Hydrologic Modeling of the Calleguas Creek Watershed with the U.S. EPA Hydrologic Simulation Program - FORTRAN (HSPF)

FINAL REPORT

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ABSTRACT

In this study, a comprehensive watershed hydrologic model of the Calleguas Creek Watershed was developed for use as a tool for watershed planning, resource assessment, and ultimately, water quality management purposes. This study was jointly funded by the Calleguas Creek Watershed Management Plan and the Ventura County Watershed Protection District (VCWPD). The modeling package selected for this application is the U.S. EPA Hydrological Simulation Program-FORTRAN (HSPF). HSPF is a comprehensive watershed model of hydrology and water quality, that includes modeling of both land surface and subsurface hydrologic and water quality processes, linked and closely integrated with corresponding stream and reservoir processes. It is considered a ***premier***, high-level model among those currently available for comprehensive watershed assessments.

A pilot study of the Arroyo Simi Watershed in the headwaters of Calleguas Creek, funded by VCWPD, provided the foundation for this effort. During this study, the pilot HSPF application to was extended to the entire area of the Callegaus Creek Watershed. Additional precipitation and evaporation data were obtained and extended to allow model simulations up to 15 years. Topographic, soils, land use, and agricultural cropping information was used to develop the model segmentation and input, and detailed streamflow data were selected to allow calibration over a 9 year period (WY 1994 – WY 2002) and validation over a separate 6 year period (WY 1988 – WY1993). Both quantitative and qualitative comparisons were performed to support the model performance evaluation effort.

Based on the model results presented and discussed in this report, we conclude that the current HSPF application to the Calleguas Creek Watershed has produced a sound, calibrated and validated hydrologic watershed model that provides a framework for watershed management analyses and needs for flood assessments, water quality issues, and impact evaluation of mitigation alternatives. The calibration and validation results, based on the weight-of-evidence approach described herein, demonstrate a **good to very good** representation of the observed data. This is the outcome of a wide range of graphical and statistical comparisons and measures of the model performance, performed at up to eight stream gage locations throughout the watershed, for annual runoff, daily and monthly streamflow, flow duration and frequency, water balance components, and hourly storm hydrographs. These comparisons demonstrate conclusively that the model is a very good representation of the water balance and hydrology of the watershed.

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ACKNOWLEDGMENTS

This study was performed by AQUA TERRA Consultants under contract to Larry Walker Associates, and was jointly funded by the Calleguas Creek Watershed Management Plan and the Ventura County Watershed Protection District (VCWPD).

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For AQUA TERRA, Mr. Anthony Donigian was the Project Manager, responsible for the overall conduct of the study, including the modeling approach, methods development, calibration and validation, and report preparation. Mr. Jason Love was the Project Engineer responsible for performing model setup and simulations, watershed GIS characterization and segmentation, analysis and processing of model results, and assistance in report preparation. Mr. Tom Jobes and Mr. Rob Dusenbury assisted in data analysis, data processing and management, and model setup.

SECTION 1.0

INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

The objective of this study is to develop a comprehensive watershed hydrologic model of the Calleguas Creek Watershed for use as a tool for watershed planning, resource assessment, and ultimately, water quality management purposes. This study is being jointly funded by the Calleguas Creek Watershed Management Plan and the Ventura County Watershed Protection District (VCWPD). The modeling package selected for this application is the U.S. EPA Hydrological Simulation Program-FORTRAN (HSPF) (Bicknell et al., 1997; 2001).

A pilot study of the Arroyo Simi Watershed (AQUA TERRA Consultants, 2003) in the headwaters of Calleguas Creek, funded by VCWPD, provides the foundation for this effort. In the Arroyo Simi pilot study, HSPF was set up and calibrated to available flow records for recent hydrologic conditions, and customized to include consideration of localized groundwater pumping impacts in Simi Valley and lawn/landscape irrigation practices on surface water flow levels. In this study, the Arroyo Simi model was revised and extended throughout the Calleguas Creek drainage to provide the needed watershed-wide hydrologic assessment tool.

HSPF is a comprehensive watershed model of hydrology and water quality, that includes modeling of both land surface and subsurface hydrologic and water quality processes, linked and closely integrated with corresponding stream and reservoir processes. It is considered a ***premier***, high-level model among those currently available for comprehensive watershed assessments. HSPF has enjoyed widespread usage and acceptance, since its initial release in 1980, as demonstrated through hundreds of applications across the U.S. and abroad. HSPF is jointly supported and maintained by **both** the U.S. EPA and the USGS, a rare occurrence where two federal agencies agree on support of a single modeling system. In addition, HSPF is the primary watershed model included in the EPA BASINS modeling system and it has recently been incorporated into the U.S. Army Corps of Engineers Watershed Modeling System (WMS). This widespread usage and support has helped to ensure the continuing availability and maintenance of the code for more than two decades, in spite of varying federal priorities and budget restrictions. HSPF is currently being used for watershed studies in more than 25 states, Canada, and Australia, in addition to a number of watersheds in both Northern and Southern California.

The headwaters of Calleguas Creek begin as Arroyo Simi, coming down from the hills at the east end of Simi Valley, California. The Arroyo Simi flows through Simi Valley and Moorpark. Between Moorpark and Camarillo the stream is known as Arroyo Las Posas, and the lower waters are Calleguas Creek proper. The main stem empties into the Pacific through the Mugu Lagoon estuary. Major tributaries include Tapo Canyon, Arroyo Santa Rosa, Conejo Creek, and Revolon Slough. The watershed to be modeled in this study is shown in Figure 1.1.

The Calleguas Creek Watershed is located primarily in Ventura County, with a small area in Los Angeles County. The watershed is surrounded to the north, east, and south by largely undeveloped hills and canyons, while the main stem flows through flat valleys consisting of a mixture of urban and agricultural land. The watershed is subject to flooding and erosion, resulting in sediment deposition downstream in Mugu Lagoon.

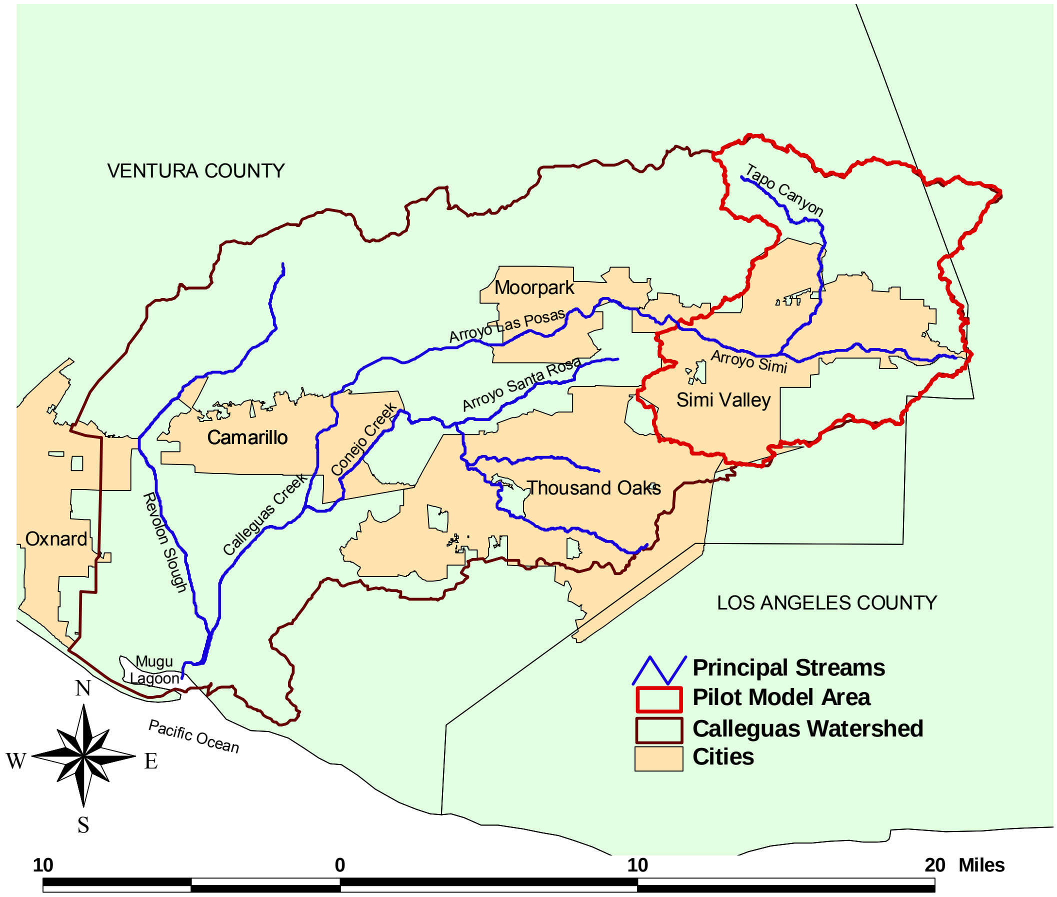


Figure 1.1 Calleguas Creek Watershed Location, Municipalities, and Major Waterbodies

1.2 EXECUTIVE SUMMARY

During this study, the pilot HSPF application to the Arroyo Simi Watershed (AQUA TERRA Consultants, 2003) was extended to the entire area of the Callegaus Creek Watershed. Additional precipitation and evaporation data were obtained and extended to allow model simulations up to 15 years. Topographic, soils, land use, and agricultural cropping information was used to develop the model segmentation and input, and detailed streamflow data were selected to allow calibration over a 9 year period (WY 1994 – WY 2002) and validation over a separate 6 year period (WY 1988 – WY1993). Both quantitative and qualitative comparisons were performed to support the model performance evaluation effort.

Table 1.1 provides a ‘weight-of-evidence’ summary of the various model-data comparisons performed for the calibration and validation of the Calleguas Creek Watershed Model and discussed in Section 4 of this report. These values represent, for each statistic and comparison, the mean and ranges of the statistics for the calibration and validation periods, across all eight stream gages used in modeling effort. The Overall Model Performance column reflects our assessment of model behavior for both the calibration and validation periods, i.e. the entire 15 year simulation. The only caveat, noted in the footnote, is the omission of the Conejo Creek validation statistics due to the questions on the rating curve during that time period that need to be resolved.

1.2.1 CONCLUSIONS

Based on the model results presented and discussed in Section 4, and summarized in Table 1.1, we conclude that the current HSPF application to the Calleguas Creek Watershed has produced a sound, calibrated and validated hydrologic watershed model that provides a framework for watershed management analyses and needs for flood assessments, water quality issues, and impact evaluation of mitigation alternatives. The calibration and validation results, based on the weight-of-evidence approach described herein, demonstrates a **good to very good** representation of the observed data. This is the outcome of a wide range of graphical and statistical comparisons and measures of the model performance for annual runoff, daily and monthly streamflow, flow duration and frequency, water balance components, and hourly storm hydrographs. These comparisons demonstrate conclusively that the model is a very good representation of the water balance and hydrology of the watershed.

Table 1.1 'Weight-of-Evidence' for Calleguas Creek Watershed Model Performance

	Calibration		Validation		Overall Model Performance
	mean	range	mean	range	
Daily Volume, % Δ	2.1	-4.7 / 6.6	3.1	-14.3 / 18.4	Good / Very Good
Monthly Volume, % Δ	2.4	-3.9 / 7.0	3.0	-14.2 / 18.1	Good / Very Good
Annual Volume, % Δ	2.2	-4.7 / 6.6	3.1	-14.3 / 18.5	Good / Very Good
Correlation Coefficient, R:					
- Daily R	0.94	0.85 / 0.98	0.96	0.93 / 0.98	Very Good
- Monthly R	0.98	0.97 / 0.99	0.99	0.97 / 0.99	Very Good
Coefficient of Variation, R^2:					
- Daily R^2	0.89	0.73 / 0.95	0.92	0.86 / 0.95	Very Good
- Monthly R^2	0.97	0.95 / 0.99	0.98	0.94 / 0.99	Very Good
Model Fit Efficiency, MFE:					
- Daily MFE	0.86	0.60 / 0.95	0.90	0.82 / 0.95	Very Good
- Monthly MFE	0.90	0.65 / 0.98	0.95	0.92 / 0.98	Very Good
Flow-Duration	Very Good		Good		Good / Very Good
Water Balance	Very Good		Very Good		Very Good
Storm Events:					
- Daily Storm Peak, % Δ	-3.3	-10.0 / 8.7	-7.6 *	-11.5 / 0.9 *	Good / Very Good
- Storm Volumes, % Δ	7.7	-0.3 / 21.0	1.1 *	-8.7 / 8.8 *	Good / Very Good
- 10% High Flows, % Δ	6.1	-5.1 / 16.7	3.2 *	-14.5 / 17.7 *	Good / Very Good

* - Means and Ranges do not include values for the Conejo Creek Validation due to questions on the rating curves (to be resolved); Conejo Creek values were -42, -32, and -22 for the storm event statistics

1.2.2 RECOMMENDATIONS

The following recommendations are provided to resolve some of the issues identified during this effort, and to enhance and support many potential uses of the model for addressing water resources and water quality issues in the Calleguas Creek Watershed:

- Investigate rating curve issues at the Conejo Creek gage, in conjunction with VCWPD staff, to re-assess the accuracy of the flow rates during the validation period, and either confirm or refute suspicions that the actual flow peaks are over-estimated by the data. Other gage sites, such as the Calleguas Creek Highway 101 gage, could also benefit from such as investigation, to confirm the accuracy of gage values for these changing, unstable channels.

- Extend the meteorologic database to allow 30 to 50 year model simulations for in-depth analyses of extreme event frequencies, flow duration curves, scenario evaluations, and design storm assessments. This would include efforts by VCWPD staff to process available strip charts of 8 to 10 selected precipitation gages to develop reliable hourly precipitation data to drive the simulations.

- Investigate additional data and information to better establish and quantify surface water importations and GW pumping, spatially within the Calleguas Watershed, to help differentiate shallow versus deep GW contributions, and improve the representation of these sources within the watershed model.

- Link the current Calleguas HSPF model with a groundwater model to help to close the water balance assessment, allow more comprehensive analyses of SW-GW interactions, and further investigate issues, related to channel losses and irrigation pumping. The integrated assessment could be performed initially as a pilot study on a subbasin, such as Conejo Creek to assess its feasibility and demonstrate its utility for SW-GW management issues throughout the Calleguas Creek Watershed.

1.3 THIS REPORT

This document is the Final Report for developing the Calleguas Creek Watershed hydrology model using HSPF. It identifies and describes the watershed characteristics and data used to support the model application, the input data development and processing, the approach followed in constructing and calibrating the model, and model performance results for both calibration and validation efforts.

The major steps in the model application process consist of:

1. Collection and development of time series data;
2. Characterization and segmentation of the watershed; and
3. Calibration and validation of the model.

Section 2 describes hydrologic, meteorologic, and other data needed for the simulation; Section 3 discusses the spatial data needed to characterize and segment the watershed; and Section 4 describes the calibration/validation process and model performance for both time periods for the Calleguas Creek Watershed model.

In recognition of the need for maintenance of an Administrative Record (AR) related to this modeling effort, during the model application process for the Calleguas Creek watershed the model inputs, documentation, and outputs have been provided for inclusion in the AR,. This Final Report is also a contribution to the AR.

SECTION 2.0

DATA NEEDS FOR WATERSHED HYDROLOGIC MODELING

Watershed modeling requires a variety of spatial, hydrography, and timeseries data to characterize and represent the hydrologic response. Spatial data include information on topography, soils, land use, and channel hydrography, and timeseries data for meteorologic variables, flow, and other data. Section 3 describes the spatial data needed for accurate watershed representation, while the timeseries data are described in this section.

Hydrologic simulation with HSPF in moderate climates, where snow accumulation and melt are not significant, requires the following time series data:

1. Precipitation
2. Potential evapotranspiration
3. Streamflow
4. Other data affecting the water balance, e.g. point sources, diversions, etc.

This section discusses the availability of these time series data, plus additional data such as point sources, diversions, irrigation practices, etc. that define the inflow and outflow of water in the watershed.

All timeseries data for the model were placed into a Watershed Data Management (WDM) file, which is a format originally developed by AQUA TERRA for the US Geological Survey for use by HSPF and other models. The primary software package for achieving this is WDMUtil (Hummel et al, 2001). This program can read data in arbitrary flat file formats and import them into the WDM, from which HSPF then reads its input data. WDMUtil also allows the user to perform a variety of data manipulation tasks, such as aggregation/disaggregation and generation of graphical displays.

2.1 PRECIPITATION

Within and near the Calleguas Creek Watershed, Ventura County WPD maintains a network of precipitation stations, most of which have been continuously operating for 30-50 years. Data are available at 36 stations currently operated in and around the watershed. These stations and the first full water year of record are listed in Table 2.1, and their locations relative to the watershed are shown in Figure 2.1. Stations listed as “Recording” or “Both” have hardcopy short-span (5-minute data) available, some of which have been processed by VCWPD for this study.

The two requirements for HSPF rainfall data series are: 1) complete records (*i.e.*, no missing data), and 2) an hourly or shorter timestep is needed for adequate calibration for this watershed. All 36 stations available were reported to be complete by VCWPD, with no missing data. Following a thorough review of both the hourly and daily precipitation, 9 daily-only and 10 hourly stations were selected to use in model simulations; in Table 2.1, the selected hourly stations are highlighted in yellow, while the daily stations are in green. The daily stations were disaggregated to an hourly interval by using one or more nearby hourly stations. The

Table 2.1 Precipitation Stations In/Near the Calleguas Creek Watershed

Station	Name	Type■	Record Begins
Hourly stations processed for model inclusion – "Model Hourly"			
168	Oxnard Airport	Both	1957
169	Thousand Oaks-Weather Station	Both	1944
190	Somis-Bard	Both	1956
193a	Santa Susana	Both	1956
194a	Camarillo-Adohr (Sanitation Plant)	Both	1956
196	Tapo Canyon	Recorder	1965
227	Lake Bard	Both	1992, 1956 (daily)
242	Tripas Canyon	Recorder	1972
250	Moorpark-Happy Camp Canyon	Recorder	1977
Possible additional hourly stations – "Other Hourly"			
17c	Port Hueneme-Oxnard Sewer Plant	Both	1989*
175	Saticoy FS	Both	1957
238	South Mountain-Shell Oil	Both	1971
Daily stations already disaggregated for pilot study – "Model Daily"			
154b	Simi County FS	Standard	1948
187	Susana Knolls County FS	Standard	1956
234a	Las Llajas Canyon	Recorder	1969
249	Simi Hills-Rocketdyne Lab	Both	1959
Other daily stations in watershed – "Other Daily"			
32	Oxnard-Water Department	Standard	1903
49a	Santa Rosa Valley-Worthington Ranch	Standard	1930
96a	Bardsdale-Lander Ranch	Standard	1932
121c	Lake Sherwood County FS	Both	1935
128b	Thousand Oaks County FS	Standard	1958
141a	Moorpark County FS	Standard	1949
177	Camarillo-Pacific Sod (Davis Ranch)	Standard	1957
188a	Newbury Park County FS	Recorder	1956
189	Somis-Deboni	Recorder	1956
191	Moorpark-Downing Ranch (Merriken)	Both	1956
192a	Moorpark-Everett	Both	1956
206b	Somis-Fuller	Both	1961
219a	Camarillo-Hauser	Standard	1965
223a	Point Mugu-USN	Standard	1946
232	Santa Monica Mts-Deals Flat	Both	1969
239	El Rio-UWCD Spreading Ground	Standard	1973
245	Santa Paula-UWCD	Both	1961
259	Camarillo-PVWD	Standard	1982
261	Saticoy-Recharge Facility	Standard	1985
263	Camarillo-Leisure Village	Standard	1985

■ Standard: Standard, non-recording gage for daily totals. Recording: Automatic recording gage with strip chart
* Daily record goes back to 1891
Hourly gage used for model simulations, Daily gage used for model simulations

methodology followed by WDMUtil for the disaggregation step is as follows: for each daily value, the hourly station that has a daily total that is closest to that value is selected, and its hourly rainfall pattern for the day is used to disaggregate the daily value. If no daily total falls within a specified tolerance, then a default triangular distribution is used.

Corrected hourly records were selected to represent the rainfall over different portions of the watershed, as represented by 19 model segments. The extent of each segment was based on the long-term isohyetal map of the county, developed by VCWPD for the pilot study, and a Thiessen network. A Thiessen analysis is a standard hydrologic technique to define the

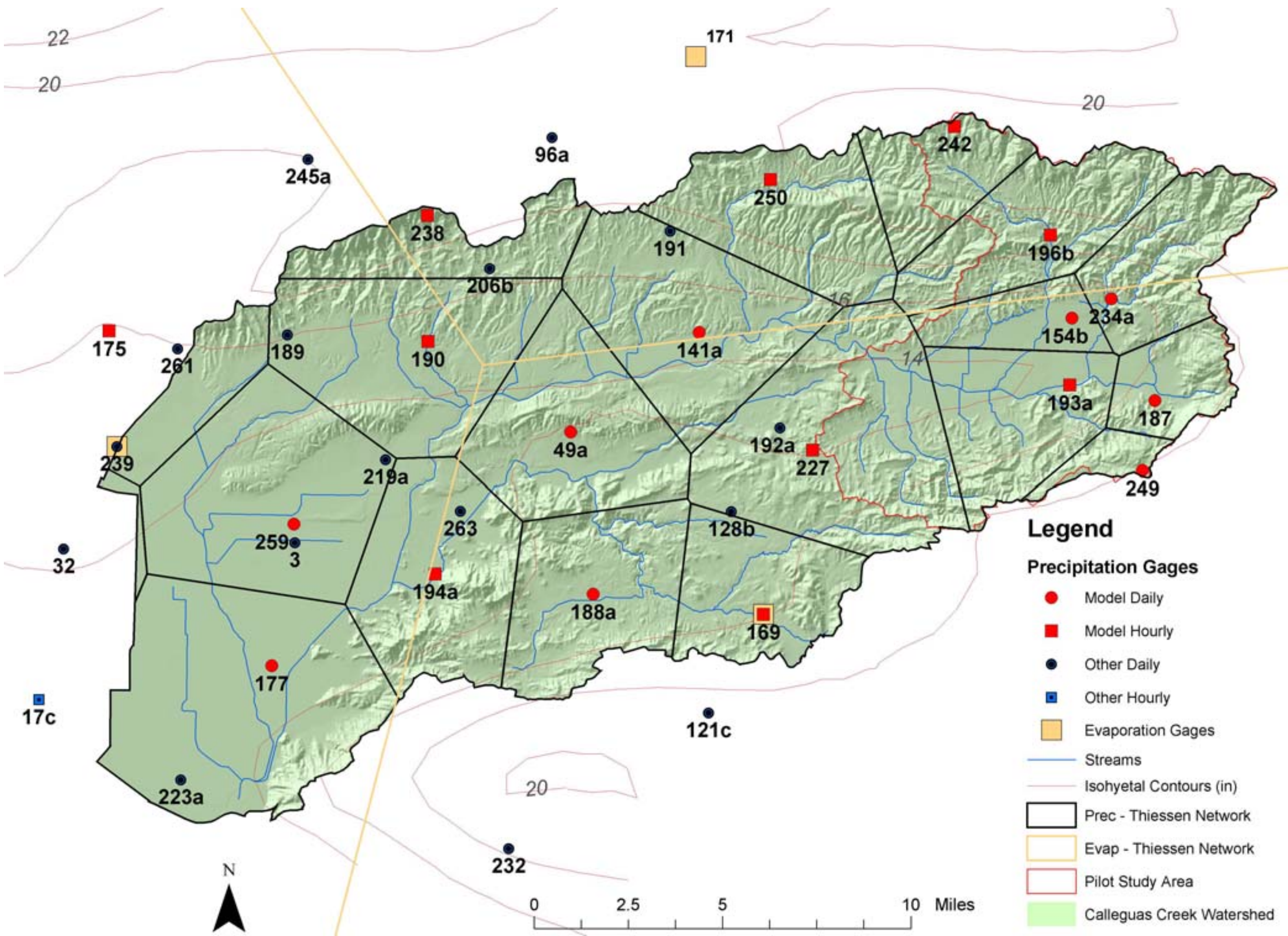


Figure 2.1 Ventura County Precipitation Gages in or near the Calleguas Creek Watershed

watershed area that will receive the rainfall recorded at the gage; it involves constructing polygons around each gage using perpendicular bisecting lines drawn at the midpoint of connecting lines between each gage. The thicker black lines in Figure 2.1 are the Thiessen polygons for the model precipitation gages. Slight revisions and adjustments were made to these polygons based on elevation, isohyetal lines, and drainage boundaries. The model segmentation is described in more detail in Section 3.1.

2.2 EVAPORATION

HSPF generally uses measured pan evaporation to derive an estimate of lake evaporation, which is considered equal to the potential evapotranspiration (PET) required by HSPF, i.e., PET = (pan evap) X (pan coefficient.) The actual simulated evapotranspiration is computed by the program based on the model algorithms that calculate dynamic soil moisture conditions, ET parameters, and the input PET data.

Pan evaporation data are available from the County at several locations in and around the Calleguas Creek Watershed. The sites are listed in Table 2.2 below. The Lake Bard site is near the boundary of the pilot study, and was used for the entire Arroyo Simi. However, further site investigation revealed that the site uses nonstandard equipment rather than a Class A pan, which can introduce significant bias in the data. As the table shows, the average value for Lake Bard is noticeably higher than those for the other sites in Ventura County. The nearest Class A stations are Thousand Oaks, nearby in the south central portion of the watershed, and Fillmore Fish Hatchery to the north. El Rio UWCD Spreading Grounds is situated at the east end of the watershed. After a thorough review of these data, the calibration used a combination of these three Class A pans, with Casitas Dam further east used to fill missing data as needed.

Table 2.2 Evaporation Stations In/Near the Calleguas Creek Watershed

Station #	Name	Average Annual (in)	Period Begins	Elevation (ft, msl)
--	Lake Cachuma	68.41	1970	781
4	Casitas Dam	59.19	1960	400
169	Thousand Oaks	61.06	1971	805
171	Fillmore Fish Hatchery	60.35	1971	465
227	Lake Bard	68.95	1968	1010
239	El Rio-UWCD	61.28	1974	105
239e	UWCD-Daily	56.15	1991	105

Table 2.3 presents the mean monthly evaporation rates for the stations listed in Table 2.2.

Pan evaporation data are less variable than rainfall; therefore, a watershed of this size generally requires only a few records. Unfortunately, only monthly data are currently available for the Ventura County stations. Daily data are preferable, but the National Climate Data Center (NCDC) has no nearby daily data sites available. Therefore, the Cachuma Lake station in Santa Barbara County was used to disaggregate monthly totals into daily values, as was done in the Arroyo Simi pilot study. This is the nearest known daily pan evaporation station with climatic and topographic features similar to the Calleguas watershed. It is expected that the relative daily pattern of the Lake Cachuma gage would be similar to gages in Ventura County.

However, during this effort it was discovered that daily records were maintained by the United Water Conservation District (UWCD) at its El Rio facility; these hard copy data were obtained (S. Bachman, personal communication, December 22, 2003) for the April 1991 through November 2003 time period and used to supplement the Lake Cachuma daily values.

Climatic maps of the region show an estimated pan coefficient of 0.70-0.75 in order to estimate lake evaporation (Environmental Data Service, 1979). The coefficient was set at 0.74 as was done in the pilot study.

Table 2.3 Monthly Evaporation Rates (in) for Stations In/Near the Calleguas Ck Watershed

	Lake Cachuma	Casitas Dam	Thousand Oaks	Fillmore Fish Hatchery	Lake Bard	El Rio-UWCD	UWCD-Daily	Mean	Min	Max
OCT	5.31	4.92	4.72	4.58	5.96	4.84	4.69	5.00	4.58	5.96
NOV	3.34	3.01	3.54	3.48	4.88	4.17	3.90	3.76	3.01	4.88
DEC	2.51	2.16	3.09	3.43	4.37	3.94	3.37	3.27	2.16	4.37
JAN	2.39	2.21	2.89	3.20	4.04	3.52	3.09	3.05	2.21	4.04
FEB	3.03	2.83	2.98	3.27	3.46	3.74	3.19	3.21	2.83	3.74
MAR	4.40	4.20	3.94	4.04	4.17	4.52	3.47	4.11	3.47	4.52
APR	6.01	5.44	5.17	5.30	5.38	5.45	5.01	5.39	5.01	6.01
MAY	7.61	6.02	6.00	5.85	6.26	5.94	5.35	6.15	5.35	7.61
JUN	8.59	6.65	6.93	6.78	7.19	6.33	5.72	6.89	5.72	8.59
JUL	9.31	7.83	7.80	7.64	8.33	6.90	6.71	7.79	6.71	9.31
AUG	8.95	7.72	7.52	7.15	7.95	6.40	6.47	7.45	6.40	8.95
SEP	6.96	6.19	5.94	5.63	6.58	5.36	5.20	5.98	5.20	6.96
TOTAL	68.41	59.19	61.06	60.35	68.95	61.28	56.15	62.20	56.15	68.95

2.3 STREAMFLOW

To calibrate the model, reliable long term records of measured ***daily*** streamflow data are compared with simulated values. The County provided such flow records for 8 principal gages on the main stem and major tributaries of Calleguas Creek. Several peak flow recorders (peak storm flows only) and recently added recording gages exist as well. The gages are listed by type in Table 2.4, and their locations appear in Figure 2.2. The main long-term gages were used for the primary calibration with the daily stations (highlighted in green in Table 2.4), while selected short-span and peak flow gages were used as consistency checks for selected storms. In addition, VCWPD staff provided detailed hourly storm hydrographs for 10 events at each major calibration gage, to assess storm simulations. The long term gage on Calleguas Creek near US 101 was washed out by a storm in December 1997 and subsequently reinstalled several hundred yards downstream. The gage was out of commission from 12/6/1997 to1/9/1998, but flow records were estimated for this time period with hydrologic comparison (i.e. relationships) with data collected at Arroyo Simi at Madera, Conejo Creek, and Calleguas Creek at Camarillo State Hospital (W. Carey, VCWPD, Personal Communication).

