Baseline Model Calibration and Validation Report

Ventura River Watershed Hydrology Model

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July 21, 2009

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Executive Summary

The Ventura County Watershed Protection District has sponsored the development of a watershed simulation model for the Ventura River, funded under a Proposition 50 grant. The simulation model is a mathematical representation of the land area, land management, stream reaches, reservoirs, and water diversions within the watershed. The simulation model converts precipitation time series and other weather inputs into predictions of flow throughout the watershed at a 15-minute time step. It can be used to support water availability and storm flow analyses, and will also support future water quality simulation.

The Ventura River watershed model is developed using the Hydrological Simulation Program – FORTRAN or HSPF, a comprehensive flow and water quality simulation model supported by the U.S. Environmental Protection Agency and the U.S. Geological Survey. The model represents 228 square miles of land area and 94 individual stream reaches, covering the entire area of the Ventura River watershed. The model also represents land use change over time, including the impacts of major fires.

This report documents the development, calibration, and validation of the watershed model for existing baseline conditions. Calibration is the process of adjusting model input parameters to obtain a fit to observed data. A validation test is then applied to a second set of data to test the performance of the model. Model calibration was conducted for the period from October 1996 through September 2006, while validation tests were done on the period from October 1986 through September 1995. A longer period, beginning in October 1967, was then simulated to evaluate model prediction of extreme high flow events. In all, the model is calibrated to seven different continuous flow monitoring gages, with peak storm event information from four additional gages. The model also represents land use change over time, including the impacts of major fires.

Calibration of the model is complete and validation was successful. In general, the model performs well in reproducing all aspects of the water balance and replicating gaged flows, although some discrepancies appear to be associated with the gage record at certain sites. The model also provides good to excellent representation of high flow events at most locations.

At this time, the simulation model is judged fully ready for use in scenario evaluation for flow prediction and analysis. Water quality simulation is proposed to be added to the model in a future phase.

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1 Introduction

The Ventura River watershed is primarily located in western Ventura County with a small portion in southeastern Santa Barbara County, CA (Figure 1-1). The watershed drains an area of about 228 square miles. Lowland portions contain urban development and agriculture (including citrus, orchards, avocado, and pasture), while the upper 50 percent of the watershed is in the steep, undeveloped terrain of the Los Padres National Forest. The Ventura River has several major tributaries including Matilija Creek, North Fork Matilija Creek, San Antonio Creek and Canada Larga, and also contains Lake Casitas, which serves as the primary water supply for the area within the watershed.

The Ventura County Watershed Protection District (VCWPD) contracted with Tetra Tech to develop a hydrologic model for the Ventura River watershed, using EPA's Hydrologic Simulation Program – FORTRAN (HSPF) model. The work, funded under a Proposition 50 grant, will result in the completion of a Baseline (existing condition) hydrologic simulation as well as a Natural Condition scenario. These model runs can be used to support a variety of water availability and storm flow analyses. In addition, the hydrologic model will provide a platform for future modeling of water quality constituents in the Ventura River.

1.1 Scope of this Report

A data report that summarized the background information and available data for the model was previously developed by Tetra Tech and submitted to VCWPD (*Data Summary Report, Ventura River Watershed Hydrology Model*, 9 May 2008). Building on the data report, Tetra Tech submitted a revised simulation plan on 13 August 2008. The simulation plan served as the draft modeling Work Plan and Quality Assurance Project Plan (QAPP) for model calibration and validation and described the proposed approach to applying the HSPF model to the Ventura River watershed.

This report, which is the third in the series, covers model calibration and validation. The three reports are cumulative, rather than independent: That is, the calibration and validation report is designed as a standalone document that incorporates relevant material contained in the two earlier reports, with relevant changes as necessary.

1.2 Role of Model Calibration and Validation

Environmental simulation models are simplified mathematical representations of complex real world systems. Models cannot accurately depict the multitude of processes occurring at all physical and temporal scales. Models can, however, make use of known interrelationships among variables to predict how a given quantity or variable would change in response to a change in an interdependent variable or forcing function. In this way, models can be useful frameworks for investigations of how a system would likely respond to a perturbation from its current state. To provide a credible basis for prediction and the evaluation of mitigation options, the ability of the model to represent real world conditions should be demonstrated through a process of model calibration and validation.

USEPA (2002) recommends following a systematic planning process to define quality objectives and performance criteria. For modeling projects, systematic planning identifies the expected outcome of the modeling, its technical goals, cost and schedule, and the criteria for determining whether the inputs and outputs of the various intermediate stages of the project, as well as the project's final product, are acceptable.

The primary objective of this work is to support VCWPD's analysis of hydrologic conditions in the Ventura River watershed, including both water availability and storm flow analyses. The simulation model should also provide a platform for future simulation of water quality. The quality objectives for this project are thus to provide accurate and defensible estimates of (1) the full water balance in the Ventura River watershed across the full range of flow and meteorological conditions, and (2) the hydrology low-recurrence, high flow events used for flood planning, while also supporting extension to water quality simulation. To accomplish these objectives, the model must simulate all the components of the water balance, while providing particular focus on high flow events. However, support for future water quality simulation will require accurate simulation of the full range of hydrologic conditions present in the watershed.

1.2.1 Objectives of Model Calibration Activities

The principal study questions for this phase of model development address the movement of water throughout the watershed. The model should support analyses of existing conditions, natural baseline conditions, and potential future conditions with and without management interventions; however, calibration will, of necessity, focus on model representation of current and recent observed conditions.

Calibration consists of the process of adjusting model parameters to provide a match to observed conditions. Calibration is necessary because of the semi-empirical nature of water quality models. Although these models are formulated from mass balance principles, most of the kinetic descriptions in the models are empirically derived. These empirical derivations contain a number of coefficients that are usually determined by calibration to data collected in the waterbody of interest.

Calibration tunes the models to represent conditions appropriate to the waterbody and watershed under study. However, calibration alone is not sufficient to assess the predictive capability of the model, or to determine whether the model developed via calibration contains a valid representation of cause and effect relationships, especially those associated with the principal study questions. To help determine the adequacy of the calibration and to evaluate the uncertainty associated with the calibration, the model is subjected to a validation step. In the validation step, the model is applied to a set of data independent from that used in calibration.

1.2.2 Hydrologic Validation Procedures

After the model is adequately calibrated, the quality of the calibration is evaluated through validation tests on separate data. This helps to ensure that the calibration is robust, and that the quality of the calibration is not an artifact of over-fitting to a specific set of observations, which can occur due to the persistence of the impacts of high-precipitation events on water storage in the model. Validation also provides a direct measure of the degree of uncertainty that may be expected when the model is applied to conditions outside of the calibration series.

