Hydrologic Modeling of the Santa Clara River Watershed with the U.S. EPA Hydrologic Simulation Program - FORTRAN (HSPF)

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EXECUTIVE SUMMARY

The purpose of the Santa Clara River (SCR) Watershed Feasibility Study as described in the PMP (October, 2003) is to determine the impact of the upstream urbanization, specifically in Los Angeles County, to the present natural state of the river in Ventura County and communities adjacent to the River that expect to develop close to the river banks. It is the goal of the watershed study to develop the necessary baseline data and analytical tools. In order to evaluate these impacts the feasibility study will include:

- A comprehensive update of hydrologic, hydraulic, and sediment (yield and transport) models for a range of flow rates for existing conditions and future conditions within the Santa Clara River. The hydrologic model provides the flow data needed as input to the hydraulic and sediment transport models.

- The hydrologic model will also be used to evaluate baseline and changes to water quality and pollutant loadings as a result of development or any proposed regional solutions to flooding or water quality problems.

- Generate computer models that can simulate the impacts of land use changes under existing, natural and future conditions, and provide data to forecast the resulting changes to streamflow in the Santa Clara River.

- Existing conditions include recently installed flood control and water supply/storage facilities. For future conditions, the modeling will include proposed land use changes, any additional flood control or sediment control facilities, and the effects of changes in sediment flow to the downstream areas as a result of proposed alternatives to mitigate flooding or water quality problems. The Natural Condition will be modeled by assuming the watershed has not been developed or subjected to extensive ranching or agricultural activities (pre-European).

This document is the Final Report for the watershed hydrology model of the Santa Clara River Watershed using the U.S. EPA Hydrologic Simulation Program FORTRAN (HSPF). This effort was funded directly and wholly by contract with the Ventura County Watershed Protection District (VCWPD). This report identifies and describes the watershed characteristics and types of data required/available for the model, the segmentation of the watershed for modeling purposes, model calibration and validation efforts, and the results for the Baseline and Natural Conditions Scenario model runs.

This effort has been designed to produce a comprehensive watershed model that meets the needs of the hydrologic model component of the SCR Watershed Feasibility Study as described above. This model was designed to:

a. Represent hydrologic conditions throughout the SCR watershed for a wide range of flow conditions continuously for both high flows, low flows and individual storm events

b. Provide continuous flow boundary conditions for the hydraulic and sediment transport models, at the appropriate spatial scales and boundary locations identified by the Feasibility Study participants
c. Provide a modeling framework for subsequent sediment yield and water quality modeling requirements of the Feasibility Study

d. Include a long-term database of 40 or more years of model input (e.g. precipitation, evaporation, diversions, POTWs) to allow long-term model simulations needed to develop the required flood (and low flow) frequency information at selected points throughout the SCR Watershed

e. Provide long-term model simulations for both Baseline (current) and Natural Condition alternatives as a basis for assessing and comparing with planned Future Condition alternatives

MODEL PERFORMANCE SUMMARY AND RECOMMENDATIONS

Table ES1 shows the 'Weight-of-Evidence' (WOE) summary of the model performance metrics for both the calibration and validation periods, discussed in this report. These values represent the mean and range of the various statistical measures which are presented for each calibration and validation site in Section 4 of the report. The last column provides the qualitative assessment of the overall model performance based on how the statistical means and ranges compare to the targets shown and discussed in Section 4.1. In the Simulation Plan and in Section 4.1, we proposed the following qualitative criteria to assess model performance:

> ***… for the Santa Clara River watershed modeling effort, we propose that the targets and tolerance ranges for 'Daily' flows should correspond to at least a 'Good' agreement at those sites with good quality flow (and rainfall) data, and those for 'Monthly' flows should correspond to 'Good to Very Good' agreement, for both calibration and validation comparisons.***

Based on the WOE summary shown in Table ES1, **we conclude that the SCR Watershed Model meets these stated criteria.** Although the model performance for daily flows is rated as **Poor to Very Good**, the lower values are due to calibration statistics for the SCR at Lang gage which had only 3 years of data for calibration, and none for validation, and demonstrated obvious rainfall problems; otherwise the overall model performance would be rated **Fair to Very Good**. The validation statistics and ratings shown in Table ES1 are based on 7 of the 10 validation sites, due to the same issues – mostly short records and non-representative rainfall. For a watershed of this size, over 1,600 square miles, and with some localized issues of data quality for both rainfall and flow, we cannot expect a uniform level of high model performance at all sites. The model performance statistics show a range in model accuracy but the majority of the statistics reflect a **Good to Very Good** overall performance. The **Fair** ratings for the flow duration assessment are primarily for low flow conditions, where uncertain ground water contributions have the greatest impact, and the **Poor** ratings for daily, and by extension selected storm hydrographs, are a direct result of rainfall and/or flow issues. In particular, the daily R and R^2 values leading to the **Poor** rating in Table ES1 are due to the calibration of the SCR gage at Lang, with the data issues noted above, leading to the lower values for the correlation statistics.

Table ES1. 'Weight-of-Evidence' for Santa Clara River Watershed Model Performance

	Calibration		Validation*		Overall Model Performance
	mean	range	mean	range	
Runoff Volume, % Δ	2.0	-7.8 /11.8	2.7	-5.8 / 7.0	Good / Very Good
Correlation Coefficient, R:					
- Daily Flow R	0.91	0.74 / 0.96	0.89	0.85 / 0.97	Fair / Very Good
- Monthly Flow R	0.97	0.91 / 0.99	0.97	0.96 / 0.99	Very Good
Coefficient of Determination, R^2:					
- Daily Flow R^2	0.82	0.55 / 0.92	0.80	0.72 / 0.94	Poor / Very Good
- Monthly Flow R^2	0.94	0.82 / 0.99	0.94	0.92 / 0.98	Very Good
Flow-Duration	Good / Very Good		Fair / Good		Fair / Very Good
Water Balance	Good / Very Good		Good / Very Good		Good / Very Good
Storm Events:					
- Daily Storm Peak, % Δ	-6.6	-35.9 / 20.1	-7.6	-13.4 / 9.5	Fair / Very Good
	* -- Based on 7 of 10 validation sites, i.e. excludes validation results at Pole, Hopper, and SCR at Hwy 99; See Tables 4.2 and 4.3.				

Recommendations

The following areas are provided as suggestions of where the SCR Watershed Model might be improved by addressing some of the issues identified in this modeling effort:

a. Those selected watersheds with identified rainfall and/or streamflow problems should be further investigated, possibly on a storm-by-storm basis, to resolve data issues that contribute to a mismatch between the model and available data. These watersheds include Pole Creek, Hopper Creek, SCR at Lang, and SCR at Hwy 99, which are the most obvious watersheds where improvements might be possible. The SCR at Lang did not have any available flow data during our validation period, but it could be applied and calibrated to an earlier historic period when flow was available before 1977. Other sites and specific events could also benefit from selected storm-by-storm investigations. These investigations would involve assessing supplemental rainfall data from ALERT stations, other nearby rainfall gages, and/or consistency and reliability of the flow records for each storm of concern to establish whether adjustments to the input rainfall data would be justified to improve the model performance for those events. Assessing the flow record would indicate whether measurement errors (or estimations of peak flows) may be contributing to the mis-match of observed values and model results.

b. Additional monitoring, both rainfall and flow, in selected locations would greatly assist and support any future updates to the SCR Watershed Model, and could help to improve the overall calibration. The primary areas of sparse rain gage coverage lie outside the main SCR valley, including the upper/middle Sespe Creek watershed, Upper Piru Creek watershed above Pyramid lake, and the Upper SCR watershed above Highway 99 and

Lang. Supplemental flow gages in these same areas would be recommended, in addition to locations above the Pyramid Lake and Castaic Lake reservoirs to better define reservoir inflows.

c. With the recent publication of the Draft Report for the Groundwater/Surface-Water Interaction Study (GSWI) (CH2M-Hill, 2008), further investigation of the ground water contributions and losses along the SCR mainstem might be appropriate, especially in the LA County portion of the river. In the current effort, the ground water discharges in this region were derived from limited data/information from the WARMF model, and were extended from the 1990-2000 period to cover combined calibration and validation periods of WYs 1987 – 2005. The GWSI study appears to cover a time period of 1975 – 2005 and may provide more reliable information on ground water discharges and channel losses, especially in the vicinity of the SCR at Hwy 99 gage.

d. Further evaluation of the reservoir simulations is warranted to investigate the cause for the selected ‘phantom’ spills due to rainfall errors, runoff/inflow over-simulations, and/or possible errors (uncertainty) in the data used in the reservoir simulations.

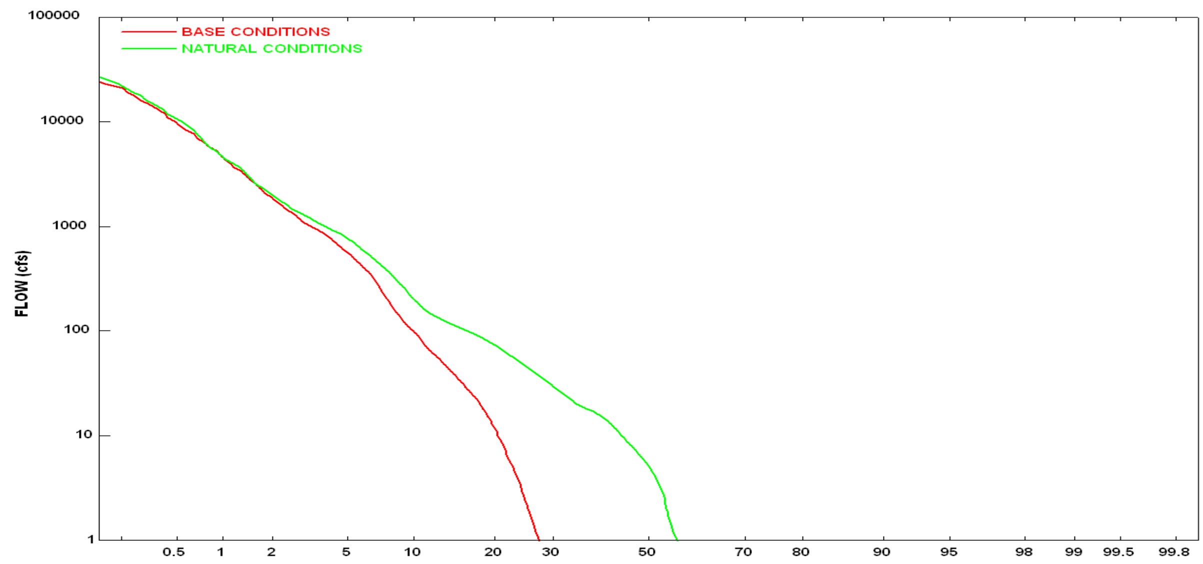
BASELINE AND NATURAL CONDITIONS SCENARIOS FOR SCR WATERSHED

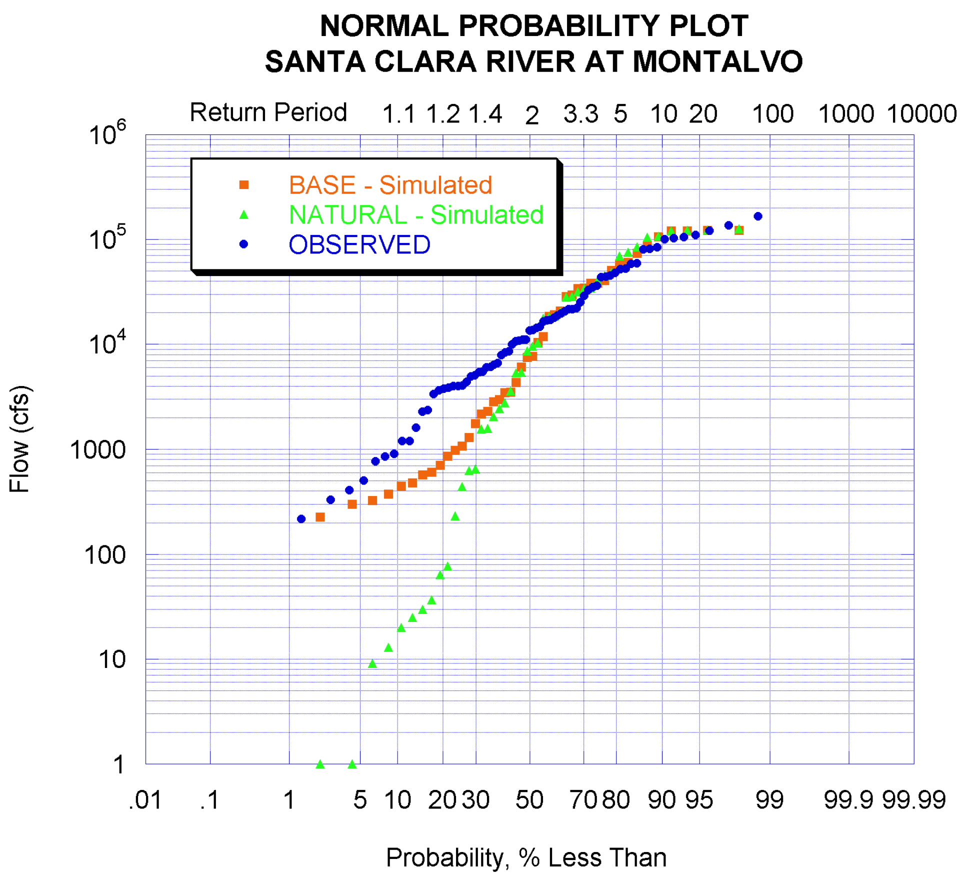
Both Baseline and Natural Conditions scenarios are required for the SCR Feasibility effort in order to establish a foundation for comparison of impacts of potential future alternative conditions on the watershed. Model changes were implemented to allow long term model runs from WY60 through WY05 for both the Baseline Condition and Natural Conditions. The Baseline represents conditions in effect during the model calibration period, i.e. land use, point sources, reservoirs, etc. used during the calibration period of WY97 through WY05 were also used for the long-term Baseline model run. For Natural Conditions, all anthropogenic impacts were removed in order to approximate how the watershed might behave under these natural, also called ‘pre-development’, conditions.

Figure ES1 shows the flow duration (Top Graph) and flood frequency (Bottom Graph) curves at Montalvo for the 46-year Baseline and Natural Condition runs; the observed flood peaks (68 annual events) are also shown in the flood frequency graphic. In Section 5, model results trace and compare the relative impacts of the two scenarios along the SCR mainstem from Saugus, to the County Line, to the confluences with Piru and Sespe Creek, and finally to Montalvo.

For most all the mainstem sites, the differences in the flow duration curves consistently show higher flow rates for the Baseline condition as compared to the Natural condition, primarily due to the influence of irrigation practices, point sources, and reservoir impacts. At Montalvo, the curves are reversed, especially below about 1000 cfs, with the Natural Condition showing higher flows than Baseline. This is mostly due to the Freeman Diversion that was extracted above the gage until the gage was moved in 2005.

For flood frequency, at Montalvo, the Baseline and Natural Conditions curves demonstrate the same general behavior as shown at the other mainstem sites, but with some dampening due to increased channel losses, surface-groundwater interactions, and water diversions and point sources. Those two curves appear to essentially match above about the 1.5 – 2 year return interval, and diverge below that level. The Observed flood peaks also show reasonably good agreement above the 2-year return interval, but with big differences below that level. This is





DAILY FLOW DURATION AT MONTALVO

Figure ES1. Baseline and Natural Conditions Daily Flow Duration (Top) and Flood Peak Frequency (Bottom) for SCR at Montalvo

likely due to a number of factors, including representation of channel losses, surface-groundwater interactions, and increased variability of rainfall coverage in the model for these relatively dry years, compared to more uniform coverage during high flow years.

In summary, both the flow duration and flood peak frequency comparisons demonstrate that the SCR HSPF Watershed model provides a logical and reasonable tool for evaluating potential changes and management alternatives for the SCR Watershed. In combination with the Weight-of-Evidence results for the calibration and validation, along with the VCWPD Design Storm efforts (Appendix L), the model has shown to be a robust representation of the hydrologic regime and behavior of the watershed. Although no model is perfect, and some improvements are recommended (as noted in Section 4.4.1), the SCR HSPF Watershed model is a viable tool and can supply the information needed for the SCR Feasibility Study.

DESIGN STORM DEVELOPMENT

Due to concerns related to the accuracy of selected rainfall records during the historic period (i.e. prior to the validation period starting in 1987), the impacts of these records on simulated annual flood peaks at selected sites, and the reliability of the use of the Log Pearson Type III analyses to estimate extreme events (e.g 100-year flood peaks) in Southern California, both VCWPD and LACDPW developed an alternate approach for design storm development. This work was performed cooperatively by both agencies and AQUA TERRA Consultants as a contract modification to the original HSPF modeling effort

The calibrated Santa Clara River HSPF model was used as the basis for generating design storm peaks and hydrographs for use in the hydraulic modeling portion of the study. The approach involved identifying a storm where saturation levels were very high across the model domain and then applying balanced design storm hyetographs for the 100-year storm for each rain gage used in the HSPF model. The gaged tributaries with long-term records were used as calibration points in the modeling. The calibration was done by adjusting the rainfall factors applied to the rain data for each subarea and associated reach at the calibration points to establish corresponding rainfall factors that could then be applied to the ungaged tributaries. The HSPF model was then run with the appropriate rainfall distributions at 5-min timesteps for the storm of interest to provide 100-year design storm peaks at the ungaged tributaries. The 100-year peaks were converted to other return intervals of interest by using multipliers developed from flow frequency analyses of long-term Ventura County and Los Angeles County stream gages. The results of these efforts are documented in Appendices L (VCWPD) and M (LACDPW), respectively.

SECTION 1.0

INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

The objective of this study is to develop a comprehensive watershed hydrologic model of the Santa Clara River Watershed for use as a tool for watershed planning, resource assessment, and ultimately, water quality management purposes. This comprehensive study is a joint effort of the Ventura County Watershed Protection District (VCWPD), Los Angeles County Department of Public Works (LACDPW), and U.S. Army Corp of Engineers (USACE) Los Angeles District, as described in the Santa Clara River Watershed Project Management Plan (USACE, 2003). The modeling package selected for this application is the U.S. EPA Hydrological Simulation Program-FORTRAN (HSPF) (Bicknell et al., 1997; 2001, 2005).

Two previous studies provide the foundation for this effort: a pilot study of the Arroyo Simi Watershed (AQUA TERRA Consultants, 2003) in the headwaters of Calleguas Creek, funded by VCWPD; and the ensuing Calleguas Creek Watershed study (AQUA TERRA Consultants, 2005), jointly funded by VCWPD and the Calleguas Creek Watershed Management Plan. In both studies, HSPF was set up and calibrated to available flow records for recent hydrologic conditions, and customized to include consideration of localized groundwater pumping impacts and lawn/landscape irrigation practices on surface water flow levels. The Calleguas model also included consideration of diversions and deep groundwater recharge losses through the streambed. In this study, initial hydrologic parameters and the procedures for representing groundwater pumping, irrigation, and channel losses were initially based on these predecessors but subjected to further review, refinement, and revisions as needed for the SCR watershed conditions.

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 Santa Clara River is the largest river system in southern California that remains in a relatively natural state. The main stem flows east-to-west from the San Gabriel Mountains of central Los Angeles County to its mouth at the Pacific Ocean between the towns of Ventura and Oxnard (see Figure 1.1). After descending from its mountainous headwaters, the river passes through the northern Los Angeles suburb of Santa Clarita, across the Los Angeles/Ventura

County line, then transitions to the mostly agricultural valley with a series of small towns, and finally discharges to the ocean.

All major tributaries flow from the north and include (from upstream to downstream) Bouquet Canyon, San Francisquito Canyon, Castaic, Piru, and Sespe Creeks. There are four major reservoirs within the tributary system. Although the Santa Clara River remains primarily in a natural physical state, the flow regime within the watershed is highly engineered to optimize delivery schedules and aquifer recharge. Bouquet Reservoir is operated by the Los Angeles City Department of Water and Power and provides important safety storage downstream from the San Andreas Fault for the water transported through the Los Angeles Aqueduct, as well as water from peak hydroelectric power generation at San Francisquito Power Plants.

Pyramid and Castaic Reservoirs are part of the State Water Project (SWP) system and are operated by the California Department of Water Resources (CDWR). Pyramid is located on Piru Creek while Castaic is located on its namesake, but the two are hydraulically connected. State water is sent through the William E. Warne Power plant into Pyramid Lake, through the Angeles Tunnel into the Castaic Power plant, and then into Castaic Lake, terminus of the West Branch of the SWP. Piru Reservoir is run by the United Water Conservation District (UWCD) and is located on its namesake creek below Pyramid. UWCD's primary operational goals are groundwater recharge, public recreation, and power generation.

The watershed drainage area is about 1646 square miles, ninety percent of which consists of rugged mountains, ranging up to 8800 feet high. Los Padres and Angeles National Forests, home to most of the major northern tributaries, comprise 47% of the watershed area. The remaining ten percent of the drainage area lies on the valley floor and coastal plain with the main stem of the Santa Clara River. The watershed is surrounded to the north, east, and south by largely undeveloped hills and canyons. The watershed is subject to severe flooding and erosion. The SCR watershed areas to be modeled in this study are shown in Figure 1.1 along with major waterbodies, municipalities, and other prominent features.

One of the goals of this effort is to provide the capability to perform long-term simulations in order to assess the impacts of alternative conditions – Baseline, Natural (pre-development) Condition, Alternative Future Conditions (e.g. land use, facilities, reservoir operations) -- on flood frequencies. A long-term data base of 46 years of model input data (precipitation, evaporation, diversions, POTWs, etc.) with the most critical being precipitation and evaporation has been developed. This data base will support long-term model runs so that model results (e.g. annual flood peaks) can be analyzed with Log Pearson III, or other procedures, to determine the 10, 20, 50 and 100 year flood peaks. In addition, the continuous long-term model results, i.e. hourly or daily flows, can provide the basis for either selecting an historic event, or adjusting such an event, to develop the 100-year event hydrograph for design purposes. This was one of the stated objectives from the PMP.

In addition, the model was used to generate storm event hydrographs for selected return intervals with synthetic input rainfall hyetographs for the corresponding rainfall return period developed from available rain gage data. This was performed by VCWPD and LACDPW for selected tributary and mainstem sites, and the results are provided in Appendices L and M, respectively.

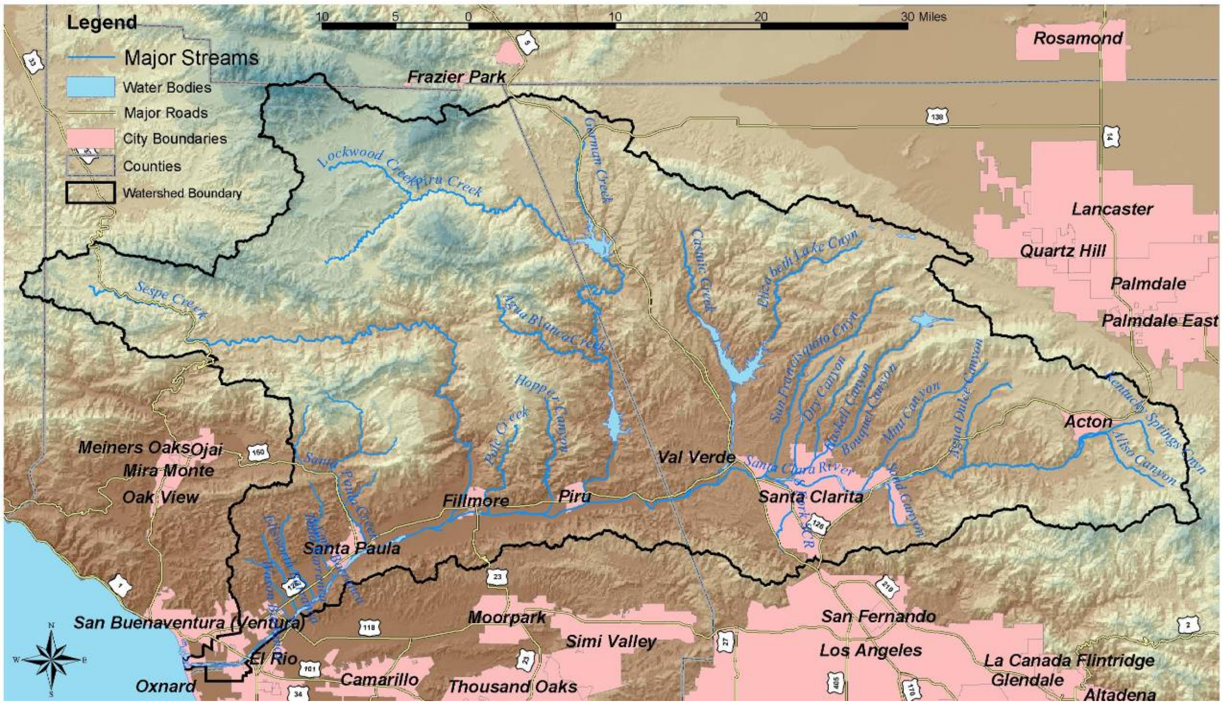


Figure 1.1 Santa Clara River Watershed Location, Municipalities, and Major Waterbodies

1.2 THIS REPORT

This document is the Final Report for the Santa Clara River Watershed hydrology model using HSPF. This effort was funded directly and wholly by contract with the VCWPD. This report identifies and describes the watershed characteristics and types of data required/available for the model, the division or segmentation of the watershed for modeling, calibration and validation efforts and results, and results of the Baseline and Natural Conditions runs.

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.
4. Scenario analyses

These steps are discussed in detail in the following sections of this report. Section 2 describes hydrologic, meteorologic, and other data needed for the simulation; Section 3 discusses other types of spatial data needed to characterize and segment the watershed, and the resulting subdivision of the watershed for modeling purposes; Section 4 describes the calibration/validation process and results, and Section 5 presents the scenario analyses and results for the Baseline and Natural Conditions scenarios.

SECTION 2.0

DATA NEEDS AND AVAILABILITY FOR THE SCR WATERSHED HYDROLOGIC MODELING

Hydrologic simulation with HSPF in climates where snow accumulation and melt are significant requires the following time series data:

1. Precipitation
2. Potential evapotranspiration
3. Air Temperature
4. Streamflow

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

All time series data for the model were placed into a Watershed Data Management (WDM) file, which is the database 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 data input, and performing a wide range of data management tasks, 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, data fill-in, and generation of graphical displays.

2.1 PRECIPITATION

Within and near the Santa Clara River Watershed, VCWPD, LACDPW, and the National Weather Service each maintain a network of precipitation stations, most of which have been continuously operating for 30 years or longer. Data have been collected at almost 100 daily stations in and around the watershed with 44 Ventura stations, 30 Los Angeles stations, and 14 NWS/NCDC stations. In addition, the LA County Fire Department maintains 10 Remote Access Weather Stations (RAWS) with hourly observations in the western portions of the watershed.

The locations of these sites in/near the watershed are shown in Figure 2.1. Stations with at least a 30-year period of record are considered “long-term”; 26 Ventura stations have 15-minute data as well, most often beginning in the mid-late 1990’s, and 15 LA stations have it beginning around the year 2000. NWS/NCDC stations are hourly with all but one also having 15-minute data starting in the early 1970’s or since they came online, whichever is later. As noted above, the RAWS stations included hourly observations with most sites beginning in the late 1980s to mid-1990s. Also shown in Figure 2.1 are isohyetal lines from the long-term isohyetal map of the county developed and provided by VCWPD (M. Bandurraga, personal communication, 2006). The development of the isohyetal map is discussed further below.

The two requirements for HSPF rainfall data are: 1) complete records (i.e., no missing data), and 2) an hourly or shorter time step is needed for adequate calibration for this watershed. While the 14 NWS/NCDC and the 10 RAWS stations were known to contain missing periods, all 91 VCWPD and LACDPW stations were originally reported to be complete, with no missing data. However, this was not the case; both the VCWPD and LACDPW data sets contained numerous missing and accumulated periods. The primary problem with the LA data was that a significant portion of the missing data were not labeled as missing within the data files; i.e., there were no missing or accumulated data flags that are normally present in meteorological data files such as these. Much of the missing data were presented as “zero” rainfall. Furthermore, many of the LACDPW stations did not have reliable or long-term short interval data. These and other data problems are discussed further below.

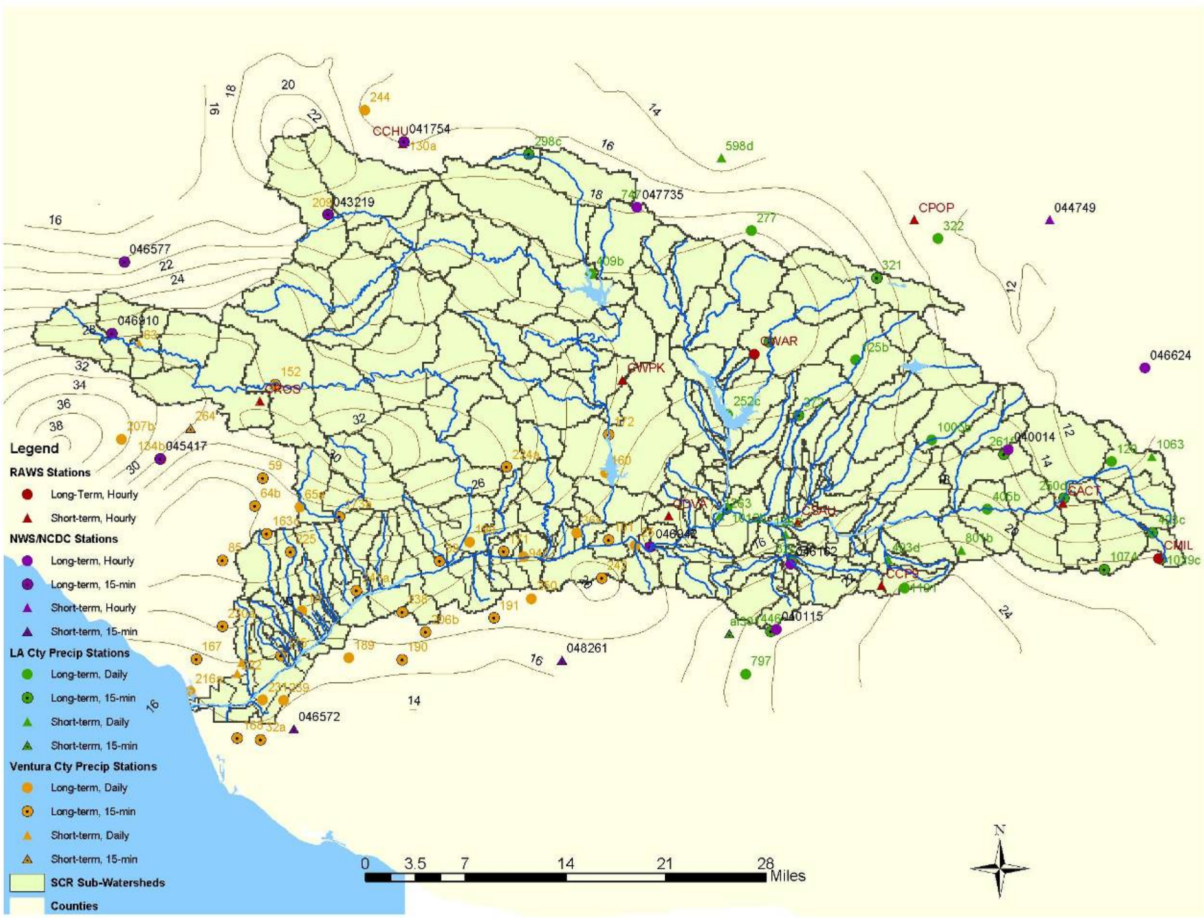


Figure 2.1 Isohyetal Pattern and Precipitation Gages in or near the Santa Clara River Watershed

Following an initial review of both the short-interval and daily precipitation, it was decided to process all of the stations that had sufficient long-term data. Given the difficulties with the data, it was determined that this would provide the most options for the calibration/validation effort and the long-term simulations. During the data correcting process, several stations were found to have such poor quality data that they were dropped from the database, or otherwise excluded from the processing. The remainder of the rainfall data then underwent a series of procedures, as listed below, to process it for use in the modeling; each of these steps is subsequently discussed in greater detail.

Rainfall Processing Procedures were as follows:

1. reformat data to WDM format and translate data quality codes
2. fill missing and accumulated data
3. disaggregate daily data to hourly time interval for modeling
4. extend selected data sets to cover calibration/validation and long term run spans

The initial step in the procedure for the rainfall data was to reformat all of the daily and short interval data to the WDM format that is required for the subsequent processing (i.e., filling and disaggregating) and modeling. This step includes processing the quality codes in the raw data and translating the "missing" and "accumulated" data codes to the WDM format along with the data. This step was accomplished using a variety of techniques, including the use of automated scripts to read, translate, and reformat the data, and manual importation of text files into WDM files.

The next step was to correct the data, which consists of filling the missing periods and distributing the accumulated totals. This step was performed using a number of scripts and other tools provided in the BASINS software package, and it made use of all of the other stations in the database. For filling missing periods, the tool searches for the nearest station that has data during the missing period, and adjusts the rainfall using the ratio of the long term annual averages of the two stations. For accumulated data, the tool uses the nearest station with data during the accumulation period, and distributes the accumulated total using the same pattern as that in the filling station. Timing differences, or lag time, is minimized by selecting the closest stations with data for the missing period.

The next processing step was disaggregating daily data at long term stations for the periods where no short interval data were available. The tool for this procedure searches a specified group of hourly stations for the one with a daily total nearest the current daily value, and distributes the total for the day using the pattern in the selected hourly station, while adjusting for the observation time (typically 8 a.m. or midnight) of the daily station. If no daily total falls within a specified tolerance, then a default triangular distribution is used. However, these procedures were applied to minimize the need for use of a triangular distribution, i.e. relatively high tolerances were used, and the most common occurrence was usually for small rainfall amounts of less than 0.1 inches/day.

The final step consisted of producing long term (1959-2005) hourly datasets for the long term simulations. This step essentially consisted of extending/filling fourteen of the selected stations where the period of record did not extend data back to 1959. Nearby stations were manually selected for extending the data sets, and the filled data were adjusted using the ratio of the long term averages of the two stations.

The LA County (and to a lesser extent Ventura County) rainfall data had a number of problems that caused the processing to be more difficult and time-consuming, and the resulting data to be less reliable. First, the stations had many more missing periods than was originally thought, and more importantly, there were numerous periods when the missing data were replaced by "0" rainfall, i.e., there were no missing data flags. In addition, there were no flags to indicate accumulated data. Once these problems were identified, the data records required painstaking analysis, including comparison of multiple stations, to replace the missing and accumulated periods with the appropriate flags so that the regular processing could be performed. This included estimating the accumulation period for apparently accumulated data. Unfortunately, a number of stations and many periods where this problem occurred were not detected until the calibration steps, and even later, during validation. This resulted in extra effort to go back and correct the identified problem rainfall data sets, and inefficiencies in re-analyzing the subsequent model results. In addition, this problem and the others that are described here, resulted in decisions during the calibration and validation to replace selected stations in the model due to the poor quality of the data. In these situations, other stations were chosen to represent the rainfall segment, or the segment rainfall was obtained from an adjacent segment.

Some problems also existed with the Ventura County data similar to the LA County data, but to a lesser degree. Generally, the accumulated rainfall periods were well identified by flags, but occasionally the missing data periods were replaced by gaps in the dates in the file. Since the data documentation stated that missing dates represent zero rainfall periods, some of the missing periods were assigned zero rainfall during the data reformatting phase, and the data processing was completed before the problem was found. When this problem was identified, all of the data had to be reformatted, filled, and disaggregated a second time to ensure that all similar gaps were identified and corrected.

Another problem with the rainfall was the confusion about the observation time of the daily data. Many LA County stations were indicated as having an observation time of 8 a.m.; however, it was apparent from the data that the observation time was incorrect, and/or the data had been shifted one day in time. Some stations apparently changed their observation times during their period of record, but this information was not available or was incorrect. This problem caused the processing, particularly the disaggregation of the data to hourly interval to be performed incorrectly in some cases, and resulted in time shifts of up to 36 hours in the rainfall. It also required laborious analysis of each record, including comparison with nearby hourly stations that are known to be accurate.

The final problem we found in several stations was the addition of nonexistent or incorrect rainfall to the record. At first, some of this was thought to be accumulated data, so it was distributed over a preceding period. Later, it was observed that the rainfall over several days to a month had been duplicated in a subsequent month. Comparison with other nearby stations indicated that the rainfall was definitely misplaced. An example of this is shown below, where the rainfall data for the first 24 days of February and April 1998 at Station 409b (DWR Pyramid Reservoir) are shown as being ***exactly*** the same each day, an obvious error.

1998	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Feb	1.37	2.65	1.12	.03	1.52	.41	2.15	.12	0	0	0	0	0	.33	.37	0	.94	0	0	.34	0	.42	1.95	2.25
Apr	1.37	2.65	1.12	.03	1.52	.41	2.15	.12	0	0	0	0	0	.33	.37	0	.94	0	0	.34	0	.42	1.95	2.25

Another type of phantom rainfall was found in several data sets. In this case, the rainfall over a period was clearly multiplied by a factor of two (and one station had a multiplier of 3 for one month) for no apparent reason. Two examples of this type of problem were found in station 408B in February-March 1998 and station 372 in May 1998. The problem of incorrect rainfall was particularly difficult to identify (prior to modeling) without painstaking analysis of each station's record. It is likely that all of these occurrences were not found, and therefore a portion of the rainfall data used for modeling still contains some instances of incorrect rainfall. However, we feel confident that we found most of the problems in the rainfall that was used for modeling, based on detailed examination and comparison of the simulated and observed flows at all of the calibration stations during the calibration and validation process.

Using the procedures outlined above, approximately 52 hourly records were processed and made available for modeling the calibration/validation period (water years 1987-2005), and most of these had periods of record to support the long term run beginning in 1959. A subset of these stations was ultimately selected to represent the rainfall over different portions of the watershed, as represented by 35 rainfall segments. The extent of each segment was based on: 1) locations and coverage of the precipitation stations, 2) the long-term isohyetal map of the county (shown in Figure 2.1), developed by VCWPD for the pilot study, 3) the Thiessen network analysis, and 4) topography and drainage patterns.

The isohyetal map is based on average annual rainfall at 120 stations in and around the watershed. The general steps performed by the VCWPD to develop the map are summarized below.

1. Location and average annual rainfall data (1970-2005) were collected for stations in Ventura, Santa Barbara. and Los Angeles Counties.
2. Missing data were filled by records from nearby stations, weighted according to the ratio of mean annual rainfall.
3. A spreadsheet was created with the data from Steps 1 and 2, and it was used to create a GIS point coverage.
4. The ArcGIS Geostatistical Analyst Extension was used to apply the Kriging regression technique to interpolate values across the watershed based on the average annual rainfall values at gage locations.
5. The “kriged” output shapfile was converted to a raster (i.e., grid) coverage.
6. This raster was smoothed using the Focal Statistics Tool in ArcToolbox (neighborhood set to circle with radius of 2).
7. Contours were then built from the smoothed raster output surface using the Surface Analyst in the Spatial Analyst Extension.

A Thiessen analysis is a standard hydrologic technique to define the 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. Initially, a rainfall segmentation map was developed consisting of 46 segments. Revisions and adjustments were made to these polygons based on elevation, isohyetal lines, drainage boundaries, and finally, due to difficulties with some of the rainfall data sets. Figure 2.2 shows the final 35 Thiessen polygons and the resulting rainfall segmentation for the model, including the rainfall station associated with each polygon. The rainfall stations used in the modeling are listed in Table 2.1 along with their periods of record.

The watershed has a major gap in its rainfall coverage in northeastern Ventura County (i.e. Sespe and Upper Piru creek watersheds) due to rugged, inaccessible regions of Los Padres and Angeles National Forests. Two options were identified as possibilities to extend the precipitation coverage into this area: (1) using the isohyetal map for the entire watershed (developed by VCWPD staff) to project precipitation from surrounding stations into this region; and/or (2) processing a selected number of ALERT station raw data to fill in where direct rainfall observations were missing. Unfortunately, the relatively short period of record of the ALERT stations, and their locations which surrounded, but did not compensate or fill-in the rainfall gap, precluded this option. Thus, the surrounding stations were used directly to model this ‘gap’ region, with adjustment factors derived from the isohyetal map (Figure 2.1).

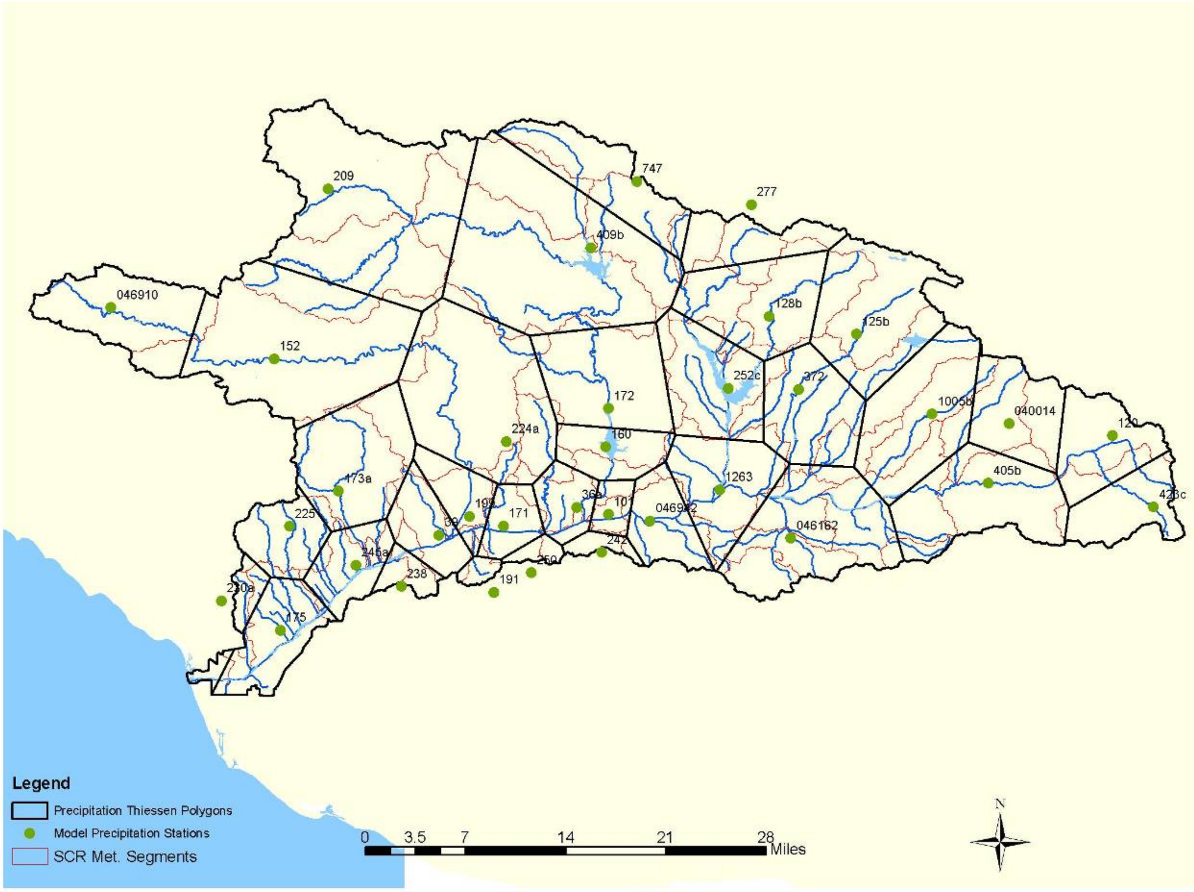


Figure 2.2 Rainfall Thiessen Network and Model Segments

Following the recommendations provided in the draft calibration report VCWPD provided data from selected ALERT stations, primarily in the Sespe Watershed, that allowed investigation and correction of rainfall problems for individual storms occurring after about 1999. The daily rainfall amounts from the available ALERT stations, including ALERT Stations numbered 20, 40, 180, 197, 268, and 280 (Provided by Scott Holder, VCWPD, personal communication dated 15 April 2008) were compared to those from the primary stations used in the calibration; as noted above, these ALERT stations were primarily in the Sespe Creek watershed (station locations are shown in Figure 2.2 in the SCR Simulation Plan (AQUA TERRA Consultants, 2006). These ALERT daily storm values were used to adjust the storm amounts included in the calibration gages for Sespe Creek (046910, 152, 224a, and 199 in Figure 2.2 above) to better represent the storm rainfall over the applied watershed area for a few selected major events, such as events in February 2000, March 2001, and December 2004-February 2005.

The model uses an hourly timestep primarily due to the lack of adequate coverage for all parts of the watershed with more precise 15-minute rainfall. In conjunction with the significant rainfall data quality problems noted above, this lack of adequate coverage precluded the use of 15-minute rainfall for the HSPF modeling of the entire watershed. It may be appropriate to consider these shorter (15-minute, or 5-minute) time interval data in selected watersheds in the future, if there is sufficient detailed coverage, but the SCR Watershed model is currently set up to run the entire watershed in a single operation for the desired time period (e.g. calibration, validation, historic time periods), which requires use of the same time interval for all model calculations throughout the entire watershed. Moreover, our experience with watersheds of this size supports, and is consistent with the use of hourly rainfall data for this modeling effort. See Section 4.3.4 for further discussion of time step issues and impacts.

Table 2.1 Precipitation Stations Used to Model the Santa Clara River Watershed

Source	Precipitation Station ID/Name	Daily		15-min / Hourly	
		Start	End	Start	End
VCWPD	36a - Piru-County Fire Station	10/02/26	09/27/05		
VCWPD	39 - Fillmore-Rancho Sespe	07/17/12	09/27/05	10/01/00	09/30/05
VCWPD	101 - Piru-Camulos Ranch	10/01/28	09/30/05	02/02/76	09/30/05
VCWPD	152 - Piedra Blanca Guard Station	10/17/49	09/27/05		
VCWPD	160 - Piru-Temescal Guard Station	11/10/49	09/27/05		
VCWPD	171 - Fillmore-Fish Hatchery	10/01/56	09/30/05	02/02/76	09/30/06
VCWPD	172 - Piru Canyon	10/01/56	09/30/05	02/02/76	09/30/05
VCWPD	173a - Santa Paula Cyn-Ferndale Ranch	12/06/56	09/30/05	02/02/76	09/30/05
VCWPD	175 - Saticoy Fire Station	10/01/56	09/30/05	02/10/76	09/30/05
VCWPD	191 - Moorpark-Downing Ranch	11/14/55	09/30/05	12/04/97	09/30/05
VCWPD	199 - Fillmore-County Fire Station	10/01/59	09/27/05		
VCWPD	209 - Lockwood Valley-County Yard	10/01/60	09/30/05	09/20/66	09/30/05
VCWPD	224a - Sespe-Westates	09/19/66	09/27/05	10/01/97	09/30/05
VCWPD	225 - Wheeler Canyon	07/01/66	09/30/06	09/03/66	09/30/05
VCWPD	230a - Ventura-Sexton Canyon	11/12/71	09/27/05	10/01/98	09/30/05
VCWPD	238 - South Mountain-Shell Oil	10/01/70	09/30/06	02/02/76	10/01/06
VCWPD	242 – Tripas Canyon	10/01/71	09/30/05	08/01/77	09/30/05
VCWPD	245a - Santa Paula-UWCD	11/01/60	09/30/05	09/16/75	09/30/05
VCWPD	65a - Upper Ojai Summit County Fire Station	10/06/24	09/30/05		
LACDPW	120 - Vincent Patrol Station	10/02/48	01/31/06		
LACDPW	125b - San Francisquito Canyon Power Hse	10/02/48	01/31/06		
LACDPW	128b - Elizabeth Lake- Warm Springs Camp	10/01/27	02/01/06		
LACDPW	252c - Castaic Lake	10/03/72	07/31/05		
LACDPW	277 - Sawmill Mountain	10/03/39	06/30/03		
LACDPW	372 - San Francisquito Power House No. 2	10/07/39	01/31/06	04/23/04	02/01/06
LACDPW	405b - Soledad Canyon	10/06/39	10/31/05		
LACDPW	409b - Pyramid Reservoir	10/02/38	05/31/05		
LACDPW	423c - Angeles Forest - Aliso Cyn	10/02/38	02/28/06	10/02/01	02/01/06
LACDPW	446 – Aliso Canyon – Oat Mountain	10/17/49	2/28/06	03/06/99	02/01/06
LACDPW	747 – Sandberg	10/01/37	06/30/05		
LACDPW	1191 – Bear Divide	10/12/71	10/31/05		
LACDPW	1005b - Mint Canyon Fire Station	07/18/46	05/31/05		
LACDPW	1263 - Valencia Reclamation Plant	10/08/85	10/31/05		
NCDC/NWS	40014 - Acton Escondido Canyon			07/01/48	01/31/06
NCDC/NWS	46162 - Newhall Soledad			07/01/68	01/31/06
NCDC/NWS	46910 - Pine Mountain Inn			01/01/65	09/30/05
NCDC/NWS	46942 - Piru Telemetering			06/01/71	10/01/05
RAWS	CWAR – Warm Springs Mountain			04/12/86	03/02/06

Highlighted – Gages used in irrigation calculations, see Section 2.5.4

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 and water balance components, based on input ET parameters and the input PET data.