2.4 OTHER DATA

Other data types often required for hydrologic simulation are point source inflows (sources of water) and diversions (removal of water), as well as irrigation and groundwater use. Water supply for the four cities in the watershed comes from outside the watershed, while the sewage treatment plant outfalls are within the model area, meaning that the imports and consumptive use of water, especially for irrigation, must be accounted for in the overall watershed water balance. Also, groundwater interactions must be accounted for insofar as they affect baseflow to the streams.

Table 2.4 Streamflow Stations in the Calleguas Creek Watershed

Station #	Name	Type	Period of Record

Long-term Calibration Stations			
802	Arroyo Simi at Royal Ave	Recording	1969 - present
803	Arroyo Simi at Madera Rd Bridge	Recording	1938 - present
800	Conejo Creek above Hwy 101	Recording	1972 - present
776	Revolon Slough at Laguna Rd	Recording	1980 - present
806	Calleguas Creek above Hwy 101	Recording	1969 - 1997
806a	Calleguas Creek at Hwy 101	Recording	1999 - present
805	Calleguas Creek at CSUCI	Recording	1969 - present
Short-term Stations			
842	Arroyo Simi below Stow	Recording	2003 - present
841	Arroyo Las Posas at Hitch Rd	Recording	1991 - present
780	Beardsley Wash at Central Ave	Recording	1994 - present
781	Santa Clara Drain	Recording	1996 - present
782	Las Posas Estates Drain	Recording	2000 - present
Peak gages			
830	Arroyo Conejo South Branch	Peak	1971 - present
831	Arroyo Simi above White Oak Creek	Peak	1971 - present
832	Arroyo Tapo below Los Angeles Ave	Peak	1970 - present
833	Bus Canyon Drain above Los Angeles Ave	Peak	1970 - present
834	Sycamore Canyon Drain bl Tierra Rejada	Peak	1971 - present
836	Arroyo Conejo below Conejo Blvd	Peak	1976 - present
838	Arroyo Santa Rosa below Blanchard Rd	Peak	1985 - present
839	Gabbert-Walnut Canyon Drain	Peak	1987 - present
778	Nyeland Acres Drain	Peak	1987 - present

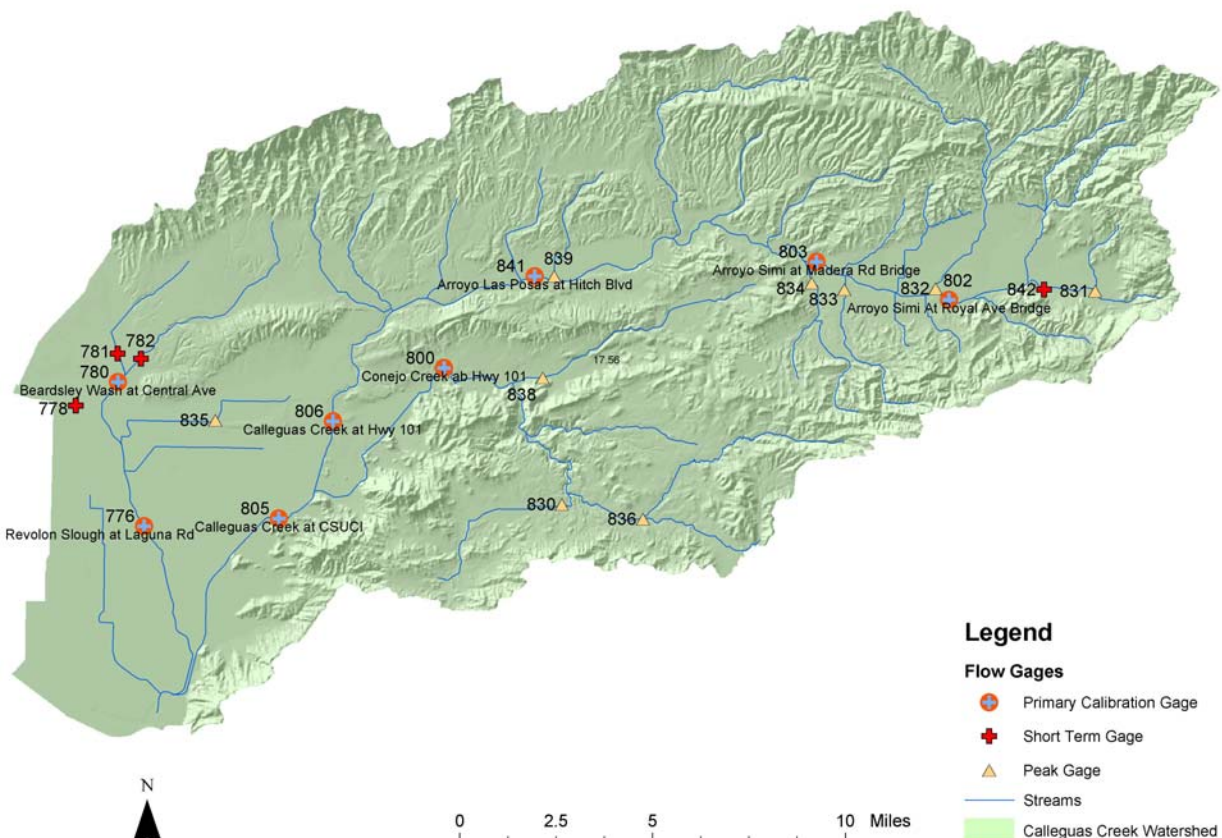


Figure 2.2 Streamflow Stations in the Calleguas Creek Watershed

2.4.1 Point Sources And Diversions

There are six significant sewage treatment plant outfalls within the Calleguas Creek watershed listed below, five of which are currently active:

1. Simi Valley Water Quality Control Plant
2. Olsen Road Wastewater Reclamation Plant (closed 2002)
3. Hill Canyon Wastewater Treatment Facility
4. Camarillo Wastewater Treatment Plant
5. Ventura County Wastewater Treatment Plant (at Moorpark)
6. Camrosa Wastewater Treatment Plant

The first four sources discharge directly to streams in the watershed. Although the Olsen Road plant is currently out of service, it was active during much of the expected simulation period, and therefore was included in the model. The last two facilities provide recharge to shallow aquifers via storage ponds; en route to the ponds, a portion of the Camrosa effluent is diverted for agricultural irrigation, and the Moorpark effluent is divided between the ponds and irrigation, and rarely discharges to the creek. The locations and discharge records were obtained for inclusion in the model.

The periods of record for all original data sets are shown in Table 2.5. Some of the data sets had multiple sources with varying observation intervals; these were compiled into a single time series with the shortest time step being maintained. Other data sets had incomplete periods of record and were filled via methods discussed below. Certain time series used by the model (i.e., flow to ponds) were entirely computed from other data sets and are not included in the table. The data were processed and set to the simulation time span of water years 1988-2002.

Table 2.5 Point Sources in the Calleguas Creek Watershed

Gage Station	Discharge Type:	Start	End	Mean Flow (cfs)	Standard Deviation	Observation Interval
Camrosa WRF	Total	7/94	12/02	2.03	0.17	Monthly
Camrosa WRF	Irrigation	5/1/95	6/30/03	0.91	0.62	Daily
Camrosa WRF	Stream	10/1/87	9/30/02	0.03	0.22	Daily
Hill Canyon WTP	Total	1/1/96	9/30/03	15.69	1.86	Daily
Hill Canyon WTP	Total	1/88	12/95	13.83	1.31	Monthly
Camarillo WTP	Total	1/1/95	9/30/03	6.25	0.95	Daily
Moorpark WTP	Total	1/1/99	9/6/03	3.33	0.34	Daily
Moorpark WTP	Stream	10/1/87	9/30/02	0.38	0.81	Daily
Olsen Road WRP	Total	1/1/96	10/22/02	0.34	0.05	Daily
Olsen Road WRP	Total	1/87	12/95	0.34	0.05	Monthly
Olsen Road WRP	Total	1981	2002	0.34	0.05	Annual
Simi Valley WRP	Total	1/80	12/02	13.27	2.06	Monthly

Figure 2.3 summarizes the POTW time series used by the model, and shows the time periods with records, and those with 'estimated' values (dashed lines).

POTW		Mean Flow (cfs)	Std Dev (cfs)
Simi WQCP		13.77	0.82
Olsen Rd		0.34	0.05
Moorpark	Total	3.30	0.13
	Ponds	2.92	0.8
	Stream	0.38	0.81
Camarillo		6.25	0.95
Hill Canyon		15.16	1.84
Camrosa	Total	2.03	0.12
	Irrig	0.91	0.51
	Ponds	1.08	0.43
	Stream	0.03	0.23

Note: --- estimated values

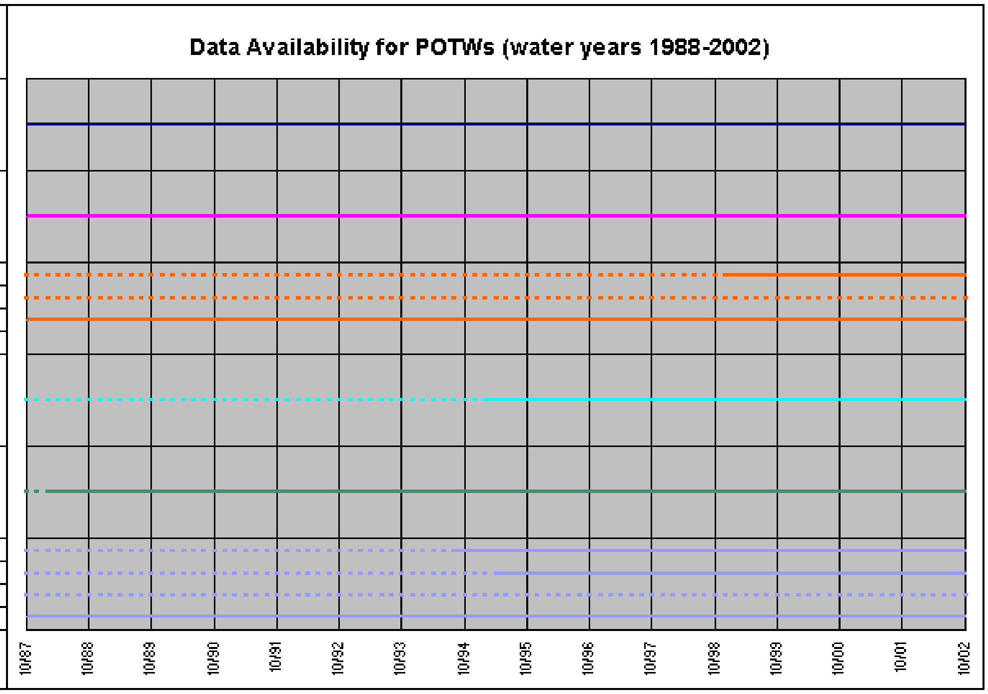


Figure 2.3 Data Availability for Calleguas Point Sources

Figure 2.4 shows the flow duration plots for each POTW, demonstrating the flow variation during the simulation period.

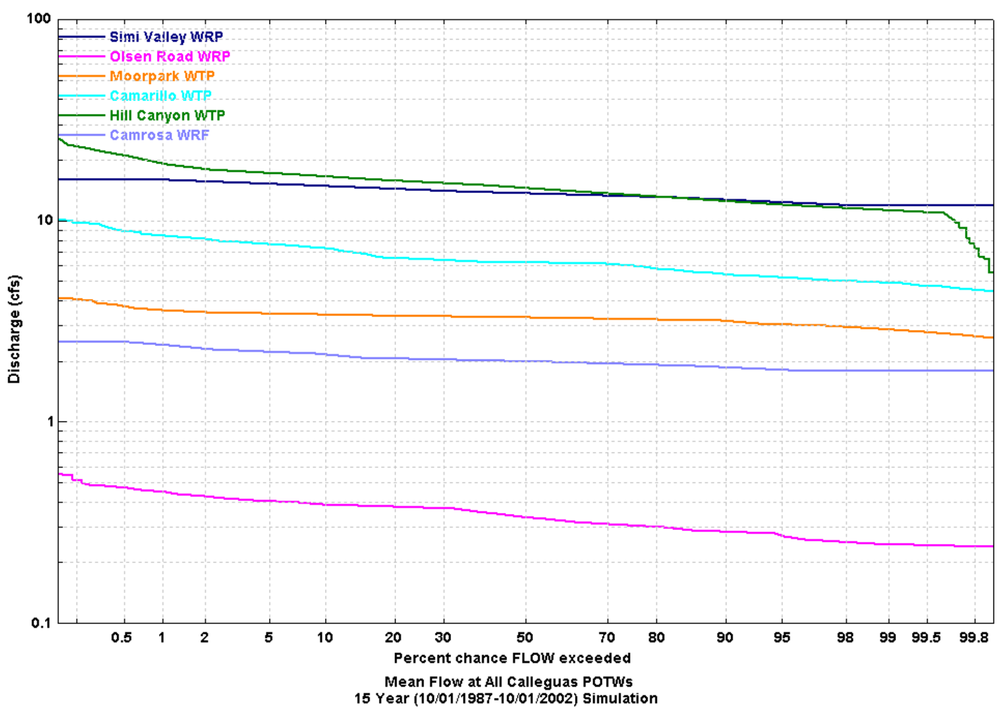


Figure 2.4 Flow Duration Curves for Calleguas Point Sources

Camrosa

The Camrosa WRF discharges to an approximately 1 ½ mile pipe with 8 water meters that travels through agricultural land, irrigating approximately 1000 acres along the way (sprinkler or drip, except 80 acres of furrow). The pipe then discharges to holding ponds that store for re-use or discharge to the stream when full, which has not happened since winter 1998.

Monthly sewer flow summaries containing average daily flow were available from July 1994 through December 2002. The period of October 1987 through June 1994 was filled by taking the average value for each day of the year over the period of record. Non-constant-interval records (approximately 3-10 day intervals) of agricultural withdrawals from pipe were available for 5/95-6/03. These records were used to create a daily time series of agricultural withdrawals using interpolation to fill missing days. The preceding period of 10/87-4/95 was filled by taking the average value for each day of the year over the period of record. Data for discharge to stream was available for the winters of 1997 and 1998; there are reportedly no other periods of discharge to stream so those values are taken as zero. Flow to ponds was determined by subtracting agricultural withdrawals and discharge to stream from the total plant flow.

Figure 2.5 shows the overall plant effluent and its various components over the course of the simulation period.

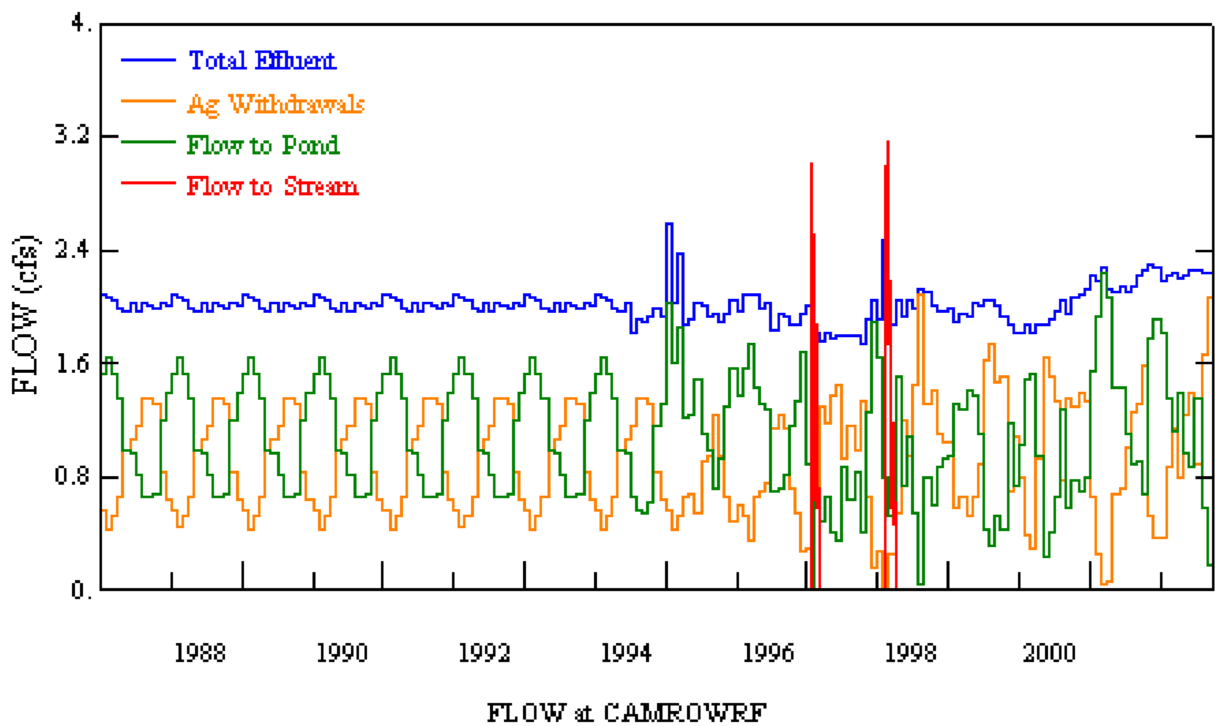


Figure 2.5 Camrosa Point Source Timeseries

Hill Canyon

Daily flows were available from January 1996 through September 2003 and monthly flows from January 1988 through December 1995. There is one short period of missing data, October 1987 through December 1987, which was filled with monthly averages from 1988-2002.

Camarillo

Daily data were available from January 1995 through September 2003. October 1987 through December 1994 was filled by taking the average value for each day of the year over the period of record. The capacity for this plant was upgraded in 1992. Monthly data from 1985 through 1995 were received just after the model validation was completed; they have been processed and included in the final model results for this Final Report.

Moorpark

Effluent flows in the following order: Percolation ponds → Reclamation → Discharge to Arroyo Simi/Arroyo Las Posas. Daily influent rates were available for 1/1/99 through 9/6/03 and were very consistently around 2 cfs for the entire period. Given the consistency of flow and the absence of historical data, the period of October 1987 through December 1998 was filled by taking the average value for each day of the year over the period of record. Influent and effluent are assumed equal for modeling purposes. The plant did not discharge to stream (all to ponds) prior to 1/25/95 because the facility was not permitted to do so, nor did it discharge for the periods 4/3/99 through Sep '01 and May '02 through Sep '02 because the tertiary facility was not in operation. The records of discharge to stream contain daily values, except October '01 through April '02 which were monthly totals. Twenty-five sporadic periods of 1-27 missing days were filled by interpolation. The difference between influent and discharge to stream is taken as flow to ponds.

Figure 2.6 shows the overall plant effluent and its various components over the course of the simulation period.

Olsen Road

Daily flows were available from 10/1/96 through 10/22/02, monthly averages for 1987 through 1995 (missing 1992 and 1994), and annual totals from '81-'02. For 1992 and 1994, the annual total was distributed to monthly average flows based on monthly values from years when data were available.

Simi Valley

Monthly hard copy data from the plant was manually entered into digital format.

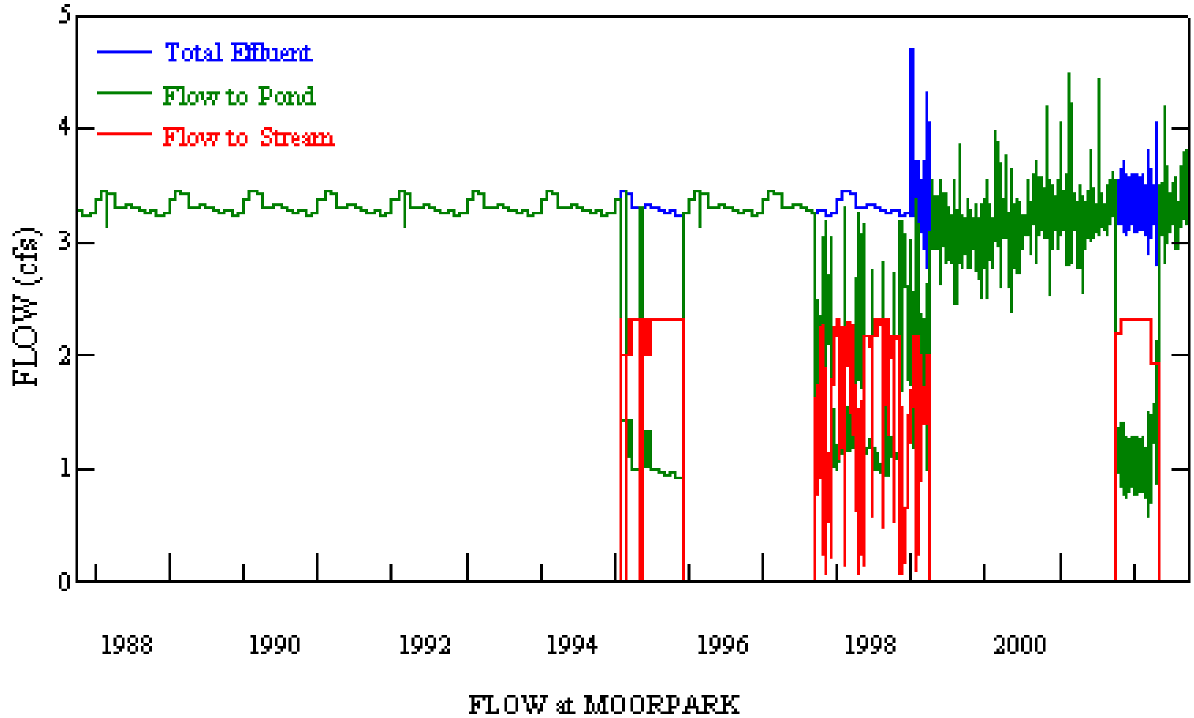


Figure 2.6 Moorpark Point Source Timeseries

Diversions / Deliveries

There are also many agricultural diversions in the lower watershed. The largest is taken from Conejo Creek just below Highway 101 by the Camrosa Water District. The Conejo Creek Diversion came online in March of 2002, near the end of the model simulation period (WY 2002). The water that is diverted from the creek is pumped to storage ponds approximately 3 miles to the south. Ultimately, the diverted water has two delivery destinations: 1) "Water Delivered to PVCWD" - This is water pumped from the storage ponds to Pleasant Valley County Water District for use as agricultural irrigation water in their district boundaries; and 2) "Water Delivered to Camrosa WD". This is water pumped from the storage ponds and used in Camrosa Water District's service area. It is used primarily for agricultural irrigation east of Calleguas Creek and can be delivered as far north as the Santa Rosa Valley.

Data were provided for the timeperiod of 7/11/2002 – 9/30/02 to quantify both the daily water diverted from the creek and transported by pipe to Camrosa's ponds as well as the daily bypass flow (i.e., water that is returned into the creek to flow downstream of the diversion). The state water right mandates that these pumps can divert up to 21.7 cfs and must allow 6 cfs to pass downstream. During storm events the pumps are shut down to prevent sediment and debris from damaging the pumps (Henry Graumlich, Camrosa Water Dist., Personal communication).

Reviewing flows recorded at the Conejo gage just upstream of the diversion and the daily bypass flow data, it was determined that the daily average bypass flow could be reasonably modeled as a constant 6 cfs for model simulations during the timeperiod the diversion was online, and within the model simulation timeperiod, i.e. March to September 2002. This approach was used since no major storm events occurred and the 6 cfs minimum flow requirement could be satisfied during this time period. Thus, it was possible to represent the diversion during this period by simply restricting the flow passed downstream to 6 cfs, once the diversion came online, and withdrawing water from the reach at the rate specified in the data for daily water diverted.

Diverted water was not explicitly returned to the system due to the following: 1) data were not readily available to describe the final delivery destination; and 2) irrigation application rates are already accounted for in the model by satisfying monthly crop and lawn evapotranspiration (ET) demands that exceed available rainfall (see Section 2.4.2).

A more sophisticated approach is included to represent the operational policy of the diversion under alternative scenarios; for alternative scenarios the diversion behaves as follows: 1) attempts to satisfy the minimum 6 cfs bypass flow; 2) diverts up to 21.7 cfs of the flow remaining after the bypass flow has been satisfied; 3) passes all remaining flows downstream; and 4) during a storm event passes all flows downstream (i.e., simulate pump being shut down). The model considers flows greater than 50 cfs as storm flows, but this threshold can be easily adjusted if needed. A separate model input file (UCI) is provided on the Project CD.

2.4.2 Irrigation

The developed land use in the Arroyo Simi pilot study area is predominantly urban (~30%), so irrigation is generally limited to lawn and landscape watering. Since the larger Calleguas watershed includes significant irrigated agricultural land, the model needs to include both urban and agricultural irrigation applications. Below we discuss the overall approach to estimating irrigation application amounts throughout the Calleguas Creek Watershed, based on the Arroyo Simi model and irrigation procedures, followed by separate discussions of the urban and agricultural irrigation procedures.

The overall approach to include both urban and agricultural irrigation applications was based on the assumption that irrigation systems are used, and amounts applied to satisfy monthly crop and lawn evapotranspiration (ET) demands that exceed available rainfall. ET demands were computed based on the landscape coefficient method described in the WUCOLS III (Water Use Classifications of Landscape Species) manual (CA DWR, 2000). Daily reference ET is given by month for each climate zone in the state, and is tabulated in the WUCOLS manual. According to the climate zone map in the manual, the Calleguas Creek Watershed falls within Zone 9, representing the South Coast Marine and transition zone to inland desert climates.

The equation for calculating ET Demand is as follows:

$$\text{ET Demand} = \text{ETo} \times \text{Kc}$$

where ET Demand = Crop/lawn evapotranspiration demands (inch)
ETo = Reference crop evapotranspiration (inch)
Kc = Crop/lawn coefficient (dimensionless)

The actual irrigation amount is usually greater than the ET demand to account for irrigation efficiencies and application losses. The actual irrigation amount is calculated as follows:

$$\text{Irrigation Application} = \text{ET Demand/Irrigation efficiency}$$

Thus with irrigation efficiencies in the range of 60 to 90%, application will be increased by about 70 to 10%, respectively, to account for losses and ensure that crop/lawn water needs are satisfied. Below we discuss the application of these equations to determine urban and agricultural irrigation applications in the Calleguas Creek Watershed.

2.4.2.1 Urban Irrigation

Within the Callegaus Creek Watershed, irrigation on urban land is generally limited to lawn watering by homes and businesses. Irrigation impacts in urban environments are usually evident at low flows, and the associated effects are shown as an increased baseflow component of the overall water balance. Although data on total annual consumptive use within the basin was available from local water companies, the amounts specifically for urban landscape watering were not determined. Since the model requires specification of irrigation amounts applied to urban land use categories, the WUCOLS procedures (described above) were used to estimate the temporal distribution of urban irrigation estimated based on the difference between plant needs and rainfall. The spatial distribution was determined from the urban land use categories within each model segment, discussed in Section 3.

In residential and most urbanized areas of the watershed, it is assumed that the dominant vegetation is turf grass, with a crop coefficient of 0.6 ("warm season" grass) from the WUCOLS manual. Commercial and private landscaping practices in the basin are bound to vary, but with a lack of species specific data for urban vegetation, a net crop coefficient of the same 0.6 was judged to be reasonable. This would be consistent with a mix of species with moderate water needs, average density, and an average microclimate factor. Therefore no distinction is made between lawn watering and other urban landscape irrigation.

The ‘potential’ irrigation timeseries is the amount of irrigation applied to the entire urban land category assuming that 100% of the category is irrigated. To reflect the fact that less than 100% coverage by irrigation is more reasonable, reduction factors are applied within the model input (i.e. UCI) that reduces this amount by the fraction of the area assumed to be irrigated. Our current model runs assume the following percentages of each urban land category are irrigated:

- low density residential – 50%
- medium density residential – 70%
- high density residential – 80%
- commercial/industrial/transportation – 85%

These percentages were developed in the Arroyo Simi application, and they provide viable irrigation amounts and reasonable water balance impacts due to the irrigation additions. However, no data were available to confirm or revise these values for the Calleguas Creek Watershed; review of a vegetation coverage for the watershed (“Vegetation Map of Callegaus Watershed”, http://www.calleguas.com/ccbrochure/veglayer.zip) did not provide any basis for calculating the fraction of urban or developed land that was irrigated. Infrared photography, if developed and available in the future, might provide a basis for refining these values by overlay onto the urban land use coverage.

Table 2.6 shows monthly values of reference ET for Zone 9 according to the WUCOLS III manual, the net lawn watering need resulting from the chosen crop coefficient of 0.6, and the gross water supply requirement based on the assumed average efficiency of 0.85. Thus the gross needs amount to almost 39 inches per year, without accounting for rainfall contributions.

Table 2.6 Monthly Reference ET and Urban Irrigation Requirements

	Reference ET		Net Crop Need		Gross Crop Need	
	Daily	Monthly	Daily	Monthly	Daily	Monthly
Oct	0.13	4.03	0.08	2.42	0.09	2.84
Nov	0.09	2.70	0.05	1.62	0.06	1.91
Dec	0.06	1.86	0.04	1.12	0.04	1.31
Jan	0.07	2.17	0.04	1.30	0.05	1.53
Feb	0.10	2.80	0.06	1.68	0.07	1.98
Mar	0.13	4.03	0.08	2.42	0.09	2.84
Apr	0.17	5.10	0.10	3.06	0.12	3.60
May	0.19	5.89	0.11	3.53	0.13	4.16
Jun	0.22	6.60	0.13	3.96	0.16	4.66
Jul	0.24	7.44	0.14	4.46	0.17	5.25
Aug	0.22	6.82	0.13	4.09	0.16	4.81
Sep	0.19	5.70	0.11	3.42	0.13	4.02
Total	1.81	55.14	1.09	33.08	1.28	38.92

2.4.2.1 Agricultural Irrigation

The lower Calleguas Creek watershed, as noted above, contains a significant fraction of agricultural land, where irrigation practices, water sources, and diversions are much more complex than for the urban land. Irrigation practices and hydrologic response vary from crop to crop. Strawberries in particular have a different hydrologic response from other crops due to the heavy use of plastic sheeting on the fields in recent years. In the last several years, many growers have replaced citrus groves with avocado and strawberries. Therefore, information regarding changes in cropping patterns, over the past two decades, as well as typical irrigation practices for each major crop were important to review and analyze.

