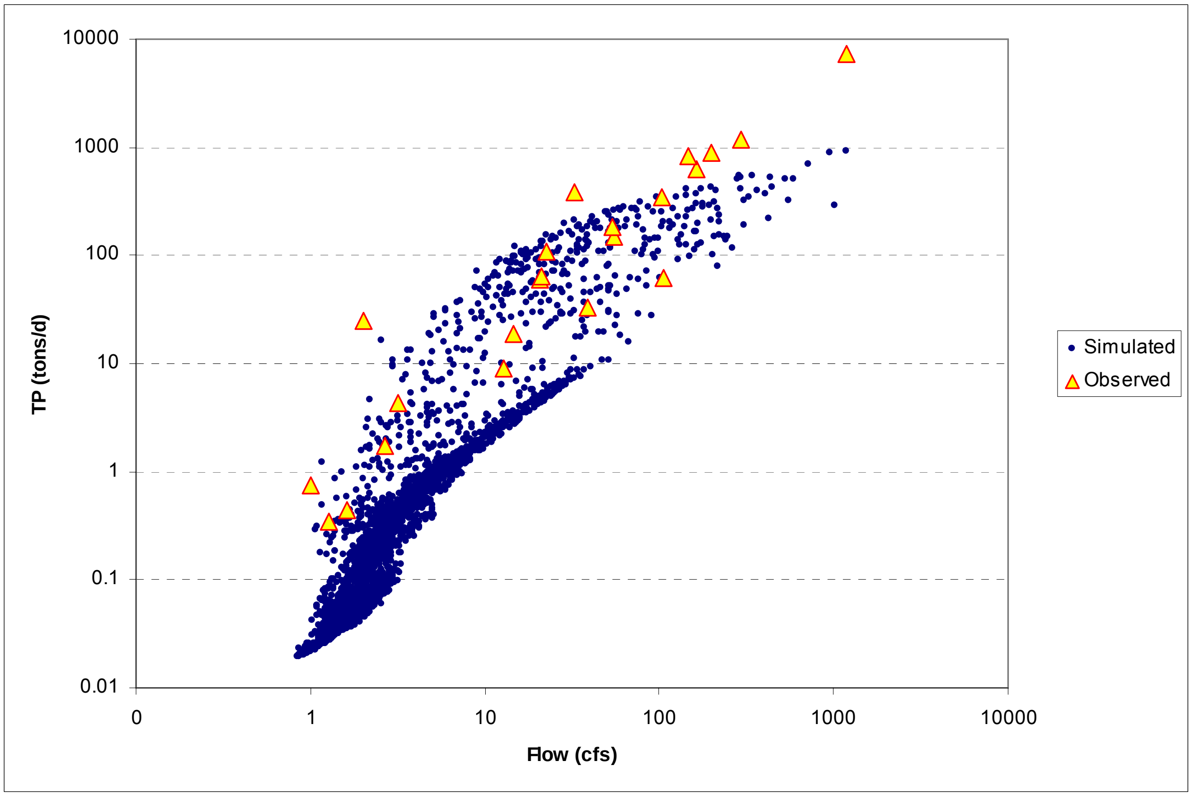


**Figure 2-12. Observed and Simulated TP Loads at Model Subwatershed #1007**

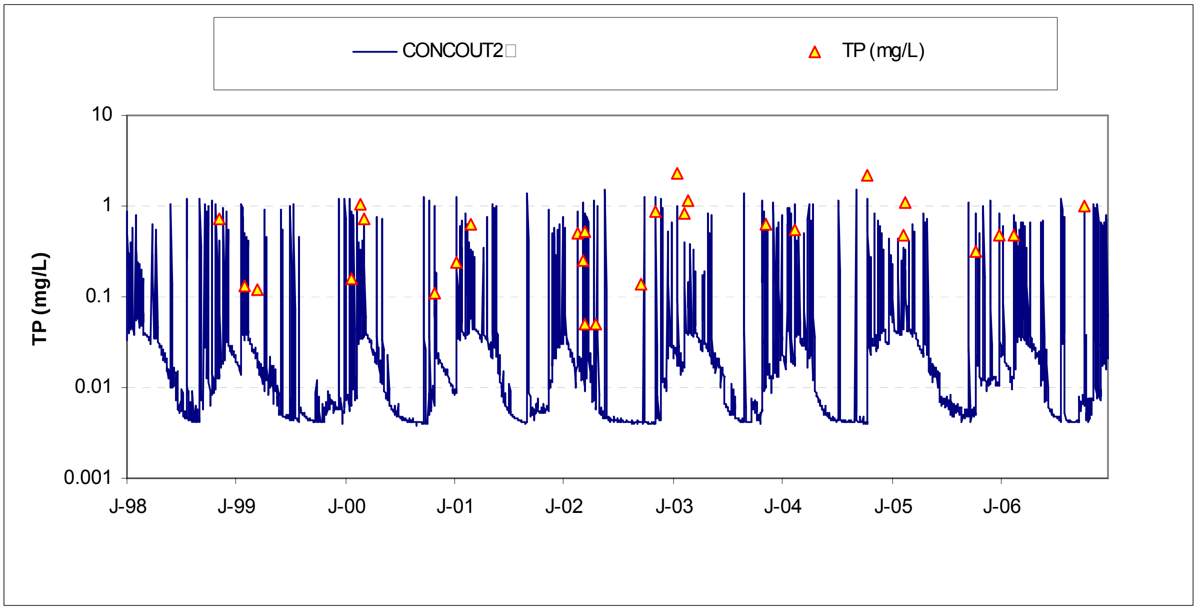


**Figure 2-13. Observed and Simulated TP Concentrations at Model Subwatershed #1007**

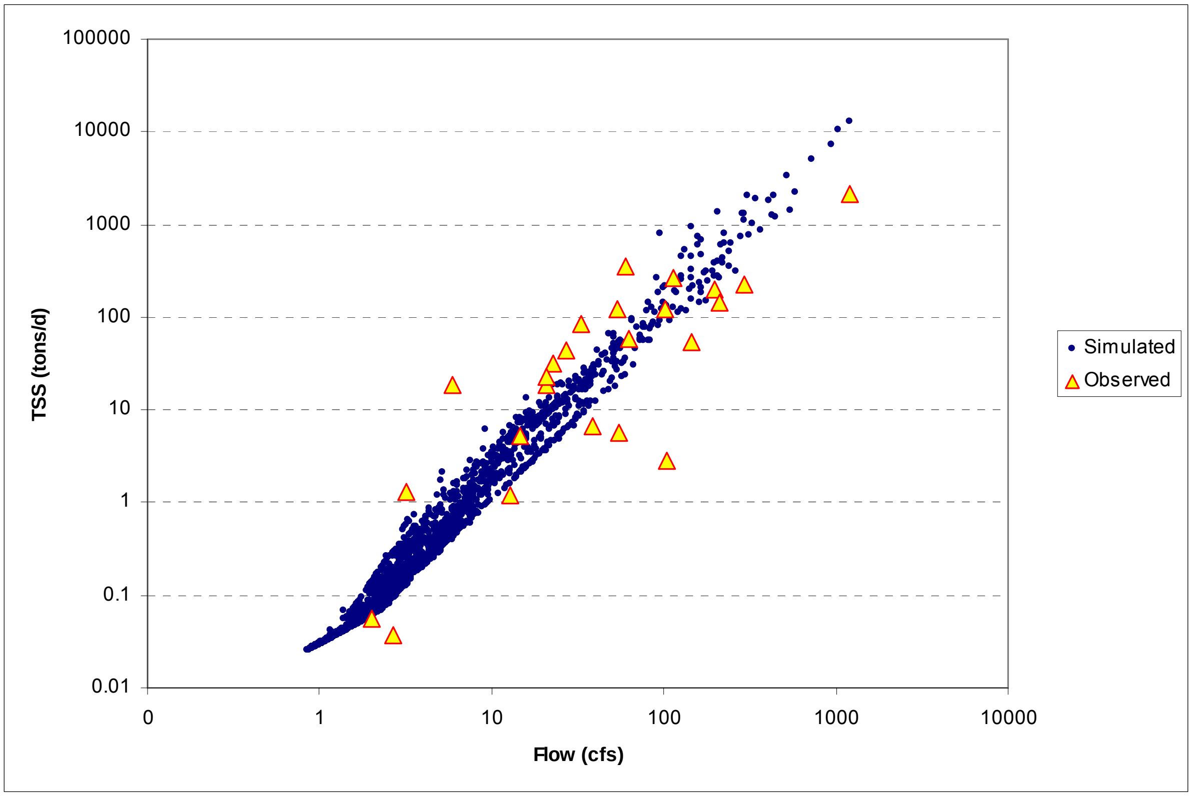


**Figure 2-14. Observed and Simulated Sediment Loads at Model Subwatershed #1007**

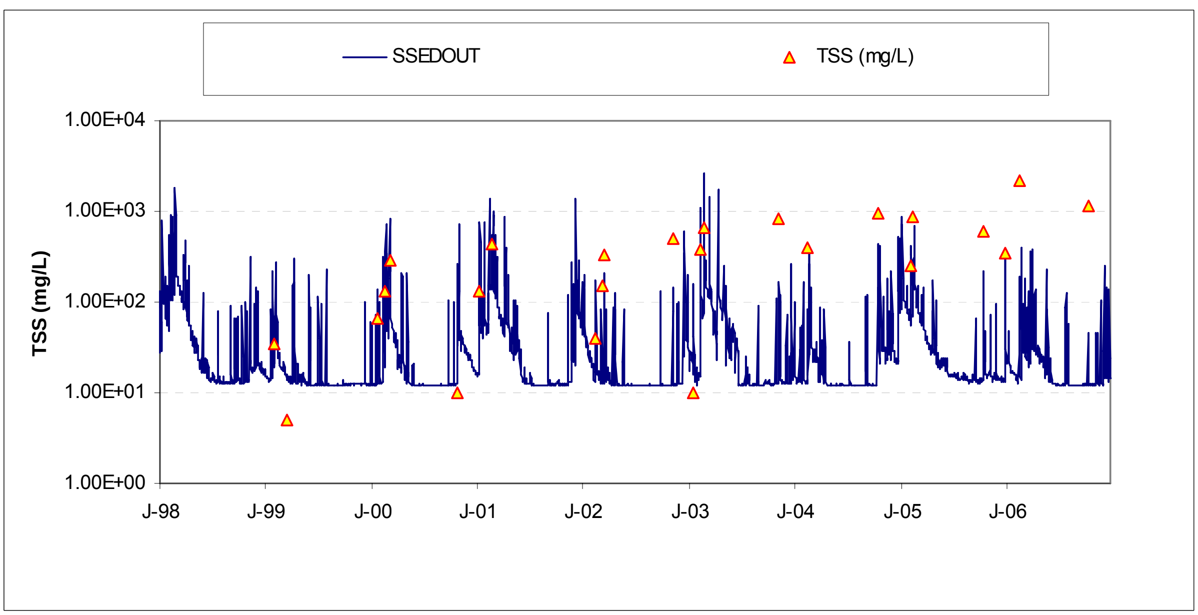


**Figure 2-15. Observed and Simulated Sediment Concentrations at Model Subwatershed #1007**

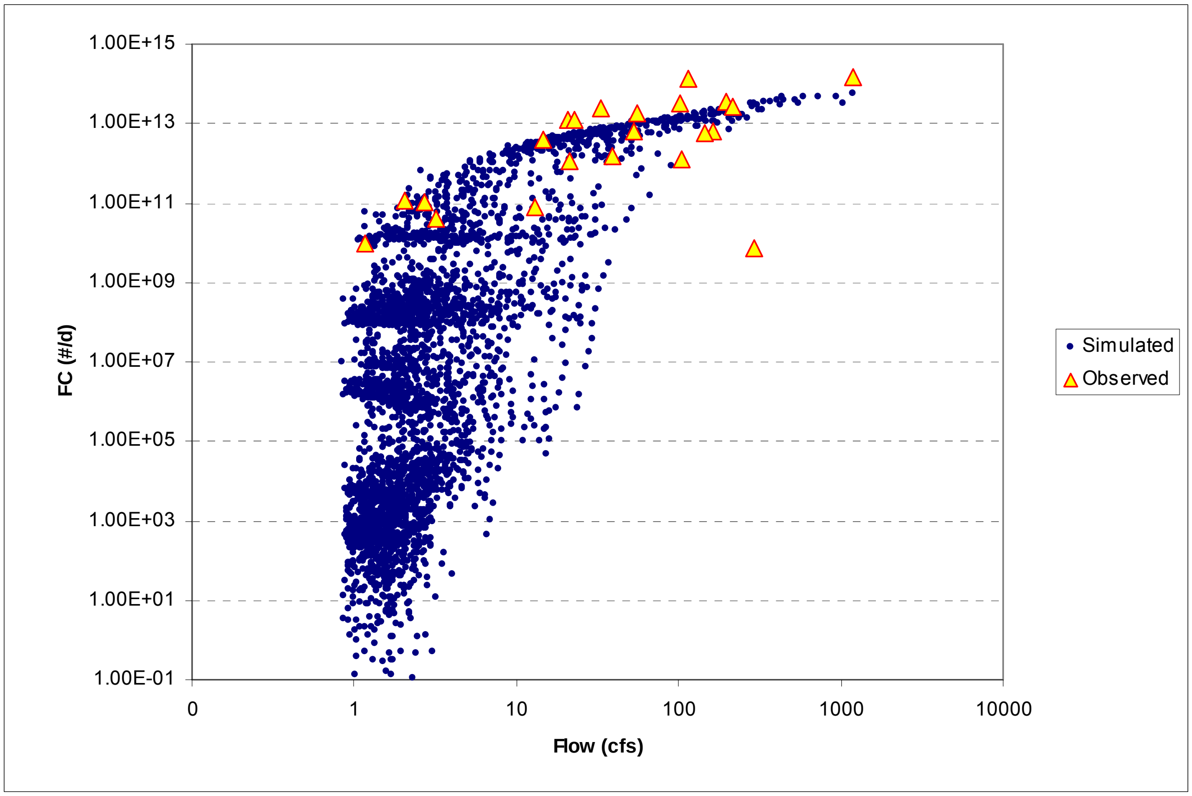


**Figure 2-16. Observed and Simulated Fecal Coliform Loads at Model Subwatershed #1007**

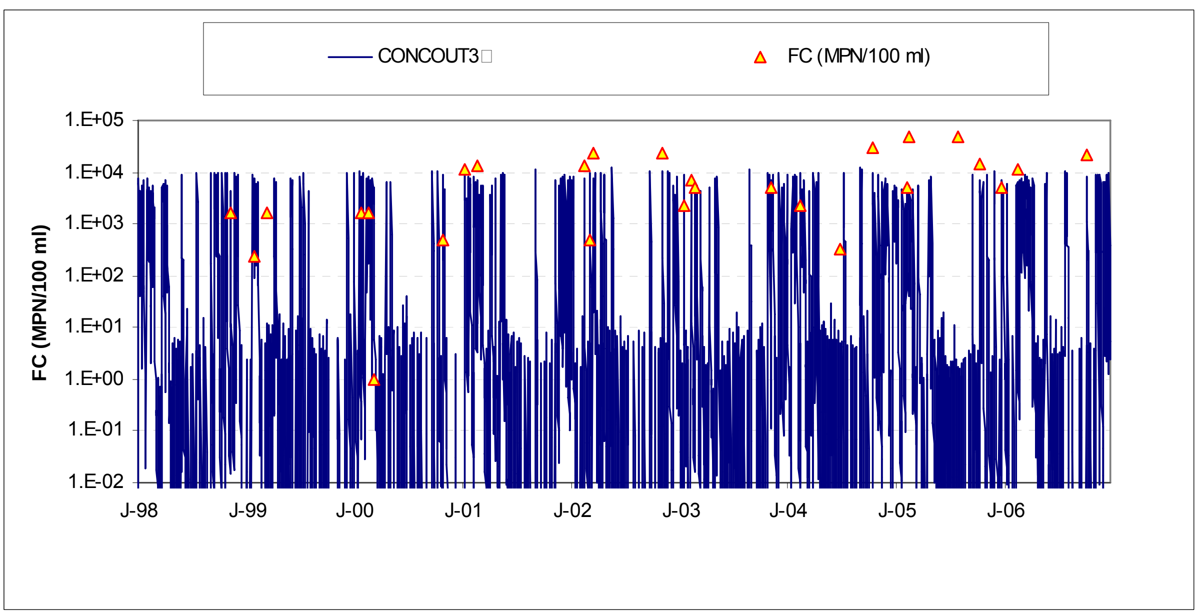


**Figure 2-17. Observed and Simulated Fecal Coliform Concentrations at Model Subwatershed #1007**

**Table 2-6. Error Statistics for Modeled Water Quality Parameters**

| Statistic | Suspended Sediment [1] | Total Nitrogen | Total Phosphorus | Fecal Coliform |
|---|---|---|---|---|
| Units | mg/L | mg/L | mg/L | #/100 mL |
| Number of Paired Data (1998 – 2006) | 24 | 26 | 28 | 27 |
| Simulated Mean | 299 | 4.24 | 0.53 | 5.35E+03 |
| Observed Mean | 451 | 4.94 | 0.63 | 1.11E+04 |
| Simulated Median | 140 | 3.62 | 0.38 | 5.61E+03 |
| Observed Median | 340 | 3.88 | 0.52 | 5.00E+03 |
| Average Error [2] | -0.33 | -0.14 | -0.16 | -0.52 |
| Average Absolute Error [2] | 0.97 | 0.58 | 0.70 | 0.79 |

[1] Modeled data are suspended sediment; observed data are TSS (total suspended solids)

[2] Ratio of error to the observed mean

# 3 Model Scenarios

Four scenarios were modeled to evaluate past (predevelopment scenario), present (existing scenario)and future (future scenario) conditions in the Agua Hedionda watershed.

1. A **Predevelopment Scenario** models all developed land as open space.
2. The **Existing Scenario** is based on 2007 land use (as of approximately January 1) and contains a representation of BMP treatment for development that occurred since 2001 as well as a small amount of treatment that occurred before that time.
3. The **Future Scenario** with the Future BMP treatment. The Future with BMPs Scenario also contains nearly 1,000 acres of redevelopment and associated new treatment planned for by the City of Vista.
4. The **Future Scenario** without the BMP treatment

As described in Section 2, landscape irrigation is simulated in the Existing and Future scenarios. The Predevelopment Scenario does not include irrigation. Further, Lake Calavera is removed in the Predevelopment Scenario. All other model forcings and parameters remain unchanged for predevelopment.

Results in the form of flow duration curves, hydrographs, total pollutant loading to the lagoon, and aerial loading by subwatershed are presented below.