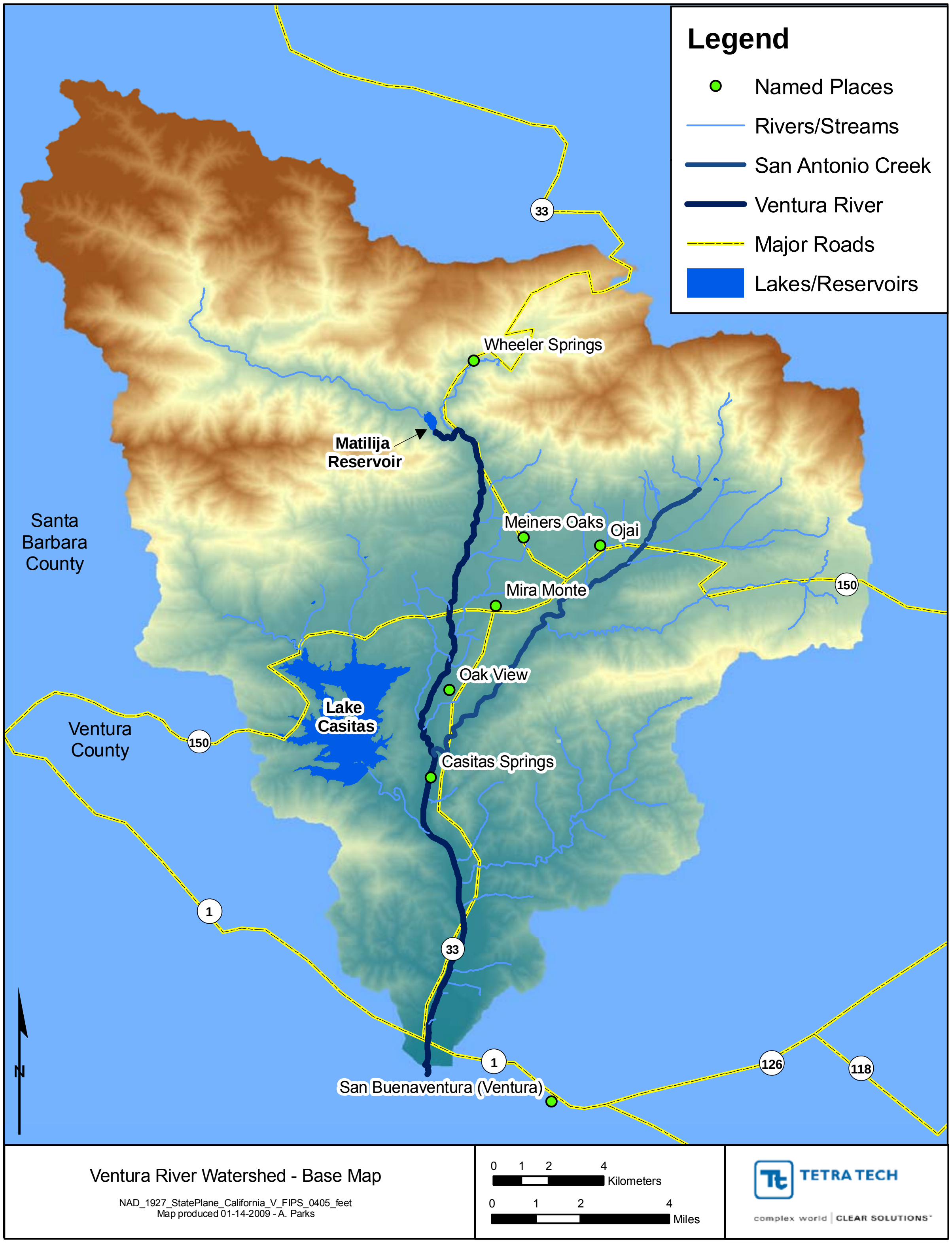

Figure 1-1. The Ventura River Watershed

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2 Meteorology

Successful hydrologic modeling depends on an accurate representation of the overall water balance. The two largest terms in the water balance are typically precipitation input and evapotranspiration output. Precipitation is specified as a direct external forcing to the model, while actual evapotranspiration is simulated as a function of potential evapotranspiration, wind, air temperature, and solar radiation. Together, these constitute the external meteorological time series needed to drive the model.

The accuracy of a hydrologic model is limited by the accuracy of the meteorological time series. In most cases, precipitation and evaporation data are the most hydrologically sensitive and spatially variable datasets used in watershed modeling; therefore having a complete quality-controlled continuous set of these data benefits the modeling effort. A major and crucial early effort for model development is thus assembly and processing of meteorology. This presents several challenges. First, precipitation data are typically available as point-in-space measurements, rather than integrated totals over subwatershed areas. Second, precipitation, temperature, and other meteorological series typically show strong spatial gradients in response to elevation (orographic effects) and aspect.

2.1 Data Sources

There are two major data sources of locally observed weather data: (1) the Ventura County Watershed Protection District (VCWPD) weather monitoring network, including both regular monitoring and ALERT flood warning monitoring stations, and (2) National Climatic Data Center (NCDC). The VCWPD weather datasets provided a relatively dense network of rainfall monitoring sites with daily, hourly, and 15-minute observations, as well as pan evaporation measurements at key locations in the watershed. The NCDC weather gages provided daily and hourly precipitation observations. In addition, data collected at the Ojai Remote Automated Weather Station (RAWS) maintained by the California Data Exchange Center (CDEC) were determined to be useful to extend coverage.

2.1.1 Precipitation

Rainfall gauging is available at multiple locations in and near the Ventura River watershed (Figure 2-1) Detailed summaries of the daily VCWPD precipitation data, sub-daily VCWPD precipitation data, NCDC precipitation data, and the ALERT stations determined to be potentially useful for the model are summarized in Table 2-1 through Table 2-4. Table 2-2 summarizes the sub-daily precipitation data provided by VCWPD. In addition to the VCWPD sites, this contains records from two NWS sites (Matilija Dam and Pine Mountain Inn) that had been processed, checked, and formatted with QA flags to match VCWPD datasets. Data not processed by VCWPD (Table 2-3 and Table 2-4) were processed in the same way as VCWPD data: missing data were patched with nearby stations using the normal ratio method, and accumulated records were disaggregated using nearby sub-daily stations

Final selection of precipitation gages attempted to avoid stations with large amounts of missing data or other QA problems while assuring good spatial representation. The assignment of precipitation stations to the model is discussed in Section 3.8. Gages with prefix A are ALERT stations: those with prefix S are ALERT storage gages for long-term totals (not used in model).