In order to develop a reasonable time series of irrigation applications for agricultural crops in the Callegaus Creek Watershed, the following steps were performed:

1. Process available cropping data to determine major crop category acreages by model segment.
2. Calculate a weighted crop coefficient for each model segment based on the crop distribution.
3. Using the weighted crop coefficient and the ETo from the WUCOLS method, calculate the estimated crop ET demand for each model segment.
4. Based on the irrigation practices in the watershed, apply an irrigation efficiency factor to develop the potential irrigation amounts applied to the agricultural land in each model segment.

Each of these steps is discussed in detail below.

Cropping Data - Cropping coverages were available as GIS data layers for both 1997 and 2002. In addition, annual crop reports from the Ventura County Agricultural Commissioners Office (1988 - 2002) were obtained and reviewed to identify major trends in cropping practices over the entire simulation period. Table 2.7 lists the dominant crops and their percentages from the 1997 and 2002 surveys. The largest acreages are used by row crops (generally peppers, tomatoes, and other vegetables), citrus, avocado, and strawberries. Figure 2.7 below shows the spatial distribution of the crops being grown during the December of 1997 survey, along with the meteorologic segments used to estimate crop coefficients (see below). It is important to note that due to the spatial scale of the model not every individual crop and field could be modeled as separate model segments; this was simply not feasible for the size of the Calleguas Creek watershed and the extent of agricultural usage.

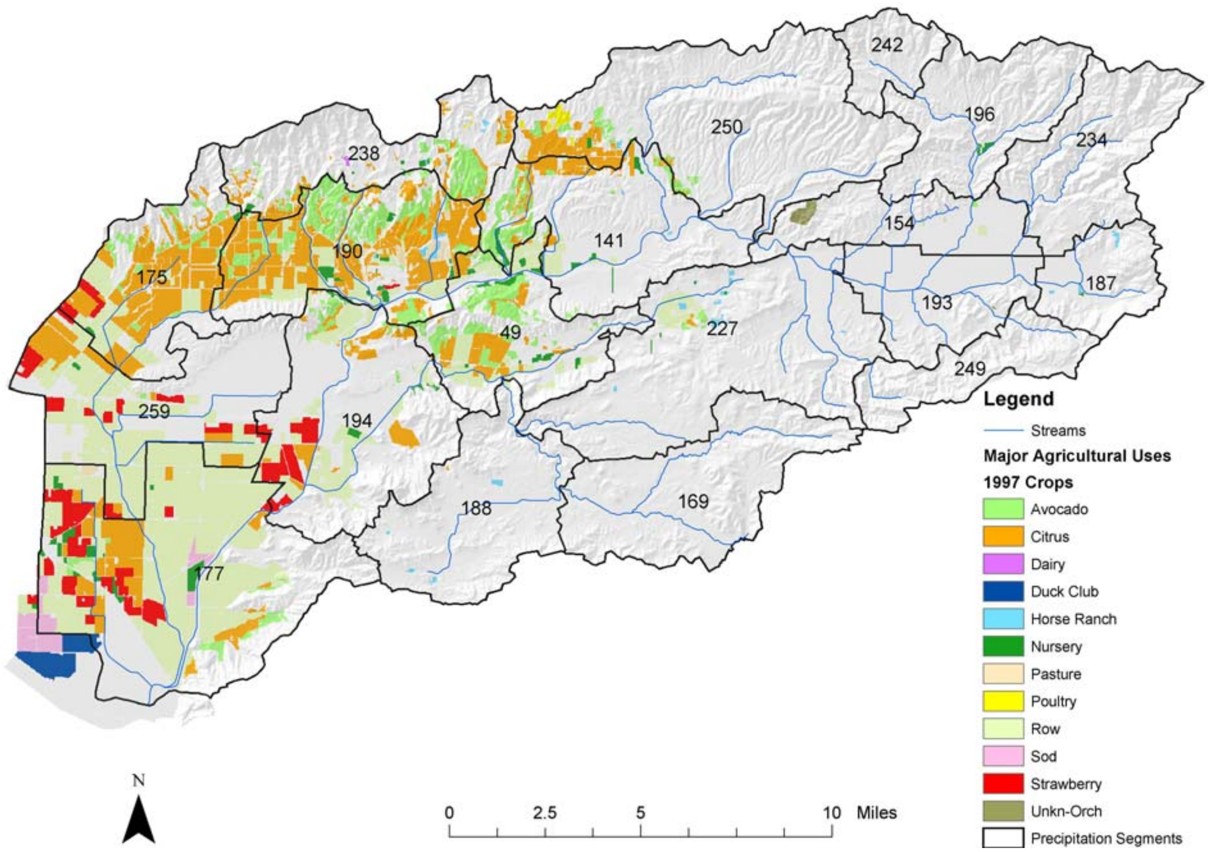


Figure 2.7 Agricultural Survey of Calleguas Watershed, December 1997

Table 2.7 shows that the four dominant crop groups – row crops, citrus, avocado, strawberry – comprise up to 95 % of the total crop acreage within the watershed. Although there have been some changes between 1997 and 2002, the major crop percentages have remained relatively constant except for strawberries which have approximately doubled during that time period. The VC annual crop reports show similar overall patterns, with row crops decreasing somewhat, citrus and avocadoes staying about the same, and strawberries increasing by factors of 2 to 3 but remaining less than 10% for the County as a whole. Based on this information, we selected the four major crop categories noted above, while incorporating the remaining crops, and used these categories to calculate the ET demand and irrigation applications.

Table 2.7 Major Crop and Livestock Acreages in Calleguas Watershed Survey, for December 1997 and August 2002

	1997 Survey		2002 Survey	
Name	**acres**	**percent**	**acres**	**percent**
Row Crops	18,264	41.3%	17,785	35.8%
Citrus	15,251	34.5%	14,490	29.2%
Avocado	5,589	12.7%	7,200	14.5%
Strawberry	3,176	7.2%	6,378	12.8%
Nursery	991	2.2%	1,781	3.6%
Pasture	363	0.8%	518	1.0%
Sod	438	1.0%	353	0.7%
Other	111	0.3%	1,190	2.4%
Total	44,184	100.0%	49,695	100.0%

Crop Coefficients – For each of the four crop categories, we estimated crop coefficients from a variety of sources, including the Fox Canyon Groundwater Management Agency web site (http://publicworks.countyofventura.org/fcgma/cropKc.htm), CA Department of Water Resources web site (www.cimis.water.ca.gov), the WUCOLS manual, Snyder et al. (2002), and other general literature. Although crop coefficients vary by crop stage during the growing season, we selected values that represented mid-season conditions with the highest levels of water use and transpiration since multiple, almost year-round, cropping periods are common within the Calleguas. This would tend to over-estimate ET demand and would require some adjustment in overall irrigation applications during calibration.

The crop coefficients selected for the four crop categories were: Row Crops, .75; Strawberry, .85; Citrus, .60; Avocado .80. Table 2.8 shows the crop distributions for the primary agricultural model segments and the resulting weighted crop coefficient for each segment. These model segments are the meteorologic regions, shown in Figure 2.7, with major fractions of agricultural land.

Table 2.8 Crop Distribution and Weighted Crop Coefficients

Met Segment	Row Crops % of Seg	Strawberry % of Seg	Citrus % of Seg	Avocado % of Seg	Weighted Crop Coefficient
49	34%	0%	29%	37%	0.72
141	20%	0%	43%	36%	0.70
175	35%	7%	53%	6%	0.68
177	73%	11%	14%	2%	0.74
190	20%	0%	58%	22%	0.67
194	50%	21%	22%	7%	0.74
238	2%	0%	40%	58%	0.72
250	3%	0%	79%	18%	0.64
259	76%	13%	10%	1%	0.75
Segment Average	46%	7%	35%	13%	0.71

ET Demand – For each model segment, the ET demand was then calculated as the product of the crop coefficient and the monthly reference ET values shown in Table 2.6. Table 2.9 shows the resulting monthly ET demand for each of the primary agricultural meteorologic segments. These numbers represent the crop demand each month in each model segment.

Table 2.9 Crop ET Demand for Primary Meteorologic Segments with Agricultural Land (inches)

Met Segment	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
49	1.57	2.03	2.92	3.70	4.27	4.79	5.40	4.95	4.13	2.92	1.96	1.35	39.99
141	1.53	1.97	2.83	3.59	4.14	4.64	5.23	4.80	4.01	2.83	1.90	1.31	38.79
175	1.47	1.90	2.74	3.47	4.00	4.48	5.06	4.63	3.87	2.74	1.83	1.26	37.46
177	1.61	2.07	2.98	3.78	4.36	4.89	5.51	5.05	4.22	2.98	2.00	1.38	40.84
190	1.46	1.89	2.71	3.43	3.97	4.44	5.01	4.59	3.84	2.71	1.82	1.25	37.13
194	1.61	2.08	2.99	3.79	4.37	4.90	5.52	5.06	4.23	2.99	2.00	1.38	40.93
238	1.56	2.02	2.90	3.67	4.24	4.75	5.35	4.91	4.10	2.90	1.94	1.34	39.68
250	1.39	1.79	2.58	3.27	3.77	4.23	4.77	4.37	3.65	2.58	1.73	1.19	35.33
259	1.62	2.09	3.01	3.81	4.41	4.94	5.56	5.10	4.26	3.01	2.02	1.39	41.24
Average	1.54	1.98	2.85	3.61	4.17	4.67	5.27	4.83	4.04	2.85	1.91	1.32	39.04

Irrigation Efficiency – To translate the expected ET demand into a potential irrigation application requires an irrigation efficiency factor to account for losses that occur and affect the amount of applied water that is actually available for the crop. Irrigation practices and associated efficiencies vary with a variety of factors including the crop type, growth stage, soil and slope conditions, water sources, etc. Contacts with the Ventura County Resource Conservation District (RCD), local NRCS, and the Ventura County Extension Agent indicate that a variety of irrigation methods are used in Ventura County, including drip, microjet, furrow and sprinkler systems. Although specific percentages are not available, these contacts indicated that the majority of users have converted to a drip/microjet, below canopy type application.

Information on irrigation efficiencies were obtained from the Center for Irrigation Technology at California State University in Fresno CA (Solomon, 1988). The typical range for drip/microjet irrigation efficiency is 75-90%,while the range for sprinkler irrigation is about 60-80%; Solomon also cites a large field study in California that found an average of 80% for drip and trickle type systems. Since the systems in the Calleguas Creek Watershed are mostly of the drip/microjet type, but also some older sprinkler and furrow systems, we selected an efficiency of 75%. This produces a 33% increase in the ET demands shown in Table 2.9, i.e. 1/.75 = 1.33, to produce the final irrigation application needs for each model segment, without accounting for the rainfall contribution.

2.4.2.3 Calculation of Daily Irrigation Applications

The final step in the irrigation calculation is to account for rainfall contributions that offset crop and lawn ET demands, and calculate the actual irrigation amount applied during each day. The model performs the following steps using the SPECIAL ACTIONS capability of HSPF:

1. The monthly values for both urban and agricultural ET demand, shown above, for each model segment, are converted to a daily demand, constant within each month.

2. The daily demand is compared to the daily rainfall:

    a. If the rainfall exceeds the demand, the excess (difference) is calculated and available to satisfy ET demands in subsequent days, until all the excess is utilized.
    b. If the ET demand exceeds the rainfall, the difference is increased for the specific irrigation efficiency - .85 for urban and .75 for agriculture – and the resulting daily amount is the irrigation application for that land use and model segment. The agricultural efficiency was discussed above, while the value of 0.85 for urban irrigation represents a well-designed and well-operated irrigation system (primarily drip/microjet) according to the WUCOLS III manual.

3. The daily irrigation amount from 2.b. is distributed within the day by applying the amount equally into three hourly applications for 6-7am, 7-8am, and 8-9am (to represent automated sprinklers on a daily schedule) for urban applications, and six hourly applications for the period between 6 am and Noon, for agricultural applications.

In performing these steps a single rainfall record was used for the urban calculations, derived as an average of gages 259, 188, 141, and 193 which cover the primary urban portions of the watershed. It was decided that homeowners and commercial irrigators would not be sensitive to small variations between gages, so urban applications would likely be more uniform since a single crop coefficient of 0.6 was used. Whereas, the agricultural applications were derived from the rainfall records at nine separate stations because the crop coefficients varied between model segments due to the cropping distribution across the watershed.

These steps and calculations are only performed in the first model runs, and the resulting time series of applications are saved in memory to use in all subsequent model runs, unless assumptions or parameters, like the crop coefficient or efficiency, are changed. During calibration it was necessary to reduce the agricultural irrigation amounts to be consistent with existing data and information on overall agricultural usage; see Section 4 for further discussion.

2.4.3 Groundwater

Groundwater wells for urban and agricultural supply and for urban dewatering exist in the watershed, and have an impact on the hydrologic regime. Dewatering pumps in Simi Valley were already included in the Arroyo Simi pilot study and are maintained in the Calleguas model, based on pump records and recorded discharges to the stream. The pumping amounts are removed from the model's groundwater storage and discharged to the stream. The case for agriculture is much more complex, and although pumping records exist, the differing scales of the data records and the model segments preclude representation of individual wells and their irrigation uses. The data are simply insufficient to accurately determine where groundwater is pumped, where it is used, and how and when it is applied for crop production, at the time scale needed for model calculations. Consequently, the irrigation demand approach described above was developed to accommodate the need to include irrigation impacts in the model.

The HSPF model attempts to represent the hydrologic cycle and water balance components for each category of land in the watershed. The calculations produce separate surface runoff (as overland flow), interflow, and baseflow components from each land category, and then based on the area of that category, the total inflow into each channel reach is calculated. Groundwater is represented as both a shallow, active groundwater storage that can contribute directly to streamflow (as baseflow), and a deep, inactive storage that represents deep aquifers that do not contribute to streamflow. The flux into the deep inactive storage is represented as deep recharge. Both of these groundwater components are evaluated as part of the model calibration process and the water balance assessment (see Section 4.0 for calibration discussion). Thus any available information or estimates of expected deep recharge are important to the calibration process.

Another groundwater issue that is considered in the model is the presence of recharge and discharge zones along the principal streams. The vast majority of the main channel reaches are discharge zones, receiving groundwater inflows from the tributary and adjacent areas, especially during winter and storm periods. However, a number of recharge areas have been identified where channel losses exist. For instance, during low flow periods in the main stem at the Hitch Blvd gage, the flow downstream at Highway 101 will frequently be zero due to channel losses as recharge to the shallow aquifers. A field survey in September, 2003 confirmed that a significant baseflow in the main stem at Somis Road disappeared entirely into the bed about a mile downstream at Seminary Bridge Road. Channel losses such as these are included in the model based on available information to quantify these losses. The draft chloride TMDL by the Los Angeles Regional Water Quality Control Board, shows a map of recharge and discharge zones along Calleguas Creek and its major tributaries (LARWQCB, 2002). Also, the USGS groundwater modeling effort (Hanson et al, 2003) identifies both channel loss regions and estimated ranges of annual losses. Channel losses are further discussed in Section 3, as represented in the stream reach characterization, and Section 4, as part of the model calibration effort.

SECTION 3.0

SEGMENTATION AND CHARACTERIZATION OF THE WATERSHED

3.1 WATERSHED AND RIVER SEGMENTATION

Whenever HSPF, or any watershed model, is applied to a watershed, the entire study area must undergo a process referred to as 'segmentation'. The purpose of watershed segmentation is to divide the study area into individual land and channel segments, or pieces, that are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior. This segmentation provides the basis for assigning similar or identical input and/or parameter values or functions to where they can be applied logically to all portions of a land area or channel length contained within a model segment. Since HSPF and most watershed models differentiate between land and channel portions of a watershed, and each is modeled separately, each undergoes a segmentation process to produce separate land and channel segments that are linked together to represent the entire watershed area.

Watershed segmentation is based on individual spatial characteristics of the watershed, including topography, drainage patterns, land use distribution, meteorologic variability, and soils conditions. The process is essentially an iterative procedure of overlaying these data layers and identifying portions of the watershed with similar groupings of these characteristics. Over the past decade, the advent of geographic information systems (GIS), and associated software tools, combined with advances in computing power, have produced automated capabilities to efficiently perform the data-overlay process.

3.1.1 Land Segmentation

The purpose of segmenting the watershed is to divide the study area into individual land segments that are assumed to produce a homogeneous hydrologic and water quality response. The segmentation then allows the user to assign identical model parameter values to those parts of the watershed that produce the same unit response of runoff (and other quantities such as chemical constituents) for a uniform set of meteorologic conditions. Where the weather patterns vary across a watershed, it is necessary to also divide the land segments by meteorology to accurately reflect spatial meteorologic variability and its effect on the hydrology and water quality of the watershed.

The Calleguas Creek Watershed has been divided into 30 model segments according to topographic and meteorologic considerations, 18 of which are carryovers or extensions of the Arroyo Simi pilot study segmentation. These were developed by aggregating a set of detailed subwatershed boundaries used by VCWPD for their Rational Method model. The model land segments are shown in Figure 3.1. The primary factors were the locations of the rain gages, Thiessen network boundaries, isohyetal contours, drainage boundaries, and differences in slope and elevation.

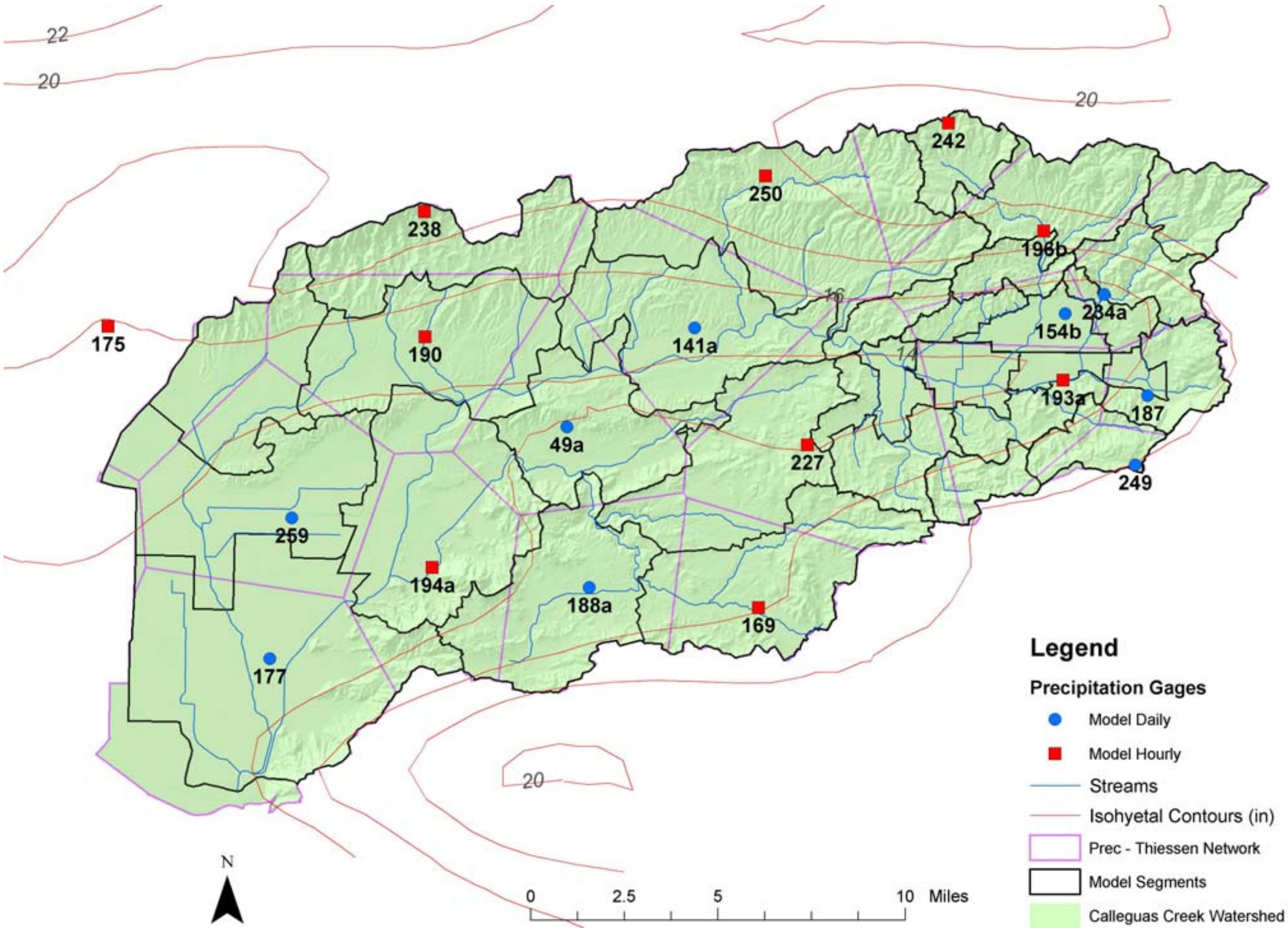


Figure 3.1 Watershed Land Segmentation

3.1.2 River Segmentation and Characterization

The river channel network in the Calleguas Creek Watershed is the major pathway by which flow, sediment and contaminants are transported from the watershed to the Pacific Ocean through Mugu Lagoon. As such, it is important to accurately represent or characterize the channel system in the HSPF model of the watershed. The river reach segmentation required consideration of river travel time, riverbed slope continuity, cross section and morphologic changes, and entry points of major tributaries. In addition, Section 303(d) reaches were represented as model reach boundaries so that flows, water balance, and volume information can be generated for use in TMDL assessments.

The channel network was divided into 119 stream reaches, including 23 detention basins with significant drainage areas. Consideration was taken of the tributary inflows, changes in channel slope and morphology, changes in slope of tributary areas, and gage locations. The reach locations are shown in Figure 3.2, and a list of their names, drainage areas, and lengths follows in Table 3.1.

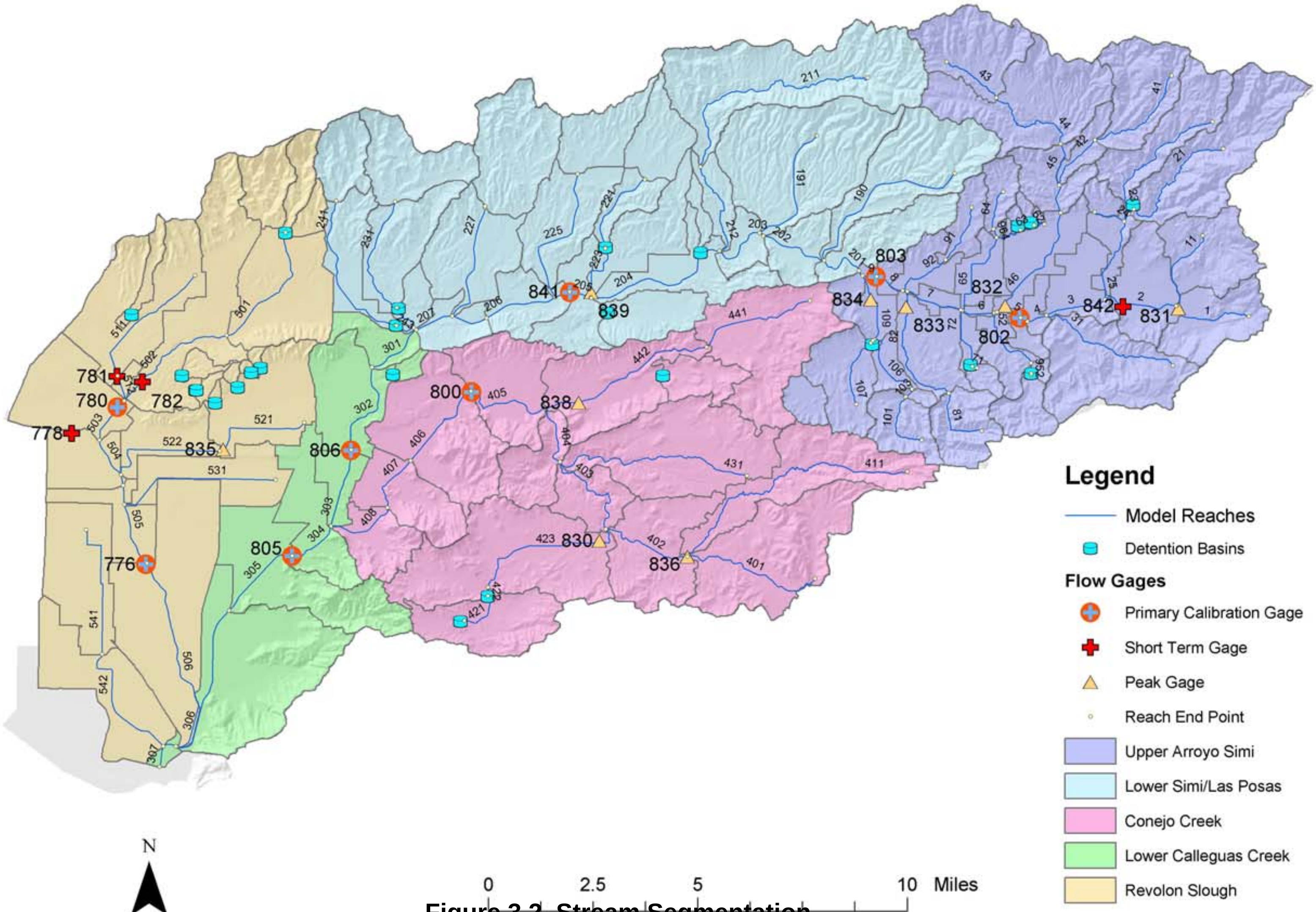


Figure 3.2 Stream Segmentation

Table 3.1 Calleguas Watershed Model Reaches, Including Detention Basins (highlighted)

Model Reach #	Name	Incremental Drainage Area (ac)	Length (mi)
Upper Arroyo Simi			
Main Stem			
1	Arroyo Simi above White Oak Creek	2110	1.91
2	Arroyo Simi above Las Llajas Canyon	2145	1.84
3	Arroyo Simi above Meier Canyon	1445	1.67
4	Arroyo Simi above Royal Ave	421	0.46
904	Arroyo Simi Royal Ave USEP Site	0	0.19
5	Arroyo Simi above Tapo Canyon	361	0.60
6	Arroyo Simi above Dry Canyon	150	0.86
7	Arroyo Simi above Bus Canyon Drain	314	1.44
8	Arroyo Simi above Madera Rd Bridge	271	0.84
9	Arroyo Simi above Sycamore Canyon	349	0.36
10	Arroyo Simi below Sycamore USEP Site	0	0.18
Tributaries			
11	White Oak Creek	2318	2.19
21	Upper Las Llajas Canyon	4328	3.56
22	Las Llajas Canyon Dam	0	0.18
23	Chivo Canyon	2528	3.88
24	Marr Diversion	380	0.79
25	Lower Las Llajas Canyon	780	2.33
31	Meier Canyon	3868	3.69
41	Windmill Canyon	2497	2.77
42	Lower Gillibrand Canyon	645	1.46
43	Upper Tripas Canyon	2557	1.60
44	Lower Tripas Canyon	4333	2.61
45	Upper Tapo Canyon	1326	1.84
46	Lower Tapo Canyon	1825	3.07
51	Runkle Canyon Debris Basin	954	0.04
952	Runkle Canyon USEP Site	138	0.25
52	Lower Runkle Canyon	980	1.79
61	Tapo Hills No. 1 Debris Basin	100	0.08
62	Tapo Hills No. 2 Debris Basin	129	0.19
63	Tapo Hills Diversion	146	1.35
64	Upper Dry Canyon	731	1.02
964	Dry Canyon USEP Site	55	0.22
65	Lower Dry Canyon	994	2.29
71	Erringer Road Debris Basin	299	0.16
72	Lower Erringer Road Drain	400	1.50
81	Upper Bus Canyon Drain	1580	1.74
82	Lower Bus Canyon Drain	1961	3.31
91	Upper North Simi Drain	834	1.51
92	Lower North Simi Drain	1026	1.34
100	Lake Bard	610	0.92
101	Upper Oak Canyon	1319	1.62
102	Upper Oak Canyon Detention Basin	0	0.03
103	Middle Oak Canyon USEP #1	158	0.23
104	Oak Canyon Detention Basins No. 1 & 2	0	0.02
105	Middle Oak Canyon USEP #2	0	0.19
106	Lower Oak Canyon	569	1.67
107	Upper Sycamore Canyon	1996	1.72
108	Sycamore Canyon Dam	0	0.08
109	Lower Sycamore Canyon	857	1.76

Table 3.1 Calleguas Watershed Model Reaches (continued)

Model Reach #	Name	Incremental Drainage Area (ac)	Length (mi)
Lower Simi/Arroyo Las Posas			
Main Stem			
201	Arroyo Simi above Alamos Canyon	2083	1.22
202	Arroyo Simi above Big Mountain Oil Field Canyon	1232	1.66
203	Arroyo Simi above Happy Camp Canyon	783	1.52
204	Arroyo Las Posas above Gabbert Canyon	2235	3.69
205	Arroyo Las Posas above Hitch Blvd	1557	0.54
206	Arroyo Las Posas above Long Canyon	1418	2.14
207	Arroyo Las Posas above Coyote Canyon	1030	1.82
Tributaries			
190	Alamos Canyon	3934	4.50
191	Campus Rd Canyon	5993	3.15
211	Happy Camp Canyon	6715	6.15
212	Happy Camp Canyon	833	2.50
192	Castro Williams Debris Basin	317	0.02
221	Gabbert Canyon	2437	2.17
222	Gabbert Canyon Debris Basin	0	0.02
223	Gabbert Canyon	2107	1.50
193	Peach Hill Wash Debris Basin	1640	0.02
225	South Grimes Canyon Wash	4321	3.62
194	Moorpark Percolation Ponds	0	0.02
227	Mahan Barranca	6150	2.97
231	Coyote Canyon	4687	3.04
232	Coyote Canyon Debris Basin	0	0.02
233	Coyote Canyon	589	0.76
241	Fox Barranca	3208	3.95
242	Fox Barranca Debris Basin	0	0.02
243	Fox Barranca	48	0.47
Lower Calleguas Creek			
301	Calleguas Creek above Highway 101	995	1.46
302	Calleguas Creek at Highway 101	2576	2.43
303	Calleguas Creek above Conejo Confluence	925	1.90
304	Calleguas Creek above CSUCI	2396	1.28
305	Lower Calleguas Creek (tidal)	4281	2.12
306	Lower Calleguas Creek (tidal)	6196	3.81
307	Lower Calleguas Creek (tidal)	209	0.82
Tributaries			
311	St. John's Debris Basin	228	0.02
195	Camrosa Percolation Ponds	0	0.02
Conejo Creek			
Main Stem			
401	Arroyo Conejo above Lang Ck	5024	3.64
402	Middle Arroyo Conejo above South Fork	3224	2,29
403	Arroyo Conejo above North Fork Conejo Creek	1350	2.82
404	Conejo Creek above Arroyo Santa Rosa	1565	1.55
405	Conejo Creek above Conejo Gage	2930	2.30
406	Conejo Creek above Conejo Diversion	4451	2.36
407	Conejo Creek above Camarillo WTP	2142	1.49
408	Lower Conejo Creek	1546	1.69
Tributaries			
411	Lang Creek	3960	7.16
421	South Fork Arroyo Conejo	2558	1.10
422	South Fork Arroyo Conejo Debris Basin	0	0.22
423	South Fork Arroyo Conejo	6027	3.94
431	North Fork Conejo Creek	5293	5.23
441	Upper Arroyo Santa Rosa	4514	2.93
442	Lower Arroyo Santa Rosa	3637	4.42
443	Santa Rosa Debris Basin	1109	0.02

Table 3.1 Calleguas Watershed Model Reaches (continued)

Model Reach #	Incremental Name	Drainage Area (ac)	Length (mi)
Revolon Slough			
Main Stem			
500	Honda West Debris Basin	816	0.02
501	Beardsley Wash	5370	3.30
502	Beardsley Wash above Santa Clara Drain	4756	3.18
503	Revolon Slough above Highway 101	2771	1.13
504	Revolon Slough below Highway 101	1551	1.26
505	Revolon Slough above Laguna Rd	1444	2.01
506	Lower Revolon Slough	6373	5.01
Tributaries			
511	Upper Santa Clara Drain	4189	3.38
512	Lower Santa Clara Drain	191	0.63
513	Romana Debris Basin	319	0.02
514	Los Posas Estates Debris Basin	157	0.02
521	Upper Camarillo Hills Drain	3076	2.49
522	Lower Camarillo Hills Drain	1608	3.05
523	West Camarillo Hills East Debris Basin	115	0.02
524	West Camarillo Hills West Debris Basin	67	0.02
525	Edgemore Debris Basin	101	0.02
526	Crestview Debris Basin	71	0.02
531	Pleasant Valley Drain	2248	3.92
541	Upper Mugu Drain	3237	3.34
542	Lower Mugu Drain	3474	3.21

The reaches in the pilot study retained their existing numbering scheme, typically with numbers less than 200. The downstream reaches are numbered as follows: the Lower Simi/Las Posas mainstem reaches have values in the 200s, the Conejo Creek main stem reaches have values in the 400s, the Lower Calleguas Creek main stem reaches have values in the 300s, and the Revolon Slough main stem reaches have values in the 500s. In all three cases, minor tributaries are numbered with successive tens, with the main branch ending in 1 and any side tributaries numbered consecutively in downstream order. Some minor exceptions to these numbering conventions occur where the initial segmentation was enhanced to include additional reaches and this numbering scheme could not be applied without major revisions. Reach numbers are used in HSPF as identifiers, and do not need to be sequential or continuous.