## 3.1 Flow Duration and Hydrographs

Hydromodification is a concern in many Southern California watersheds. An evaluation of simulated hydrographs provides insight into the potential impact that changes in the rates and volumes of streamflow can have on stream channels.

An evaluation of flow duration at a downstream point in the watershed provides an integrated picture of the effects on hydrology. In Figure 3-1, a flow duration curve representing flows to a point on lower Agua Hedionda Creek shows the highest 5 percentile flows (based on 1997-2006). The control of peak flows from future development (Future with BMPs) near the zero percentile results in decreases in flows to a level close to those under existing conditions (Figure 3-2). None of the developed scenarios reach the levels of the Predevelopment Scenario. Low flows under future conditions are elevated due to both increased irrigation (i.e., more land developed and therefore irrigated) and BMP-related infiltration (in the case of Future w/ BMPs). Both HSCs and SWTs in the model allow for some infiltration of stormwater, which contributes to increased baseflow. Due to the absence of simulated irrigation, flow is zero at the low flow percentile range for the predevelopment condition.

An individual storm event was selected to demonstrate additional differences in hydrographs between the model scenarios. The storm selected occurred from February 12-14, 2001. The daily rainfall total for February 12 and 13, was 0.3 and 2 inches, respectively (a 2-inch rainfall approximates the 2-year, 24-hour design storm). Hydrographs are presented for two locations: one on the lower Agua Hedionda Creek (model ID 1007) and one at the outlet of Buena Creek. Three additional hydrographs at upper Agua Hedionda Creek, upper Calavera Creek, and La Mirada Creek are provided in Appendix D.

The differences in storm peaks are more apparent in the hydrographs (Figure 3-3 and Figure 3-4). Peaks under the Future BMP Scenario are reduced to or below Existing levels in nearly every case. Finally, a focus on the tails of the storm events reveals persistence over time of higher flows in the Future BMPs Scenario. Though its effect in the Agua Hedionda watershed is unclear, this increase in the duration of elevated flows has been associated with a potential for additional stream channel impacts. Studies have indicated that controlling only the peak flow may not be fully protective of stream channels due to an increase in the duration of erosive bankfull and sub-bankfull events (Brown and Caraco, 2001). Attempts to mitigate the problem have often incorporated extended detention and slow release of a channel protect volume. This issue should be explored further during the development of the Hydromodification Plan being pursued under another project.

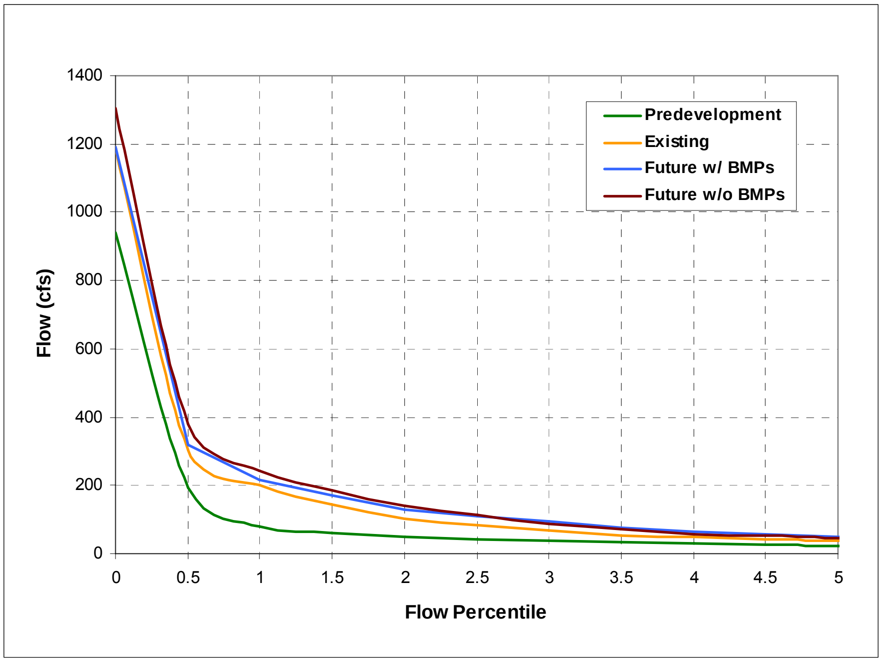


**Figure 3-1. Outlet of Model ID 1007- Flow Duration for Highest Flows**

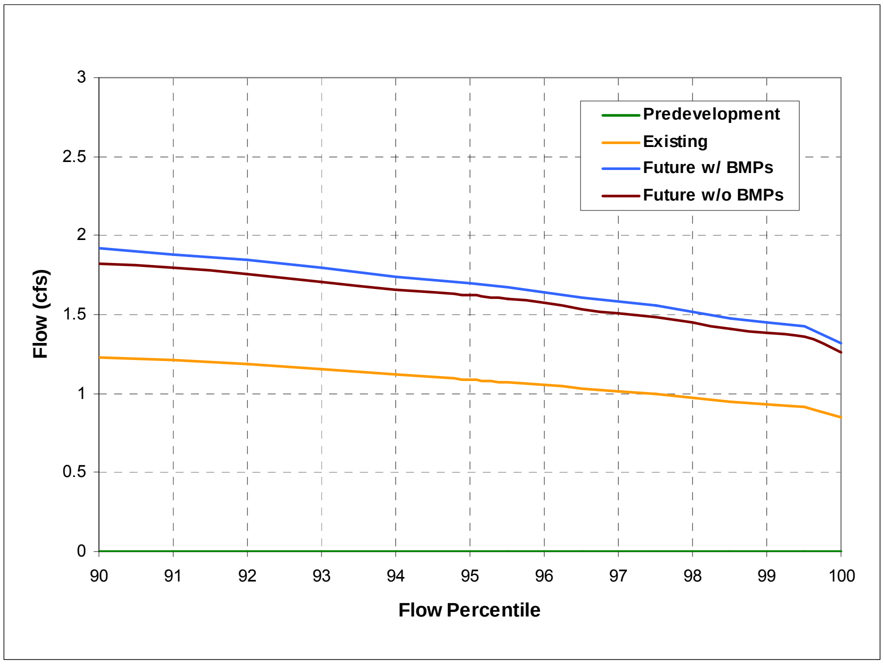


**Figure 3-2. Outlet of Model ID 1007- Flow Duration for Lowest Flows**

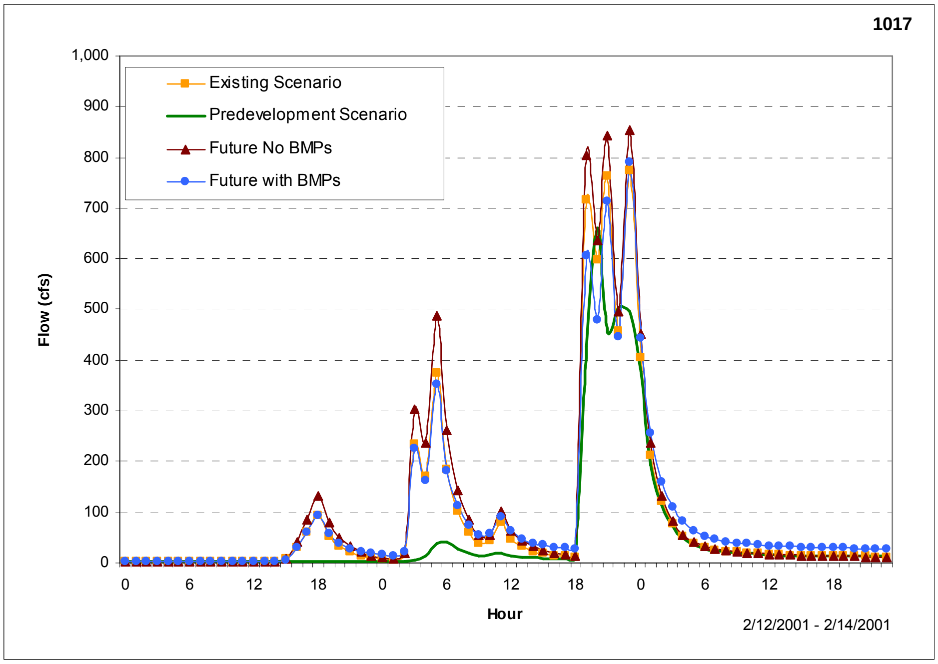


**Figure 3-3. Storm Hydrograph at the Outlet of Buena Creek**

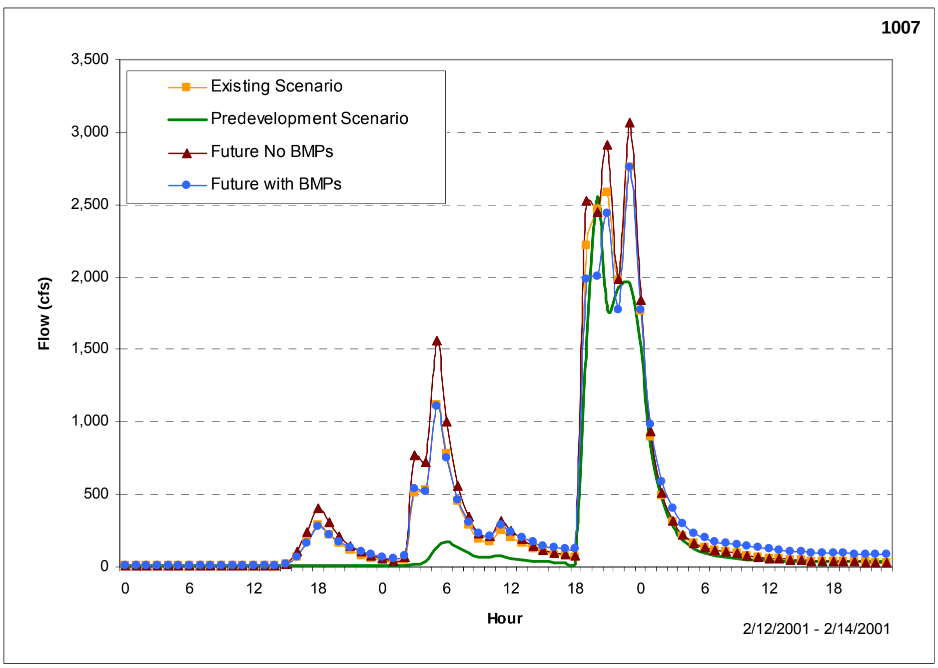


**Figure 3-4. Storm Hydrograph at the El Camino Real Bridge**

## 3.2 Pollutant Loading to Agua Hedionda Lagoon

Pollutant loading to the lagoon is a concern due to its impaired status for bacteria and sediment. While this analysis does not provide the EPA-required TMDL (this will occur later in time under another effort), it can provide a relative understanding of current and future conditions.

As expected, pollutant loading to the lagoon (represented at the outlet of model ID 1004) based on 1997 – 2006 in the predevelopment scenario (all developed land as open space) is lower than existing and future scenarios (Table 3-1; Additional results are provided in Appendix E). The least difference is seen with sediment loading. This may be due to the naturally erodible nature of the landscape in the Agua Hedionda watershed. Future development without BMPs would result in large increases in all variables.

**Table 3-1. Percent Change in Average Annual Loading Relative to the Existing Scenario**

| Pollutant | Predevelopment | Future w/o BMPs | Future w/ BMPs |
|---|---|---|---|
| TN | -63% | 9% | -6% |
| TP | -86% | 12% | -5% |
| Fecal | -93% | 13% | -12% |
| Sediment | -11% | 7% | -7% |

Though not intuitive at first glance, the Future BMPs Scenario results in loading slightly lower than the Existing Condition, a desirable result. This results from two overriding phenomena that offset increases due to development of open space: treated development of agricultural land and redevelopment. Agricultural land decreases from about 9 percent of the land use to less than 1 percent in the future land use. Agricultural land of the conventional type tends to have higher loading rates of pollutants compared to low and medium density developments that have water quality treatment BMPs. As discussed in the model setup for land use, more than 13 percent of the developed parcels in the Existing Condition are "redeveloped" either through a specific redevelopment effort or through increases in density. All land that is redeveloped in this sense will be treated in the future, whereas most of the corresponding existing parcels were not treated.

## 3.3 Spatial Trends in Pollutant Loading

Pollutant loading by subwatershed for the Existing Scenario provides an understanding of the spatial patterns in pollutant loading (Figure 3-5 through Figure 3-8). Four parameters (TN, TP, fecal coliform, and sediment) follow similar patterns in the magnitude of unit area loading. Except for sediment, the highest loading tends to occur in the watersheds of Roman Creek, upper La Mirada Creek, and along the lower Agua Hedionda Creek where large tracts of agricultural land are located. Sediment loading is highest in subwatersheds 1018 (Middle Mainstream Buena Creek) and 1023 (Upper Agua Hedionda Creek) due in large measure to lower density residential development and the soil properties of these areas (i.e., more exposed soil).

Trends in pollutant loading in the future throughout the watershed are also driven by development of agricultural land and redevelopment (Table 3-2). Decreases in loading relative to existing conditions generally mask the increase in loading that may be derived from the development of open space even though a third of open space is planned for development. Increases in loading greater than 1 percent occur in no more than four subwatersheds for each variable. Most of the area-averaged increases in loading occur in the uppermost portion of the watershed.

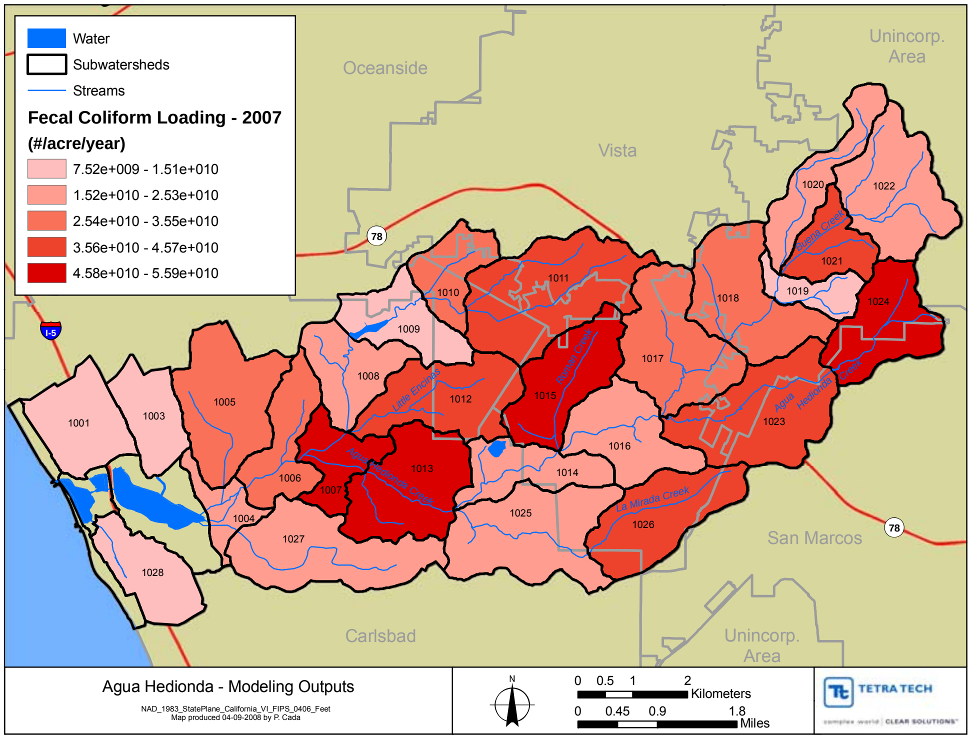


Figure 3-5. Existing (2007) Fecal Coliform Loading (#/ac/yr)

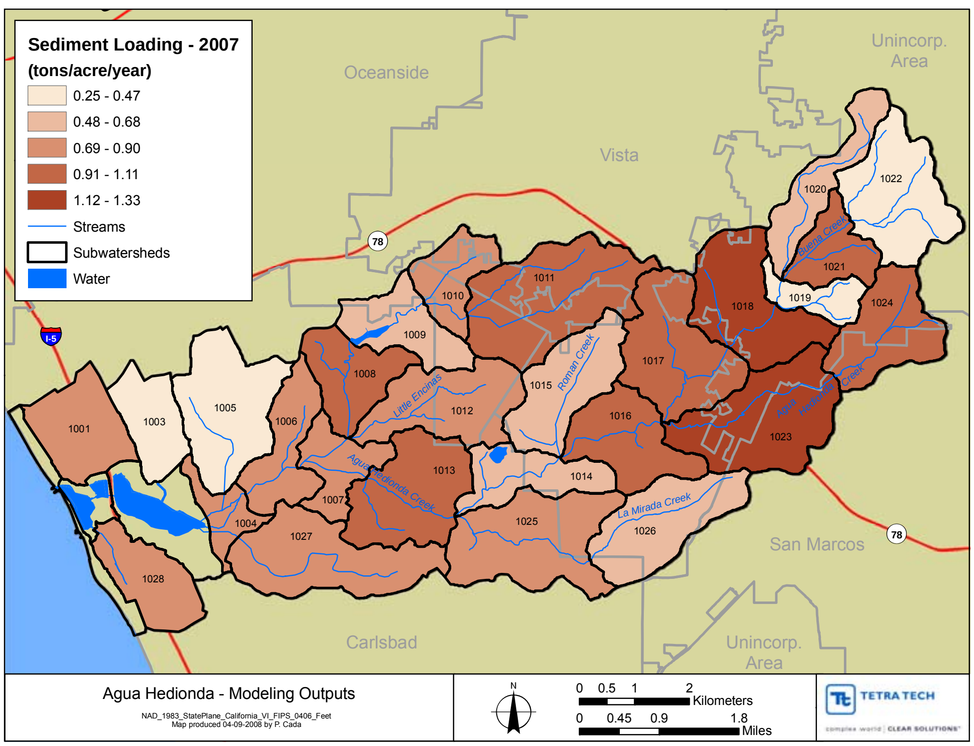


Figure 3-6. Existing (2007) Sediment Loading (ton/ac/yr)