Pan evaporation data are available from both the VCWPD and LACDPW, at various sites within each county, and *'reference evapotranspiration'* is available from the California Irrigation Management Information System (CIMIS) (http://wwwcimis.water.ca.gov/cimis/welcome/) at a limited number of selected locations in and around the Santa Clara River Watershed. R*eference Evapotranspiration,* ETo, refers to the total evaporative losses (evaporation and plant transpiration) from a reference crop, usually a short-turf grass growing under fully satisfied moisture conditions, i.e. no moisture stress. ETo values for other crops are estimated with a crop coefficient applied to the ETo, as discussed below in Section 2.5.

Figure 2.3 shows the locations of about 27 evaporation stations within and near the SCR Watershed. In addition, the map displays the relevant CIMIS *'reference evapotranspiration'* (ETo) zones which are regions of similar climate and vegetation characteristics used by the CIMIS to define ETo values for water use and irrigation demand estimation (discussed further below). Generally pan evaporation is the largest number, followed by ETo, and then PET; as noted above, pan coefficients (either annual or monthly) are used to transform pan evaporation into PET.

Similar to precipitation, HSPF requires complete records for PET (i.e. no missing data), and preferably at a daily interval, as opposed to monthly values, in order to best represent vegetation and soil evaporative processes during seasonal transitions that may occur within a month.

After review of the available evaporation data identified in the SCR HSPF Simulation Plan (AQUA TERRA Consultants, 2006) (Figure 2.3), the stations for use in the model were selected based on geographical locations and their periods of record; the selected stations are grouped by source and listed in Table 2.2. For modeling purposes, there is a reasonable distribution of evaporation stations across the watershed, as shown in Figure 2.2, with noticeable gaps in coverage in northeastern Ventura County (same region as the precipitation gap discussed above) and the far eastern watershed in LA County.

The El Rio UWCD Spreading Grounds provides long-term coverage for the coastal plain at the west end of the watershed. This area is represented by CIMIS Zones 3 and 4, which are almost identical in terms of monthly and annual total ETo values. The Fillmore Fish Hatchery provides long-term coverage for the lower river valley represented by Zone 9. Matilija provides coverage for the western spur of the watershed in Zone 10. Piru-Temescal and Castaic represent the mid-range altitudes of the high desert mountains in Zone 14, while Pyramid represents the more northern portions of that region. Piedra Blanca and Lockwood are located at high elevations in the mountainous landscape of the northern and northwestern regions of SCR watershed in Zone 14. The Bouquet station is also located in Zone 14 in the mid-elevation landscape and it covers the north-eastern portion of the watershed in LA County. The far eastern portion of the watershed shows a lack of evaporation stations within the watershed boundaries, so we relied on the neighboring stations at Pacoima Reservoir, Big Tujunga Dam, and Palmdale.

Fortunately, pan evaporation data are less spatially variable than rainfall; therefore, a watershed of this size generally requires many fewer stations than precipitation stations. Unfortunately, only monthly data are available for the majority of the stations shown in Table 2.2 including those with long-term records. Daily data are only available at a limited number of the stations, and primarily for later time periods. The NCDC Lake Cachuma station in Santa Barbara County

Figure 2.3 Evaporation Gages in or near the Santa Clara River Watershed

Table 2.2 Evaporation Stations Used In the Santa Clara River Watershed Model

Source	Evaporation Station ID/Name	Monthly		Daily	
		Start	End	Start	End
VCWPD	152 - Piedra Blanca Guard Station	10/51	09/77		
VCWPD	160 - Piru-Temescal Guard Station	10/51	12/05	10/01/95	09/30/96
VCWPD	171 - Fillmore Fish Hatchery	10/69	11/05		
VCWPD	209 - Lockwood Valley-County Yard	10/70	07/92		
VCWPD	236 - Matilija Dam Weather Station	01/69	09/05		
VCWPD	239 - El Rio – UWCD	10/72	11/05	04/01/91	07/31/06
NCDC	41253** - Cachuma Reservoir			02/01/55	01/31/06
LACDPW	33 A - Pacoima Reservoir	10/81	09/05	10/01/87	09/30/05
LACDPW	46 D - Big Tujunga Dam	10/81	09/05	10/01/91	09/30/05
LACDPW	252 C - Castaic Reservoir	10/81	12/05		
LACDPW	409 B - Pyramid Reservoir	10/81	12/05		
LACDPW	1058 B - Palmdale	10/81	09/05	10/01/91	09/30/05
LACDWP	9008 - Bouquet Reservoir	01/97	02/06	01/01/97	02/28/06

** NCDC coop station ID

was used to disaggregate monthly to daily values; it is the nearest known, and only, long-term (> 30 years) daily pan evaporation station with climatic and topographic features similar to portions of the Santa Clara River watershed. A site visit of the Lake Cachuma area indicated no apparent reasons (e.g. coastal fog, vegetation, topography, climate) for evaporation patterns to vary compared to the SCR watershed; we also performed correlation analyses for monthly, summed wet season months (October to March of water year) and each wet season month for Cachuma Reservoir station and the other stations to evaluate the use of the Cachuma data and found significant agreement, so these correlation analyses helped to confirm this assumption. The Cachuma data also were used to disaggregate monthly totals into daily values for both the Calleguas and Arroyo Simi studies, and also provided the basis for developing the long-term daily evaporation timeseries needed for scenario runs.

We also investigated both DWR and LA Department of Water and Power for any other evaporation data, but none were available. During the Calleguas HSPF effort we obtained daily data sheets from UWCD for their El Rio site from April 1991 through November 2003, which were processed and input to the WDM file. For this study VCWPD provided an extension of the El Rio daily data through July 2006 to cover the needed calibration period.

With the various mis-matches of daily and monthly data, and the existence of a number of missing time periods, the evaporation data required processing to generate the complete hourly PET timeseries required by HSPF. Stations with daily time series having missing points were filled using the nearest daily stations with the values adjusted by ratios, based on longterm averages at each station, to account for the geographical differences.

We extended the stations with monthly time series back to 1956 using nearby stations and longterm ratios, and then we disaggregated the monthly evaporation to daily using the daily distribution (within each month) for the Cachuma station, for those time periods when daily data were not available. Finally, the resulting daily data timeseries were then disaggregated to hourly using the Disaggregate-Evapotranspiration utility in WDMUtil, which distributes each daily value based on the pattern of daylight at the given latitude on that day. Cloud cover is not usually considered when distributing daily evaporation to hourly due to the lack of hourly cloud cover data and the relatively small impact it would have on both PET (versus Actual ET) and on model results.

Table 2.3 Monthly and Annual Pan Evaporation Rates (in) for stations used in the SCR Watershed Model.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Tujunga	7.7	5.1	4.4	3.8	4.0	4.6	6.0	7.5	9.2	11.6	11.8	9.6	**85.2**
Pacoima	8.0	6.9	6.1	5.6	5.1	5.4	6.7	6.6	7.2	9.3	10.1	9.1	**86.2**
Palmdale	5.5	3.1	2.0	1.9	2.4	4.5	6.6	8.9	11.4	12.6	11.5	7.8	**78.2**
Bouquet	6.4	4.3	3.6	4.5	6.3	5.1	6.1	8.2	8.7	11.0	10.7	8.0	**82.8**
Castaic	6.5	4.9	3.8	3.7	2.8	4.4	4.5	6.0	7.4	8.5	8.9	7.7	**69.2**
Pyramid	6.2	4.7	3.8	3.2	3.1	4.5	4.6	7.0	9.2	9.6	9.2	8.2	**73.3**
Piedra	5.0	2.7	1.8	1.6	2.3	3.4	4.6	6.0	7.6	9.0	8.6	6.9	**59.5**
Piru-Tem.	5.8	3.7	2.7	2.3	2.4	3.3	4.5	5.8	7.1	9.1	9.0	7.3	**62.9**
Fillmore.	4.5	3.4	3.3	3.2	3.3	4.2	5.3	6.0	6.8	7.6	7.1	5.6	**60.3**
Lockwood	4.9	2.5	1.2	0.5	1.3	2.9	4.2	6.8	8.0	9.1	8.3	6.6	**56.1**
Matilija	5.2	3.2	2.2	2.2	2.8	4.0	5.6	6.4	7.6	9.1	8.9	7.1	**64.4**
El Rio.	4.8	4.2	3.9	3.5	3.7	4.6	5.5	6.1	6.3	7.0	6.5	5.4	**61.5**
Cachuma	5.4	3.4	2.9	2.5	3.0	4.4	6.0	7.5	8.6	9.5	9.0	7.0	**69.1**
Mean	**5.8**	**4.0**	**3.2**	**3.0**	**3.3**	**4.3**	**5.4**	**6.8**	**8.1**	**9.5**	**9.2**	**7.4**	**69.9**
Min	4.5	2.5	1.2	0.5	1.3	2.9	4.2	5.8	6.3	7.0	6.5	5.4	48.0
Max	8.0	6.9	6.1	5.6	6.3	5.4	6.7	8.9	11.4	12.6	11.8	9.6	99.2

These efforts produced the complete pan evaporation timeseries (hourly values) for all 12 stations used in the SCR HSPF model, as listed in Table 2.2, for the entire period from October 1956 to September 2005, a 50-year span. The mean monthly and annual values for each of those 12 stations, along with the Cachuma Reservoir station, are listed in Table 2.3. Elevations for those stations are listed in Table 2.4

Table 2.4 Elevations for Evaporation Stations used for the SCR Watershed Model

Station Name	Elevation (ft)
Pacoima Reservoir	1950
Big Tujunga Dam	2300
Castaic Reservoir	1515
Pyramid Reservoir	2610
Palmdale	2543
Bouquet	3000
Piedra Blanca Guard Station	3065
Piru-Temescal Guard Station	1080
Fillmore Fish Hatchery	465
Lockwood Valley-County Yard	5150
Matilija Dam Weather Station	1060
El Rio - UWCD	105
Cachuma Reservoir	781

The final adjustment of the pan evaporation data is to transform it into PET with an appropriate pan coefficient. Climatic maps of the region show an estimated pan coefficient of 0.70-0.80 in order to estimate lake evaporation (NWS, 1982a, 1982b). The coefficient used in the Arroyo-Simi and Calleguas studies was 0.74. For the SCR Watershed, LACDPW provided monthly pan coefficients for the LA County stations (actually developed by the US Weather Bureau for Lake

Table 2.5 Monthly Pan Coefficients for both LA County and Ventura County.

Month	Castaic (LA County) Pan Coef.	Ratio	Ventura County Pan Coef.
October	0.93	1.18	0.871
November	0.97	1.23	0.909
December	0.95	1.20	0.890
January	0.82	1.04	0.768
February	0.63	0.80	0.590
March	0.68	0.86	0.637
April	0.66	0.84	0.618
May	0.68	0.86	0.637
June	0.77	0.97	0.721
July	0.74	0.94	0.693
August	0.78	0.99	0.731
September	0.87	1.10	0.815
Annual Average	0.79		0.740

Elsinore), so we used that same monthly distribution to calculate monthly pan coefficients for VC evaporation stations. Using the LA County pan coefficient monthly distribution, we defined monthly ratios based on the mean annual value of 0.79 (month pan coefficient divided by annual average) and then multiplied the VC value of 0.74 by each monthly ratio to obtain the monthly pan coefficient (see Table 2.5). These values were used for each of the VC evaporation stations to convert pan evaporation into PET for use in HSPF.

The final step in defining the use of evaporation data for the SCR HSPF model is to assign the 12 PET time series to the appropriate portions of the watershed representing the areas that will experience the PET demand calculated at each of the stations. Analogous to the precipitation gage assignments (discussed above), Thiessen polygons were determined for each of the selected evaporation stations and were then overlaid onto the hydrography and subbasin boundaries, as shown in Figure 2.4. The color-coded and shaded areas associated with each gage identify the areas of the watershed that receive that stations PET data when performing its hydrologic calculations for all land within the shaded region. Although this final step is really part of the watershed segmentation process (to be discussed in Section 3), we've included it here as it is the natural conclusion to the evaporation data development process.

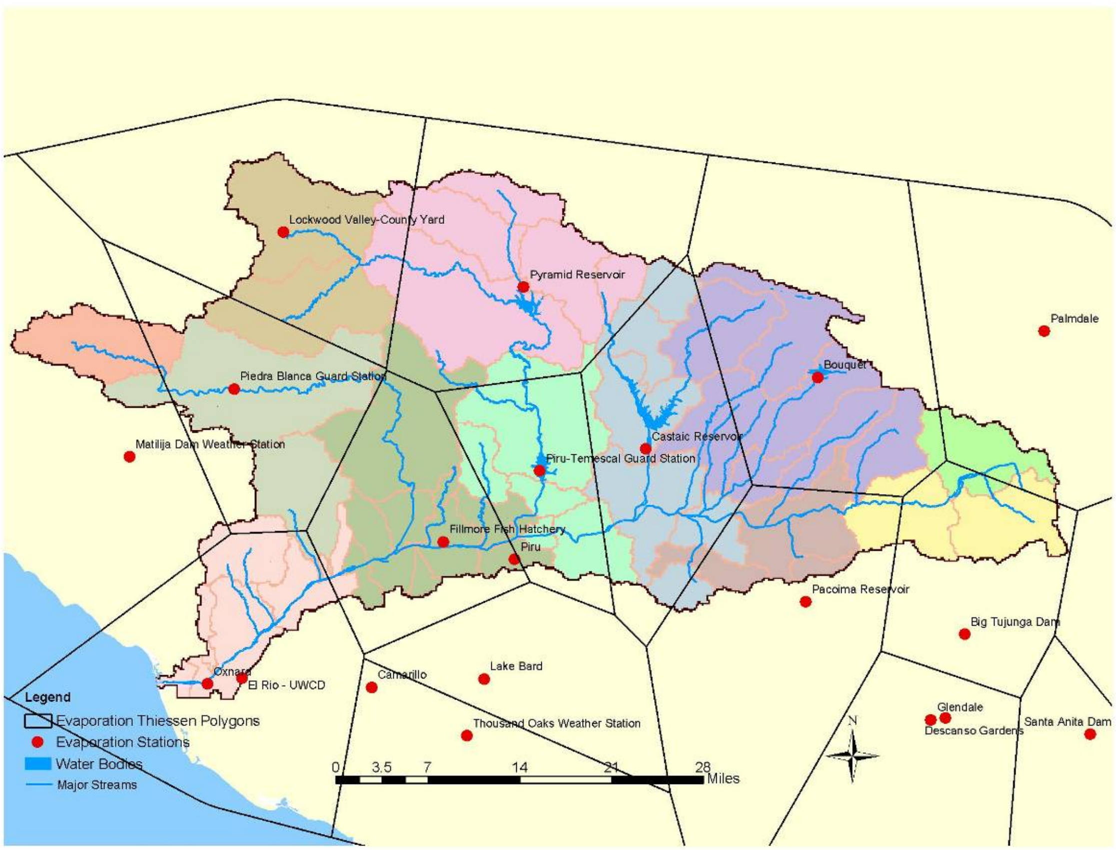


Figure 2.4 Thiessen Polygons for Evaporation Stations used in the SCR Watershed Model

2.3 AIR TEMPERATURE AND SNOW DATA

Due to the high elevations in the upper watershed, snow was considered in the Santa Clara River HSPF model for a limited number of high elevation model segments or subbasins. Consequently, hourly air temperature time series were required as input to the model with the simplified degree-day snow simulation option selected within HSPF. Fortunately, there is an extensive collection of 32 air temperature gages in and around the watershed, including 7 CIMIS, 10 Remote Automated Weather Stations (RAWS), 1 Automated Surface Observing System (ASOS), and 14 National Climatic Data Center (NCDC) sites. Data were acquired from the NCDC. The NCDC stations report daily highs and lows, which were distributed to hourly with the *Disaggregate:Temperature* utility in WDMUtil. Ultimately, these stations may be used when water quality and water temperature simulation is required for the SCR Watershed.

The air temperature stations are grouped by source and listed in Table 2.6; long-term stations are highlighted in yellow. Their locations relative to the watershed are shown in Figure 2.5. Areas on the map with regular winter snowfall correlate roughly to the green and blue shading at elevations above 5000 feet. This corresponds primarily to the upper regions of the Piru Creek (above Pyramid Lake) and Sespe Creek watersheds.

Once the spatial and temporal coverages of the air temperature stations were reviewed, records for several of the NCDC gages were purchased from the Western Regional Climate Center. After analyzing the data for different stations, we found that some stations had missing periods and others had shorter records than expected. Using the closest stations and a lapse rate of 3.5°F/1000 feet (from the HSPF manual), we filled the missing points with the following equation:

$$T_M = T_A + \left(\frac{3.5}{1000}\right) * \left(E_A - E_M\right)$$

Where: T_M, T_A = missing and available temperature values
E_M, E_A = elevations of stations with missing and available data

We then extended the temperature records to the longest period possible. The WDM utility software was used to disaggregate the daily maximum/minimum (TMAX and TMIN) to an hourly time series. For the modeling purposes, we focused on stations located at higher altitudes and those in the vicinity of the regions in the upper Sespe and Piru creek watersheds where significant annual snowfall, in the range of 5 to 10 inches per year, often occurs and may be evident on the ground for more than a few days, i.e. one to two months in some years. These were the regions where snow was modeled.

We also obtained the available snow data for Mount Wilson from the NCDC, located at elevation 5710 feet, at NCDC Station 046006 (see Figure 2.5), located approximately 20 miles southwest of the eastern boundary of the SCR Watershed. The only available snow data for Ventura County, to our knowledge, was provided to us by Mr. Tom Johnson (Johnson Weather Watch, personal communication, 26 April 2007). Mr. Johnson provided a summary of mean snow conditions (from a 1969 publication titled “The Climate of Ventura County”), copies of mean annual snow isolines, and other synoptic data on snowfall and snow depths. These data served as a basis (1) to identify the regions most often experiencing significant snow fall, and (2) to calibrate the snow parameters where snow was simulated in the upper segments of Sespe Creek and Upper Piru Creek.

Based on these data and information, we selected Chuchupate (CCHU) and Rose Valley (CROS) temperature stations to be included in the snow modeling since they were at high elevations and the closest stations to the model segments where snow was simulated. The data for these two stations were filled and extended back to 1959 to cover the potential time period of alternative scenario model runs.

Table 2.6 Air Temperature Gages in the Santa Clara River Watershed*

Source	Air Temperature Station ID/Name	Daily / Hourly	
		Start	End
CIMIS	101 - Piru	08/27/91	02/20/05
CIMIS	133 - Glendale	08/07/96	05/02/06
CIMIS	152 - Camarillo	01/21/00	03/16/06
CIMIS	156 - Oxnard	10/11/01	05/02/06
ASOS	047735 - Sandberg	03/01/48	03/01/06
RAWS	CCHU - Chuchupate	02/17/99	02/21/06
RAWS	CROS - Rose Valley	11/09/93	03/02/06
RAWS	CWPK - Whitaker Peak	10/14/99	03/02/06
RAWS	CWAR - Warm Springs Mtn	04/12/86	03/02/06
RAWS	CDVA - Del Valle	11/23/98	03/02/06
RAWS	CSAU - Saugus	09/03/94	03/02/06
RAWS	CCP9 - Camp 9	09/02/95	03/02/06
RAWS	CMIL - Mill Creek Summit	04/06/89	03/02/06
RAWS	CACT - Acton	01/01/95	03/02/06
RAWS	CPOP - Poppy Park	09/02/95	03/02/06
NCDC	041013 - Bouquet Canyon	07/01/96	03/20/06
NCDC	047957 - Santa Paula	01/01/1894	01/01/06
NCDC	040014 - Acton Escondido	10/01/18	03/31/06
NCDC	040798 - Big Tujunga Dam	01/01/32	03/31/06
NCDC	042941 - Fairmont	02/01/09	01/31/06
NCDC	044628 - La Crescenta	01/01/18	01/31/06
NCDC	044749 - Lancaster Wm J Fox Fld	04/01/74	03/31/06
NCDC	044863 - Lebec	07/01/48	12/31/05
NCDC	046006 - Mt Wilson CBS	07/01/48	01/31/06
NCDC	046399 - Ojai	01/01/31	01/01/06
NCDC	046602 - Pacoima Dam	05/01/43	01/31/06
NCDC	046624 - Palmdale	01/01/03	01/31/06
NCDC	046940 - Piru 2 ESE	06/01/59	01/31/06
NCDC	048014 - Saugus Power Plant	07/01/18	01/31/06

* -- Longterm stations highlighted in yellow

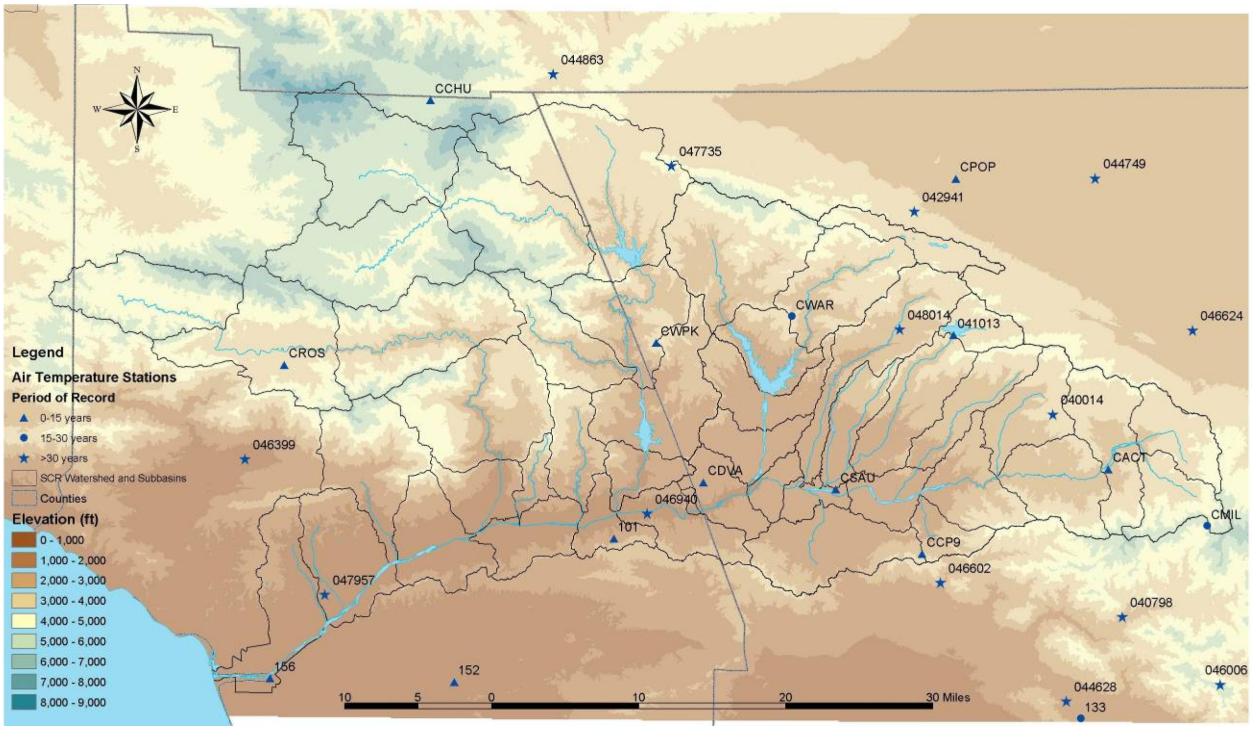


Figure 2.5 Air Temperature Gages in or near the Santa Clara River Watershed

2.4 STREAMFLOW

To calibrate the HSPF model, reliable long-term, continuous records of measured streamflow data are compared with simulated values, with the comparisons performed by multiple graphical and statistical methods (discussed in Section 4). Flow data are available for an extensive array of stream gages throughout the watershed, on the Santa Clara River and its main tributaries, as described in the Simulation Plan. The Simulation Plan identified and listed almost 40 such stations from data received from both VCWPD and LACDPW. These stations and their data were reviewed in order to select those stations with reliable and relatively complete records (i.e. few missing values) for the entire time period of the model calibration and validation, extending from WY 1988 (October 1987) through WY 2005 (September 2005). This effort produced the reduced list of stations listed in Table 2.7 and whose locations are shown in Figure 2.6; the table includes both the County and USGS identification numbers, whereas the map shows just the County IDs, but it also includes all the original stations listed in the Simulation Plan.

Table 2.7 includes all the stations used in the calibration/validation efforts, along with those used in modeling the reservoirs (further discussed in Section 4); the yellow highlighted stations in Table 2.7 were used in the calibration/validation, and the blue highlighted stations were used in the reservoir simulation. A number of the stations are co-located or have been moved during their record period; these are discussed separately below. The only non-highlighted station in Table 2.7 is for the SCR at 12th Street Bridge which was active starting on 1/18/05 so its data were compared only for the last few months of the calibration period, as a consistency check with the other mainstem gages and to fill in a few missing values for VCWPD Gage 724 at Freeman Diversion.

Table 2.7 Streamflow Stations for Model Calibration and Validation in the SCR Watershed

County ID	Station Name	USGS ID	County	Period of Record	
				Start	End
F092C	Santa Clara R At Old Hwy 99 Nr Saugus	11108000	Los Angeles	10/01/29	09/30/05
F093B	Santa Clara R Ab Rr Station Nr Lang	11107745	Los Angeles	10/01/49	09/30/05
F377	Bouquet C Nr Saugus	11107860	Los Angeles	10/01/70	09/30/03
U106 U107	Castaic C Blw Mwd Div Blwstaic Lk Nrstaic Castaic Lagoon Parshall Fl Nrstaic	11108134 11108135	Los Angeles	10/01/76	09/30/05
U201	Canada De Los Alamos Ab Pyramid Lk	11109395	Los Angeles	10/01/76	09/30/03
F328A	Mint Canyon Creek At Sierra Hwy	11107770	Los Angeles	11/05/01	09/30/05
790 790A	Piru C Bl Pyramid Lk Nr Gorman Piru C Ab Frenchmans Flat	11109525 11109550	Los Angeles	10/01/76	09/30/05
U203	WB Aqueduct A William Warne PP Nr Gorman	11109398	Los Angeles	10/01/95	09/30/05
701	Hopper Creek Near Piru	11110500	Ventura	10/01/30	09/30/05
705A	Piru Creek Above Lake Piru	11109600	Ventura	10/01/55	09/30/05
707 707A	Santa Clara River At L.A.-Ventura Co. Line Santa Clara R Nr Piru	11108500 11109000	Ventura	10/01/27	09/30/05
708 708A 719 724	Santa Clara River At Montalvo Santa Clara R A Saticoy Saticoy Div Nr Saticoy Santa Clara River at Freeman Diversion	11114000 11113920 11113900 NA	Ventura	10/01/27 10/07/04	09/30/04 09/30/05
709A	Santa Paula C Nr Santa Paula	11113500	Ventura	10/01/27	09/30/05
710A	Sespe C Nr Fillmore	11113000	Ventura	08/31/11	09/30/05
711	Sespe Creek Near Wheeler Springs	11111500	Ventura	10/01/47	09/30/05
713	Pole Creek At Sespe Creek		Ventura	03/01/74	09/30/05
714	Piru Creek Below Santa Felicia Dam	11109800	Ventura	10/01/55	09/30/05
716	Piru C Bl Buck C Nr Pyramid Lk	11109375	Ventura	10/01/76	09/30/03
720	Santa Clara River at 12th Street	NA	Ventura	01/18/05	09/30/05

As noted above, several stream gages have been moved over the course of their lifetime for reasons including safety, accessibility, and accuracy. For calibration and validation purposes, the records from those gages were combined into one continuous time series, with the flows adjusted by drainage area ratios. The paired or grouped gages that fall into this category are: 708, 708A, 719, and 724; 707 and 707A; 790 and 790A; and U106 and U107; however, only the first two groups were used in calibration as the other two were used in the reservoir simulations. For the first two groups, mass curve analyses of the combined records indicated no systematic differences so the combined record was judged acceptable.

Stations 708, 708A, 719, and 724 collectively represent flow at the Santa Clara River outlet. Station 708 was installed by the USGS at the Hwy 101 Bridge near Montalvo in 1927. The gage was moved upstream to the Hwy 118 Bridge near Saticoy in the late 1990's. The USGS ceased operating the gage entirely after WY 2004. In 2005 the VCWPD began operating Station 724 upstream at the Freeman Diversion, collecting flow data through the end of WY 2005. There are no tributaries between Stations 708 and 708A, but ephemeral tributaries, such as Wason Barranca and Ellsworth Barranca, drain into the Santa Clara River between Stations 719 and 708A.

The 'County Line Station' 707 was installed in 1952 by the USGS just downstream of the Los Angeles/Ventura County border. The gage was moved downstream to the Newhall Ranch

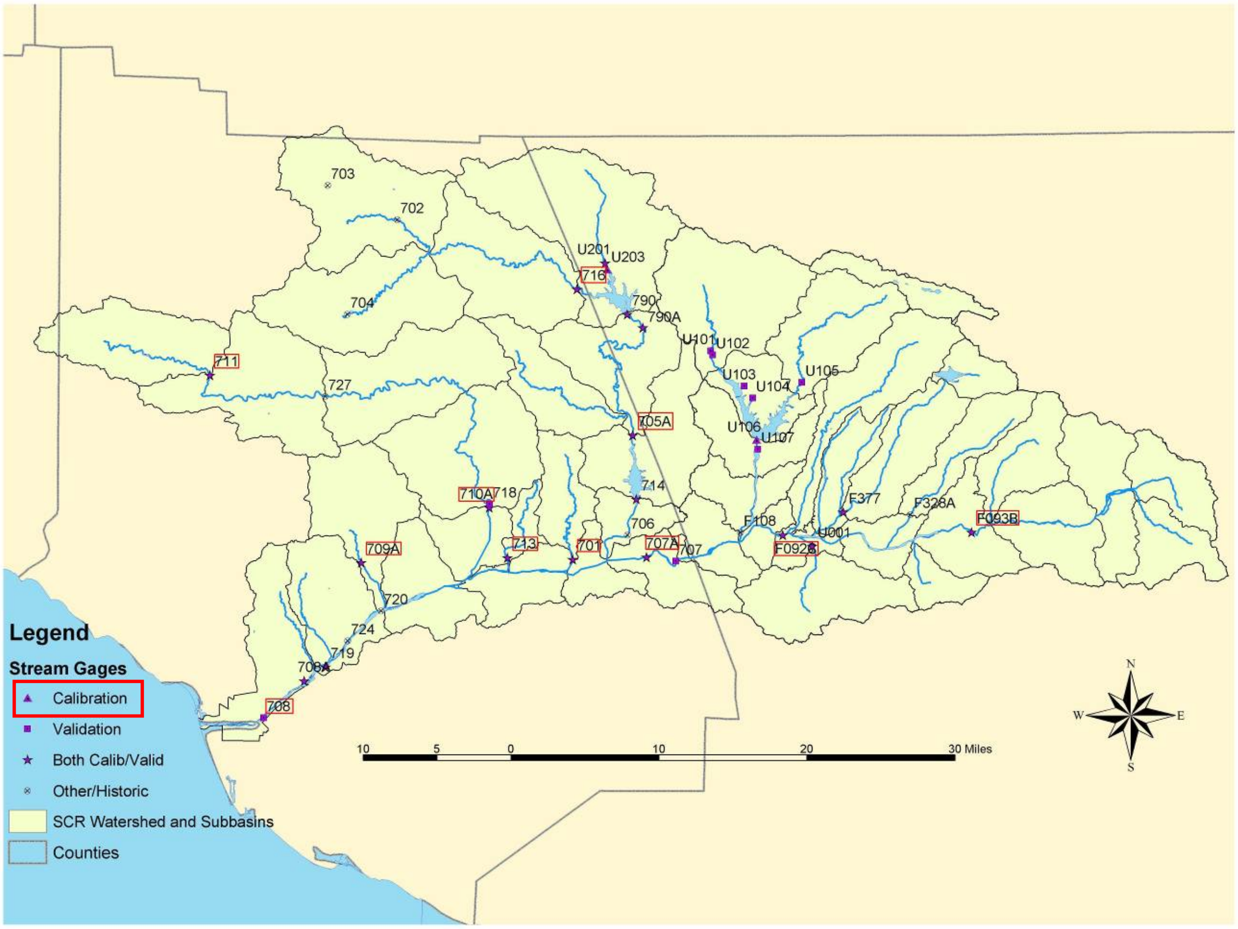


Figure 2.6 Streamflow Stations in the Santa Clara River Watershed

Bridge near Piru in 1996. The ephemeral Salt and Tapo Canyons drain into the Santa Clara River between Stations 707 and 707A.

Stations 790 and 790A are on Piru Creek just downstream of Pyramid Lake, and Stations U106 and U107 are on Castaic Creek just downstream of Castaic Lake. These paired stations are a mile or so apart and were designated as separate stream reach boundaries in the model setup.

The streambed of the mainstem of the Santa Clara River is generally sandy, flat, and wide. During major storms, fluvial processes are constantly shifting the streambed, and any incised low flow channel will be filled in by deposition. The flood flow channel that remains is very often broad and flat, varying from 300 to 1,000 ft wide. The annual conservation release from Lake Piru by the UWCD will gradually cut a low flow channel on its own, which will typically happen over the course of several weeks following the onset of conservation releases in the summer (McEachron, 2005).

A major consequence of the shifting streambed, a process that was also observed in the Calleguas Study and is evident in some of the SCR tributaries, is that streamflow readings can be inaccurate if measures are not taken to account for the dynamic and shifting channel bed. VCWPD and the USGS send out crews during storms, and at regular intervals, to take field measurements for storm hydrographs and channel cross-sections, and these measurements are used to periodically adjust gaged flows and rating curves for quality assurance.

Station histories and rating curves were received for many of the sites listed in Table 2.7, and were reviewed and processed as part of the model development effort. In addition, the rating curves were used to develop the stage-discharge-storage relationships (FTABLES) used in HSPF (see Section 3), and the station histories were reviewed to assess the accuracy and reliability of the monitored flows for selected time periods during the calibration and validation efforts (see Section 4).

2.5 OTHER DATA

The upper watershed of the Santa Clara River system is in a relatively natural state, but the flow regime is highly engineered and regulated to maximize the utility of water as a natural resource for much of the lower basin. Water uses include not only municipal supply and agricultural irrigation, but also groundwater recharge (Saticoy, El Rio, and Piru Spreading Grounds and Noble Pit), aquaculture (Fillmore Fish Hatchery), power generation (William E. Warne, Castaic, and San Francisquito power plants), and recreation. A series of reservoirs and aqueducts have been constructed to complement the natural stream network and facilitate storage, power generation, recreation, and timely distribution of the water supply to irrigation, municipal drinking water, and groundwater recharge facilities.

The State Water Project (SWP) is a key component of the overall water supplies in Ventura and Los Angeles Counties. Water is delivered via the California Aqueduct, which is the major conveyance facility of the State Water Project and extends 444 miles from the Sacramento-San Joaquin Delta down to Southern California. The SWP has been delivering water to the Castaic Lake Water Agency (CLWA) since 1979, the United Water Conservation District (UWCD), and, to a much lesser extent, the Ventura County Watershed Protection District (VCWPD, formerly the Ventura County Flood Control District), since 1997.

Given their significant impact on the flow regime, a comprehensive hydrologic simulation of the SCR Watershed required additional data for representing reservoirs, irrigation, wastewater treatment plant (WWTP) effluent, groundwater pumping, and groundwater recharge facilities. Imports and use of water, especially for irrigation, were included in the overall watershed water balance, and groundwater-surface water interactions, such as channel losses and gains were accounted for insofar as they affected baseflow to the streams.

2.5.1 State Water Project, Water Supplies and Imported Water

Municipal water supplies within the watershed are obtained from local groundwater in aquifers underlying the service areas, imported water from the State Water Project, and a relatively minor amount of recycled water. The Castaic Lake Water Agency (CLWA) and UWCD are the main water wholesalers in the watershed. The CLWA service area includes Santa Clarita and the majority of urban areas in the Los Angeles County portion of the watershed, excluding Acton (see Figure 1.1 for reservoir and city locations). The UWCD Oxnard-Hueneme (OH) System serves cities and urban areas in the Oxnard plain, including the cities of Oxnard, Ventura, Port Hueneme, and two U.S. Naval bases. The Piru, Fillmore, and Santa Paula basins, which all contain their namesake towns in Ventura County along the Santa Clara River upstream from the Oxnard Plain, are served by groundwater wells with the vast majority of the water (> 90%) used for irrigation. (UWCD, 2004).

There are two significant sources of imported water within the Santa Clara River watershed, the California Aqueduct and the Los Angeles Aqueduct. The former, part of the SWP network, feeds the William E. Warne Power Plant located in central northern part of the watershed, above Pyramid Lake, and just inside the LA County border. From Pyramid Lake, water is routed through the Angeles tunnel into the Castaic Power Plant and then into Castaic Lake, terminus of the West Branch of the SWP, via Elderberry Reservoir/Forebay. This is how state water is imported into the watershed for local use.

The Los Angeles Aqueduct is funded by its namesake city and supplies the Los Angeles Power Plant and Reservoir located just outside the SCR Watershed boundary in LA County. Although its water essentially passes through the watershed on its way to the City of Los Angeles, the local flow regime is affected during the interim between its arrival and departure. Some of the water transported through the Los Angeles Aqueduct is stored in the Bouquet Reservoir, which is in the Bouquet Creek watershed upstream of the City of Santa Clarita. The reservoir, completed in 1934, is owned by LADWP and provides important safety storage downstream from the San Andreas Fault. In addition, the remainder of the flow continues down the aqueduct along San Francisquito Creek to LA County, and is also used for peak hydroelectric power generation at San Francisquito Power Plants 1 and 2 located near the aqueduct.

2.5.2 Reservoir Operations

In addition to Pyramid Lake, Elderberry Forebay, Castaic Lake, and Bouquet Reservoir, all mentioned above, there are two other major reservoirs in the watershed that are included in the model. They are Lake Piru, downstream from Pyramid Lake, and Castaic Afterbay/Lagoon. Figure 2.7 developed by the USGS shows a schematic of these six major reservoirs and their interconnections; it also shows the nearby flow gaging stations which are used directly in the model. This section presents a summary of the data available to represent these reservoirs, while their model representation is discussed later in Sections 3 and 4.

Pyramid Lake receives water from local sources as well as the State Water Project (via the California Aqueduct). Water that flows through the Los Angeles Tunnel to Elderberry Forebay generates power in the Castaic Power Plant, and some of it is pumped back to Pyramid Lake for additional power generation (CA DWR, 2007a). Pyramid also is operated for water storage and flood protection, and to provide water to Piru Creek and Lake Piru, primarily for agriculture, groundwater recharge, and flow maintenance. Pyramid releases approximately the natural inflows to Piru Creek (M. McEachron, UWCD, Santa Paula, CA, Personal communication, 2007). During significant rainfall events, when natural inflows are high, some of the flow will be retained, either for later release at the request of downstream users in the watershed, or appropriated by the State Water Project for delivery to outside users via Castaic Lake.

The Piru Reservoir, owned and operated by UWCD, was created with the construction of the Santa Felicia Dam in 1955. As shown in Figure 2.7, Lake Piru and Santa Felicia Dam are downstream of the SWP's Pyramid Reservoir, allowing UWCD to directly receive and store water without specialized conveyance systems (UWCD, 1999). It also receives runoff water from the local watershed. Water storage at Lake Piru allows for strategic conservation releases aimed at recharging downstream groundwater basins and aquifers, which provide irrigation and drinking water, and ultimately help fight against saltwater intrusion on the Oxnard Plain. Low flow release volumes are also utilized by downstream landowners who hold riparian rights.

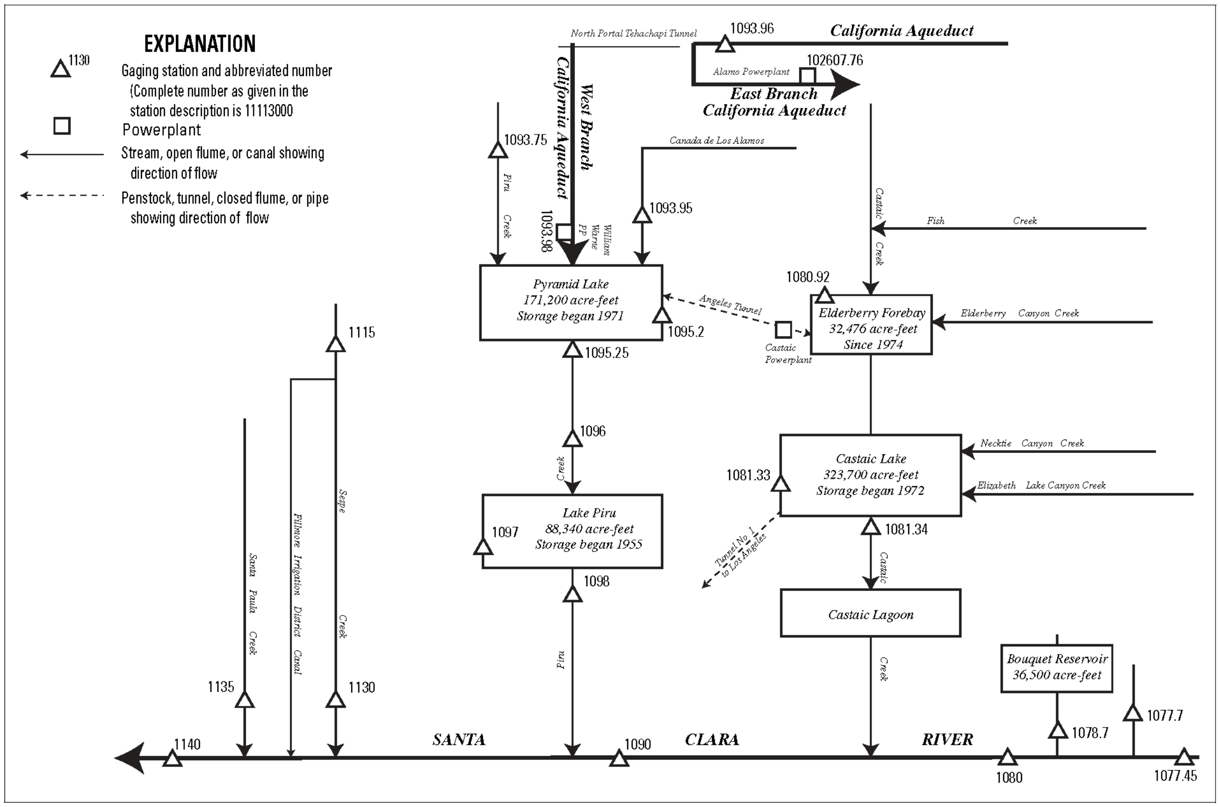


Figure 2.7 Schematic of Reservoirs in the Santa Clara River Watershed (USGS, 2004)

Power generation occurs during water conservation releases as a portion of the releases are diverted through the Santa Felicia Hydroelectric Plant.

Elderberry Forebay is adjacent to and just upstream from Castaic Lake, and serves as the interim transfer point for SWP water that is delivered from Pyramid Lake to Castaic Lake. The pipes carrying water from Pyramid via the Castaic Power Plant, plus the pipes that return some of the water back to Pyramid terminate in Elderberry Forebay. This reservoir also receives natural inflows, primarily from the Castaic Creek watershed. Outflows from Elderberry to Castaic Lake consist of the natural inflows, plus the SWP water from Pyramid Lake that is ultimately delivered to water users, primarily major water supply treatment plants servicing the LA Basin.

The operation of the major reservoirs (Pyramid, Piru, Elderberry, and Castaic) is not based on any strictly-followed set of rules (M. McEachron, UWCD, Santa Paula, CA, Personal communication, 2007.); therefore, developing a reliable defined procedure for predicting outflows to downstream creeks, which is a main requirement for the modeling, is problematic. Fortunately, a relatively complete database of storages, imports, inflows, outflows, and inter-reservoir transfers is available to allow the modeling of the major reservoirs during recent time periods that correspond to the model calibration and validation periods. The primary database used to model the water imports and reservoir outflows was obtained from the CA DWR (CA DWR, 2007b) and U.S. Geological Survey (USGS, 2007).

The CA DWR provides monthly operations reports for the SWP reservoirs. These were available in electronic format with daily data for the period 1990 – 2006. Prior to that, the reports were available only in paper format, so monthly totals were converted to electronic format. Tables 2.8 and 2.9 show examples of the data for Elderberry Forebay, showing the daily storages, inflows and outflows for a month. These tables were available for January 1990 – December 2006 on the CA DWR website (wwwoco.water.ca.gov/monthly/monthly.menu.html.) The data were downloaded and reformatted to model-accessible format. Data for October 1986 – December 1999 were provided by CA DWR (J. Rollins, CA DWR, Personal communication, 2007) in the form of paper copies, and were reformatted to model format on a monthly basis instead of daily. The resulting database covered the calibration and validation periods, i.e., WY 1987 - 2005.

Streamflow station data collected by USGS and other agencies were used either directly or indirectly to model the reservoirs. The two gages on Piru Creek below Pyramid Lake (11109525) and Santa Felicia Dam (11109800) were used for Pyramid Lake and Lake Piru outflows, respectively. Others were likely the source of the inflow and outflow data used by CA DWR to compile the daily water balances for Pyramid, Elderberry, Castaic, and Castaic Lagoon that were used to model these reservoirs.

Table 2.8 Example of Reservoir Data For Elderberry Forebay (CA DWR, 2007b)

Table 26. Elderberry Forebay

Daily Operation

(in acre-feet except as noted)

Capacity: 32,476 ac-ft

January 2005

Date	Water Surface Elevation (in feet)	Storage	Storage Change	Inflow		Outflow			Computed Losses (-) And Gains (+)
				Castaic Powerplant Generation 1/	Natural	Castaic Powerplant Pumpback 1/	To Castaic Lake Natural	To Castaic Lake Project 1/	
Dec 31	1522.40	24,274							
1	1516.40	21,732	-2,542	2,152	199	0	199	4,827	133
2	1516.10	21,609	-123	256	214	0	214	553	174
3	1520.70	23,540	1,931	1,754	995	790	995	0	967
4	1516.80	21,897	-1,643	1,972	471	0	471	3,915	300
5	1520.10	23,283	1,386	1,332	227	11	227	0	65
6	1519.00	22,816	-467	2,084	186	0	186	2,562	11
7	1516.20	21,650	-1,166	1,525	436	0	436	3,192	501
8	1513.70	20,636	-1,014	901	1,385	1,164	1,385	0	-751
9	1523.90	24,930	4,294	2,159	11,577	0	11,577	0	2,135
10	1522.40	24,274	-656	512	7,245	1,405	7,245	0	237
11	1510.40	19,338	-4,936	541	1,956	0	1,956	0	-5,477
12	1512.50	20,159	821	3,364	1,112	0	1,112	0	-2,543
13	1515.93	21,537	1,378	4,127	697	0	697	703	-2,046
14	1521.70	23,970	2,433	3,384	490	822	490	0	-129
15	1518.90	22,774	-1,196	397	373	0	373	1,942	349
16	1517.60	22,229	-545	358	282	0	282	1,154	251
17	1518.70	22,690	461	322	251	0	251	0	139
18	1520.10	23,283	593	473	214	0	214	0	120
19	1521.60	23,927	644	403	179	0	179	0	241
20	1521.90	24,057	130	4	157	0	157	0	126
21	1522.30	24,230	173	44	130	0	130	0	129
22	1522.50	24,317	87	0	122	0	122	0	87
23	1522.80	24,448	131	0	116	0	116	0	131
24	1523.30	24,666	218	54	116	0	116	0	164
25	1523.60	24,798	132	4	113	0	113	0	128
26	1519.60	23,070	-1,728	0	107	0	107	1,827	99
27	1519.80	23,155	85	0	103	0	103	0	85
28	1520.10	23,283	128	0	104	0	104	0	128
29	1520.30	23,369	86	0	94	0	94	0	86
30	1520.40	23,411	42	0	88	0	88	0	42
31	1514.70	21,039	-2,372	63	85	0	85	2,446	11
Total			-3,235	28,185	29,824	4,192	29,824	23,121	-4,107

1/ Values supplied by LADWP, not verified by DWR.