Lake Bard, which has no outflows except for water supply withdrawals, was not included in the model.

Each reach segment was analyzed to compute the tributary areas of the land use categories and the hydraulic characteristics of the reach. The drainage area for each reach was derived by grouping the detailed subwatersheds obtained from Ventura County into the individual reach drainages. Several detention basins and other short reaches in the Arroyo Simi study area are represented without separate direct drainage areas because the local drainage was negligible compared to the upstream area.

The reach hydraulic behavior is specified in an FTABLE (function table), which contains the reach surface area, volume, and discharge as functions of depth, i.e. an expanded rating curve. The method used in developing the FTABLE depends on the model objectives and available data, and can range from: 1) simply using a single cross-section at the outlet, applying Manning's equation to calculate cross-sectional outlet area and depth for a given flow rate, and then assuming the channel to be prismatic along its length and calculating the corresponding surface area and volume; or 2) entering the geometric and hydraulic properties into a more complex hydraulic model, such as HEC-RAS, and allowing the model to develop the relationships.

For the Arroyo Simi study area, FTABLES were generated for reaches using rating tables at gage sites and/or Manning's equation with cross-sections provided in CAD drawings from the County. Cross-sections for unrated and unsurveyed tributaries were estimated as simple trapezoidal channels. FTABLES for reaches downstream of the Arroyo Simi study area were developed using HEC-RAS. The geometric data for the HEC-RAS model were provided in GIS shapefiles from the County. Rating curves were input into the HEC-RAS model at reaches where gages were located. During the computations, the program then uses the water surface elevation from the rating curve instead of computing a value. The channel and floodplain roughness were assigned based on values provided by the County and using photographs from field visits in conjunction with literature values presented in Roughness Characteristics of Natural Channels (Barnes, 1967) and Hydraulic Design Handbook (Mays, 1999). Figure 3.3 shows example FTABLES.

```
FTABLE    306                                         |  FTABLE    422
ROWS COLS   Example Reach with Channel Losses         |  ROWS COLS   Example Detention Basin
  26    5                                             |    26    4
    DEPTH      AREA    VOLUME      DISCH CHAN-LOSS    |      DEPTH      AREA    VOLUME      DISCH
     (ft)   (acres) (acre-ft)      (cfs)     (cfs)    |       (ft)   (acres) (acre-ft)      (cfs)
     0.00      0.00      0.00       0.00      0.00    |       0.00      0.00      0.00       0.00
     0.05    116.80      3.02       1.46      1.94    |      12.00      0.05      0.43       1.00
     0.07    116.81      3.59       2.13      2.11    |      13.00      0.14      1.47      13.45
     0.08    116.84      4.30       3.10      2.31    |      14.00      0.23      2.50      25.90
     0.10    116.86      4.65       4.52      2.40    |      15.00      0.31      3.61      43.85
     0.13    116.89      5.86       6.59      2.70    |      16.00      0.38      4.72      61.80
     0.16    116.94      7.38       9.60      3.02    |      17.00      0.45      5.92      73.45
     0.20    117.01     10.44      14.00      3.60    |      18.00      0.51      7.12      85.10
     0.26    117.09     13.20      20.41      4.05    |      19.00      0.57      8.39      94.60
     0.32    117.19     16.63      29.75      4.54    |      20.00      0.62      9.70     103.30
     0.40    117.31     20.97      43.38      5.10    |      21.00      0.68     11.18     115.10
     0.51    117.42     23.91      63.24      5.44    |      22.00      0.74     12.65     126.90
     0.63    117.64     33.31      92.20      6.43    |      23.00      0.79     14.27     144.30
     0.80    117.88     41.97     134.41      7.21    |      24.00      0.85     15.93     158.50
     1.00    118.17     52.98     195.96      8.10    |      25.00      0.90     17.65     170.60
     1.25    118.54     66.80     285.68      9.10    |      26.00      0.96     19.42     181.50
     1.56    119.01     84.61     416.50     10.24    |      27.00      1.01     21.24     191.60
     1.96    119.55    107.51     607.21     11.55    |      28.00      1.06     23.13     200.90
     2.45    120.09    136.78     885.25     13.02    |      29.00      1.11     25.10     208.90
     3.06    120.76    174.44    1290.60     14.71    |      30.00      1.16     27.13     217.20
     3.83    122.49    222.95    1881.55     16.63    |      31.00      1.21     29.19     225.20
     4.76    130.62    288.35    2743.10     18.91    |      32.00      1.25     31.25     232.80
     5.88    139.36    381.20    3999.15     21.74    |      33.00      1.29     33.32     240.20
     7.24    141.92    504.59    5830.33     25.01    |      34.00      1.33     35.39     247.30
     8.90    144.20    664.81    8500.00     28.71    |      37.00      2.00     40.00     300.00
    11.14    148.07    900.17   12750.00     33.41    |      40.00      3.00     80.00     800.00
 END FTABLE306                                        |   END FTABLE422
```

Figure 3.3 Example FTABLES for a Reach with Channel Losses and a Detention Basin

3.1.2.1 Detention Basins and Ponds

FTABLES for the detention basins were developed using stage-storage and stage-discharge curves provided by the County and listed within the Detention Dams and Debris Manual (Ventura County, 1999). The Detention Dams and Debris Manual also provides the surface area of the full basin; using these data it was then possible to approximate a relationship between stage, volume, and surface area to generate a reasonable stage-surface area curve. The model uses the surface area to determine the volume of precipitation and evaporative loss per interval that occur within the waterbody, usually a small fraction of the overall water balance. Therefore, this approximation was deemed more than sufficient especially since the detention basins will typically be empty.

FTABLES were also developed to represent storage ponds utilized for water re-use and ground water recharge by Ventura County Wastewater Treatment Plant (Moorpark) and Camrosa Water Reclamation Facility. At Moorpark there are approximately 30 ponds that can store treated wastewater. The ponds on average are an acre in size, are approximately 6-8 feet deep, and have percolation rates that average about 5 inch/day (Chip Weaver, Ventura County, Personal communication). Moorpark varies the number of ponds used by season. However, information describing historic pond usage was not readily available. Therefore, an 'aggregate' FTABLE was developed which assumed all 30 ponds would be continually used. This resulted in percolation rates up to 4.4 cfs with an average of 2.8 cfs.

At Camrosa there are two ponds that store tertiary treated wastewater. These ponds have a combined surface area of 15 acres, capacity of approximately 150 ac-ft, and for the time period of 3/1998 to 9/2001 had a mean depth of 5.7 feet with percolation rates estimated at 0.8 cfs (Henry Graumlich, Camrosa Water Dist., Personal communication). Once again an 'aggregate' FTABLE was developed to represent these characteristics. At each interval of the model simulation, precipitation and evaporation fluxes are accounted for in the ponds; if water is available it is discharged to the nearby model reach based on the percolation rates specified in the FTABLE.

3.1.2.2 Channel Losses

Streamflow infiltration occurs in numerous streams within the Calleguas Creek Watershed. Model reaches corresponding to channels where streamflow infiltration was deemed to occur were identified and setup to simulate channel losses. The FTABLE provided the means to simulate these losses by adding an additional outflow gate and discharge column to the FTABLE. The losses are specified as a function of the depth, area, volume, and discharge relationship. Initial values of channel transmission losses were estimated using the U.S. Bureau of Reclamation's Moritz formula and channel hydraulic conductivities reported by the USGS (Hanson et al, 2003). The formula is usually expressed as follows:

$$O = K\,(Q/V)^{0.5}\,L$$

where:
- O = channel loss (L^3/T)
- K = hydraulic conductivity (L/T)
- Q = discharge (L^3/T)
- V = mean flow velocity (L/T)
- L = channel reach length (L)

There is significant variation in the literature for reported hydraulic conductivities for a given material as well as the spatial variation of material within a given reach. Thus, in the study performed by the USGS the hydraulic conductivities were adjusted through calibration while maintaining reasonable values and overall transmission losses. The same approach was adopted in this application. The two example FTABLES in Figure 3.3 represent a channel with losses and a detention basin.

3.2 LAND USE

Land use affects the hydrologic response of a watershed by influencing infiltration, surface runoff, and water losses from evaporation or transpiration by vegetation. The movement of water through the system, and subsequent erosion and chemical transport, are all affected significantly by the vegetation, (*i.e*., crops, pasture, or open) and associated characteristics.

The Calleguas Creek Watershed is a mix of urban and agricultural lowlands and upland open areas, with the latter comprising approximately 44% of the total area. Agriculture covers 25% of the watershed, concentrated mostly in the western end in the Oxnard Plain. The urban areas, including Simi Valley, Moorpark, Thousand Oaks, and Camarillo, are comprised of low-density residential (15%) and commercial/industrial areas (5%), with smaller areas of public facilities (4%) and medium- (4%) and high-density (2%) residential zones.

Table 3.2 below shows the acreages of each land use. Land use data were derived from a GIS coverage provided by the County from a survey in 1997. The agricultural land was represented by one category and all agricultural land is irrigated in some manner (refer to Section 2.4.2). The non-agricultural land was aggregated into the same categories as were used in the Arroyo Simi pilot study: Open, Commercial/Industrial, and High-, Medium-, and Low-density Residential. Table 3.3 presents the resulting aggregated land use distribution by the five major subbasins within the watershed. The area totals in Table 3.2 are more than those in Table 3.3 because the Unclassified area does not drain to the outlet, the Water and Floodways are included as water surfaces, and the Lake Bard drainage is not part of the contributing areas in Table 3.3.

Table 3.2 - Land Use in the Calleguas Creek Watershed

Category	Area (ac)	Percent
Agriculture	54,767	25.12
Open Space and Recreation	94,989	43.58
Total Rural	149,756	68.70
Commercial	3,779	1.73
Industrial	5,443	2.50
Transportation	1,529	0.70
Public Facilities	9,409	4.32
Residential, <1 du/ac	2,580	1.18
Residential, 1-5 du/ac	29,353	13.47
Residential, 5-12 du/ac	8,844	4.06
Residential, >12 du/ac	3,565	1.64
Total Urban	64503	29.59
Unclassified	3,963	1.69
Water and Floodways	32	0.01
Total	217,984	100.00

The aggregated land use coverage was then intersected with the final meteorologic and topographic model segmentation to determine the area of each modeled land category within each model segment. Then, this resulting coverage was intersected with reach drainage areas to define the model land use categories that drain to each model reach.

Table 3.3 - Aggregated Land Use in the Calleguas Creek Watershed by Major Basin

	OPEN		LO DEN RES		MID DEN RES		HI DEN RES		COMM		AG		EIA		Total
Major Basin	**acres**	**%**	**acres**	**%**	**acres**	**%**	**acres**	**%**	**acres**	**%**	**acres**	**%**	**acres**	**%**	**acres**
Upper Arroyo Simi	35,186	70%	7,425	15%	2,344	5%	485	1%	1,656	3%	-	0%	3,374	7%	50,470
Lower Simi/Las Posas	29,400	55%	4,947	9%	762	1%	52	0%	1,067	2%	14,756	28%	2,334	4%	53,318
Conejo Creek	22,167	45%	14,495	29%	1,181	2%	1,564	3%	1,974	4%	3,093	6%	4,801	10%	49,276
Lower Calleguas Creek	5,512	31%	472	3%	863	5%	43	0%	1,229	7%	8,222	46%	1,463	8%	17,804
Revolon Slough	5,090	12%	2,147	5%	1,484	3%	119	0%	2,986	7%	27,638	65%	2,970	7%	42,433
Grand Total	97,355	46%	29,487	14%	6,634	3%	2,264	1%	8,912	4%	53,709	25%	14,941	7%	213,302

The effective impervious area (EIA) land use category, which represents impervious areas whose drainage is directly connected to the stream, rather than routed to adjacent pervious areas where it may infiltrate into the soil, was derived by assigning EIA fractions to a detailed set of 'urban' land use categories. The fraction of each urban category designated as effectively impervious was derived from values provided by the County, with slight modifications based on literature values for studies in similar areas, and visual analysis of aerial photos of the area. The total effective impervious area of each model segment is then represented as a single entity within the model. The final fractions assigned are shown in Table 3.4.

Table 3.4 Ventura County Land Use Category EIA

Model Land Use	Major VC Category	Minor VC Category	EIA
Open	Open Space & Recreation	All	0%
	Unclassified	All	0%
Low-density Residential	Residential: <1 unit/ac	Residential Estate	5%
	Residential: 1-4.99 units/ac	Rural 1+ acre	5%
		Very Low Density 0-2 d.u. per acre	5%
		Very Low 0-2 d.u. per acre 20000 sq ft min lot size	5%
		Low Density 2-4.5 d.u. per acre	10%
		Medium 3.26-3.7 d.u. per acre bonus range 3.8-5.0 d.u. per acre	10%
Medium-density Residential	Residential: 5-11.99 units/ac	All	25%
High-density Residential	Residential: >12 units/ac	High 10.1-15 d.u. per acre bonus range 15.1-18.75 d.u. per acre	35%
		High Node 10.1-15 d.u. per acre bonus range 15.1-18.75	35%
		Mobile Home 5.1-8.0 d.u. per acre bonus range 8.1-12.0 d.u. per acre	35%
		Very High 18.76-25.0 d.u. per acre bonus range 25.1-50.0 d.u. per acre	40%
		Very High Node 18.76-25.0 d.u. per acre bonus range 25.1-50.0	40%
Commercial & Industrial	Public Facilities & Institutions	Brandeis-Bardin Institute	10%
		Community Activity Facility Overlay	25%
		Existing Community (per area plan or community map)	25%
		Schools	35%
		Fire Station	35%
		Hospital	35%
		Law Enforcement Office	40%
		Civic Center	50%
		Library	50%
	Industrial	All	70%
	Commercial	All	50%
	Transportation & Utilities	All	70%

SECTION 4.0

CALIBRATION AND VALIDATION

4.1 CALIBRATION/VALIDATION PROCEDURES AND COMPARISONS

As in the Arroyo Simi pilot study, calibration of the Calleguas watershed was a cyclical process of making parameter changes, running the model and producing comparisons of simulated and observed values, and interpreting the results. The procedures have been well established over the past 20 years as described in the HSPF Application Guide (Donigian et al., 1984) and recently summarized by Donigian (2002). The hydrology calibration process is greatly facilitated with the use of the HSPEXP, an expert system for hydrologic calibration, specifically designed for use with HSPF, developed under contract for the USGS (Lumb, McCammon, and Kittle, 1994). This package gives calibration advice, such as which model parameters to adjust and/or input to check, based on predetermined rules, and allows the user to interactively modify the HSPF Users Control Input (UCI) files, make model runs, examine statistics, and generate a variety of comparison plots. HSPEXP still has some limitations, such as 'how much' to change a parameter and relative differences among land uses, which requires professional modeling experience and judgment. The post-processing capabilities of GenScn (e.g., listings, plots, statistics, etc.) (Kittle et al., 1998) were also used extensively during the calibration/validation effort; GenScn is the recommended model user interface and framework for use of the final model by VCWPD and others.

Calibration of HSPF to represent the hydrology of the Calleguas Creek Watershed is an iterative trial-and-error process. Simulated results are compared with recorded data for the entire calibration period, including both wet and dry conditions, to see how well the simulation represents the hydrologic response observed under a range of climatic conditions. In the mediterranean-type climate of central and southern California, with pronounced wet and dry seasons, it is equally important to assess model behavior under both conditions.

By iteratively adjusting specific calibration parameter values, within accepted and physically realistic ranges, the simulation results are changed until an acceptable comparison of simulation and recorded data is achieved.

The standard HSPF hydrologic calibration is divided into four phases:

- **Establish an annual water balance.** This consists of comparing the total annual simulated and observed flow (in inches), and is governed primarily by the input rainfall and evaporation and the parameters LZSN (lower zone nominal storage), LZETP (lower zone ET parameter), and INFILT (infiltration index). Other important factors can include external fluxes such as diversions, irrigation, groundwater pumping, and deep groundwater recharge losses, all of which were considered in the Calleguas Creek Watershed.

- **Adjust low flow/high flow distribution.** This is generally done by adjusting the groundwater or baseflow, because it is the easiest to identify in low flow periods. Comparisons of mean daily flow are utilized, and the primary parameters involved are INFILT, AGWRC (groundwater recession), and BASETP (baseflow ET index). For the Calleguas watershed, irrigation applications and practices have significant impacts on the low flow simulation, as do the major point sources, which contribute most or all of summer flows in some reaches.

- **Adjust stormflow/hydrograph shape.** The stormflow, which is compared in the form of short time step (1 hour) hydrographs, is largely composed of surface runoff and interflow. Adjustments are made with the UZSN (upper zone storage), INTFW (interflow parameter), IRC (interflow recession), and the overland flow parameters (LSUR, NSUR, and SLSUR). INFILT also can be used for minor adjustments.

- **Make seasonal adjustments.** Differences in the simulated and observed total flow over summer and winter are compared to see if runoff needs to be shifted from one season to another. These adjustments are generally accomplished by using seasonal (monthly variable) values for the parameters CEPSC (vegetal interception), LZETP, and UZSN. Adjustments to KVARY (variable groundwater recession) and BASETP are also used.

The procedures and parameter adjustments involved in these phases are more completely described by Donigian (2002), and the HSPF hydrologic calibration expert system (HSPEXP) (Lumb et al., 1994).

The same model-data comparisons will be performed for both the calibration and validation periods. The specific comparisons of simulated and observed values include:

- Annual and monthly runoff volumes (inches)
- Daily time series of flow (cfs)
- Flow frequency (flow duration) curves (cfs)
- Storm event hydrographs, e.g. hourly values (cfs)

In addition to the above comparisons, the water balance components (input and simulated) are reviewed. This effort involves displaying model results for individual land uses for the following water balance components:

- Precipitation
- Total Runoff (sum of following components)
    - Overland flow
    - Interflow
    - Baseflow
- Potential Evapotranspiration
- Total Actual Evapotranspiration (ET) (sum of following components)
    - Interception ET
    - Upper zone ET
    - Lower zone ET
    - Baseflow ET
    - Active groundwater ET
- Deep Groundwater Recharge/Losses

Although observed values are not available for each of the water balance components listed above, the average annual values must be consistent with expected values for the region, as impacted by the individual land use categories. This is a separate consistency, or reality, check with data independent of the modeling (except for precipitation) to insure that land use categories and the overall water balance reflect local conditions.

Table 4.1 lists general calibration/validation tolerances or targets that have been provided to model users as part of HSPF training workshops over the past 10 years (e.g. Donigian, 2000). The values in the table attempt to provide some general guidance, in terms of the percent mean errors or differences between simulated and observed values, so that users can gage what level of agreement or accuracy (i.e. very good, good, fair) may be expected from the model application.

The caveats at the bottom of the table indicate that the tolerance ranges should be applied to **mean** values, and that individual events or observations may show larger differences, and still be acceptable. In addition, the level of agreement to be expected depends on many site and application-specific conditions, including the data quality, purpose of the study, available resources, and available alternative assessment procedures that could meet the study objectives.

Table 4.1 General Calibration/Validation Targets or Tolerances for HSPF Applications (Donigian, 2000)

	% Difference Between Simulated and Recorded Values		
	Very Good	Good	Fair
Hydrology/Flow	< 10	10 - 15	15 - 25
Sediment	< 20	20 - 30	30 - 45
Water Temperature	< 7	8 - 12	13 - 18
Water Quality/Nutrients	< 15	15 - 25	25 - 35
Pesticides/Toxics	< 20	20 - 30	30 - 40

CAVEATS: Relevant to monthly and annual values; storm peaks may differ more
Quality and detail of input and calibration data
Purpose of model application
Availability of alternative assessment procedures
Resource availability (i.e. time, money, personnel)

Figure 4.1 provides value ranges for both correlation coefficients (R) and coefficient of determination (R^2) for assessing model performance for both daily and monthly flows. The figure shows the range of values that may be appropriate for judging how well the model is performing based on the daily and monthly simulation results. As shown, the ranges for daily values are lower to reflect the difficulties in exactly duplicating the timing of flows, given the uncertainties in the timing of model inputs, mainly precipitation, and for the Calleguas Creek watershed this would include irrigation applications.

Given the uncertain state-of-the-art in model performance criteria, the inherent errors in input and observed data, and the approximate nature of model formulations, **absolute** criteria for watershed model acceptance or rejection are not generally considered appropriate by most modeling professionals.

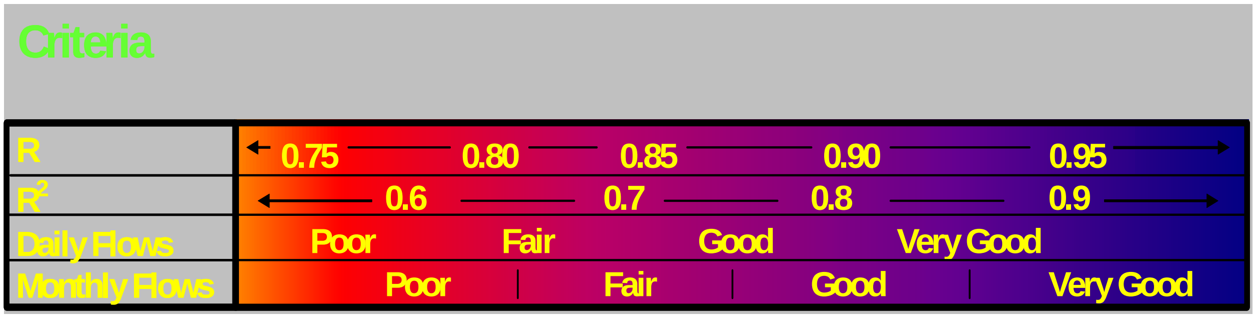


Figure 4.1 R and R^2 Value Ranges for Model Performance

And yet, most decision makers want definitive answers to the questions – "How accurate is the model?", "Is the model good enough for this evaluation?". Consequently, for the Calleguas Creek watershed modeling effort, we propose that the targets and tolerance ranges for **'Daily'** flows should correspond to a **'Fair to Good'** agreement, and those for **'Monthly'** flows should correspond to **'Good'** agreement for both calibration and validation comparisons. For the Calleguas Creek watershed, the level of expected agreement is tempered by the complexities of the irrigation diversions and water management activities, the quality of the available precipitation and flow data, and the available information to help characterize the watershed and quantify the urban and agricultural impacts on water-related activities. These tolerances would be applied to comparisons of simulated and observed mean flows, annual runoff volumes, mean monthly and seasonal runoff volumes, and daily flow duration curves. Larger deviations would be expected for individual storm events and flood peaks in both space and time. The values shown above have been derived primarily from HSPF experience and selected past efforts on model performance criteria; however, they do reflect common tolerances accepted by many modeling professionals.

4.2 CALIBRATION AND VALIDATION TIME PERIODS

The principal time series data needed for hydrologic simulation (rainfall, evaporation, and observed flow) were developed to support model runs for the entire Calleguas Creek Watershed for WYs 1988 through 2002, covering the time span from October 1987 through September 2002. The only major limitation to a longer time period of model runs, either for additional calibration/validation, or for running alternative watershed scenarios, is the timespan for the hourly rainfall datasets that were digitized for this effort by VCWPD staff. In addition to the two hourly rainfall stations used in the Arroyo Simi pilot study, the records for six stations were digitized for the WY88-02 period to cover the remaining portions of the watershed (as described in Section 2.1).

Selecting the calibration and validation time periods, within the overall modeling timespan, involves other factors, including land use coverage, POTW discharge data, and construction and installation of the detention basins within the watershed. The vast majority of the detention basins that are being modeled were built prior to 1980, so no impact is expect on the selected time period. The land use coverage used in the model segmentation is dated 1997, and we know of no older coverages that are available. Since the HSPF model currently requires the use of a single set of land use data for the entire span of calibration, the model representation of land use conditions will be most accurate for a time period within a few years of 1997. The majority of the POTW discharge data is much improved (i.e. daily versus monthly records) for the years since about 1994 and 1995. The usual practice in modeling is to use the best and most representative data and information on the watershed for the calibration period, in order to minimize the uncertainties of 'estimated' model inputs and watershed conditions. So all these factors point to designating the most recent data for the calibration, with the earlier data used for validation.

The Arroyo Simi pilot study (AQUA TERRA Consultants, 2003) calibration period covered water years 1988-1995, based on similar considerations, with a validation period of 1996-2000. However, the validation period presented problems because four of the five years were dry, and 1998 was an extremely wet one with record rainfall, where major storms caused monitoring problems with instrumentation (i.e. washed out gage stations) at a number of sites. The final report for the pilot study recommended revisiting the calibration and validation periods, and considering calibrating on the most recent period and/or expanding the calibration period to additional years.

Following these recommendations, for this larger study of the entire Calleguas Watershed, the following calibration and validation time periods were selected:

Calibration: WY 1994 – WY 2002 (October 1993 – September 2002)
Validation: WY 1988 – WY 1993 (October 1987 – September 1993)

The addition of water years 2001 and 2002 to the datasets in this project allowed us to extend the calibration to nine years, encompassing both extreme wet (1998) and dry (2002) years. It is rare when a calibration period can include such extremes, and it provides a rigorous test of the model to be able to represent both conditions. The 6-year validation period includes a reasonable balance of dry (1989, 1990), near-normal (1988, 1991) and wet (1992, 1993) years, but overall tends to be a dryer period than the calibration.

4.3 CALIBRATION AND VALIDATION RESULTS

As noted above, model calibration was performed on nine WYs from October 1993 through September 2002 at each of the following gage sites:

- Arroyo Simi at Royal Ave (#802)
- Arroyo Simi at Madera Road Bridge (#803)
- Arroyo Las Posas at Hitch Blvd (#841)
- Callegaus Creek at/above Highway 101 (#806/806a)
- Conejo Creek above Highway 101 (#800)
- Calleguas Creek at CSUCI (California State University Channel Islands) (#805)
- Beardsley Wash at Central Ave (#780)
- Revolon Slough at Laguna Road (#776)

Validation was performed for six water years from October 1987 through September 1993, at each of these same sites, except that the Arroyo Las Posas gage only had data for three years (WYs 1991-93), and no data were available for the Beardsley gage.