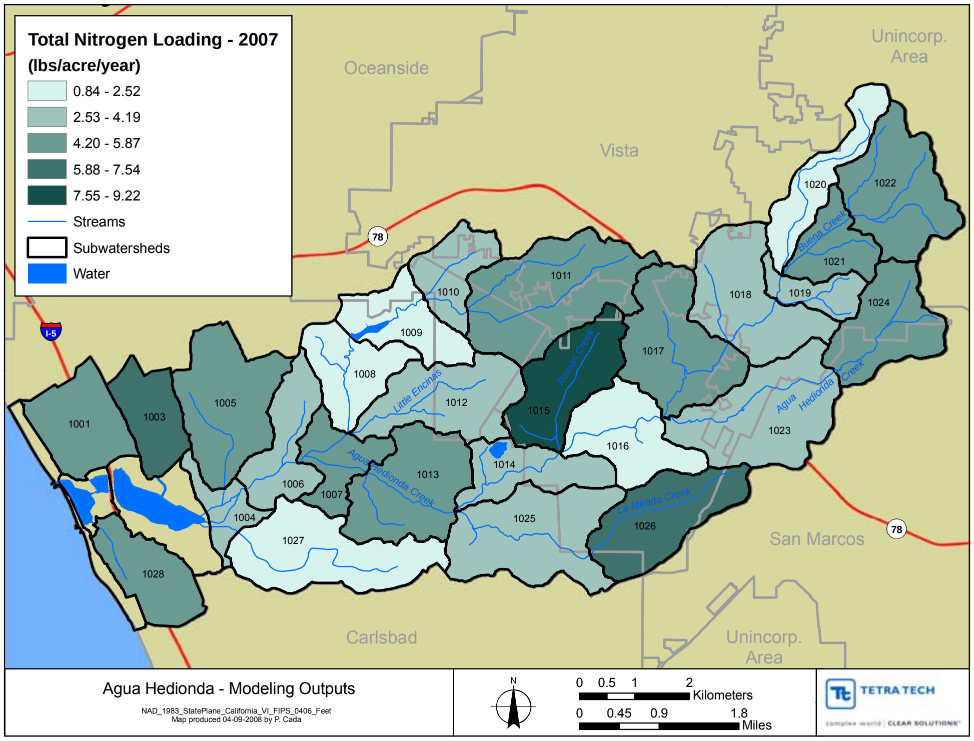


**Figure 3-7. Existing (2007) Nitrogen Loading (lb/ac/yr)**

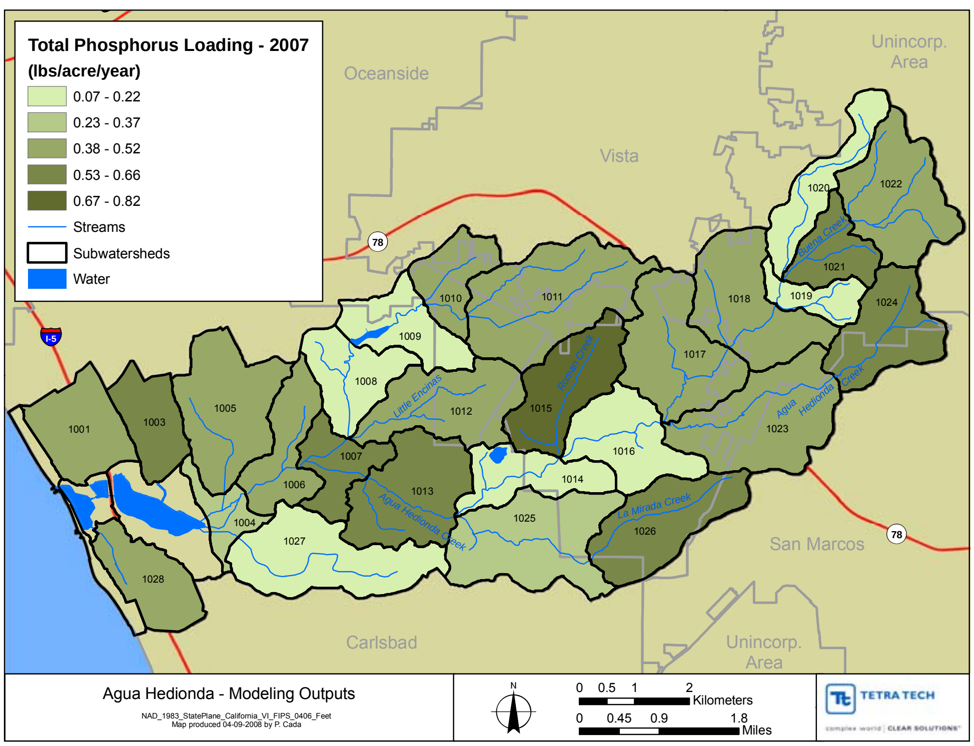


**Figure 3-8. Existing (2007) Phosphorus Loading (lb/ac/yr)**

**Table 3-2. Percent Change in Pollutant Loading by Subwatershed (Existing vs. Future with BMPs)**

| BASIN_NAME | MODEL_ID | Sediment | TP | TN | Fecal Coliform |
|---|---|---|---|---|---|
| Upper Agua Hedionda Lagoon | 1001 | -3% | -3% | -6% | -1% |
| Upper Agua Hedionda Lagoon | 1003 | 0% | -3% | -6% | 0% |
| Upper Agua Hedionda Lagoon | 1004 | -4% | -2% | -3% | 0% |
| North Tributary of Lagoon | 1005 | 0% | 1% | 0% | -5% |
| Lower Agua Hedionda Creek | 1006 | -2% | -12% | -12% | -28% |
| Confluence of Calavera and Agua Hedionda | 1007 | -7% | -16% | -17% | -31% |
| Lower Calavera Creek | 1008 | -8% | -13% | -13% | -34% |
| Middle Calavera Creek | 1009 | 1% | 0% | 1% | 1% |
| Upper Calavera Creek | 1010 | -8% | 27% | 21% | -10% |
| Headwaters of Calavera Creek | 1011 | -17% | -7% | -10% | -9% |
| Little Encinas Creek | 1012 | 1% | -6% | -5% | -3% |
| Middle Agua Hedionda Creek | 1013 | -14% | -35% | -35% | -39% |
| Confluence of Roman and Agua Hedionda | 1014 | -8% | -10% | -13% | -7% |
| Roman Creek | 1015 | -5% | -1% | -2% | -2% |
| Confluence of Buena and Agua Hedionda | 1016 | -40% | -47% | -45% | -10% |
| Lower Mainstem Buena Creek | 1017 | -8% | -2% | -3% | -3% |
| Middle Mainstem Buena Creek | 1018 | -60% | -17% | -28% | -44% |
| Upper Mainstem Buena Creek | 1019 | -1% | 3% | -4% | 22% |
| North Fork Buena Creek | 1020 | -52% | -49% | -61% | -40% |
| Lower South Fork Buena Creek | 1021 | -49% | -39% | -56% | -33% |
| Upper South Fork Buena Creek | 1022 | 11% | -28% | -30% | 8% |
| Upper Agua Hedionda Creek | 1023 | -39% | -19% | -24% | -22% |
| Headwaters of Agua Hedionda Creek | 1024 | 47% | 6% | 9% | 48% |
| Lower La Mirada Creek | 1025 | -30% | -8% | -14% | -16% |
| Upper La Mirada Creek | 1026 | -50% | -78% | -75% | -52% |
| South Tributary of Lagoon | 1027 | -6% | -27% | -23% | -6% |
| Lower Agua Hedionda Lagoon | 1028 | -5% | -6% | 27% | -4% |

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# 4 Geomorphic Analysis

A geomorphic analysis of the stream channels in the Agua Hedionda watershed was conducted to evaluate how geomorphic processes have influenced the existing channel morphologies, and to investigate the need for and appropriateness of measures installed in the stream channels to address problematic erosion or deposition. The analysis seeks to distinguish between natural variability in geomorphic conditions and impacts due to human influence. The analysis of the geomorphic condition includes two components: 1) observations made during a field assessment, and 2) a review of historic data (e.g., aerial photography and topographic maps).

## 4.1 Field Assessment

The field assessment was performed between September 30 – October 3, 2007 by a team of one hydraulic engineer and one fluvial geomorphologist. Reaches were identified throughout the watershed with the objective of covering as wide a range of conditions as possible over the four-day period. Other factors that influenced the selection of the reaches were: reach access, adjacent development pressures, sufficient distance from the influence of hydraulic structures, and previous studies and reports. The initially selected reaches were presented to stakeholders at a meeting on September 29, 2007, and some reaches were shifted, removed, or added based on stakeholder input. Due to time constraints, not all of the initially identified reaches were visited in the field; however the reaches visited were selected to cover conditions throughout the watershed.

Given the alluvial nature of most of the stream reaches, a channel evolution model (CEM) was used to categorize the geomorphic condition (Figure 4-1). The basis of a CEM is that alluvial channels undergo a predictable progression of changes in response to a disturbance. Therefore, given an existing CEM class, it is appropriate to expect a progression of future processes (i.e., incision, widening, and aggradation) to shape the channel morphology. The conditions illustrate observations made during a single point in time. Without at least two points, trends cannot be explicitly quantified but can be inferred based on observations of ongoing processes.

The future geomorphic condition of observed stream reaches is inferred using existing CEM classes. Class II channels are most at risk for future incision and widening – leading to massive sediment input to the system. Class V channels are stabilizing naturally, and barring additional disturbances, will likely reach a new state of equilibrium without management. Thus, Class II through Class IV channels present the greatest risk in terms of supplying excessive sediment to the streams. The existing CEM classes span the range of possibilities, so it is logical to expect a variety of future conditions.

Based on the field assessment, the existing geomorphic condition of stream channels in the Agua Hedionda watershed spans the full range of possibilities. Some reaches do not exhibit indicators of instability (e.g., the upper reach of La Mirada Creek and the upper reach of Little Encinas Creek) whereas other reaches are typical of incising and widening reaches (e.g., the upper reach of two headwater tributaries to Buena Creek, the central portion of Agua Hedionda Creek, and the upper reach of Calavera Creek), and some reaches appear to have naturally reached a state of post-disturbance equilibrium (e.g., the upper reach of Agua Hedionda Creek).

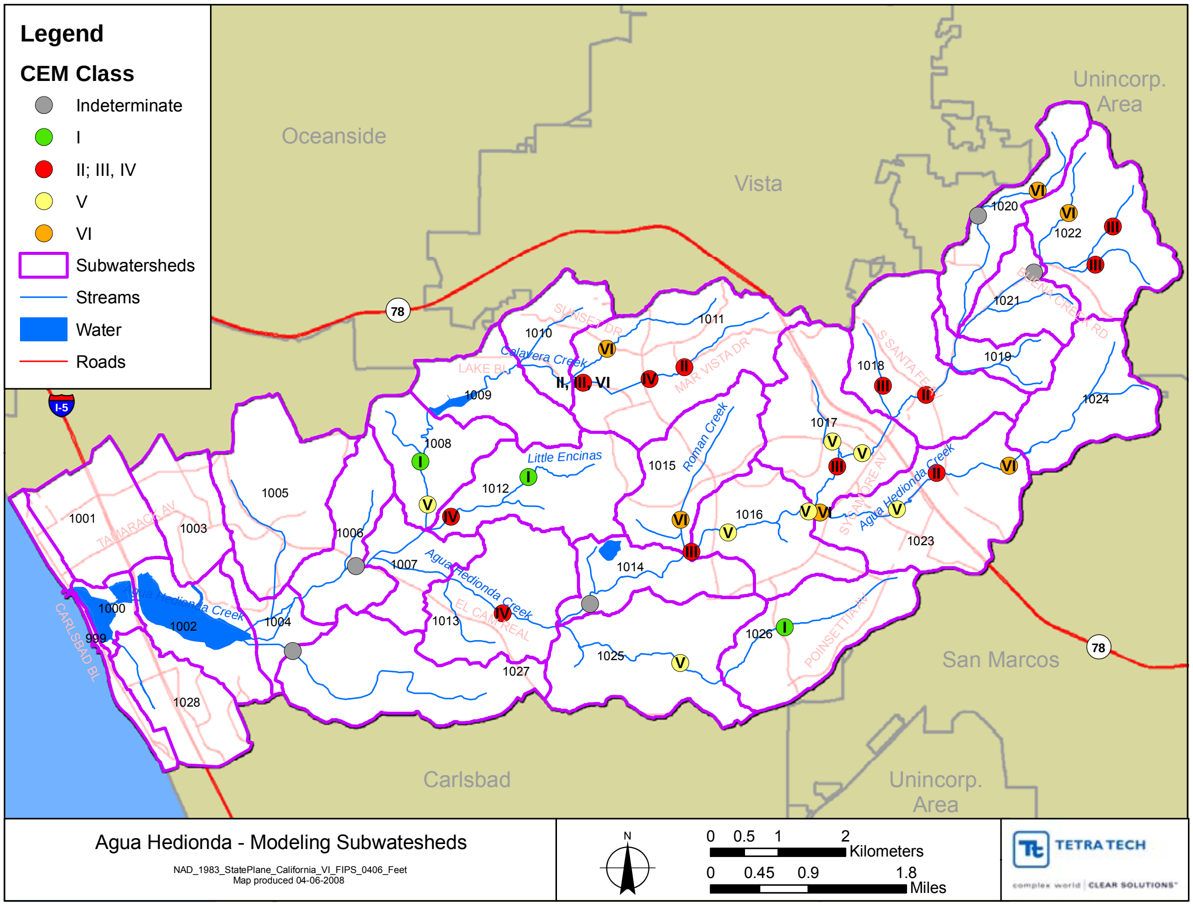


**Figure 4-1. Channel Evolution Model Classes for Assessed Stream Reaches**

## 4.2 Review of Historic Data

The review of historic data began with a search to obtain a comprehensive series of historical aerial photographs. The maps were obtained through the Davidson Library at University of California, Santa Barbara (UCSB). Available data included photographs for the years 1939, 1963, 1976, 1980, 1990-91, 2002, and 2005. While additional coverage between 1939 through 1963 was desirable, it was not available. A comparison between years showed that the channel alignments between 1963 through 1990 were virtually identical as were 2002 and 2005; therefore the only years presented in the analyses are 1939, 1963, 1990, and 2002. The 1976 and 1980 photographs were not analyzed since they provided redundant information. The 2002 photographs were used instead of the 2005 photographs because the extremely high resolution of the 2005 photographs makes them difficult to use at the scale needed for mapping analysis. The available aerial photographs represent conditions that range from relatively sparse development to current levels of development. The 1939 and 1963 periods show the change from a natural undeveloped watershed to one with increasing areas of agriculture. Following the 1963 period progressively more urban development can be seen throughout the watershed.

Figures below reflect the channel alignment observed in the photographs for each of the years. Note that due to difficulties in rectifying older aerial photographs, the channel alignments are not perfectly normalized. A similar channel sinuosity with an offset in alignment indicates little or no channel movement; the offset is likely an artifact of image rectification.

In addition to the analysis of the historical aerial photograph, an attempt was made to obtain historical topographic information to perform similar qualitative geomorphic analyses. Very little historical topography was available – only USGS mapping from 1901 (surveyed in 1891) and 1948 (surveyed by aerial mapping in 1946) could be obtained. The current USGS maps have recent photorevision dates, but utilize the same topographic data from 1946. Recent topographic mapping was generated from LiDAR data collected in 2005 for the cities of Vista and Carlsbad. The 1901 quad was developed with 25-foot contours, the 1948 quad was mapped at 20-foot contours, and the 2005 LiDAR data was converted to 2-foot contours. Profiles for Agua Hedionda, Buena Creek, and Calavera Creek were created from the historical topographic maps as well as from topographic mapping flown in 2005. Considering the differences in the resolution of the various data sources, Agua Hedionda Creek and Buena Creek, showed no obvious changes in stream profile trends from the 1891 survey to 2005, but Calavera Creek experienced profile changes associated with the construction of Calavera Lake in 1940. This profile assessment is in general terms of entire reaches and does not reflect localized changes that may have occurred. But it does indicate that no large scale changes (other than at Calavera Lake) have occurred in the vertical profile of the channel. Localized changes in profile are discussed in more detail in the following sections.

The historical aerial photograph analysis was continuous along the stream reaches studied. For presentation purposes, the reaches have been grouped into the following major reaches and are discussed below:

1. Lower Agua Hedionda Creek – from the lagoon to the Buena Creek confluence
2. Upper Agua Hedionda Creek – from the confluence of Buena Creek to the headwaters
3. Buena Creek – from the confluence with Agua Hedionda Creek to the headwaters
4. Calaveras Creek – from the confluence with Agua Hedionda Creek to Melrose Drive downstream of Melrose Drive
5. Other tributaries – including Little Encinas Creek, La Mirada Creek, and Roman Creek

### 4.2.1 Lower Agua Hedionda Creek

The most prominent feature of this reach is the Agua Hedionda Lagoon. The outlet of the lagoon is operated by the San Diego Gas and Electric Company (SDG&E) and the connection to the ocean is maintained through dredging operations and constructed riprap jetties. Prior to the power plant operations, the status of the ocean outlet varied and the lagoon outlet was intermittently closed to the ocean. A closed outlet apparently allowed for a larger lagoon footprint in 1939, as shown in Figure 4-2. In 1939 the open water of the lagoon was approximately 314 acres while open water in 2002 was approximately 190 acres. SDG&E dredged the entire lagoon in 1954 to create water storage for the Cabrillo Power Plant cooling water intake. The lagoon was dredged again in 1998.

Between the lagoon and the El Camino Real crossing, Agua Hedionda Creek has a flat slope of approximately 0.5 percent. The mild slope and the variation in the lagoon boundary are the likely contributors to the channel movement that is seen in this reach (see Figure 4-2). Through this reach the movement seen over time in the channel alignment is not a likely indicator of instability but a reflection of the natural depositional processes that occur within this channel. This reach of the creek is not constrained by development. The field assessment revealed a wide, flat area in which multiple shallow channels are located. The dense vegetation coupled with the substantial deposition leads to a reach where multiple channels are constantly forming, migrating, and filling.

The location of the stream is consistent over time at the crossing under El Camino Real. This road was present in the earliest photographs analyzed (1939) and the bridge has prevented any lateral channel movement. During the field assessment, anecdotal evidence was provided that approximately 5-feet of sandy, depositional material was recently dredged from the stream channel between the El Camino Real and Cannon Road crossings.