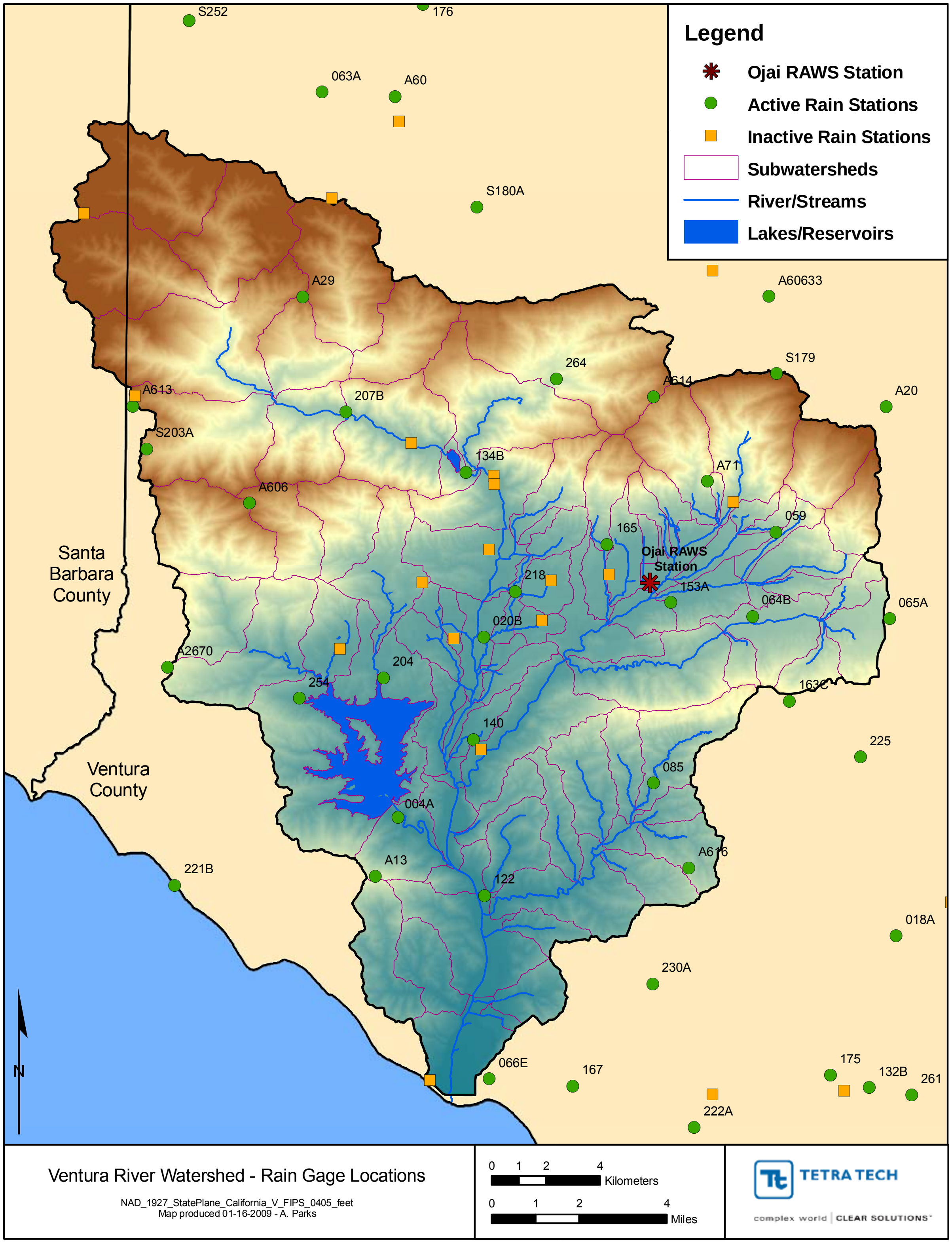

Figure 2-1. Precipitation Station Locations for the Ventura River Watershed

Table 2-1. Inventory of Daily VCWPD Precipitation Data with 20 Water-Year Summary (10/1/1987 – 9/30/2007)

Station Name	Station ID	Elevation (ft)	Data Collection Period		Percent Missing 1987-2007	Percent Estimated 1987-2007	Precipitation (in/yr)	
			Start	End			Measured	Processed
Casitas Dam	D004	400	9/30/1927	9/23/2007	0.3%	4.2%	24.1	25.4
Ventura River County Water District	D020	650	9/30/1925	9/23/2007	0.4%	12.8%	23.0	23.0
Ojai-County Fire Station	D030	900	9/30/1905	9/23/2007	0.2%	1.1%	22.3	22.3
Santa Ana Valley-Selby Ranch	D044	660	9/29/1927	6/5/1993	71.9%	-	7.1	24.3
Ojai-Thacher School	D059	1,440	9/30/1915	9/23/2007	0.2%	24.2%	20.7	20.7
Upper Ojai-Happy Valley	D064	1,250	9/29/1900	9/23/2007	0.2%	1.0%	24.0	24.0
Upper Ojai Summit-County Fire Station	D065	1,560	9/30/1924	9/23/2007	0.2%	4.7%	26.6	26.6
Ventura-Downtown (Courthouse)	D066	40	9/30/1872	9/23/2007	0.2%	0.2%	16.9	16.9
Canada Larga	D085	760	6/29/1934	9/23/2007	0.2%	2.1%	22.9	23.3
Sheldon Ranch-Matilija Canyon	D107	950	9/30/1930	6/7/1948	100.0%	-	0.0	26.2
Ventura-Kingston Reservoir	D122	215	9/30/1934	9/23/2007	0.2%	2.1%	20.7	20.8
Matilija Dam	D134	1,020	9/30/1948	9/23/2007	0.2%	6.2%	29.3	30.5
Oak View-County Fire Station	D140	520	9/29/1949	9/23/2007	0.2%	1.4%	22.9	22.9
Piedra Blanca Guard Station	D152	3,065	9/29/1949	9/25/2007	0.2%	5.3%	25.5	26.3
Ojai-Bower Tree Farm	D153	800	9/30/1949	9/23/2007	0.3%	11.6%	21.9	23.2
Sulphur Mountain	D163	2,570	9/30/1956	2/3/2008	0.3%	6.7%	26.4	27.9
Ojai-Stewart Canyon	D165	960	9/29/1956	12/27/2006	3.9%	0.7%	22.0	22.3
Ventura-Hall Canyon	D167	180	9/29/1956	9/23/2007	0.2%	4.7%	17.3	17.6
Lake Casitas-Upper	D204	600	9/30/1959	9/23/2007	0.4%	2.6%	23.1	24.5
Matilija Canyon	D207	1,540	9/29/1959	9/23/2007	0.2%	0.5%	36.0	36.4
Meiners Oaks-County Fire Station	D218	730	9/30/1964	9/23/2007	0.3%	6.1%	23.9	24.4

Station Name	Station ID	Elevation (ft)	Data Collection Period		Percent Missing 1987-2007	Percent Estimated 1987-2007	Precipitation (in/yr)	
			Start	End			Measured	Processed
Sea Cliff - County Fire Station	D221	50	5/30/1966	9/23/2007	0.3%	0.3%	16.1	16.2
Wheeler Canyon	D225	900	6/29/1966	9/23/2007	0.3%	2.0%	23.0	23.9
Ventura-Sexton Canyon	D230	880	9/29/1971	9/23/2007	0.2%	0.9%	20.8	20.9
Casitas Station - Station Canyon	D254	630	8/30/1979	9/23/2007	0.3%	0.2%	25.2	25.6
Oak View-Raap	D258	520	9/29/1981	7/13/1992	76.2%	2.2%	4.2	21.9
Ventura-Emma Wood State Bch	D260	15	9/29/1982	6/17/1995	61.6%	3.2%	5.7	17.5
Wheeler Gorge	D264	1,900	9/29/1982	9/25/2007	0.2%	2.9%	30.7	31.2

Table 2-2. Inventory of Hourly ("H") and 15-Minute ("F") Precipitation Data Supplied by VCWPD with 20 Water-Year Summary (10/1/1987 – 9/30/2007)