This section presents and discusses the qualitative and quantitative comparisons (discussed above in Section 4.1) of model results with the observed data, performed for both periods and all sites. To streamline the results presentation, we have included only selected graphical results at a few gages sites, to accompany this discussion, while Appendices A through H provide complete sets of graphical displays for each of the above gage sites, for both calibration and validation; readers are referred to these appendices for a closer examination of specific displays of model results.

In reviewing these model results, it is important to keep in mind the following general issues:

1. The Arroyo Simi pilot application of HSPF provided a good start for this modeling effort on the Calleguas Creek Watershed. A number of data issues identified in that effort, such as incorrect hourly rainfall distributions and observation times, and selected storm event hydrographs and timing, were resolved in this work and provided important corrections to the model input and calibration. Also, the model parameters, land use categories, and impervious area (EIA) fractions developed in the Arroyo Simi application did not require major adjustments in this effort, and provided the initial values for the remaining portions of the Calleguas Watershed.

2. Like the Arroyo Simi, the overall water balance for the Calleguas Creek Watershed is controlled and comprised of the input precipitation, imported water, and the runoff discharged from the watershed; the difference between these input and output quantities represents all other losses, which are mostly evapotranspiration and any deep groundwater or subsurface losses (e.g. channel losses and gage underflow). For the Calleguas Creek Watershed, the average annual precipitation is about 15 inches, the discharge at CSUCI is about 3 inches. One estimate of imported water (both surface and deep groundwater) is about 100,000 acre feet per year, or about 6 inches over the watershed (Hajas, 2003). Therefore, all other losses must make up the remaining 18 inches. The model input and simulations must approximate these quantities in order to accurately model the hydrologic regime of the watershed.

3. The major differences between the Arroyo Simi and the lower Calleguas watersheds, and the respective models, include the extent of imported water, the impact of agriculture and associated groundwater pumping and irrigation, POTW discharges, and channel losses to groundwater. Although the Arroyo Simi model included the application of imported water supply into the watershed by the City of Simi Valley, as irrigation applications and return flow from urban lawn/landscape watering, the western half of the Calleguas watershed is a major agricultural region using both imported and local groundwater for irrigation. The relatively flat flow-duration curves for the Arroyo Simi at Madera, Las Posas at Hitch, Conejo Creek, and Revolon Slough (above 10-20 % exceedance) demonstrate the classic evidence of irrigation impacts (both agriculture and urban) in a semi-arid environment, along with POTW discharges. This produces a relatively constant baseflow in the range of 5 to 15 cfs which is at least partially originating from this return flow. Thus, the irrigation impacts and POTW contributions are critical to developing a valid representation of the watershed.

4. The well-drained soils (silty clay loams, sandy loams, etc) in the hills, and the sandy channel bottoms of the tributaries and natural portions of the Arroyo Simi, Las Posas, and Calleguas mainstem, all contribute to some degree of channel and deep groundwater losses which are not measured at the downstream gages. The dynamic and ephemeral nature of the streams above Royal and the Calleguas Creek above Highway 101, as shown by the sharp drop in the flow-duration curve, indicates that these losses do occur and need to be considered in the water balance and the channel routing.

4.3.1 Annual and Simulation Period Runoff Volumes

Table 4.2 shows the simulation period runoff statistics computed by the HSPEXP, while Table 4.3 shows the daily and monthly percent mean differences, along with correlation statistics, for each gage site for both the calibration (top half of table) and validation results (bottom half). In Table 4.2, all the observed and simulated values are in inches (over the entire watershed), except for the 'Average storm peak' which are in cfs. The specific values are as follows:

- The Total Flow represents the average annual runoff over the simulation period.
- The Total of 10% and 25% highest and 50% lowest, within the table, represent the corresponding exceedances from the flow duration curve, converted to inches.
- The storm statistics are derived from 15-20 selected events during each simulation period, including the total storm volume (in inches) and the average peaks of the selected storms.
- The Winter flow represents the average annual volume of flow (in inches) occurring during the winter months of December through March.

Our primary observations and conclusions from the results in Table 4.2 are as follows:

a. For the calibration, the percent differences between observed and simulated values are primarily less than 10%, and almost exclusively less than 15%, with the exception of the Beardsley gage. Specifically, at five of the 8 flow gages, the calibration differences are about 10% or less, corresponding to a Very Good calibration, two are less than 15% for a Good calibration, and the last is a Fair calibration. This overall level of agreement corresponds to a Good to Very Good calibration at all sites, and a Fair calibration at Beardsley, based on the criteria noted in Section 4.1.

b. For the validation, the differences are larger but still within the range of a Fair to Good validation. The Madera and CSUCI gages are less than 10% difference (except for 1 low flow difference) for a Very Good validation, the Royal gage is less than about 15% for a Good rating, and three of the remaining are within 20% for a Fair rating.

c. The Conejo gage is an exception, for the validation. Although the total flow difference is about -9%, the remaining differences are much higher, up to -42%. This result is entirely unexpected, especially since the calibration results for the Conejo have been consistently Very Good (i.e. within 5% or less) for most all calibration runs. This will be discussed further below.

Tables 4.4 through 4.7 show tabulations of the annual simulated and observed runoff volumes, along with precipitation, residuals (simulated – observed) and percent differences for **each year** of the calibration and validation for all gages. The averages are also shown for the entire calibration and validation periods, along with the Full Period values for the entire 15 year simulation time period. As expected, the year to year differences are larger than for the overall period, with percent differences usually in the range of ±25%. The larger percent differences are often associated with extremely dry years, with very small residuals but large percent values, such as 1999 at the Calleguas Creek Highway 101 gage with a residual of +0.17 inches but 170% because the observed runoff was only 0.10 inches (Table 4.5). Another

Table 4.2 HSPEXP Calibration and Validation Statistics

CALIBRATION												
	Royal			Madera			Arr Posas / Hitch			Calleguas Cr @ 101		
Avg. Annual Statistics	Obs	Sim	% Δ	Obs	Sim	% Δ	Obs	Sim	% Δ	Obs	Sim	% Δ
Total Flow - in	2.18	2.07	-4.7	3.23	3.25	0.5	3.68	3.92	6.4	1.78	1.84	3.5
Total of 10% highest flows - in	2.18	2.06	-5.1	2.07	2.11	1.9	2.07	2.33	12.4	1.74	1.83	4.7
Total of 25% highest flows - in	2.18	2.07	-4.8	2.36	2.43	2.6	2.39	2.71	13.4	1.78	1.84	3.3
Total of 50% lowest flows - in	0.00	0.00	n/a	0.51	0.49	-3.2	0.84	0.80	-4.9	0.00	0.00	n/a
Storm Statistics												
Total annual storm flow - in	1.53	1.52	-0.3	1.21	1.35	11.6	1.36	1.47	8.2	1.20	1.26	5.5
Average storm peak - cfs	430	423	-1.8	726	789	8.7	1431	1360	-5.0	1902	1712	-10.0
Seasonal Statistics												
Winter flow (Dec-Mar) - in	2.02	1.92	-5.2	2.22	2.22	-0.1	2.38	2.59	8.7	1.58	1.70	7.5
	Arr. Conejo			Calleguas Cr @ CSUCI			Beardsley			Revolon Slough		
Avg. Annual Statistics	Obs	Sim	% Δ	Obs	Sim	% Δ	Obs	Sim	% Δ	Obs	Sim	% Δ
Total Flow - in	7.64	7.83	2.6	3.18	3.39	6.6	2.29	2.42	5.9	6.64	6.46	-2.7
Total of 10% highest flows - in	3.76	3.89	3.6	2.07	2.35	13.9	1.67	1.95	16.7	3.92	3.95	1.0
Total of 25% highest flows - in	4.72	4.81	1.9	2.38	2.62	10.3	1.83	2.09	14.6	4.62	4.57	-1.0
Total of 50% lowest flows - in	1.78	1.87	4.5	0.45	0.46	1.8	0.27	0.20	-26.5	1.16	1.13	-2.8
Storm Statistics												
Total annual storm flow - in	1.98	2.09	5.7	1.36	1.48	9.4	1.20	1.45	21.0	2.43	2.44	0.1
Average storm peak - cfs	1001	981	-2.0	2998	2889	-3.6	274	261	-4.9	1031	951	-7.7
Seasonal Statistics												
Winter flow (Dec-Mar) - in	4.55	4.64	1.8	2.31	2.47	7.3	1.69	2.05	21.6	4.35	4.33	-0.5

VALIDATION												
	Royal			Madera			Arr Posas / Hitch			Calleguas Cr @ 101		
Avg. Annual Statistics	Obs	Sim	% Δ	Obs	Sim	% Δ	Obs	Sim	% Δ	Obs	Sim	% Δ
Total Flow - in	2.70	2.31	-14.3	3.06	3.28	7.3	4.38	5.12	17.0	1.35	1.60	18.5
Total of 10% highest flows - in	2.70	2.31	-14.5	2.26	2.25	-0.1	3.04	3.43	12.9	1.35	1.59	17.7
Total of 25% highest flows - in	2.70	2.31	-14.4	2.47	2.59	4.8	3.35	3.94	17.7	1.35	1.60	18.1
Total of 50% lowest flows - in	0.00	0.00	n/a	0.35	0.38	9.2	0.63	0.68	6.7	0.00	0.00	n/a
Storm Statistics												
Total annual storm flow - in	1.69	1.54	-8.7	1.24	1.31	5.4	2.17	2.36	8.7	0.93	1.01	8.8
Average storm peak - cfs	387	365	-5.8	627	632	0.9	1103	1002	-9.2	1287	1140	-11.5
Seasonal Statistics												
Winter flow (Dec-Mar) - in	2.59	2.20	-15.2	2.34	2.37	1.3	3.39	3.89	14.7	1.31	1.52	16.5
	Arr. Conejo			Calleguas Cr @ CSUCI			Revolon Slough					
Avg. Annual Statistics	Obs	Sim	% Δ	Obs	Sim	% Δ	Obs	Sim	% Δ			
Total Flow - in	7.97	7.26	-8.8	2.86	3.07	7.6	4.94	4.63	-6.4			
Total of 10% highest flows - in	4.76	3.70	-22.3	1.94	2.11	8.6	2.93	2.77	-5.3			
Total of 25% highest flows - in	5.58	4.50	-19.5	2.21	2.33	5.5	3.49	3.38	-3.1			
Total of 50% lowest flows - in	1.42	1.74	23.1	0.35	0.46	31.7	0.80	0.64	-19.4			
Storm Statistics												
Total annual storm flow - in	2.68	1.81	-32.3	1.20	1.20	0.2	1.70	1.57	-7.6			
Average storm peak - cfs	1210	700	-42.2	2051	1911	-6.8	583	506	-13.2			
Seasonal Statistics												
Winter flow (Dec-Mar) - in	5.49	4.47	-18.5	2.16	2.27	4.9	3.37	2.95	-12.5			

Table 4.3 Daily and Monthly Statistics for Calibration and Validation

	Royal		Madera		Arr Posas / Hitch		Calleguas Cr @ 101		Arr. Conejo		Calleguas Cr @ CSUCI		Beardsley[1]		Revolon Slough	
Calibration	daily	monthly	daily	monthly	daily	monthly	daily	monthly	daily	monthly	daily	monthly	daily	monthly	daily	monthly
% Mean Difference	-4.74	-3.88	0.47	0.93	6.38	6.56	3.52	3.48	2.55	2.72	6.64	7.01	5.04	5.36	-2.72	-2.75
R	0.92	0.98	0.96	0.98	0.95	0.99	0.95	0.99	0.96	0.98	0.96	0.99	0.85	0.97	0.98	0.99
R^2	0.84	0.95	0.92	0.97	0.90	0.98	0.91	0.98	0.92	0.96	0.92	0.98	0.73	0.95	0.95	0.99
Model Fit Efficiency	0.83	0.93	0.88	0.90	0.89	0.93	0.90	0.97	0.92	0.94	0.91	0.90	0.60	0.65	0.95	0.98
Validation																
% Mean Difference	-14.33	-14.25	7.26	7.22	16.99	16.89	18.45	18.08	-8.81	-8.93	7.54	7.72			-6.37	-6.61
R	0.97	0.99	0.98	0.99	0.96	0.99	0.93	0.99	0.96	0.99	0.97	0.99			0.95	0.97
R^2	0.95	0.99	0.95	0.99	0.93	0.97	0.86	0.97	0.93	0.99	0.94	0.98			0.90	0.94
Model Fit Efficiency	0.94	0.97	0.95	0.98	0.93	0.95	0.86	0.96	0.82	0.92	0.94	0.97			0.89	0.93

1 – No data available for model validation at this site

example is the Royal gage in 2002, with a residual of 0.05 inches but that corresponds to 42% due to the observed runoff value of only 0.12 inches (Table 4.4).

At the opposite extreme, large differences are shown for the 1998 year with its extreme rainfall totals, representing the highest rainfall total for the entire period of record for many of the gages. The storms of February 1998 also washed out monitoring equipment at a number of gage sites so records are estimated and/or reconstructed from other information. These estimated values clearly have a higher degree of uncertainty. Overall the year to year simulation is considered Fair to Good at six of the eight calibration sites; the remaining two sites are Calleguas at Highway 101 and Beardsley which are likely affected more by dynamic channel losses and local groundwater interactions than the other sites.

4.3.2 Daily and Monthly Comparisons

Table 4.3 shows the daily and monthly percent mean differences, along with correlation statistics, for each gage site. The percent mean difference values are essentially the same as the corresponding values for the Total Flow difference from Table 4.3; these are simply calculated with daily and monthly values respectively. For the calibration, the differences are all less than 7% indicating a Very Good calibration for these comparisons. For the validation, the differences are somewhat larger, with four of the sites showing differences less than 10% still indicating a Very Good validation, one site less than 15% representing a Good validation, and two sites less than 20% corresponding to a Fair validation. Overall the validation is consistent with the calibration.

The correlation coefficient (R) is a measure of the linear dependence between two random variables, i.e. simulated and observed daily or monthly flow, and varies between $\pm$ 1. The correlation coefficient will be positive if larger than mean values are likely to be paired with larger than mean values (and smaller with smaller) when comparing the two timeseries. However, if larger than mean values appear with smaller than mean values (and vice versa), the correlation coefficient will be negative, indicating an inverse relationship. A high correlation coefficient indicates the stochastic dependence is high and the variables have a joint linear tendency. The correlation coefficients for the calibration (Table 4.3) at **all sites** are greater than **0.92 for daily** values and **0.97 for monthly** values, with the only exception being the daily value of 0.85 at Beardsley. Based on the criteria in Figure 4.1, this corresponds to the high end **Table**

4.4 Annual Simulated and Observed Volumes for Calibration and Validation @ Royal and Madera

ROYAL					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1994	10.07	0.43	0.44	-0.01	-2.00%
1995	28.36	4.86	5.73	-0.87	-15.10%
1996	11.05	0.70	0.68	0.02	2.90%
1997	13.62	0.76	0.87	-0.11	-12.40%
1998	37.79	8.59	7.95	0.63	7.90%
1999	9.01	0.37	0.51	-0.14	-27.50%
2000	12.24	0.84	0.80	0.04	5.60%
2001	18.35	1.92	2.47	-0.55	-22.30%
2002	5.03	0.17	0.12	0.05	42.10%
Average	16.17	2.07	2.17	-0.10	-4.70%
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1988	18.31	1.02	1.05	-0.03	-2.40%
1989	8.23	0.36	0.33	0.04	11.00%
1990	5.65	0.24	0.20	0.04	17.30%
1991	14.13	1.30	1.50	-0.20	-13.30%
1992	28.74	5.46	6.05	-0.58	-9.70%
1993	29.02	5.47	7.04	-1.57	-22.30%
Average	17.35	2.31	2.69	-0.38	-14.30%
Full Time Period					
Average	16.64	2.17	2.38	-0.21	-8.80%
MADERA					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1994	10.30	1.49	1.86	-0.36	-19.50%
1995	27.11	6.00	5.48	0.53	9.60%
1996	12.56	2.01	2.15	-0.14	-6.60%
1997	14.13	2.11	2.10	0.01	0.40%
1998	36.89	9.85	8.14	1.71	21.00%
1999	9.56	1.53	2.09	-0.55	-26.40%
2000	12.18	1.89	2.23	-0.34	-15.40%
2001	16.61	3.18	3.51	-0.33	-9.30%
2002	5.68	1.16	1.54	-0.38	-24.80%
Average	16.11	3.25	3.23	0.02	0.50%
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1988	16.59	2.09	2.24	-0.15	-6.60%
1989	8.94	1.21	1.25	-0.04	-3.30%
1990	6.59	1.02	1.22	-0.20	-16.70%
1991	13.95	2.18	2.02	0.16	7.80%
1992	26.27	6.12	5.32	0.80	15.10%
1993	28.20	7.05	6.28	0.77	12.30%
Average	16.76	3.28	3.05	0.22	7.30%
Full Time Period					
Average	16.37	3.28	3.16	0.12	3.60%

Table 4.5 Annual Simulated and Observed Volumes for Calibration and Validation @ Arroyo Los Posas / Hitch and Calleguas Cr @ 101

ARROYO POSAS/HITCH					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1994	11.03	2.00	1.89	0.11	5.70%
1995	25.84	6.06	5.64	0.42	7.50%
1996	14.13	2.51	Missing Data	--	--
1997	15.07	2.72	2.51	0.21	8.50%
1998	35.79	10.44	7.69	2.75	35.80%
1999	8.84	2.04	2.57	-0.53	-20.60%
2000	13.22	2.54	2.92	-0.38	-12.90%
2001	17.46	3.81	4.24	-0.43	-10.20%
2002	6.06	1.73	2.01	-0.28	-13.90%
Average	16.38	3.76	3.68	0.08	2.10%
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1991	11.96	2.59	2.65	-0.06	-2.40%
1992	22.04	5.80	4.98	0.82	16.40%
1993	26.83	6.98	5.40	1.57	29.10%
Average	20.27	5.12	4.34	0.78	18.00%
Full Time Period					
Average	17.36	4.12	3.84	0.27	7.10%
CALLEGUAS CR @ 101					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1994	11.30	0.37	0.35	0.02	6.30%
1995	28.48	4.08	2.95	1.13	38.10%
1996	13.20	0.71	0.77	-0.06	-8.00%
1997	14.75	0.86	0.69	0.17	24.50%
1998	37.58	7.73	8.48	-0.75	-8.80%
1999	9.67	0.28	0.10	0.17	169.90%
2000	13.11	0.70	0.55	0.15	26.40%
2001	17.87	1.70	2.00	-0.30	-15.10%
2002	6.29	0.18	0.13	0.04	31.40%
Average	16.92	1.84	1.78	0.06	3.50%
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1988	14.05	0.69	0.67	0.02	3.50%
1989	10.21	0.30	0.15	0.15	101.20%
1990	5.90	0.20	0.12	0.08	70.90%
1991	12.91	0.92	0.92	0.00	0.00%
1992	22.12	3.37	3.04	0.33	10.80%
1993	26.30	4.13	3.22	0.92	28.60%
Average	15.25	1.60	1.35	0.25	18.50%
Full Time Period					
Average	16.25	1.75	1.61	0.14	8.80%

Table 4.6 Annual Simulated and Observed Volumes for Calibration and Validation @ Conejo Creek and Calleguas Cr @ CSUCI

CONEJO					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1994	10.69	4.32	5.16	-0.84	-16.30%
1995	27.28	12.29	12.99	-0.70	-5.40%
1996	12.19	5.36	5.50	-0.13	-2.40%
1997	14.78	6.26	6.35	-0.09	-1.40%
1998	34.62	16.83	16.11	0.73	4.50%
1999	11.16	5.12	5.13	-0.01	-0.20%
2000	14.33	6.24	5.27	0.96	18.30%
2001	16.98	9.18	7.82	1.36	17.40%
2002	5.69	4.87	4.39	0.48	10.90%
Average	16.41	7.83	7.64	0.19	2.60%
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1988	11.84	5.56	5.70	-0.14	-2.40%
1989	10.04	4.92	4.74	0.18	3.80%
1990	5.45	4.26	3.85	0.41	10.60%
1991	11.44	5.82	5.12	0.70	13.70%
1992	22.64	11.01	12.77	-1.76	-13.80%
1993	24.95	12.01	15.58	-3.57	-22.90%
Average	14.39	7.26	7.96	-0.70	-8.80%
Full Time Period					
Average	15.61	7.62	7.76	-0.14	-1.80%
CALLEGUAS CR @ CSUCI					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1994	10.29	1.45	1.47	-0.02	-1.20%
1995	25.72	6.26	6.09	0.18	2.90%
1996	11.14	1.98	1.91	0.07	3.50%
1997	14.47	2.39	2.50	-0.11	-4.40%
1998	37.21	10.23	8.13	2.10	25.90%
1999	8.12	1.55	1.63	-0.08	-5.00%
2000	10.62	2.12	1.91	0.21	11.00%
2001	16.14	3.63	3.71	-0.07	-2.00%
2002	5.87	0.94	1.32	-0.37	-28.20%
Average	15.51	3.39	3.18	0.21	6.60%
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1988	12.93	1.97	2.00	-0.03	-1.50%
1989	9.58	1.55	1.53	0.01	0.90%
1990	4.81	1.28	0.98	0.30	30.20%
1991	11.48	2.19	1.98	0.21	10.70%
1992	21.73	5.36	4.67	0.69	14.70%
1993	23.65	6.09	5.96	0.13	2.20%
Average	14.03	3.07	2.85	0.22	7.60%
Full Time Period					
Average	14.92	3.27	3.05	0.22	7.20%

Table 4.7 Annual Simulated and Observed Volumes for Calibration and Validation @ Beardsley and Revolon Slough

BEARDSLY					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1994	10.29	0.37	Missing Data	--	--
1995	25.72	5.44	2.81	2.63	93.60%
1996	11.14	0.80	1.22	-0.42	-34.70%
1997	14.47	1.04	1.58	-0.55	-34.60%
1998	37.21	8.22	6.52	1.71	26.20%
1999	8.12	0.49	1.00	-0.51	-50.90%
2000	10.62	0.89	1.56	-0.67	-42.80%
2001	16.14	2.09	2.77	-0.68	-24.50%
2002	5.87	0.39	0.83	-0.44	-53.00%
Average	15.51	2.19	2.29	-0.09	-4.00%
Full Time Period					
Average	15.51	2.29	2.28	0.01	0.40%
REVOLON SLOUGH					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1994	11.07	2.71	4.05	-1.33	-33.00%
1995	24.86	11.19	11.09	0.10	0.90%
1996	11.12	4.24	5.03	-0.79	-15.80%
1997	14.39	6.05	5.50	0.55	9.90%
1998	36.22	16.51	15.92	0.59	3.70%
1999	8.92	3.20	4.21	-1.00	-23.80%
2000	12.20	4.46	4.36	0.10	2.40%
2001	16.08	6.94	6.79	0.14	2.10%
2002	5.87	2.86	2.84	0.02	0.70%
Average	15.64	6.46	6.64	-0.18	-2.70%
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Difference
1988	11.84	2.17	3.13	-0.95	-30.50%
1989	7.82	1.92	2.96	-1.04	-35.10%
1990	4.66	1.76	2.34	-0.58	-24.80%
1991	11.25	3.57	4.14	-0.57	-13.90%
1992	21.10	8.56	7.96	0.60	7.60%
1993	23.12	9.79	9.11	0.67	7.40%
Average	13.30	4.63	4.94	-0.31	-6.30%
Full Time Period					
Average	14.70	6.03	5.96	0.07	1.20%

of a Very Good calibration. The validation values are about the same and actually slightly higher, with all values being greater than 0.93; note that Beardsley is excluded since no validation data were available.

In reality, this high level of agreement is likely aided by the fact that in California most ephemeral streams in summer months usually show little or no flow, like the Arroyo Simi above Royal. In addition, effluent dominated streams in this climate have almost their entire flow contributed by POTW discharges during these summer periods, and the model uses these discharges as inputs. These are not difficult conditions to model. The criteria in Figure 4.1 were derived mostly from perennial streams in various regions across the country, and are not specific to arid and semi-arid regions common to California. Although, correlation statistics need to remain a part of the weight-of-evidence approach to model performance, their values may need to be viewed with more stringent criteria for ephemeral and effluent dominated streams.

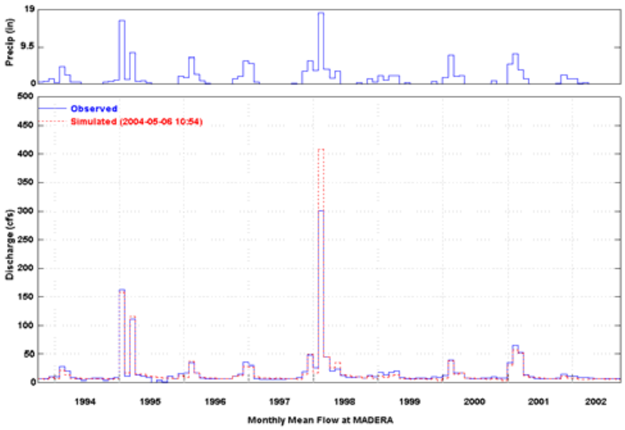
Both the coefficient of determination (R^2) and the model fit efficiency (MFE) are direct measures of the fraction of the variance of the observed data series explained by the model. If the model residuals are normally distributed, the MFE would be nearly equal to the coefficient of determination (R^2). Both the MFE and R^2 provide more rigorous tests than the correlation coefficient because they consider the magnitude of the differences between observed and simulated values in addition to their joint behavior. For the calibration, the R^2 and MFE values for both daily and monthly flows follow the same pattern as the correlation coefficient: values at all sites are consistently greater than 0.90, except for the Royal and Beardsley sites, indicating a Very Good calibration. For Royal, the R^2 values of 0.84 (daily) and 0.95 (monthly) still correspond to a Very Good calibration. For Beardsley, the daily value of 0.73 of R^2 corresponds to a Good calibration, while the monthly value of 0.95 indicates a Very Good calibration.

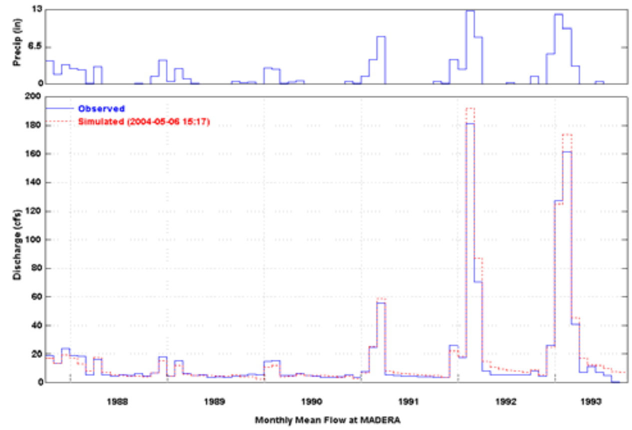
The daily and monthly MFE values, for both calibration and validation, are consistent and are very similar to the respective R^2 values, for all sites except Beardsley, indicating approximately normally distributed residuals. Note that the Beardsley MFE values are considerably lower than the R^2 values for the calibration; an indication that other factors are influencing the flow conditions. Also note that the daily MFE values for Conejo are much lower (0.82) for the validation versus the calibration (0.92), although many of the sites show an improvement in the MFE. This reflects the problems noted earlier with the peak flow simulations at Conejo.

As noted earlier, the Appendices include extensive plots of model results for each gage site and each year of the simulation. In addition, daily and monthly scatter plots are shown, along with regression lines and correlation statistics. Figure 4.2 is a sample of the monthly results (extracted from the Appendices) for both the calibration and validation periods for the gage sites at Madera, Conejo Creek, and Calleguas Creek at CSUCI. These plots and those in the appendices show that the model clearly follows the seasonal pattern of the monthly flows and generally does a very good job of reproducing the monthly values within acceptable tolerances. The February 1998 flows are clearly over-simulated but the remaining monthly pattern is well represented at all gages. The monthly flow validation for these gages is very good, except for the under-simulation of the high 1992 and 1993 flows at Conejo (to be discussed further below)

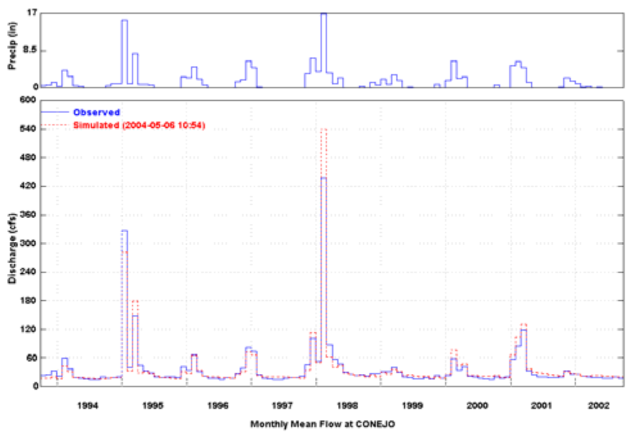
Calibration ***Validation***

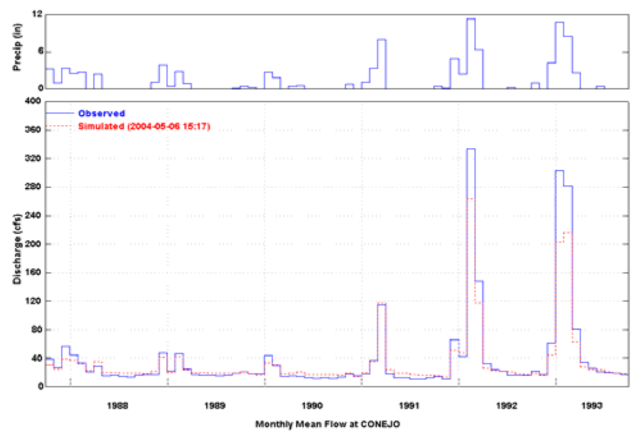
ARROYO SIMI @ MADERA



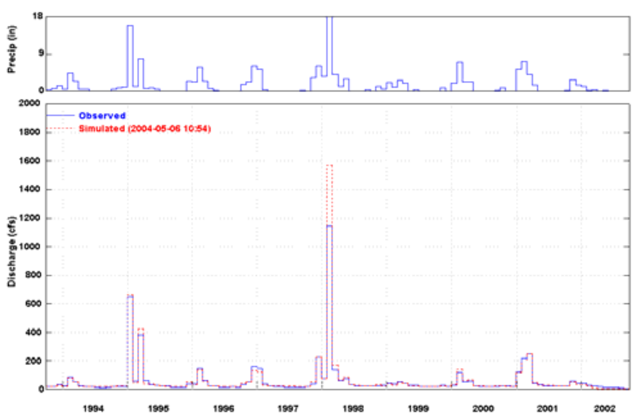


CONEJO CREEK





CALLEGUAS CREEK @ CSUCI



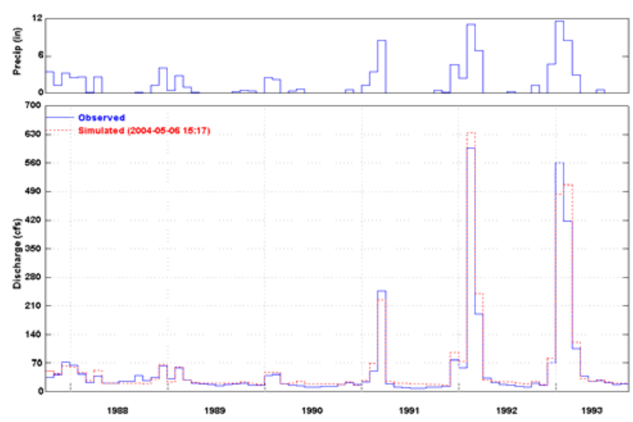


Figure 4.2 Calibration and Validation Monthly Flow Simulation at Madera, Conejo, and Calleguas Creek CSUCI

Table 4.8 shows the mean monthly flow values for each gage site for the entire 15 year simulation period compared to observed values, along with residuals and percent differences. The same comments noted above for the monthly simulation apply here: the differences are generally in the ± 25% range, larger percent differences are seen for summer months with low flow values and residuals, and the Beardsley gage shows the largest differences likely impacted by groundwater interactions. The overall seasonal pattern is well represented at the majority of the gage sites.