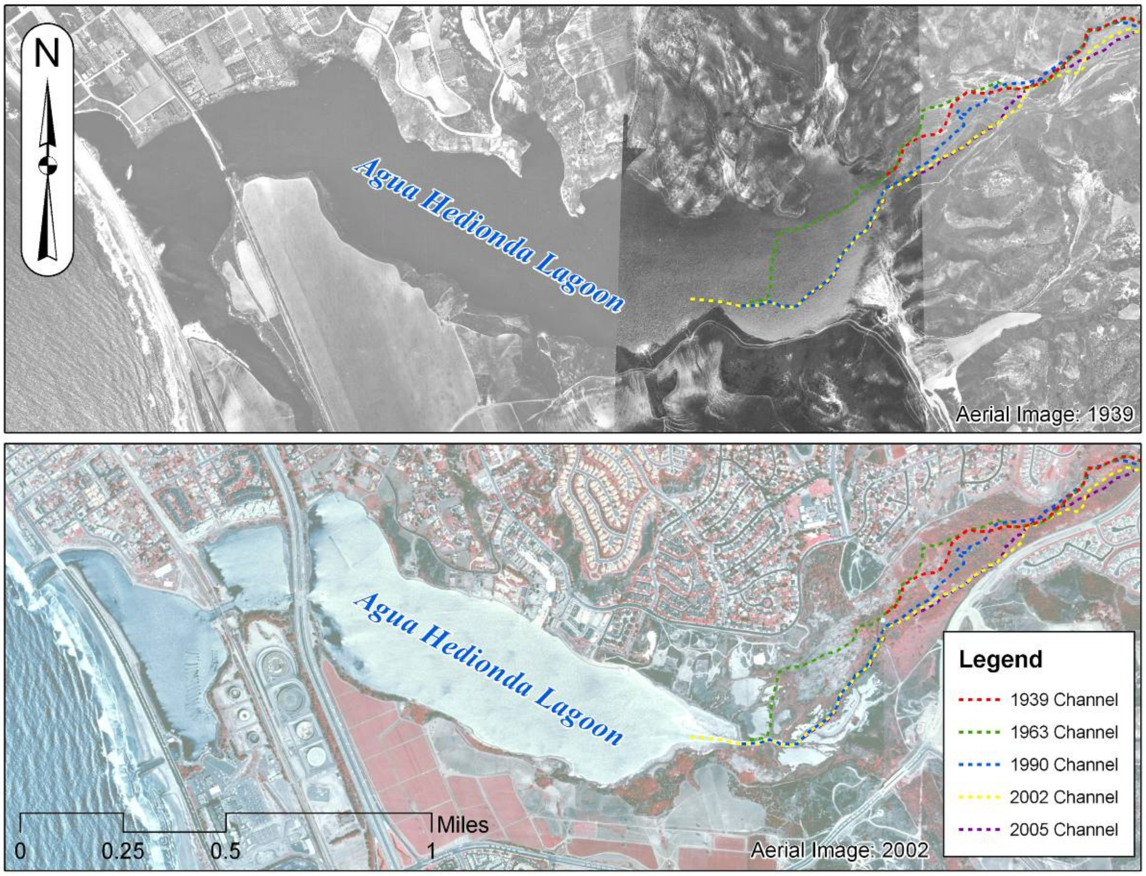


**Figure 4-2. Comparison of the Lagoon within Lower Agua Hedionda Creek in 1939 and 2002**

Through the reach located upstream of the Calavera Creek confluence some movement can be seen in the channel. Historical aerial photographs show that during earlier time periods this reach included areas of sandy braided channels. The most significant channel movement is shown in Figure 4-3. A plateau exists downstream of the La Mirada Creek confluence that allows for more significant movement of the channel. However it should be noted that this channel movement is localized to the plateau area where the slope of the channel changes from steep (3.1 percent upstream of the confluence) to gentle (1.2 percent downstream of the confluence). Sediment load may have been greater in the past due to traditional ranching and agriculture activities in the watershed and this plateau would be a likely site of downstream deposition. During the field assessment, the presence of Sunny Creek road along this portion of the reach, as well as associated residences, was observed to constrain the lateral migration extent of the creek. These development impacts may be responsible for changing the morphology of the creek from a multiple channel braided system to a single channel system. A single channel with a deeper cross section would also encourage additional transport of sediment through this reach into downstream reaches – locations where excessive deposition was observed (or where dredging actions were evident). While these changes do not necessarily indicate an unstable channel, additional runoff volumes from the developing watershed have the potential to more regularly inundate the road, and to scour the single channel causing bank erosion and collapse. Sections of this reach east of the Sunny Creek area through the Dawson Reserve, the Vista open space area, and Green Oak Ranch were observed where the toe of the bank has been undercut and adjacent trees have fallen into the creek or are in imminent danger of falling. It is also possible that observed erosion in the plateau area may be due to a shift from sediment producing human activities, such as ranching and agriculture, to a developed urban environment upstream which has likely reduced sediment load sources.

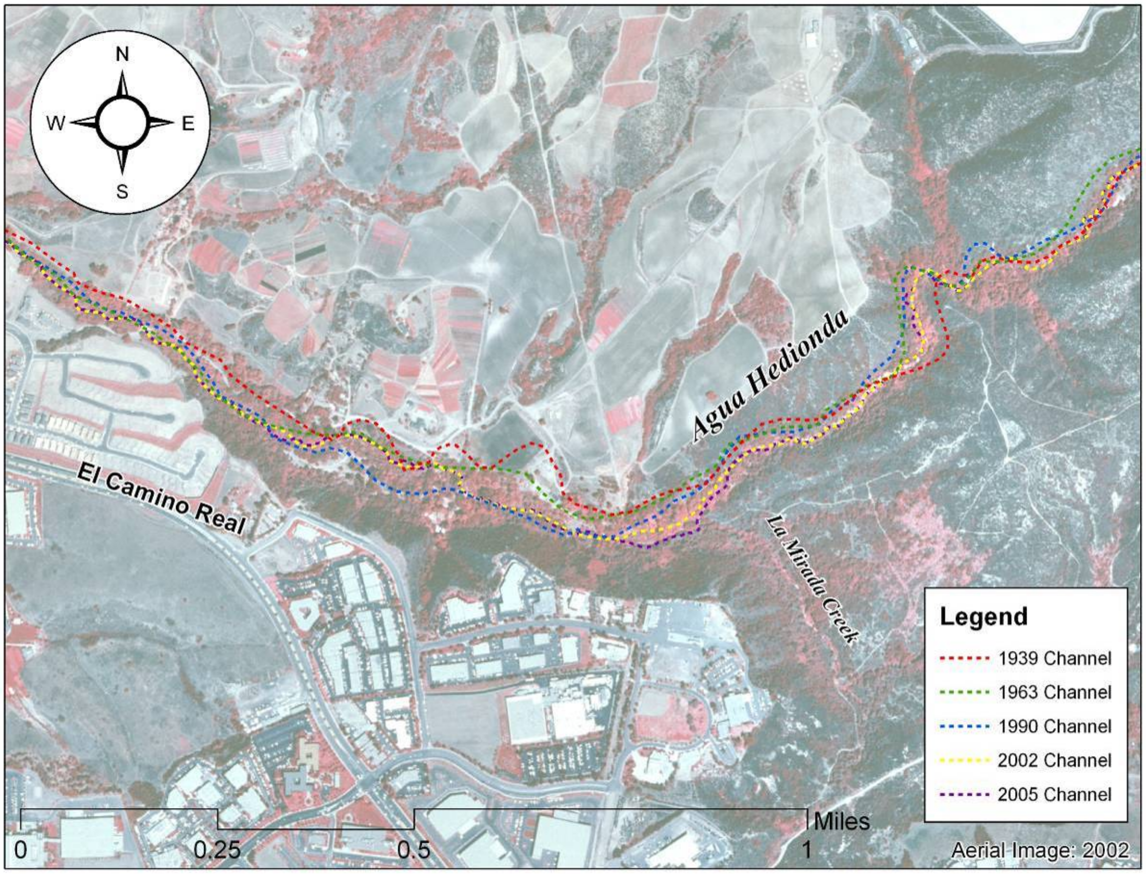


**Figure 4-3. Channel Analysis in Lower Agua Hedionda Creek**

### 4.2.2 Upper Agua Hedionda Creek

Very little movement in the channel alignment is seen in this reach over time. This is true in the lower portion of the reach between the confluence with Buena Creek and the Cherimoya Drive crossing where urban development has constrained the channel. In the upper reaches upstream of Cherimoya Drive where development is more limited or setback further from the creek, the natural topography generally confines the stream channel as shown in Figure 4-4. In the upper portion of this study reach the channel slope is approximately 2.8 percent.

The field assessment indicates less bank erosion than what was seen in Lower Agua Hedionda Creek. The lower half of the reach appears to have year round base flow while the upper half appears to be ephemeral. Two lakes were observed in the upper reaches where the channel was impounded. Given the similarity in the alignment of the channel in the upper half of this reach since 1939, and the observations made during the field assessment, it does not appear that development in the watershed has substantially impacted the morphology of the stream channel above the Cherimoya Drive crossing. Between the confluence with Buena Creek and Cherimoya Drive, several locations were identified where the sanitary sewer impacts the creek through either grade control structures associated with a sewer crossing or manholes adjacent to or within the active channel. Further, the extent of development has limited the stream to a narrow channel where flooding impacts were reported by adjacent residents.

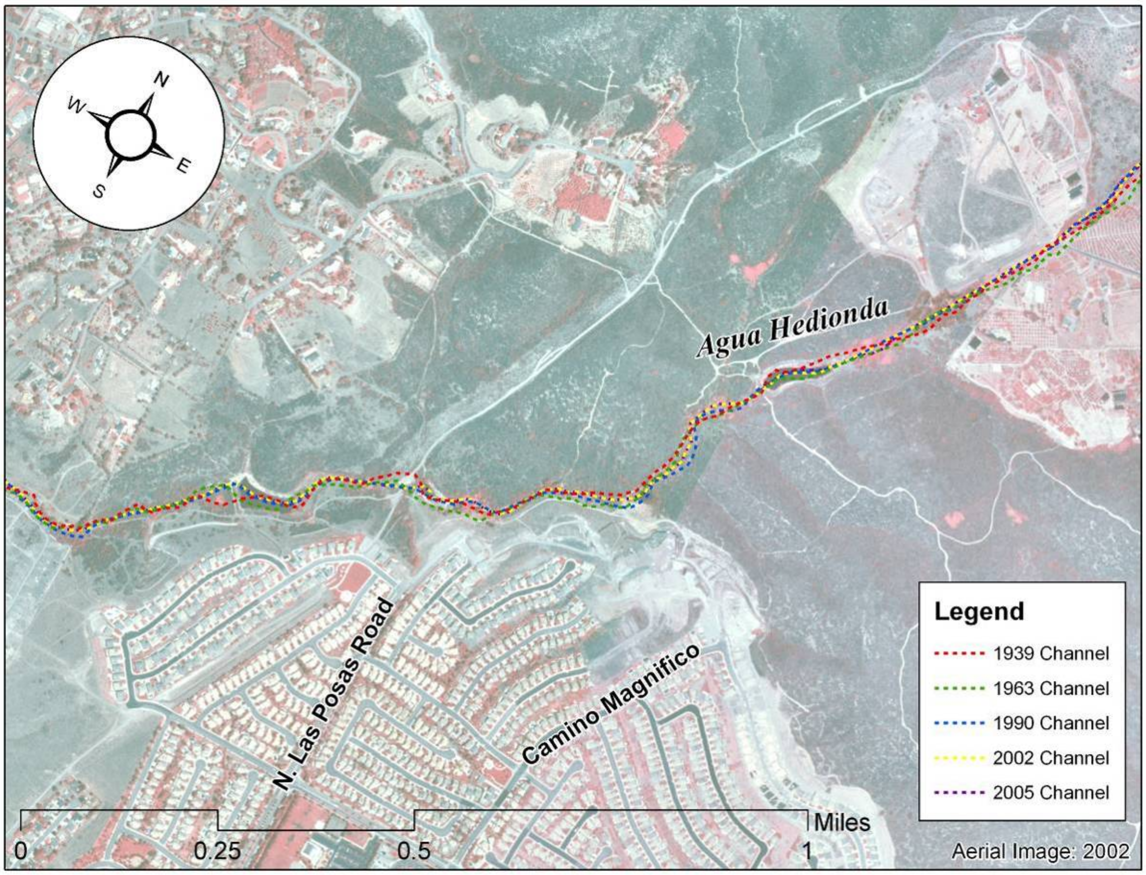


**Figure 4-4. Channel Analysis of Upper Agua Hedionda Creek**

## 4.2.3 Buena Creek

Figure 4-5 shows a typical reach of Buena Creek. The entire length of the creek exhibits very little to no movement in the channel alignment. Buena Creek Road follows the alignment of the creek through much of the reach and this may be contributing to the lateral stability of the channel. Both the creek and the road are located in the bottom of a relatively narrow valley, so the natural topography also contributes to the consistency of the channel alignment. This road can be seen in the aerial photographs as early as 1939. The channel slope near the middle portion of the channel reach is approximately 2.0 percent.

The field assessment shows some of the most impacted stream lengths due to manmade constraints. There are a significant number of culverts along this creek as well as significant constraints due to adjacent development. Some erosion at the toe of the banks was seen; but minimal compared to the bank erosion seen in lower Agua Hedionda. While access to the channel was limited by the numerous private landowners, it is likely that the existing culverts limit the potential for lateral migration and serve as grade controls keeping the grade in check. The observations of the headwater channels feeding Buena Creek revealed dynamic erosional processes, likely due to newer development and landowner actions within and along the channels. This erosion appears to be localized, and is not indicative of geomorphic conditions along the mainstem of Buena Creek.

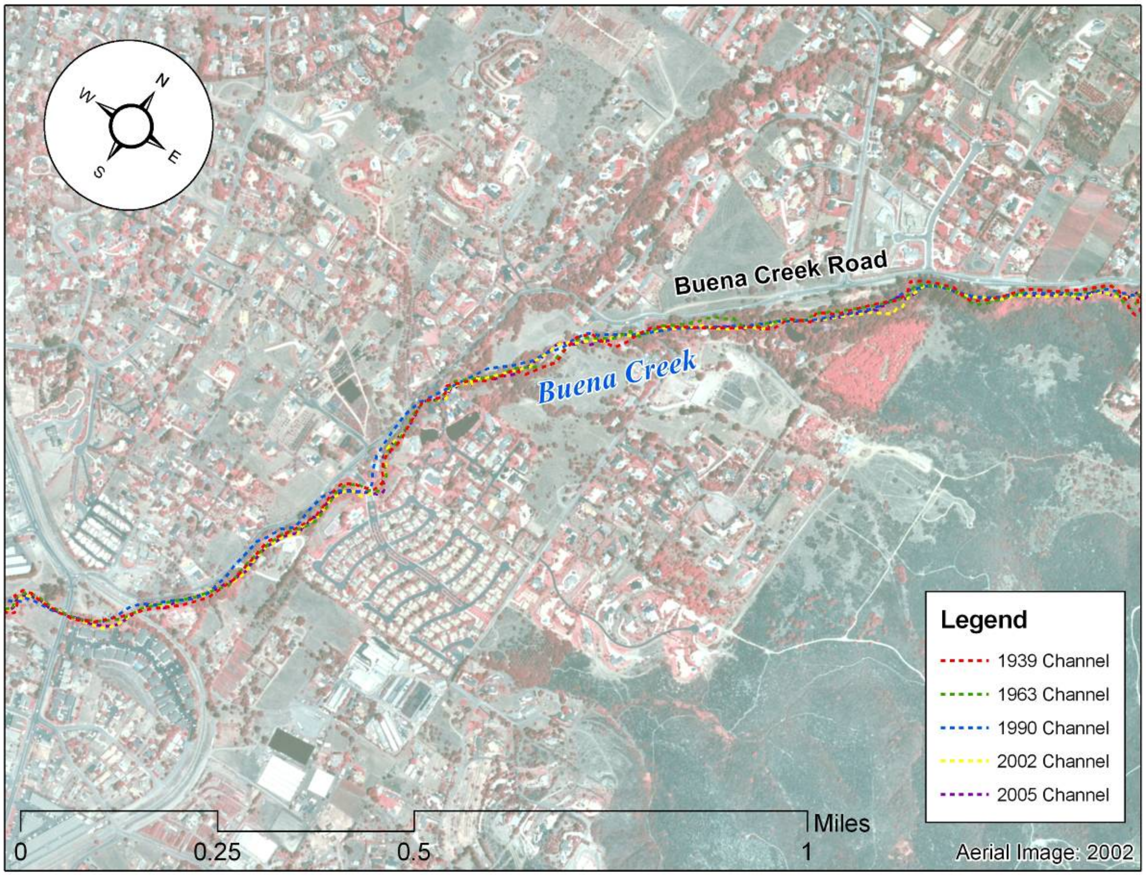


**Figure 4-5. Buena Creek Channel Analysis**

## 4.2.4 Calavera Creek

The most prominent feature in this reach is Calavera Lake. This lake was constructed in 1940. As part of the construction the stream immediately downstream of the lake was realigned to the northwest as shown in Figure 4-6. The rest of the creek shows very little change in the alignment of the creek. Unlike the other creeks in the watershed, the lower half of the assessed portion of the creek runs through a protected open space park or reserve and is minimally impacted by surrounding development. Upstream of the lake the channel slope is approximately 1.4 percent while downstream of the lake the channel slope is approximately 0.7 percent.

Field assessments along Calavera Creek focused on the reach of the creek bounded on the upstream end by Buena Vista Drive and on the lower end by the lake due to the impact of human actions. Upstream of Melrose Drive the alignment of the channel along a sanitary sewer line between a nursery and an equestrian training area is leading to channel incision and widespread bank erosion. The creek is piped between Melrose Drive and Lake Boulevard. Along Lake Boulevard, the realigned channel is experiencing significant bank erosion. Numerous failed attempts at grade control (e.g., stacks of gravel meter bags or concrete sills) were observed. The ongoing incision and bank erosion threatens the sidewalk along the road, and the retaining/privacy wall for the community along the other bank. While some of the grade controls in Oak Riparian Park are working as designed, some are flanked and entirely ineffective or buried with deposition. While these observations indicate an active channel in this reach, the effects on sedimentation in the lagoon are limited by the sediment trapping capacity of Calavera Lake. Without this lake, downstream deposition is expected to be a more significant issue.