Station Name	Station ID	Elevation (ft)	Data Collection Period		Percent Missing 1987-2007	Percent Estimated 1987-2007	Precipitation (in/yr)	
			Start	End			Measured	Processed
Ojai-County Fire Station	H030	760	6/12/2000	9/22/2007	63.6%	-	7.2	20.9
Santa Ana Valley-Selby Ranch	F044	660	11/26/1956	6/7/1993	71.9%	-	7.1	27.8
Ojai-Thacher School	F059	1,440	10/29/2001	9/22/2007	70.5%	-	6.5	23.2
Upper Ojai-Happy Valley	F064	1,320	12/5/1979	9/22/2007	0.2%	0.01%	23.9	23.9
Ventura-Downtown (Courthouse)	F066	120	10/1/2000	9/22/2007	65.4%	-	6.1	17.6
Canada Larga	F085	760	11/16/1966	9/22/2007	0.2%	-	23.3	23.3
Oak View-County Fire Station	F140	520	11/16/1992	9/22/2007	25.7%	0.01%	18.2	23.3
Piedra Blanca Guard Station	F152	3,065	4/20/1959	9/24/2007	0.2%	-	26.2	26.2
Sulphur Mountain	F163	2,680	3/24/1989	9/22/2007	7.5%	2.5%	24.8	28.1
Ojai-Stewart Canyon	F165	960	10/3/1956	9/22/2007	0.2%	-	22.3	22.3
Ventura-Hall Canyon	F167	180	12/3/1956	9/22/2007	0.2%	-	17.6	17.6
Matilija Canyon	F207	1,540	12/17/1959	9/22/2007	0.2%	0.04%	35.7	36.4
Sea Cliff - County Fire Station	F221	50	5/18/1966	9/22/2007	0.3%	0.003%	16.1	16.2
Wheeler Canyon	F225	900	9/3/1966	9/22/2007	0.3%	0.01%	23.4	23.9
Ventura-Sexton Canyon	F230	880	1/31/1972	9/22/2007	0.2%	-	20.9	20.9
Matilija Dam Weather Station NWS	F236	1,060	5/3/1971	5/1/2007	9.1%	-	28.2	29.7
Casitas Station - Station Canyon	F254	630	9/20/1979	9/22/2007	0.3%	0.01%	25.2	25.6
Oak View-Raap	F258	520	11/25/1981	11/10/1992	74.7%	-	4.2	20.1
Ventura-Emma Wood State Bch	F260	15	1/14/1983	8/17/1995	61.6%	0.10%	6.1	16.4
Wheeler Gorge	F264	1,900	9/3/1985	9/22/2007	0.2%	0.01%	30.5	31.1
Pine Mountain Inn	F063	4,220	13/13/2003	9/30/2007	80.3%	1.10%	5.8	29.3

Note: The Pine Mountain Inn 15-minute site record was constructed from records of the NWS Pine Mountain site (Table 2-3) supplemented with data from nearby ALERT sites during periods of gage malfunction. The Matilija Dam record also consists of processed NWS data.

Table 2-3. Inventory of Daily and Hourly NCDC Precipitation Data with 20 Water-Year Summary (10/1/1987 – 9/30/2007)

Station Name	Station ID	Elevation (ft)	Data Collection Period		Percent Missing 1987-2007	Percent Estimated 1987-2007	Precipitation (in/yr)	
			Start	End			Measured	Processed
Daily: Juncal Dam	044422	2,227	1/1/1948	12/31/2006	6.1%	-	32.9	33.4
Daily: Ojai	046399	710	1/1/1948	12/31/2006	7.3%	-	21.2	22.5
Daily: Santa Paula	047957	237	1/1/1948	12/31/2006	4.7%	-	17.5	17.9
Daily: Ventura	049285	105	1/1/1948	12/27/2006	29.8%	-	11.5	16.5
Hourly: Carpinteria Reservoir	CA1540	385	11/14/1968	12/27/2006	21.5%	-	14.6	18.8
Hourly: Matilija Dam	CA5417	1,060	3/1/1969	12/27/2006	8.6%	-	27.9	29.7
Hourly: Oxnard WSFO	CA6572	63	5/2/1998	12/31/2006	71.5%	-	3.3	12.0
Hourly: NWS Pine Mountain	CA6910	4,220	1/1/1965	12/27/2006	7.5%	-	25.5	27.1
Hourly: Oxnard Airport	23136	89	10/17/1999	2/24/2008	60.3%	-	4.8	12.3
Hourly: Camarillo Airport	93110	11	3/5/1998	2/24/2008	52.2%	-	5.2	11.0

Table 2-4. Inventory of ALERT Precipitation Data for the Ventura River Watershed Model with 20 Water-Year Summary (10/1/1987 – 9/30/2007)

Station Name	Station ID	Data Timestep	Elevation (ft)	Data Collection Period		Percent Missing	Percent Estimated	Precipitation (in/yr)	
				Start	End			Measured	Processed
Tommys Creek ALERT	A40	Hourly	5,250	9/28/1998	10/1/2005	65.0%	0.70%	7.6	23
Senior Gridley Canyon ALERT	A71	15-min	2,540	10/24/1992	9/22/2007	25.4%	2.20%	18.3	23.1
Ortega Hill	A180	Hourly	5,175	9/28/1998	9/30/2007	55.0%	-	10.4	24.9
Matilija Hot Springs at No. Fork (Type B)	A612	15-min	307	11/2/1998	9/22/2007	55.5%	2.22%	11.9	27.8
Old Man Mountain ALERT	A613	15-min	4,370	9/28/1998	9/22/2007	55.1%	1.60%	13.4	31.4
Nordhoff Ridge (Type C)	A614	15-min	4,100	10/5/1997	9/22/2007	50.1%	1.56%	17.3	35.3
Canada Larga-Verde Canyon	A616	15-min	1,580	11/7/1998	9/23/2007	55.6%	1.32%	10.2	23.8

Analysis of data from several ALERT flood warning monitoring stations suggests that the precipitation volumes at these gages may not be representative of precipitation volumes for gages with similar elevations within the watershed (Figure 2-2). High elevation ALERT gages are known to not measure snow accumulation accurately. The HSPF Model has a parameter called SNOWCF (SNOW Catch-efficiency Factor), which is a calibration factor that accounts for the inefficiency of the precipitation monitoring gage in capturing snow volumes. This parameter is a multiplication factor that is applied to precipitation volume data during snow events. The ratio of the annual precipitation totals to the observed winter precipitation totals at standard gages provides an estimate for what the SNOWCF value could be. Since the factor is applied only during snow events, which coincides with the periods when the gage is not effective in capturing snowfall, SNOWCF provides us with a way to selectively adjust precipitation in a way that is consistent with our understanding of the gage deficiency based on elevation-corrected comparison to seasonal and annual totals from standard rain gages.