Table 2.9 Example of Reservoir Data For Castaic Lake (CA DWR, 2007b)

Table 27. Castaic Lake

Daily Operation

(in acre-feet except as noted)

Capacity: 323,699 ac-ft

January 2005

Date	Water Surface Elevation (in feet)	Storage	Storage Change	Inflow			Outflow		Computed Losses (-) And Gains (+)
				From Elderberry Forebay /1		Natural	Deliveries	Released To Castaic Lagoon	
				Natural	Project				
Dec 31	1498.05	287,108							
1	1499.74	290,640	3,532	199	4,827	231	1,499	12	-214
2	1499.41	289,949	-691	214	553	112	1,344	12	-214
3	1499.20	289,509	-440	995	0	409	1,303	12	-529
4	1500.52	292,280	2,771	471	3,915	276	1,310	12	-569
5	1499.92	291,018	-1,262	227	0	138	1,388	12	-227
6	1500.58	292,406	1,388	186	2,562	86	1,498	12	64
7	1501.82	295,023	2,617	436	3,192	302	1,480	12	179
8	1503.02	297,570	2,547	1,385	0	1,464	1,624	12	1,334
9	1506.25	304,487	6,917	11,577	0	13,672	1,751	7,562	-9,019
10	1506.97	306,042	1,555	7,245	0	11,096	1,721	13,472	-1,593
11	1508.38	309,100	3,058	1,956	0	3,511	1,736	5,806	5,133
12	1509.19	310,865	1,765	1,112	0	1,611	1,736	1,493	2,271
13	1511.88	316,750	5,885	697	703	1,057	1,637	651	5,716
14	1509.46	311,455	-5,295	490	0	621	1,736	651	-4,019
15	1509.26	311,018	-437	373	1,942	391	1,557	651	-935
16	1508.96	310,364	-654	282	1,154	312	1,557	651	-194
17	1508.05	308,383	-1,981	251	0	257	1,634	651	-204
18	1507.05	306,215	-2,168	214	0	219	1,709	651	-241
19	1506.09	304,142	-2,073	179	0	183	1,726	651	-58
20	1505.25	302,336	-1,806	157	0	169	1,715	0	-417
21	1504.53	300,792	-1,544	130	0	157	1,734	0	-97
22	1503.78	299,189	-1,603	122	0	148	1,721	0	-152
23	1503.06	297,655	-1,534	116	0	143	1,735	0	-58
24	1502.31	296,062	-1,593	116	0	145	1,726	0	-128
25	1501.55	294,452	-1,610	113	0	131	1,732	0	-122
26	1501.62	294,600	148	107	1,827	124	1,930	0	20
27	1500.52	292,280	-2,320	103	0	117	2,430	0	-110
28	1499.56	290,263	-2,017	104	0	129	2,202	0	-48
29	1498.55	288,150	-2,113	94	0	116	2,202	0	-121
30	1497.52	286,005	-2,145	88	0	113	2,226	0	-120
31	1497.68	286,338	333	85	2,446	113	2,237	0	-74
Total			-770	29,824	23,121	37,553	53,536	32,986	-4,746

1/ Values supplied by LADWP, not verified by DWR.

2.5.3 Point Sources

There are nine wastewater treatment plants (WWTP's) located in the SCR watershed. Eight of these have outfalls within the model boundaries and are listed in Table 2.10. The City of Ventura operates a water reclamation plant (WRP) that discharges into the SCR Estuary, but this plant was not considered because it discharges outside of the model area.

The Saugus and Valencia WRP's provide tertiary treatment and discharge directly to the Santa Clara River. The Santa Paula plant is the only other plant that discharges directly to the river. It is, however, facing major fines for failing to comply with water quality standards, and it is slated to be replaced by a water recycling facility (WRF) adjacent to its current site. The Fillmore percolation ponds overflow into the river during very wet periods. The rest of the treatment facilities discharge entirely into percolation ponds, which may contribute baseflow to the SCR.

The Montalvo Municipal Improvement District Treatment Plant is near the Hwy 101 bridge. Treated effluent is discharged into percolation ponds. The Saticoy Sanitary District Treatment Plant is near the Hwy 118 bridge and is currently undergoing expansion and upgrading to tertiary treatment. The locations of the WWTPs are presented and discussed in Section 3 as part of the initial model segmentation.

Table 2.10 Wastewater Treatment Plants with Outfalls in the Santa Clara River Watershed

Facility Name	Receiving Water Body	Avg Outflow (MGD)	Monthly		Daily	
			Start	End	Start	End
Saugus WRP	Santa Clara River	5.3	02/73	12/85	01/02/86	11/10/07
Valencia WRP	Santa Clara River	9.6	01/71	12/86	01/01/87	11/10/07
Piru WWTP	Percolation Ponds	0.15			01/01/88	06/30/05
Saticoy WWTP	Percolation Ponds	0.11			04/01/88	12/31/05
Fillmore WWTP	Percolation Ponds / River	1.0			01/01/86	06/30/98
Santa Paula WWTP	Santa Clara River	2.0			01/01/86	12/31/05
Todd Road Jail	Percolation Ponds	0.05			01/01/01	02/11/06
Montalvo WWTP	Percolation Ponds	0.26			01/01/86	12/31/05

The Saugus WRP and the Valencia WRP are clearly the largest and most significant plants with effluents discharging to the Santa Clara River, as shown by the average outflow numbers in Table 2.10. Daily timeseries for these plants were obtained from a variety of sources: VCWPD provided the majority of the data, the LA County Sanitation Districts provided data from1/1/1986 to 11/10/2007 to extend the timeseries through the calibration period (F. Guerrero, LACSD, personal communication, 2007), and selected data from the SCR-WARMF model was used to fill in missing values for a few of the smaller plants. To support execution of long-term model runs, we used monthly volumes (i.e. average daily discharge in each month) obtained from the available period of record to extend the timeseries back to about 1959. For most plants the flows are sufficiently small, especially when compared to the natural wet weather flows, so that these estimation procedures were judged to be adequate.

2.5.4 Diversions

A number of diversions exist within the SCR Watershed and influence the flow recorded at various downstream gages, primarily along the mainstem. Table 2.11 summarizes the diversions included in the model.

The Freeman Diversion was constructed in 1991 to replace its earthen dike predecessor, providing more durability and an increase in maximum diversion capacity from approximately 375 cfs to 460 cfs. The approximately 60,000 AF of water diverted annually by Freeman feeds the groundwater recharge facilities at Saticoy and El Rio Spreading Grounds and Noble Pit, as well as supplying the Pleasant Valley and Pumping Trough Pipelines. Both pipelines deliver irrigation water to land outside the watershed. Most artificial recharge at El Rio is pumped back through nearby extraction wells for irrigation or delivery to adjacent subbasins. The pump-back rate is 44% historically (Hanson et al., 2003). The Oxnard-Hueneme (OH) drinking water system is supplied by groundwater wells located adjacent to El Rio Spreading Grounds. So, it is a reasonable assumption that the Freeman diversion indirectly supplies the OH system.

The Piru Spreading Grounds, which cover an area of about 44 acres, are fed by a smaller diversion (approximately 6,000 AF/year) out of Piru Creek located about one mile above its confluence with the Santa Clara River. The Fillmore Fish Hatchery pumps approximately 12,000 AF of water annually from the Santa Clara River approximately 12 miles west of the county line.

In addition, agricultural irrigation throughout the lower watershed is supplied mainly by groundwater and some surface-water diversions. The Watershed Analysis Risk Management Framework (WARMF) model (Systech, 2002) provides data on virtually all of these smaller diversions in the watershed from WY 1990-2000. The Newhall, Rancho Camulos, and Richardson (Santa Paula downstream of 12th St) diversions were included in the WARMF model data. The Sespe Creek diversion was calculated as the difference in daily flows between USGS gages 11113000 (Sespe Creek near Fillmore) and 11113001 (Sespe Creek + Fillmore Irrigation Co CN nr Fillmore CA). Missing periods were filled and extended to cover the calibration and validation periods with the time pattern shown during the available data period.

The data for representing the diversions in the model were provided by VCWPD and UWCD, and, as noted above, supplemented as needed with the WARMF model data. As shown in Table 2.11, all the diversions except for Freeman and Piru are relatively small and impact only extreme low flow conditions in the watershed.

Table 2.11 Diversions in the SCR Watershed

Diversion Station/Site	Average Daily Diversion flow, (cfs)	Data Periods
Freeman	83.8	10/1/55-12/31/05
Piru	8.3	1/1/56-2/28/06
Newhall Land	0.5	10/1/89-12/31/01
Camulos	0.8	10/1/89-9/30/00
Fillmore	1.6	10/1/89-12/31/00
Richardson	0.4	10/1/89-12/31/01

2.5.5 Irrigation

The Santa Clara River watershed includes significant areas of both agricultural and developed residential land, so the model considers both urban and agricultural irrigation applications for a complete water balance accounting. Below we discuss the overall approach to estimating irrigation applications, followed by separate presentations of the urban and agricultural irrigation procedures. These procedures were developed in the Arroyo Simi (AQUA TERRA Consultants, 2003) and Calleguas Creek (AQUA TERRA Consultants, 2005) modeling efforts, and have also been applied to watersheds in the San Francisco Bay Area (Donigian and Bicknell, 2007).

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, and as seen in Figure 2.3, the Santa Clara River watershed is spread across a range of ETo zones, transitioning from the South Coast Marine 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 SCR Watershed.

Urban Irrigation

In an urban environment, irrigation is generally limited to lawn watering by homes and businesses. Although consumptive use information may be available, it is generally restricted to annual values. For the model, the spatial and temporal distribution is needed and is estimated based on the difference between plant needs and rainfall. 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.

In residential and most urbanized areas, it is assumed that the dominant vegetation is turf grass, with a crop coefficient of 0.6 ("warm season" grass). Commercial 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 landscape irrigation.

The daily crop irrigation need is calculated as the difference between lawn ET demand and rainfall. The irrigation demand is divided into three hourly applications for 6-7am, 7-8am, and 8-9am (to represent automated sprinklers on a daily schedule), and an irrigation efficiency factor is applied to increase the actual application. The model currently uses 0.85 for this factor, which represents a well-designed and well-operated irrigation system according to the WUCOLS III manual.

The irrigation time series 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, application factors are used within the model input (i.e. UCI) to limit the application amount by the fraction of the area assumed to be irrigated. Our model runs assume the following percentages of each urban land category are irrigated, and thereby receive these percentages of the calculated total irrigation amounts:

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

These percentages appear to provide reasonable water balance impacts due to the irrigation additions, and they produce viable irrigation amounts based on the Arroyo Simi, Calleguas, and SF Bay Area applications. Irrigation amounts and water balance checks for the SCR Watershed indicate that these percentages produce reasonable irrigation applications.

Tables 2.12A-E below show monthly reference ETo values from the WUCOLS III manual for Zones 3, 4, 9, 10, and 14, 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. As noted above, this value of 0.85 for urban irrigation represents a well-designed and well-operated irrigation system (primarily drip/microjet). The gross needs amount ranges from around 33 inches per year at the coast to 41 inches per year in the high desert.

Table 2.12A - Monthly ETo and Urban Irrigation Requirements for CIMIS Zone 3

	Reference ET		Net Crop Need		Gross Crop Need	
Month	Daily	Monthly	Daily	Monthly	Daily	Monthly
Oct	0.11	3.41	0.07	2.05	0.08	2.41
Nov	0.08	2.48	0.05	1.49	0.06	1.75
Dec	0.06	1.86	0.04	1.12	0.04	1.31
Jan	0.06	1.86	0.04	1.12	0.04	1.31
Feb	0.08	2.48	0.05	1.49	0.06	1.75
Mar	0.12	3.72	0.07	2.23	0.08	2.63
Apr	0.16	4.96	0.10	2.98	0.11	3.50
May	0.17	5.27	0.10	3.16	0.12	3.72
Jun	0.19	5.89	0.11	3.53	0.13	4.16
Jul	0.18	5.58	0.11	3.35	0.13	3.94
Aug	0.17	5.27	0.10	3.16	0.12	3.72
Sep	0.14	4.34	0.08	2.60	0.10	3.06
Avg/Total	0.13	47.12	0.08	28.27	0.09	33.26

Table 2.12B - Monthly ETo and Urban Irrigation Requirements for CIMIS Zone 4

	Reference ET		Net Crop Need		Gross Crop Need	
Month	Daily	Monthly	Daily	Monthly	Daily	Monthly
Oct	0.11	3.41	0.07	2.05	0.08	2.41
Nov	0.08	2.48	0.05	1.49	0.06	1.75
Dec	0.06	1.86	0.04	1.12	0.04	1.31
Jan	0.06	1.86	0.04	1.12	0.04	1.31
Feb	0.08	2.48	0.05	1.49	0.06	1.75
Mar	0.11	3.41	0.07	2.05	0.08	2.41
Apr	0.15	4.65	0.09	2.79	0.11	3.28
May	0.17	5.27	0.10	3.16	0.12	3.72
Jun	0.19	5.89	0.11	3.53	0.13	4.16
Jul	0.19	5.89	0.11	3.53	0.13	4.16
Aug	0.18	5.58	0.11	3.35	0.13	3.94
Sep	0.15	4.65	0.09	2.79	0.11	3.28
Avg/Total	0.13	47.43	0.08	28.46	0.09	33.48

Table 2.12C - Monthly ETo and Urban Irrigation Requirements for CIMIS Zone 9

	Reference ET		Net Crop Need		Gross Crop Need	
Month	Daily	Monthly	Daily	Monthly	Daily	Monthly
Oct	0.13	4.03	0.08	2.42	0.09	2.84
Nov	0.09	2.79	0.05	1.67	0.06	1.97
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	3.10	0.06	1.86	0.07	2.19
Mar	0.13	4.03	0.08	2.42	0.09	2.84
Apr	0.17	5.27	0.10	3.16	0.12	3.72
May	0.19	5.89	0.11	3.53	0.13	4.16
Jun	0.22	6.82	0.13	4.09	0.16	4.81
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	5.89	0.11	3.53	0.13	4.16
Avg/Total	0.15	56.11	0.09	33.67	0.11	39.61

Table 2.12D - Monthly ETo and Urban Irrigation Requirements for CIMIS Zone 10

	Reference ET		Net Crop Need		Gross Crop Need	
Month	Daily	Monthly	Daily	Monthly	Daily	Monthly
Oct	0.11	3.41	0.07	2.05	0.08	2.41
Nov	0.08	2.48	0.05	1.49	0.06	1.75
Dec	0.06	1.86	0.04	1.12	0.04	1.31
Jan	0.06	1.86	0.04	1.12	0.04	1.31
Feb	0.08	2.48	0.05	1.49	0.06	1.75
Mar	0.12	3.72	0.07	2.23	0.08	2.63
Apr	0.16	4.96	0.10	2.98	0.11	3.50
May	0.17	5.27	0.10	3.16	0.12	3.72
Jun	0.19	5.89	0.11	3.53	0.13	4.16
Jul	0.18	5.58	0.11	3.35	0.13	3.94
Aug	0.17	5.27	0.10	3.16	0.12	3.72
Sep	0.14	4.34	0.08	2.60	0.10	3.06
Avg/Total	1.81	55.14	1.09	33.08	1.28	38.92

Table 2.12E - Monthly ETo and Urban Irrigation Requirements for CIMIS Zone 14

	Reference ET		Net Crop Need		Gross Crop Need	
Month	Daily	Monthly	Daily	Monthly	Daily	Monthly
Oct	0.13	4.03	0.08	2.42	0.09	2.84
Nov	0.07	2.17	0.04	1.30	0.05	1.53
Dec	0.05	1.55	0.03	0.93	0.04	1.09
Jan	0.05	1.55	0.03	0.93	0.04	1.09
Feb	0.08	2.48	0.05	1.49	0.06	1.75
Mar	0.12	3.72	0.07	2.23	0.08	2.63
Apr	0.17	5.27	0.10	3.16	0.12	3.72
May	0.22	6.82	0.13	4.09	0.16	4.81
Jun	0.26	8.06	0.16	4.84	0.18	5.69
Jul	0.28	8.68	0.17	5.21	0.20	6.13
Aug	0.25	7.75	0.15	4.65	0.18	5.47
Sep	0.19	5.89	0.11	3.53	0.13	4.16
Avg/Total	0.16	57.97	0.09	34.78	0.11	40.92

These urban irrigation procedures have been developed and used in past modeling efforts (as noted above), and have provided reasonable impacts on the overall water balance, particularly on the low flow portions of the flow duration curves. Consequently, we have applied these same procedures for the urban areas within the SCR watershed model with comparable results that will be presented in Section 4.

Agricultural Irrigation

The Santa Clara River valley contains a significant fraction of agricultural land, where irrigation practices, water sources, and diversions are complex. The extent and spatial representation of agricultural irrigation in the model is a function of the available data. There are a handful of local irrigation providers, such as the UWCD, which account for most or all of the agricultural use of imported state water. Additionally, the WARMF model contains extensive diversion data for WY 1990-2000, which were used to extrapolate estimates for diversions, wherever necessary, over the entire HSPF simulation period.

For Calleguas Creek Watershed study, in order to develop a reasonable time series of irrigation applications for agricultural crops, the following steps were performed, and these same steps were also performed for this study:

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.
5. Follow similar procedures as used in the Calleguas Creek study to determine daily irrigation applications across the watershed and distribute into hourly amounts applied to the agricultural land.

The first step in the development of the agricultural irrigation application time series is the definition of crops grown and their spatial distribution throughout the watershed. For the Calleguas Study an August 2002 survey provided such spatial data, and the corresponding GIS coverage for the Ventura County portions of the SCR Watershed. For the LA County portions, contacts with the LA County Agricultural Commissioners Office, other local agencies, and online searches produced no comparable GIS crop coverage for use in this study. Fortunately we did discover a recent study by Salas et al (2006) of Applied GeoSolutions, LLC (AGLLC) that focused on agricultural irrigation water use in California which developed such GIS coverages for LA County. Figure 2.8 is a composite of the Ventura County August 2002 crop survey and the LA County crop coverage from the AGLLC study.

The AGLLC study started with county land use surveys of irrigated cropland available from the CA DWR web site (www.landwateruse.water.ca.gov), and then composited this into a statewide coverage. For counties with coverages only partially available, which included LA County, they applied a methodology using the USDA National Agricultural Statistics Service (NASS) online database (www.usda.gov/nass/) for year 2002 and the U.S. National Land Cover Data Set (NLCD) to distribute the irrigated cropland within the counties. Salas et al (2006) describe this coverage as follows:

> *"The contemporary map of irrigation … is…based on the DWR database and supplemented for missing counties and regions with data from the NLCD high-resolution national landcover product and 2002 county-scale data from the 2002 Agricultural Census … dated as 2000 (though it represents several different years from the late 1990s to the early 2000s)…"*

Table 2.13 lists the dominant crops in Ventura County from the 2002 survey, and in LA County the major crop categories from the AG LLC coverage; these correspond to the spatial coverage shown in Figure 2.8. Section 3 discusses the overall land use coverage used to define the model categories as part of the watershed segmentation process. The total agricultural land shown in Table 2.13 is slightly less than the coverage area contained in the model; these values are only used to calculate weighted crop coefficients.

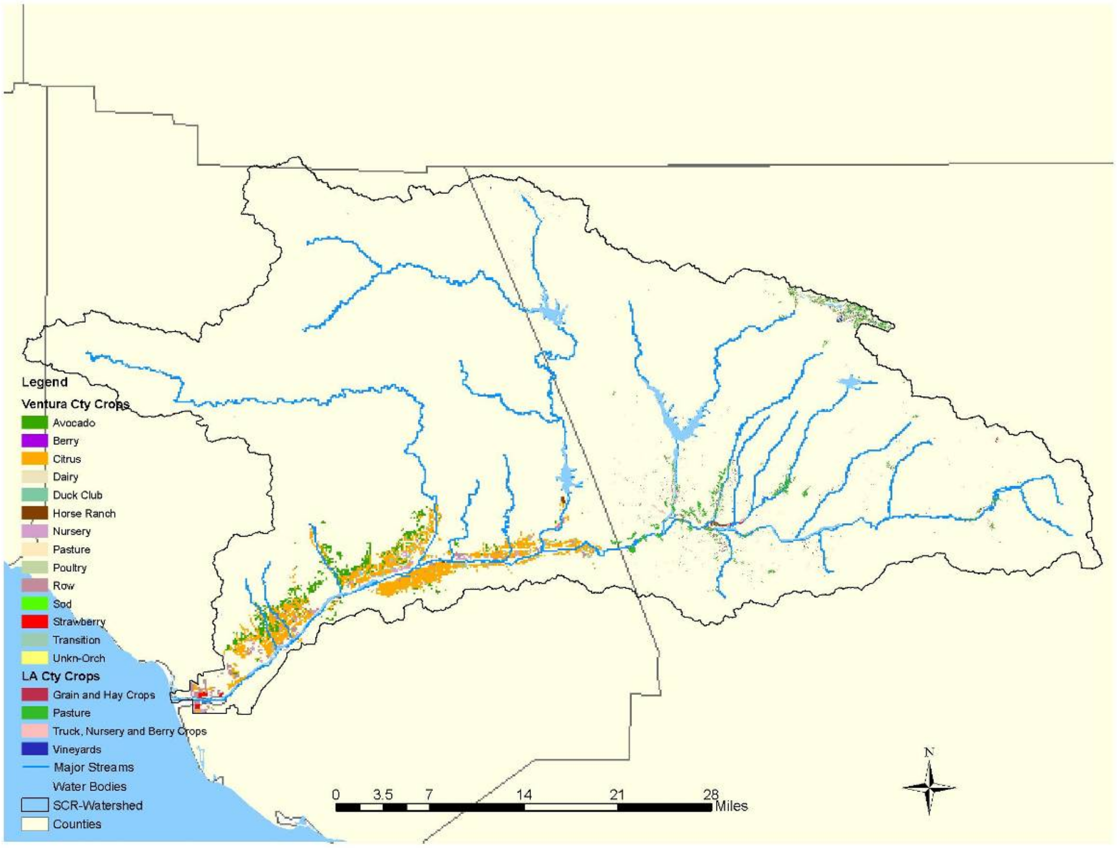


Figure 2.8 Agricultural Land in the SCR Watershed

Table 2.13 Major crops in Ventura and Los Angeles counties, circa 2002

Crop	Ventura County		Los Angeles County	
	Acreage	Percent	Acreage	Percent
Citrus	18,467	60.6%		
Avocado	5930	19.5%		
Row crops	2549	8.4%		
Transition	1395	4.6%		
Nursery	1217	4.0%		
Pasture	601	2.0%		
Strawberry	211	0.7%		
Horse Ranch	110	0.4%		
Pasture			4830	53.5%
Truck, Nursery and Berry			1888	20.9%
Vineyards			2318	25.7%
Total	30,480	100.0%	9,036	100.0%

It is important to note that, due to the spatial scale of the model, not every individual crop and field can be modeled as separate model segments; this was simply not feasible for neither the Calleguas Creek Watershed study, nor the SCR Watershed in this effort due to the extent of agricultural cropland. The cropping information in Table 2.13 was aggregated into the three categories – row crops, citrus, avocado – for Ventura County and two categories – orchards and vineyards, irrigated cropland/pasture – for LA County, for calculation of the weighted crop coefficients by model segment, as described in Step 2 above. The crop coefficient, Kc, values for each category are also shown in Table 2.14. These are the same values as was used in the Calleguas Study, and the same information sources were reviewed to develop values for the LA County crop categories.

Table 2.14 Crop Coefficients (Kc) for Ventura and LA County Crop Categories

	Ventura County		LA County	
Land Use	**Crop Category**	**Kc**	**Crop Category**	**Kc**
Agriculture	Row Crops	0.75	Orchards and Vineyards	0.70
	Citrus	0.6	Irrigated Cropland, Pasture	0.75
	Avocado	0.8		
Urban	0.6			

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; we assumed similar practices also applied to LA County agriculture. 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 SCR Watershed are mostly of the drip/microjet type, but also some older sprinkler and furrow systems, we selected an **efficiency of 75%,** the same value as was used in the Calleguas Study. This produces a 33% increase in the ET demands, calculated in Step 3 above, to produce the final irrigation application needs for each model segment, without accounting for the rainfall contribution.

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.

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 fewer number of rainfall records were used for the irrigation calculations; these are shown in Table 2.1. It was decided that homeowners and agricultural irrigators would not be sensitive to small variations between gages, so applications would likely be more uniform, especially for urban areas since a single crop coefficient of 0.6 was used for all urban irrigated land. The irrigation applications were derived from the rainfall records at 14 separate stations (shown in Table 2.1) in the vicinity of the primary urban and agricultural lands. The agricultural 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 the model database (WDM file) 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.

2.5.6 Groundwater Recharge and Discharge, and Surface Water Interactions

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 process that involves a transfer between surface water and active or deep, inactive groundwater must be considered by the model.

In the SCR watershed, groundwater wells provide much of water for human use through pumping from an extensive network of alluvial aquifers and the Saugus Formation in the river valley, thereby transforming deep, inactive groundwater into surface water. Most of the extracted groundwater (> 90%) is used for agricultural irrigation. Irrigation methods and sources of water have varied over time, and complete historical data are not available.

In the Calleguas Model, it was assumed that all agricultural irrigation water was derived from deep aquifers and/or local channel losses recharging the alluvial aquifers. The model calculated deep recharge, irrigation applications, and channel losses were compared to all available annual estimates for these fluxes in order to assess the accuracy of the modeled water balance. A similar approach was applied for this SCR Watershed modeling effort.

Another groundwater-surface water interaction issue is the presence of recharge and discharge zones along the SCR channel. Areas of rising groundwater are observed at the mouth of Soledad Canyon (just southwest of Arrastre Canyon), a geologic constriction called the Piru Narrows east of Highway 5, the Blue Cut gaging station just west of the Los Angeles-Ventura County line, the Fillmore Narrows at the Fillmore Fish Hatchery, the Willard gaging station just east of the City of Santa Paula, and on a bedrock-alluvium contact near the toe of South Mountain east of Saticoy near Freeman Diversion Dam. See Section 4.3.6 and Figure 4.23 for identification of these zones and corresponding stream reaches. Figure 2.9 (from Luhdorff and Scalmanini, 2005) shows the major ground water basins along the mainstem of the SCR, with the Piru and upper Fillmore basins being primarily recharge regions (through channel losses), and the SCR Valley-East, lower Fillmore and Santa Paula basins being primarily discharge (or accretion, rising ground water) regions, although recharge and discharge zones are often coincident within a basin. Rising ground water flows into the river are controlled by the volume of groundwater in storage, or the fullness of the groundwater subbasins (AMEC Earth & Environmental, 2005).

Channel losses (recharge) to alluvial aquifers occur in Soledad Canyon where it is entered by Arrastre Canyon, in the eastern upstream portions of the Piru, Fillmore and Santa Paula Basins, and in the Oxnard forebay area west of the Freeman Diversion (AMEC Earth & Environmental, 2005). One result of these channel losses is a “Dry Gap” along the main stem of the Santa Clara River just upstream from the Piru Creek confluence, which has been observed for centuries to run only ephemerally.

There is significant literature documenting studies on recharge and discharge zones of the Santa Clara River, which served as the basis for modeling channel gains and losses in the model. In particular, Murray McEachron of UWCD constructed a model with specific algorithms to estimate channel losses/gains along individual sections of the river between the county line and the Freeman Diversion (McEachron, 2005). Also, the WARMF model (Systech Engineering, Inc., 2002) performed simulations for the period of 1990 to 2000, and used data from McEachron and other groundwater studies to estimate both recharge (channel losses) and discharge (accretion) values for much of the study area shown in Figure 2.9. Both of these efforts, along with consultation with Murray McEachron at UWCD, were the basis for representing the complex ground water-surface water interactions for the SCR mainstem. Details of the representation are discussed in Section 4.3.6.

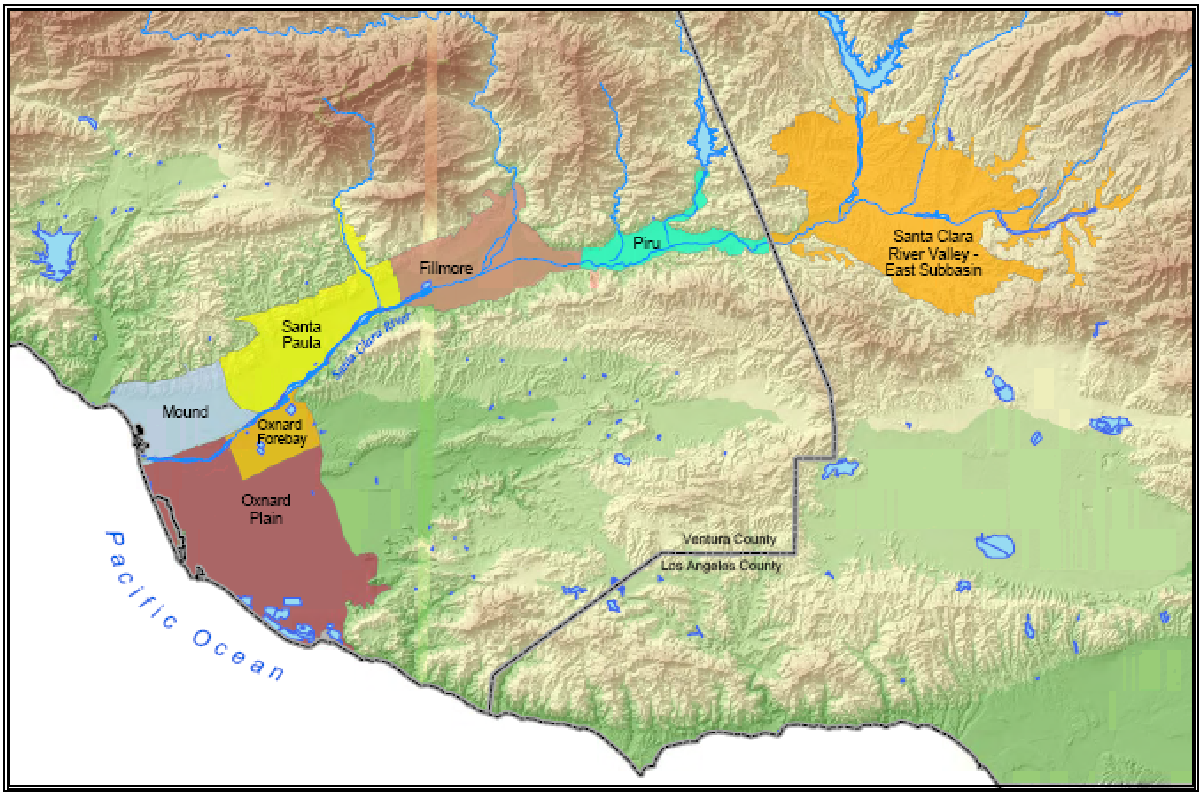


Figure 2.9 SCR Ground Water Basins (From Luhdorff & Scalmanini, 2005)

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. River segmentation is an analogous process of identifying the drainage network within the watershed, assessing stream morphologic characteristics for uniformity and gradients, and selecting those sites on each of the modeled waterways where model results are needed and/or desired. These sites are typically confluences of tributaries and downstream waterways, changes in channel characteristics, stream gage locations, TMDL boundaries, etc. The segmentation process is essentially an iterative procedure of overlaying these data layers and information, and identifying portions of the watershed and the stream system 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 major considerations in land segmentation, in addition to meteorologic variability (discussed in Section 2), are drainage patterns, slopes/topography, land use, and soils. GIS coverages were obtained or created for each attribute and overlain with each other, and then GIS overlay and matrix operations were used to group lands with similar characteristics. Since the hydrology and hydrography of the watershed is paramount to the development of the watershed model, the delineation of subbasins and the stream network is the basic foundation upon which the data coverages are superimposed. The delineation methods and data used for the SCR Watershed are discussed further below.

The land use coverage is based on the Southern California Association of Governments (SCAG) land use designations, with coverages corresponding to land use conditions for 1990, 1993, 2001, and 2005 (actually the 2001 coverage revised by LACDPW); the land use data development is discussed in Section 3.2. The soils coverage is based on data from the NRCS Soil Mart, which is provided in SSURGO format, and is discussed in Section 3.3.

For topography and drainage patterns that define subwatersheds, a number of data sources and procedures were used to define the final subwatershed boundaries. The delineation of the contributing drainage area to each reach was performed within a geographic information system (GIS) framework using the ArcHydro suite of delineation tools (Maidment, 2003). The process involved a combination of automated and manual delineation techniques. The following GIS data were used in the process:

- NHDPlus - NHDPlus is an integrated suite of geospatial data sets that incorporates many of the best features of the National Hydrography Dataset (NHD), the National Elevation Dataset (NED), the National Land Cover Dataset (NLDC), and the Watershed Boundary Dataset (WBD).
- Digital Elevation Model (DEM) – DEMs of 10 meter resolution were acquired from the USGS NED web site (http://seamless.usgs.gov/website/seamless/viewer.php), and from LACDPW (B. WIllardson, personal communication, 2006). These DEMs are of a finer resolution than the one supplied with NHDPlus.
- LA_ModSegs_Ford.shp - A GIS shapefile provided by Los Angeles (LA) County that defined previously delineated subbasin boundaries within the more urbanized and flatter portions of the County.
- VC_ModSegs_Sed.shp - A GIS shapefile provided by Ventura County that defined previously delineated subbasin boundaries within the more urbanized and flatter portions of the County.

The NHDPlus dataset includes elevation, flow accumulation, and flow direction grids. These grids were used to automate the delineation process for reaches with high topographic variation, e.g., the mountainous northern regions of the watershed. The grids have undergone significant processing to ensure that drainage patterns are consistent with the 1:100,000 scale NHD and WBD using the "New England Method" (Dewald, 2006). These grids are the most hydrologically accurate 30 meter DEMs available to the water resources community.

In the flatter more urbanized regions of the watershed, calculating relatively small reach drainage boundaries from a 30 meter DEM can be problematic, even when using the NHDPlus dataset. Fortunately, the combination of the GIS shapefiles provided by the Counties and the 10 meter DEM allowed drainage divides to be developed in these regions. For these areas, existing drainage boundaries were used unless there were obvious errors. If errors were found, a combination of orthophotos, road coverages, and the 10 meter DEM were used to develop a modified drainage divide.

The preliminary model land and river segments, with delineated subwatersheds for each stream reach, were presented in the SCR Watershed Simulation Plan (AQUA TERRA Consultants, 2006). The primary factors that produced the preliminary segmentation included:

a. locations of the rain gages,
b. Thiessen network boundaries,
c. isohyetal contours,
d. drainage boundaries from the GIS coverages noted above
e. differences in slope and elevation,
f. locations of streamflow gages

g. locations of debris basins,
h. TMDL impaired waters boundaries.

The preliminary segmentation of the SCR Watershed resulted in approximately 110 model segments, and a comparable number of stream reaches. As a result of subsequent presentation and discussions with the Study Partners, and numerous iterations and interactions, it was subsequently revised to include and/or address the following:

a. the barrancas (Adams, Todd, Elsworth) near the SCR outlet were added as separate subwatersheds,
b. separate delineation of selected ungaged tributaries (requested by FEMA) as specified by VCWPD, i.e. Patterson Drain, El Rio Drain, Orcutt Canyon, Grimes Canyon, and Basolo Ditch.
c. subdivision of selected mainstem and tributary stream segments to provide greater spatial definition, and in some cases to match separate water quality and sediment sampling points (e.g. UWCD, LAC sediment breakpoints)
d. provide mainstem reach boundaries (i.e. breakpoints) for 16 mainstem bridges.

Many of the bridges and water quality sampling points coincided with existing streamflow gages, and were thus already included as separate reach boundaries. The final model segmentation is shown in Figure 3.1, with 209 model subwatersheds and 192 stream reaches. This level of spatial discretization was judged to provide ample definition of the drainage network, the major tributaries, spatial variation in climate and watershed characteristics, along with groundwater recharge/discharge areas, channel loss segments, etc. to meet the overall objectives of the study. Figure 3.1 shows the segmentation for the December 2008 model version; additional tributaries and reaches were added for the Design Storm work and are described in Appendices L and M.

Figure 3.2 shows the precipitation station locations as compared to the model segments/subbasins to which the rainfall is applied. Table 3.1 lists these precipitation stations, theirs names, the model segments which receive that rainfall, and the multiplier factor (referred to as an MFACT in the model) that adjusts the gage rainfall to better represent the amount falling on the model segment. It is used to adjust the point (i.e. gage) rainfall to approximate the effective rainfall over the watershed area to which it is applied. It is estimated as the ratio of the mean segment/subbasin rainfall, calculated from the isohyetal map (Figure 2.1), to the mean gage rainfall. As such, MFACT is NOT a calibration factor, but for suspect rainfall records, and sparse coverage, MFACT may be also used in an attempt to adjust/correct poor, or inaccurate, gage data to better represent the actual rain falling on the segment area.

It should be noted that although debris basin locations are shown in Figure 3.1 for both counties, and separate subwatersheds have been delineated for each debris basin, the Study Partners agreed that the flow detention provided by these facilities was minimal; they are designed primarily as debris basins, with very little detention, and therefore it was not necessary (or worth the effort required) to represent them in the model (M. Bandurraga, personal communication, email on 7 December 2006). Thus, these debris basin areas are included in the model so that their contributing areas provide downstream flow, but no detention is modeled. Since they are shown as separate model subwatersheds, their detention impacts can be considered in any future model revisions if needed, or for modeling of smaller subwatersheds where their impacts may be more evident. Debris basins with a surface area greater than 1 acre, are designated as 'DB' in Table 3.4, the list of stream reaches.

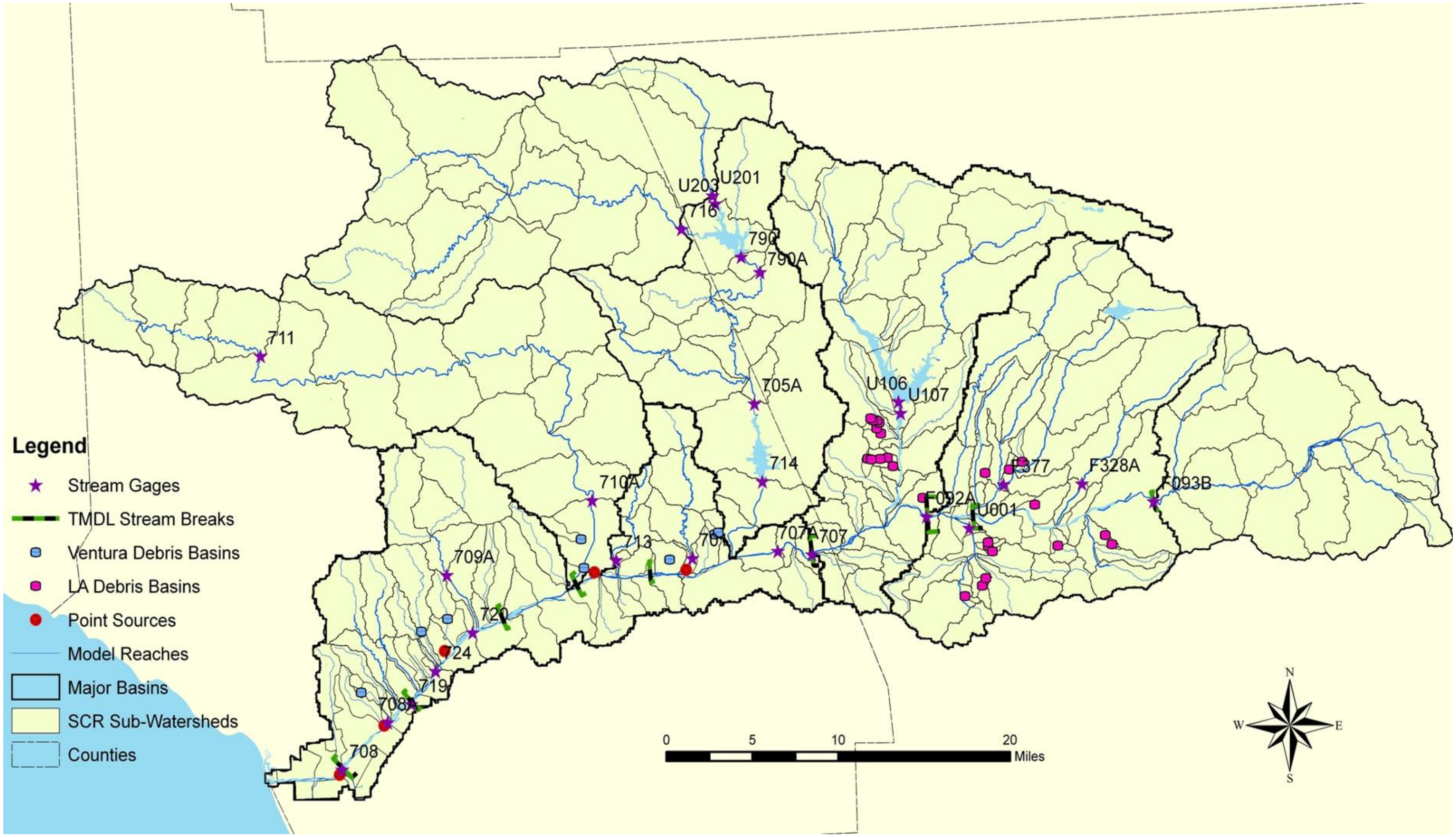


Figure 3.1 Final SCR Watershed Model Segmentation (Model dated December 2008)

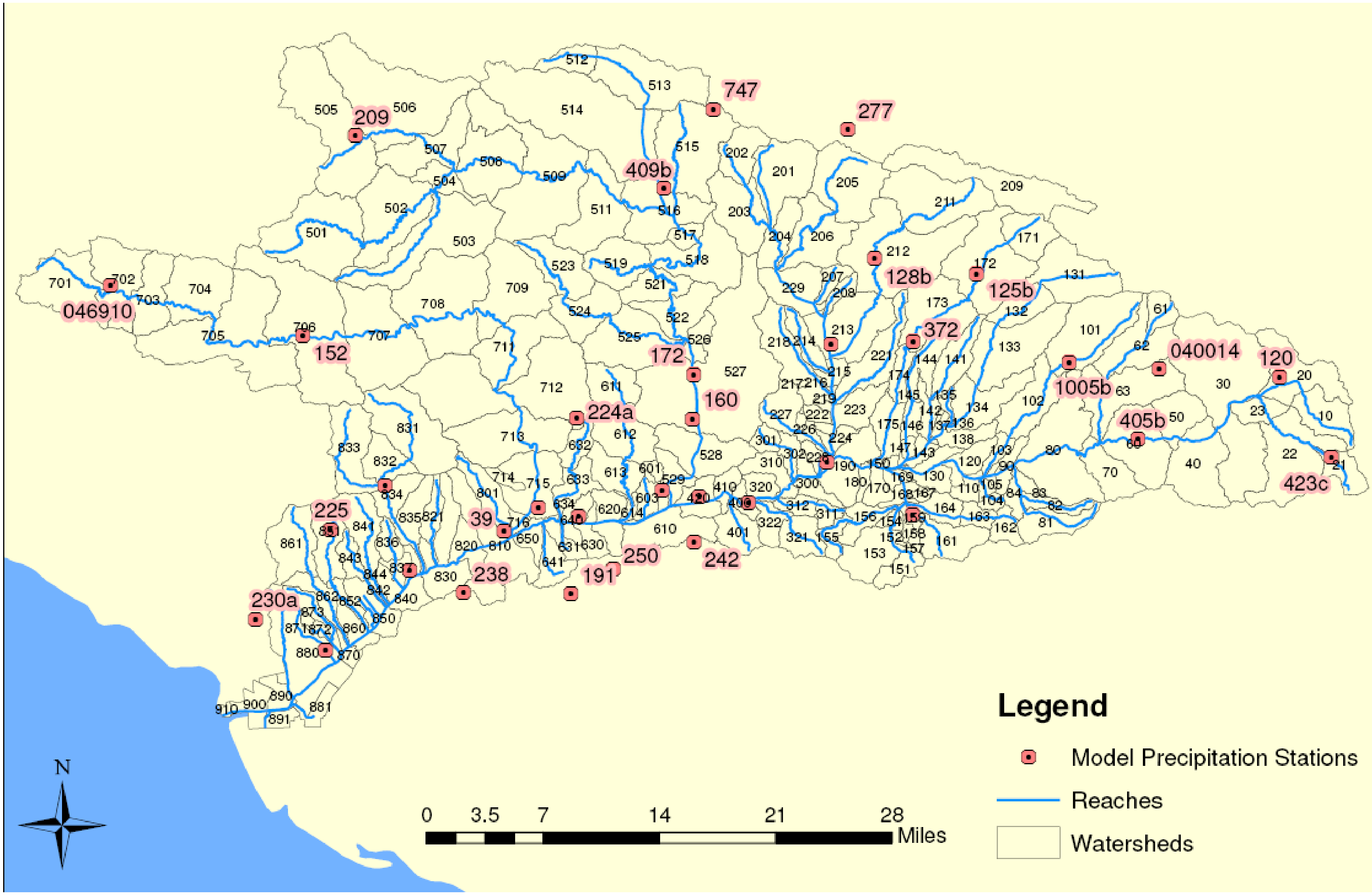


Figure 3.2 Final SCR Watershed Model Precipitation Gages, Segment Locations, and Numbering (Model dated December 2008)

Table 3.1 Precipitation Stations and Corresponding Model Segments and Multipliers

Station ID	Station Name	Model Segments	Multipliers
423C	Angeles Forest - Aliso Cyn	10,21,22,31	0.90
261F/40014	Acton - Escondido Canyon	20,23,30	1.20
405B	Soledad Canyon	40,50,60,70	1.10
120	Vincent Patrol Station	61-63	1.15
1191	Bear Divide	100,104,105,110,120,162,163,80-84,90	0.95
1191	Bear Divide	103	0.80
1005B	Mint Canyon Fire Station	101,102	0.80
1005B	Mint Canyon Fire Station	134-138	1.00
46162	Newhall - Soledad Div. Hdqtrs.	130,139,143,147,150,164-170	0.80
372	San Francisquito Power Hse #2	131-133,141,142,144-146,173,174,221	0.80
446	Aliso Canyon - Oat Mountain	151-154,156-159,161	0.80
125B	San Francisquito Power Hse	171,172,209	0.80
1263	Valencia Reclamation Plant	155,175,180	0.85
1263	Valencia Reclamation Plant	190,222-228,300-302,311	1.00
277	Sawmill Mountain	201,205	1.00
747	Sandberg	202,203,515	1.00
CWAR	Warm Springs	204,206-208	1.00
128B	Elizabeth Lake-Warm Springs	211,212	1.00
252C	Castaic Lake	213-219,229	1.00
46942	Piru Telemetering	310,312,320-322,400,401,410	1.00
101	Piru-Camulos Ranch (Recorder)	420	0.94
152	Piedra Blanca Guard Station	501-504	0.84
152	Piedra Blanca Guard Station	705-708	1.05
209	Lockwood Valley-County Yard	505-507	1.12
409B	Pyramid Reservoir	508,509,511,516-519,523	1.12
409B	Pyramid Reservoir	512-513	0.84
409B	Pyramid Reservoir	514	0.93
172	Piru Canyon	521,522,525-527	1.00
160	Piru-Temescal Guard Station	528	1.00
36A	Piru-County Fire Station	529,601-603,613,614	1.10
242	Tripas Canyon	610	0.94
224A	Sespe-Westates	611,612	0.96
224A	Sespe-Westates	632	0.94
224A	Sespe-Westates	524,709,711-713	0.97
171	Fillmore-Fish Hatchery	620,630,631,633,634,640	1.03
191	Moorpark-Downing Ranch	641	0.94
46910	Pine Mountain Inn	701-704	1.07
199	Fillmore-County Fire Station	722-728	1.03
39	Fillmore-Rancho Sespe	801,810,650	1.00
238	South Mountain-Shell Oil	820	0.94
173A	Santa Paula Canyon-Ferndale	821,835	1.07
65A	Upper Ojai Summit-County Fire	831-834	1.07
245A	Santa Paula-UWCD	830,836,837,840,842,844,853,854	0.94
225	Wheeler Canyon	841,843,851,861	0.94
175	Saticoy Fire Station	850,852,860,862,870-874,880-882,890,891	0.94
230A	Ventura-Sexton Canyon	883,900,910	1.00

3.1.2 River Segmentation and Model Characterization

The river channel network in the SCR Watershed is the major pathway by which flow, sediment and contaminants are transported from the watershed to the Pacific Ocean. As such, it is important to accurately represent or characterize the channel system in the HSPF model of the SCR Watershed. The river reach segmentation requires consideration of river travel time, riverbed slope continuity, cross section and morphologic changes, and entry points of major tributaries. When partitioning the channel segments, additional considerations include stream gage locations, major tributary confluences, major diversions, Total Maximum Daily Load (TMDL) stream segments, PCS (Permit Compliance System) facilities, sediment study boundaries, debris basins, TSS sampling points, and groundwater recharge/discharge zones.