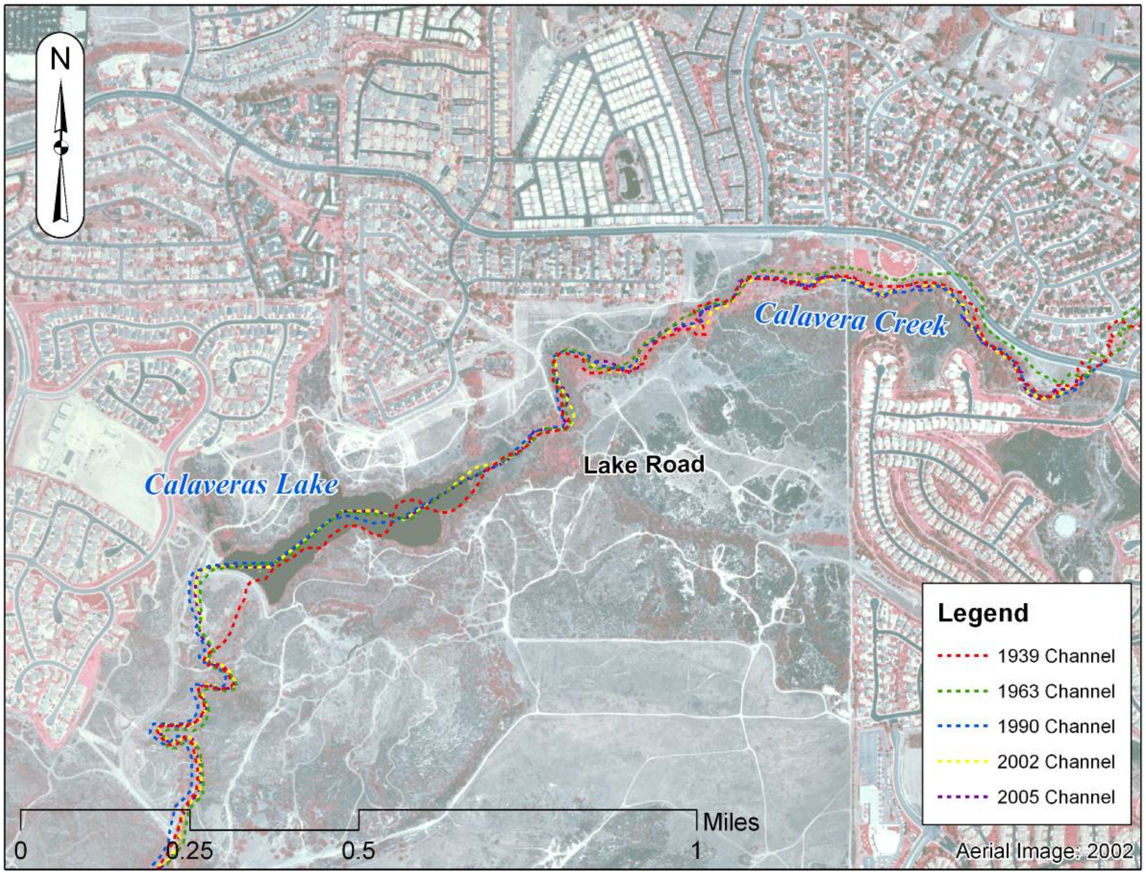


**Figure 4-6. Calavera Creek Channel Analysis**

## 4.2.5 Other Tributaries

Historical aerial photographs for Little Encinas Creek, Roman Creek, and La Mirada Creek were not analyzed in depth. Similar to the larger streams in the watershed a quick review indicated that the alignment of the channel has remained fairly constant over time.

Field assessment of Little Encinas Creek indicates that this stream is significantly impacted by adjacent development. There are several culvert crossings and historic dredging activities have been reported through the highly modified reach through the Rancho Carlsbad Mobile Home Park just downstream of Little Encinas Creek's confluence with Calavera Creek. This channel also shows some recent erosion effects, in particular just upstream of the confluence with Calavera Creek where an adjacent parking lot has been impacted by channel erosion. The field assessment of Roman Creek showed significant stream obstruction from the large boulders throughout the reach. This large rock is likely contributing to the stability of the creek, and more importantly, limiting propagation of incision occurring at the confluence with Agua Hedionda Creek. Field assessment of La Mirada indicates that the channel is aggrading. Depositional features were seen throughout and the bank heights are relatively low. Anecdotal evidence was provided that large scale sediment traps were installed in La Mirada Creek, but these features were not observed during the field assessment.

## 4.3 Conclusions of Geomorphic Analysis

The geomorphic analysis of the stream channels in the Agua Hedionda watershed provides insight into the influence of geomorphic processes on the existing channel morphology, establishing a basis for identifying appropriate locations for measures to control excessive erosion or deposition. Further, the historic context provided through the aerial photograph review allows for preliminary assessments of morphologic change due to natural variability versus impacts due to human influence. In conjunction, the field assessment and aerial photograph analyses revealed that the stability of the channel has been negatively impacted over time at many locations throughout the stream system. These impacts are most significant over a short reach of Calavera Creek and most of the lower reach of Agua Hedionda Creek. Impacts were observed at other locations throughout the watershed; however none of those impacts are as severe.

Sediment has been identified as impairment to the Agua Hedionda Lagoon. Calculations would need to be performed to determine the volume of sediment deposited in the lagoon as well as the volume of sediment that has been lost from the channel banks. A mass balance of the sediment through the system would help identify if the lagoon sediment issues are a result of channel erosion. Though this type of analysis is beyond the scope of this project, an estimate of total sediment loading to the lagoon has been provided as described in Section 3.2 and graphed in Appendix E.

## 4.4 Comparison with Hydrologic Modeling Results

To compare modeling results with the geomorphic analysis, a hydrologic metric, Tqmean, was developed for the Predevelopment and Existing Scenario using the GeoTools package (Raff et al., 2007). Demonstrated by Konrad and Booth (2002), Tqmean is the proportion of time that channel discharge is above the annual daily-averaged mean level. It is inversely correlated to urban development and has been shown to be a predictor of geomorphic response of streams to urbanization.

The difference in Tqmean between the Predevelopment and Existing scenarios provides an indicator of the impact of urbanization on the flow regime or channel hydromodification (Figure 4-7). The subwatersheds with the least percentage change would be expected to have the least impact on channel morphology. The preceding channel analysis identified the Upper Agua Hedionda Creek and most of the mainstem of Buena Creek as exhibiting little channel movement over time. These areas correspond well to the subwatersheds with the least change in Tqmean (i.e., the light orange and yellow shaded areas in the upper portion of the watershed). The impacted reaches on the upper Calavera Creek noted in the geomorphic analysis also correspond to subwatersheds with large changes in Tqmean (c.f. subwatersheds 1011 and 1010 in Figure 4-7). La Mirada Creek is aggrading corresponding to a moderate Tqmean difference in the upper drainage area.

Areas where the two lines of evidence, the geomorphic analysis and the model, do not converge are at Little Encinas Creek and Roman Creek. The expected impact to Roman Creek based on the difference in Tqmean is not realized, apparently due to the presence of large rock contributing to stability. Field characterization near the outlet showed a channel that may have been impacted in the past but was equilibrating to watershed conditions. Open space preservation represented in the model within the Little Encinas watershed appears to be neutralizing area-averaged impacts in the model that are in fact realized on the ground in some locations.

Finally, the cause of channel movement along the Agua Hedionda Creek is unclear based on the geomorphic analysis. The hydrologic metric chosen suggests a modest level of impact from development.

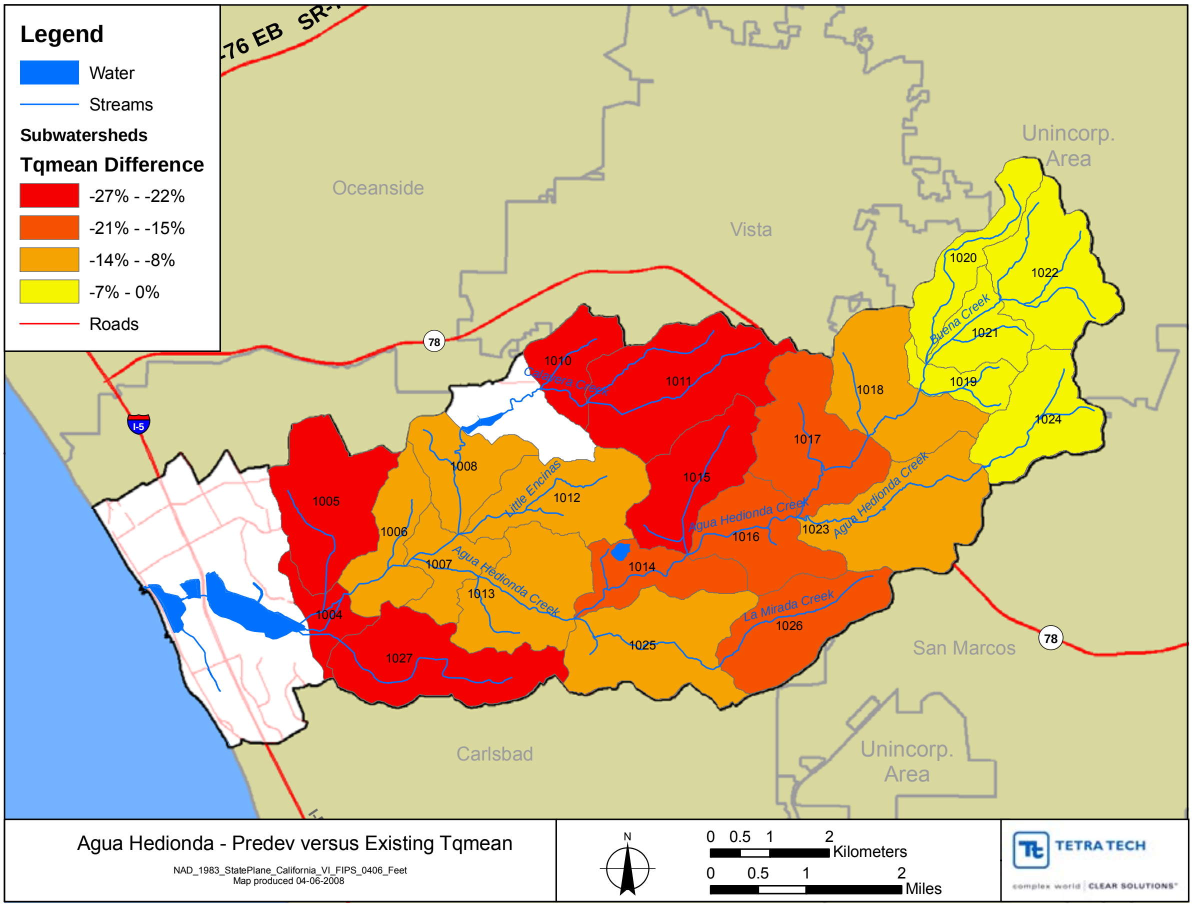


**Figure 4-7. Changes in Hydrologic Metric (Tqmean) from Predevelopment to Existing**

# 5 Summary and Next Steps

The modeling and geomorphic analysis provides an understanding of existing and potential future conditions in the watershed with respect to changes in the hydrologic regime and impacts on pollutant loading.

The results suggest that channel modification due to past watershed development has occurred in many parts of the watershed. A combination of stabilization, restoration, and stormwater retrofit practices will be needed to address these existing impacts. Planned new development has the potential to further degrade stream channels in the Agua Hedionda watershed, though the impacts can be mitigated to a large extent by existing BMP requirements that address peak flows from future development. As discussed in Section 3.1, the need for additional protection measures should be explored during the development of the San Diego Region Hydromodification Plan.

Agua Hedionda Lagoon and many of its tributaries are impaired and not supporting designated beneficial uses under the Clean Water Act Section 303(d). Future development with BMPs as represented herein should result in an overall decrease in sediment, bacteria, and nutrient loading to the lagoon due to three factors: (1) preservation of open space, (2) the conversion of agricultural land to residential and non-residential development that is treated by stormwater BMPs, and (3) the redevelopment with associated stormwater BMP treatment of significant portions of the watershed. The modeling results are sensitive to these changes. In particular, if the planned redevelopment does not occur as represented in the model scenarios (e.g., without LID and BMPs as required by the 2007 Order), the watershed could be at greater risk of degradation. Further, since the assimilative capacity of the lagoon has not been determined to date, additional reductions beyond those predicted by this watershed model in the future scenario could be needed.

The modeling results presented here will be used to target management recommendations in the WMP. In addition, an evaluation of additional LID implementation is planned for select subwatersheds and development types.

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# Appendix A. SANDAG Land Use Category Groupings

**Table A-1. SANDAG Land Use Category Groupings**

| SANDAG LULC Code | SANDAG LULC Description | Tetra Tech LULC Description |
|---|---|---|
| 1000 | Spaced Rural Residential | Very Low/Low/Med/High Density Resid. |
| 1110 | Single Family Detached | Very Low/Low/Med/High Density Resid. |
| 1120 | Single Family Multiple-Units | Single Family Multiple Units |
| 1200 | Multi-Family Residential | Multifamily |
| 1300 | Mobile Home Park | Multifamily |
| 1409 | Other Group Quarters Facility | Multifamily |
| 1501 | Hotel/Motel (Low-Rise) | Multifamily |
| 1503 | Resort | Multifamily |
| 2101 | Industrial Park | Warehouse/Industrial/Transportation |
| 2103 | Light Industry - General | Warehouse/Industrial/Transportation |
| 2104 | Warehousing | Warehouse/Industrial/Transportation |
| 2105 | Public Storage | Warehouse/Industrial/Transportation |
| 4112 | Freeway | Warehouse/Industrial/Transportation |
| 4113 | Communications and Utilities | Warehouse/Industrial/Transportation |
| 4117 | Railroad Right-of-Way | Warehouse/Industrial/Transportation |
| 4118 | Road Right-of-Way | Warehouse/Industrial/Transportation |
| 4119 | Other Transportation | Warehouse/Industrial/Transportation |
| 5004 | Neighborhood Shopping Center | Lt. Commercial/Office/Institutional |
| 5005 | Specialty Commercial | Lt. Commercial/Office/Institutional |
| 5006 | Automobile Dealership | Lt. Commercial/Office/Institutional |
| 5007 | Arterial Commercial | Lt. Commercial/Office/Institutional |
| 5008 | Service Station | Lt. Commercial/Office/Institutional |
| 5009 | Other Retail Trade and Strip | Lt. Commercial/Office/Institutional |
| 6002 | Office (Low-Rise) | Lt. Commercial/Office/Institutional |
| 6003 | Government Office/Civic Center | Lt. Commercial/Office/Institutional |
| 6102 | Religious Facility | Lt. Commercial/Office/Institutional |
| 6105 | Fire/Police Station | Lt. Commercial/Office/Institutional |
| 6109 | Other Public Services | Lt. Commercial/Office/Institutional |

| SANDAG LULC Code | SANDAG LULC Description | Tetra Tech LULC Description |
|---|---|---|
| 6509 | Other Health Care | Lt. Commercial/Office/Institutional |
| 6802 | Other University or College | Lt. Commercial/Office/Institutional |
| 6804 | Senior High School | Lt. Commercial/Office/Institutional |
| 6805 | Junior High School or Middle School | Lt. Commercial/Office/Institutional |
| 6806 | Elementary School | Lt. Commercial/Office/Institutional |
| 6809 | Other School | Lt. Commercial/Office/Institutional |
| 7205 | Golf Course Clubhouse | Lt. Commercial/Office/Institutional |
| 4103 | General Aviation Airport | Heavy Commercial |
| 4114 | Parking Lot - Surface | Heavy Commercial |
| 4116 | Park and Ride Lot | Heavy Commercial |
| 5001 | Wholesale Trade | Heavy Commercial |
| 5003 | Community Shopping Center | Heavy Commercial |
| 7210 | Other Recreation - High | Parks/Recreation |
| 7601 | Park - Active | Parks/Recreation |
| 7604 | Beach - Active | Parks/Recreation |
| 7606 | Landscape Open Space | Parks/Recreation |
| 7607 | Residential Recreation | Parks/Recreation |
| 7204 | Golf Course | Open/Recreation |
| 8001 | Orchard or Vineyard | Agriculture |
| 8002 | Intensive Agriculture | Agriculture |
| 8003 | Field Crops | Agriculture |
| 1190 | Single Family Residential Without Units | Open |
| 7603 | Open Space Park or Preserve | Open |
| 7605 | Beach - Passive | Open |
| 9101 | Vacant and Undeveloped Land | Open |
| 9200 | Water | Water |
| 9201 | Bay or Lagoon | Water |
| 9202 | Lake/Reservoir/Large Pond | Water |
| 9501 | Residential Under Construction | Transitional |
| 9503 | Industrial Under Construction | Transitional |

# Appendix B. Model Sediment Parameters

Based on the SCWRRP regional sediment approach (personal communication, D. Ackerman, 1/22/2008), the following parameters for the sediment module were used as initial values. Some adjustment was necessary based on local conditions and observed data.

**PERLNDs**

SMPF 1.0

KRER (Fixed at 0.23 by SCWRRP). The presented model varies this parameter by soil group and land use (area-weighted average) as follows:

SSUGRO soil data for San Diego County was utilized to calculate weighted KRER values for each land use and soil hydrologic group (HSG) within the Aqua Hedionda watershed. A weighted average of soil slope (*S*) and soil erodibility factors (*K*) were calculated for each soil map unit in ArcGIS using Soil Data Viewer. The land use classification layer (which contained HSG values for each parcel) was subsequently intersected with both the aggregated slope and K factor layers. In a spreadsheet program, slope and K factor values were subtotaled and area weighted for each land use classification and soil hydrologic group across the watershed. In order to calculate *KRER* values, length-slope (*LS*) factors were first calculated according to the Wischmeier and Smith (1978) equation:

$$LS = (0.045\ L)^b \cdot (65.41 \sin^2 \theta_k + 4.56 \sin \theta_k + 0.065)$$

where $\theta_k = \tan^{-1}(S/100)$, $S$ in the slope in percent, $L$ is the slope length, and $b$ equals the following values: 0.5 for $S \geq 5$, 0.4 for $3.5 \leq S \leq 5$, 0.3 for $1 \leq S \leq 3$, and 0.2 for $S < 1$. An $L$ value of 15 meters was used for all $LS$ calculations, and $LS$ values were not allowed to exceed 5. Finally, KRER values were calculated using the following equations:

$$KRER = G \cdot K \cdot LS$$

where G accounts for unit conversion and was assigned a value of 4.102.

JRER Set all to 1.81 (SCWRRP used 2.0)

AFFIX All set at 0.005

COVER All set at 0.10 by SCWRRP

NVSI Set to 0

KSER Set to 1.8

JSER Set to 2.0

KGER Set to 0

JGER Set to 2.0 (inactive)

DETS 0.5 tons/ac

**IMPLNDs**

KEIM and JEIM varies by land use. The following values for impervious surfaces for general land use categories were used.

| | Industrial | LDR | HDR | Commercial | Open/Park |
|---|---|---|---|---|---|
| KEIM | 0.07 | 0.03 | 0.015 | 0.10 | 0.20 |
| JEIM | 1.5 | 1.5 | 1.5 | 1.5 | 2.0 |

ACCSDP Use 0.037 tonnes/ha/d = 0.0165 tons/ac/d

REMDSP Set at 0.20

Upland Sediment Fractions

SSURGO data was used to set the fraction of total sediment from land that is sediment class (Table B-1). Adjustments to account for deposition en route were made based on the assumption that 50 percent of the sand and 30 percent of silt is deposited using watershed delivery ratios in Vanoni, 1975. Table B-2 provides the resulting land fractions for the model.