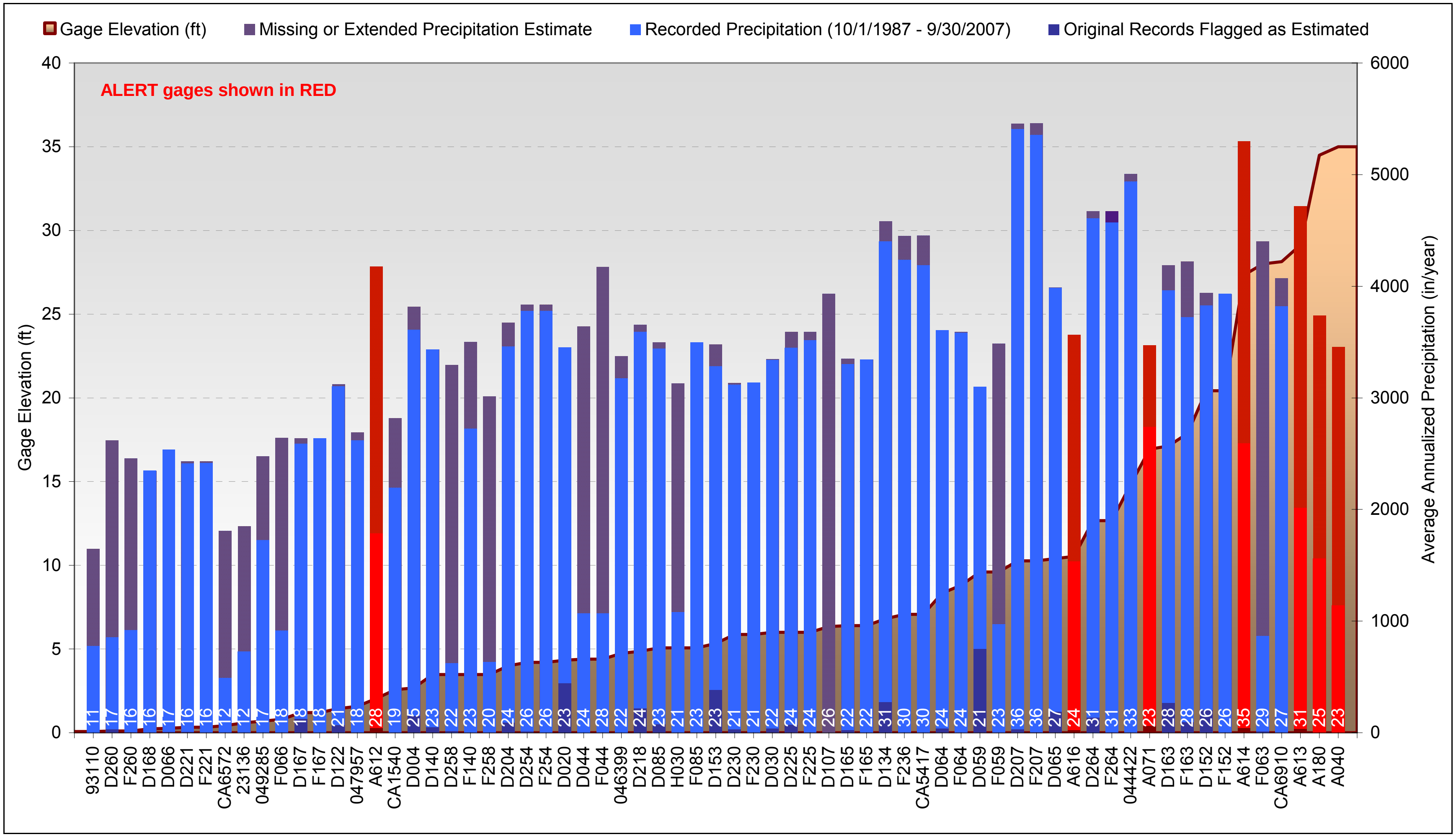

Figure 2-2. Average Annual Precipitation Totals versus Gage Elevation

2.1.2 Evaporation Data

Much of the precipitation volume that falls on a watershed is returned to the atmosphere, either through direct evaporation or through plant transpiration. Together, these processes are referred to as evapotranspiration. The strength of these processes depends on a variety of factors, including solar energy, air temperature, relative humidity, and wind. The total amount of water that could be removed via evapotranspiration with unlimited supply is known as potential evapotranspiration (PEVT), which is typically one of the most sensitive inputs for the overall flow balance of a watershed model.

PEVT time series can be either estimated or measured. Given an extended weather dataset of solar radiation, wind speed, relative humidity, and air temperature, PEVT can be estimated using one of several approaches, such as the Penman (1948) Method. The Penman method for PEVT can provide a high level of accuracy, but only insofar as the input forcings are accurately measured. For Ventura County there are no direct local measurements of solar radiation, and estimation of effective solar radiation is impeded by lack of detailed time series information on cloud cover. In addition, time series for relative humidity and wind speed are available at only a few locations (e.g., Point Mugu) that are likely not representative of conditions throughout the watershed. It is therefore preferable to base PEVT on measured series of pan evaporation.

Within the Ventura River watershed, evaporation has been measured by weather monitoring stations at Casitas Dam and Casitas Dam Recreational Area (considered as one location for this analysis), and Matilija Dam. Three other datasets were provided for nearby locations outside of the watershed, including Cachuma, El Rio Spreading Grounds, and Piedra Blanca Guard Station. Table 2-5 is a summary and inventory of measured evaporation data in and around the Ventura River watershed.

Table 2-5. Evaporation Measurement Locations in and around Ventura River Watershed

Station Name	Station ID	Elevation (ft)	Data Collection Period		Percent Missing
			Start	End	
Casitas Dam & Recreational Area	Casitas	400	1/1/1993	9/30/2007	60%
Piedra Blanca Guard Station	152	3,065	9/1/1951	9/30/1977	86%
Matilija Dam Weather Station	236	1,060	9/1/1969	9/30/2007	3%
El Rio-UWCD Spreading Grounds	239	105	9/1/1972	1/31/2007	6%
Cachuma Reservoir	Cachuma	-	6/1/1956	9/30/2006	5%

It is clear that PEVT is not homogeneous across the Ventura River watershed. The biggest difference in PEVT occurs between the flatter, lower-lying coastal areas and the higher more inland areas. The El Rio-UWCD Spreading Grounds pan (239), located in Ventura County a few miles from the coast, showed a seasonal trend that was distinctly different from the others. Observations from field visits have also suggested that coastal fog has an influence on evaporation behavior. Both of these points are supported by an analysis of California Irrigation Management System (CIMIS) data. CIMIS has interpreted 18 unique reference evapotranspiration zones in California, five of which are present in the Ventura watershed. Two zones run parallel to the coastline (going inland six to seven miles) and have descriptions reflecting greater and lesser fog influence, while the three interior zone descriptions reflect drier conditions.

As part of the development of the Santa Clara River watershed model, Aqua Terra (2008) undertook a significant effort of calculating, patching, and disaggregating PEVT data at multiple stations, mostly based on applying the long-term daily pan evaporation record available at Cachuma Reservoir to monthly totals at other locations. Pan evaporation was converted to PEVT based on monthly plant/pan coefficients established by Los Angeles County. PEVT series created for the Santa Clara study included Matilija Dam (in the Ventura River watershed), El Rio Spreading Grounds (coastal, close to the mouth of the Ventura River watershed), and Piedra Blanca Guard Station (high elevation, near upper end of Ventura River watershed) through December of 2005. In addition, VCWPD provided processed daily pan evaporation for Casitas Dam for 1993-2007.

A representative set of PEVT stations is needed to reflect spatial changes across the watershed. PEVT increases with elevation due to decreased atmospheric density and less fog, but also decreases with elevation as a function of decreases in temperature. The final Ventura River model includes four different PEVT stations to represent different regions of the watershed:

1. Coastal Zone: Uses records at El Rio-UWCD Spreading Grounds. Only monthly trials are reported, so daily estimates are generated by reference to Cachuma. The PEVT series through 2005 was already generated for the Santa Clara model. To extend this series through September 2007, Tetra Tech first calculated daily estimates of PEVT at Cachuma by applying the monthly pan coefficients (Table 2.5 in Aqua Terra, 2008) to the daily pan evaporation record. The daily PEVT series for El Rio was then extended by multiplying the daily Cachuma series times the ratio of El Rio to Cachuma pan evaporation. (This approach was used because there are two months of missing data at El Rio in 2006.) The daily series was then disaggregated to an hourly series using WDMUtil, which assumes a daily distribution proportional to insolation as a function of latitude and time of year. Comparison of 2006-2007 results to reported monthly totals at El Rio shows a close fit for most months, but suggests that December – April PEUT might be underestimated by about 37 percent.
2. Near-Coastal Zone: Uses daily records at Casitas Dam for 1993-2007 for periods in which two pan series are available these were averaged. The pan evaporation was converted to hourly PEVT by applying monthly pan coefficients and disaggregating from daily to hourly. Prior to 1993, a surrogate series at Casitas Dam was developed by multiplying the Cachuma PEVT times the ratio of Casitas to Cachuma pan evaporation.
3. Inland Zone: Uses records at Matilija Dam. As with El Rio, these had already been developed through 2005 by Aqua Terra, using monthly pan evaporation totals recorded at Matilija. The record was extended through 2007 by multiplying the Casitas PEVT series times the long-term ratio of Matilija to Casitas.
4. High-Elevation Zone: Uses records at Piedra Blanca. Monthly measurements are reported through 1977 and used to establish relationships to Cachuma data. These had also been developed through 2005 by Aqua Terra and were extended by multiplying the Cachuma PEVT times the ratio of Piedra Blanca to Cachuma pan evaporation, then disaggregating from daily to hourly records.