Section 303(d) TMDL reach endpoints are represented explicitly as model reach boundaries so that flows, water balance, and volume information can be generated for use in TMDL assessments. Table 3.2 describes the ten TMDL segments of the Santa Clara River.

Table 3.2 US EPA Reach designations for the Santa Clara River

EPA Reach #	Description
1	Santa Clara Estuary to Highway 101
2	Highway 101 to Freeman diversion dam
3	Freeman diversion dam to above Santa Paula Creek and below Timber Canyon
4	Above Timber Canyon to above Grimes Canyon
5	Above Grimes Canyon to Propane Road
6	Propane Road to Blue Cut gaging station
7	Blue Cut gaging station to west pier Highway 99
8	West pier Highway 99 to Bouquet Canyon Road
9	Bouquet Canyon Road to Lang gaging station
10	Above Lang gaging station

Hydraulic Characterization of River and Reservoir Segments

Once the final reach segmentation was established, each reach segment was then analyzed to define its hydraulic behavior and characteristics, and compute the tributary areas of the land use categories that drain to each reach.

Within the channel module (RCHRES) of HSPF, the stream hydraulic behavior of each waterbody (stream/river or reservoir) is represented by a hydraulic function table, called an FTABLE, which defines the flow rate, surface area, and volume as a function of the water depth. In order to develop an FTABLE, the waterbody geometric and hydraulic properties (e.g., slope, cross-section, Manning's n) must be first defined using data or estimated values. Once the geometry and hydraulic properties have been defined, it is necessary to develop the FTABLE as a function of the depth of water (i.e. stage) at the outlet. The method used in developing the FTABLEs for streams and rivers 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.

All of the FTABLEs for the streams and rivers within the Santa Clara River Watershed model application were initially developed using HEC-RAS. VCWPD provided a HEC-RAS application (developed from 1991 topography) of the SCR mainstem from its outlet up to the county line. HEC-RAS applications for the remaining reaches were developed using the HEC-GeoRAS interface for ArcGIS (Ackerman, 2005) and digital elevation models (DEMs) of varying resolution. The resolution of the DEMs ranged from 5 meters in Los Angeles County (i.e. LIDAR coverage) to 30 meters in the Mountainous northern parts of Ventura County, where less resolution was required to define the channel. In addition, scanned topographic drawings (provided to AQUA TERRA as TIF files) along the main stem were also available to augment the LIDAR data, as needed.

Additional reach-dependent hydraulic properties that were input into the HEC-RAS model included channel and floodplain roughness and rating curves. The channel and floodplain roughness were defined by assigning a unique Manning's n value for the right floodplain, channel, and left floodplain (as you look downstream) within HEC-RAS. Manning's coefficients for different channel conditions (e.g. concrete box, channel, box culvert, natural) were obtained or estimated from field photos, County standard values (from each County), and literature values.

Available rating curves, provided by the USGS for selected gages, were input into the HEC-RAS model and compared to simulated curves to ensure reasonable Manning's n values and geometry were being used. The FTABLES were developed by simulating a series of steady state flows through each of the reaches and then using the HEC-RAS interface to develop tables relating outlet depth to cumulative surface area and cumulative volume for each flow rate. Thirty five flow rates were simulated through each reach; the range of flow rates simulated in each reach was based on the range of nearby historically gauged flows. Table 3.3 shows example FTABLES. Subsequently during calibration, and during the Design Storm effort, selected FTABLES were extended to accommodate flow rates higher than those used in the initial FTABLE development, and during the calibration/validation period.

FTABLEs for the reservoirs and lakes (i.e., Piru Lake, Castaic and Elderberry Lake, Castaic Lagoon, and Bouquet) were developed using stage-storage and stage-surface area relationships provided in tables and figures from a variety of sources. The FTABLES for the reservoirs contain the same type of depth/elevation, surface area, and volume information (as for the river segments) developed from stage-storage curves compiled and/or provided by the CA DWR, Ventura County, LA County, and UWCD. Detailed depth/surface area/volume curves were available for Pyramid, Castaic, and Piru. The Elderberry and Castaic Lagoon curves were developed from the stage-storage time series that were available from CA DWR. The Lake Piru stage-storage curve changes more quickly than the others, since it is experiencing significant sedimentation. The Piru stage-storage curve measured in approximately 1996 was used in both the calibration and validation periods. Spillway discharge curves as a function of elevation above the spillway were provided for Lake Piru, and were estimated for the other four lakes using spillway/weir discharge equations and approximate spillway sizes.

Table 3.3 Example FTABLES for a Reach With and Without Channel Losses

FTABLE 704
ROWS COLS Example Reach without Channel Losses
35 4

depth ft	SA acre	VOL acre-ft	Q ft3	RES-TIME hours
0.00	0.00	0.00	0.00	0.00
0.31	2.45	0.30	1.00	3.63
1.11	8.91	3.89	25.00	1.88
1.46	11.03	6.49	50.00	1.57
1.84	13.28	10.58	100.00	1.28
2.10	14.94	14.06	150.00	1.13
2.35	16.35	17.33	200.00	1.05
2.52	17.63	20.53	250.00	0.99
2.92	19.58	26.04	350.00	0.90
3.20	20.64	30.44	450.00	0.82
3.58	22.18	37.54	600.00	0.76
4.05	23.69	45.94	800.00	0.69
4.44	25.05	54.10	1000.00	0.65
4.81	26.25	61.78	1200.00	0.62
5.30	27.86	72.80	1500.00	0.59
6.07	30.27	90.07	2000.00	0.54
6.73	32.36	106.21	2500.00	0.51
7.33	34.22	121.59	3000.00	0.49
7.91	35.86	135.97	3500.00	0.47
8.44	37.57	150.69	4000.00	0.46
8.93	39.15	164.63	4500.00	0.44
9.38	40.69	178.65	5000.00	0.43
9.83	42.11	192.24	5500.00	0.42
10.25	43.64	205.60	6000.00	0.41
11.79	49.32	257.49	8000.00	0.39
13.16	54.24	305.94	10000.00	0.37
16.07	63.46	413.51	15000.00	0.33
18.51	71.23	518.58	20000.00	0.31
22.39	80.01	702.76	30000.00	0.28
25.24	85.82	867.69	40000.00	0.26

END FTABLE704

FTABLE 529
ROWS COLS Example Reach with Channel Losses
35 5

depth ft	SA acre	VOL acre-ft	Q ft3	LOSS cfs
0.00	0.00	00.00	0.00	10.81
0.24	5.63	00.50	1.00	10.81
0.80	18.59	05.50	25.00	11.76
1.04	23.80	09.19	50.00	16.49
1.35	30.23	15.30	100.00	25.95
1.58	34.53	20.57	150.00	35.41
1.76	37.98	25.40	200.00	44.86
1.91	40.95	29.93	250.00	54.32
2.17	45.97	38.36	350.00	73.24
2.38	50.17	46.17	450.00	92.16
2.65	55.52	57.13	600.00	120.54
2.96	61.49	70.70	800.00	158.38
3.22	66.59	83.42	1000.00	196.22
3.43	71.08	95.48	1200.00	234.05
3.73	77.00	112.68	1500.00	290.81
4.15	85.33	139.41	2000.00	385.41
4.51	92.27	164.32	2500.00	480.00
4.83	98.30	187.87	3000.00	574.59
5.13	103.65	210.33	3500.00	669.19
5.40	108.44	231.85	4000.00	763.78
5.66	112.82	252.61	4500.00	858.38
5.90	116.89	272.74	5000.00	952.97
6.12	120.67	292.32	5500.00	1047.57
6.33	124.22	311.40	6000.00	1142.16
7.10	140.22	385.87	8000.00	1520.54
7.76	160.68	458.52	10000.00	1898.92
9.13	194.92	622.61	15000.00	2844.86
10.26	216.31	769.09	20000.00	3790.81
12.08	249.79	1033.65	30000.00	5682.70

END FTABLE529

Figure 3.3 shows the river and reservoir reach segments, and each of the segments is listed in Table 3.4 along with its length and local drainage area; as noted above, debris basins are designated as 'DB' in the table. The reach numbers were assigned to correspond to the major subbasins, but to also provide an indication of where in the watershed the reach resides. Thus, the numbering scheme was as follows:

a. SCR mainstem reaches, numbers 10 to 910, but no single digits.
b. Upper SCR to Lang, numbers from 10 to 70
c. Upper SCR at highway 99, numbers 80 to 180
d. Castaic, numbers 200 to 300
e. Upper Piru, numbers in 500s
f. Pyramid-Piru, numbers 400 to 500s
g. Sespe Creek, numbers in 700s
h. SCR Mainstem and Ventura Tributaries, numbers 600s to 900s

Note that Figure 3.3 and Table 3.4 describe the SCR HSPF Model dated December 2008, prior to the addition of the tributary analyses for Design Storm development as described in Appendices L and M.

3.1.2.1 Channel Losses

Streamflow infiltration occurs in numerous streams within the SCR 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 but that McEachron (2006) provides estimates of channel losses to compare to model values. The two example FTABLES in Table 3.3 represent a channel with losses and a detention basin. Calibration of channel losses is discussed in Section 4.

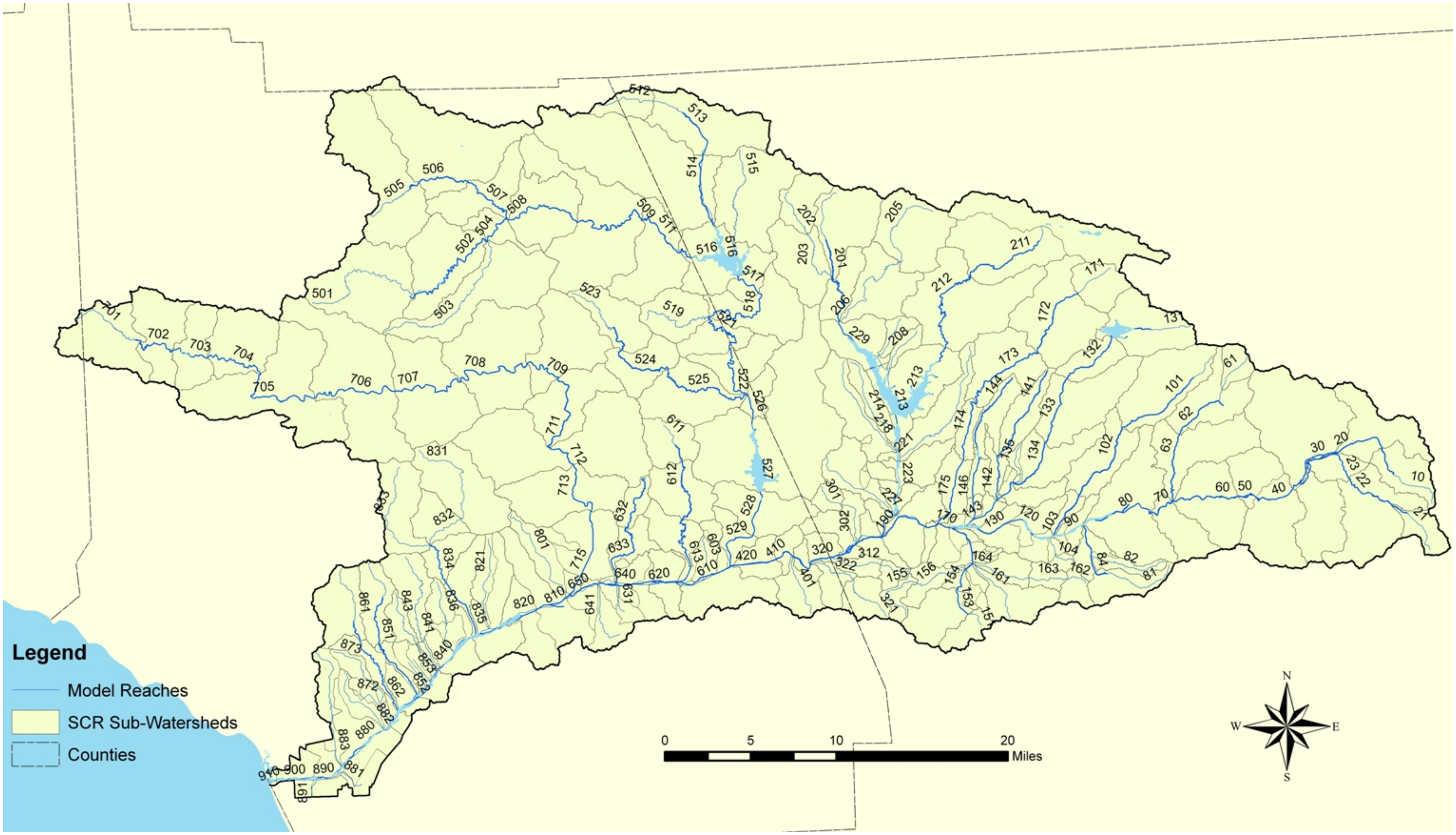


Figure 3.3 SCR Watershed Stream Reach Numbers and Locations (Model dated December 2008)

Table 3.4 SCR Watershed Model Reach Designations (Model dated December 2008)

Model	Name	Drainage Area (ac)	Length (mi)
10	Kentucky Springs Cyn	4952	5.44
20	Santa Clara River	8014	3.56
21	Aliso Canyon	3039	4.06
22	Aliso Canyon	11438	3.70
23	Aliso Canyon	2542	1.98
30	Santa Clara River	17045	1.92
31	Santa Clara River	7355	1.92
40	Santa Clara River	9024	2.52
50	Santa Clara River	4461	1.21
60	Santa Clara River	9042	4.34
61	Agua Dulce Canyon	2240	2.66
62	Agua Dulce Canyon	6890	3.99
63	Agua Dulce Canyon	9761	4.43
70	SCR Nr Lang	4732	1.97
80	Santa Clara River	14415	4.85
81	Sand Canyon	4057	5.77
82	Iron Canyon	1892	5.17
83	Saddleback DB	39	0.00
84	Sand Canyon	2167	2.96
90	Santa Clara River	1765	1.26
100	Santa Clara River	423	0.65
101	MINT Canyon	10774	7.53
102	MINT Canyon	6673	5.28
103	MINT Canyon	1351	2.92
104	Oakdale DB	805	1.41
105	Trib DS of OakdaleDB	589	1.16
110	Santa Clara River	1465	1.33
120	Santa Clara River	2849	1.89
130	Santa Clara River	3206	2.69
131	BOUQUET Reservoir	8063	2.00
132	BOUQUET Canyon	3856	4.03
133	BOUQUET Canyon	10753	4.43
134	BOUQUET Canyon	6235	3.48
135	PD 2099 Shadow DB	601	2.11
136	PD 2099 Shadow DB	126	0.76
137	PD 1386 Copper Hill DB	166	0.00
138	BOUQUET Canyon	2664	1.17
139	BOUQUET Canyon	93	0.37
141	Haskell Canyon	4384	6.34
142	Haskell Canyon	1862	2.86
143	BOUQUET Canyon	1331	2.57
144	Dry Creek Lake	3838	6.03
145	Dry Canyon Reservoir	52	0.00
146	Dry Canyon Reservoir	1510	2.51
147	Dry Canyon	667	1.30
150	Santa Clara River	469	1.31
151	South Fork SCR	2533	1.26
152	PD 1358 LA Salle DB	150	0.00
153	South Fork SCR	5558	1.78
154	South Fork SCR	815	1.52
155	Pico Canyon	1749	4.46
156	Pico Canyon	2686	3.68
157	Wildwood DB	412	0.00
158	Wildwood DB trib	452	0.00
159	South Fork SCR	610	0.55
161	Newhall Creek	5239	4.42
162	Placerita Ck	1957	1.33

163		Placerita Ck		1640		2.61
164		Placerita Ck		2500		3.43
165		PD 2097 Stratford DB		155		0.00
166		PD 2097 Cardiff DB		112		0.00
167		2DB tribs to S. FRK SCR		350		0.00
168		South Fork SCR		1150		1.60
169		South Fork SCR		919		1.16
170		Santa Clara River		1890		0.86
171		San Francisquito CYN		4407		2.54
172		San Francisquito CYN		12797		5.04
173		San Francisquito CYN		8253		5.88
174		San Francisquito CYN		2177		4.05
175		San Francisquito CYN		3769		4.43
180		SCR @ HY99		854		0.72
190		Santa Clara River		6025		3.51
201		Castaic Creek		8443		6.28
202		Salt Creek		4322		3.48
203		Salt Creek		7476		4.73
204		Castaic Creek		3874		3.87
205		Fish Canyon		9780		5.86
206		Fish Creek		7674		7.68
207		Elderberry Cyn		1623		2.80
208		Necktie Canyon		1357		3.22
209		Elizabeth LK Cyn		11231		0.00
211		Elizabeth LK Cyn		11306		6.67
212		Elizabeth LK Cyn		16830		7.39
213		Castaic Lake		7543		2.00
214		Castaic Lgn Tb		2634		5.83
215		Castaic Lagoon		1109		1.00
216		Castaic Creek		164		0.58
217		PD2049-MUSTANG DB		143		0.00
218		Marple Cyn		6717		7.13
219		Castaic Creek		351		0.52
221		Castaic Cyn Trib		6324		10.22
222		Castaic - 3 DBs		906		0.00
223		Castaic Creek		4322		2.10
224		Castaic Creek		1272		1.13
225		PD2284 DB		50		0.00
226		PD2284 DB Trib		317		0.00
227		Castaic Cyn Trib		4742		5.89
228		Castaic Creek		1122		1.79
229		Elderberry Forebay		5126		1.00
300		Santa Clara River		2364		1.50
301		San Martinez Cyn		1481		1.86
302		San Martinez Cyn		1717		2.96
310		Santa Clara River		2898		1.75
311		Potrero Cyn		1247		1.95
312		Potrero Cyn		1624		2.84
320		SCR @ VC/LA Line		2009		1.83
321		Salt Canyon		3446		3.83
322		Salt Canyon		2433		3.58
400		Santa Clara River		1276		1.54
401		Tapo Cyn		3695		4.01
410		SCR Nr Piru		1717		1.26
420		Santa Clara River		3060		2.50
501		Piru Creek		14417		10.86
502		Piru Creek		11389		8.00
503		Mutau Creek		14750		11.55
504		Piru Creek		2745		2.20

505		Lockwood Creek		17648		5.08
506		Lockwood Creek		19894		3.48
507		Lockwood Creek		7396		4.17
508		Piru Creek		9123		5.51
509		Piru Creek		19803		6.89
511		Piru Creek		9628		3.69
512		Gorman Creek		2790		3.61
513		Gorman Creek		10951		5.40
514		Alamos Creek,Los		25656		3.94
515		Apple Canyon		13073		7.61
516		Pyramid Lake		8029		5.00
517		Piru Creek		1588		1.73
518		Piru Creek		8912		6.32
519		Fish Creek		5762		6.81
521		Piru Creek		3961		4.69
522		Piru Creek		5621		4.28
523		Agua Blanca Creek		6128		6.53
524		Agua Blanca Creek		5674		4.60
525		Agua Blanca Creek		9646		7.17
526		Piru Cr.Abv piru		2266		1.46
527		Lake Piru		32073		4.00
528		Piru Creek		7404		2.80
529		Piru Creek		2668		3.19
601		Warring Cyn DB		680		0.00
602		Real Wash DB		166		0.00
603		Edwards & Rl Cyn		1811		2.75
610		Santa Clara River		7066		3.24
611		Hopper Cyn		4664		2.69
612		Hopper Cyn		6367		4.80
613		Hopper Cyn		4197		4.72
614		Hopper Cyn		744		1.38
620		Santa Clara River		3662		1.95
630		Santa Clara River		2017		0.80
631		Basolo Ditch		1061		2.04
632		Pole Creek		2298		4.23
633		Pole Creek		2928		4.24
634		Pole Creek		347		0.80
640		Santa Clara River		2905		2.27
641		Grimes Canyon		3024		4.22
650		Santa Clara River		1830		2.20
701		Sespe Creek		9474		6.27
702		Sespe Creek		7985		3.08
703		Sespe Creek		5792		2.64
704		Sespe Creek		8489		4.37
705		Sespe Creek		20596		6.31
706		Sespe Creek		21963		6.29
707		Sespe Creek		15063		5.39
708		Sespe Creek		16813		6.34
709		Sespe Creek		10944		2.93
711		Sespe Creek		8622		5.71
712		Sespe Creek		23928		2.03
713		Sespe Creek		11051		4.13
714		Jepson Wash DB		887		0.00
715		Sespe Creek		7417		4.01
716		Sespe Creek		761		1.62
801		Boulder Creek		3983		6.89
810		Santa Clara River		7886		1.93
820		Santa Clara River		5186		1.87
821		Orcutt Canyon		2371		6.08

830		SCR VC720 @ 12 St		6910		2.58
831		Santa Paula Creek		11154		6.72
832		Santa Paula Creek		3882		2.95
833		Sisar Creek		7375		7.62
834		Santa Paula Creek		3136		2.85
835		Santa Paula Creek		3779		3.87
836		Fagan Cyn DB		1880		3.17
837		Fagan Cyn		1363		2.03
840		Santa Clara River		3963		2.93
841		Adams Barranca		5398		7.42
842		Adams Barranca		412		2.04
843		Ohara Canyon		2006		4.41
844		Haines Barranca		227		2.02
850		SCR @ Freeman Div		1722		1.97
851		Wheeler Canyon		4788		5.87
852		Todd Barranca		1246		4.64
853		Todd Barranca		800		1.70
854		Todd Barranca		1223		2.43
860		Santa Clara River		2287		1.46
861		Aliso Canyon		6538		5.31
862		Ellsworth Bar.		2765		5.67
870		SCR @ Saticoy		745		0.76
871		Franklin Bar. DB		323		0.00
872		Franklin Barranca		603		1.64
873		Wason Barranca		1996		5.67
874		Wason Barranca		244		1.11
880		SCR @ Montalvo		6153		3.92
881		El Rio Drain		1686		1.86
882		Brown Barranca		2049		4.71
883		Harmon Barranca		3695		8.38
890		Santa Clara River		1768		2.04
891		Patterson Rd Drain		1136		1.14
900		Santa Clara River		2504		2.16
910		Santa Clara River		256		0.56

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 land use coverage used in the SCR Watershed model is initially based on the Southern California Association of Governments (SCAG) land use designations, with coverages corresponding to land use conditions for 1990, 1993, 2001, and 2005 (actually the 2001 coverage revised by LACDPW); The 2001 coverage was revised by LA County based on their aerial photography and some categories were refined and/or re-assigned. The coverage was re-named '2005' but is still considered 2000/2001 data (B. Willardson, LADPW, personal communication 2007), and shows some slight effects on land use assignments in LA County only.

The Santa Clara River Watershed is a mix of urban and agricultural lowlands and upland open areas, with the latter (referred to as 'Vacant, Undifferentiated') comprising approximately 87% of the total area. Agriculture covers 4% of the watershed, concentrated along the river valley. The urban areas, including Santa Clarita, Piru, Fillmore, Santa Paula, and Ventura, are comprised of commercial/industrial areas (4.2%), medium to high-density residential (2%), low-density residential (1.3%), with smaller areas as public facilities (0.1%).

Table 3.5 below shows the acreages of each SCAG land use classification for each of the four designated years.

Table 3.5 Land Use in the Santa Clara River Watershed from SCAG

Land Use Category	1990		1993		2001		2005	
	Area (sq mi)	% of Total	Area (sq mi)	% of Total	Area (sq mi)	% of Total	Area (sq mi)	% of Total
Agriculture	65.8	4.0	65.5	4.0	64.5	3.9	64.5	3.9
Open/Recreational Space	5.3	0.3	11.0	0.7	11.7	0.7	11.7	0.7
Vacant Undifferentiated	1439.7	87.5	1437.6	87.3	1427.7	86.7	1427.7	86.7
Total Rural	1510.8	91.8	1514.2	92.0	1503.9	91.4	1504.0	91.4
Commercial	4.7	0.3	5.1	0.3	6.7	0.4	6.9	0.4
Industrial	62.7	3.8	62.7	3.8	62.4	3.8	63.1	3.8
Transportation	5.1	0.3	5.1	0.3	5.2	0.3	5.2	0.3
Schools	1.5	0.1	1.5	0.1	1.8	0.1	1.8	0.1
LD Residential	18.9	1.1	19.6	1.2	21.3	1.3	21.8	1.3
Mid-High Residential	31.5	1.9	26.5	1.6	33.8	2.1	32.4	2.0
Total Urban	124.4	7.6	120.5	7.3	131.3	8.0	131.2	8.0
Water and Floodways	10.8	0.7	10.9	0.7	10.8	0.7	10.8	0.7
Total Overall	1646	100.0	1646	100.0	1646	100.0	1646	100.0

Although the SCAG land use data provided a reasonable mix of urban categories for the model, both the agriculture and the large 'vacant/undifferentiated' (almost 87% of the watershed) groups needed better definition in order to allow their representation and contributions within the model. As discussed in Section 2.5, the agriculture category was assumed to be all irrigated, and was further subdivided based on crop survey data for Ventura County and irrigated cropland data for LA County (Applied GeoSolutions, 2006); this was needed to estimate an average (weighted) crop coefficient

(Kc) for the agricultural land needed in defining crop water needs and irrigation demand (see section 2.5.5).

To differentiate the large 'vacant/undifferentiated' (almost 87% of the watershed) into categories that can better define the actual vegetation types and their characteristics, we used the LANDFIRE Rapid Assessment 'Potential Natural Vegetation Group' (PNVG) coverage (www.landfire.gov) (U.S. Forest Service, 2002), shown in Figure 3.4, which provides good detail on the type and distribution of vegetation across the entire watershed. The development and background of the PNVG coverage is described as follows:

> *"The LANDFIRE Rapid Assessment (RA) potential natural vegetation group (PNVG) spatial data layer delineates vegetation communities that are likely to exist under the natural range of variability in biophysical environments and ecological processes, including fire and other disturbances. This biophysical classification was based originally on Kuchler's work (1964), modified during the Coarse-Scale Fire Regime Condition Class (FRCC) Assessment (Schmidt and others 2002), refined in the development of the Interagency FRCC Guidebook (Hann and others 2004), and then further refined during the RA process. In this process, the RA team conducted twelve week-long workshops throughout the conterminous United States to garner input from over 250 local land managers. Experts collaborated to refine the PNVG classification, write PNVG descriptions, model each PNVG to determine reference conditions, and assign mapping rules for each PNVG." (Hann et al., 2004).*

Although SCAG provided Total Impervious Area (TIA) percentages for each land use category, it is the ***effective impervious area*** **(EIA)** that is required by HSPF and most watershed models. EIA 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, and basically behave like pervious runoff. EIA values were derived from information provided by VCWPD during the Calleguas study, from LACDPW 2006 Hydrology Manual and Standard Imperviousness Values, and on literature values for studies in similar areas. The values were reviewed by the Study Partners and selected sub-categories were adjusted to accommodate special conditions. The EIA percentages were assigned to detailed SCAG 'urban' land use categories, and then these percentages are multiplied by the detailed category areas within each model segment to determine the amount of EIA within each model urban category. The total effective impervious area of each model segment is then represented as a single entity within the model. The final fractions assigned to each SCAG sub-category within each model category are shown in Table 3.6.

The aggregated land use coverage was intersected with the final meteorologic and topographic model segmentation to determine the area of each modeled land category (Section 3.1.1) within each model segment.

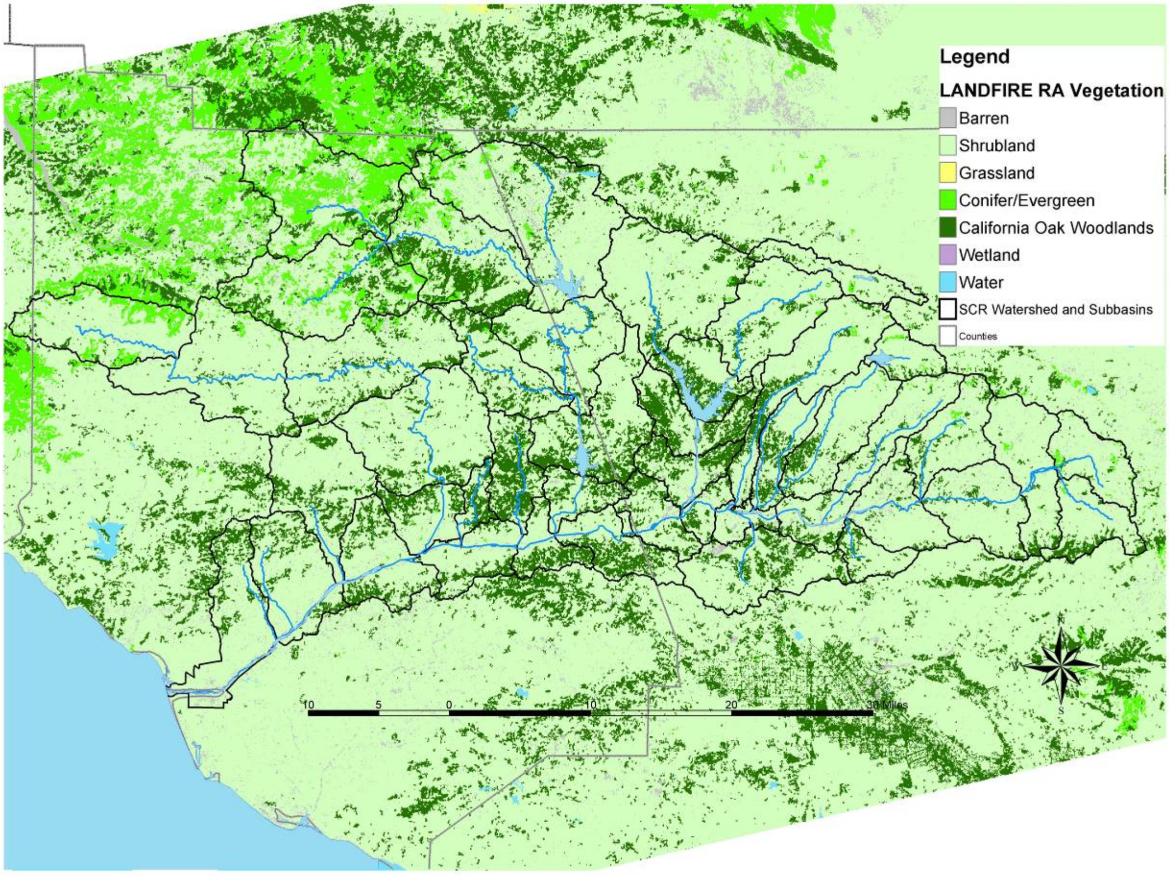


Figure 3.4 LANDFIRE Rapid Assessment 'Potential Natural Vegetation Group' coverage

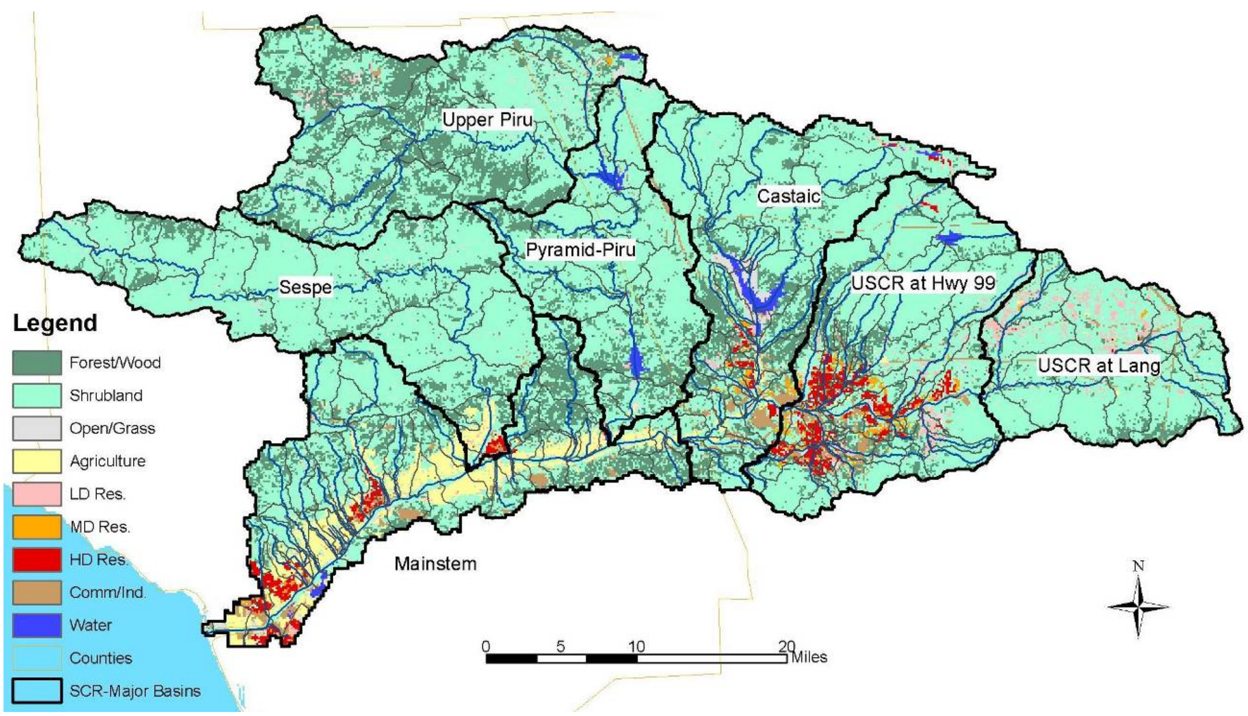


Figure 3.5 Model Land Use Categories and Distribution within the SCR Watershed

Table 3.6 Land Use and EIA Values for SCAG, LANDFIRE-RA, and Model Categories

Model	Aggregated SCAG	LANDFIRE	SCAG Land Use Description	% SCAG (	% Model C	EIA %	TIA %
Forest/ Shrub/ Wood		Forest	Vacant Undifferentiated	0.880		0	1
		Woodland		18.220		0	1
		Shrubland		66.55	85.7	0	1
Open/ Grassland	Open/Recreational Space		Abandoned Orchards and Vineyards	0.017		0	2
			Beach Parks	0.003		0	10
			Developed Regional Parks and Recreation	0.022		0	2
			Golf Courses	0.134		0	3
			Non-Irrigated Cropland and Improved Pasture Land	0.335		0	2
			Undeveloped Local Parks and Recreation	0.001		0	2
			Undeveloped Regional Parks and Recreation	0.343		0	1
			Wildlife Preserves and Sanctuaries	0.013		0	2
		Grassland	Vacant Undifferentiated	2.380	3.2	0	1
Agriculture	Agriculture		Irrigated Cropland and Improved Pasture Land	0.642		0	2
			Nurseries	0.091		0	15
			Orchards and Vineyards	2.817	3.6	0	2
LD Residential	LD Residential		Dairy, Intensive Livestock, and Associated Facilities	0.006		20	42
			Developed Local Parks and Recreation	0.048		5	10
			Horse Ranches	0.156		20	42
			Cemeteries	0.016		5	10
			Low-Density Single Family Residential	0.352		10	21
			Mobile Home Courts and Subdivisions, Low-Density	0.010		20	42
			Other Agriculture	0.057		10	42
			Other Open Space and Recreation	0.122		3	10
			Poultry Operations	0.001		20	62
			Rural Residential, Low-Density	0.973	1.7	10	10
MD-Residential	MD-Residential		Duplexes, Triplexes and 2-or 3-Unit Condominiums and Townho	0.029		35	55
			Low-Rise Apartments, Condominiums, and Townhouses	0.172		25	86
			Mixed Residential	0.000		25	59
			Pre-Schools/Day Care Centers	0.001		10	68
			Rural Residential, High-Density	0.031		25	15
			Under Construction	0.359	0.6	30	91
HD-Residential	HD-Residential		Commercial Recreation	0.035		40	90
			High-Density Single Family Residential	1.510		40	42
			Medium-Rise Apartments and Condominiums	0.015		40	86
			Mixed Multi-Family Residential	0.003		40	74
			Trailer Parks and Mobile Home Courts, High-Density	0.072	1.6	40	91
Commercial and Industrial	Commercial		Chemical Processing	0.001		70	91
			Commercial Storage	0.016		70	90
			Communication Facilities	0.004		70	82
			Correctional Facilities	0.032		70	91
			Fire Stations	0.009		70	91
			Government Offices	0.015		70	91
			High-Rise Major Office Use	0.001		70	91
			Hotels and Motels	0.009		70	96
			Low- and Medium-Rise Major Office Use	0.028		70	91
			Major Medical Health Care Facilities	0.003		70	74
			Mineral Extraction - Oil and Gas	0.554		70	10
			Mineral Extraction - Other Than Oil and Gas	0.110		70	10
			Mixed Urban	0.001		70	89
			Modern Strip Development	0.124		70	96
			Motion Picture and Television Studio Lots	0.015		70	82
			Older Strip Development	0.008		70	97
			Open Storage	0.051		70	66
			Other Public Facilities	0.004		70	91
			Other Special Use Facilities	0.003		70	86
			Police and Sheriff Stations	0.002		70	91
			Regional Shopping Center	0.010		70	95
			Religious Facilities	0.022		35	82
			Retail Centers (Non-Strip With Contiguous Interconnected Off-S	0.061		70	96
			Special Care Facilities	0.004		70	74
			Wholesaling and Warehousing	0.018		70	91
	Industrial		Base (Built-up Area)	0.000		70	65
			Electrical Power Facilities	0.943		70	47
			Liquid Waste Disposal Facilities	0.016		70	96
			Maintenance Yards	0.013		70	91
			Manufacturing, Assembly, and Industrial Services	0.175		70	91
			Mixed Commercial and Industrial	0.006		70	91
			Natural Gas and Petroleum Facilities	0.018		70	91
			Packing Houses and Grain Elevators	0.010		70	96
			Research and Development	0.010		70	91
			Solid Waste Disposal Facilities	0.066		70	15
			Water Storage Facilities	0.030		70	91
			Water Transfer Facilities	0.028		70	96
	Schools		Colleges and Universities	0.019		35	47
			Elementary Schools	0.058		35	82
			Junior or Intermediate High Schools	0.016		35	82
			Senior High Schools	0.029		35	82
			Trade Schools and Professional Training Facilities	0.001		35	91
	Transportation		Airports	0.017		80	91
			Bus Terminals and Yards	0.001		70	91
			Freeways and Major Roads	0.263		70	91
			Mixed Transportation	0.018		75	90
			Non-Attended Public Parking Facilities	0.001		70	91
			Park-and-Ride Lots	0.003		70	91
			Railroads	0.002		70	15
			Truck Terminals	0.005	2.9	85	91

In summary, the GIS land use data processing included the following:

a. The SCAG coverage was first superimposed and clipped with the SCR watershed coverage resulting from the reach segmentation.

b. Then the LANDFIRE-RA vegetation coverage was superimposed to differentiate the "Vacant-Undifferentiated" SCAG land use category, into two primary vegetation types: forest/woodland, shrubland.

c. Then the EIA values (Table 3.6) were intersected with the combined SCAG/LANDFIRE coverage to determine the nine model categories and their areas within each reach drainage. The model land uses included the following:

   - Forest/Woodland
   - Shrubland
   - Open/Grass
   - Agriculture
   - Low Density Residential
   - Medium Density Residential
   - High Density Residential
   - Commercial/Industrial

d. These steps were performed separately, using the Spatial Analyst tool in ArcGIS, for both 2001 and 1993 to generate the aggregated model land use coverages used for the calibration period and validation periods, respectively.

e. This final adjusted coverage was then superimposed with the final reach segmentation to define the model land use categories that drain to each model reach; this defines the time series linkages between the land areas and the channels within the model needed to define the stream network for HSPF.

f. For the Agricultural areas, the final coverage was superimposed with the Ventura County Crops and the LA County crop coverages to calculate average (weighted) Crop Coefficients (Kc) for the agricultural land within each meteorologic segment as needed in defining crop water needs and irrigation demand (see section 2.5.4).

g. Using additional ArcGIS functionality (i.e. Raster Calculator), the final model land use categories coverage was superimposed with the meteorological segments grid to determine the watershed areas assigned to each meteorologic gage, and then the mean land slope per each land use category (using ArcGIS Zonal Statistics) was calculated for input to the model.

The final land use areas and percentages for the major subbasins are listed in Table 3.7, and their spatial distribution within the watershed is shown in Figure 3.5.

Table 3.7 Final Model Land Use Categories by Major Subbasin in the SCR Watershed

CALIBRATION																			
Land Use 2001	**Forest/Wood**		**Shrubland**		**Open/Grass**		**Agriculture**		**LD Residential**		**MD Residential**		**HD Residential**		**Commercial**		**EIA**		
Basin	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Total**
Castaic	28,725	19	104,177	69	6,357	4	1,511	1	1,310	1	973	1	948	1	4,562	3	3,324	2	151,886
Main Stem	36,889	22	80,748	47	4,800	3	31,556	19	2,221	1	498	0	3,086	2	5,425	3	5,287	3	170,511
Pyramid-Piru	21,259	19	85,391	76	2,603	2	358	0	274	0	4	0	34	0	1,139	1	678	1	111,740
Sespe	22,858	13	138,362	82	3,966	2	2,602	2	471	0	22	0	389	0	407	0	532	0	169,609
Upper Piru	59,094	36	96,478	58	7,955	5	29	0	879	1	65	0		0	750	0	758	0	166,008
Upper SCR at Hwy 99	20,025	12	109,133	67	5,369	3	473	0	4,324	3	2,791	2	6,000	4	5,051	3	9,026	6	162,193
Upper SCR at Lang	9,248	9	77,100	77	2,476	2	265	0	6,959	7	123	0	55	0	2,081	2	2,149	2	100,455
Grand Total	**198,097**	**19**	**691,389**	**67**	**33,526**	**3**	**36,793**	**4**	**16,438**	**2**	**4,476**	**0**	**10,513**	**1**	**19,415**	**2**	**21,754**	**2**	**1,032,402**
VALIDATION																			
Land Use 1993	**Forest/Wood**		**Shrubland**		**Open/Grass**		**Agriculture**		**LD Residential**		**MD Residential**		**HD Residential**		**Commercial**		**EIA**		
Basin	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Total**
Castaic	28,699	19	105,060	69	6,659	4	1,441	1	1,248	1	638	0	670	0	4,802	3	2,657	2	151,875
Main Stem	36,921	22	80,780	47	5,184	3	31,867	19	2,129	1	637	0	2,806	2	5,643	3	4,963	3	170,929
Pyramid-Piru	21,234	19	85,223	76	2,526	2	444	0	245	0	4	0	25	0	1,238	1	677	1	111,617
Sespe	22,903	14	138,407	82	3,929	2	2,642	2	472	0	32	0	353	0	384	0	489	0	169,611
Upper Piru	59,176	36	96,555	58	8,071	5	24	0	678	0		0	4	0	774	0	695	0	165,980
Upper SCR at Hwy 99	20,375	13	112,451	69	5,451	3	719	0	3,990	2	1,899	1	4,728	3	4,990	3	7,396	5	161,998
Upper SCR at Lang	9,292	9	78,012	78	2,488	2	188	0	6,206	6	99	0	43	0	2,076	2	1,956	2	100,361
Grand Total	**198,600**	**19**	**696,490**	**67**	**34,308**	**3**	**37,324**	**4**	**14,968**	**1**	**3,308**	**0**	**8,630**	**1**	**19,908**	**2**	**18,834**	**2**	**1,032,370**

3.3 SOIL TYPES

As does land use type, soil type also affects the hydrologic response of a watershed. Variables affected by soil type include infiltration, surface runoff, interflow, groundwater storage, and deep groundwater losses. Movement of water into and through the subsurface matrix is controlled primarily by the soils permeability. As such, soil types in the Santa Clara River watershed were divided into the four SCS hydrologic soil groups, A through D. Type D soils have low infiltration rates (impermeable) and type A are relatively porous with high infiltration.

The soils coverage is based on data from the NRCS Soil Mart, which is provided in SSURGO format. All soil types, excluding extensive rock outcroppings, were grouped into one of the four SCS Soil Groups (A-D) based on soil texture. The slopes coverage was derived from the DEM using basic GIS functionality.

The soil categorization in the NRCS coverages is very detailed, so the soils were aggregated into one of the four SCS groups based on their engineering properties (i.e., USDA texture). Open water and large areas of continuous exposed bedrock were left in their own categories. Areas of partial or shallow bedrock are marked by stipple in Figure 3.6, which shows the general soil distribution throughout the watershed.

The Santa Clara River watershed contains all four SCS soil hydrologic groups, A though D. Loam is the most common soil material found throughout the watershed. It most often forms complexes with sand and clay. The mountainous highlands are relatively sandy, and shallow or exposed bedrock is common. Most of the relatively impermeable clay material lies on the valley floor, although there is also a large area of D soils around Castaic Reservoir. Soil group C is the least prevalent of the soil groups and mostly occurs in the central and northwest portions of the watershed. Overall, the watershed is 45.2% covered by type A soils, 31.8% by type B, 6.4% by type C, and 14.3% by type D. The remaining portions are covered by large areas of shallow or exposed bedrock (1.6%) and open water (0.6%). Figure 3.6 shows the distribution of the four SCS soil groups, along with large sections of near-surface and/or exposed bedrock, across the watershed.

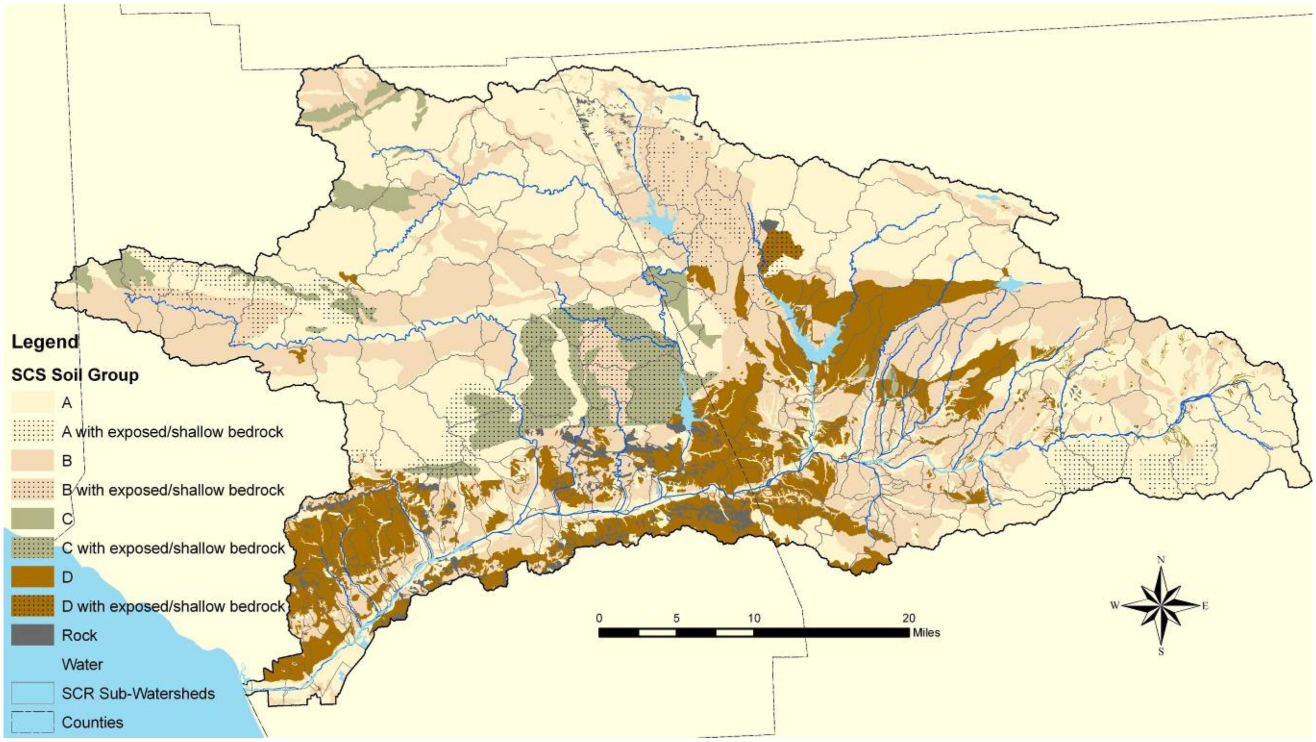


Figure 3.6 SCS Soil Group Distribution within the SCR Watershed

SECTION 4.0

CALIBRATION AND VALIDATION

4.1 CALIBRATION/VALIDATION PROCEDURES AND COMPARISONS

As in the Arroyo Simi and Calleguas studies, calibration of the Santa Clara River 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.