Figures 4.3 through 4.5 show sample daily flow simulations at these same three gages - Madera, Conejo Creek, Calleguas CSUCI – for one selected year within each of the calibration and validation periods. These figures need to be viewed at this scale, so we recommend the readers examine the daily results year by year in the Appendices to fully assess the daily simulations. The daily patterns shown by the model clearly reflect the observations; the same issue of the February 1998 over-simulation and the under-simulation at Conejo (Figure 4.4) is shown in these figures. Note that the simulated peak flows in Figure 4.4 at Conejo demonstrate almost a constant relationship to the observed; this raised the issue of whether the rating curve may be over-estimating actual flows.

4.3.3 Flow Frequency Comparisons

Figures 4.6 and 4.7 show the flow duration curves for the six gage sites, with complete flow records for the validation period, for both the calibration and validation periods; the Beardsley gage did not have any validation data, and the Arroyo Las Posas at Hitch only covered three of the six years. The comparisons show very good to excellent agreement of the flow duration curves for the calibration period through the full range of flows observed at each gage. This is a primary component of the weight-of-evidence assessment for model performance as the flow duration curves reflect the overall hydrologic regime of the contributing watershed at each gage. Note that the drop off in the observed curve at Madera at 98% exceedance is due to missing data that were filled with zero values. For the Calleguas Creek CSUCI gage, the drop in flow at about 94% exceedance reflects the impacts of the Conejo diversion which started in March 2002 and limited the by-pass flow to 6 cfs, except during high flows and storm periods. This was implemented in the model as a constant 6 cfs bypass, whereas in reality the diversion pumps are limited to about 20 cfs, so any excess is added to the bypass. The model representation of this is being further refined.

The validation flow duration curves show similar overall shapes as the calibration curves but there are larger differences between the observed and simulated curves. In reviewing these model results, note the following:

a. At Madera, the validation curves show a slight over-simulation between about 5 to 20 cfs, but otherwise the agreement is very good. Again, the drop off in the observed curve at about 97% exceedance is due to missing flow values.

b. The Conejo validation curve shows the largest deviations between simulated and observed of all the gages. As mentioned earlier, this is disturbing because of the obvious excellent agreement between the curves during the calibration period. The differences in high flows will be discussed below. The low flows, with greater than 50-70% exceedance are over-simulated by up to 5 cfs during the validation period, whereas the low flow simulation during the calibration was excellent, with almost perfect agreement. Since the low flows at the Conejo gage are controlled almost entirely by the

Table 4.8 Monthly Simulated and Observed Volumes (inches) for Full Time Period (WY 1988 –WY 2002)

ROYAL

Month	Average Precipitation	Average Simulated	Average Observed	Average Residual	Percent Differ.
Oct	0.55	0.03	0.02	0.01	27.33%
Nov	0.88	0.04	0.04	0.00	8.64%
Dec	2.15	0.15	0.17	-0.02	-11.07%
Jan	3.60	0.43	0.52	-0.10	-18.27%
Feb	5.11	1.06	1.01	0.04	4.30%
Mar	3.02	0.40	0.53	-0.13	-25.18%
Apr	0.81	0.05	0.05	-0.01	-11.75%
May	0.32	0.02	0.02	0.00	4.67%
Jun	0.07	0.00	0.00	0.00	-11.88%
Jul	0.01	0.00	0.00	0.00	-30.33%
Aug	0.00	0.00	0.00	0.00	0.00%
Sep	0.11	0.00	0.00	0.00	-0.27%
Totals	16.64	2.17	2.37	-0.20	-8.51%

MADERA

Month	Average Precipitation	Average Simulated	Average Observed	Average Residual	Percent Differ.
Oct	0.55	0.11	0.12	-0.01	-9.91%
Nov	0.98	0.12	0.14	-0.02	-16.35%
Dec	2.23	0.23	0.28	-0.05	-17.33%
Jan	3.67	0.50	0.55	-0.05	-9.78%
Feb	4.73	1.03	0.91	0.12	12.69%
Mar	2.92	0.53	0.52	0.01	2.88%
Apr	0.76	0.18	0.16	0.02	12.38%
May	0.34	0.15	0.13	0.02	19.09%
Jun	0.09	0.12	0.09	0.03	29.09%
Jul	0.01	0.11	0.08	0.03	33.21%
Aug	0.00	0.10	0.08	0.02	22.65%
Sep	0.08	0.09	0.08	0.01	12.86%
Totals	16.37	3.28	3.15	0.12	3.88%

ARROYO POSAS/HITCH

Month	Average Precipitation	Average Simulated	Average Observed	Average Residual	Percent Differ.
Oct	0.06	0.14	0.14	0.00	1.54%
Nov	0.41	0.16	0.19	-0.03	-15.38%
Dec	1.02	0.31	0.30	0.01	2.29%
Jan	2.24	0.63	0.59	0.04	6.64%
Feb	4.00	1.20	1.09	0.11	9.88%
Mar	4.99	0.69	0.67	0.02	3.65%
Apr	3.48	0.23	0.19	0.04	22.95%
May	0.67	0.20	0.16	0.03	19.74%
Jun	0.33	0.15	0.14	0.02	11.67%
Jul	0.12	0.14	0.13	0.01	9.43%
Aug	0.04	0.13	0.13	0.01	4.78%
Sep	0.00	0.13	0.13	0.00	0.54%
Totals	17.36	4.12	3.85	0.26	6.78%

CALLEGUAS CR @ 101

Month	Average Precipitation	Average Simulated	Average Observed	Average Residual	Percent Differ.
Oct	0.61	0.02	0.01	0.01	89.43%
Nov	1.02	0.04	0.03	0.01	43.21%
Dec	2.23	0.13	0.12	0.01	9.13%
Jan	3.70	0.37	0.31	0.06	18.76%
Feb	4.63	0.78	0.74	0.04	5.27%
Mar	2.85	0.35	0.29	0.06	20.03%
Apr	0.71	0.04	0.03	0.00	12.79%
May	0.31	0.02	0.02	0.00	-9.20%
Jun	0.11	0.00	0.02	-0.01	-85.60%
Jul	0.02	0.00	0.01	-0.01	-94.02%
Aug	0.00	0.00	0.01	-0.01	-95.30%
Sep	0.04	0.00	0.01	-0.01	-91.12%
Totals	16.25	1.75	1.60	0.15	9.21%

CONEJO

Month	Average Precipitation	Average Simulated	Average Observed	Average Residual	Percent Differ.
Oct	0.51	0.35	0.37	-0.01	-3.38%
Nov	1.00	0.37	0.40	-0.03	-6.94%
Dec	2.22	0.65	0.75	-0.10	-13.45%
Jan	3.48	1.13	1.33	-0.20	-14.84%
Feb	4.42	1.69	1.71	-0.02	-0.96%
Mar	2.75	1.10	1.12	-0.01	-1.25%
Apr	0.73	0.48	0.49	-0.01	-1.88%
May	0.32	0.42	0.38	0.05	12.63%
Jun	0.10	0.38	0.32	0.06	17.37%
Jul	0.03	0.36	0.30	0.07	23.52%
Aug	0.00	0.34	0.29	0.05	16.84%
Sep	0.07	0.33	0.30	0.03	9.66%
Totals	15.61	7.62	7.75	-0.13	-1.65%

CALLEGUAS CR @ CSUCI

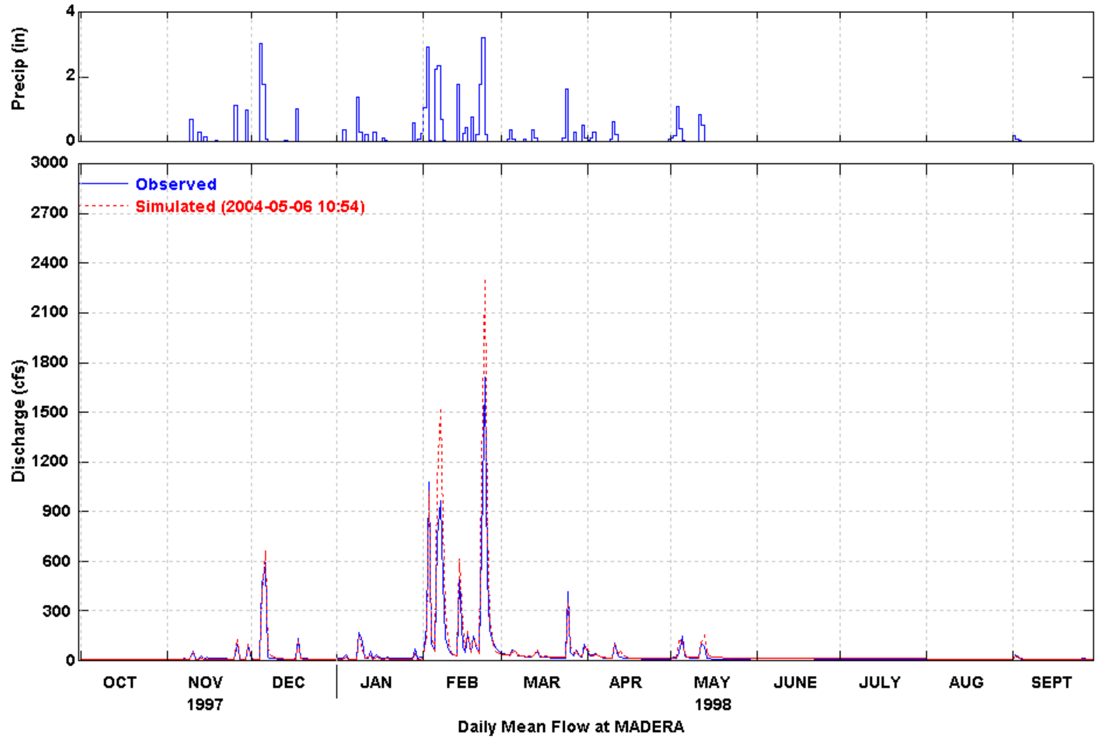
Month	Average Precipitation	Average Simulated	Average Observed	Average Residual	Percent Differ.
Oct	0.51	0.11	0.10	0.01	9.43%
Nov	1.01	0.13	0.13	0.00	3.56%
Dec	2.29	0.27	0.28	-0.01	-1.88%
Jan	3.30	0.57	0.60	-0.03	-5.07%
Feb	4.20	1.01	0.85	0.16	18.72%
Mar	2.61	0.54	0.51	0.03	6.24%
Apr	0.58	0.15	0.15	0.00	-1.91%
May	0.27	0.12	0.11	0.01	7.44%
Jun	0.09	0.10	0.09	0.01	10.38%
Jul	0.03	0.09	0.08	0.02	21.42%
Aug	0.00	0.09	0.07	0.02	21.32%
Sep	0.03	0.08	0.07	0.01	14.51%
Totals	14.92	3.27	3.04	0.23	7.47%

BEARDSLY

Month	Average Precipitation	Average Simulated	Average Observed	Average Residual	Percent Differ.
Oct	0.03	0.04	0.06	-0.02	-38.41%
Nov	0.30	0.05	0.07	-0.02	-34.49%
Dec	1.27	0.10	0.18	-0.08	-42.77%
Jan	2.14	0.45	0.36	0.10	26.73%
Feb	3.60	0.87	0.74	0.13	17.27%
Mar	4.37	0.47	0.32	0.15	48.28%
Apr	2.66	0.08	0.09	-0.01	-13.17%
May	0.68	0.07	0.08	-0.01	-17.30%
Jun	0.37	0.05	0.06	-0.01	-20.07%
Jul	0.07	0.04	0.06	-0.02	-26.95%
Aug	0.02	0.04	0.06	-0.03	-39.22%
Sep	0.00	0.04	0.07	-0.03	-43.59%
Totals	15.51	2.29	2.15	0.14	6.62%

REVOLON SLOUGH

Month	Average Precipitation	Average Simulated	Average Observed	Average Residual	Percent Differ.
Oct	0.44	0.24	0.27	-0.03	-10.55%
Nov	1.04	0.27	0.31	-0.04	-12.61%
Dec	2.18	0.52	0.53	-0.02	-2.96%
Jan	3.29	1.01	0.97	0.04	3.77%
Feb	4.10	1.47	1.55	-0.08	-5.16%
Mar	2.56	0.89	0.88	0.00	0.25%
Apr	0.69	0.34	0.32	0.01	3.88%
May	0.26	0.29	0.29	0.01	3.28%
Jun	0.07	0.26	0.23	0.03	10.83%
Jul	0.03	0.26	0.21	0.05	25.41%
Aug	0.00	0.25	0.19	0.07	35.04%
Sep	0.04	0.24	0.19	0.04	22.78%
Totals	14.70	6.03	5.95	0.08	1.40%



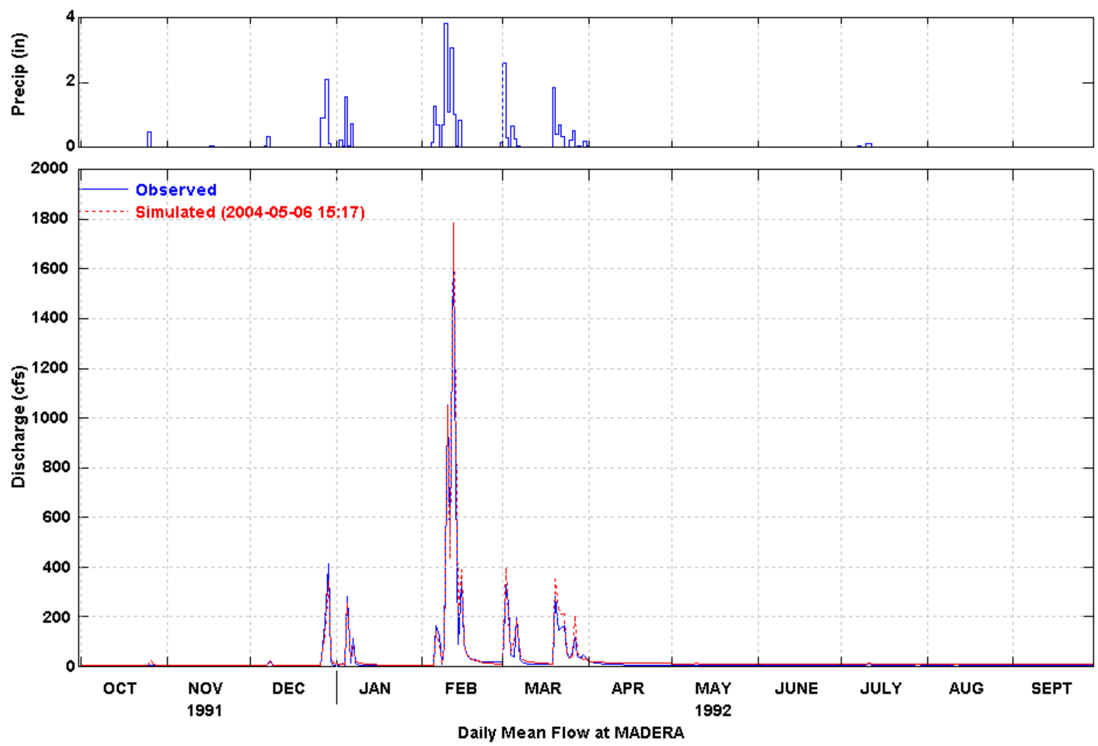
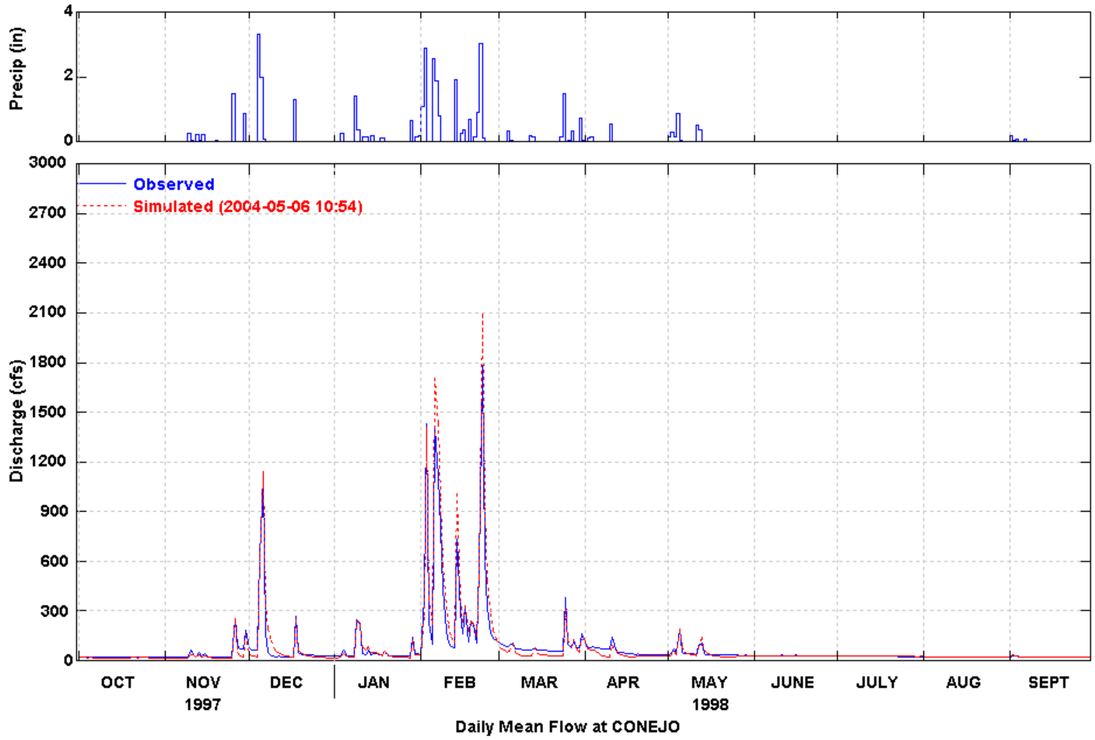


Figure 4.3 Daily Flow Simulation at Madera for 1998 (Calibration) and 1992 (Validation)



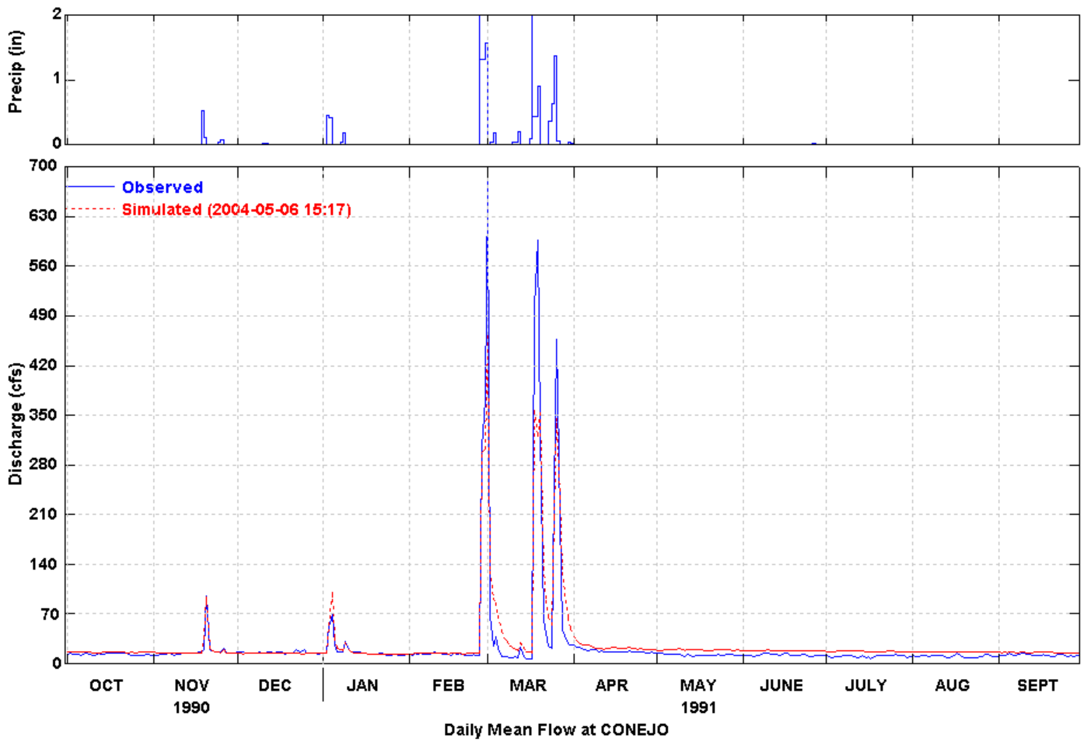
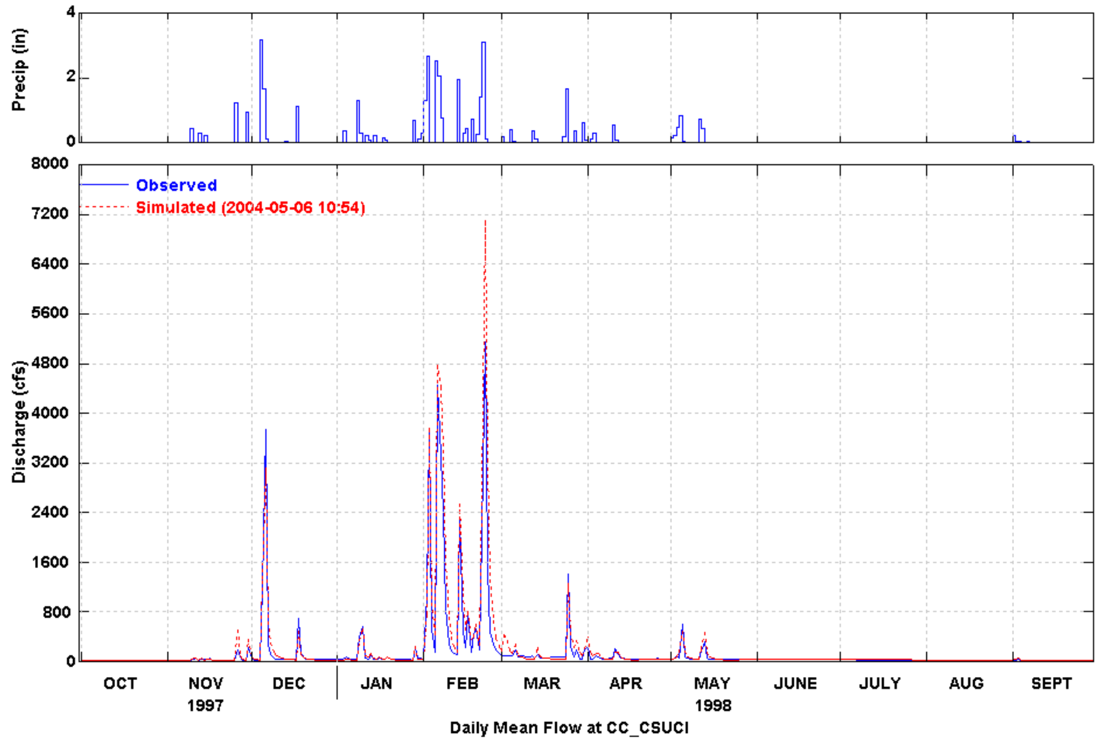


Figure 4.4 Daily Flow Simulation at Conejo for 1998 (Calibration) and 1992 (Validation)



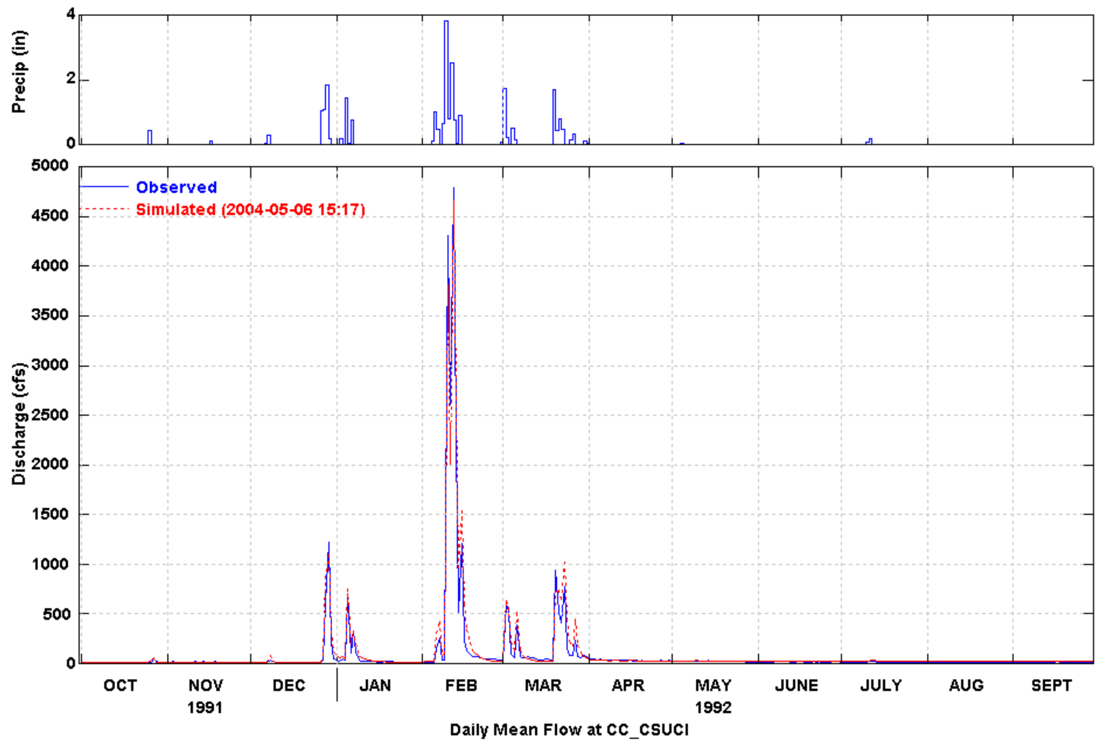
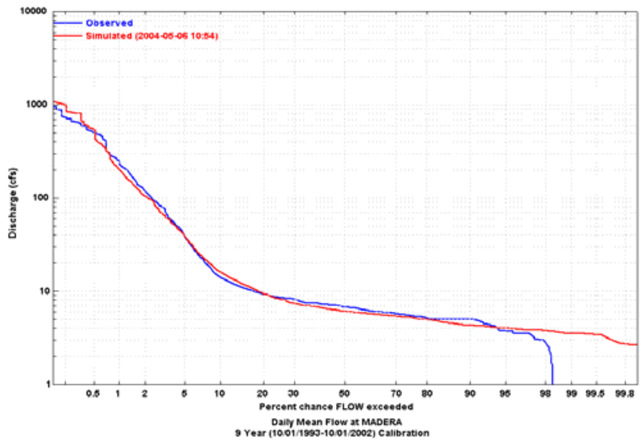
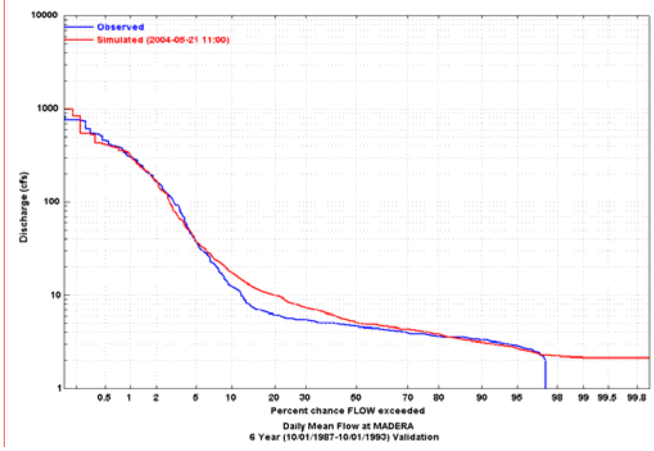


Figure 4.5 Daily Flow Simulation at Calleguas Creek CSUCI for 1998 (Calibration) and 1992 (Validation)