2.1.3 Air Temperature

For the hydrology model, air temperature is required only for the high-elevation snow simulation. However, future applications of the model may require complete coverage of air temperature for water quality simulation. Four air temperature series were developed corresponding to the four PEVT stations described in the previous section. The Coastal Zone is assigned measured temperature series at Point Mugu NF, the Near-Coastal Zone uses measured temperature at Casitas Dam, and the Inland Zone uses measured temperature at Ojai (046399). A detailed observed temperature series was not available for the High-Elevation Zone. Therefore, a surrogate time series was developed by applying an elevation lapse rate to convert the Ojai series (elevation 710 ft MSL) to a nominal elevation of 3500 ft MSL, equivalent to -7.246 degrees C.

2.2 Interfacing with the HSPF Model

Daily, hourly, and 15-minute meteorological records were treated as independent datasets for processing purposes. For any given day, daily data were disaggregated to hourly using the distribution from one of the nearby index stations which had the closest daily total volume as the station being disaggregated (details are provided in Tetra Tech, 2008). The corresponding hourly time series was always included as an index station; therefore, in cases where the daily dataset was derived by summing up the hourly or 15-minute data, the process would revert back to an hourly time step.

For each gage location, quality-controlled processed hourly precipitation time series have been generated and archived in a WDM file for the entire monitoring time interval of all component gage records. Depending on the station, the hourly time series may represent a conglomerate of precipitation data measured at a daily, hourly, or 15-minute time step. Fifteen-minute data are available at selected locations; however, since they are relatively newer gages in most cases, the data records are often not available for an extended time period. The 15-minute gages are relatively high quality, with very few flagged records or qualifiers. For this reason, the 15-minute data are also archived, and can be used to support simulation on a 15-minute time step as required.

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3 Hydrologic Response Unit Representation

Land cover specification in HSPF should reflect the features of the landscape that most affect hydrology and pollutant transport. In urban areas, it is important to estimate the division of land use into pervious and impervious components. In rural areas, vegetation is more important. Agricultural practices and crops (or crop rotations) should be well represented when present. Depending on the goals of the model, if soil hydrologic groups are not homogenous in a watershed, it may be important to further divide pervious land cover by soil hydrologic group so that infiltration processes are better represented. Slope may also be an important factor, especially if steep slopes are prevalent; high slopes influence runoff and moisture storage processes. The combination of land use, soils, and slope influence provide a sound physical basis for representing Hydrologic Response Units (HRUs) of a model. This section details the approach for HRU development for the Ventura River HSPF model. The HSPF model simulates conditions in the watershed for an extended time period (i.e., several decades), so HRUs should also reflect all relevant types of land use over time, especially in developed areas. While it is not feasible to represent continuous land use and land cover change over time, the model incorporates several distinct land use/land cover time periods.

3.1 Land Use

A number of land cover GIS products are available for the Ventura River watershed. The NLCD land cover data provide a useful overview, but have limitations in urban areas. The U.S. Forest Service LANDFIRE dataset (www.landfire.gov) provides a high level of detail about vegetation, but does not represent development. Both are discussed in more detail in the Data Summary Report (Tetra Tech, 2008). The strongest GIS product for representing developed land uses is the Southern California Association of Governments (SCAG) land use data, which documents land use in 1990, 1993, 2001, and 2005. Land use is classified using a modified Anderson system, with up to three levels of detail represented by a four digit number. In all, there are over 100 distinct classes.

The SCAG land use was intersected with the study area boundary, and the land area in each class was tabulated to determine the ones with significant area. After reviewing the results, the classes were lumped into 17 groups, designed primarily to allow visualization of the data. (Many of these groups are not used during the final land use processing for the model.) The results of the reclassification are shown in Figure 3-1.

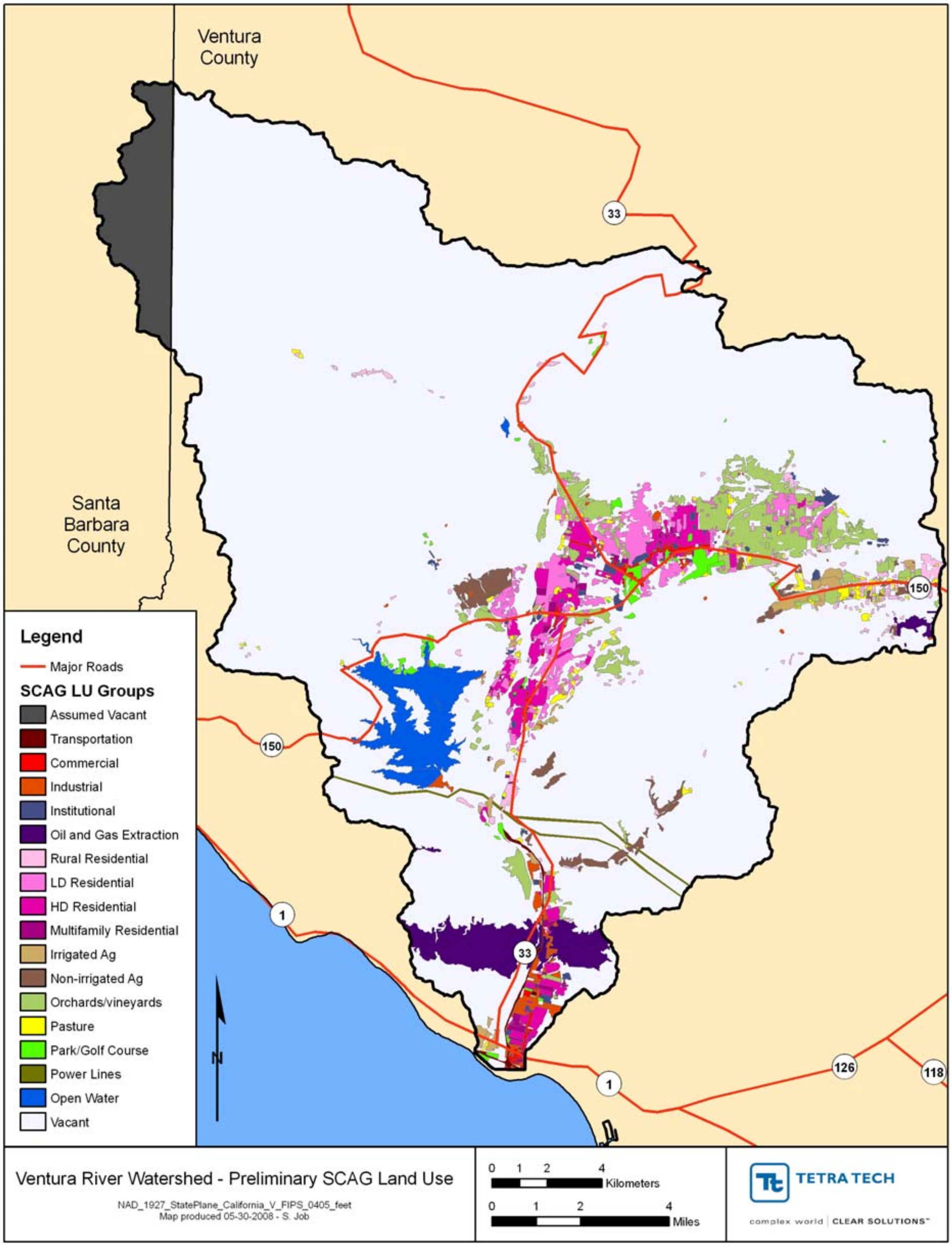

Figure 3-1. Preliminary SCAG Land Use Groups (Year 2005) for the Ventura River Watershed

Note: SCAG does not cover Santa Barbara County; however, this remote area of the watershed is predominately vacant.