Calibration of HSPF to represent the hydrology of the Santa Clara River 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 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 are considered in the Santa Clara River 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 Santa Clara River 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, 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 in Donigian et al. (1984), and the HSPF hydrologic calibration expert system (HSPEXP) (Lumb et al., 1994).

The same model-data comparisons are 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)
- Storm event periods, e.g. hourly values (cfs)
- Flow frequency (flow duration) curves (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.

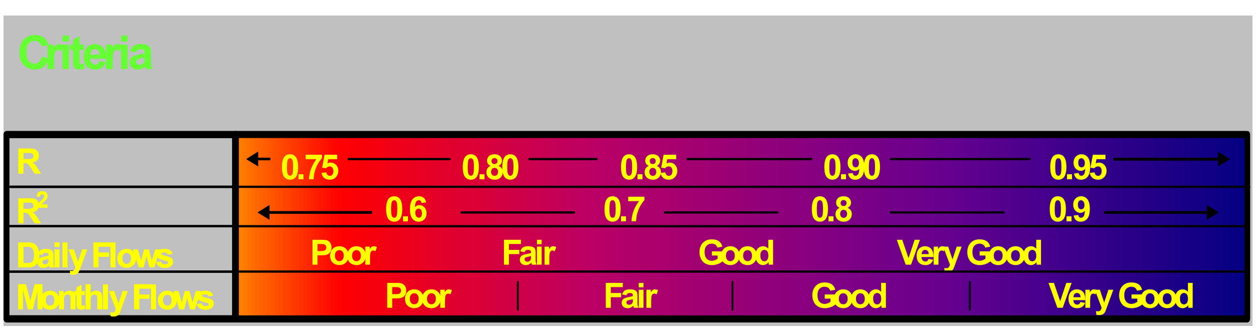
Table 4.1 General Calibration/Validation Targets or Tolerances for HSPF Applications (Donigian, 2000)

	% 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 the correlation coefficient (R) and the coefficient of determination (R^2) for assessing model performance for both daily and monthly flows. The correlation coefficient is the statistical measure of the linear dependence between the observed and simulated flow, indicating whether the simulated and observed values vary in similar fashion. Fundamentally the value indicates how closely a change in one variable is explained by a change in the other. The coefficient of determination is simply the squared value of the correlation coefficient, and it indicates how much of the variance in the observed flow is explained by the simulated values. Figure 4.1 shows the range in R and R^2 values that may be

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



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 Santa Clara River watershed this would include irrigation.

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. 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 Santa Clara River watershed modeling effort, we propose that the targets and tolerance ranges for **'Daily'** flows should correspond to at least a **'Good'** agreement at those sites with good quality flow data, and those for **'Monthly'** flows should correspond to **'Good to Very Good'** agreement, for both calibration and validation comparisons.

For the Santa Clara River 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 calibration (rainfall, evaporation, air temperature, and observed streamflow) indicates that long-term simulations are possible at selected gages within the watershed. Meteorologic data are a fundamental necessity for the model to run, and those data must span the entire simulation period. Partial periods of record, while not ideal, can still be used for consistency checks as part of the calibration and validation process. For the Santa Clara River watershed model, there is adequate daily streamflow data for most sections of the watershed, so the meteorologic data are the limiting factor. Air temperature and evaporation have less spatial variability than precipitation, and both have data with sufficient periods of record to support long-term (> 40 years) simulations for scenario analyses, i.e. baseline, natural condition, future condition. Precipitation data support model calibration and validation simulations spanning WY 1987 through 2005, thus the calibration and validation periods are as follows:

- Calibration: WY 1997-2005
- Validation: WY 1987-1996.

The calibration period was selected as the later time span because it covers a wider range of wet (1998, 2001) and dry years, included the most extensive coverage for POTW and diversion data, and provides a starting point for future conditions. As discussed in Section 3.2, the 2001 SCAG land use provides the base land use coverage (with some adjustments as discussed) used for the calibration period, and the 1993 SCAG land use is the base coverage for the validation period, representing the approximate midpoints of each time period.

4.3 CALIBRATION AND VALIDATION RESULTS FOR THE SCR WATERSHED

Our approach to calibration and validation of the SCR Watershed with HSPF initially focused on the relatively natural, undeveloped areas in the upper portions of the watershed in both counties in order to provide the best estimate of HSPF hydrologic parameters without the complicating issues of irrigation, water regulations, importations, and channel losses. Figure 4.2 shows the major calibration/validation sites and watersheds. Thus Sespe Creek, Piru Creek, Santa Paula Creek, and Upper Santa Clara River (near Lang) were the initial focus of calibration efforts. Sespe and Piru creeks also allowed us to calibrate and assess the impacts of snow simulation in their upper reaches.

The next round of calibration sites included moving further downstream from the Upper SCR to the SCR at Highway 99, and then including the Hopper and Pole creek tributaries in Ventura County. We also investigated and performed initial calibrations on Mint Canyon and Bouquet Canyon creeks, but these efforts were discontinued after finding significant mismatches between rainfall and runoff, during limited periods of available data, indicating errors in one or the other; the WARMF model application also noted significant data problems with these gages.

Modeling of the major reservoirs was performed next as they provide major contributions to the SCR mainstem, and is needed in order to calibrate to the downstream and mainstem SCR stations. The model includes representation of the major reservoirs – Pyramid, Castaic (including Elderberry Forebay and Castaic Lagoon), and Piru; their representation is discussed below in Section 4.3.5.

With the major tributaries and reservoirs calibrated, we were then able to focus on the SCR mainstem sites and the gage above Lake Piru, downstream of Pyramid Lake (i.e. VC gage 705A). The mainstem sites included the County Line gages (707 and 707A), and the series of gages near the SCR outlet (708, 708A, 719, 724) which were adjusted and combined into a single timeseries (as discussed in Section 2.4) representing the outflow at the historic Montalvo gage #708. Calibration of these downstream and mainstem areas also included consideration and adjustment of channel losses and surface-groundwater interactions, in addition to irrigation applications in the major developed portions of the watershed.

Model parameterization was initially derived from the prior Calleguas and Arroyo Simi HSPF applications, with subsequent adjustments as part of the calibration process, described above. The general approach to the adaptation of the prior study parameters was as follows:

a. Parameter adjustments focused primarily on LZSN and INFILT changes, as a function of soils, land use, and slope conditions, to obtain reasonable overall water balances. These values were assigned based on spatially varying soil conditions across the watershed. Thus, C and D soils have lower LZSN and INFILT values than A and B soils (see Figure 3.5).
b. We didn't see any major differences in soils between the two counties – both seemed to have the full range Hydrologic Soil Groups (HSGs) (A through D) along with shallow and exposed bedrock.
c. Then adjustments to the interflow and baseflow parameters were made to improve agreements in the flow duration curves, daily time series, and storm events.

d. Urban parameters were set to generate more surface (overland) runoff than the natural land uses, i.e. lower INFILT, lower LZSN, and lower UZSN (although this did not always apply to irrigated land categories).
e. The groundwater parameters – AGWRC, BASETP, etc – are usually watershed specific as they are a function of local GW and riparian conditions; thus they are calibrated to local conditions.
f. Upland areas, generally with higher slopes, are also usually set to generate more runoff than the valley areas.

The remainder of this section discusses the qualitative and quantitative comparisons (presented above in Section 4.1) of the model results with the observed data, performed for both calibration and validation for all sites. To streamline the results presentation, we have included only selected graphical comparisons for a few selected gages, to accompany this discussion, while the Appendices (provided on CD) include complete sets of model results for each of the gage sites and for both the calibration and validation periods; readers are referred to these Appendices for closer examination of the model results for individual gages.

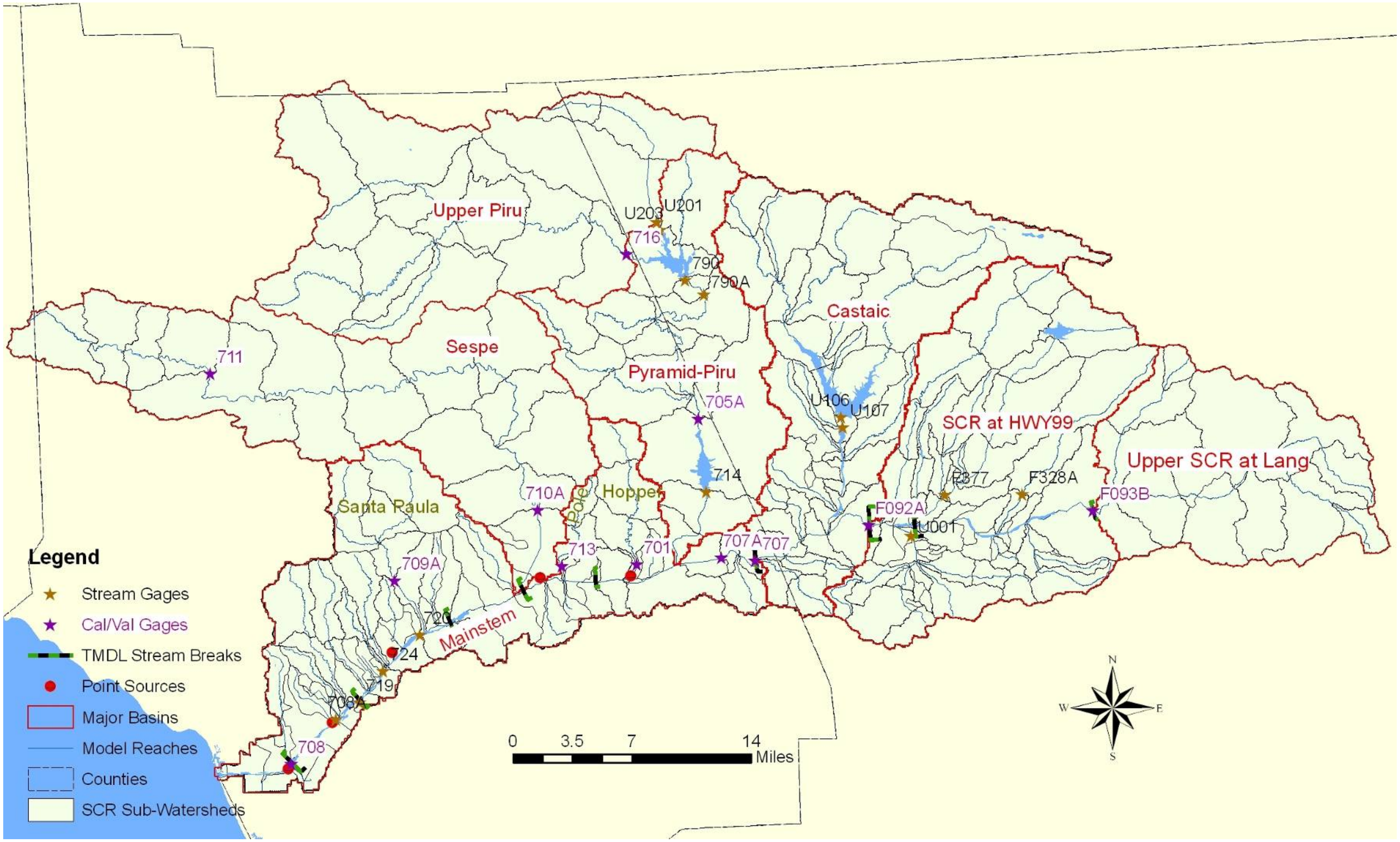


Figure 4.2 Calibration and Validation Stations within the SCR Watershed

4.3.1 Summary Calibration/Validation Results

Tables 4.2 and 4.3 present the summary statistics of the calibration and validation results, respectively, for each of the calibration and validation gage sites. The tables show the following model metrics and statistics:

- Mean annual flow, simulated and observed
- Time period of the simulation
- % volume error, i.e. ((Sim-Obs)/Obs) * 100%
- Daily and monthly correlation coefficient, R, and coefficient of determination, R^2 values
- % difference in storm peaks, for selected (10 to 30 storms, depending on time period)

The results presented in Tables 4.2 and 4.3 indicate the following:

a. The % volume errors for the calibration period (Table 4.2) are mostly less than **±10%**, with two exceptions (SCR @ Lang, and @ Hwy 99), indicating a **Good to Very Good** calibration of mean annual flow, based on the targets/tolerances listed in Table 4.1. The exceptions for the SCR @ Lang and Hwy 99 reflect a very short period of only 3 years for calibration, difficulties in accurate monitoring at this site (as noted during field visits), the driest conditions in the entire SCR, and data issues for accurate rainfall inputs (as discussed in Section 2.1). All of these issues and conditions combine to present very difficult sites to accurately calibrate.
b. The % volume errors for the validation period (Table 4.3) are also all less than **±10%**, but with exceptions at SCR @ Hwy 99 and Hopper Creek, with many sites better than the calibration, although fewer sites are included due to data issues. This confirms that the model is a **Very Good** validation for mean annual flow.
c. From Figure 4.1, R^2 values greater than 0.75 for daily comparisons, and greater than 0.80 for monthly comparisons, indicate a Good or better calibration or validation. The calibration results show that the daily R^2 values meet this criterion for 10 of the 11 calibration sites (with the one exception at SCR @ Lang), and ALL the monthly R^2 values meet this criterion. In fact, the monthly R^2 values show 9 of the 11 sites are greater than or equal to 0.92, reflecting a **Very Good** Calibration.
d. For the validation, the daily R^2 values meet the criterion for 4 of the 9 sites, with one additional site at 0.73 and one at 0.72. The validation monthly R^2 values exceed 0.90 for all but two sites, again reflecting a **Very Good** validation.
e. The % difference in storm peaks for the calibration period show that all but two of the sites, the problematic SCR @ Lang site and Upper Piru, show values less than **± 20%,** reflecting a **Fair to Good** calibration of storm peaks, and 7 of the 11sites are **±10%** reflecting a **Very Good** storm peak simulation. For the storm peak validation, all but two of the % differences are less than **±20%,** and 6 of 9 sites show values less than **±15%,** corresponding to a **Good** validation. So even though there is some drop in accuracy of the simulation between the calibration and validation periods, as might be expected, the results still demonstrate a **Good or better** validation. When rainfall records are suspect, especially for the validation period, these types of differences are to be expected; further investigation of rainfall timing/distribution for individual events is warranted. Also, both Pole and Hopper should be further investigated as improvements to the Sespe simulation seemed to make those sites worse for the validation period.

Table 4.2 Calibration Statistics for the SCR Watershed Model

Gage Name	Gage ID	Time Period	Flow (in)		% Vol Error	Daily		Monthly		Daily Peaks % Diff.
			Sim.	Obs.		R	R^2	R	R^2	
Sespe at Wheeler Springs (RCH704)	711	10/1/02-9/30/05	9.8	8.9	9.5	0.95	0.91	0.98	0.97	4.7
Sespe at Fillmore (RCH713)	710A	10/1/96-9/30/05	10.3	10.9	-6.1	0.96	0.92	0.99	0.98	-5.5
Pole (RCH633)	713	10/1/96-9/30/05	7.2	7.2	0.9	0.88	0.77	0.94	0.88	-8.3
Hopper (RCH613)	701	10/1/96-9/30/05	8.8	8.8	-0.5	0.90	0.81	0.96	0.92	-2.8
Santa Paula (RCH834)	709A	10/1/96-9/30/05	13.7	13.6	0.3	0.94	0.89	0.99	0.98	1.9
Upper Piru (RCH511) (Piru Bl. Buck Cr.)	716	10/1/96-9/30/03	2.8	2.9	-1.5	0.89	0.78	0.99	0.97	-35.9
SCR at Lang. RCH 70	F093B	10/1/02-9/30/05	1.7	1.5	12.1	0.74	0.55	0.91	0.82	20.1
SCR at HWY 99 (RCH180)	F092C	10/1/02-9/30/05	1.8	1.6	10.3	0.95	0.91	0.99	0.99	-8.3
SCR at Co. Line (RCH 410)	707A	10/1/96-9/30/05	2.3	2.3	1.0	0.89	0.79	0.98	0.96	-17.6
Piru Ab. Piru (RCH526)	705A	10/1/96-9/30/05	2.9	3.2	-7.9	0.91	0.83	0.97	0.94	-16.3
SCR at Montalvo (RCH880)	708	10/1/96-9/30/05	3.2	3.0	2.1	0.96	0.91	0.98	0.96	-4.4

Table 4.3 Validation Statistics for the SCR Watershed Model

Gage Name	Gage ID	Time Period	Flow (in)		% Vol Error	Daily		Monthly		Daily Peaks % Diff.
			Sim.	Obs.		R	R^2	R	R^2	
Sespe at Wheeler Springs (RCH704)	711	10/1/86-9/30/96	7.2	7.3	-1.0	0.91	0.82	0.98	0.96	3.8
Sespe at Fillmore (RCH713)	710A	10/1/93- 9/30/96	10.5	9.8	7.0	0.92	0.84	0.97	0.94	9.6
Pole (RCH633)	713	10/1/86- 9/30/96	6.2	6.6	-5.8	0.55	0.30	0.84	0.70	61.4
Hopper (RCH613)	701	10/1/86-9/30/96	7.6	4.6	67.0	0.86	0.73	0.96	0.93	86.0
Santa Paula (RCH834)	709A	10/1/86-9/30/96	10.1	10.2	-0.8	0.90	0.81	0.98	0.96	-11.1
Upper Piru (RCH511) (Piru Bl. Buck Cr.)	716	10/1/88-9/30/96	3.8	3.8	0.5	0.85	0.72	0.96	0.92	-13.4
SCR at Lang. RCH 70	F093B	NO OBSERVED FLOW								
SCR at HWY 99 (RCH180)	F092C	10/1/86-9/31/91	0.3	0.5	-42.0	0.66	0.43	0.84	0.71	-18.0
SCR at Co. Line (RCH 320)	707	10/1/86-9/30/96	1.6	1.5	2.9	0.88	0.78	0.95	0.90	-19.0
Piru Ab. Piru (RCH526)	705A	10/1/86-9/30/96	2.5	2.6	-2.3	0.86	0.74	0.96	0.93	-1.6
SCR at Montalvo (RCH880)	708	10/1/89-9/30/93	3.5	3.4	1.2	0.97	0.94	0.99	0.98	6.6

4.3.2 Annual Flow Volumes

Tables 4.4 through 4.8 show the annual flow volumes for all calibration and validation gage sites, along with the annual precipitation, residuals (simulated flow minus observed flow), and the percent differences; all the precipitation and flow values are in 'inches' over the drainage area, so the precipitation and flow values can be compared. The gage sites in each of the tables are as follows:

- Table 4.4: Sespe Creek, at Wheeler Springs and at Fillmore
- Table 4.5: Pole Creek and Hopper Creek
- Table 4.6: Santa Paula Creek and Piru Creek below Buck Creek
- Table 4.7: Upstream SCR gages at Lang, Highway 99, and County Line
- Table 4.8: Piru Creek above Lake Piru, and SCR at Montalvo

The calibration and validation periods, and comparison statistics, are shown separately, along with their summaries. For gages with continuous records of flow for both the calibration and validation periods, or some portions thereof, the 'Full Time Period' results are also shown in each of these tables.

The model results presented in these tables indicate the following:

a. Although the separate calibration, validation, and Full Time Period results indicate **Good to Very Good** model simulations (i.e. Percent differences <10% to 15%), there are significant variations in the year-to-year agreements, with some large Percent Differences shown in these tables.
b. The agreement, as shown by the Percent Difference, is generally much better for the wetter years with large flow volumes; these differences are mostly less than 25% for a **Fair** simulation, and many are less than 15% for a **Good** simulation. So the annual simulations can be characterized as **Fair to Good**.
c. The largest Percent Differences are primarily for low runoff sites and dry years with annual volumes less than a few inches of flow. This is especially true for the Upper SCR sites that show annual flow volumes of less than 1 to 2 inches (see Table 4.7), with the model under-simulating by 50%. At these sites, the short time periods of recorded flow, difficulties in accurately monitoring low flow/depth conditions, and complicating/complex groundwater interactions, along with the precipitation issues discussed in Section 2.1, make accurate flow simulations challenging and problematic. This is clearly shown for the short validation period for the SCR gage at Highway 99, where the annual flow volumes are essentially constant, at about 0.5 inches each year, and the short period of 1987-91 is during an especially dry period, averaging less than half the precipitation that fell during the calibration period.
d. Similar problems are evident for selected years for the Santa Paula and Piru creeks, as shown in Table 4.6. In this upper portion of the watershed reliable rainfall gages were sparse, and the model results demonstrate the impact of highly suspect rainfall values for selected years, especially dry years with runoff less than a few inches.
e. Year-to-year differences in the model simulations are likely due to a variety of causes, including inaccurate precipitation – i.e. precipitation gages not accurately representing what fell on the watershed, in individual years – model responses to the precipitation, complicating groundwater interactions, and suspect values for flow.
f. Pole Creek demonstrates an issue with questionable flow values. Table 4.5 shows annual observed flows of 10.5 and 10.8 inches for WY93 and WY94, respectively, whereas the precipitation amounts for these two years were 41.1 and 13.6 inches, respectively. Clearly, the 10.8 inches in WY94 is suspect as it is highly unlikely that this

amount was produced by just 13.6 inches of rainfall; in addition the daily timeseries for 1994 show the flow increasing dramatically on about January 15 ***prior to*** any significant rainfall occurring. VCWPD has subsequently indicated that they noticed a significant increase in baseflow following the January Northridge earthquake which occurred on 17 January 1994 (M. Bandurraga, personal communication, 3 April 2008). Apparently the subsurface geologic shifts impacted the local groundwater system and increased baseflows for some time, more than a year, on Pole Creek and to a less obvious extent on Hopper Creek. The model is not capable of representing this type of change and impact to the watershed system.

g. Table 4.8 shows that the model results for the SCR outlet at Montalvo indicate a **Good** overall calibration and a **Fair/Good** validation. This is based on the differences during the high flow years, and relatively small residuals for most years even though the Percent Differences may be high for a number of the low flow years.

h. The Hopper Creek validation results changed significantly from the Draft Report calibration, following improvements to the Sespe rainfall and model results. These Hopper Creek results should be further investigated as they appear to consistently over-simulate the observations.

Table 4.4 Annual Simulated and Observed Volumes (inches) for Sespe Creek

Sespe at Wheeler Springs (RCH704)					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
2003	27.7	3.2	2.3	0.9	40.1%
2004	15.5	0.7	0.6	0.1	17.3%
2005	58.1	25.4	23.9	1.5	6.3%
Average	33.8	9.8	8.9	0.8	9.5%
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
1987	12.0	0.3	0.5	-0.2	-38.8%
1988	27.4	2.8	2.9	-0.1	-4.3%
1989	12.3	0.2	0.5	-0.3	-54.3%
1990	9.7	0.1	0.2	-0.1	-53.0%
1991	27.4	6.6	5.2	1.4	26.6%
1992	40.3	13.3	11.8	1.5	12.3%
1993	53.2	22.4	27.8	-5.3	-19.2%
1994	18.3	0.5	1.3	-0.8	-61.1%
1995	57.6	25.4	21.8	3.7	16.8%
1996	16.6	0.6	1.0	-0.4	-41.9%
Average	27.5	7.2	7.3	-0.1	-1.0%
Full Time Period					
Average	28.9	7.8	7.7	0.1	1.7%
Sespe at Fillmore (RCH713)					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
1997	25.1	6.2	6.1	0.1	2.0%
1998	61.2	29.7	29.1	0.7	2.3%
1999	15.6	0.9	1.7	-0.8	-48.6%
2000	22.7	4.2	3.3	0.9	27.0%
2001	29.9	9.7	10.9	-1.2	-11.2%
2002	8.3	0.3	0.6	-0.3	-53.3%
2003	26.5	3.8	3.9	-0.2	-4.1%
2004	15.6	2.2	2.2	0.0	0.1%
2005	64.0	35.6	40.7	-5.1	-12.6%
Average	29.9	10.3	10.9	-0.7	-6.1%
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
1994	16.7	1.0	2.2	-1.2	-54.0%
1995	55.7	28.1	25.0	3.1	12.3%
1996	18.0	2.3	2.2	0.1	3.0%
Average	30.1	10.5	9.8	0.7	6.7%
Full Time Period					
Average	29.9	10.3	10.7	-0.3	-3.1%

Table 4.5 Annual Simulated and Observed Volumes (inches) for Pole and Hopper Creeks*

Pole (RCH633)					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
1997	23.8	5	3.4	1.7	48.9%
1998	52.2	20.9	14.8	6.1	40.7%
1999	12.4	2.6	2.6	-0.1	-3.3%
2000	18.9	3.0	2.4	0.6	25.6%
2001	25.3	5.9	6.3	-0.3	-6.1%
2002	8.0	1.3	1.2	0.1	6.3%
2003	23.5	2.2	1.6	0.6	40.5%
2004	13.6	1.6	2.6	-1.1	-40.0%
2005	51.1	22.7	29.6	-6.9	-23.3%
Average	25.4	7.2	7.2	0.1	0.9%
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
1987	9.1	0.7	1.2	-0.5	-41.5%
1988	21.2	1.2	1.6	-0.4	-22.3%
1989	11.2	0.5	1.1	-0.6	-54.2%
1990	10.1	0.5	0.4	0	2.7%
1991	20.2	4.6	1.7	2.9	171.4%
1992	31.0	9.2	5.0	4.3	85.8%
1993	43.3	18.5	10.5	8.0	75.9%
1994	14.3	2.5	10.8	-8.3	-76.6%
1995	46.3	20.7	29.3	-8.5	-29.2%
1996	17.3	3.8	4.5	-0.7	-15.8%
Average	22.4	6.2	6.6	-0.4	-5.8%
Full Time Period					
Average	23.8	6.7	6.9	-0.2	-2.5%

Hopper (RCH613)					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
1997	25.6	0.1	2.5	-0.3	-12.8%
1998	59.0	29.4	26.8	2.7	9.7%
1999	14.7	0.9	1.2	-0.3	-26.0%
2000	20.9	4.1	2.5	1.6	66.0%
2001	24.9	5.9	5.2	0.7	11.9%
2002	8.4	0.2	0.5	-0.3	-62.0%
2003	25.0	3.6	1.3	2.3	177.0%
2004	14.7	1.9	1.4	0.6	39.1%
2005	58.6	30.9	38.0	-7.0	-18.7%
Average	28.0	8.8	8.8	0	-0.5%
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
1987	10.0	0.1	0.4	-0.3	-85.4%
1988	23.8	3.0	1.2	1.8	145.2%
1989	11.2	0.2	0.3	-0.1	-35.7%
1990	12.2	0.6	0.4	0.3	81.8%
1991	22.4	6.7	3.2	3.5	107.5%
1992	33.3	11.9	5.3	6.6	125.8%
1993	49.2	24.3	13.8	10.4	75.4%
1994	15.1	1.2	3.0	-1.8	-59.1%
1995	50.8	24.6	16.5	8.1	49.3%
1996	19.4	3.5	1.6	1.9	113.6%
Average	24.8	7.6	4.6	3.0	66.6%
Full Time Period					
Average	26.3	8.1	6.6	1.5	18.3%

* - The January 1994 Northridge Earthquake appears to have produced increased baseflows for both Pole and Hopper Creeks.

Table 4.6 Annual Simulated and Observed Volumes (inches) for Santa Paula and Piru Creeks

Santa Paula (RCH834)					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
1997	26.2	10.3	8.5	1.8	21.4%
1998	59.3	34.3	37.9	-3.6	-9.5%
1999	14.1	1.5	2.6	-1.1	-44.1%
2000	23.4	6.6	4.0	2.6	63.6%
2001	33.4	14.2	11.5	2.7	23.2%
2002	8.4	0.8	1.2	-0.4	-33.5%
2003	26.8	5.7	4.0	1.7	42.5%
2004	17.9	4.6	2.4	2.2	92.9%
2005	68.8	45.0	50.4	-5.4	-10.7%
Average	30.9	13.7	13.6	0.1	0.3%
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
1987	11.0	1.1	1.5	-0.4	-25.2%
1988	20.9	2.0	3.4	-1.4	-41.0%
1989	12.2	1.0	1.4	-0.4	-27.2%
1990	11.8	0.8	1.2	-0.4	-33.1%
1991	25.7	8.7	7.1	1.6	22.3%
1992	38.9	18.9	15.8	3.1	19.4%
1993	50.7	30.3	33.6	-3.2	-9.6%
1994	16.5	2.2	3.9	-1.7	-44.3%
1995	54.4	31.9	29.7	2.2	7.4%
96	18.2	4.0	4.1	-0.1	-3.3%
Average	26.0	10.1	10.2	-0.1	-0.8%
Full Time Period					
Average	28.3	11.8	11.8	0.0	-0.1%
Piru Bl. Buck Cr. (RCH511)					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
1997	15.2	1.0	1.3	-0.2	-18.5%
1998	42.3	12.1	11.2	0.8	7.9%
1999	12.8	0.6	1.4	-0.8	-56.0%
1990	15.8	0.7	1.2	-0.5	-40.6%
2001	24.1	4.5	3.6	0.8	22.2%
2002	5.2	0.3	0.4	-0.1	-33.4%
2003	19.2	0.7	1.1	-0.3	31.1%
Average	19.2	2.8	2.9	-0.1	-1.5%
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
1989	9.3	0.2	0.5	-0.3	-61.2%
1990	6.3	0.1	0.2	-0.1	-57.3%
1991	17.4	1.0	1.6	-0.6	-38.5%
1992	29.1	5.3	6.4	-1.2	-18.1%
1993	38.4	12.5	10.5	2.0	18.9%
1994	12.9	0.5	1.5	-1.0	-65.6%
1995	37.9	10.6	8.6	2.0	23.5%
1996	10.5	0.5	1.3	-0.7	-57.3%
Average	20.2	3.8	3.8	0.0	0.5%
Full Time Period					
Average	19.8	3.4	3.4	0.0	-0.4%

Table 4.7 Annual Simulated and Observed Volumes (inches) for SCR Upstream Sites

SCR at Lang. (RCH 70)					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
2003	16.3	0.5	0.1	0.4	285%
2004	8.6	0.2	0.0	0.2	4319%
2005	30.0	4.6	4.5	0.0	9.0%
Average	18.3	1.7	1.5	0.2	12.1%
SCR at HWY 99 (RCH180)					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
2003	14.6	0.5	0.4	0.1	24.3%
2004	9.0	0.3	0.2	0.1	42.9%
2005	32.5	4.4	4.1	0.3	7.2%
Average	18.7	1.8	1.6	0.2	10.4%
SCR at HWY 99 (RCH180)					
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
1987	5.7	0.5	0.5	-0.3	-55.4%
1988	16.1	0.3	0.5	-0.2	-38.0%
1989	9.2	0.3	0.4	-0.1	-35.6%
1990	6.5	0.1	0.4	-0.3	-66.0%
1991	14.6	0.4	0.5	-0.1	-15.9%
Average	10.4	0.3	0.5	-0.2	-41.7%
Full Time Period					
Average	13.5	0.9	0.9	0.0	-2.9%
SCR at Co. Line (RCH 410)					
Calibration					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
1997	12.3	1.1	1.1	0.0	0.3%
1998	34.2	5.3	5.8	-0.5	-8.4%
1999	9.6	1.0	1.2	-0.2	-12.4%
2000	11.9	1.1	1.3	-0.2	-12.3%
2001	15.4	1.4	1.0	0.4	45.9%
2002	4.7	0.9	0.7	0.2	27.3%
2003	15.7	1.9	1.0	0.9	85.2%
2004	9.5	1.2	1.0	0.2	23.5%
2005	36.4	6.7	7.8	-1.1	-14.5%
Average	16.6	2.3	2.3	0.0	-1.0%
SCR at Co. Line (RCH 320)					
Validation					
Water Year	Precipitation	Simulated Flow	Observed Flow	Residual	Percent Error
1987	6.0	1.3	0.7	0.5	76.4%
1988	17.2	1.0	0.9	0.1	10.7%
1989	9.9	1.0	1.0	0.0	-2.2%
1990	6.9	0.6	0.7	-0.1	-16.8%
1991	14.5	0.8	1.0	-0.2	-21.5%
1992	24.1	2.3	2.0	0.3	15.3%
1993	32.1	4.9	4.4	0.5	11.8%
1994	9.8	0.9	1.0	0.0	-5.1%
1995	24.5	2.1	2.5	-0.4	-14.6%
1996	10.1	1.1	1.3	-0.3	-19.5%
Average	15.5	1.6	1.5	0.0	2.9%

Table 4.8 Annual Simulated and Observed Volumes (inches) for Piru and SCR @ Montalvo

Piru Ab. Piru (RCH526)					
Calibration					
Water		Simulated	Observed		Percent
Year	Precipitation	Flow	Flow	Residual	Error
1997	14.3	1.2	1.3	-0.1	-8.8%
1998	41.1	7.0	8.8	-1.9	-21.4%
1999	12.9	1.5	1.7	-0.3	-14.6%
2000	14.3	1.2	1.4	-0.2	-13.1%
2001	24.0	3.4	3.6	-0.3	-7.0%
2002	4.9	0.7	0.7	-0.1	-7.4%
2003	18.6	1.2	1.3	-0.1	-6.0%
2004	10.3	0.9	0.8	0.0	3.4%
2005	44.9	9.5	9.0	0.5	5.8%
Average	20.6	2.9	3.2	-0.2	-7.9%
Validation					
Water		Simulated	Observed		Percent
Year	Precipitation	Flow	Flow	Residual	Error
1987	8.3	0.4	0.5	-0.1	-14.5%
1988	20.1	1.1	1.4	-0.3	-23.7%
1989	8.7	0.4	0.5	-0.2	-33.3%
1990	5.8	0.3	0.3	0.0	-9.8%
1991	16.9	1.8	1.6	0.2	13.5%
1992	28.5	4.4	5.1	-0.6	-12.7%
1993	37.4	8.1	7.1	1.0	14.5%
1994	12.6	1.3	1.5	-0.2	-15.6%
1995	36.5	6.1	6.4	-0.3	-4.5%
1996	9.9	1.5	1.6	0.0	-2.4%
Average	18.5	2.5	2.6	-0.1	-2.3%
Full Time Period					
Average	19.5	2.7	2.9	-0.1	-5.0%
SCR at Montalvo (RCH880)					
Calibration					
Water		Simulated	Observed		Percent
Year	Precipitation	Flow	Flow	Residual	Error
1997	17.2	1.0	0.8	0.2	31.4%
1998	45.0	9.6	8.6	1	11.0%
1999	12.3	0.1	0.1	0.0	-59.3%
2000	16.1	0.8	0.6	0.1	20.5%
2001	23.1	2.5	1.9	0.5	28.8%
2002	6.2	0.1	0.0	0.0	47.0%
2003	20.5	0.7	0.6	0.2	31.4%
2004	12.1	0.5	0.3	0.1	38.8%
2005	48.0	12.1	13.6	-1.5	-11.3%
Average	22.3	3.0	3.0	0.1	2.1%
Validation					
Water		Simulated	Observed		Percent
Year	Precipitation	Flow	Flow	Residual	Error
1990	7.7	0.0	0.0	0.0	66.3%
1991	17.6	1.4	0.9	0.4	46.2%
1992	28.2	3.7	3.0	0.7	22.9%
1993	38.3	8.9	9.8	-1.0	-9.8%
Average	22.9	3.5	3.4	0.0	1.2%
Full Time Period					
Average	22.5	3.2	3.1	0.1	2.9%

4.3.3 Flow Duration and Daily Flow Results

Figures 4.3 and 4.4 show the flow duration/frequency curves for both the calibration and validation periods at six of the calibration sites; the remaining ones are included in the Appendices, as noted earlier. The scales on these figures are log-probability, which include a vertical logarithmic scale for flow and a horizontal probability scale for 'percent chance of exceedance'. These scales essentially expand the horizontal time scale to provide a closer examination of the extreme high and low flow conditions.

Figures 4.5 through 4.7 provide selected plots of the daily flows, simulated and observed for both calibration and validation WYs, for Sespe Creek at Fillmore, SCR at County Line, and SCR at Montalvo. Complete results for all calibration gage sites are provided in the Appendices.

Review of these model results, and those included in the Appendices, indicates the following:

a. The flow duration curves for the calibration period are consistently a **Good to Very Good** representation of the observed curves, and the two curves generally agree throughout the great majority of the range of flows observed at each site.

b. The agreement shown in Figures 4.3 and 4.4 is generally representative of model results for all the calibration sites, but some of the comparisons are somewhat worse, such as at the upper Piru and Lang gage sites. However, some of these sites also demonstrate some questionable or suspect flow values indicating possible errors in measurement. In addition, issues of erroneous or non-representative rainfall (as discussed in Section 2.4) were more prevalent, and had significant impacts for these two sites.

c. The validation results are shown to be consistent with the calibration curves for most all sites, but some demonstrate larger differences between the curves, such as at Hopper Creek, SCR at County Line, and the lower part of SCR at Montalvo. Thus, the validation results for flow duration are considered **Fair to Very Good**, due to these differences. Comparing two results, calibration and validation, side-by-side, as shown in the figures, is a very useful, visual demonstration of the model behavior, and it provides insight into observed data issues that may be contributing to the differences.

d. It is clear from the figures and the Appendices that the largest differences -- both between the observed and simulated in each figure, and between the calibration and validation figures -- are primarily at low flow conditions. This is not unexpected as this portion of the flow duration curve is the region impacted most directly by complex surface water and ground water interactions. These interactions, represented in the model by channel losses and ground water accretion, or discharge, are the two largest uncertainties in the modeling effort. However, the low flow differences contribute a relatively small amount to the annual flows and can be considered secondary in importance.

e. In addition to the difficulties in representing low flow behavior, low flow rates are inherently difficult to accurately measure under the conditions at many of the sites, with changing alluvial, sandy beds; multiple meandering channels; dynamic scouring and deposition impacting water levels; and the associated problems related to water levels below minimum depths for monitoring devices. Thus, we normally placed lower significance on the portions of the flow durations curves in the range of 1 to 10 cfs since these low values could be less reliable.

f. The Hopper Creek gage site was one that showed significant differences between the calibration and validation (see Figure 4.3), with the simulated validation flows considerably greater than the observed values for flows above about 20 cfs. As noted earlier, the January 1994 Northridge Earthquake appears to have produced very unusual behavior(also shown in Appendix D, Figure 32), with flows increasing in January 1994 and subsequent baseflow conditions remaining non-zero throughout the rest of the year. Similar behavior is shown in Figure 32 of Appendix C for Pole Creek. However, the Hopper Creek results were just the opposite in the Draft Report, so further investigation is needed.

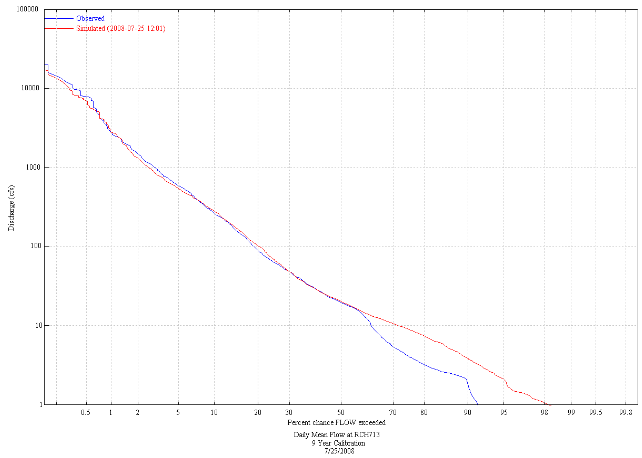
g. The Montalvo gage shows very good agreement for both the calibration and validation periods (Figure 4.4), except for the region of the validation flow duration curves less than 100 cfs, where the observed is considerably lower than the simulated. Again, this is likely due groundwater conditions being inconsistent between the two time periods, and not represented in the limited data available to represent those conditions in the model. Comparing just the two observed curves in Figure 4.4, during the calibration period the flow duration curve continues almost a straight-line decline in this region; whereas for the validation period the observed curve drops precipitously at about 100 cfs possibly due to somewhat dryer conditions during validation.

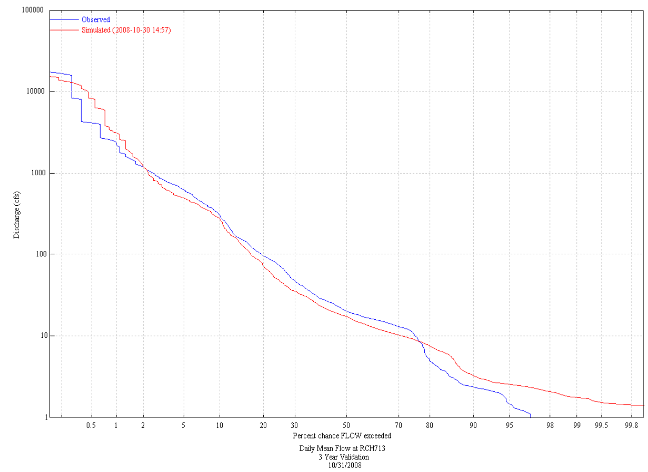
h. The few selected annual time series of daily simulated and observed flow values, in Figures 4.5 to 4.7, demonstrate generally **Good to Very Good** agreement for the Sespe (Fillmore), SCR (County Line), and SCR (Montalvo) sites, respectively. Each of the appendices provides these same plots for the entire calibration and validation periods; readers are welcome to review these graphs to better assess the model performance for specific years and conditions. The model shows it tracks the observed values well throughout both periods; some storm peaks are high, some are low, and others are quite accurate. This is to be expected in this type of modeling effort, and reinforces the need to look at multiple types of comparisons to fully assess model performance.

i. Figure 4.5 for Sespe Creek clearly demonstrates the issue of non-representative rainfall, which plagued a number of the watersheds; a rain event in mid-March 1995 clearly shows a model response that is consistent with the other events shown in January 1995. The rainfall for the March event produced almost a 14,000 cfs peak in the model results, which is consistent with the January event rainfalls and peak flows, but little or no response is shown in the observed flows for the March time period. It is likely that the event happened to hit the specific rain gage, but not much of the rest of the watershed – for this time period, the model results for Santa Paula, Pole, and Hopper creeks show similar rainfall totals, but they also show a definitive flow response albeit much less than the simulated peaks. Further investigation is recommended.