**Table B-1. Sediment Fractions by Hydrologic Soil Group**

| HSG | Sand | Silt | Clay |
|---|---|---|---|
| B | 65 | 23 | 12 |
| C | 68 | 19 | 14 |
| D | 54 | 21 | 24 |

**Table B-2. Sediment Fractions Adjusted for Watershed Delivery**

| HSG | Sand | Silt | Clay |
|---|---|---|---|
| B | 33 | 16 | 51 |
| C | 34 | 13 | 53 |
| D | 27 | 15 | 58 |

## RCHRES

Parameters were initially set as follows, but were modified during calibration.

```
  SANDFG
*** RCHRES
*** x -  x SNDFG
  601  676   3
  END SANDFG

  SED-GENPARM
*** RCHRES   BEDWID   BEDWRN      POR
*** x -  x     (FT)     (FT)
  601  676     35.0      4.0      0.4
  END SED-GENPARM

  SAND-PM
*** RCHRES        D       W      RHO    KSAND   EXPSND
*** x -  x     (IN)  (IN/SEC)  (GM/CM3)
  601  676    0.005     0.02      2.5     .005      3.0
  END SAND-PM
```

```
  SILT-CLAY-PM                       SILT PARAMETERS
*** RCHRES        D         W      RHO    TAUCD    TAUCS        M
*** x -  x      (in)  (in/sec)   gm/cm3   lb/ft2   lb/ft2  lb/ft2.d
  601  676   0.0004    .0001      2.2     .0100    .1300  0.00300
  END SILT-CLAY-PM

  SILT-CLAY-PM                       CLAY PARAMETERS
*** RCHRES        D         W      RHO    TAUCD    TAUCS        M
*** x -  x        (in)  (in/sec)   gm/cm3   lb/ft2   lb/ft2  lb/ft2.d
  601  676  0.00006   .00005      2.0   0.0010    .0650    .0030
  END SILT-CLAY-PM

  SSED-INIT
*** RCHRES    Suspended sed concs (mg/l)
*** x -  x      Sand      Silt      Clay
  601  676      0.0       0.0       0.0
  END SSED-INIT

  BED-INIT
*** RCHRES   BEDDEP  Initial bed composition
*** x -  x      (ft)      Sand      Silt      Clay
  601  676      2.0      0.38      0.46      0.16
  END BED-INIT
```

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# Appendix C. Model Hydrology Parameters

**Table C-1. 110 pwat-parm2**

| defid | deluid | lzsn | infilt | kvary | agwrc |
|---|---|---|---|---|---|
| 2 | 1 | 2.5 | 0.2 | 0 | 0.995 |
| 2 | 3 | 2.5 | 0.2 | 0 | 0.995 |
| 2 | 4 | 2.5 | 0.2 | 0 | 0.995 |
| 2 | 5 | 2.5 | 0.2 | 0 | 0.995 |
| 2 | 6 | 2.5 | 0.2 | 0 | 0.995 |
| 2 | 7 | 2.5 | 0.2 | 0 | 0.995 |
| 2 | 8 | 2.5 | 0.2 | 0 | 0.995 |
| 2 | 9 | 2.5 | 0.2 | 0 | 0.995 |
| 2 | 10 | 2.75 | 0.22 | 0 | 0.95 |
| 2 | 11 | 2.75 | 0.22 | 0 | 0.95 |
| 2 | 12 | 2.75 | 0.22 | 0 | 0.95 |
| 2 | 15 | 2.75 | 0.22 | 0 | 0.95 |
| 2 | 16 | 2.75 | 0.22 | 0 | 0.95 |
| 2 | 17 | 2.75 | 0.22 | 0 | 0.95 |
| 2 | 18 | 0 | 0 | 0 | 0 |
| 2 | 20 | 0 | 0 | 0 | 0 |
| 2 | 21 | 0 | 0 | 0 | 0 |
| 2 | 22 | 0 | 0 | 0 | 0 |
| 2 | 23 | 0 | 0 | 0 | 0 |
| 2 | 24 | 0 | 0 | 0 | 0 |
| 2 | 25 | 0 | 0 | 0 | 0 |
| 2 | 26 | 0 | 0 | 0 | 0 |
| 2 | 27 | 0 | 0 | 0 | 0 |
| 3 | 1 | 2.235 | 0.127 | 0 | 0.995 |
| 3 | 3 | 2.235 | 0.127 | 0 | 0.995 |
| 3 | 4 | 2.235 | 0.127 | 0 | 0.995 |
| 3 | 5 | 2.235 | 0.127 | 0 | 0.995 |
| 3 | 6 | 2.235 | 0.127 | 0 | 0.995 |
| 3 | 7 | 2.235 | 0.127 | 0 | 0.995 |
| 3 | 8 | 2.235 | 0.127 | 0 | 0.995 |
| 3 | 9 | 2.235 | 0.127 | 0 | 0.995 |
| 3 | 10 | 2.43 | 0.145 | 0 | 0.95 |

| defid | deluid | lzsn | infilt | kvary | agwrc |
|---|---|---|---|---|---|
| 3 | 11 | 2.43 | 0.145 | 0 | 0.95 |
| 3 | 12 | 2.43 | 0.145 | 0 | 0.95 |
| 3 | 15 | 2.43 | 0.145 | 0 | 0.95 |
| 3 | 16 | 2.43 | 0.145 | 0 | 0.95 |
| 3 | 17 | 2.43 | 0.145 | 0 | 0.95 |
| 3 | 18 | 0 | 0 | 0 | 0 |
| 3 | 20 | 0 | 0 | 0 | 0 |
| 3 | 21 | 0 | 0 | 0 | 0 |
| 3 | 22 | 0 | 0 | 0 | 0 |
| 3 | 23 | 0 | 0 | 0 | 0 |
| 3 | 24 | 0 | 0 | 0 | 0 |
| 3 | 25 | 0 | 0 | 0 | 0 |
| 3 | 26 | 0 | 0 | 0 | 0 |
| 3 | 27 | 0 | 0 | 0 | 0 |
| 4 | 1 | 3.25 | 0.044 | 0 | 0.995 |
| 4 | 3 | 3.25 | 0.044 | 0 | 0.995 |
| 4 | 4 | 3.25 | 0.044 | 0 | 0.995 |
| 4 | 5 | 3.25 | 0.044 | 0 | 0.995 |
| 4 | 6 | 3.25 | 0.044 | 0 | 0.995 |
| 4 | 7 | 3.25 | 0.044 | 0 | 0.995 |
| 4 | 8 | 3.25 | 0.044 | 0 | 0.995 |
| 4 | 9 | 3.25 | 0.044 | 0 | 0.995 |
| 4 | 10 | 3.5 | 0.05 | 0 | 0.95 |
| 4 | 11 | 3.5 | 0.05 | 0 | 0.95 |
| 4 | 12 | 3.5 | 0.05 | 0 | 0.95 |
| 4 | 15 | 3.5 | 0.05 | 0 | 0.95 |
| 4 | 16 | 3.5 | 0.05 | 0 | 0.95 |
| 4 | 17 | 3.5 | 0.05 | 0 | 0.95 |
| 4 | 18 | 0 | 0 | 0 | 0 |
| 4 | 20 | 0 | 0 | 0 | 0 |
| 4 | 21 | 0 | 0 | 0 | 0 |
| 4 | 22 | 0 | 0 | 0 | 0 |
| 4 | 23 | 0 | 0 | 0 | 0 |
| 4 | 24 | 0 | 0 | 0 | 0 |
| 4 | 25 | 0 | 0 | 0 | 0 |

| defid | deluid | lzsn | infilt | kvary | agwrc |
|---|---|---|---|---|---|
| 4 | 26 | 0 | 0 | 0 | 0 |
| 4 | 27 | 0 | 0 | 0 | 0 |

defid parameter group id

deluid land use id

lzsn lower zone nominal soil moisture storage (inches)

infilt index to the infiltration capacity of the soil (in/hr)

kvary variable groundwater recession (1/inches)

agwrc base groundwater recession (none)

**Table C-2. 120 pwat-parm3**

| defid | deluid | petmax | petmin | infexp | infild | deepfr | basetp | agwetp |
|---|---|---|---|---|---|---|---|---|
| 2 | 1 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 3 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 4 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 5 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 6 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 7 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 8 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 9 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 10 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 11 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 12 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 15 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 16 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 17 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 18 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 20 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 21 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 22 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 23 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 24 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 25 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 26 | 40 | 35 | 2 | 2 | 0 | 0.026667 | 0 |
| 2 | 27 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 1 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |

| defid | deluid | petmax | petmin | infexp | infild | deepfr | basetp | agwetp |
|---|---|---|---|---|---|---|---|---|
| 3 | 3 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 4 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 5 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 6 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 7 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 8 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 9 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 10 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 11 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 12 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 15 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 16 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 17 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 18 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 20 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 21 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 22 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 23 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 24 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 25 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 26 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 3 | 27 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 1 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 3 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 4 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 5 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 6 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 7 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 8 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 9 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 10 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 11 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 12 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 15 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 16 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |

| defid | deluid | petmax | petmin | infexp | infild | deepfr | basetp | agwetp |
|---|---|---|---|---|---|---|---|---|
| 4 | 17 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 18 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 20 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 21 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 22 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 23 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 24 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 25 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 26 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |
| 4 | 27 | 40 | 35 | 2 | 2 | 0 | 0.038333 | 0 |

defid parameter group id

deluid land use id

petmax air temperature below which e-t will is reduced (deg F)

petmin air temperature below which e-t is set to zero (deg F)

infexp exponent in the infiltration equation (none)

INFILD ratio between the maximum and mean infiltration capacities over the PLS (none)

deepfr fraction of groundwater inflow that will enter deep groundwater (none)

basetp fraction of remaining potential e-t that can be satisfied from baseflow (none)

agwetp fraction of remaining potential e-t that can be satisfied from active groundwater (none)

### Table C-3. 120 pwat-parm3

| defid | deluid | cepsc | uzsn | nsur | intfw | irc | lzetp |
|---|---|---|---|---|---|---|---|
| 2 | 1 | | | 0.3 | 0.8 | 0.3 | |
| 2 | 3 | | | 0.3 | 0.8 | 0.3 | |
| 2 | 4 | | | 0.3 | 0.8 | 0.3 | |
| 2 | 5 | | | 0.3 | 0.8 | 0.3 | |
| 2 | 6 | | | 0.3 | 0.8 | 0.3 | |
| 2 | 7 | | | 0.3 | 0.8 | 0.3 | |
| 2 | 8 | | | 0.3 | 0.8 | 0.3 | |
| 2 | 9 | | | 0.3 | 0.8 | 0.3 | |
| 2 | 10 | | | 0.3 | 0.65 | 0.35 | |
| 2 | 11 | | | 0.3 | 0.65 | 0.35 | |
| 2 | 12 | | | 0.3 | 0.65 | 0.35 | |
| 2 | 15 | | | 0.3 | 0.65 | 0.35 | |

| defid | deluid | cepsc | uzsn | nsur | intfw | irc | lzetp |
|---|---|---|---|---|---|---|---|
| 2 | 16 | | | 0.3 | 0.65 | 0.35 | |
| 2 | 17 | | | 0.3 | 0.65 | 0.35 | |
| 2 | 18 | | | 0.3 | 0.65 | 0.35 | |
| 2 | 20 | | | 0.3 | 0.65 | 0.35 | |
| 2 | 21 | | | 0.3 | 0.65 | 0.35 | |
| 2 | 22 | | | 0.3 | 0.65 | 0.35 | |
| 2 | 23 | | | 0.3 | 0.65 | 0.35 | |
| 2 | 24 | | | 0.3 | 0.65 | 0.35 | |
| 2 | 25 | | | 0.3 | 0.65 | 0.35 | |
| 2 | 26 | | | 0.3 | 0.65 | 0.35 | |
| 2 | 27 | | | 0.3 | 0.65 | 0.35 | |
| 3 | 1 | | | 0.3 | 0.65 | 0.3 | |
| 3 | 3 | | | 0.3 | 0.65 | 0.3 | |
| 3 | 4 | | | 0.3 | 0.65 | 0.3 | |
| 3 | 5 | | | 0.3 | 0.65 | 0.3 | |
| 3 | 6 | | | 0.3 | 0.65 | 0.3 | |
| 3 | 7 | | | 0.3 | 0.65 | 0.3 | |
| 3 | 8 | | | 0.3 | 0.65 | 0.3 | |
| 3 | 9 | | | 0.3 | 0.65 | 0.3 | |
| 3 | 10 | | | 0.3 | 0.55 | 0.35 | |
| 3 | 11 | | | 0.3 | 0.55 | 0.35 | |
| 3 | 12 | | | 0.3 | 0.55 | 0.35 | |
| 3 | 15 | | | 0.3 | 0.55 | 0.35 | |
| 3 | 16 | | | 0.3 | 0.55 | 0.35 | |
| 3 | 17 | | | 0.3 | 0.55 | 0.35 | |
| 3 | 18 | | | 0.3 | 0.55 | 0.35 | |
| 3 | 20 | | | 0.3 | 0.55 | 0.35 | |
| 3 | 21 | | | 0.3 | 0.55 | 0.35 | |
| 3 | 22 | | | 0.3 | 0.55 | 0.35 | |
| 3 | 23 | | | 0.3 | 0.55 | 0.35 | |
| 3 | 24 | | | 0.3 | 0.55 | 0.35 | |
| 3 | 25 | | | 0.3 | 0.55 | 0.35 | |
| 3 | 26 | | | 0.3 | 0.55 | 0.35 | |
| 3 | 27 | | | 0.3 | 0.55 | 0.35 | |
| 4 | 1 | | | 0.3 | 0.5 | 0.3 | |

| defid | deluid | cepsc | uzsn | nsur | intfw | irc | lzetp |
|---|---|---|---|---|---|---|---|
| 4 | 3 | | | 0.3 | 0.5 | 0.3 | |
| 4 | 4 | | | 0.3 | 0.5 | 0.3 | |
| 4 | 5 | | | 0.3 | 0.5 | 0.3 | |
| 4 | 6 | | | 0.3 | 0.5 | 0.3 | |
| 4 | 7 | | | 0.3 | 0.5 | 0.3 | |
| 4 | 8 | | | 0.3 | 0.5 | 0.3 | |
| 4 | 9 | | | 0.3 | 0.5 | 0.3 | |
| 4 | 10 | | | 0.3 | 0.45 | 0.35 | |
| 4 | 11 | | | 0.3 | 0.45 | 0.35 | |
| 4 | 12 | | | 0.3 | 0.45 | 0.35 | |
| 4 | 15 | | | 0.3 | 0.45 | 0.35 | |
| 4 | 16 | | | 0.3 | 0.45 | 0.35 | |
| 4 | 17 | | | 0.3 | 0.45 | 0.35 | |
| 4 | 18 | | | 0.3 | 0.45 | 0.35 | |
| 4 | 20 | | | 0.3 | 0.45 | 0.35 | |
| 4 | 21 | | | 0.3 | 0.45 | 0.35 | |
| 4 | 22 | | | 0.3 | 0.45 | 0.35 | |
| 4 | 23 | | | 0.3 | 0.45 | 0.35 | |
| 4 | 24 | | | 0.3 | 0.45 | 0.35 | |
| 4 | 25 | | | 0.3 | 0.45 | 0.35 | |
| 4 | 26 | | | 0.3 | 0.45 | 0.35 | |
| 4 | 27 | | | 0.3 | 0.45 | 0.35 | |

defid parameter group id

deluid land use id

petmax air temperature below which e-t will is reduced (deg F)

petmin air temperature below which e-t is set to zero (deg F)

infexp exponent in the infiltration equation (none)

INFILD ratio between the maximum and mean infiltration capacities over the PLS (none)

deepfr fraction of groundwater inflow that will enter deep groundwater (none)

basetp fraction of remaining potential e-t that can be satisfied from baseflow (none)

agwetp fraction of remaining potential e-t that can be satisfied from active groundwater (none)

**Table C-4. 130 pwat-parm4**

| | Range | Variability |
|---|---|---|
| cepsc interception storage capacity (inches) | 0.01-0.03 | Monthly |
| uzsn upper zone nominal storage (inches) | 0.18-0.56 | Monthly |
| nsur Manning's n for the assumed overland flow plane (none) | 0.3 | Annual |
| intfw interflow inflow parameter (none) | 0.45-0.8 | Annual |
| irc interflow recession parameter (none) | 0.3-0.35 | Annual |
| lzetp lower zone e-t parameter (none) | 0.01-0.7 | Monthly |

# Appendix D. Additional Calibration Graphs and Tables

## Hydrology

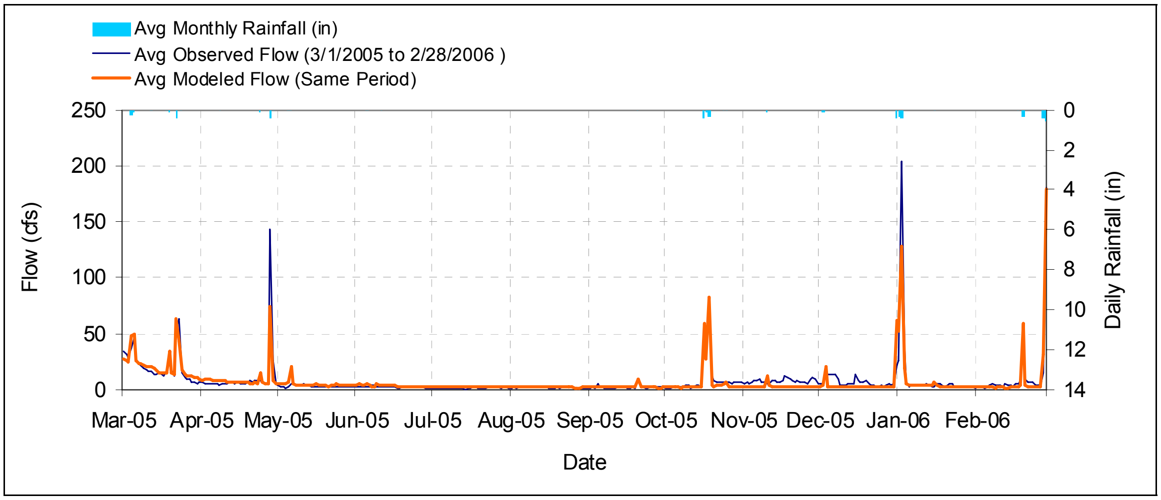


**Figure D-1. Mean Daily Flow: Model Outlet 1007 vs. Agua Hedionda Creek at El Camino Real Bridge**

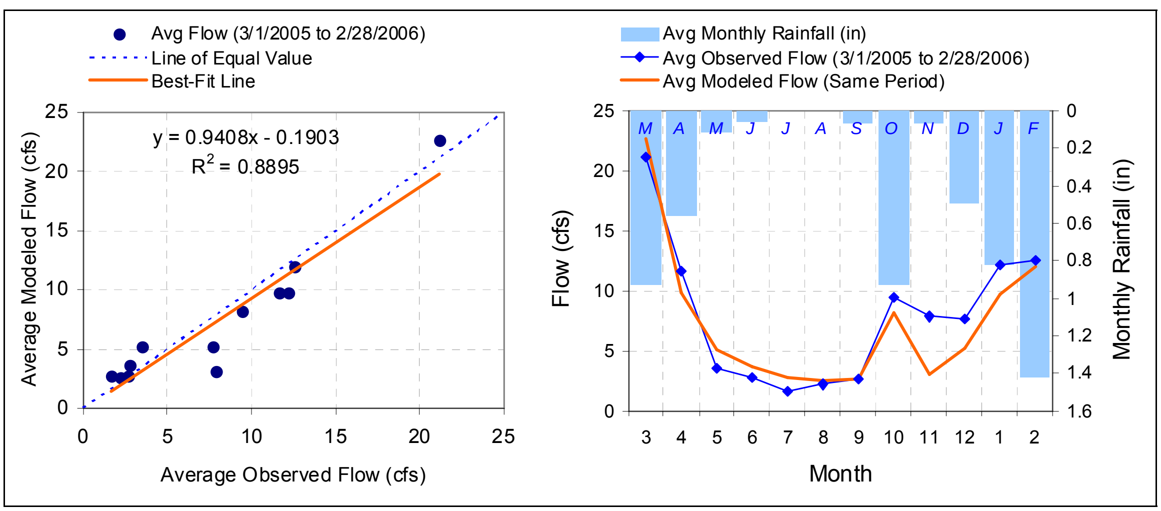


**Figure D-2. Seasonal Regression and Temporal Aggregate: Model Outlet 1007 vs. Agua Hedionda Creek at El Camino Real Bridge**