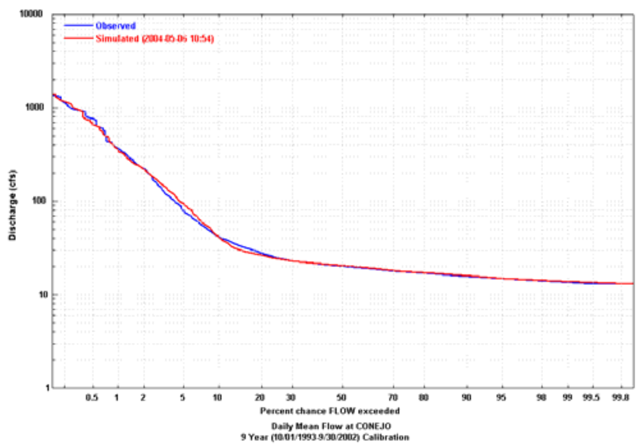
Calibration ***Validation***

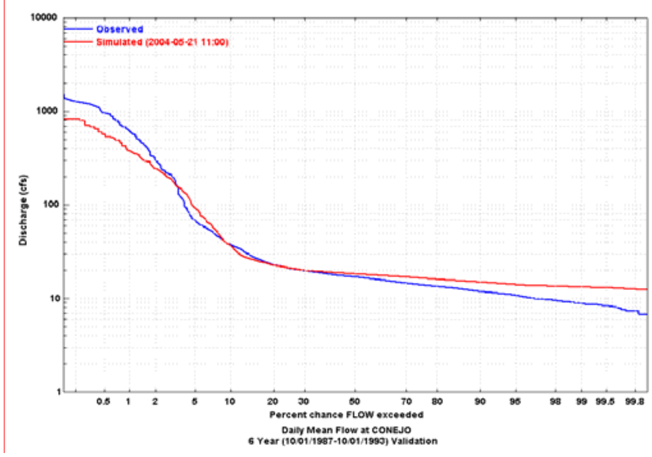
ARROYO SIMI @ MADERA



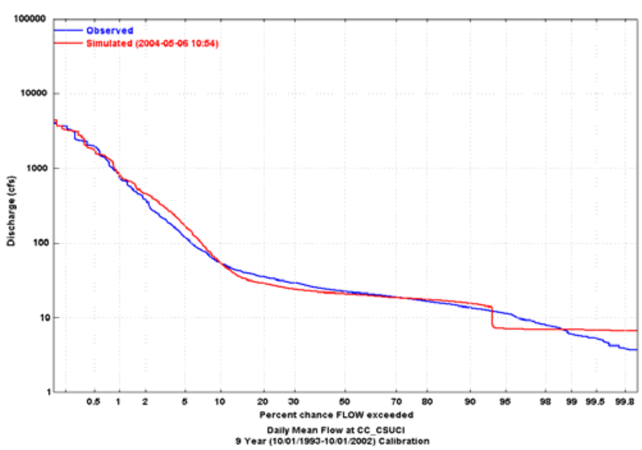


CONEJO CREEK





CALLEGUAS CREEK @ CSUCI



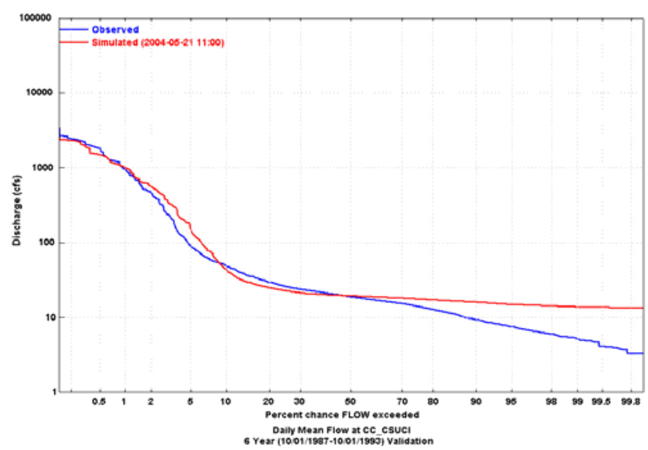
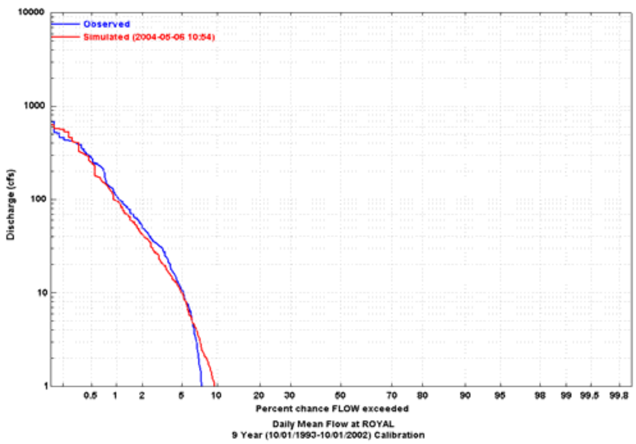
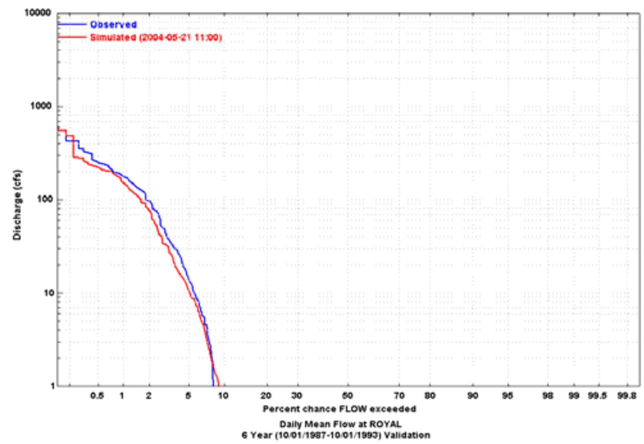


Figure 4.6 Calibration and Validation Flow Duration Curves at Madera, Conejo, and Calleguas Creek at CSUCI

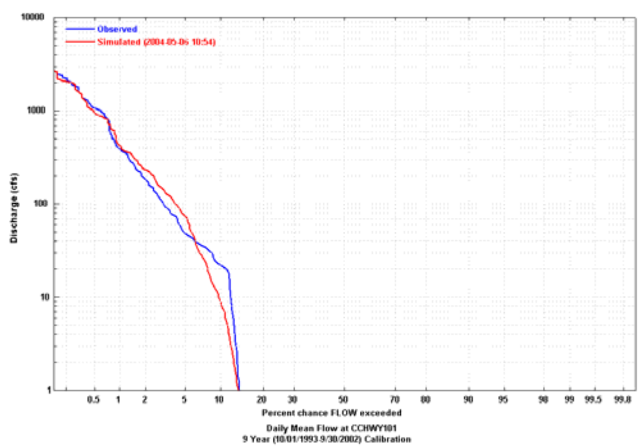
Calibration ***Validation***

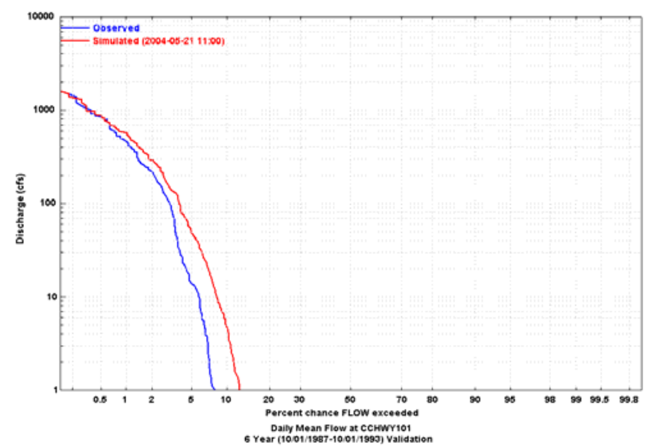
ARROYO SIMI @ ROYAL



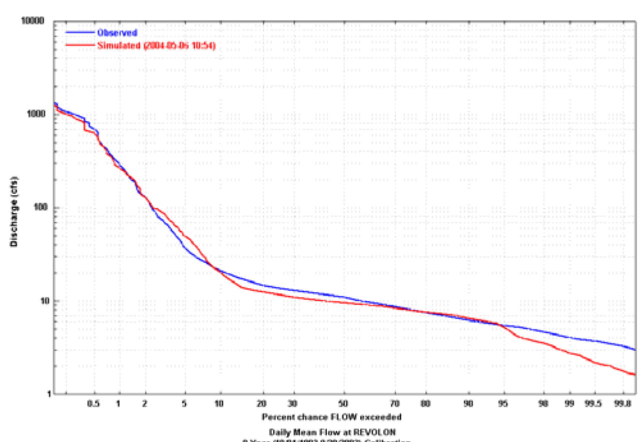


CALLEGUAS CREEK @ HWY 101





REVOLON SLOUGH



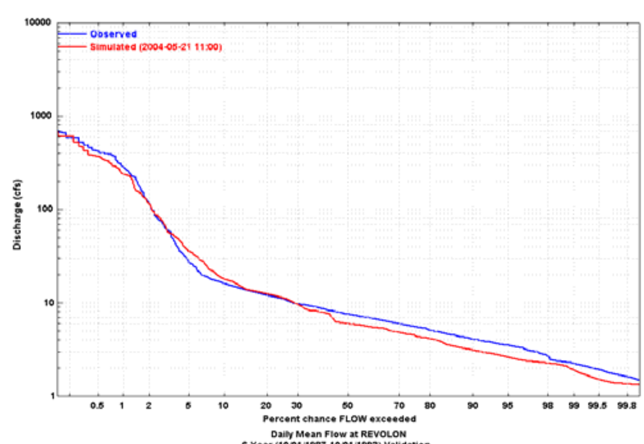


Figure 4.7 Calibration and Validation Flow Duration Curves at Royal, Calleguas Creek at Highway 101, and Revolon Slough

discharge from the Hill Canyon POTW, the differences in the validation curves are likely due to errors in the discharge values in the model. As discussed in Section 2.4, the Hill Canyon discharge data included daily records from 1996 and monthly records for the earlier time period. Also, three months of record from October 1987 through December 1988 were missing and needed to be estimated from monthly averages. The monthly values and estimated period do not reflect daily discharge variations that are evident in the 1996-2002 period when daily records were available. Thus the differences in the low flow validation period are likely due to inaccuracies in the POTW discharge values.

c. For the Conejo Creek flow duration curves, the differences between the observed and simulated values at high flows will be discussed in greater detail below, under storm event simulations. However, it is important to note how the **observed curves** differ for the two periods: for the calibration the high flow portion is almost linear above about 30 cfs, and the simulated curve is almost identical. For the validation, the observed flow duration curve shows a steep rise from 60 to 200 cfs, and then starts to level off, producing much higher values and a more rounded shape. The different shapes of the two observed curves imply some changes occurred between the calibration and validation time periods. The simulated curves indicate that the model predictions are much more consistent for the two time periods; this consistency is a common result and characteristic of watershed models.

d. For the CSUCI gage, the validation flow duration curves are consistent with the calibration results and show good agreement except for the low flows below about 15 cfs, occurring 30% or less of the time. As noted in Section 2.4, the Camarillo WTP discharge consisted of daily records from 1995 with only monthly totals available for earlier 1987 -1994 time period. Thus, some of the difference in the low flow simulation is due to monthly discharge estimates which would hide any daily variations that would likely include some lower flow values.

e. For the Arroyo Simi at Royal and Revolon Slough gages shown in Figure 4.7, the calibration and validation curves show similar shapes and values, and are a good to very good representation of the observed curves, confirming the model is a good representation of the contributing watersheds.

f. Also, in Figure 4.7, the curves for Calleguas Creek at Highway 101 show a similar general shape for both the calibration and validation periods. However, the calibration period curve shows a very good agreement, while the validation curve shows good agreement at high flows above about 500 cfs. For the flows below 500 cfs, the simulated curve is displaced above the observed, with differences of about 10 to 20 cfs or less at flows less than about 100 cfs. Since the channel is ephemeral in that region, it appears the model is under estimating channel losses under very dry conditions, possibly due to low groundwater levels during the extended dry period from 1987 to 1991.

4.3.4 Storm Event Comparisons

The final step in model calibration and validation is to examine representation of individual storm hydrographs in both time periods. During calibration, adjustments to surface, interflow, and recession parameters may be performed to improve overall agreement after examining a number of individual event simulations. Individual storm simulations will show larger deviations from observed values than for daily and monthly totals, often due to dynamic variations in rainfall spatial distributions not accurately represented by the gage network. Also, we will often see timing differences due to clock errors, either in the rainfall or flow gage instrumentation. Consequently it is necessary to examine a number of storm events to assess the simulation accuracy; this is performed by reviewing the mean daily flow results, storm volumes and peaks, and individual hydrographs often at hourly time intervals.

The daily flow simulations were discussed above and are provided in the appendices for each year of the simulation. As noted earlier, the storm statistics shown in Table 4.2 are derived from 15-20 selected events during each simulation period, and include the total storm volume (in inches) and the average peaks of the selected storms. For detailed comparisons, the VCWPD staff provided hourly storm hydrographs for 10 events at each calibration site over the 15-year simulation period; the Appendices show the detailed simulated and observed flow values for each of these 10 events. For clarity and convenience, Figures 4.8 and 4.9 each show two events for the Arroyo Simi at Madera, Conejo Creek, and Calleguas Creek at CSUCI for both the calibration and validation time periods.

The events in Figures 4.8 and 4.9 are representative of the overall storm simulation results. Our conclusions based on these results, and those in Table 4.2 and the Appendices, are as follows:

a. The percent differences for storm volumes and peaks shown in Table 4.2 are consistently less than 10 to 15 %, indicating a Good to Very Good calibration and validation. The validation differences are somewhat higher than calibration values, but most are still less than 10% and six of the seven sites are less than 15%. The lone exception being the Conejo gage site.

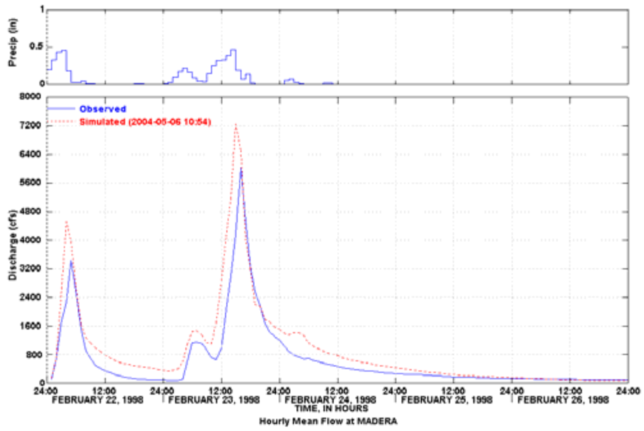
b. The daily simulation results were discussed earlier (Section 4.3.2) and demonstrate a consistently Good to Very Good simulation for daily values and correlation statistics.

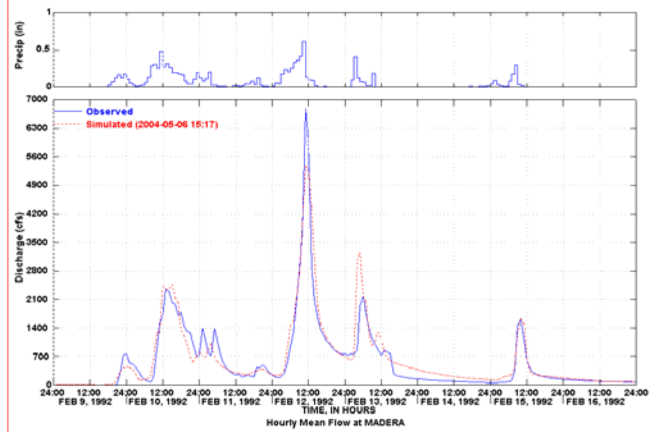
c. The hydrograph shapes and peaks are generally well represented by the model, tracking the observed data, for numerous storm events. Timing differences of a few hours between observed and simulated peaks are evident for selected events, but the differences are small and are not consistent across all events.

d. Individual storm peaks may vary considerably from observed values, sometimes up to 30% or more, but the overall average peaks for the 15-20 selected storms are within the 10-15% range for a Good to Very Good rating. The Conejo gage results for the validation period is the exception, and that is discussed below.

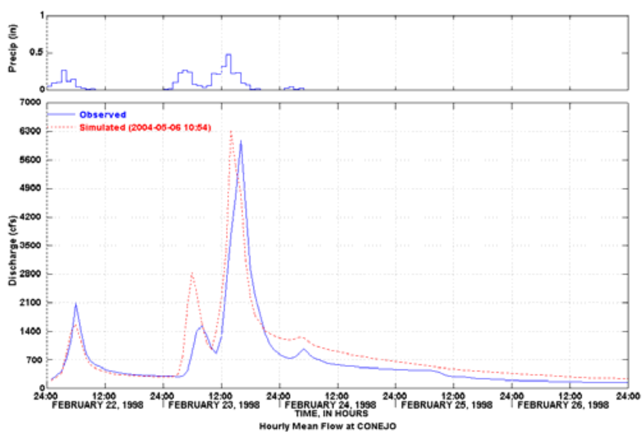
Calibration ***Validation***

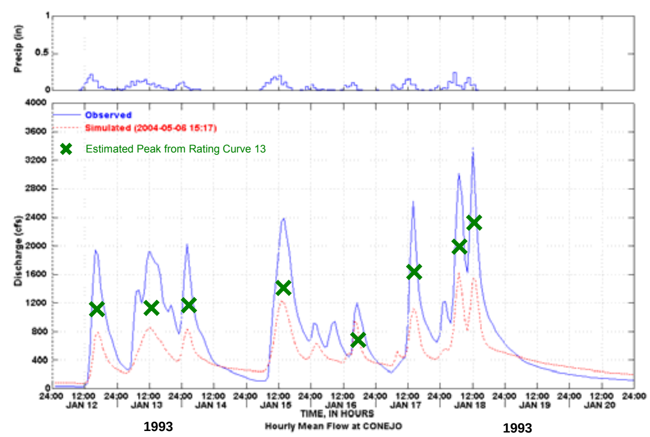
ARROYO SIMI @ MADERA



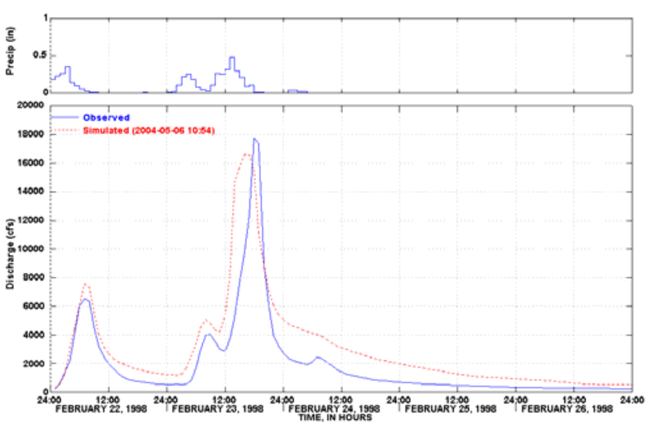


CONEJO CREEK





CALLEGUAS CREEK @ CSUCI



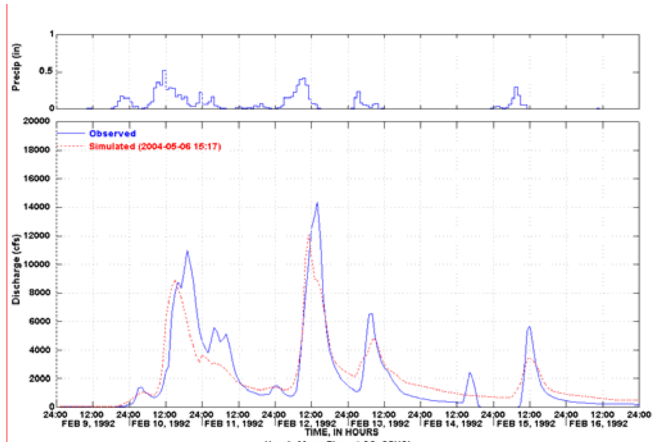
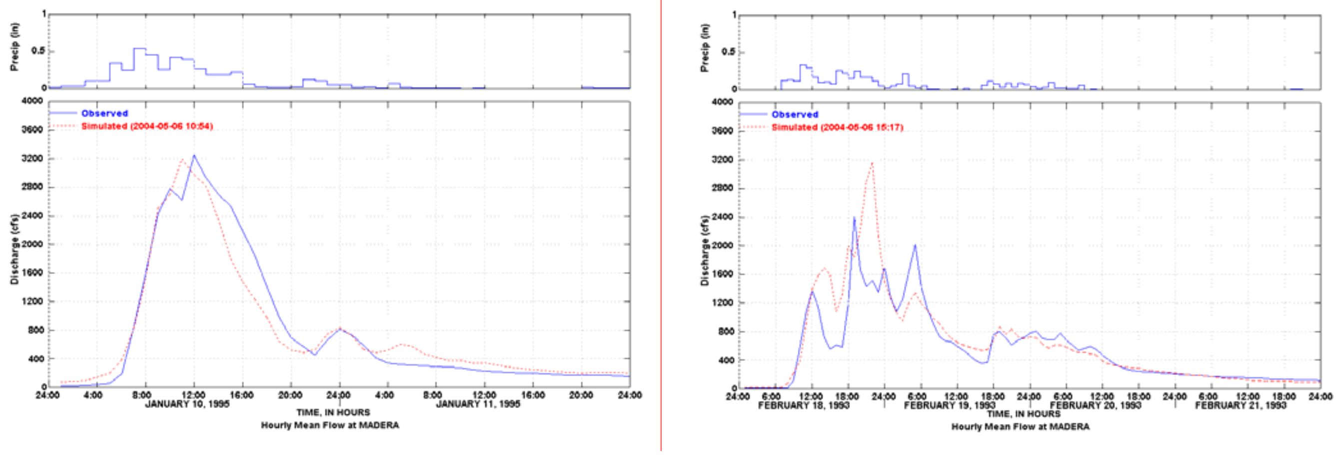


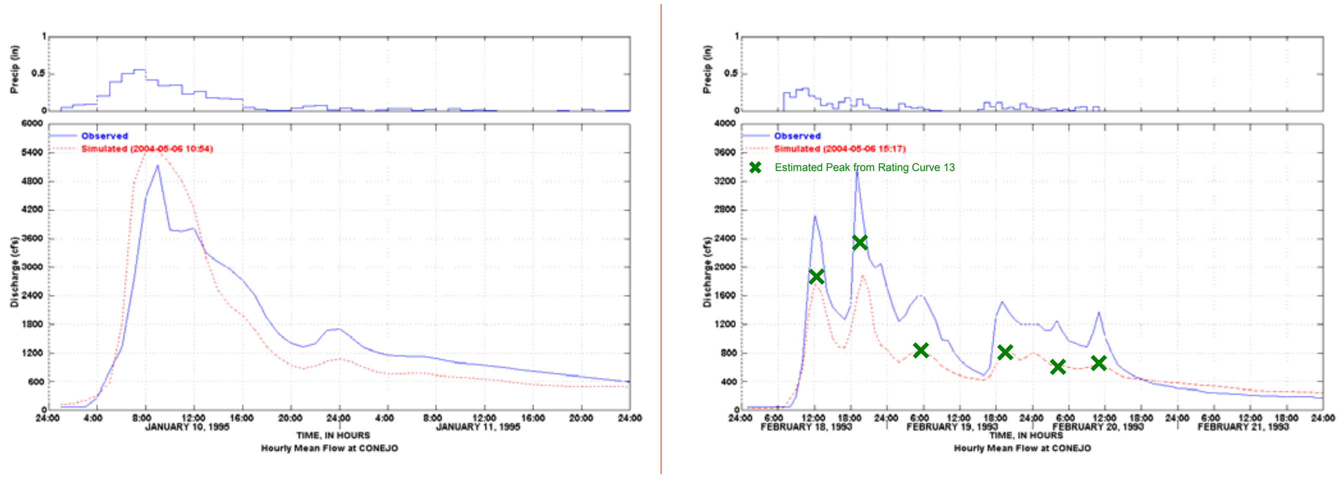
Figure 4.8 Selected Storm Event Simulations, Calibration (February 1998) and Validation (February 1992, January 1993)

Calibration ***Validation***

ARROYO SIMI @ MADERA



CONEJO CREEK



CALLEGUAS CREEK @ CSUCI

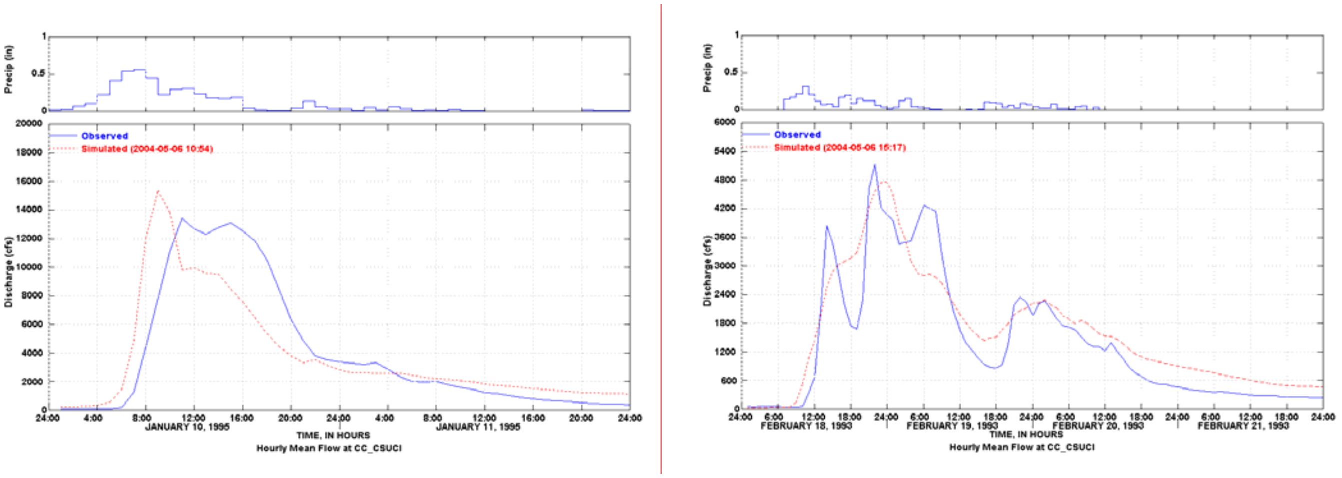


Figure 4.9 Selected Storm Event Simulations, Calibration (January 1995) and Validation (February 1993)

4.3.4.1 Conejo Creek Validation and Gage Issues

The significant differences between the calibration results and the validation results for the Conejo gage for storm peaks and volumes are inconsistent with the results at the other gage sites, and required further investigation. The following conditions and issues were identified in evaluating the validation problems:

a. During the calibration, the Conejo gage was the one site with the best overall model performance in all aspects of the simulation. The model parameters extended from the Arroyo Simi pilot application worked well, the Hill Canyon Discharge records accurately defined the baseflow conditions, and the flow duration curves consistently showed good agreement between simulated and observed values. Mathematical models tend to show consistent behavior; given the same antecedent/existing conditions, the same parameters, and the same input/forcing functions, the equations will produce the same values. Consequently, when model results show inconsistent differences with field observations, further investigation of the observations is needed.

b. The channel at the Conejo gage is a natural channel that is subject to bed and bank erosion at relatively low to moderate flows. The right bank, as you look downstream, tends to slump and widen during larger events. In the early years of gage operation, the channel was routinely cleared of willows; the channel is now overgrown in places with willows as this maintenance practice is no longer performed. The dynamic nature of the channel has required numerous rating curves to be developed, and shifts to be applied, over the lifetime of the gage. Figure 4.10 shows the progression of rating curves, from #10 which covered WY88 through February 1992, to #14 which started in February 1998 and was used through WY 2003. Note the **reduction** in flow values at the same gage height as the curves shift from #10 to #14. The rating has been generally qualified as ‘good’ for continuous low-flow data and ‘fair to poor’ for higher-stage measurements. The USGS defines an ‘excellent’, ‘good’, and a ‘fair’ rating to have 95 percent of the daily recorded discharges within 5, 10, and 15 percent, respectively, of the true value. Records that do not meet these criteria are rated as poor, with greater than 15% error.

c. Some of the larger events have required estimation via hydrologic comparison with streamflow records collected at Calleguas Ck at Camarillo St. Hospital and Calleguas Creek above Hwy 101 (e.g., 1/5/1995-1/17/1995, 1/17/1995-1/26/1995, 2/4/1998-2/6/1998, 2/10/1998-2/12/1998, 2/26/1998-2/27/1998). Water Year 1992 was the last year a cable car located at the gage could make high stage measurements.

d. According to the documented station history (W. Carey, VCWPD, Personal communication, 5/17/2004), “rating #13 (starting on 2/6/1998) was developed from great effort to determine accurate flows at the site based on waded measurements and it was apparent from past ratings and slope area, that the low and mid-range portions of previous ratings were poorly defined”. From Figure 4.10., it is apparent the rating curve relationship was significantly modified for the low to mid range flows between curves #12 and #13, e.g., at 6 ft, rating #12 would result in flows of ~ 1700 cfs whereas rating #13 results in ~ 990 cfs, . The switch to rating #13 occurred at the beginning of water year 1997, which followed a year of relatively small events.