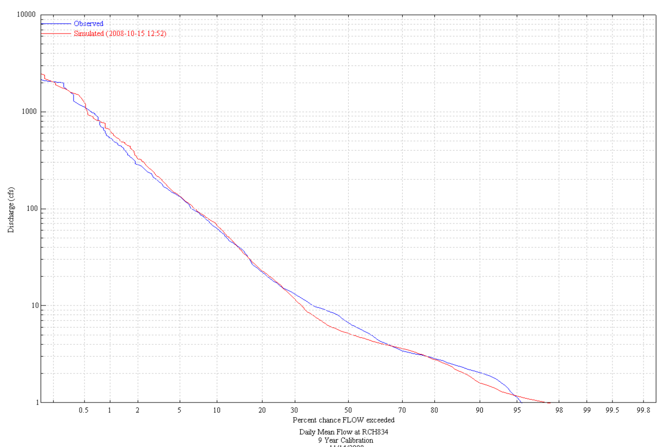
Calibration | **Validation**

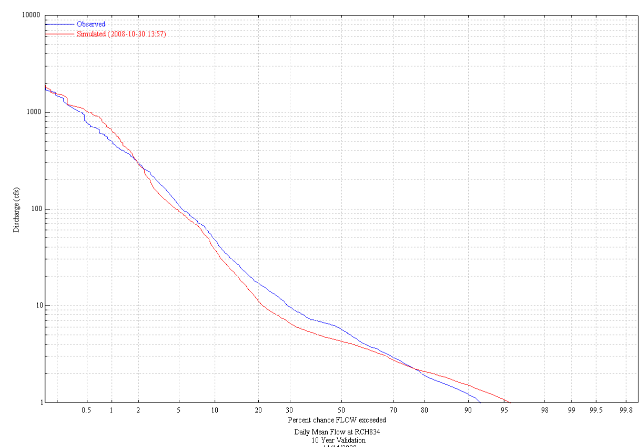
SESPE CREEK AT FILLMORE



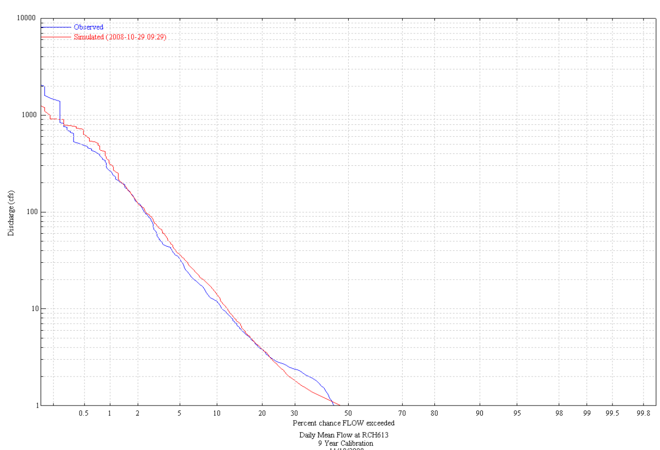


SANTA PAULA CREEK





HOPPER CREEK



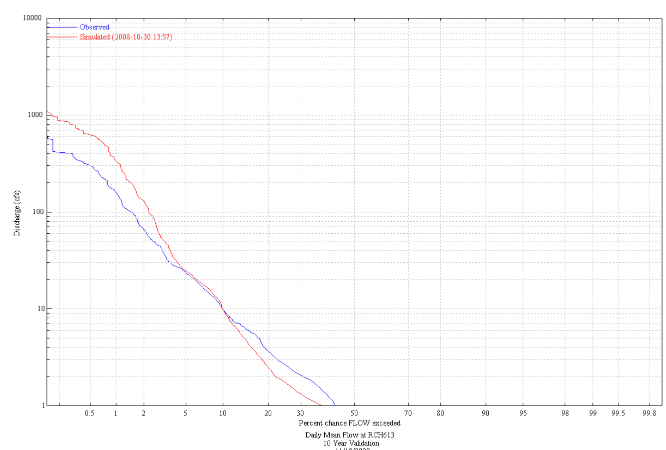
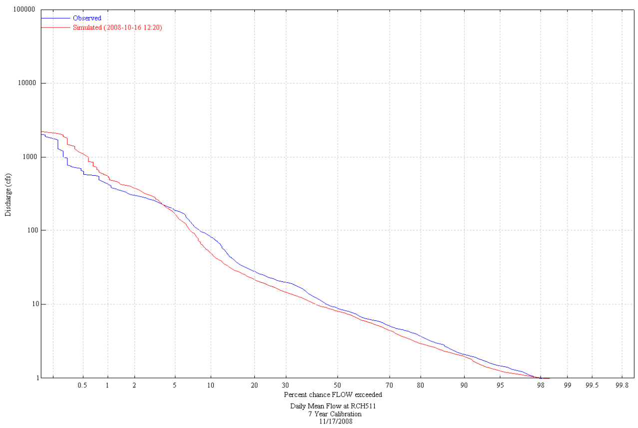
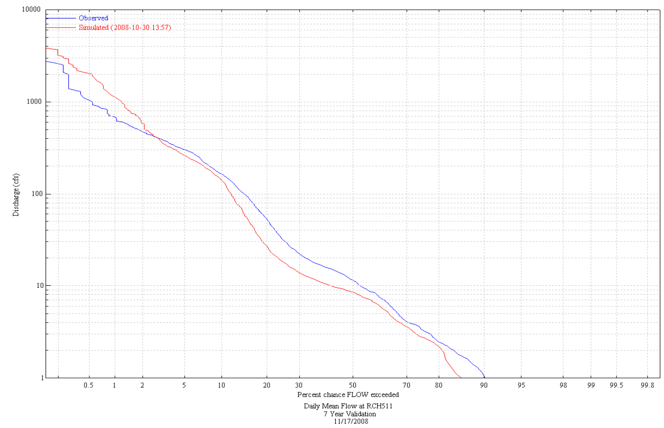


Figure 4.3 Flow Duration Curves for Sespe, Santa Paula, and Hopper Creeks

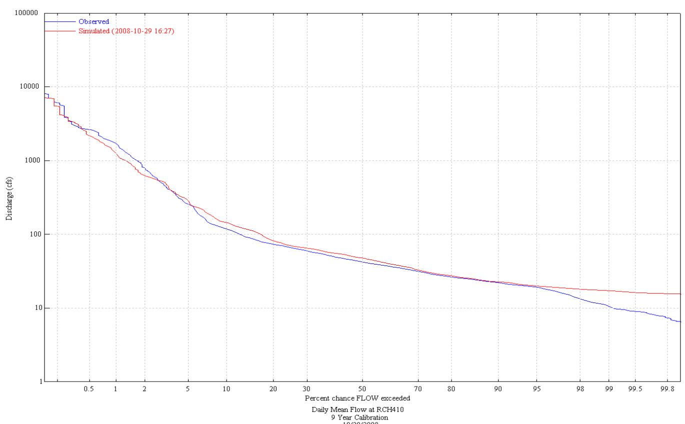
Calibration | *Validation*

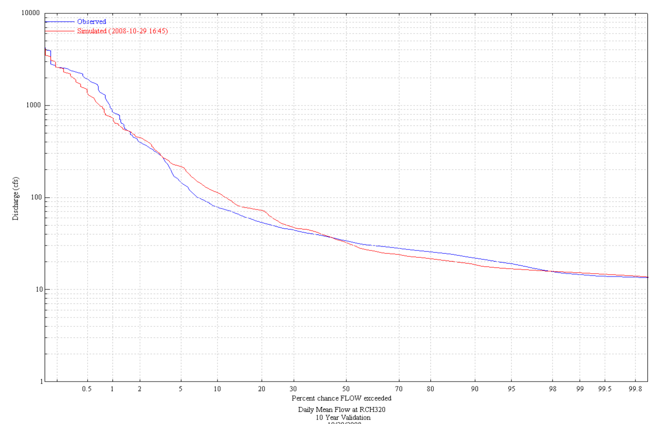
PIRU CREEK ABOVE LAKE PIRU



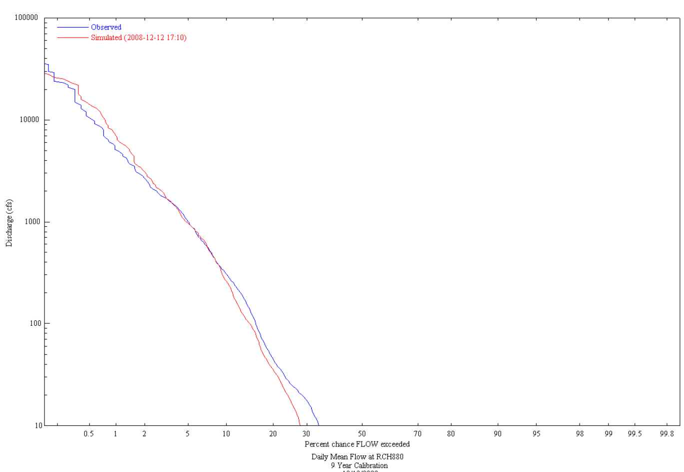


SANTA CLARA RIVER AT COUNTY LINE





SANTA CLARA RIVER AT MONTALVO



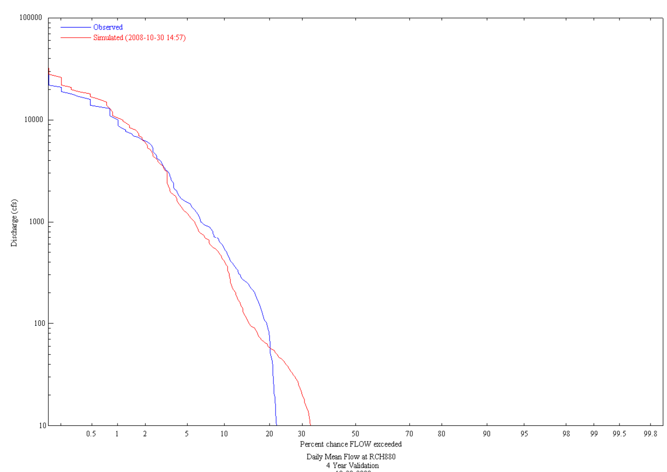
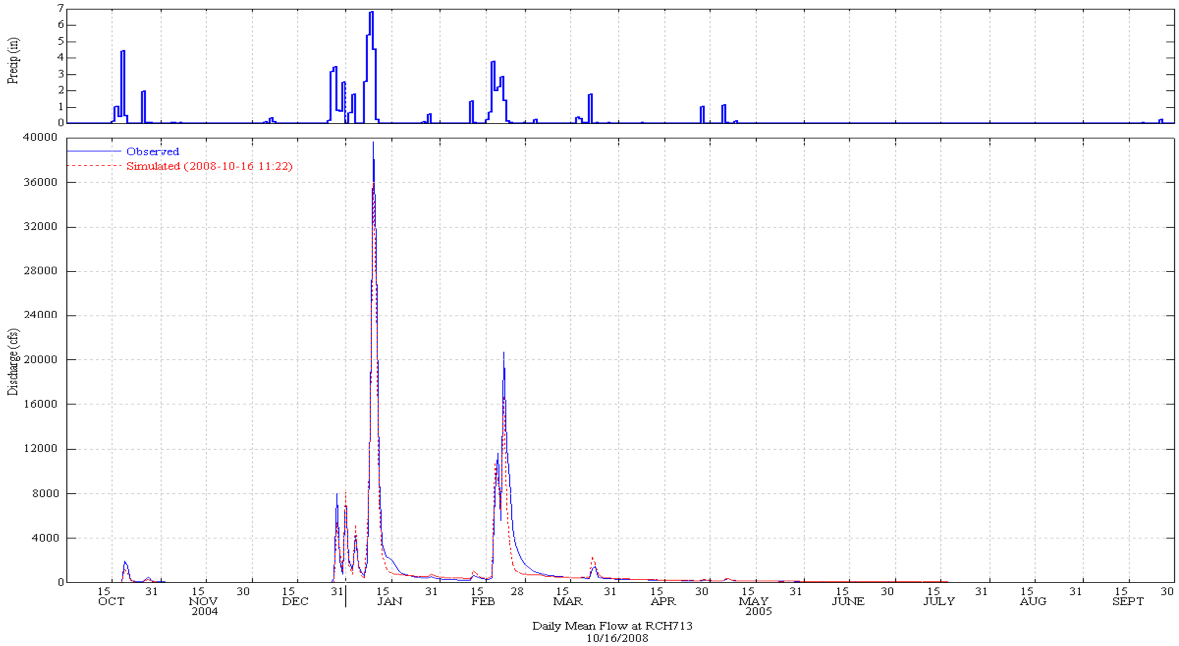


Figure 4.4 Flow Duration Curves for Piru and Santa Clara River Stations

Calibration – WY 2005



Validation – WY 1995

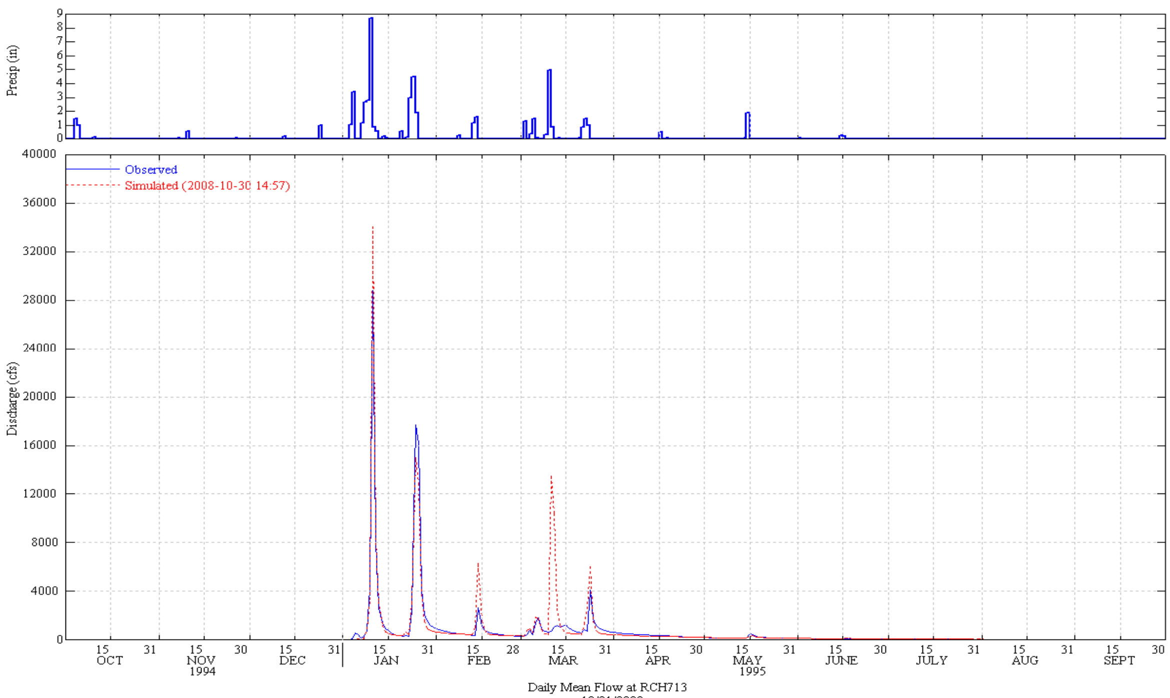
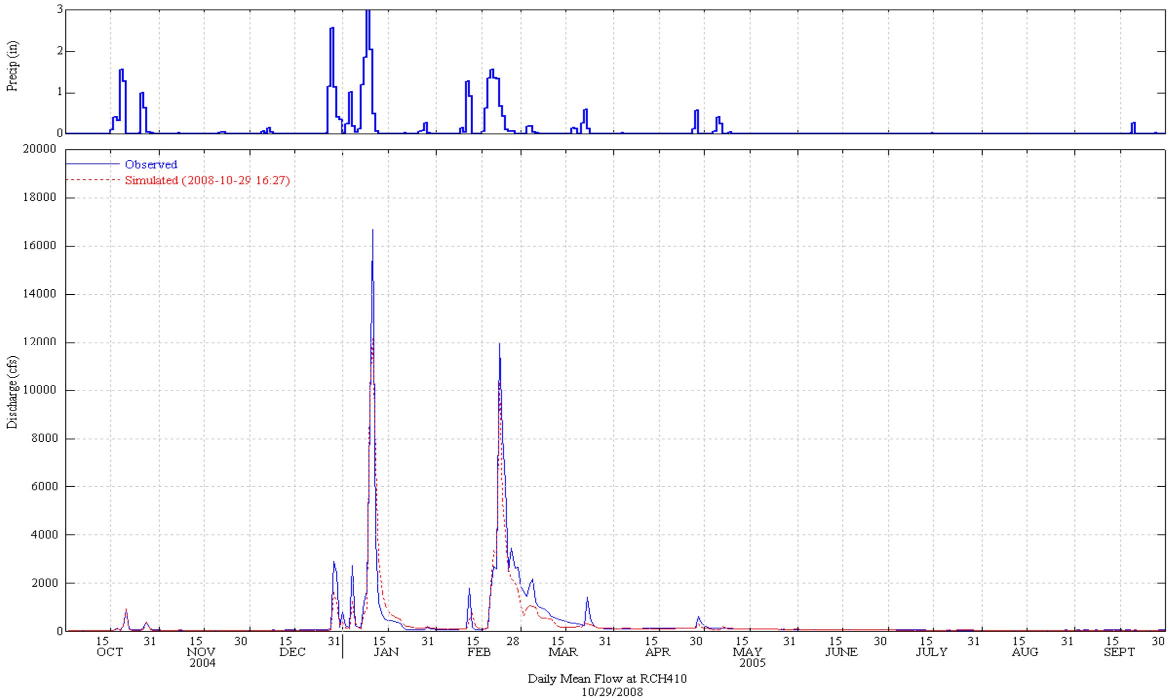


Figure 4.5 Simulated and Observed Daily Flow for Sespe Creek at Fillmore for Calibration (WY 2005) and Validation (WY 1995)

Calibration – WY 2005



Validation – WY 1993

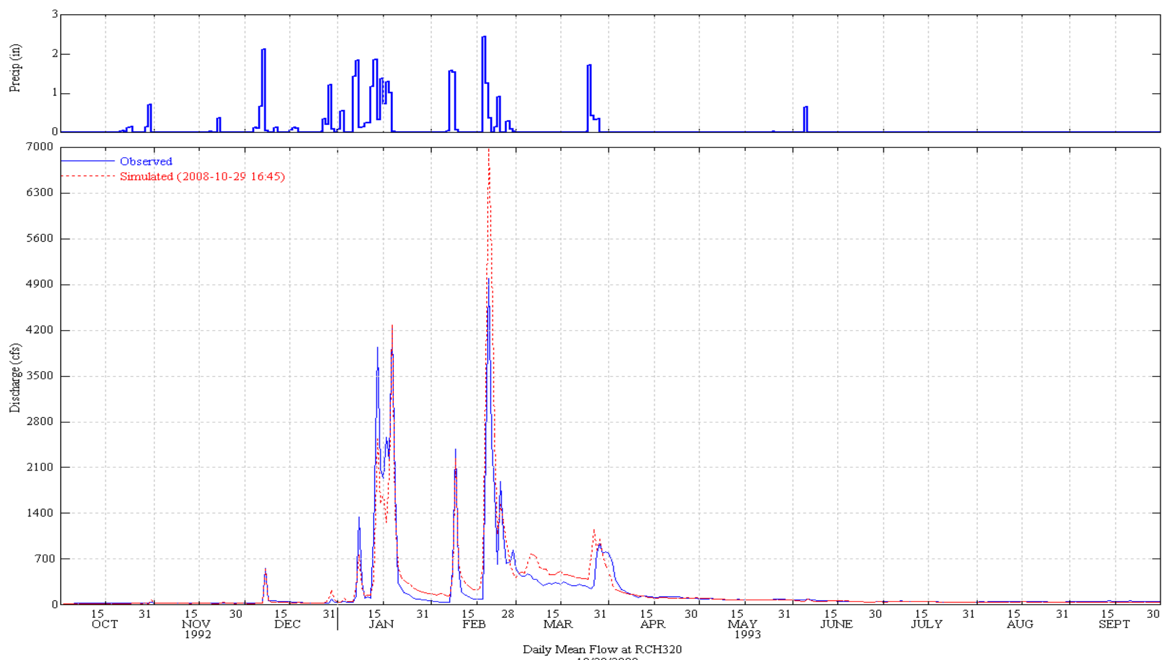
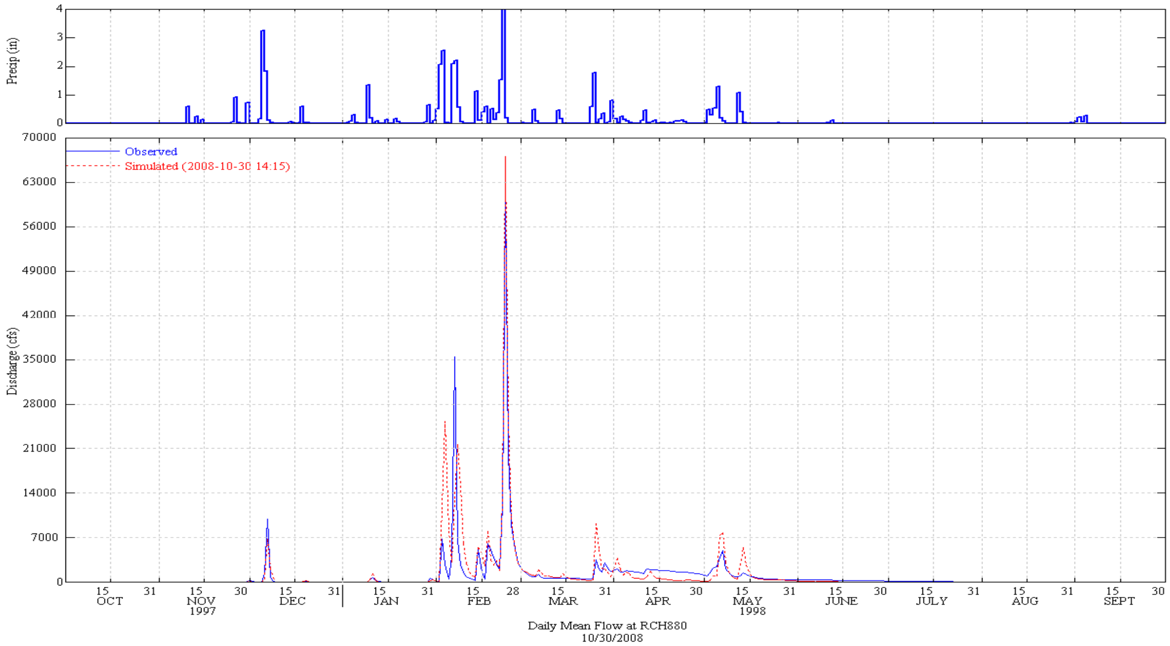


Figure 4.6 Simulated and Observed Daily Flow for Santa Clara River at County Line for Calibration (WY 2005) and Validation (WY 1993)

Calibration – WY 1998



Validation – WY 1993

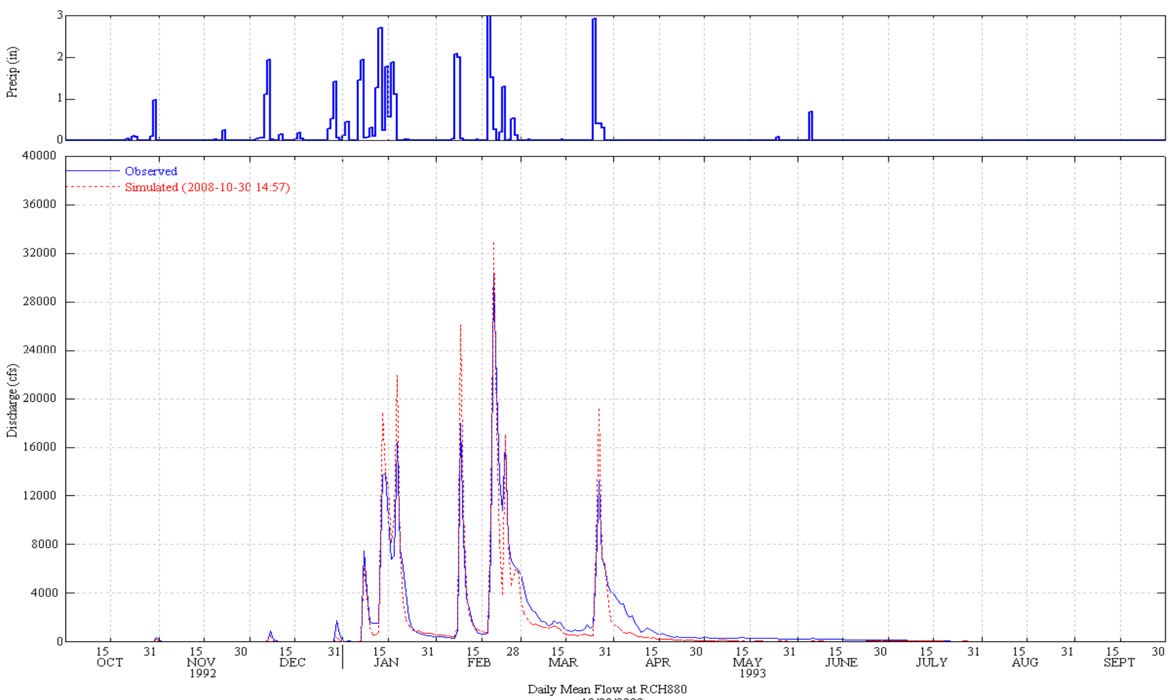


Figure 4.7 Simulated and Observed Daily Flow for Santa Clara River at Montalvo for Calibration (WY 1998) and Validation (WY 1993)

4.3.4 Storm Event Simulations

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, reflecting individual storm paths across the watershed, and 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. In addition, the errors detected in rainfall distributions and amounts discussed in Section 2.1 caused significant variations in the simulations of storm hydrographs, so we focused more on those events with relatively accurate total daily volumes.

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 Tables 4.2 and 4.3 are derived from 10-30 selected events during each simulation period, and they represent the average percent difference of the peaks of the selected storms. For detailed comparisons, the VCWPD and LACDPW staff provided short-interval (hourly or less) storm hydrographs for selected events at each calibration site; the Appendices show the detailed simulated and observed flow values for the selected events with available short-interval flow. For clarity and convenience, Figures 4.8 through 4.11 each show two events for Sespe Creek at Fillmore, SCR at County Line, and SCR at Montalvo (Figures 4.10 and 4.11) for the calibration and validation time periods.

The events in Figures 4.8 through 4.11 are representative of some of the better overall storm simulation results; a number of the events show considerable differences between simulated and observed flows, and much of the difference is due to non-representative rainfall issues. Our conclusions based on these results, and those in Tables 4.2 and 4.3, and the Appendices, are as follows:

a. There is a wide range in the accuracy of the storm simulations, largely as a function of the accuracy of the rainfall data driving the simulations of the individual storms. The storm simulations are generally in the range of **Fair to Good,** although some are Poor but many are Very Good. The model shows a clear consistency between the rainfall and the resulting runoff, and when that consistency is not demonstrated in the observed rainfall and/or runoff, the observations may be suspect.

b. The daily flows, correlation statistics, and % Difference in storm peaks, discussed above, indicated a **Good to Very Good** simulation accuracy for most gages. It is expected that the accuracy will drop as one focuses on individual events. From a review of the storm plots in the Appendices, it is apparent that the largest differences tend to be for the smaller sites and smaller events, and vice versa: the better simulations are often for the larger sites and events.

c. The storm simulations shown in Figures 4.8 to 4.11 demonstrate a generally Good to Very Good representation of the observed flow data, and there are many plots in the Appendices with a similar level of agreement. These are some of the largest sites, and their results are produced by rainfall at numerous gages, so any errors at individual rain gages will have a lesser impact than for smaller sites where only 1 or 2 gages may be available to drive the simulation.

d. Figure 4.10 shows the storm hydrographs for the two largest events at Montalvo during the calibration period, corresponding to February 1998 and 2005. The February 1998 event washed out the USGS gage so only daily flow values were estimated and available. The simulation shows a peak flow of about 120,000 cfs on February 23, 1998, with a daily flow of about 60,000 cfs; the USGS shows an estimated peak of 84,000 cfs, whereas VCWPD provide flow peak data for this event showing an estimated peak of 144,000 cfs (M. Bandurraga, personal communication, 2007), more consistent with the model estimate. Also, for the February 2 – 9, 1998 events, the model simulations are much more consistent with the rainfall data than the daily observed flow estimates, with peaks on February 3 and 7 that follow peak rainfall amounts, whereas the daily observed peak values are shown for one day earlier each time.

e. The February 2005 event shown in Figure 4.10 is a **Very Good** representation of the observed hydrograph throughout most of the event. The lower simulated flow rates, after about 2 am on February 21, until about midnight February 22, appear to be more consistent with the rainfall pattern for that time period than the observed flow values since the peak rainfall occurred at midnight on February 20 and then decreased throughout the rest of the storm. The observed flow for that time period seems to indicate that additional rainfall may have contributed to the continued rising peak but was not included in the model input.

f. The model sensitivity to time step is an issue that was discussed extensively among Project Team members during the study effort, and the impact is most evident when comparing storm event simulations. The choice of the hourly time step, as noted in Section 2.1 was based on the time step of the majority of the available rainfall data, the large size of the watershed, and the requirement for the same time step for all model operations throughout the watershed. Model sensitivity to the time step will vary based on a number of factors, including watershed or subwatershed size, slope, number (and length) of stream reaches, and accuracy and coverage of the precipitation data. As watershed size increases, channel routing, travel time, and increased storage all serve to reduce the sensitivity of peak flows to the time step.

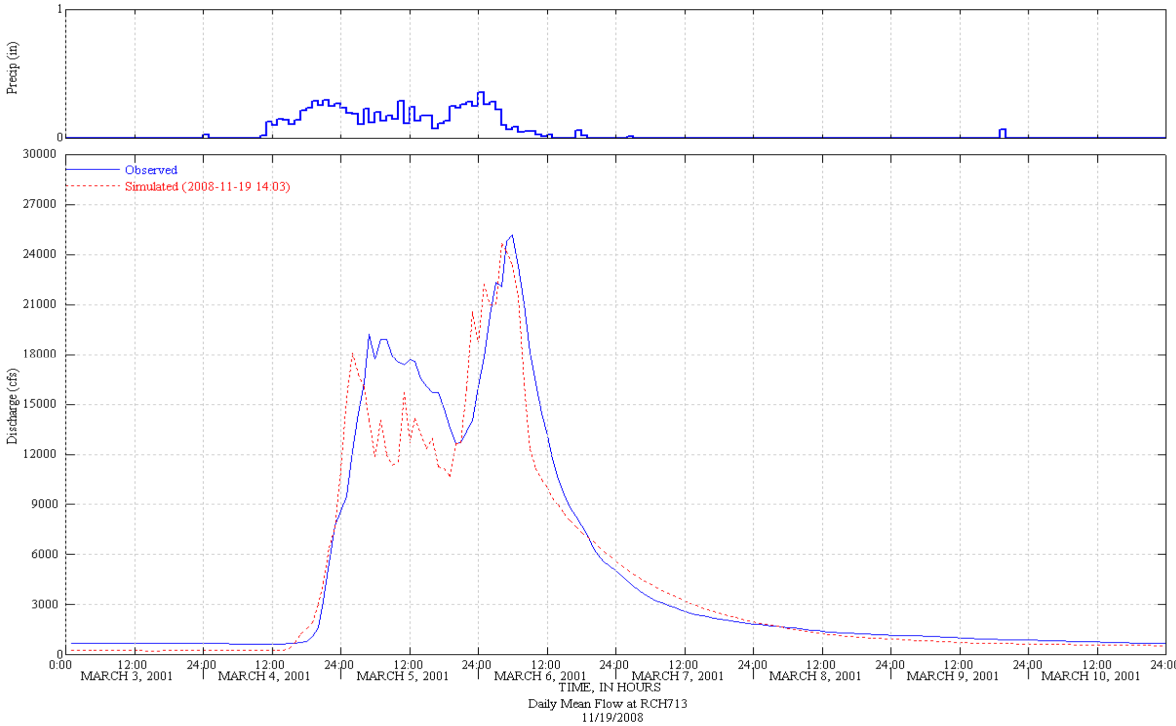
   In response to questions on the model sensitivity to the time step, model runs were performed on the Santa Paula watershed as part of the Design Storm Development effort with multiple time steps – 5 minute, 15 minute, hourly. Since the Design Storm effort used a generated rainfall hyetograph at a 5-minute interval, and for a 100-year event, this provided an extreme case to assess sensitivity. Table 4.9 shows the results of the model runs at the three different time steps, along with averaging the results over the same time intervals. Thus, the column of flows under the '5-Minute' time step shows how the values change when you average the model results to obtain 15-minute and hourly values; the numbers decrease slightly (to 55,422 from 57,115) for the 15-minute average, then considerably more for the hourly value (42,996).

   However, when the flows are averaged to obtain hourly values (the last row of the table), all the model runs for each time step show very little variation in the peak flows from 42,996 (5-minute) to 40,872 (hourly). The 15-minute values (second row of table) also show little change between the 5-minute and 15-minute time steps. Since Santa Paula Creek is about 40 square miles, this general level of sensitivity of peak flows to the time step is likely for other such small tributaries. However, as noted above, the sensitivity will be considerably less for larger drainage areas and for the normal range of storms, as opposed to the 100-year event used in this assessment. Appendices L and M, which document the Design Storm effort, for mostly small tributaries, show that relatively small rainfall adjustment factors were needed to match expected 100-year peak flows, at the gaged sites, using the 5-minute time step. These runs, and the results noted above, further support the use of the model at the shorter time intervals as used in the Design Storm Development effort.

Table 4.9 Time Step Sensitivity Results for Santa Paula Creek, 100-Year Design Storm

Peak Flows for Santa Paula Creek, 100-year Design Storm, cfs				
Time Interval of Average Flows		Model Simulation Time Step		
		5 - Minute	15 - Minute	Hourly
5 - Minute		57,115		
15 - Minute		55,422	55,362	
Hourly		42,996	42,292	40,872

Calibration Event – March 2001



Validation Event – January 1995

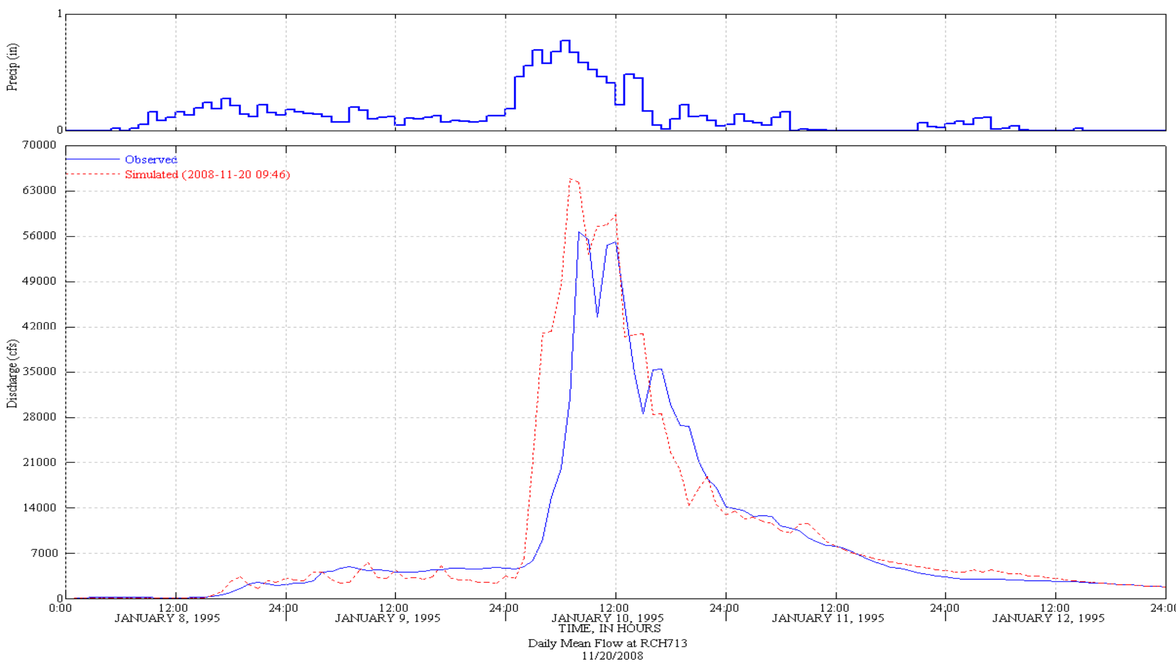
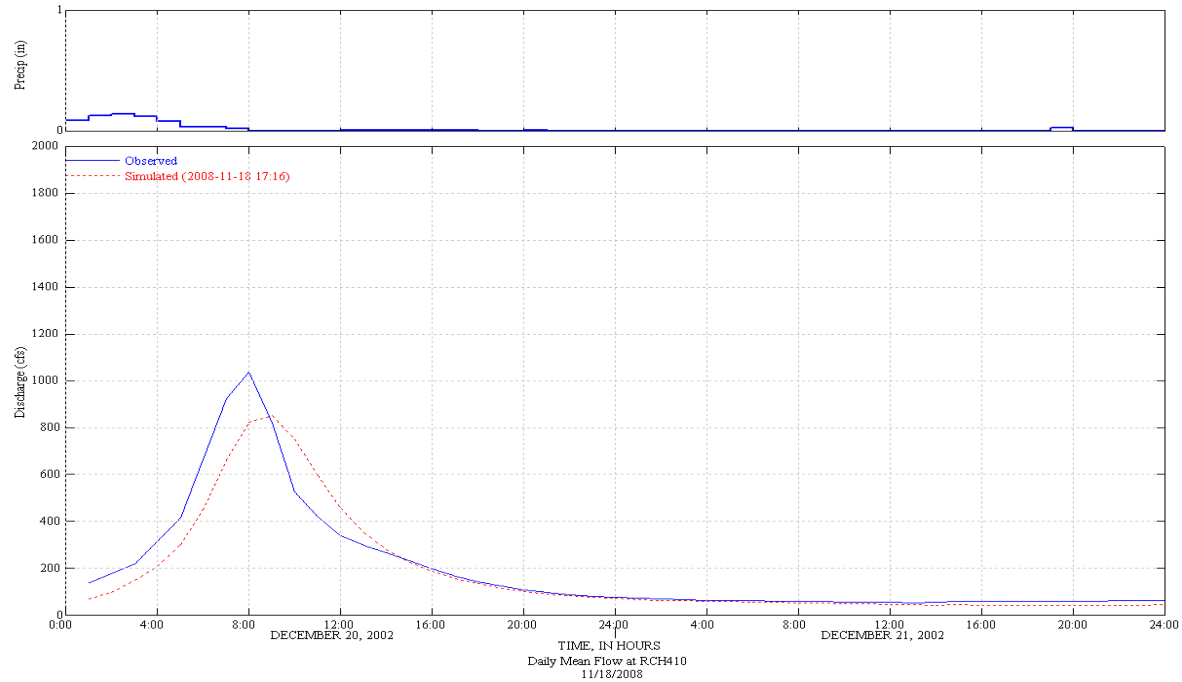


Figure 4.8 Simulated and Observed Storm Events for Sespe Creek at Fillmore for Calibration (March 2001) and Validation (January 1995)

Calibration Event – December 2002



Validation Event – January 1993

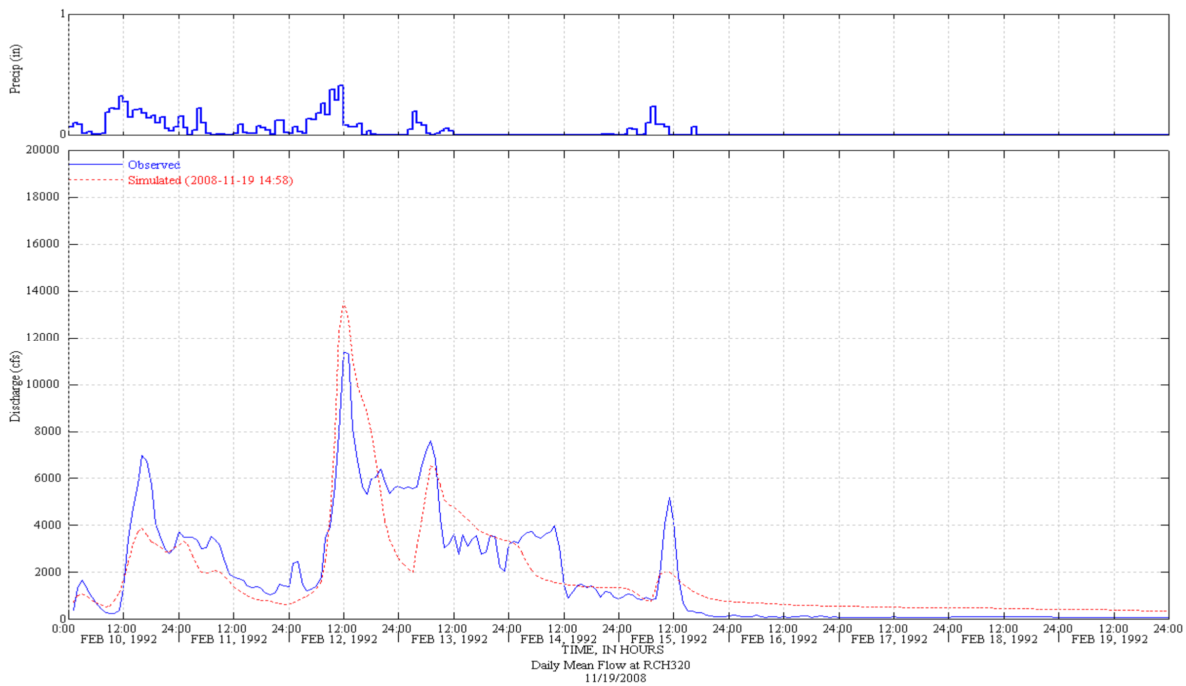
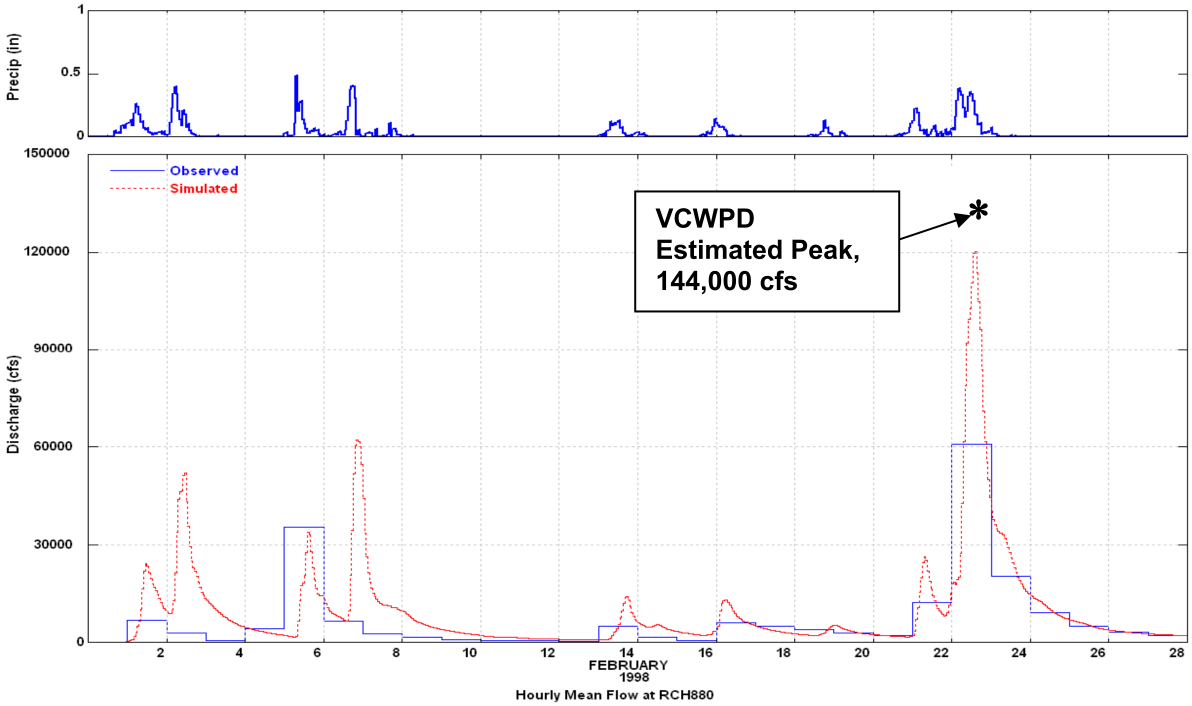


Figure 4.9 Simulated and Observed Storm Events for Santa Clara River at County Line for Calibration (December 2002) and Validation (February 1992)

Calibration Event – February 1998



Calibration Event – February 2005

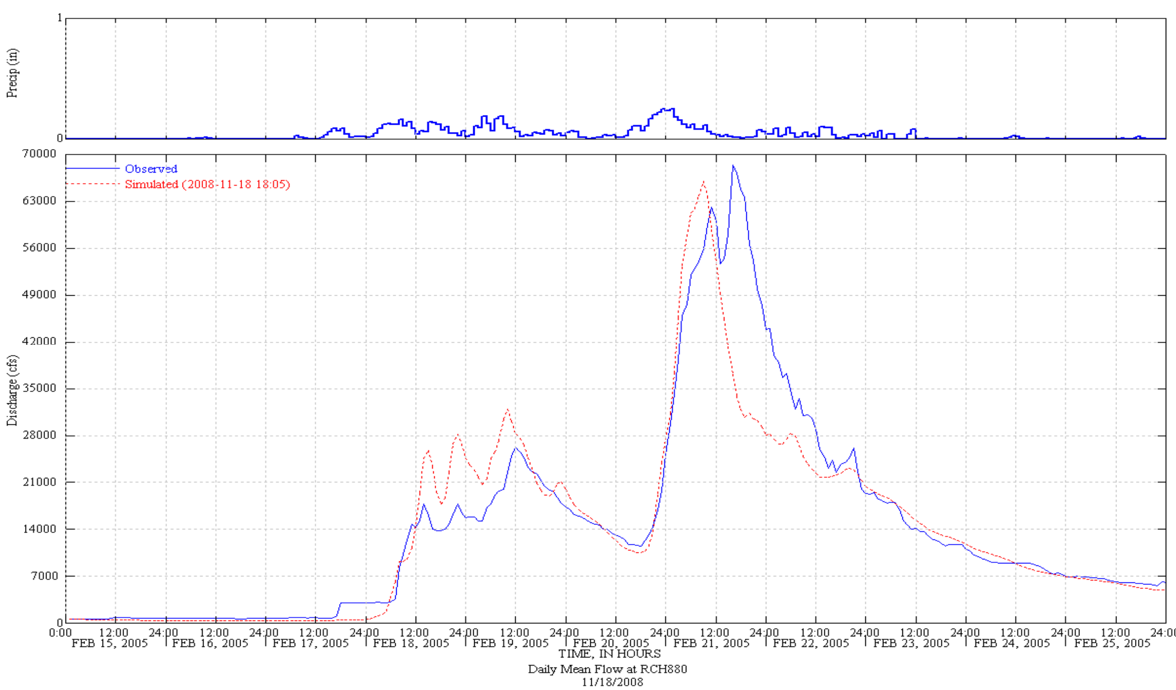
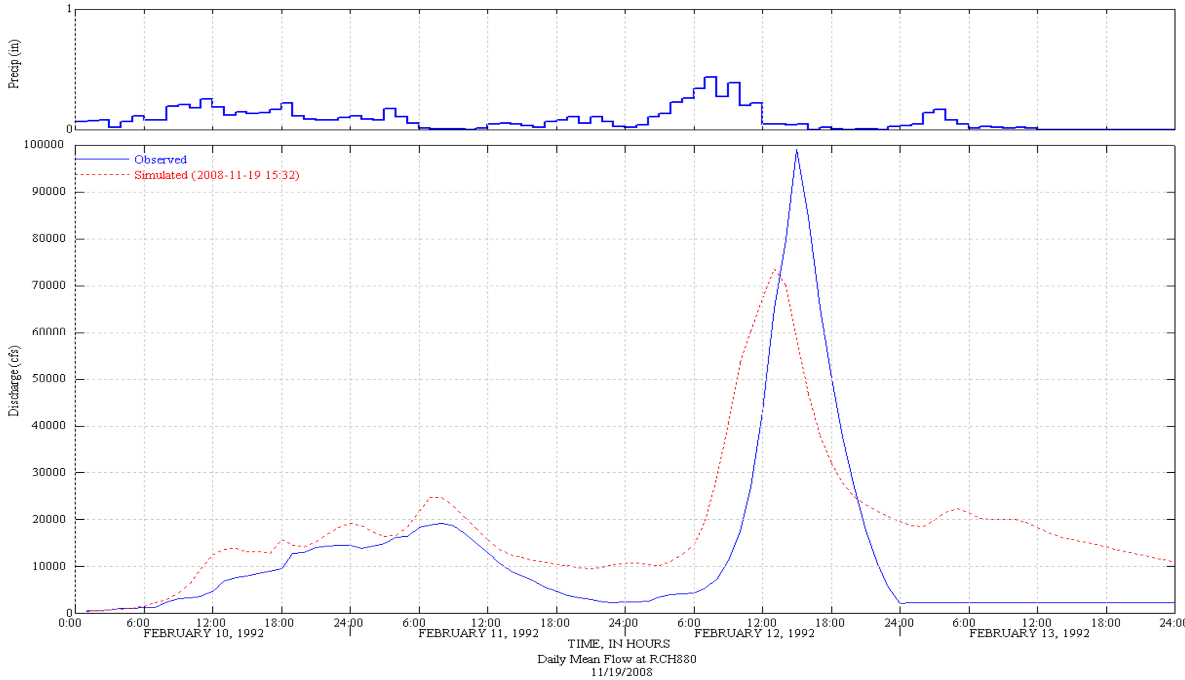


Figure 4.10 Simulated and Observed Storm Events for Santa Clara River at Montalvo for Calibration (February 1998 and February 2005)

Validation Event – February 1992



Validation Event – February 1993

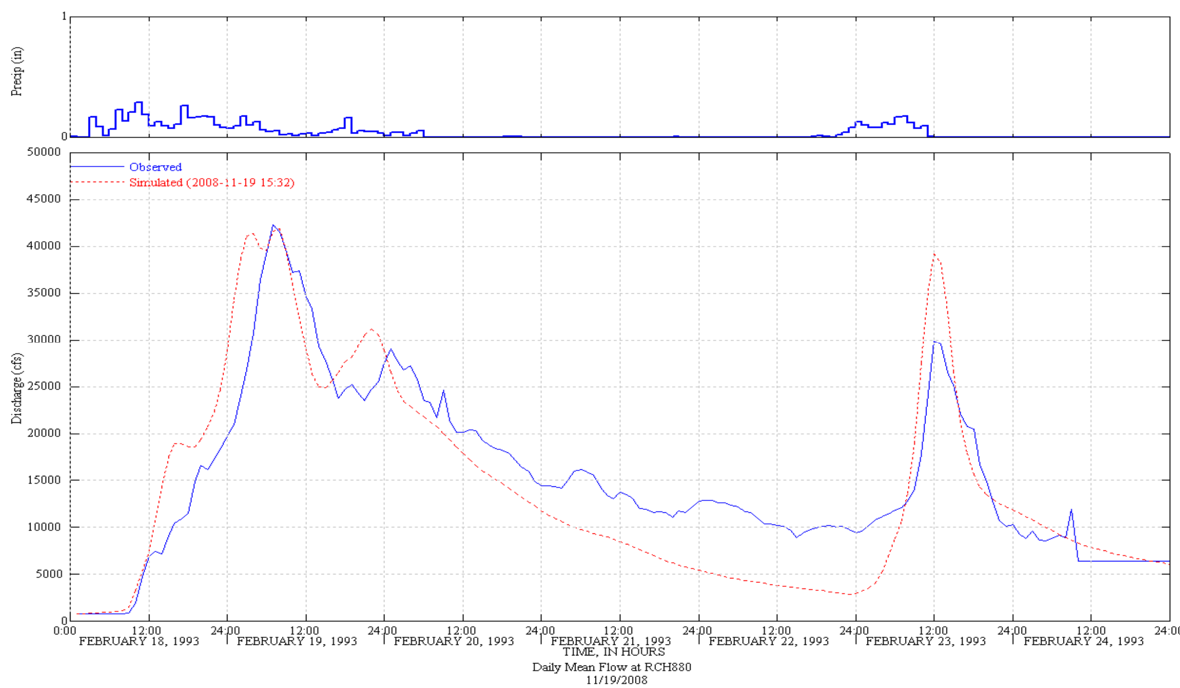


Figure 4.11 Simulated and Observed Storm Events for Santa Clara River at Montalvo for Validation (February 1992 and February 1993)

4.3.5 Reservoir Simulation

The data available to support the simulation of the major reservoirs in the SCR Watershed was described in Section 2.5.2. The general methodology consisted of specifying (using recorded input daily time series) the SWP water imports, inter-reservoir transfers, and reservoir outflows. In addition, an error term, representing the errors in measuring all of the inflows and outflows was included for each reservoir; note that this error term is calculated by DWR, not by the model, to balance their storage and flux calculations. This error term also includes the evaporation losses and rainfall gains; therefore, direct evaporation and rainfall to the water surfaces were generally not included in the reservoir models to avoid double counting of these terms. Since Lake Piru was modeled without the error term, evaporation and rainfall were included in the Lake Piru water balance. For each reservoir, the watershed model provides the natural inflow, and the reservoir storage fluctuates in response to the specified and natural inflows and outflows. When the reservoir storages are lower than observed, then the simulated natural/local inflows are assumed to be too low, and vice versa when reservoir storages are higher than observed.

The FTABLES (i.e., the stage-storage-discharge tables) for the reservoirs were developed as described in Section 3. The Lake Piru stage-storage curve changes more quickly than the others, since it is experiencing significant sedimentation. The Piru stage-storage curve measured in approximately 1996 was used in the both the calibration and validation periods. Spillway discharge curves as a function of elevation above the spillway were provided by UWCD for Lake Piru, and were estimated for the other four lakes using spillway/weir discharge equations and approximate spillway sizes.

The releases from Bouquet Reservoir are highly regulated and consistent on a seasonal basis. Since no data are available to quantify the water imported to Bouquet from the Los Angeles Aqueduct, this lake is not explicitly modeled. The measured releases from Bouquet are input in the form of a daily time series to the modeled reach downstream of the lake as a boundary condition. These data were provided by VCWPD, and covered the period 1980-2006. For the long term run, the general pattern of Bouquet releases (i.e., 5 cfs for October - March and 1 cfs for April - September) was reproduced over the earlier missing period (1958-1979). Figure 4.12 shows the Bouquet releases that were input to the model.

The model of Pyramid Lake included the following separately-defined inflows and outflows:

- inflow from the SWP
- outflows to Castaic Power Plant/Elderberry Forebay
- inflow/pumpback from Elderberry Forebay
- natural releases
- recreation releases
- deliveries/releases to United Water Conservation District.

The natural, recreation, and UWCD releases were added to the downstream channel. In addition, any simulated release over the spillway, which occurred when the storage exceeded the capacity, was also added to the downstream reach. While there have been no historical spillway releases, the capacity was exceeded during several large storms during the simulation period. The data to model Pyramid inflows and outflows was described above. This database was complete for the calibration and validation periods, but not for the earlier simulated period (1959-1986).