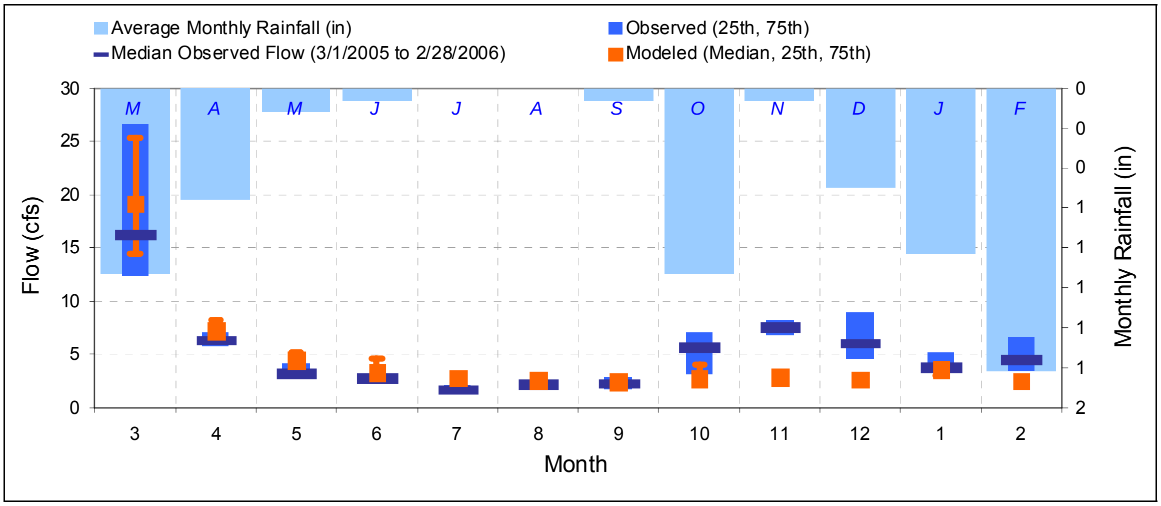


**Figure D-3. Seasonal Medians and Ranges: Model Outlet 1007 vs. Agua Hedionda Creek at El Camino Real Bridge**

**Table D-1. Seasonal Summary: Model Outlet 1007 vs. Agua Hedionda Creek at El Camino Real Bridge**

| MONTH | OBSERVED FLOW (CFS) | | | | MODELED FLOW (CFS) | | | |
|---|---|---|---|---|---|---|---|---|
| | MEAN | MEDIAN | 25TH | 75TH | MEAN | MEDIAN | 25TH | 75TH |
| Mar | 21.19 | 16.24 | 12.51 | 26.59 | 22.70 | 19.20 | 14.46 | 25.38 |
| Apr | 11.66 | 6.37 | 5.79 | 7.05 | 9.80 | 7.18 | 6.53 | 8.22 |
| May | 3.52 | 3.24 | 2.81 | 4.13 | 5.17 | 4.41 | 3.94 | 5.24 |
| Jun | 2.75 | 2.78 | 2.39 | 3.21 | 3.68 | 3.29 | 2.86 | 4.53 |
| Jul | 1.68 | 1.66 | 1.29 | 2.17 | 2.77 | 2.81 | 2.60 | 2.96 |
| Aug | 2.21 | 2.22 | 1.93 | 2.56 | 2.57 | 2.59 | 2.38 | 2.73 |
| Sep | 2.65 | 2.25 | 1.72 | 2.88 | 2.70 | 2.37 | 2.29 | 2.51 |
| Oct | 9.49 | 5.72 | 3.08 | 7.12 | 8.16 | 2.69 | 2.28 | 4.05 |
| Nov | 7.87 | 7.53 | 6.76 | 8.21 | 3.09 | 2.82 | 2.61 | 2.95 |
| Dec | 7.73 | 6.03 | 4.65 | 8.95 | 5.20 | 2.62 | 2.46 | 2.75 |
| Jan | 12.18 | 3.82 | 3.48 | 5.22 | 9.70 | 3.58 | 2.98 | 4.02 |
| Feb | 12.56 | 4.54 | 3.42 | 6.66 | 12.01 | 2.48 | 2.31 | 2.84 |