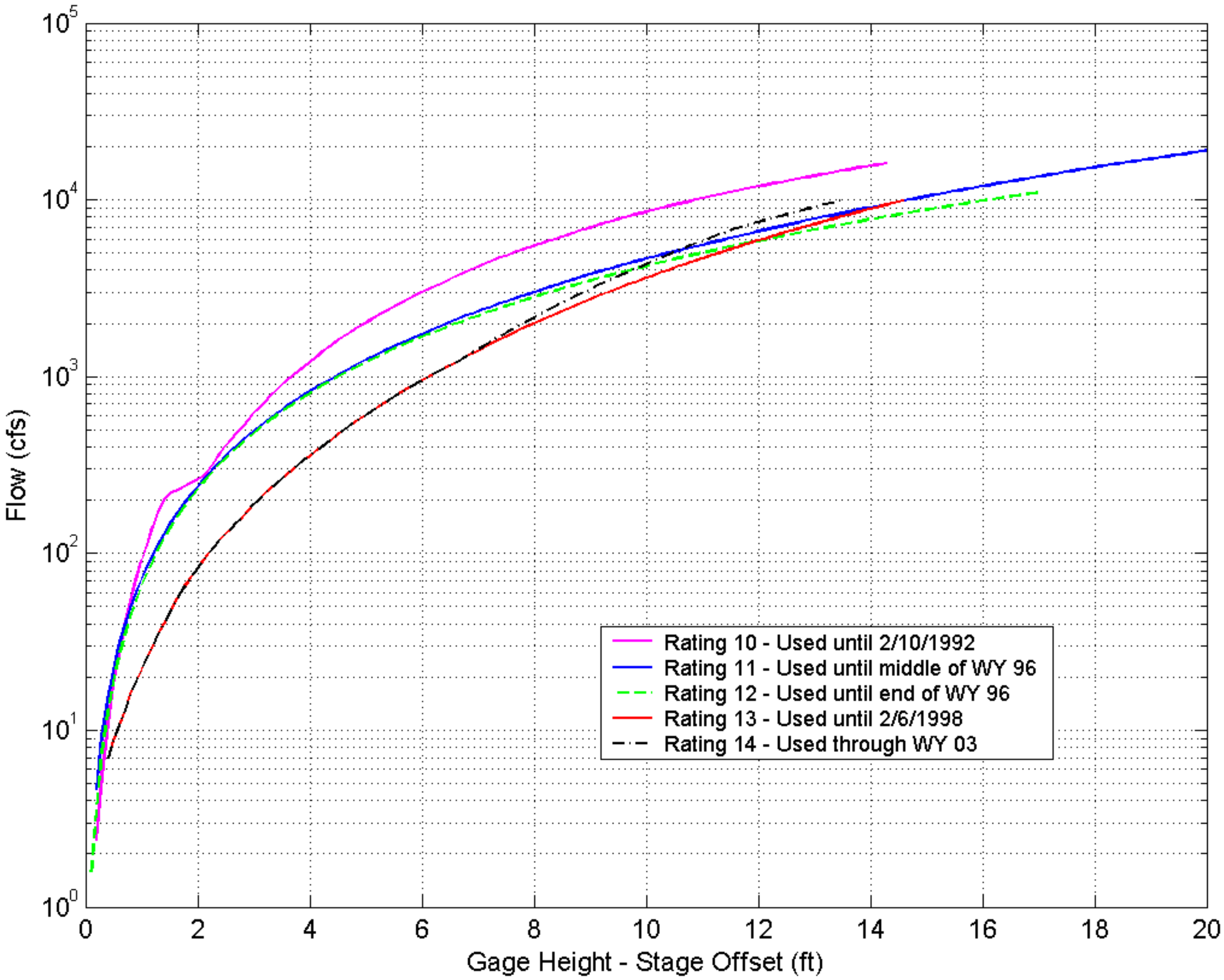


Figure 4.10 Conejo Creek Gage Rating Curves for WY 1987 – WY 2002

e. To demonstrate the potential impact of these shifts and changes in the rating curves on the observed flows and model comparisons, the adjusted peaks are shown in Figures 4.8 and 4.9 for the January and February 1993 storms for the Conejo gage. These adjusted peaks, shown by the green **X,** represent the peak flow values based on rating #13 as opposed to #11 which was used during those storm periods. Clearly these adjusted peaks are much lower than the record values, and are much closer to the model-predicted flow peaks.

In summary, accurately measuring flows in unstable and changing channels like the Conejo site is a major challenge even with today's sophisticated instrumentation. The data problems and suspicions discussed above are not a criticism of the VCWPD hydrography staff, who have been extremely helpful in investigating and better understanding these measurement issues, but a realization of the difficulties involved with monitoring these types of channels.

It is clear that the model tends to somewhat underestimate the mid range flows for time periods when rating curves #10-#12 were used; this is especially true for the validation time period (WY 88 – WY 93) and the early portion of the calibration period (WY94-96). For water years 1997 through 2002, the model tends to be in much better agreement with the data. It is unclear if the rating curves prior to #13 were inaccurate or if the dynamic nature of the channel caused the relationship to drastically shift for the low to mid range flows. However, these observations do provide compelling evidence that low to mid range flows were poorly defined for some time period prior to rating curve #13 being used, and were likely over estimated. Further investigation of the recorded flows, and possible adjustment should be considered.

4.3.4.2 Storms of February 1998

In the Arroyo Simi pilot study, the storms of February 1998 precluded a complete model validation due to uncertainties in both the rainfall and flow data associated with that storm. Following the recommendations from that effort, the tasks listed below were included in this study:

a) The VCWPD staff revisited the hourly rainfall distribution procedures and made concerted efforts to accurately distribute daily rainfall totals to hourly values, from the recorder strip charts, and ensure proper timing during the day. These procedures greatly improved the overall timing and representation of the storm events, and helped to resolve many of the model-data differences noted in the Arroyo Simi study. The same procedures were then applied to all the remaining hourly stations used for the Calleguas Creek Watershed.

b) Further investigation and comparisons among rainfall stations identified selected rainfall errors at a few of the daily stations that directly impacted the February 1998 period. Specifically, precipitation adjustments were made for the Tripas Canyon (242) and South Mountain-Shell Oil (238) gages for days that were flagged as ‘estimated’ and appeared to be inconsistent with data recorded at surrounding gages. For example, daily totals that were estimated at Tripas Canyon on 2/25/1998-2/28/1998, with daily accumulations up to 1.77 inches, occurred on days that no other gage in the surrounding watershed received precipitation; these values were determined to be incorrectly estimated and set to 0.0.

c) Regressions between the Royal and Madera gages, and other gages within the watershed, for the February 1998 storms indicated that the daily values at Royal may be under estimated by up to 25-30%. This reflects difficulty in accurately measuring extreme high flows, and the associated uncertainty in the recorded values.

d) With the extension of the model throughout the Calleguas Creek Watershed, the model results showed much improved behavior at other gages for the February 1998 storms. This confirmed that the model parameters were appropriate and that much of the differences noted were due to extreme spatial variations in the storm rainfall pattern; analysis of the February 6 storm patterns showed that both 5-year and 100-year return events occurred in that storm within a 5 mile radius (D, Curtis, OneRain Inc. Personal communication, 4/19/2004). Use of radar images to better define the rainfall pattern could be used to improve the model input, but the resources required were not available for this effort.

e) In this study, we reversed the calibration and validation periods, compared to the Arroyo Simi pilot, so that the calibration covered the most recent time period with the most accurate data, numerous high flow years, and the February 1998 period. This provided a better foundation for the calibration effort.

The end result of these efforts and adjustments, as shown in Figure 4.8 and the Appendices, is a Fair to Good simulation of the extreme February 1998 storms, which resulted from the wettest February on record, and a Good to Very Good overall representation of other storms and high flow periods at most of the other calibration gages. As noted above, the storm simulations in Figures 4.8 and 4.9, and those in the Appendices, demonstrate a Good to Very Good representation of events for both the calibration and validation periods.

4.3.5 Water Balance Analysis

The overall water balance for the Calleguas Creek Watershed is controlled and comprised of the input precipitation, imported water, and the runoff discharged from the watershed; the difference between these input and output quantities represents all other losses, which are mostly evapotranspiration and any deep groundwater or subsurface losses (e.g. channel losses and gage underflow). For the Calleguas Creek Watershed, the expected ranges of these components of the water balance are as follows:

Precipitation	14 – 22 inches
Irrigation	0 – 30 inches
Runoff	2 – 4 inches
Potential ET	43 – 45 inches
Actual ET	10 – 35 inches

For the Calleguas Creek Watershed model, the precipitation and potential ET are inputs specified by the data defined in Section 2. The runoff represents the range of flow measured at the gaging stations. The irrigation represents an overall range from unirrigated open lands to intensive agriculture based on the procedures discussed in Section 2.4.2. The actual ET is calculated by the model spanning a range of open shrub to irrigated conditions.

Table 4.9 shows the model-calculated water balances, in inches, for the separate land use categories; these values are weighted across the watershed and represent average values over the 15 year simulation period. The impacts of irrigation are evident when comparing the one inch of runoff from open non-irrigated land, to the range of 5 to 8 inches from irrigated urban and agriculture. Clearly, both urbanization and agricultural development have major impacts on the hydrologic regime, and the model allows for quantification of those impacts.

The 'GW Inflow' values in Table 4.9 include the 'Deep' values that represent the model calculated values for deep recharge that is assumed to reach deep aquifers that don't provide return flow to the stream, while the 'Active' values are assigned to shallow aquifer storage that does return to the stream as baseflow. Thus the Active inflow amounts equal the sum of the Baseflow discharge and GW evaporative losses, listed under Evapotranspiration.

Table 4.9 Water Balance by Land Use Category for WY 1988 – WY 2002 (inches)

	OPEN	LOW DENSITY RES	MED DENSITY RES	HI DENSITY RES	COMM/ INDUS/ TRANS	AG	EIA
Influx							
Rainfall	18.08	16.44	15.69	16.53	15.79	15.91	16.02
Irrigation	0.00	16.07	22.50	25.71	27.32	25.76	
Total	18.08	32.51	38.19	42.24	43.11	41.67	16.02
Runoff							
Surface	0.18	0.90	1.54	1.02	2.02	1.37	13.60
Interflow	0.37	1.13	1.24	1.37	1.46	0.89	
Baseflow	0.58	2.84	3.64	5.47	5.27	2.68	
Total	1.13	4.87	6.41	7.86	8.75	4.95	
GW Inflow							
Deep	2.09	6.50	7.82	9.90	7.20	2.68	
Active	0.86	3.81	4.69	6.94	6.90	4.12	
Total	2.95	10.31	12.51	16.84	14.10	6.81	
Pumping	-0.02	0.00	0.00	0.00	-1.05	0.00	
Evapotranspiration							
Potential	43.95	43.85	44.27	43.79	44.28	44.64	44.09
Intercep St	3.16	2.59	2.62	2.61	2.59	2.93	
Upper Zone	1.48	3.01	5.40	4.80	8.52	4.59	
Lower Zone	10.02	14.44	14.78	15.37	14.31	25.21	
Ground Water	0.00	0.00	0.00	0.00	0.00	0.00	
Baseflow	0.28	0.97	1.05	1.46	1.39	1.05	
Total Actual	14.94	21.01	23.84	24.23	26.81	33.79	2.42

Table 4.10 shows the water balance by the 5 major subbasins, delineated in Figure 3.2, designated as Upper Arroyo Simi, Lower Simi/Las Posas, Conejo Creek, Lower Calleguas, and Revolon Slough; these values are also averages over the 15 year period, and the units are both inches over the subbasin and acre-feet. The final column in Table 4.10 represents the weighted averages for the entire Calleguas Creek Watershed. Figures 4.11 and 4.12 schematically show the water balances for the entire watershed and each subwatershed, respectively. These fluxes use the values from Figure 4.10, except that the outflow for each subwatershed is calculated as the sum of inflow, runoff, and POTWs less channel losses.

Table 4.10 also shows 'Reach Fluxes' as the bottom rows of the table, representing POTW discharges (i.e. point sources), pumping and dewatering in the Arroyo Simi, and channel losses that are evident in many parts of the watershed, but are most significant in the Arroyo Las Posas between Madera and Calleguas Creek from above 101 to the confluence with Conejo Creek.

In reviewing these water balance results, the following observations are provided:

- If irrigation amounts calculated in the model are reasonably accurate, they represent an addition of almost 70% of the annual rainfall, and account for about 40% of total combined rainfall plus irrigation, or total moisture, incident on the watershed.

- One recent estimate of total imported water (both surface and deep groundwater) is about 112,000 acre feet per year (100 MGD), or about 6 inches over the watershed (Hajas, 2003). This would compare to the total irrigation of 192,370 ac-ft/yr less the Deep GW recharge of 56,380 ac-ft/yr, for a difference of about 136,000 ac-ft/yr in the model. This difference of about 20% may be reasonable agreement depending on the accuracy of the 100 MGD estimate.

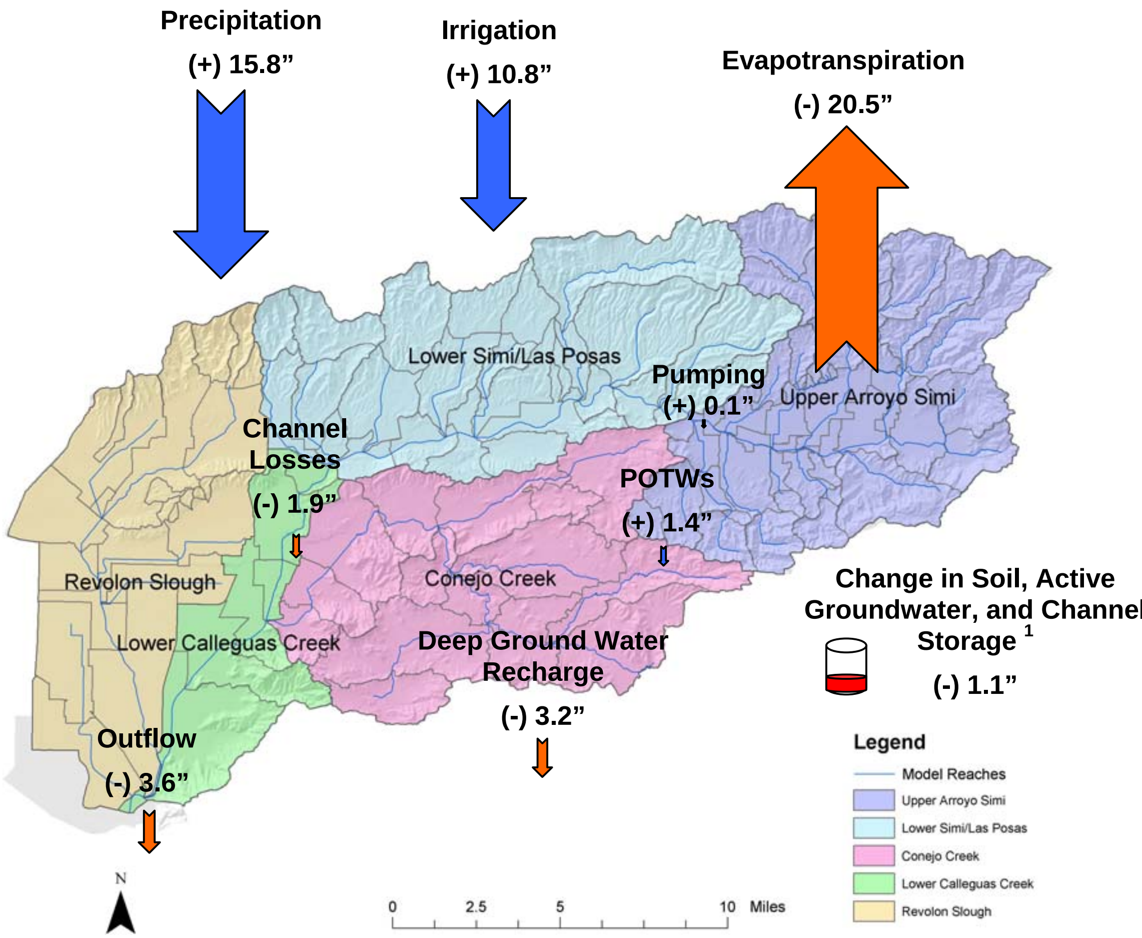
- A recent groundwater modeling effort by the USGS (Hanson et al., 2003) provides an estimated range for groundwater recharge of 100,000 to 140,000 ac-ft/yr. Table 4.10 shows total Deep and Active GW inflow of 101,184 ac-ft/yr plus channel losses entering groundwater of 33,581 ac-ft/yr, for a total of about 135,000 ac-ft/yr. This value is consistent with the upper end of the USGS range.

- The Nutrient TMDL by Larry Walker Associates (2001) provides estimates of agricultural irrigation of about 2 ac-ft/yr, within an annual range of 1.7 to 2.3 ac-ft/yr depending on wet or dry climate conditions. These estimates are consistent with our model values of about 26 inches or 2.2 ac-ft/yr.

In summary, the model water balances are reasonable and consistent with other available information, and show realistic differences across land uses and irrigation conditions.

Table 4.10 Water Balance by Major Subbasin for WY 1988 – WY 2002

	Upper Arroyo Simi		Lower Simi \ Los Posas		Conejo Creek		Lower Calleguas		Revolon Slough		Total	
	in.	ac-ft	in.	ac-ft	in.	ac-ft	in.	ac-ft	in.	ac-ft	in	ac-ft
Influx												
Rainfall	16.88	70,590	17.66	78,450	14.68	60,280	13.69	20,300	14.64	51,770	15.83	281,390
Irrigation	4.58	19,140	8.29	36,810	8.61	35,340	16.23	24,070	21.78	77,010	10.82	192,370
Total	21.46	89,730	25.95	115,260	23.29	95,620	29.92	44,370	36.42	128,780	26.65	473,760
Runoff												
Surface-Imp	0.45	1,875	0.28	1,257	0.33	1,351	1.31	1,941	1.68	5,926	0.69	12,350
Surface-Perv	0.95	3,951	0.63	2,808	1.36	5,575	1.03	1,519	0.87	3,061	0.95	16,914
Interflow	0.61	2,528	0.54	2,413	0.58	2,362	0.82	1,219	0.92	3,258	0.66	11,780
Baseflow	0.94	3,909	0.70	3,099	1.99	8,168	2.24	3,316	3.43	12,140	1.72	30,632
Total	2.95	12,260	2.15	9,577	4.26	17,460	5.40	7,995	6.90	24,390	4.03	71,682
GW Inflow												
Deep	3.72	15,570	4.24	18,850	3.58	14,700	1.71	2,537	1.34	4,723	3.17	56,380
Active	1.24	5,191	1.19	5,276	2.77	11,360	3.63	5,387	4.69	16,590	2.46	43,804
Total	4.96	20,760	5.43	24,130	6.35	26,060	5.34	7,924	6.03	21,310	5.64	100,184
Pumping	-0.22	-936	0.00	0	0.00	0	0.00	0	0.00	0	-0.05	-936
Evapotranspiration												
Potential	40.83	170,700	42.13	187,200	39.58	162,500	41.16	61,030	41.65	147,300	41.00	728,730
Intercep St	2.86	11,960	2.86	12,700	2.59	10,630	2.68	3,979	2.72	9,618	2.75	48,887
Upper Zone	1.99	8,305	1.94	8,622	1.86	7,640	4.20	6,222	5.47	19,340	2.82	50,129
Lower Zone	10.61	44,360	14.93	66,340	11.56	47,460	15.66	23,220	19.72	69,720	14.13	251,100
Ground Water	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Baseflow	0.25	1,042	0.50	2,224	0.78	3,205	1.18	1,747	0.87	3,063	0.63	11,281
Impervious	0.17	689	0.10	464	0.24	969	0.20	293	0.17	595	0.17	3,010
Total Actual	15.88	66,360	20.33	90,350	17.03	69,900	23.92	35,460	28.95	102,300	20.50	364,370
Reach Fluxes												
POTWs (+)	0.00	0	2.31	10,256	3.74	15,367	0.01	19	0.00	0	1.44	25,642
Pumping (+)	0.47	1,954	0.00	0	0.00	0	0.00	0	0.00	0	0.11	1,954
Channel Losses \ Diversion (-)	-0.09	-389	-4.05	-17,998	-0.04	-167	-9.97	-14,782	-0.07	-245	-1.89	-33,581



1 - Change in Storages calculated prior to rounding fluxes

Figure 4.11 Water Balance Components for the Calleguas Creek Watershed for WY 1988 – WY 2002

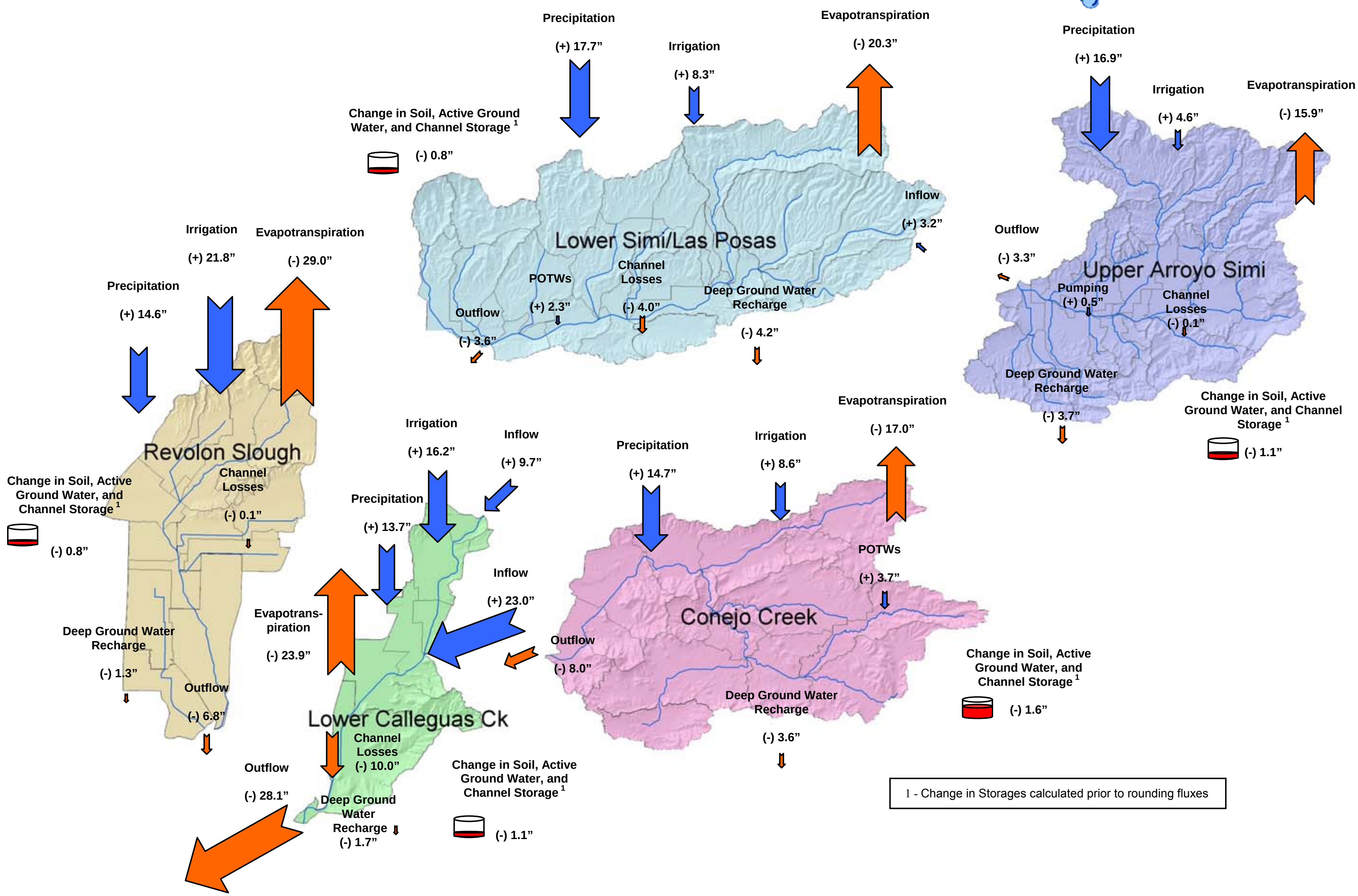


Figure 4.12 Water Balance Components for Subwatersheds of the Calleguas Creek Watershed for WY 1988 – WY 2002

SECTION 5.0

CONCLUSIONS AND RECOMMENDATIONS

Table 5.1 provides a 'weight-of-evidence' summary of the various model-data comparisons performed for the calibration and validation of the Calleguas Creek Watershed Model and discussed in Section 4. These values represent, for each statistic and comparison, the mean and ranges of the statistics for the calibration and validation periods, across all gages as listed in Tables 4.2 and 4.3. The Overall Model Performance column reflects our assessment of model behavior for both the calibration and validation periods, i.e. the entire 15 year simulation. The only caveat, noted in the footnote, is the omission of the Conejo Creek validation statistics due to the questions on the rating curve that need to be resolved.

5.1 CONCLUSIONS

Based on the model results presented and discussed in Section 4, and summarized in Table 5.1, we conclude that the current HSPF application to the Calleguas Creek Watershed provides a sound, calibrated and validated hydrologic watershed model that provides a framework for watershed management analyses and needs for flood assessments, water quality issues, and impact evaluation of mitigation alternatives. The calibration and validation results, based on the weight-of-evidence approach described herein, demonstrates a **good to very good** representation of the observed data. This is the outcome of a wide range of graphical and statistical comparisons and measures of the model performance for annual runoff, daily and monthly streamflow, flow duration, water balance components, and storm event simulations. These comparisons demonstrate conclusively that the model is a very good representation of the water balance and hydrology of the watershed.

5.2 RECOMMENDATIONS

The following recommendations are provided to resolve some of the issues identified during this effort, and to enhance and support many potential uses of the model for addressing water resources and water quality issues in the Calleguas Creek Watershed:

- Investigate rating curve issues at the Conejo Creek gage, in conjunction with VCWPD staff, to re-assess the accuracy of the flow rates during the validation period, and either confirm or refute suspicions that the actual flow peaks are over-estimated by the data. Other gage sites, such as the Calleguas Creek Highway 101 gage, could also benefit from such as investigation, to confirm the accuracy of gage values for these changing, unstable channels.

- Extend the meteorologic database to allow 30 to 50 year model simulations for in-depth analyses of extreme event frequencies, flow duration curves, scenario evaluations, and design storm assessments. This would include efforts by VCWPD staff to process available strip charts of 8 to 10 selected precipitation gages to develop reliable hourly precipitation data to drive the simulations.

- Investigate additional data and information to better establish and quantify surface water importations versus GW pumping, spatially within the Calleguas Watershed, to help differentiate shallow versus deep GW contributions, and improve the representation of these sources within the watershed model.

- Link the current Calleguas HSPF model with a groundwater model to help to close the water balance assessment, allow more comprehensive analyses of SW-GW interactions, and further investigate issues, related to channel losses and irrigation pumping. The integrated assessment could be performed initially as a pilot study on a subbasin, such as Conejo Creek to assess its feasibility and demonstrate its utility for SW-GW management issues.

Table 5.1 'Weight-of-Evidence' for Calleguas Creek Watershed Model Performance

	Calibration		Validation		Overall Model Performance
	mean	range	mean	range	
Daily Volume, % Δ	2.1	-4.7 / 6.6	3.1	-14.3 / 18.4	Good / Very Good
Monthly Volume, % Δ	2.4	-3.9 / 7.0	3.0	-14.2 / 18.1	Good / Very Good
Annual Volume, % Δ	2.2	-4.7 / 6.6	3.1	-14.3 / 18.5	Good / Very Good
Correlation Coefficient, R:					
- Daily R	0.94	0.85 / 0.98	0.96	0.93 / 0.98	Very Good
- Monthly R	0.98	0.97 / 0.99	0.99	0.97 / 0.99	Very Good
Coefficient of Variation, R^2:					
- Daily R^2	0.89	0.73 / 0.95	0.92	0.86 / 0.95	Very Good
- Monthly R^2	0.97	0.95 / 0.99	0.98	0.94 / 0.99	Very Good
Model Fit Efficiency, MFE:					
- Daily MFE	0.86	0.60 / 0.95	0.90	0.82 / 0.95	Very Good
- Monthly MFE	0.90	0.65 / 0.98	0.95	0.92 / 0.98	Very Good
Flow-Duration	Very Good		Good		Good / Very Good
Water Balance	Very Good		Very Good		Very Good
Storm Events:					
- Daily Storm Peak, % Δ	-3.3	-10.0 / 8.7	-7.6 *	-11.5 / 0.9 *	Good / Very Good
- Storm Volumes, % Δ	7.7	-0.3 / 21.0	1.1 *	-8.7 / 8.8 *	Good / Very Good
- 10% High Flows, % Δ	6.1	-5.1 / 16.7	3.2 *	-14.5 / 17.7 *	Good / Very Good

* - Means and Ranges do not include values for the Conejo Creek Validation due to questions on the rating curves (to be resolved); Conejo Creek values were -42, -32, and -22 for the storm event statistics

SECTION 6.0

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APPENDICES

APPENDIX A	**HYDROLOGY CALIBRATION / VALIDATION RESULTS FOR THE CALLEGUAS CREEK WATERSHED ABOVE ROYAL**
APPENDIX B	**HYDROLOGY CALIBRATION / VALIDATION RESULTS FOR THE CALLEGUAS CREEK WATERSHED ABOVE MADERA**
APPENDIX C	**HYDROLOGY CALIBRATION / VALIDATION RESULTS FOR THE CALLEGUAS CREEK WATERSHED ABOVE HITCH BLVD.**
APPENDIX D	**HYDROLOGY CALIBRATION / VALIDATION RESULTS FOR THE CALLEGUAS CREEK WATERSHED ABOVE HYW. 101**
APPENDIX E	**HYDROLOGY CALIBRATION / VALIDATION RESULTS FOR THE CALLEGUAS CREEK WATERSHED ABOVE CONEJO**
APPENDIX F	**HYDROLOGY CALIBRATION / VALIDATION RESULTS FOR THE CALLEGUAS CREEK WATERSHED ABOVE CALIFORNIA STATE UNIVERSITY CHANNEL ISLAND (CSUCI)**
APPENDIX G	**HYDROLOGY CALIBRATION / VALIDATION RESULTS FOR THE CALLEGUAS CREEK WATERSHED ABOVE BEARDSLEY**
APPENDIX H	**HYDROLOGY CALIBRATION / VALIDATION RESULTS FOR THE CALLEGUAS CREEK WATERSHED ABOVE REVOLON**