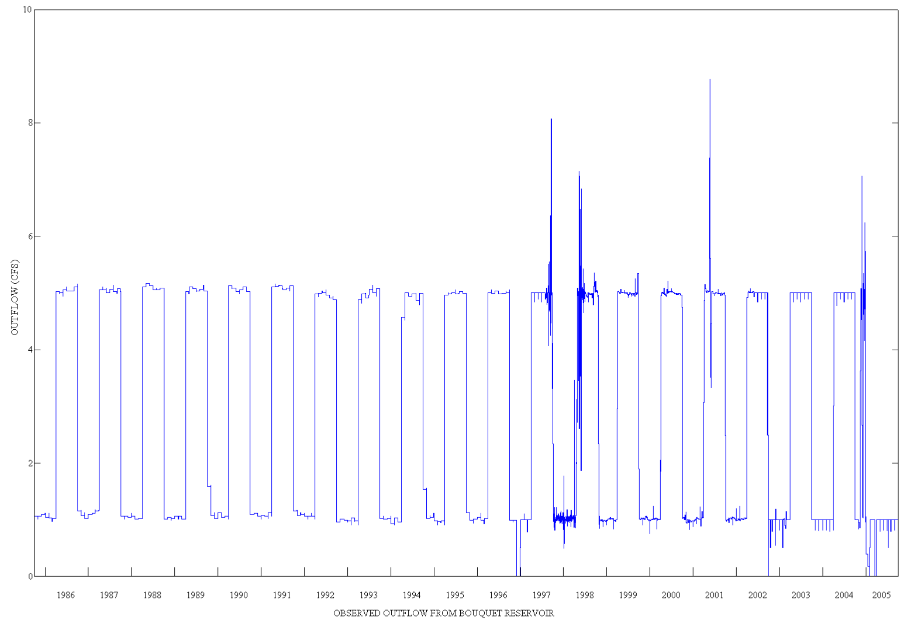


Figure 4.12 Bouquet Reservoir Outflow

Lake Piru was modeled using the daily flows at USGS station 11109800, which is the station below the Santa Felicia Dam. The outflow from the spillway bypasses this gage. The spillway outflows are modeled the same as the other reservoir spillways, i.e., whenever the reservoir storage exceeds the capacity, spills occur. The difference in Lake Piru is that spills have occurred occasionally, and a measured time series of spillway outflows was available for comparison with the simulated spills. Both of these data sets covered the time period 1955-2006.

The model of Elderberry Forebay included the following separately-defined inflows and outflows:
1) inflow from Pyramid Lake via Castaic Power Plant
2) outflow/pumpback to Pyramid Lake
3) natural inflow releases to Castaic Lake
4) Project (SWP) deliveries/releases to Castaic Lake.

Similarly to Pyramid Lake, any simulated release over the Elderberry spillway, which occurred when the storage exceeded the capacity, was also routed to Castaic Lake. While there have been no historical spillway releases, the capacity was exceeded during several large storms during the simulation period. The daily flow time series for items 1 – 4 were obtained from the CADWR SWP database. These time series covered the calibration and validation periods.

Castaic Lake was modeled similarly to Pyramid Lake and Elderberry Forebay. The following separately-defined inflows and outflows were specified to the model:
1) natural releases from Elderberry,
2) Project deliveries from Elderberry Forebay,
3) releases to Castaic Creek and
4) State Water Project delivery outflows

The SWP delivery outflows are removed from the model, since they are transported to water suppliers in pipes. If the simulated storage exceeds the capacity, spills occur over the spillway. As above, there have been no historical spills; however, there were several spills in the model. The data for items 1 - 4 were obtained from the CA DWR database, and covered the calibration and validation periods.

Castaic Lagoon (also called Castaic Afterbay) was modeled in the same manner as the other SWP-related reservoirs. The inflows and outflows that were specified were the following:

1) inflows from Castaic Lake
2) releases to Castaic Creek (categorized as surface, subsurface, and recreation in the DWR database).

If the simulated storage of the Lagoon exceeds the capacity, spills occur over the spillway. As above, there have been no historical spills; however, there were several spills in the model. The data for items 1 and 2 were obtained from the CADWR SWP database, and covered the calibration and validation periods. The release data for the Lagoon were available only as monthly totals rather than the daily time step of the other reservoirs. For the calibration period, these monthly totals were converted to a daily time interval using the pattern of releases from Castaic Lake. This was done to prevent artificial spills from occurring from the lagoon when storms resulted in large inflows to the lagoon and the daily lagoon release was based on a monthly average release rate.

Calibration of the watersheds contributing to the major reservoirs (i.e., Pyramid, Piru, Elderberry, and Castaic) was assisted by comparing simulated and observed storages in the reservoirs. For each of the reservoirs, all of the inflows and outflows except natural inflows (i.e., imports, from outside the watershed, inter-reservoir transfers, and regulated outflows) were defined in the input data (see Section 2.5.2 for a description of the data). Therefore, comparison of storages and unregulated outflows (or spills) provided measures of the quality of calibration of natural inflows from the contributing watershed areas. If storages and spills were too high, natural inflows were reduced by adjusting parameters in the upstream watersheds to reduce runoff appropriately, and vice versa. Figures 4.13 and 4.14 show the monthly averaged storages of the five reservoirs that were modeled in this way. Lake Pyramid and Piru Lake (which are both on Piru Creek) are shown in Figure 4.13 and Castaic Lake, Elderberry Forebay, and Castaic Lagoon storages are shown in Figure 4.14. As exhibited by the Pyramid curve, the storage is slightly under-simulated in 1997, but a large storm in January 1998 fills the reservoir and leads to somewhat over-simulated storages for 1998. However, the winters of 98/99 and 99/00 are apparently under-simulated in this watershed. Storms in February 2001 again fill the reservoir, and the storages are in fairly good agreement for the remaining five years of the calibration. However, there is another slight over-filling in the winter of 2005. In general, the Pyramid storages show a good match for all periods except 1999-2000, which is an extremely dry period in the watershed.

Another effect of the over-fillings of Pyramid Lake described above can be seen more clearly in Figure 4.15, where the simulated spillway outflow is shown. Pyramid Lake has never experienced outflows over its spillway, so these simulated flows indicate an over-simulated storm period, caused partly by unrepresentative rainfall records and errors in the measurement of the various components of the reservoir's water balance components. In particular, measurement of the natural inflow is subject to errors, and this would have the same effect on the comparison of storages as rainfall errors.

The excess outflows from Pyramid flow downstream, and cause the Lake Piru storages to be over-simulated as well. The results can be seen in Figure 4.16, where the spillway flows from Lake Piru are shown. As indicated, Lake Piru does occasionally overflow; however, the Pyramid

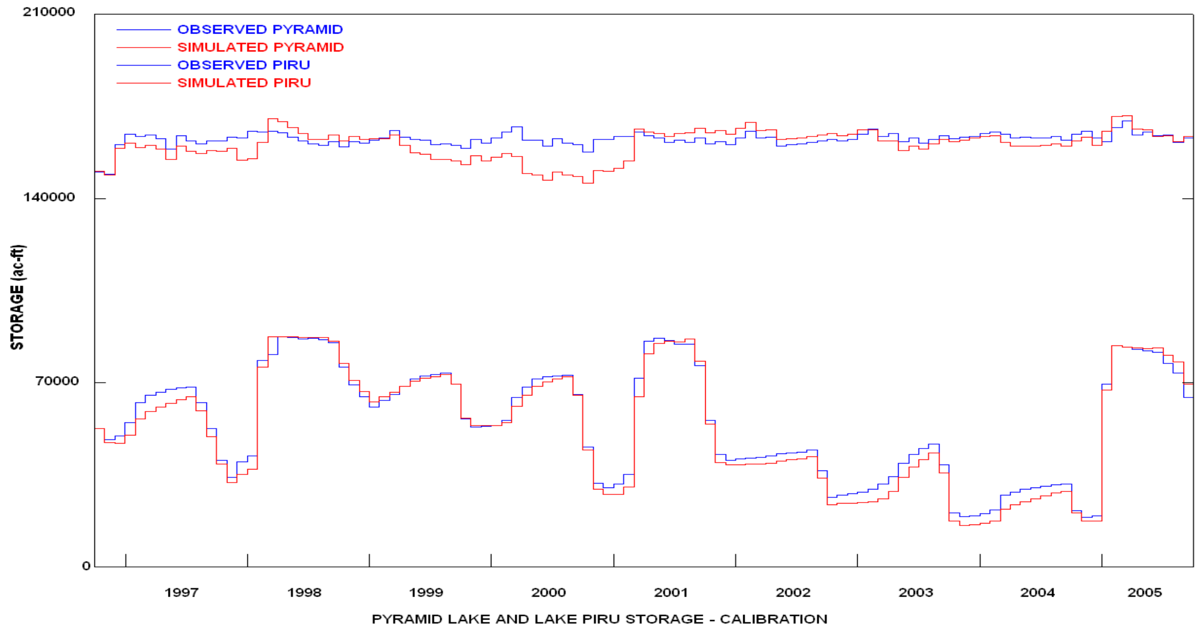


Figure 4.13 Pyramid Lake and Lake Piru Storage - Calibration

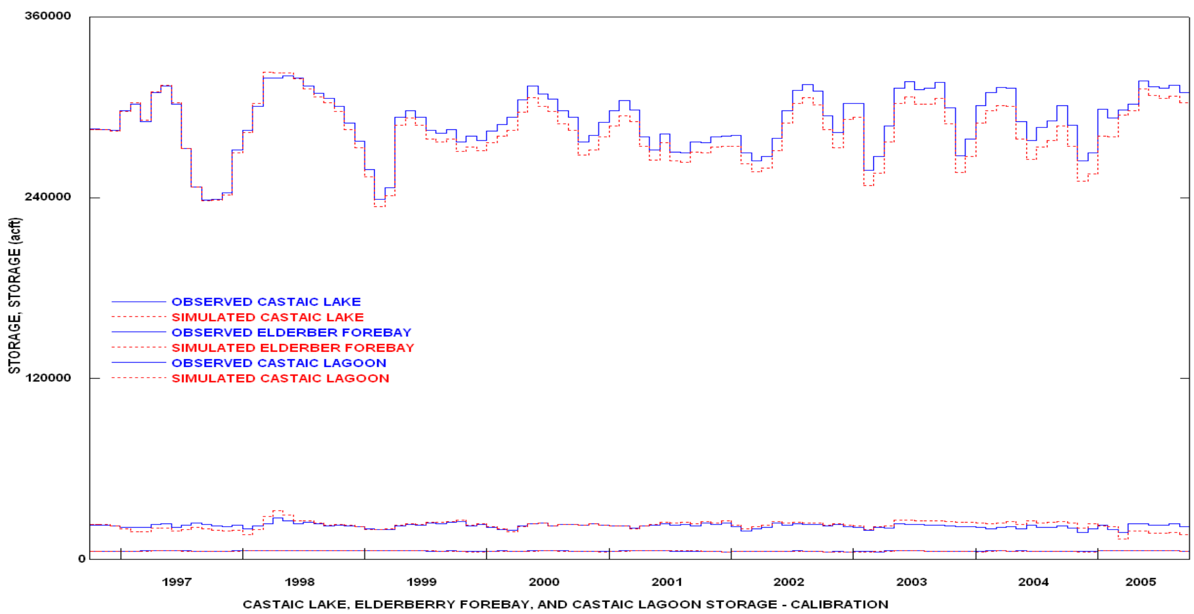


Figure 4.14 Castaic Lake, Elderberry Forebay, and Castaic Lagoon Storage - Calibration

overflows result in the Lake Piru spillway flows to be over-simulated in 1998 and to a lesser degree in 2005; the January 2005 overflows are actually well simulated, although this is not evident at the scale of Figure 4.16. Figure 4.17 shows the spillway flows for Castaic Lake and Castaic Lagoon. Since the Lagoon or Afterbay is small compared to Castaic Lake, and is kept relatively full, any spills from Castaic Lake will be immediately replicated in the Lagoon. This is seen during the large 1998 storm period. In January – February 2005 during a very wet period, there are no spills from Castaic Lake; however, since the Lagoon is nearly full, the natural inflow to the Lagoon is sufficient to cause a series of small spills.

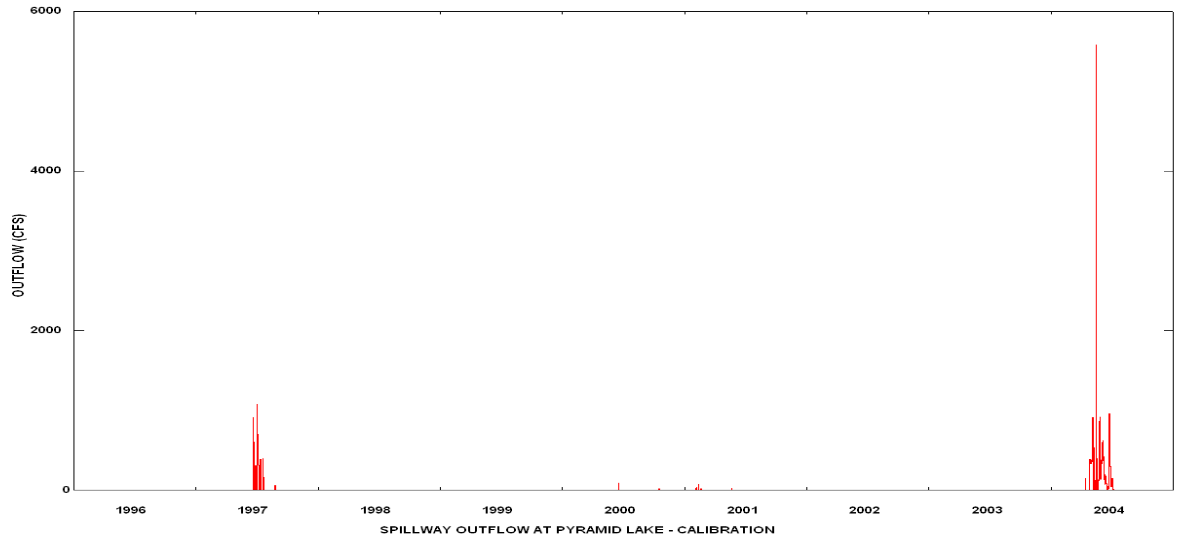


Figure 4.15 Pyramid Lake Spillway Outflow - Calibration

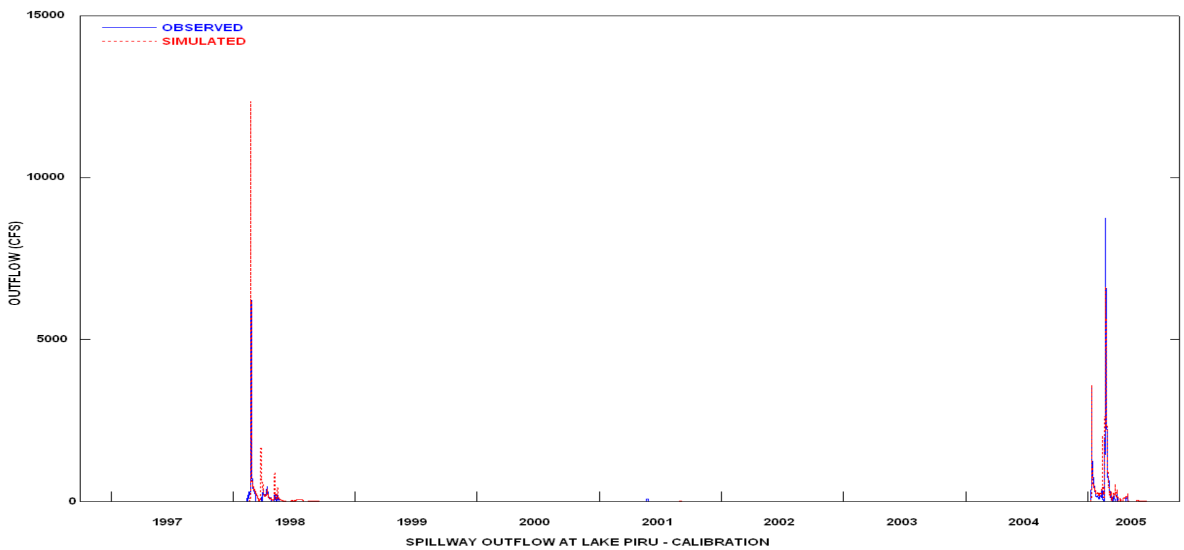
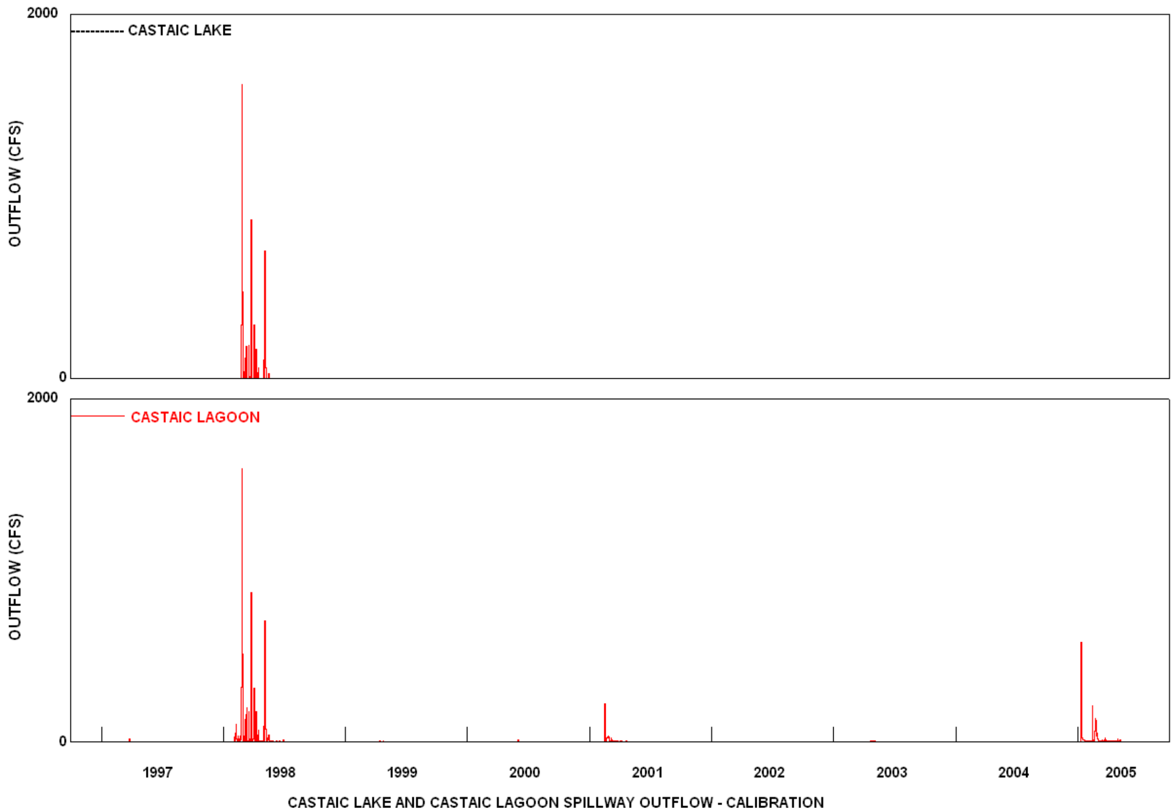


Figure 4.16 Lake Piru Spillway Outflow - Calibration

Figure 4.17 Castaic Lake and Castaic Lagoon Spillway Outflow - Calibration



The storages for the validation period are shown in Figures 4.18 and 4.19. Figure 4.18 shows the Pyramid and Piru storages, and Figure 4.19 shows the Elderberry, Castaic, and Castaic Lagoon storages. As indicated by the Pyramid storage curve in the 1988-1992 period, there appears to be a systematic trend to under-simulation of the natural inflows, or since the reservoir simulation is so dependent on measured flows, possibly there is a problem with the measurement of these flows. While the Lake Piru storages also show apparent under-simulation in 1988-1991, there is better agreement here.

The Castaic and Elderberry storages shown in Figure 4.19 are interesting because while the agreement is better than for Pyramid and Piru, the differences are contradictory in the 1995-1996 water years. The fact that Castaic is under-simulated while Elderberry is over-simulated suggests that measurement errors may be part of the problem, since some of the same watersheds contribute local inflows to both of these lakes. If natural inflow is too high for one, it should be too high for both.

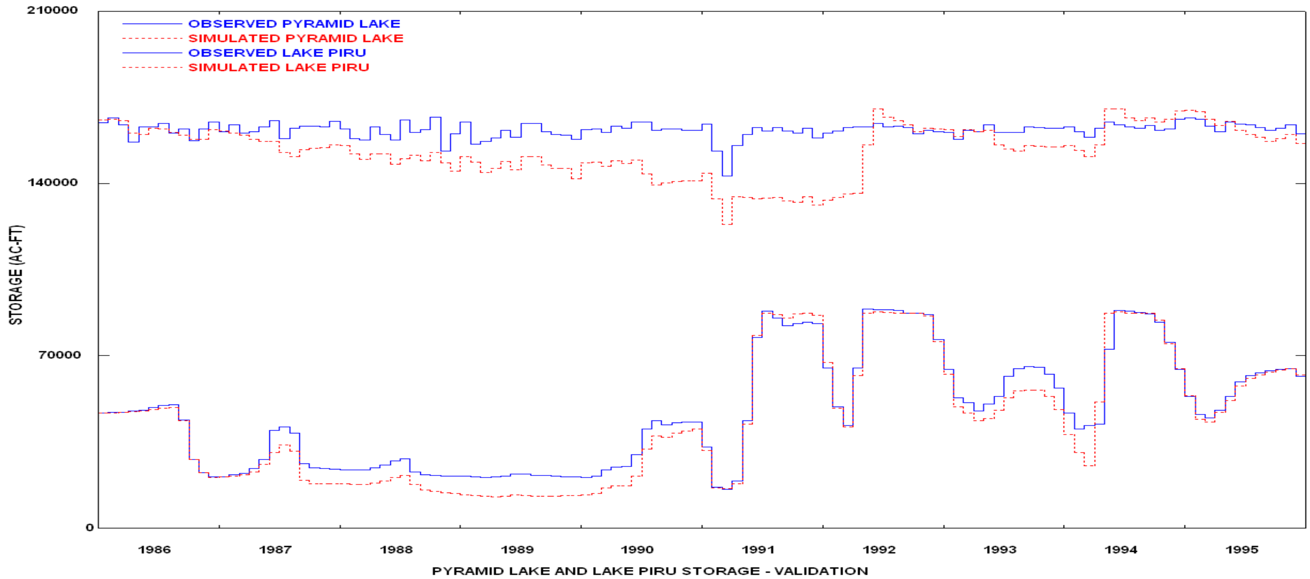


Figure 4.18 Pyramid Lake and Lake Piru Storage - Validation

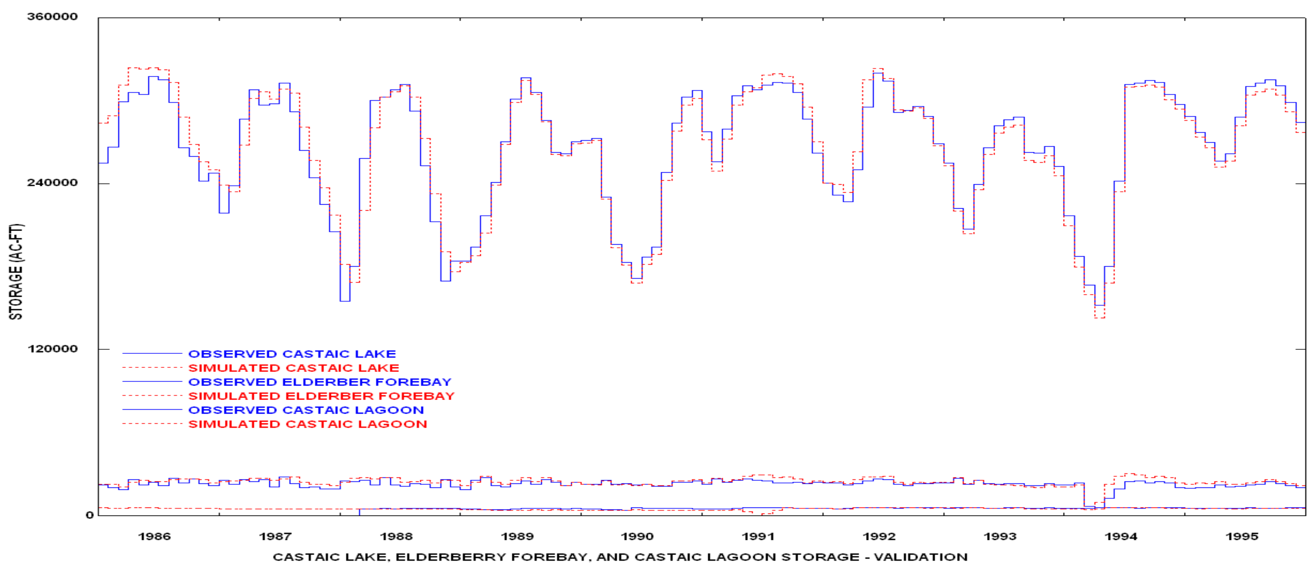


Figure 4.19 Castaic Lake, Elderberry Forebay, and Castaic Lagoon Storage - Validation

The validation period spillway outflows for Pyramid, Piru, and the Castaic/Castaic Lagoon are shown in Figures 4.20, 4.21, and 4.22, respectively. For all of these, the spillway outflows indicate an over-simulation of selective storm periods. However, these occur primarily in 1992 and 1993 (and 1995 in Pyramid and Piru), when the reservoirs are relatively full, and any slight over-simulation of a storm would cause a spill.

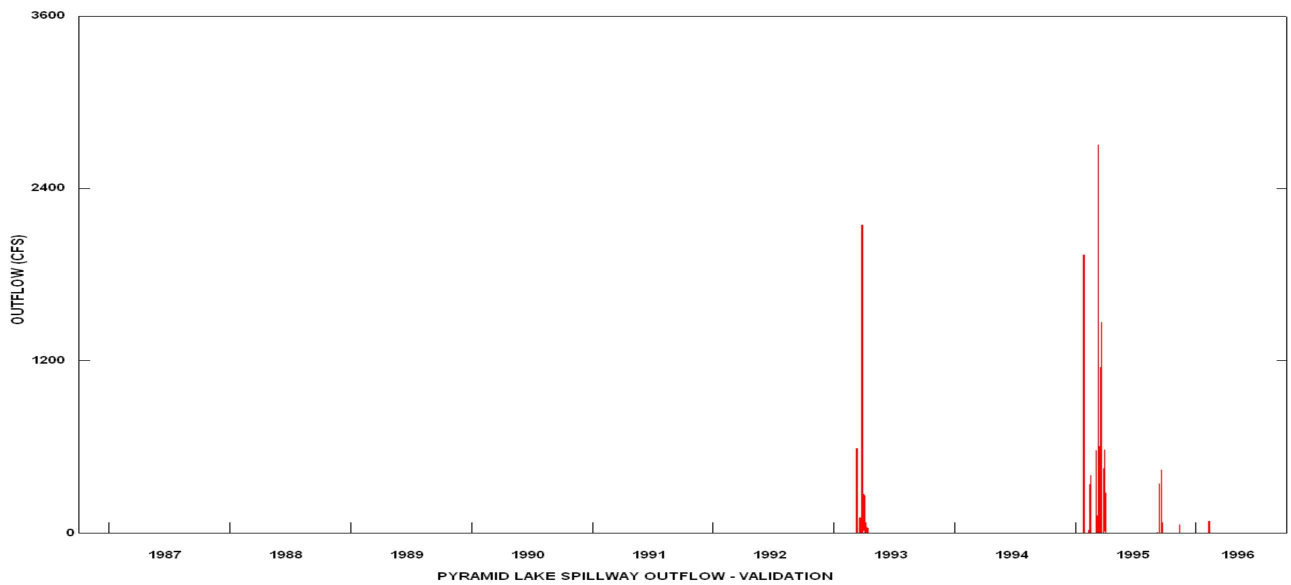


Figure 4.20 Pyramid Lake Spillway Outflow - Validation

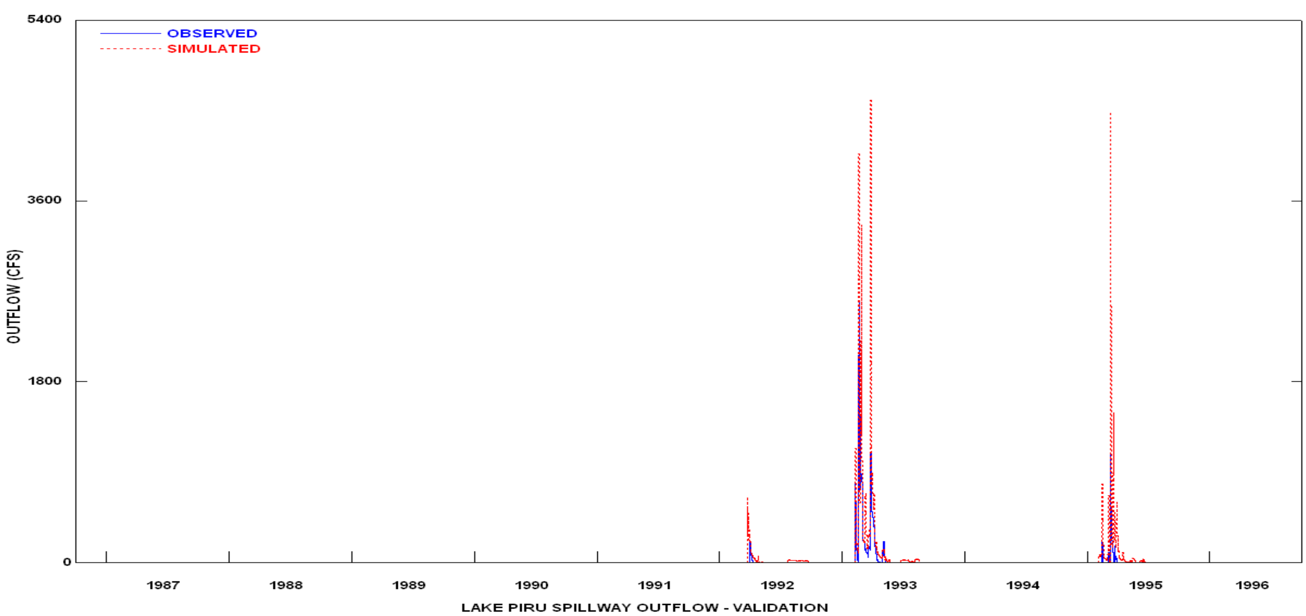


Figure 4.21 Lake Piru Spillway Outflow - Validation

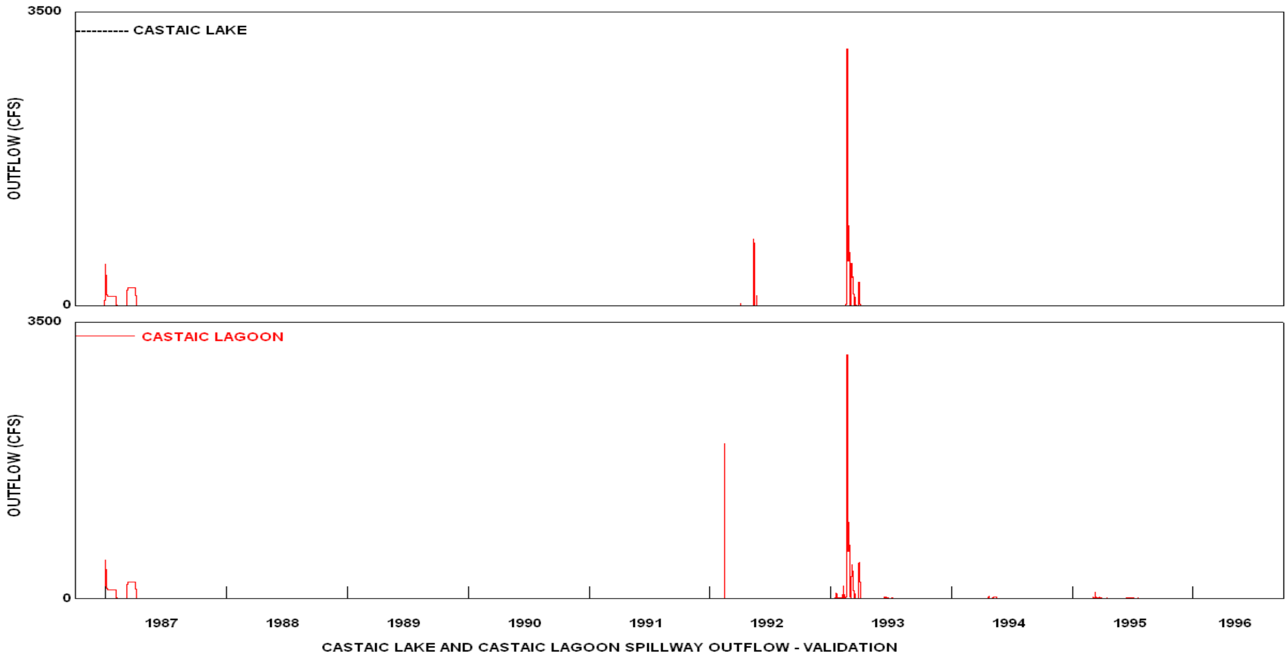


Figure 4.22 Castaic Lake and Castaic Lagoon Spillway Outflow - Validation

4.3.6 Channel Losses, Ground Water Recharge, and Discharge

Section 2.5.5 discussed the ground water recharge and discharge zones along the SCR mainstem, and noted the availability of the McEachron and WARMF models as sources of information on these processes and fluxes. Since these ground water-surface water interactions have a significant impact on low, and sometimes, low-moderate flows, these interactions were important to include in the model. Figure 4.23 shows the HSPF model reaches mapped onto the McEachron gaining and losing reaches. Since McEachron's model ended at the County Line, the WARMF model provided timeseries of ground water discharge (accretion) from/within the Santa Clara Valley East ground water subbasin as the gaining region east of the County Line.

Our approach to representing these ground water – surface water interactions included the following:

a. McEachron's ground water discharge values, as daily timeseries, were mapped onto the corresponding HSPF model reaches and input directly to the model.
b. WARMF model values for ground water discharge east of the County Line were mapped onto the corresponding HSPF model reaches and input directly to the model.
c. McEachron's recharge, channel losses, were tabulated and mapped onto the corresponding HSPF model reaches, and the channel losses within the model were calibrated to these values on a reach-by-reach basis.

The McEachron model provided discharge and recharge (channel losses) daily time series from 1959 to 2005. The WARMF model provided daily time series for ground water discharge

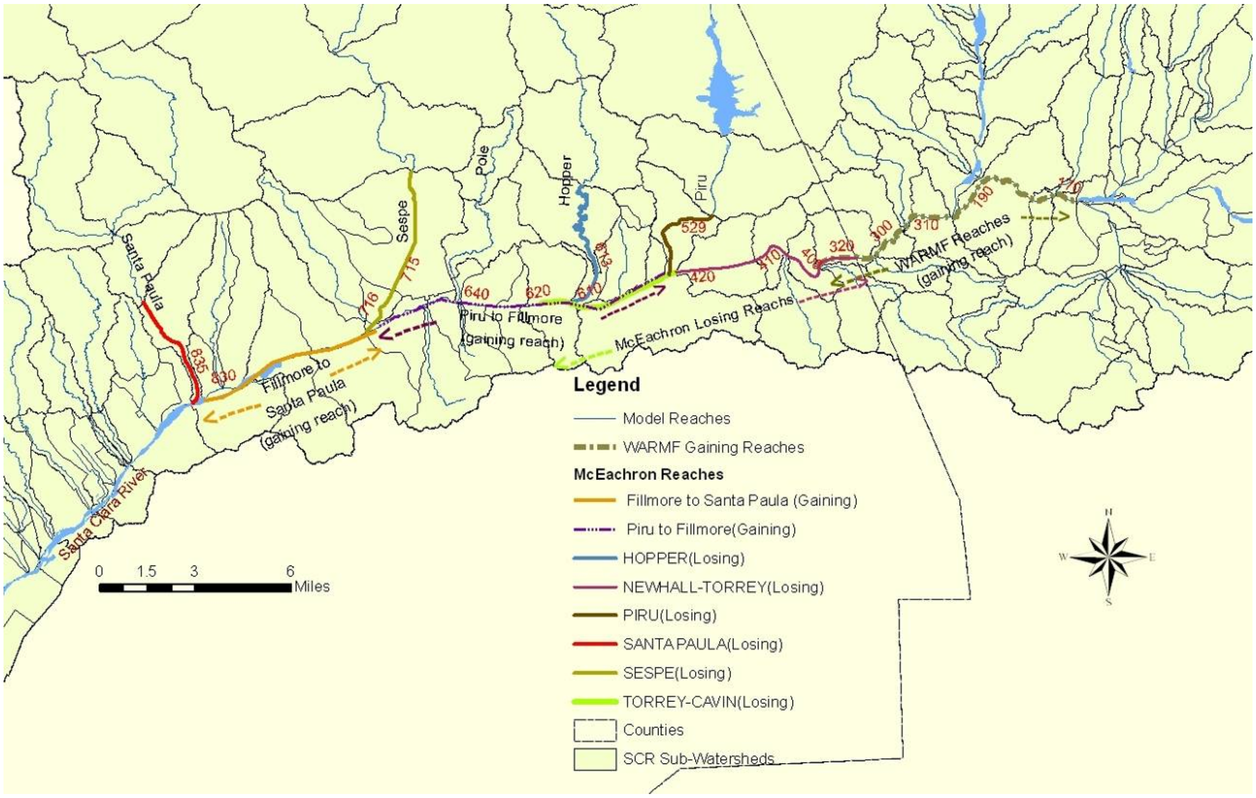


Figure 4.23 Ground Water Gaining and Losing Reaches for the SCR Mainstem

(accretion or gains) from 1990 to 2000. We extended the WARMF time series for the remaining time periods as follows:

a. For Reaches 180, 190, 300, 310, and 320, we assigned the monthly values of the 1990-2000 WARMF time series to the 2001-2005 time period.
b. For Reach 170, we assigned the monthly average of the 1990-2000 WARMF period to the 2001-2005 time period.
c. For all reaches, the 1987-89 time period was filled as the monthly average for the entire 1990-2005 time period.

Table 4.10 shows ground water discharge values by year from the WARMF model, along with the corresponding HSPF model reach numbers, that were input to represent the ground water gains; the reach numbers correspond to those shown in Figure 4.23. The table also includes the McEachron discharge values that were input to the model reaches for the Piru to Fillmore and Fillmore to Santa Paula regions of the model.

Table 4.11 shows the results of the calibration of the HSPF model channel losses to the McEachron annual values, along with the corresponding results from the validation period. Although there are some differences on a reach-by-reach basis, i.e. McEachron reaches compared to the HSPF reaches, the biggest differences are for relatively small recharge amounts and the totals agree extremely well, for both calibration and validation. This appears to indicate that the channel losses, or alluvial ground water recharge, is very consistent with McEachron's model, and is likely a good overall representation of these processes as they impact the flows on the SCR mainstem.

However, we have no corresponding confirmation of how well the ground water discharge contributions agree with reality, other than the comparison of observed and simulated flows at Montalvo (actually the combined record of different historic gage sites, as noted in Section 2). A recently completed ground water study for the Sanitation Districts of LA County and the LA Regional Water Quality Control Board (CH2M-Hill, 2008) may provide an opportunity to re-visit and re-evaluate the ground water and surface water interactions in the model with more detailed calculations of the relevant ground water recharge and discharge components.

Table 4.10 Mean Annual Ground Water Discharge Values (ac-ft/yr) from the WARMF and McEachron Models

	Water Year	WARMF Model Data						McEachron Model	
		RCH170	RCH190	RCH300	RCH180	RCH310	RCH320	Piru to Fillmore	Fillmore to Santa Paula
Validation	**1987**	4728	9205	5747	2480	694	973	972	25468
	1988	4728	9205	5747	2486	694	973	1008	25432
	1989	4728	9205	5747	2480	694	973	0	9419
	1990	1788	4376	2045	894	244	462	0	3768
	1991	1222	2838	1395	596	167	301	0	3875
	1992	1484	5491	1687	727	203	580	5568	17754
	1993	9449	12478	10743	4656	1306	1317	22296	37522
	1994	3058	7804	3470	1520	411	826	16287	29236
	1995	7130	11160	8120	3511	984	1181	19852	34512
	1996	4125	7458	4692	2039	566	789	12788	25766
	Total	42441	79218	49392	21390	5964	8376	78771	212752
	Average	**4244**	**7922**	**4939**	**2139**	**596**	**838**	**7877**	**21275**
Calibration	**1997**	2611	9115	2969	1270	358	964	4519	21611
	1998	13920	15399	15810	6856	1914	1627	18248	38083
	1999	3625	11899	4310	1860	519	1259	15178	37719
	2000	3207	7613	4519	1955	543	806	4424	29110
	2001	4793	7488	4716	2045	566	793	8328	37182
	2002	4793	9115	2975	1288	352	963	4215	30368
	2003	4793	15375	15792	6850	1908	1626	423	25671
	2004	4793	11864	4292	1860	519	1256	1818	20454
	2005	4793	7643	4537	1961	543	808	19018	36235
	Total	47329	95511	59920	25945	7219	10099	76171	276433
	Average	**5259**	**10612**	**6658**	**2883**	**802**	**1122**	**8463**	**30715**

4.3.7 Water Balance Analysis

As part of the calibration effort, water balances are checked for each land use to ensure that the model is representing the water balance in a reasonable fashion for each land use, and that appropriate differences in water balances fluxes between and among the land uses are adequately represented.

Tables 4.12 and 4.13 show water balance averages for the calibration period, WY97 to WY05, for model segments in the USCR above Lang (segment 30) and the Sespe Creek Watershed (segment 720), respectively. The runoff and evaporation fluxes are subdivided into the runoff components – surface, interflow, baseflow – while the ET components include the Total Potential ET along with the fluxes from each compartment.

These two segments are indicative of the range of hydrologic regimes and conditions in the watershed; Sespe shows a mean annual rainfall of 29 inches while the value for the USCR is 11 inches. Note the difference between the irrigated and non-irrigated land uses, with the irrigation leading to considerably more runoff, deep groundwater losses, and actual ET in both watershed segments.

Table 4.11 McEachron and HSPF Model Mean Annual Channel Losses (ac-ft/yr) in SCR Streams

CALIBRATION:

McEachron Reach	HSPF Model Reach #s	McEachron Model Loss	HSPF Model Loss	Ratio
NEWHALL-TORREY	320 (50%),400, 410, 420	43777	41249	0.94
TORREY-CAVIN	610, 620 (50%)	74	268	3.64
HOPPER	613, 614	1422	2485	1.75
SESPE	715, 716	5454	6419	1.18
SANTA PAULA	835	2950	2287	0.78
PIRU	529	17855	16353	0.92
Total		**71532**	**69061**	0.97

VALIDATION:

McEachron Reach	HSPF Model Reach #s	McEachron Model Loss	HSPF Model Loss	Ratio
NEWHALL-TORREY	320 (50%),400, 410, 420	34790	30575	0.88
TORREY-CAVIN	610, 620 (50%)	84	241	2.87
HOPPER	613, 614	1093	2141	1.96
SESPE	715, 716	3394	5472	1.61
SANTA PAULA	835	2729	1841	0.67
PIRU	529	14811	14179	0.96
Total		**56901**	**54449**	0.96

4.3.8 ANNUAL FLOOD PEAKS

Table 4.14 presents the annual flood peaks at selected sites on the SCR, including County Line, Sespe Creek, and Montalvo. The specific dates are also listed for each peak, both observed and simulated, since in some cases the peaks do not occur on the same day. This information was specifically requested by Project Team members, while noting that this type of comparison is not entirely valid nor consistent; the simulated values are the highest hourly peak during the water year, whereas the observed peaks may be instantaneous or derived from a short (5 or 15 minute) sampling interval. Therefore the simulated values are expected to be somewhat lower than the observed. Timing differences of 1 day, or possibly even 2 days at the larger sites, are not significant, as they could be due to rainfall timing issues or values for individual time intervals that span before or after midnight, i.e. small differences that result in peaks on different days. Differences of many days are likely due to input rainfall amounts and/or timing problems.

Comparison of the peak values, and dates, in Table 4.13 indicates the following:

a. As expected there are fewer mis-matches of timing of the peaks at Montalvo than at the other upstream sites. Thus the likelihood of timing mismatches tends to increase as the drainage area decreases, and sparsity of rain gages increase.

Table 4.12 Water Balances by Land Use for Segment 30 in the USCR Watershed, WY97-WY05

	FOREST/ WOOD	SHRUBLAND	OPEN/ GRASS	AGRI.	LOW DENSITY RES.	MED. DENSITY RES.	HI. DENSITY RES.	COMM/ INDUS.	EIA
Rainfall	10.88	10.88	10.88	10.88	10.88	10.88	10.88	10.88	10.88
Irrigation									
Canopy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Surface	0.00	0.00	0.00	24.87	17.36	24.31	27.78	29.52	
Runoff									
Surface	0.00	0.01	0.01	0.70	0.11	0.10	0.13	0.17	8.87
Interflow	0.02	0.07	0.10	1.83	0.36	0.44	0.46	0.46	
Baseflow	0.14	0.23	0.27	3.73	1.77	2.73	3.23	3.47	
Total	0.17	0.30	0.38	6.26	2.23	3.27	3.82	4.10	
Deep Groundwater	0.39	0.51	0.58	9.08	4.22	6.61	7.83	8.43	
Evaporation									
Potential	63.77	63.77	63.77	63.77	63.77	63.77	63.77	63.77	63.77
Intercep St	2.68	2.49	2.36	2.44	2.13	2.12	2.12	2.11	
Upper Zone	0.64	0.81	0.86	12.91	2.88	4.14	4.94	5.39	
Lower Zone	6.92	6.66	6.55	0.00	14.97	16.19	16.55	16.70	
Ground Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Baseflow	0.14	0.19	0.20	3.63	1.66	2.63	3.12	3.37	
Total Actual	10.38	10.14	9.97	18.98	21.64	25.07	26.73	27.57	2.01

Table 4.13 Water Balances by Land Use for Segment 720 in the Sespe Watershed, WY97- WY05

	FOREST/ WOOD	SHRUBLAND	OPEN/GRASS	LOW DENSITY RES.	COMM/ INDUS.	EIA
Rainfall	28.88	28.88	28.88	28.88	28.88	28.88
Irrigation						
Canopy	0.00	0.00	0.00	0.00	0.00	
Surface	0.00	0.00	0.00	16.17	27.48	
Runoff						
Surface	2.29	3.13	3.46	7.09	7.76	26.42
Interflow	3.93	3.54	3.84	4.03	4.22	
Baseflow	3.89	4.01	4.33	8.89	14.02	
Total	10.12	10.68	11.62	20.01	26.00	
Deep Groundwater	1.63	1.68	1.72	3.59	5.34	
Evaporation						
Potential	40.76	40.76	40.76	40.76	40.76	40.76
Intercep St	3.03	2.87	2.76	2.56	2.56	
Upper Zone	2.55	2.66	2.72	3.85	6.75	
Lower Zone	10.53	9.89	9.15	13.13	13.71	
Ground Water	0.00	0.00	0.00	0.00	0.00	
Baseflow	0.95	0.97	0.81	1.87	1.99	
Total Actual	17.05	16.39	15.43	21.41	25.01	2.47

Table 4.14 Observed and Simulated SCR River Annual Flood Peaks at Montalvo, Sespe Creek, and County Line

Water	Santa Clara River at Montalvo				Sespe Creek near Fillmore				Santa Clara River at County Line			
Year	Observed	Date	Simulated	Date	Observed	Date	Simulated	Date	Observed	Date	Simulated	Date
1987	851	03/06/87	326	11/17/86	-	-	24	03/06/87	-	-	669	11/18/86
1988	13,500	02/29/88	20,900	02/29/88	-	-	24,400	02/29/88	1,460	11/18/87	1,450	02/28/88
1989	-	-	226	12/20/88	-	-	81	02/09/89	3,900	02/28/89	1,190	12/16/88
1990	1,200	02/17/90	1,080	02/17/90	-	-	1,150	02/17/90	1,870	02/17/90	766	02/17/90
1991	25,000	03/19/91	29,300	03/19/91	16,300	03/19/91	21,300	03/18/91	6,960	03/01/91	2,670	03/01/91
1992	104,000	02/12/92	73,800	02/12/92	44,000	02/12/92	60,100	02/12/92	12,300	02/12/92	15,300	02/12/92
1993	44,300	02/19/93	40,400	02/19/93	-	-	37,900	02/23/93	10,700	02/18/93	8,280	02/19/93
1994	-	-	2,970	02/20/94	2,590	02/07/94	1,810	02/20/94	-	-	868	02/20/94
1995	-	-	120,000	01/10/95	65,000	01/10/95	70,200	03/10/95	17,100	01/10/95	7,670	01/10/95
1996	17,000	02/20/96	7,500	02/20/96	4,870	02/21/96	4,660	02/20/96	4,450	02/20/96	1,080	02/20/96
1997	20,500	12/22/96	19,100	12/22/96	19,800	12/22/96	22,800	12/22/96	303	03/24/97	2,530	12/22/96
1998	84,000	02/23/98	120,000	02/23/98	62,500	02/03/98	59,500	02/23/98	-	-	15,500	02/22/88
1999	763	04/12/99	376	04/12/99	445	02/09/99	246	04/11/99	277	04/12/99	568	04/12/99
2000	6,370	02/23/00	6,090	02/23/00	4,900	02/23/00	5,420	03/06/00	2,440	02/23/00	1,620	02/21/00
2001	32,900	03/06/01	38,100	03/06/01	25,900	03/06/01	24,700	03/06/01	1,230	03/06/01	16,900	02/16/01
2002	331	11/24/01	478	11/24/01	93	11/24/01	38	11/24/01	729	11/24/01	1,040	11/24/01
2003	13,600	02/12/03	11,900	03/15/03	7,630	02/12/03	6,530	03/15/03	2,330	02/12/03	3,280	02/12/03
2004	19,600	02/26/04	34,300	02/26/04	17,700	02/25/04	28,400	02/26/04	2,640	02/26/04	4,340	02/26/04
2005	136,000	01/10/05	121,000	01/10/05	85,300	01/10/05	78,000	01/10/05	32,000	01/10/05	16,500	02/21/05

b. There is generally good agreement for many events, but significant differences for others. Investigation of the big differences would involve examination of the individual storm rainfall amounts, on a storm-by-storm basis, to assess whether the input rainfall is appropriate. Our recommendations in Section 4.4.1 discuss this further.

c. The big timing differences tend to be for small to moderate events, althought here are exceptions. For example, for Sespe Creek, the observed peak on 1/10/95 is **65,000 cfs** whereas the simulated annual peak of 70,200 cfs occurred on 3/10/95, possibly due to rainfall issues. However, examining the flow simulation on 1/10/95 indicates a simulated peak on that day of **64,200 cfs**, an excellent match with the observed peak.

d. For 1997, ALL the peaks occur on 12/22/96, except for the observed peak at County line which is noted at 3/24/97; the simulated peak at County Line is consistent with the downstream peaks at Sespe and Montalvo. This leads to some questioning of the observed County Line Peak, although it is entirely possible that the storm was concentrated in the lower watershed.

e. For 2001, ALL the peaks are relatively consistent and similar in value except for the simulated peak at County Line; that simulated peak occurs on 2/16/01, and is more than an order of magnitude greater than the observed, whereas all the other peaks occur on 3/06/01. This clearly indicates a rainfall issue, especially since no significant reservoir spill from Castaic occurred that year.