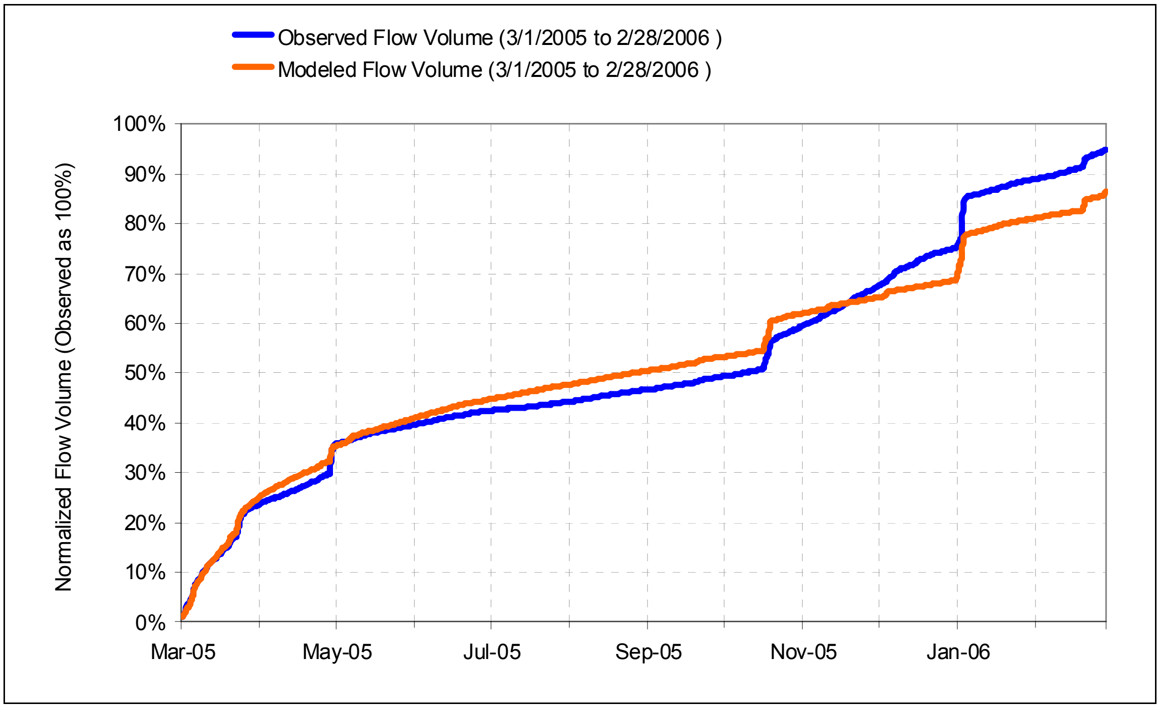


**Figure D-4. Flow Accumulation: Model Outlet 1007 vs. Agua Hedionda Creek at El Camino Real Bridge**

## Water Quality

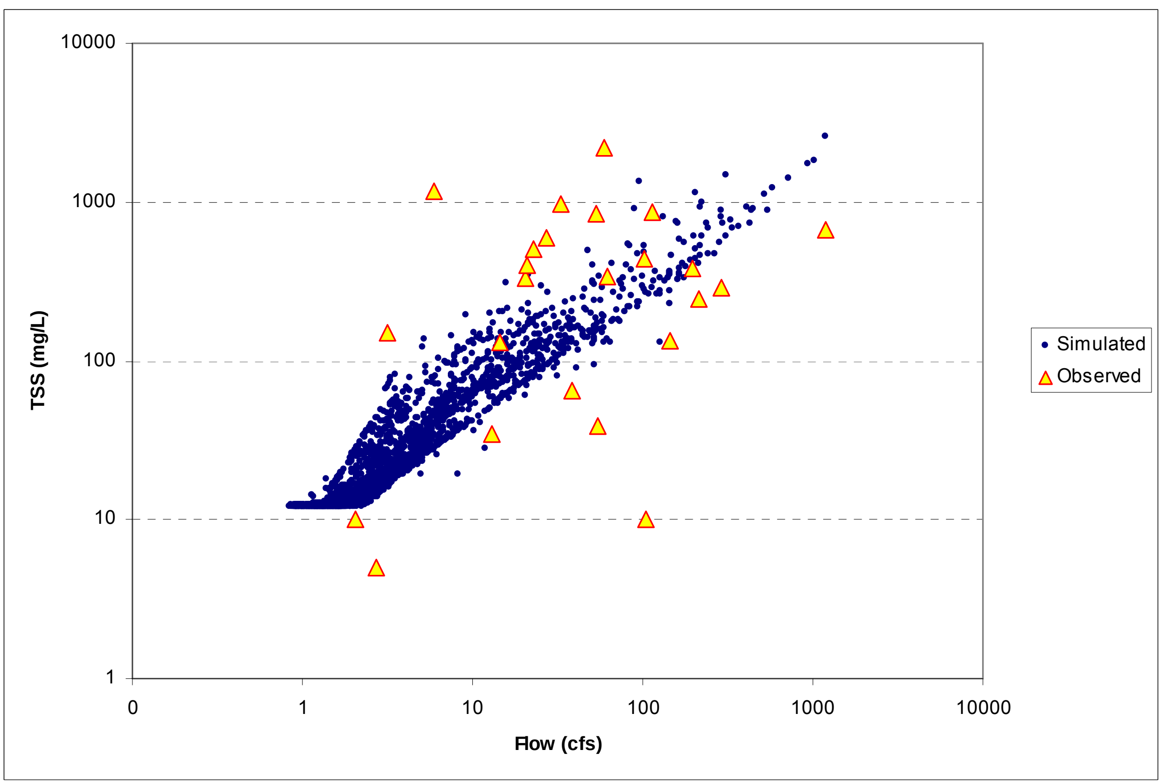


**Figure D-5. Observed and Simulated Sediment Concentrations at Model Subwatershed #1007**

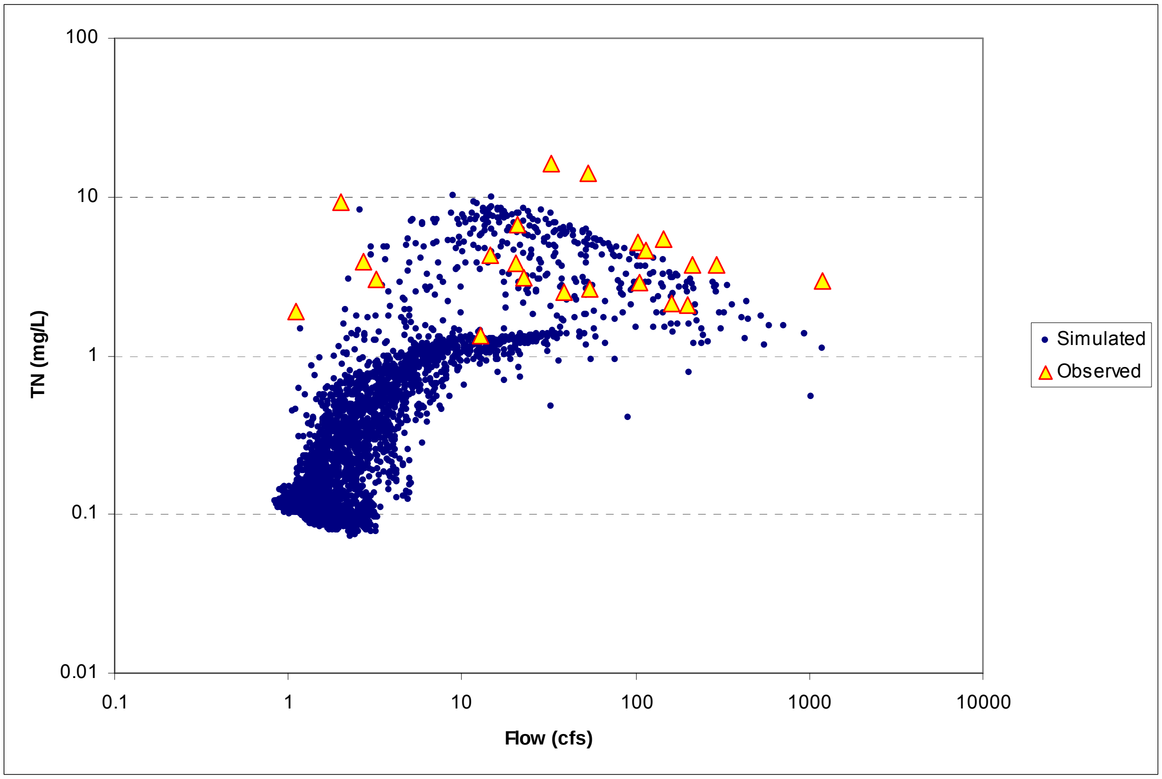


**Figure D-6. Observed and Simulated TN Concentrations at Model Subwatershed #1007**

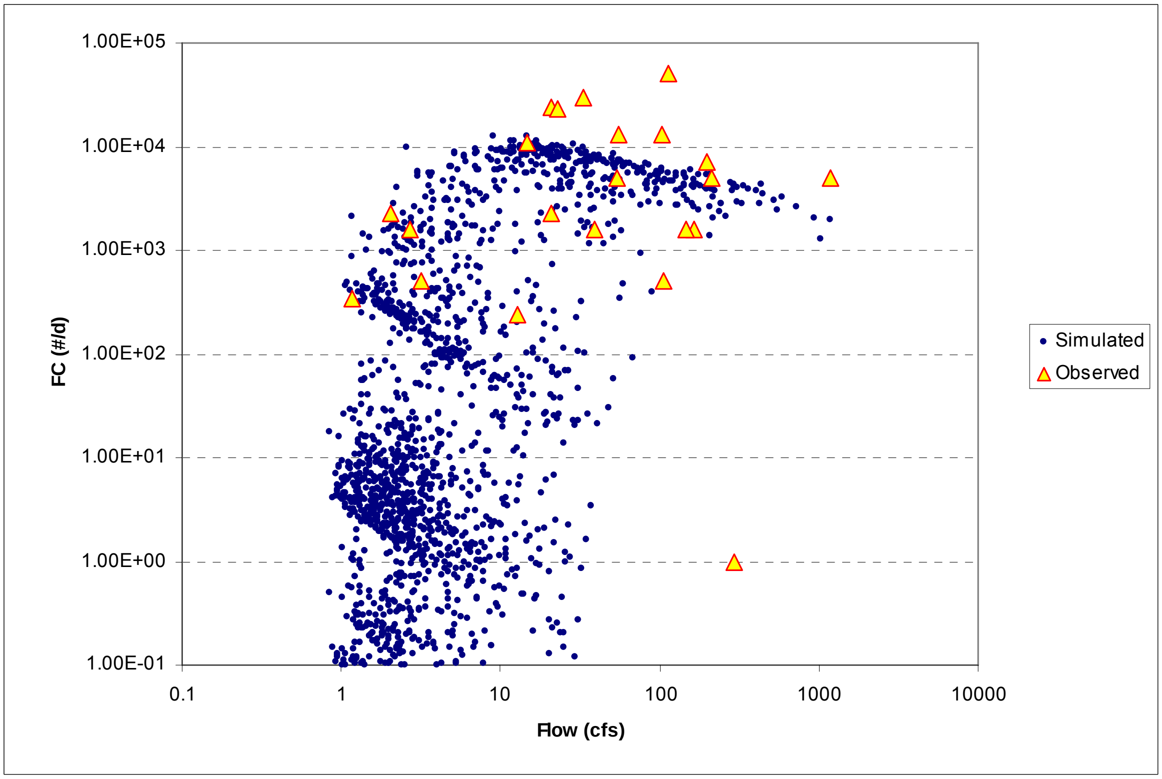


**Figure D-7. Observed and Simulated Fecal Concentrations at Model Subwatershed #1007**

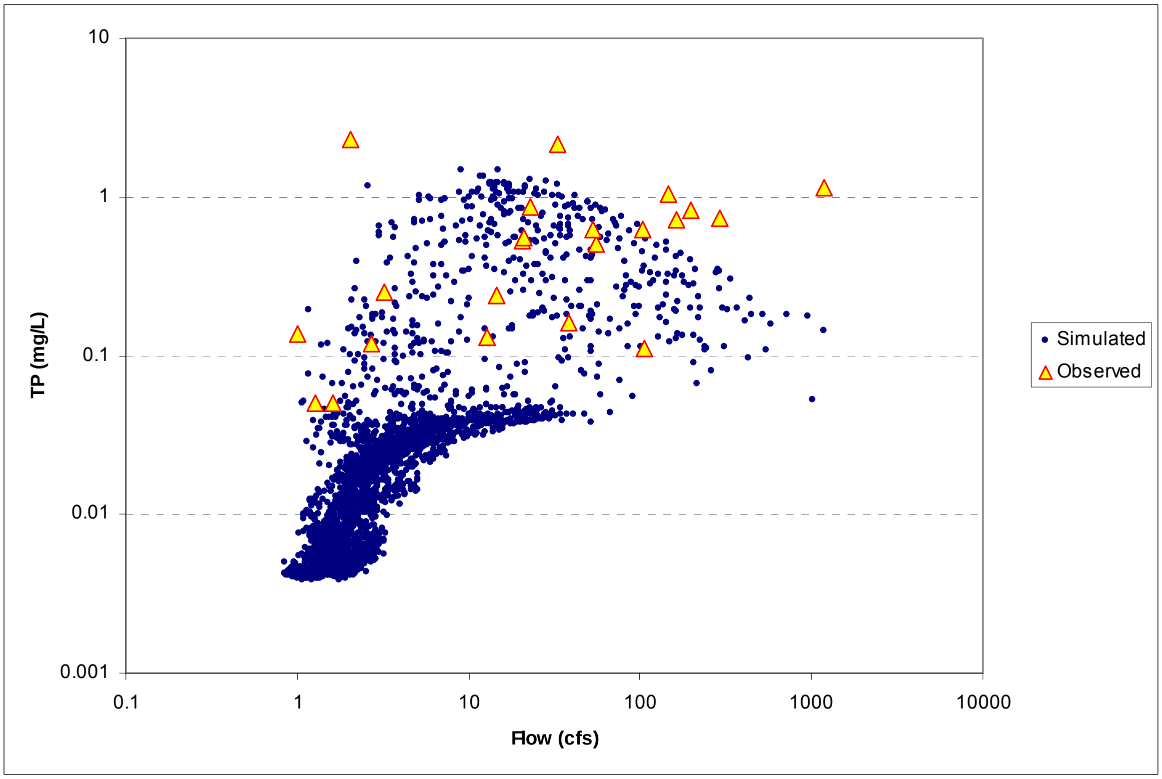


**Figure D-8. Observed and Simulated TP Concentrations at Model Subwatershed #1007**

**Table D-2. Average Annual Modeled Loading Rates by Land Use**

| | PO_FECAL | PO_TN | PO_TP | SEDLOAD |
|---|---|---|---|---|
| | #/ac/yr | lb/ac/yr | lb/ac/yr | ton/ac/yr |
| Open Space | 1.57E+09 | 1.35 | 0.05 | 0.63 |
| Agriculture | 3.86E+10 | 4.33 | 0.41 | 0.57 |
| Transitional | 1.70E+09 | 1.43 | 0.05 | 0.74 |
| Open Recreation | 1.03E+10 | 2.96 | 0.11 | 1.35 |
| Parks/Recreation | 1.82E+10 | 2.46 | 0.18 | 1.34 |
| Very Low Density Residential | 2.42E+10 | 2.13 | 0.14 | 1.23 |
| Low Density Residential | 3.75E+10 | 2.83 | 0.21 | 1.19 |
| Medium Density Residential | 4.92E+10 | 3.47 | 0.27 | 1.11 |
| High Density Residential | 1.09E+11 | 7.93 | 1.02 | 0.78 |
| Multi-Family Residential | 1.21E+11 | 9.44 | 1.18 | 0.53 |
| Lt. Commercial/Office/Institutional | 5.67E+09 | 6.71 | 0.59 | 0.82 |
| Warehouse/Industrial/Transportation | 7.17E+09 | 6.84 | 0.72 | 0.69 |
| Heavy Commercial | 8.21E+09 | 7.43 | 0.82 | 0.66 |

# Appendix E. Additional Model Results

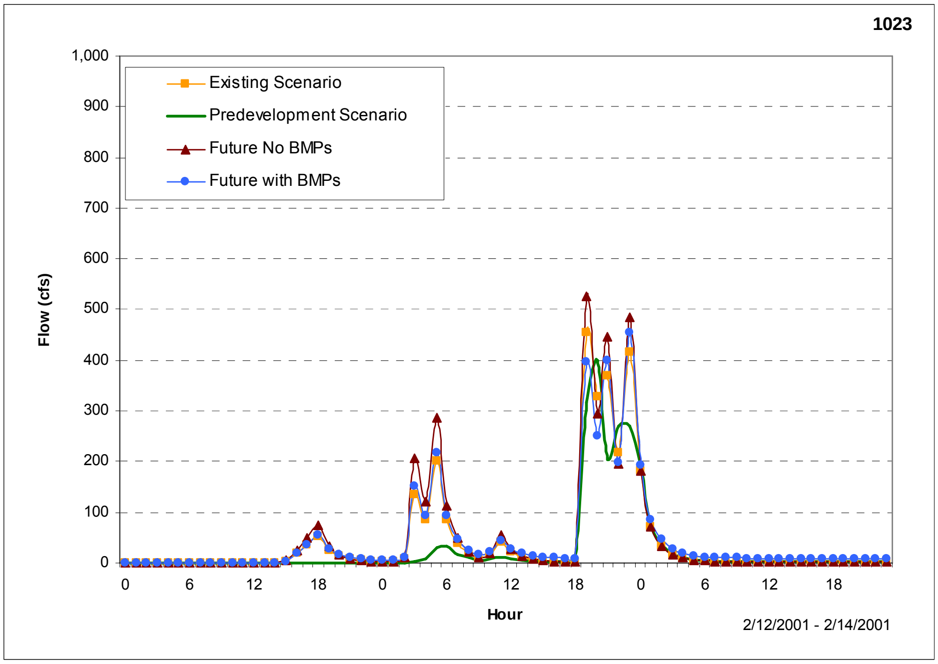


**Figure E-1. Storm Hydrograph at the Upper Agua Hedionda Creek (Model ID#1023)**

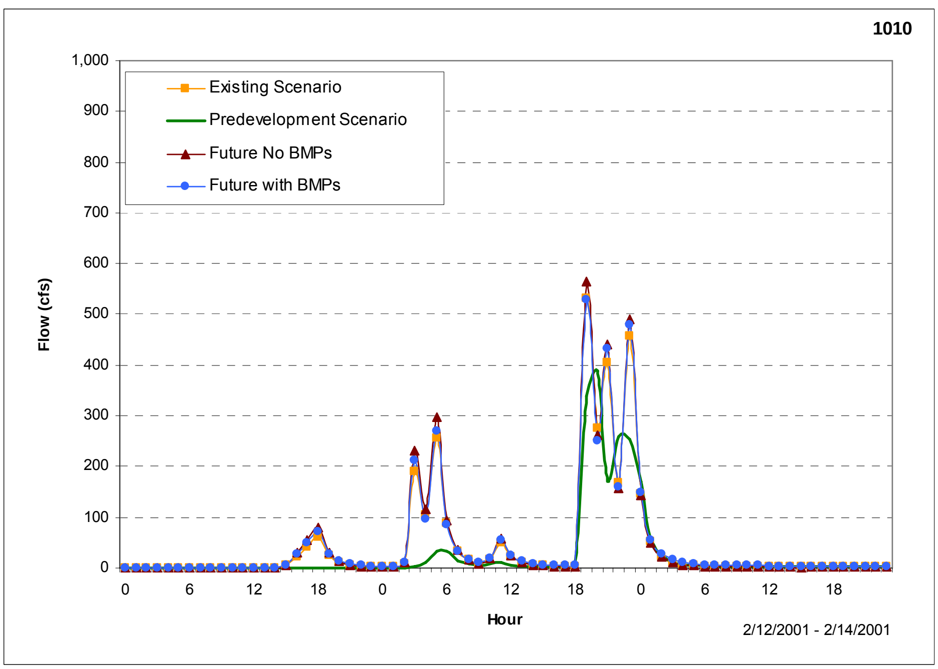


**Figure E-2. Storm Hydrograph at the Upper Calavera Creek (Model ID#1010)**

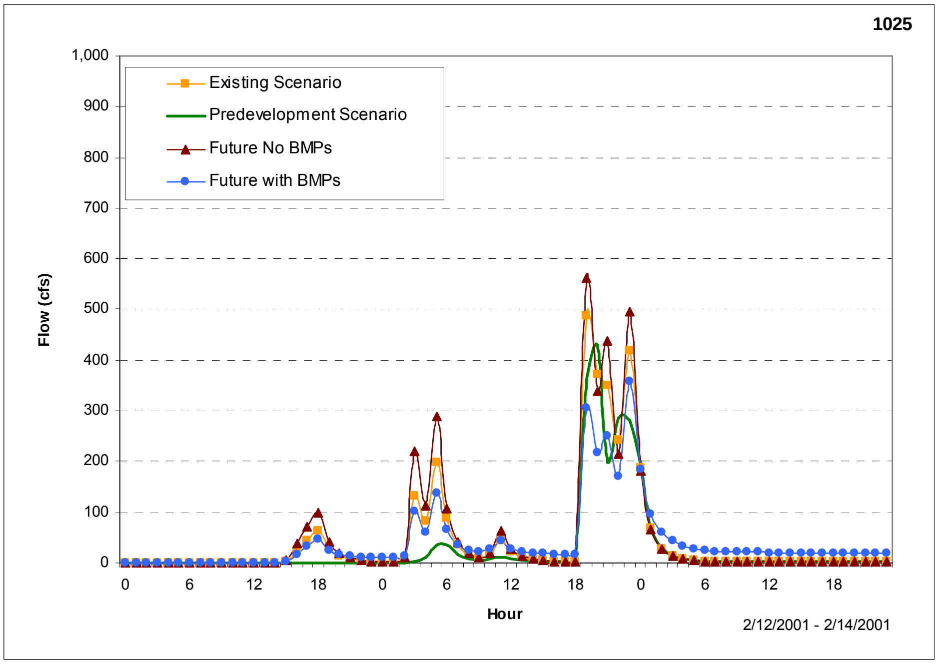


**Figure E-3. Storm Hydrograph at Outlet of La Mirada Creek**

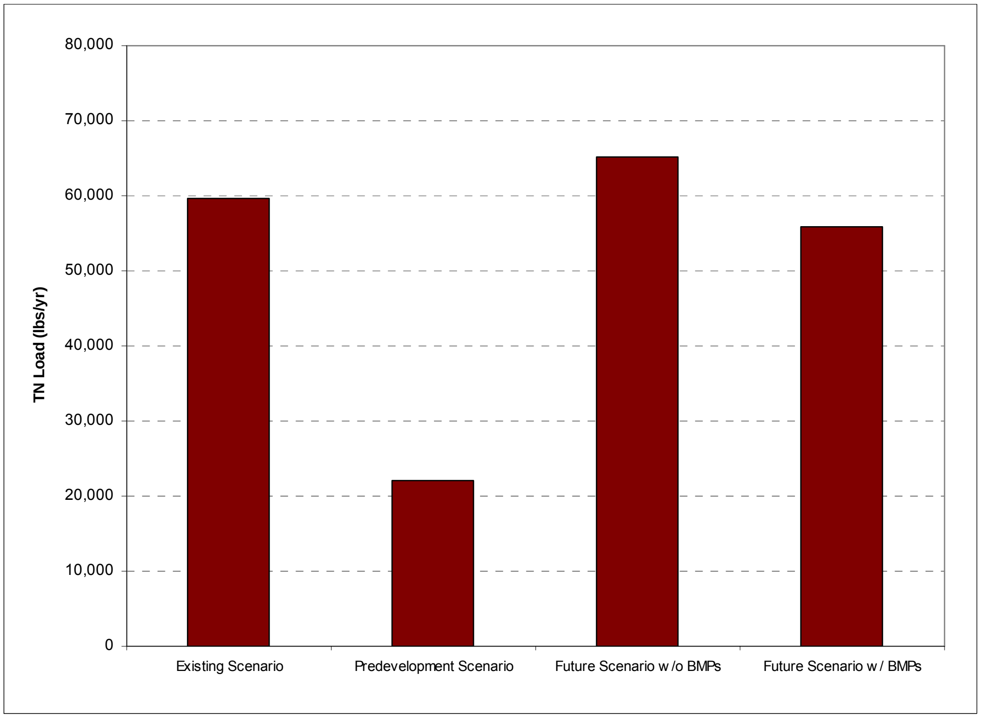


**Figure E-4. Comparison of Average Annual Nitrogen Loading to the Lagoon (at Model ID#1004)**

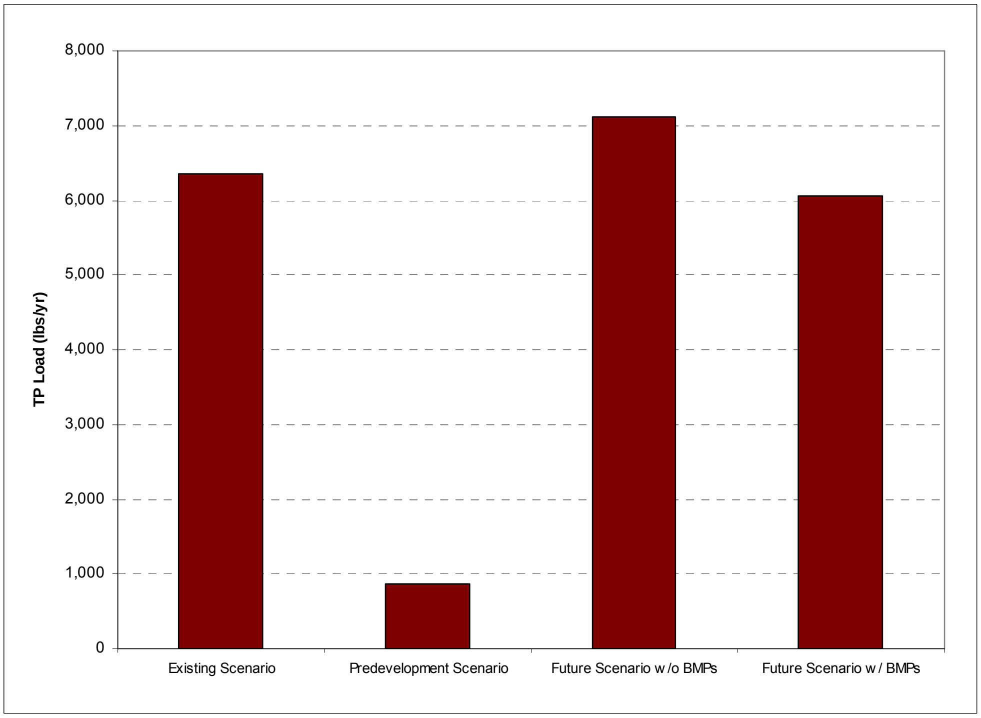


**Figure E-5. Comparison of Average Annual Phosphorus Loading to the Lagoon (at Model ID#1004)**

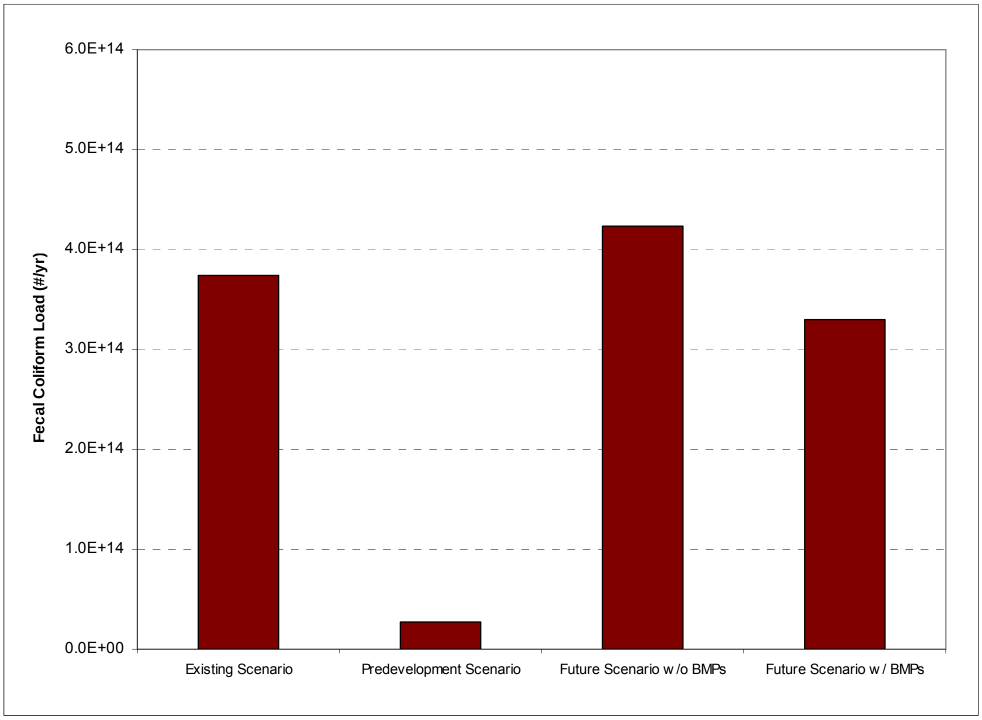


**Figure E-6. Comparison of Average Annual Fecal Coliform Loading to the Lagoon (at Model ID#1004)**

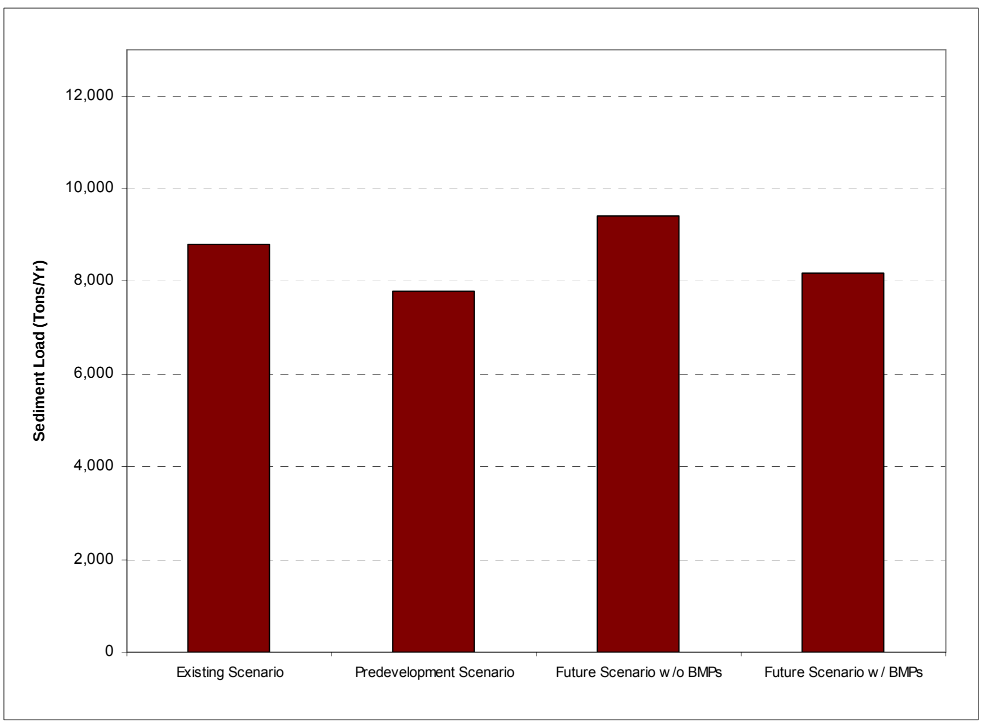


**Figure E-7. Comparison of Average Annual Sediment Loading to the Lagoon (at Model ID#1004)**