The SCAG data provide a high level of detail for developed areas, but no information about vegetation in the undeveloped areas. The northwestern corner of the watershed in Santa Barbara County is not included in the SCAG data, but this area is undeveloped. Land cover in this area can be specified directly from LANDFIRE vegetation classes. LANDFIRE provides several vegetation-based spatial data products, each with specific utility for use in fire dynamics modeling. Initially, the Potential Natural Vegetation Group (PNVG) dataset was considered for this project, and was shown in the Data Summary Report. After some investigation, the LANDFIRE Existing Vegetation Type (EVT) dataset has been selected for representing land cover in the undeveloped areas of the Ventura watershed. PNVG was found to be poorly correlated with recent aerial photographs in the watershed, while EVT was well correlated with the aerial photographs. PNVG represents vegetation likely to exist under purely natural conditions, and natural disturbance regimes, including fire. Vegetation classes for PNVG are assigned based on a set of rules that accounts for the biophysical setting, including ecoregion, meteorology, elevation/slope/aspect, soils, and existing vegetation to represent what is likely to be present in the absence of human disturbance. In the Ventura watershed, the PNVG rules do not appear to produce an accurate approximation of existing vegetation, in part because PNVG appears to underestimate the amount of forest cover in the watershed, which is consistent with a policy of fire suppression. EVT, on the other hand, is intended to represent current vegetation class, and uses a combination of satellite imagery, field data, and biophysical gradient data. Undeveloped EVT classes (which specify dominant plant species) were lumped into a few broad categories, as shown in Figure 3-2, representing barren, grassland, chaparral/scrub, and forest.

Both orchards and other types of agriculture exist in the watershed. As identified by SCAG, orchards occupy about 3 percent of the total watershed area, and over 20 percent of the developed area, while irrigated and non-irrigated agriculture make up a combined total of about 1.25 percent of the watershed, and about 10 percent of the developed area. Agriculture is therefore a small fraction of the total watershed area, but a significant component of some model subbasins. The accuracy of SCAG data for representing agriculture is not known. Given the importance of irrigation to the hydrology of the watershed, an independent assessment of irrigated land area is reported in Section 3.4.

The SCAG land use specifies a significant area as “Oil and Gas Exploration.” As shown in the aerial photo in Figure 3-3, these areas have a distinct footprint and pattern of disturbance, and are represented as a combination of vegetated and barren PERLNDs (the HSPF designation for pervious land). The vegetated and barren land covers are tabulated using differences in their spectral signature (i.e., bare soil is lighter than vegetation).

The HRU approach simulates all land use classes across the entire period of simulation. Land use change is represented by changing the acreage from specific land use classes that is linked to stream reaches. Different land use patterns are represented for each of the four SCAG coverages, with additional accounting for effects of major fires (see Section 3.5).

To enable simulation prior to the first SCAG coverage in 1990, a compatible surrogate was developed for the period around 1978 In the Simulation Plan, the Geographic Information Retrieval and Analysis System (GIRAS) land use/land cover data were cited as a potential source for estimating pre-1985 developed conditions in the watershed. After examining the GIRAS data, Tetra Tech determined the spatial resolution of the data was too coarse for estimating pre-1985 developed conditions; furthermore, the classification criteria apparently differed from those used during interpretation of SCAG land use. As a result, a different method was employed. A GIS parcel database with attributes representing the year structures were built was used to back-cast developed conditions prior to 1985. The year-built attribute values were continuous throughout the modeling time period, but 1978 was selected as a representative break-point for defining conditions from 1967 to 1984. The year 1978 is prior the first major fire that is modeled (Creek Road Fire in 1979). In addition, there was relatively little change in developed land cover on a watershed scale during the same time period.