In summary, these results, along with the '% Difference in Peaks' shown in Tables 4.2 and 4.3, indicate a fair to good simulation of individual storm peaks, although significant differences are evident for specific events. The majority of these differences can be attributed to rainfall gage coverage, amounts, and timing issues.

4.4 MODEL PERFORMANCE SUMMARY AND RECOMMENDATIONS

Table 4.15 shows the 'Weight-of-Evidence' (WOE) summary of the model performance metrics for both the calibration and validation periods, discussed above in the previous sections. These values represent the mean and range of the various statistical measures which are presented for each calibration and validation site in Tables 4.2 and 4.3. The last column provides the qualitative assessment of the overall model performance based on how the statistical means and ranges compare to the targets shown and discussed in Section 4.1. In the Simulation Plan and in Section 4.1, we proposed the following:

> ***… for the Santa Clara River watershed modeling effort, we propose that the targets and tolerance ranges for 'Daily' flows should correspond to at least a 'Good' agreement at those sites with good quality flow (and rainfall) data, and those for 'Monthly' flows should correspond to 'Good to Very Good' agreement, for both calibration and validation comparisons.***

Based on the WOE summary shown in Table 4.15, **we conclude that the SCR Watershed Model meets these stated criteria.** Although the model performance for daily flows is rated as **Poor to Very Good**, the lower values are due to calibration statistics for a few sites such as the SCR at Lang gage which had only 3 years of data for calibration, and none for validation, and demonstrated obvious rainfall problems. The validation statistics and ratings shown in Table 4.15 are based on 7 of the 10 validation sites, due to the same issues – mostly short records and non-representative rainfall. For a watershed of this size, over 1,600 square miles, and with some localized issues of data quality for both rainfall and flow, we cannot expect a uniform level of high model performance at all sites. The model performance statistics show a range in model accuracy but the majority of the statistics reflect a **Good to Very Good** overall performance. The **Fair** ratings for the flow duration assessment are primarily for low flow

Table 4.15 'Weight-of-Evidence' for Santa Clara River Watershed Model Performance

	Calibration		Validation*		Overall Model Performance
	mean	range	mean	range	
Runoff Volume, % Δ	2.0	-7.8 /11.8	2.7	-5.8 / 7.0	Good / Very Good
Correlation Coefficient, R:					
- Daily R	0.91	0.74 / 0.96	0.89	0.85 / 0.97	Fair / Very Good
- Monthly R	0.97	0.91 / 0.99	0.97	0.96 / 0.99	Very Good
Coefficient of Determination, R^2:					
- Daily R^2	0.82	0.55 / 0.92	0.80	0.72 / 0.94	Poor / Very Good
- Monthly R^2	0.94	0.82 / 0.99	0.94	0.92 / 0.98	Very Good
Flow-Duration	Good / Very Good		Fair / Good		Fair / Very Good
Water Balance	Good / Very Good		Good / Very Good		Good / Very Good
Storm Events:					
- Daily Storm Peak, % Δ	-6.6	-35.9 / 20.1	-7.6	-13.4 / 9.5	Fair / Very Good
	* -- Based on 7 of 10 validation sites, i.e. excludes validation results at Pole, Hopper, and SCR at Hwy 99; See Tables 4.2 and 4.3.				

conditions, where uncertain ground water contributions have the greatest impact, and the **Poor** ratings for daily, and by extension selected storm hydrographs, are a direct result of rainfall and/or flow issues. In particular, the daily R and R^2 values leading to the **Poor** rating in Table 4.11 are primarily due to the calibration of SCR at Lang, which only had three years of data for calibration and the contributing watershed demonstrated non-representative rainfall problems; thus, leading to the lower values for the correlation statistics in Tables 4.2 and 4.3.

4.4.1 Recommendations

The following areas are provided as suggestions of where the SCR Watershed Model might be improved by addressing some of the issues identified in this modeling effort:

a. Those selected watersheds with identified rainfall and/or streamflow problems should be further investigated, possibly on a storm-by-storm basis, to resolve data issues that contribute to a mismatch between the model and available data. These watersheds include Pole Creek, Hopper Creek, SCR at Lang, and SCR at Hwy 99, which are the most obvious watersheds where improvements might be possible. The SCR at Lang did not have any available flow data during our validation period, but it could be applied and calibrated to an earlier historic period when flow was available before 1977. Other sites and specific events could also benefit from selected storm-by-storm investigations. These investigations would involve assessing supplemental rainfall data from ALERT stations, other nearby rainfall gages, and/or consistency and reliability of the flow records for each storm of concern to establish whether adjustments to the input rainfall data would be justified to improve the model performance for those events. Assessing the flow record would indicate whether measurement errors (or estimations of peak flows) may be contributing to the mis-match of observed values and model results.

b. Additional monitoring, both rainfall and flow, in selected locations would greatly assist and support any future updates to the SCR Watershed Model, and could help to improve the overall calibration. The primary areas of sparse rain gage coverage lie outside the main SCR valley, including the upper/middle Sespe Creek watershed, Upper Piru Creek watershed above Pyramid lake, and the Upper SCR watershed above Highway 99 and Lang. Supplemental flow gages in these same areas would be recommended, in addition to locations above the Pyramid Lake and Castaic lake reservoirs to better define reservoir inflows.

c. With the recent publication of the Draft Report for the Groundwater/Surface-Water Interaction Study (GSWI) (CH2M-Hill, 2008), further investigation of the ground water contributions and losses along the SCR mainstem might be appropriate, especially in the LA County portion of the river. In the current effort, the ground water discharges in this region were derived from limited data/information from the WARMF model, and were extended from the 1990-2000 period to cover combined calibration and validation periods of WYs 1987 – 2005. The GWSI study appears to cover a time period of 1975 – 2005 and may provide more reliable information on ground water discharges and channel losses, especially in the region of the SCR at Hwy 99.

d. Further evaluation of the reservoir simulations is warranted to investigate the cause for the selected ‘phantom’ spills due to rainfall errors, runoff/inflow over-simulations, and/or possible errors (uncertainty) in the data used in the reservoir simulations.

In addition, a number of research-type issues were identified by VCWPD in the Scope of Work, and discussed in the Simulation Plan, but were not fully addressed in this effort due to inadequate data, the rainfall and flow problems noted above, and/or insufficient resources to tackle some of the research issues. Each of these are discussed below along with recommendations for additional efforts that might be pursued.

1. **Potential impacts of changing land use.** Current models do not normally allow continually changing land use conditions, but HSPF has recently been refined to allow an approximate representation of these changing conditions. Unfortunately, the detailed land use/cover data needed to define and impose such dynamic changes within the model (perhaps on an annual basis) was simply not available at the scale of the SCR Watershed. We recommend this be further pursued for a smaller subwatershed, as a pilot study, where such annual coverages might be available, to establish and confirm the modeling approach and identify any technical issues that would need to be addressed at the larger SCR Watershed scale.

2. **Modeling of dynamic groundwater levels.** As noted above, the recent completion of the GWSI Study might provide an opportunity to input more detailed (and hopefully, more accurate) ground water fluxes into the model, especially in the LA County portion of the watershed. Both ground water gains and losses defined by that study could be used in conjunction with approaches used by AQUA TERRA in prior studies, where channel losses are represented as inflows to a 'subsurface reach' (or series of 'reaches') which were then routed to downstream and down-gradient reaches to approximate subsequent discharge to the surface stream. For these 'subsurface' reaches, FTABLES were developed from bed conductivity information, and were actually calibrated to nearby groundwater levels adjacent to the stream. This approach could be adapted to use the GWSI information, but include the dynamic interaction with ground water within the SCR Watershed model. We recommend that this be further investigated as resources allow.

3. **Potential effects of high sediment yields/concentrations on runoff volumes and flow values.** To our knowledge, this issue is not normally considered in watershed models, and we found very little information on which to make a quantitative assessment of such impacts. VCWPD provided adjusted peak flows, for flows above 1,100 cfs, for the Pole Creek Watershed (M. Bandurraga, personal communication, 2007); however, other simulation problems such as the rainfall and flow issues tend to dominate the model differences and especially at the smaller sites, so that any correction of peak flows for high sediment concentrations would not be significant. We recommend that VCWPD re-consider this issue when sediment is simulated as part of the SCR Feasibility Study when sediment concentration data and/or modeled values might be available as a basis for the adjustment.

4. **Hydrologic effects of wildfires.** Current operational watershed models are not capable of accurately representing wildfire impacts on hydrology. A few investigators have, or are attempting to, represent the hydrologic impacts of wildfires (e.g. Earles et al., 2004) but most of these are with single event type models looking at specific storms. A complete assessment of wildfire impacts on the SCR Watershed was not possible as part of this effort due to resources that would have been required for such a detailed evaluation for all parts of the watershed. However, a pilot effort was conducted, as requested by VCWPD, on the Piru Watershed between the outflow from Pyramid Lake and the Piru Creek confluence with the SCR, to assess the potential impacts of the Ranch Fire of 2006. The procedures and approach were as follows:

a. The study area was the incremental drainage area downstream of Pyramid Lake to the Piru Creek confluence with the SCR.
b. Pyramid lake outflows provided the upper boundary condition.
c. The model was run for the calibration period of WY97 to WY05.
d. The Ranch Fire consumed approximately 68% of the drainage area.
e. The model parameter adjustments were as follows:
    1. Reduce interception by 90%
    2. Reduce infiltration by 35% - based on LA Burn Methodology (Willardson and Walden, 2003).
    3. Reduce UZSN (upper zone soil moisture storage) by 50%
    4. Reduce soil ET parameter (LZETP) by 70%
    5. Reduce riparian ET to zero
    6. No changes in lower zone soil moisture storage, LZSN

In brief, the model results showed that the storm peaks at the SCR confluence can increase by up to a factor of 10 times (i.e. an order of magnitude), and the mean annual runoff volume can increase by about 20%. The effects are much greater on the first events of the rainy season, as might be expected, as the later peaks occur with high moisture conditions so most of the response depends more on the rainfall volumes, and less on the soil/land conditions. Similar results were obtained in an analysis of the impacts of the 2006 Day Fire on Sespe Creek, but with smaller relative changes for the more extreme events since those events are controlled more by rainfall volumes and less by soil/vegetation conditions (AQUA TERRA Consultants, 2008). That study showed a 20% - 25% increase in mean annual runoff, under burned conditions, with flood peaks increasing about 10%, for peaks greater than 30,000 cfs, and 25% - 30% for peaks in the range of 10 – 30,000 cfs. An assessment of the burn impacts on a 100-year design storm is shown in Figure 4.24, demonstrating only a projected 5% increase for such an extreme event.

We recommend a pilot type study to pursue the representation of the impacts of the burn conditions on the model calibration and validation. Currently, the model is calibrated to ‘average’ conditions across the watershed, conditions that are static and unchanging in terms of land cover conditions. A pilot study would select one watershed and impose the above type parameter adjustments at the onset of a wildfire, based on available fire records, and then impose a recovery time for each changed parameter, such as is included in the LA County Burn Policy Methodology (Willardson and Walden, 2003) that uses a ‘fire factor’ to adjust selected storm peaks, and notes an approximate 5-year recovery period following a burn event. This would be imposed for each fire that occurred during the simulation period.

In addition, AQUA TERRA is currently performing a research effort to develop and evaluate model algorithm enhancements to represent the impacts of prescribed burning on both hydrology and water quality for the Strategic Environmental Research and Development Program (SERDP), a joint DOD, DOE, and EPA effort. The initial effort is directed to the Fort Benning Army Installation near Columbus GA. The results of this effort should result in an enhanced capability within HSPF to represent fire impacts, and could be applied to the SCR Watershed in future studies.

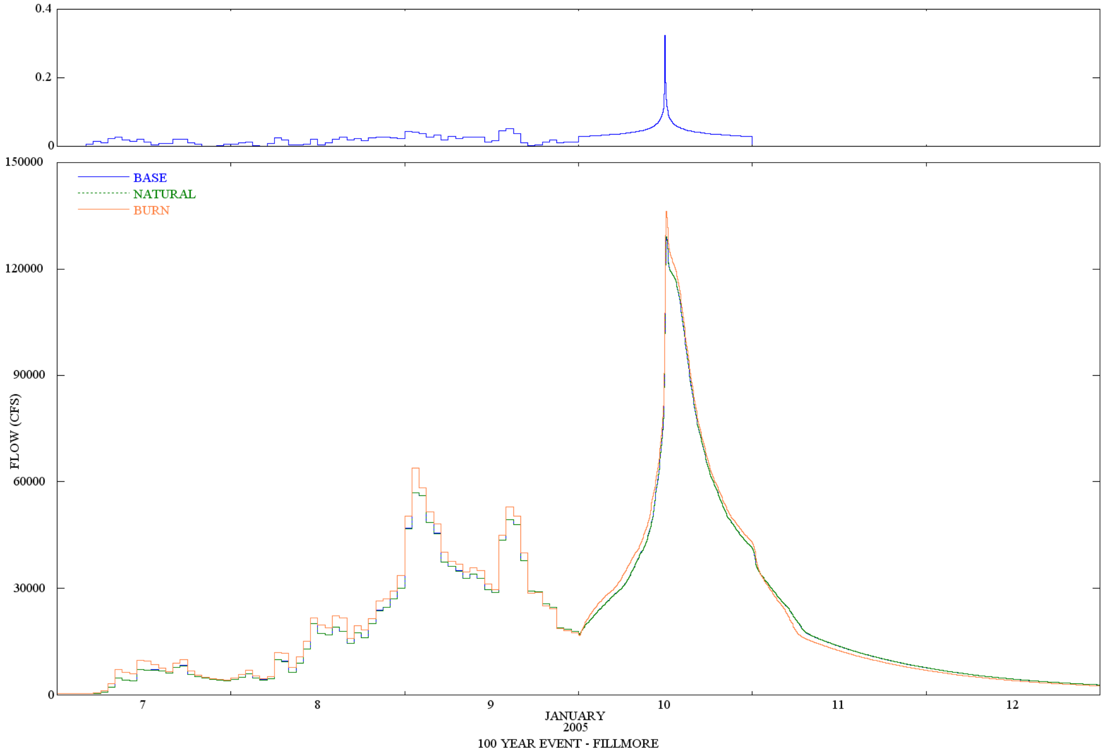


Figure 4.24 Impacts of 2006 Day Fire Conditions on 100-Year Storm on Sespe Creek (at Fillmore)

SECTION 5.0

BASELINE AND NATURAL CONDITIONS SCENARIOS FOR SCR WATERSHED

Both Baseline and Natural Conditions scenarios are required for the SCR Feasibility effort in order to establish a foundation for comparison of impacts of potential future alternative conditions on the watershed. Below we discuss the model changes implemented to allow long term model runs from WY60 through WY05 for both the Baseline Condition and Natural Conditions, followed by the model results for selected SCR mainstem sites.

5.1 MODEL CHANGES FOR BASELINE CONDITIONS

The following changes are implemented in the SCR Watershed model in order to represent **Baseline Conditions** and allow 46-year simulations throughout the watershed:

- Land use conditions used for the calibration period of WY97 to WY05 were used for the Baseline run. Thus **the Baseline run is not representing the actual physical changes in the watershed over that 46-year time period,** but how the watershed would respond to the historic meteorologic conditions if they occurred under the physical conditions represented by the calibration period.

- Model runs were performed for the entire time period from WY60 through WY05

- Model runs were performed as **three (3) separate model runs:** WY60 – WY86, WY87 – WY96, WY97 – WY05. The three runs were required to impose the same land use conditions as during the calibration period, i.e. the validation period was re-run with the land use conditions of the calibration period.

- Precipitation timeseries were extended back to WY60 using the closest station that covered that time period multiplied by the ratio of mean annual values at the two stations.

- Evaporation timeseries were extended back to WY60 based on the Lake Cachuma data and the ratio of the mean annual values for each station.

- Diversions and point sources were extended back to WY60 using mean annual values from the period of available data since their contributions were generally small, except for the Freeman and Piru diversions for which data were available from the McEachron model (2005).

- Ground water gains and losses were extended back based on mean monthly values obtained from the calibration and validation time periods.

5.1.1 Reservoir Representation in Baseline Run

The reservoir simulation methodology described above (Section 4.3.5) was used for the calibration and validation runs since the major database of storages, inflows, and outflows for Pyramid, Castaic, Elderberry, and Castaic lagoon covers the time span of those simulations. However, for the long term Baseline run (1959-2005), this procedure was modified to account for the absence of data from the SWP for these reservoirs prior to 1987. This run was also performed in **three** parts: the period from 1959 – 1987, the validation period (1987 – 1996), and the calibration period (1997-2005) because of the different procedures used to simulate the reservoirs, and precipitation gage changes for the earlier time period.

For the portion of this run prior to 1988, a simplified set of reservoir outflow time series was developed based entirely on the simulated natural inflows. It is important to remember that this run is NOT attempting to duplicate the historic flows during this time period, but how the watershed would respond if the historic meteorologic conditions occurred with the watershed reflecting the physical conditions of the calibration period. **In some cases, such as for Pyramid and Castaic, the reservoirs were built and came online during this time period; the model does not reflect conditions prior to reservoir construction and operation.**

In addition, no water imports from the SWP were modeled as these are essentially routed through the watershed with little impact on SCR main stem and peak flows. This period was simulated using the following additional assumptions that are based on discussions with UWCD (McEachron, personal communication, 2007):

- The basic operational concepts for Castaic are those that are in effect at the current time, i.e., natural inflows are generally released immediately except for high flows (> 100 cfs), which are retained until major downstream water users request their release. If the flows are not needed for downstream use, and no request occurs within several days, the water is appropriated by the SWP for delivery to external water suppliers.

- The specifics of the Castaic operation are: outflows were set equal to inflows when less than 200 ac-ft/day; between 200 and 4,000 ac-ft/day, 200 ac-ft/day were released, and the remainder was released over a five day period starting 10 days after the inflow. When inflows were greater than 4,000 ac-ft/day, half of the inflow was released immediately, and the other half was appropriated by the SWP and removed from the system (i.e., delivered to water users).

- Pyramid Lake outflows were set equal to natural inflows for all inflows less than 8,000 ac-ft/day. If inflows were greater than 8,000 ac-ft/day, half was released and the remainder was appropriated by the SWP.

- Lake Piru operation was the same as for the calibration/validation periods; historical release data were available for the entire period.

- Bouquet Reservoir outflows for the period 1959-1979 were the same as historical releases over the 1980-2006 period, i.e., 1 cfs for April - September and 5 cfs for October – March.

- For Elderberry Forebay and Castaic Lagoon, outflows were set equal to inflows.

5.2 MODEL CHANGES FOR THE NATURAL CONDITIONS SCENARIO

To represent natural, or pre-development, conditions on the SCR Watershed, we implemented changes that attempt to remove all the human impacts on the watershed hydrologic response, and represent how the watershed may have responded prior to all development. Thus, the following changes to the Baseline model setup were implemented:

- Remove all irrigation inputs for both urban and agricultural landscape watering.
- Eliminate all impervious areas, which will be reassigned to pervious land categories with associated pervious land parameter values.
- Current Baseline model land use categories are as follows:
    - Forest/Wooded
    - Shrub/Scrub
    - Open/Grass
    - Agriculture
    - Low Density Residential
    - Medium Density Residential
    - High Density Residential
    - Commercial/Industrial

    - For the Natural Conditions run, we distributed all the agriculture and urban land into the three undeveloped categories - Forest/Wooded, Shrub/Scrub, Open/Grass – based on the relative proportion of these categories within each model reach subbasin, i.e. the area draining to each of the 209 model reaches. Performing this conversion at this small scale will provide the best approximation to undeveloped or natural conditions on the watershed. Thus the converted land uses the parameters for the undeveloped categories within each subbasin.
- Remove all reservoirs and water imports/diversions included within the Baseline setup, including removal of Castaic, Pyramid, Piru, and Bouquet reservoirs, and elimination of the Freeman Diversion, and replace with free-flowing stream reaches.
- Eliminate all point sources currently discharging in the watershed.
- Regarding groundwater gains/losses, the Baseline model currently includes channel losses to groundwater, for selected stream reaches, as a function of flow depth within each reach, i.e. the loss is calculated by the model as a 'pseudo-diversion' so that it can be summed and evaluated. Ground water gains are input as timeseries from the McEachron Model and WARMF. We have included these in the Natural Conditions as they represent natural processes and, in any case, will likely have little impact on flood peak values.

5.3 MODEL RESULTS FOR BASELINE AND NATURAL SCENARIOS

There are a variety of ways in which to analyze and compare model output for such an extensive and comprehensive model covering an area of almost 1600 square miles with hundreds of stream reaches, land segments, and subwatersheds. In this section we focus on selected sites on the SCR mainstem to demonstrate the changes that have been imposed by development within the overall watershed. Similar analyses, and other types of comparisons can be performed, as needed, by the Study Partners for other sites and tributary watersheds as the SCR Feasibility Study moves forward. In addition, the model can be used to project the impacts of other changes, including alternative development scenarios, climate change scenarios, and water resources management practices.

The comparisons included here are focused on the impacts on the flow duration (FD) curves and flood frequency analyses for selected mainstem sites. Figures 5.1 and 5.2 show flow duration curves for six sites along the mainstem. It begins with the upper reaches near Saugus, to the County Line area, to the confluences with Piru Creek and Sespe Creek, and ultimately finishes with the last gaging site near Montalvo. Thus the results are presented in a logical upstream to downstream order to help visualize the impacts as one travels with the river flow. These results demonstrate the following:

1. The differences in the FD curves consistently show the higher flow rates for the Baseline condition as compared to the Natural condition, primarily due to the influence of irrigation practices, point sources, and reservoir impacts. Clearly the water imports and use within the watershed have increased overall flow rates, and especially baseflow levels below about 100 cfs.

2. The impacts of reservoir storage are shown in Figure 5.2, below the Piru Creek confluence (top curves) where the high flow rates, above about 200 cfs, are lower for the Baseline Condition than the Natural Condition. The large fraction of the Piru Creek tributary controlled by the reservoirs results in the reduced high flows. The same differences are shown further downstream, below Sespe and at Montalvo, although the relative reduction is diminished.

3. The FD curves also demonstrate the impacts of the Dry Gap area, running from near the County Line to above the Sespe confluence. The FD curves show continuous flow for the Baseline Condition extending from the County Line (Figure 5.1) to below Piru (Figure 5.2), but mostly ephemeral conditions from Piru to below the Sespe confluence.

4. At Montalvo, the FD curves are reversed, especially below about 1000 cfs, with the Natural Condition showing higher flows than Baseline. This is mostly due to the Freeman Diversion that was extracted above the gage until about 2005.

Figures 5.3 through 5.5 show annual flood peaks on normal probability scales to identify flood frequencies and return intervals for five SCR mainstem sites, for both Baseline and Natural Conditions. For comparison purposes, the County Line (Figure 5.3) and Montalvo plots (Figure 5.5) also show the observed annual flood peaks for the available period of record, which extends close to 70 years. These differences in flood peaks demonstrate behavior similar to the FD curves, as follows:

1. In Figure 5.3, the differences at Saugus (Top Graph) show the changes brought by urban development, a clear downward displacement of the flood peaks at all return intervals. This region above the Saugus (Old Highway 99) gage has the highest urban

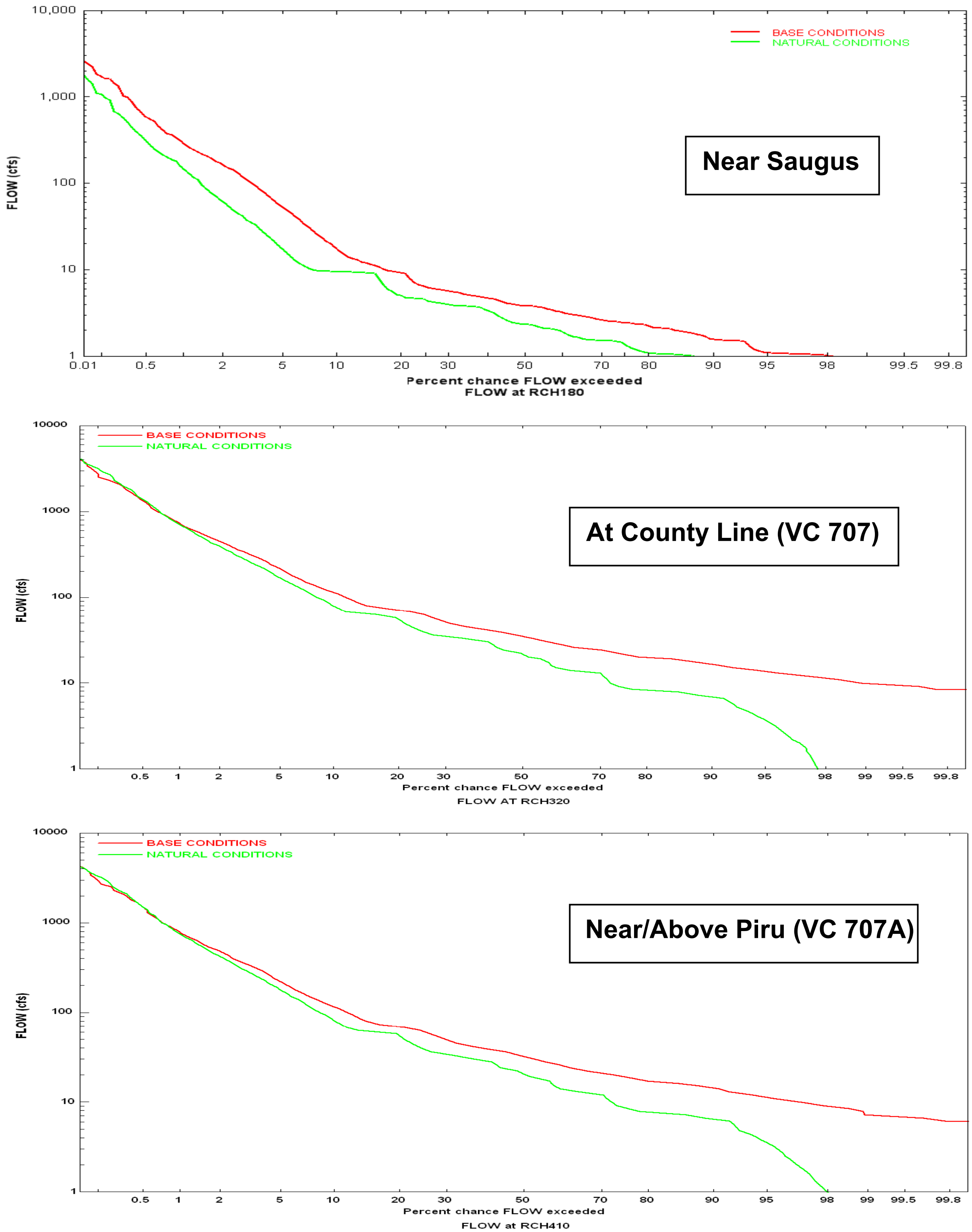


Figure 5.1 Flow Durations Curves for SCR Mainstem near Saugus (Top), at County Line (Middle), and near/above Piru (Bottom)

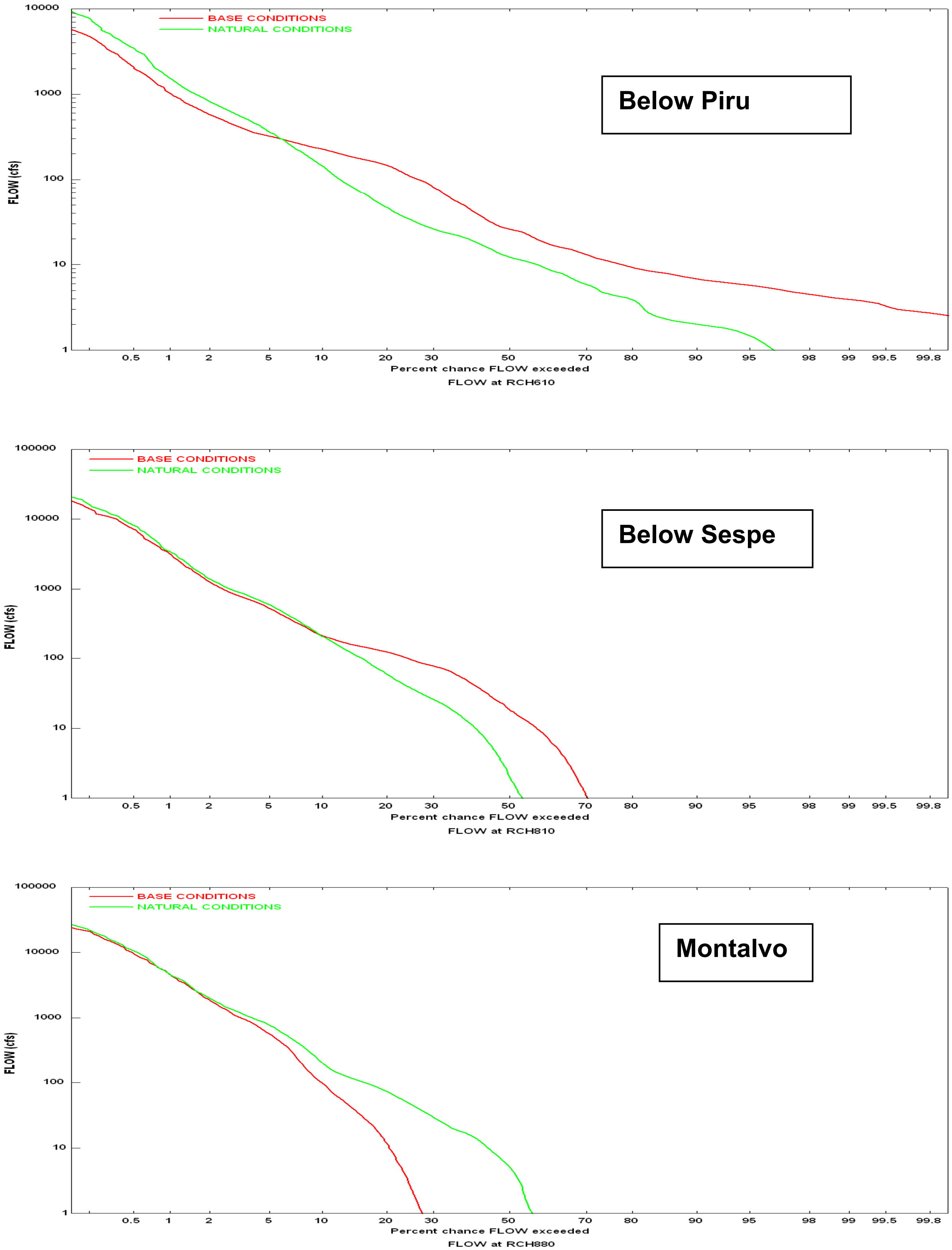


Figure 5.2 Flow Durations Curves for SCR Mainstem below Piru (Top), Below Sespe (Middle), and at Montalvo (Bottom)

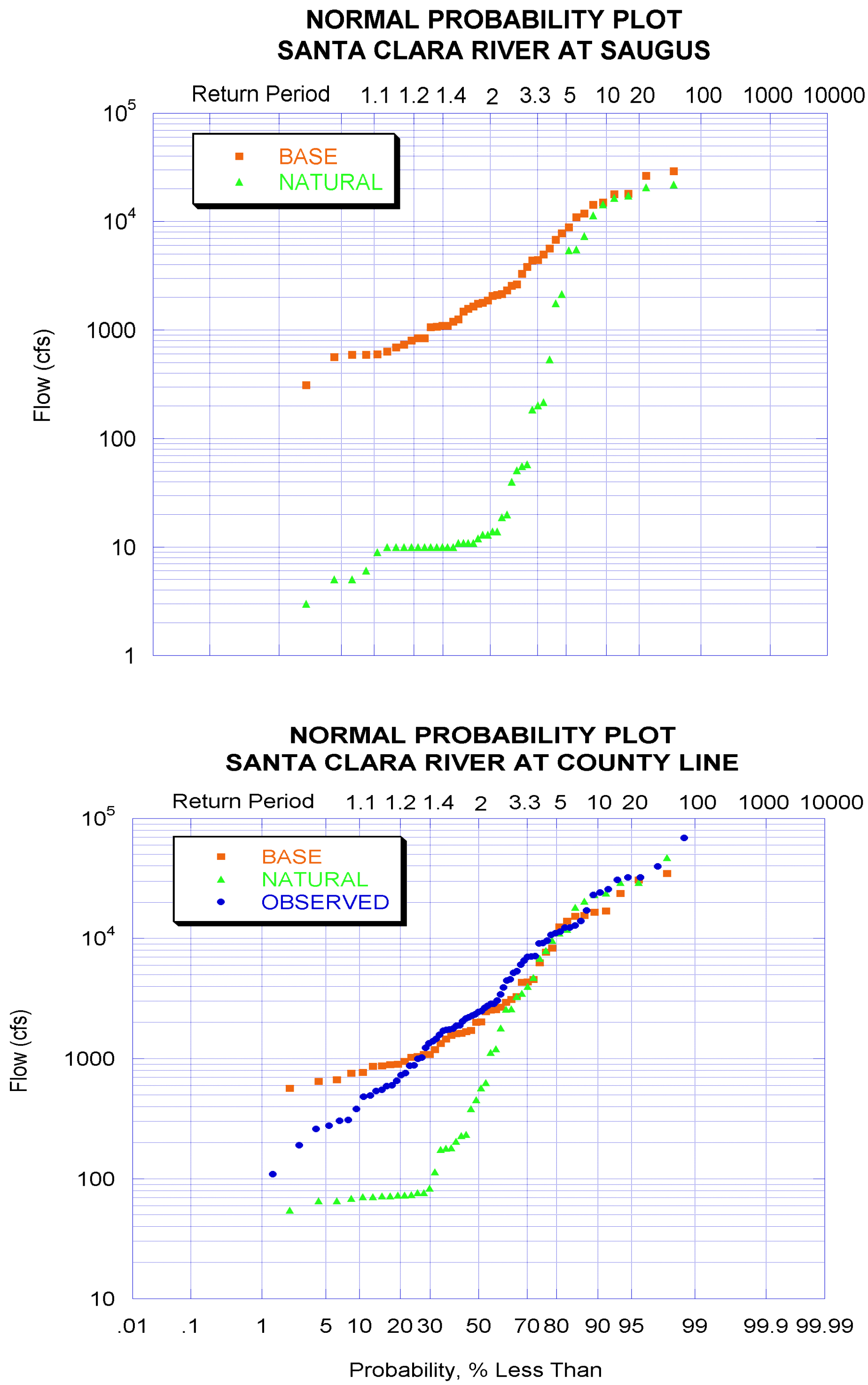
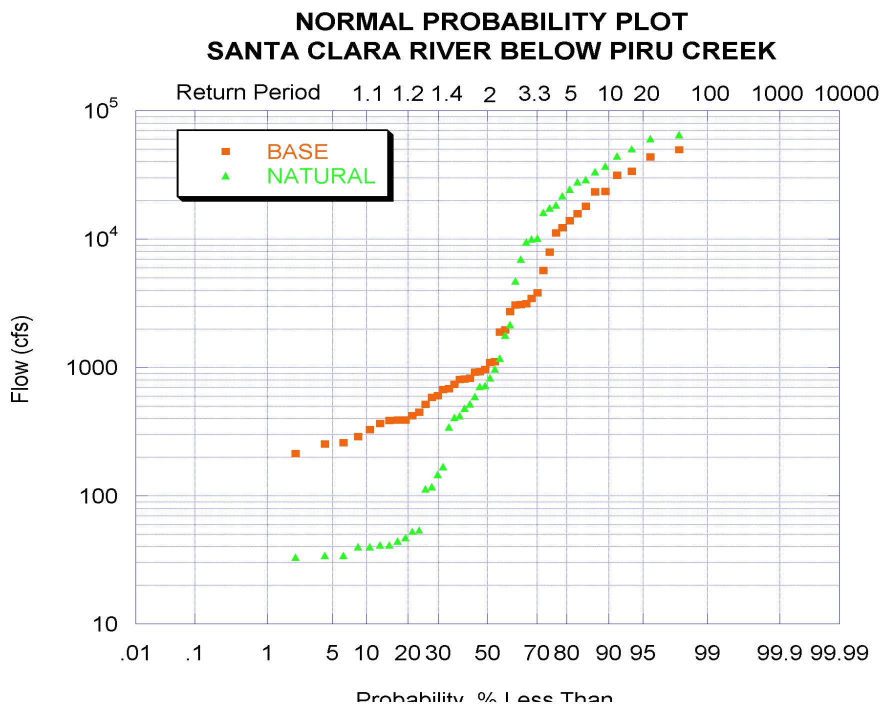


Figure 5.3 Baseline and Natural Condition Flood Peak Frequencies for SCR Mainstem at Saugus (Top) and County Line (Bottom)



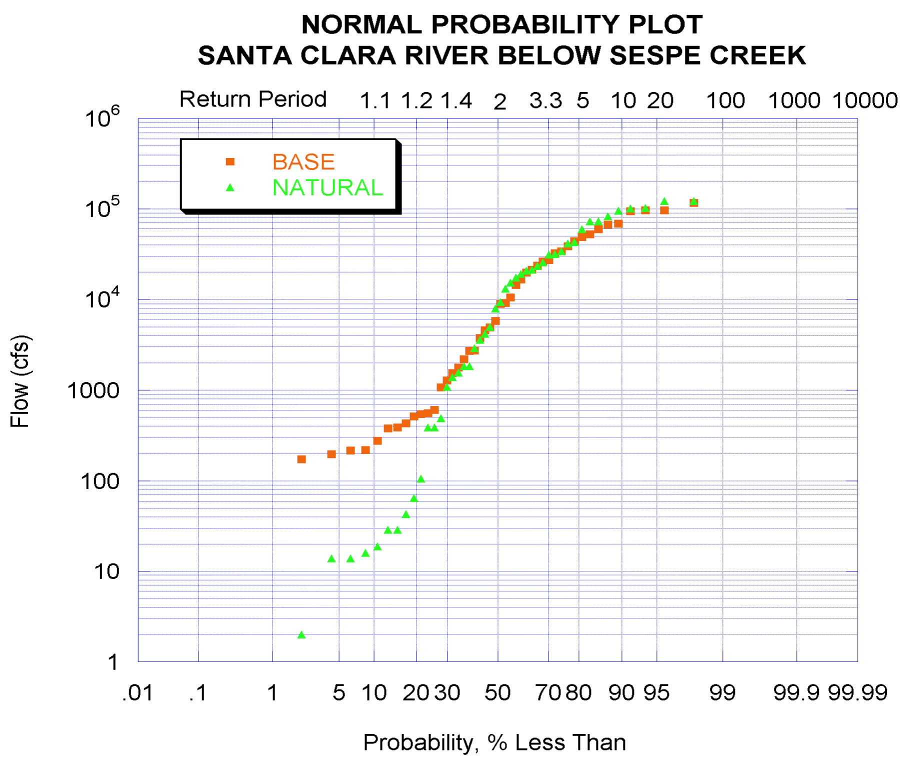


Figure 5.4 Baseline and Natural Condition Flood Peak Frequencies for SCR Mainstem Below Piru (Top) and Below Sespe (Bottom)

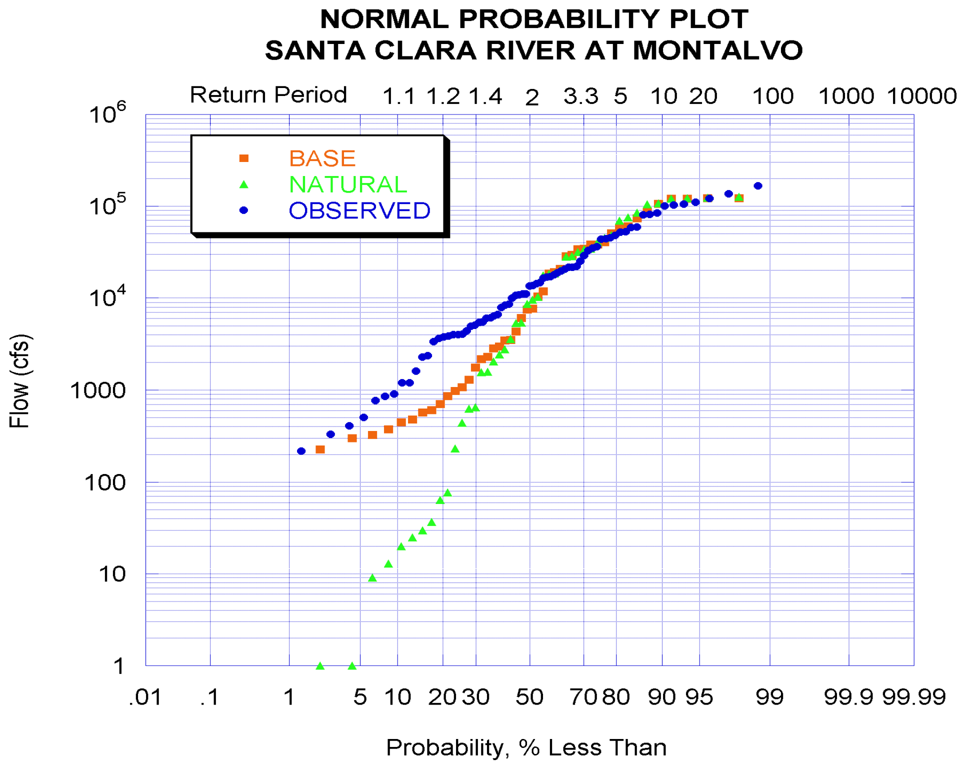


Figure 5.5 Baseline and Natural Condition Flood Peak Frequencies for SCR Mainstem at Montalvo

of any region of the entire SCR Watershed. The urban and agricultural area comprises 18% of the region, and conversion of this to Natural Conditions, along with elimination of point sources, produces the dramatic differences seen in Figure 5.3 especially at the more frequent flood peaks, less than about 5 – 10 year return intervals.

2. The flood peaks at County Line (Bottom Curve in Figure 5.3) also show the lower flood peaks, below about 2 – 3 year events, for the Natural Conditions, but with some reduced high flood peaks likely due to the added Castaic reservoir storage upstream of this site.

3. The Observed flood peaks in Figure 5.3 demonstrate reasonable agreement with the Baseline Conditions above the 1.4 year return interval. Below this level, for relatively low (or dry year) flood peaks, the model Baseline and Observed diverge with the model predicting higher flood peaks. This is likely a combination of rainfall issues, with more spatial variability in rainfall during relatively dry years, and associated problems in rainfall representation in the model; for relatively wet years and the resulting high peak flood flows, rainfall is generally more uniform and thus better represented by the gages used in the model and the agreement is better for these wet years.

4. At the SCR mainstem site below the Piru confluence (Figure 5.4, Top Graph), the two curves cross at about the 2 – 3 year return interval, demonstrating the traditional impacts of reservoir storage (both Castaic and Pyramid-Piru) with reduced flood peak flows.

5. At the SCR mainstem site below Sespe (Figure 5.4 Bottom Graph), the same impacts are shown as for the Below Piru site except the differences are reduced due to the effects of the primarily natural inflows from Sespe Creek.

6. At Montalvo (Figure 5.5), the Baseline and Natural Conditions curves demonstrate the same general behavior as shown at the other mainstem sites but with some dampening due to channel losses, surface-groundwater interactions, and water diversions and point sources. Those two curves appear to essentially match above the 1.5 – 2 year return interval, and diverge below that level. The Observed flood peaks also show reasonably good agreement above the 2-year return interval, but with big differences below that level. This is likely due to a number of factors, including representation of channel losses, surface-groundwater interactions, and increased variability of rainfall coverage in the model for these relatively dry years (as noted above).

7. The differences in the flood frequency curves at the lower flood peak values are one of the main reasons an alternate approach was selected for the Design Storm development. Due to concerns related to the accuracy of selected rainfall records during the historic period (i.e. prior to the validation year starting in 1987), the impacts of these records on simulated annual flood peaks at selected sites, and the reliability of the use of the Log Pearson Type III analyses to estimate extreme events (e.g., 100-year flood peaks) in Southern California, both VCWPD and LACDPW developed an alternate approach for design storm development.

   The calibrated Santa Clara HSPF model was used as the basis for generating design storm peaks and hydrographs for use in the hydraulic modeling portion of the study. The approach involved identifying a storm where saturation levels were very high across the model domain and then applying balanced design storm hyetographs for the 100-yr storm for each rain gage used in the HSPF model. The gaged tributaries with long-term records were used as calibration points in the modeling. The calibration was done by adjusting the rainfall factors applied to the rain data for each subarea and associated reach at the calibration points to establish corresponding rainfall factors that could then be applied to the ungaged tributaries. The HSPF model was then run with the appropriate rainfall distributions at 5-min timesteps for the storm of interest to provide 100-year design storm peaks at the ungaged tributaries. The 100-year peaks were converted to other return intervals of interest by using multipliers developed from flow frequency analyses of long-term Ventura County and Los Angeles County stream gages. This work was performed cooperatively by both agencies and AQUA TERRA Consultants as a contract modification to the original HSPF modeling effort. The results of these efforts are described in Appendices L (VCWPD) and M (LACDPW), respectively.

In summary, both the FD and flood peak frequency comparisons demonstrate that the SCR HSPF Watershed model provides a logical and reasonable tool for evaluating potential changes and management alternatives for the SCR Watershed. In combination with the Weight-of-Evidence results for the calibration and validation, along with the Design Storm efforts (Appendices L and M), the model has shown to be a robust representation of the hydrologic regime and behavior of the watershed. Although no model is perfect, and some improvements are recommended (as noted in Section 4.4.1), the SCR HSPF Watershed model is a viable tool and can supply the information needed for the SCR Feasibility Study.

SECTION 6.0

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