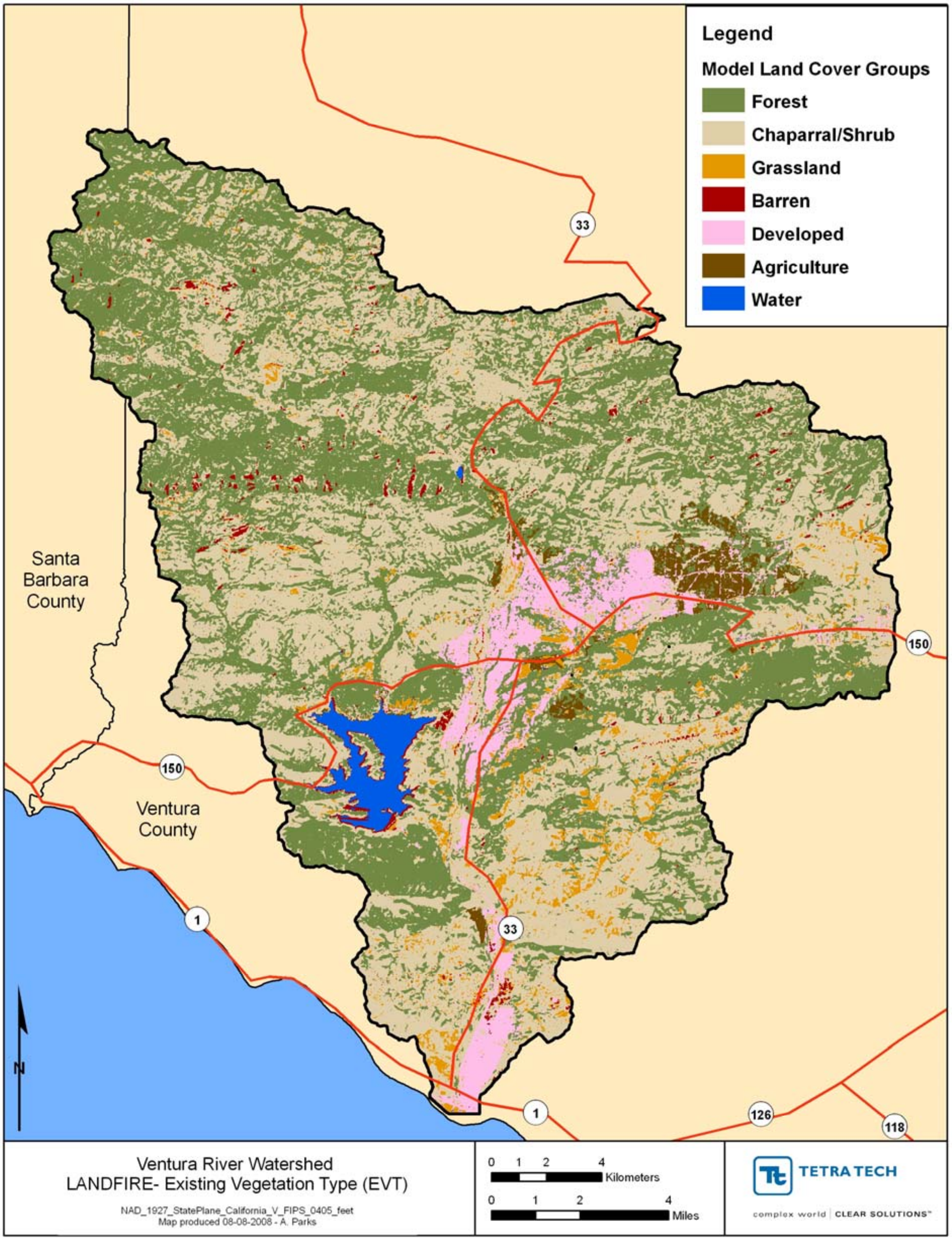

Figure 3-2. Undeveloped Land Cover in the Ventura River Watershed

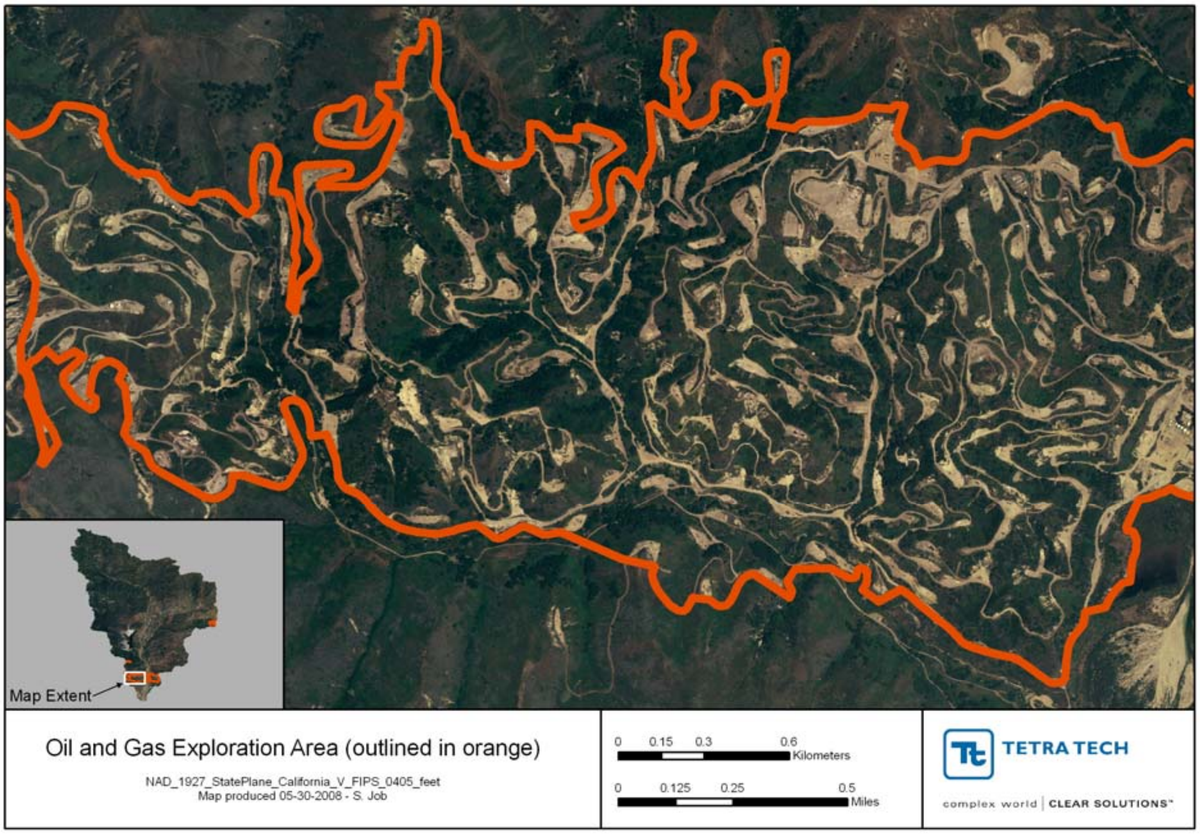

Figure 3-3. Aerial Photo of Oil and Gas Exploration Area

Parcels developed between 1979 and 1990 were overlaid on the 1990 model land use, and any areas shown as developed in 1990 were converted back to the undeveloped LANDFIRE EVT condition. Any parcel development following 1990 was assumed to be included with the SCAG developed land use. About 1,050 acres of developed land were converted back to undeveloped land cover, less than 1 percent of the watershed area.

3.2 Impervious Cover

Developed land uses contain both pervious and impervious fractions, which are simulated separately in HSPF. The HSPF impervious land uses are properly represented as directly connected impervious areas (termed IMPLNDs in HSPF) and these areas need to be determined carefully. SCAG provides average impervious estimates for each land use category, but using an average may be problematic given the goal of having well-calibrated hydrology. The NLCD 2001 impervious area grid dataset provides a potential solution; each 30x30 meter grid cell has an assignment of percent imperviousness (0 to 100). NLCD impervious area can be combined with the SCAG developed area polygons for a better estimate of impervious area. This approach was used successfully in the Clinton River HSPF model in Michigan, a watershed located along a gradient of land uses ranging from rural agriculture to urban core. The Clinton watershed had a polygon-based land use dataset based on a regional government analysis (similar to the SCAG land use). In this approach, the average impervious area of each polygon is determined from the NLCD data; the polygon land use attributes are then exported and pervious and impervious area are calculated for each polygon, and then summed by subwatershed. However, there is a drawback – the

NLCD impervious dataset is weak in rural areas; according to their published methods, there were numerous classification errors in rural areas (typically areas of bare soil misclassified as impervious), so they created a mask a short distance from roads, and performed the spectral classification within the mask only. As a result, a significant fraction of rural development outside of the mask is not captured. A review of the NLCD impervious data in the Ventura River watershed shows the same trend – NLCD impervious cover in urban and suburban areas is well correlated to development, but only follows roads in rural areas.

Therefore, IMPLND area is estimated using the Clinton River approach in urban and suburban areas where the NLCD impervious cover appears to work, while average impervious area values for SCAG polygons are applied in rural areas.

The Simulation Plan initially called for adjusting the tabulated impervious area to Effective Impervious Area (EIA), using the method of Southerland (1995). However, sensitivity analyses suggested that this step was not necessary and did not improve calibration results - presumably because the NLCD underestimates total impervious areas in this watershed.

3.3 Soil Hydrologic Group and Slope

Many HSPF watershed parameters are expected to vary systematically with soil hydrologic group and/or slope, so these characteristics need to be incorporated into the HRU analysis. (Slope is specified directly to the model; however, some related parameters, such as infiltration rate, are often simulated differently in areas of higher slopes, defined as grades greater than 10 percent) NRCS soil hydrologic group polygons and slope severity derived from a 10 m DEM (classified as less than or greater than 10 percent) are shown in Figure 3-4 and Figure 3-5. Note the disparity in the level of detail in the soil data in the northern versus southern portions of the watershed. Apparently, data for the rough, undeveloped terrain in the northern portion were developed with a lower level of effort and/or at a larger scale. Regardless, the two areas have a distinctly different spatial scale for soils data.

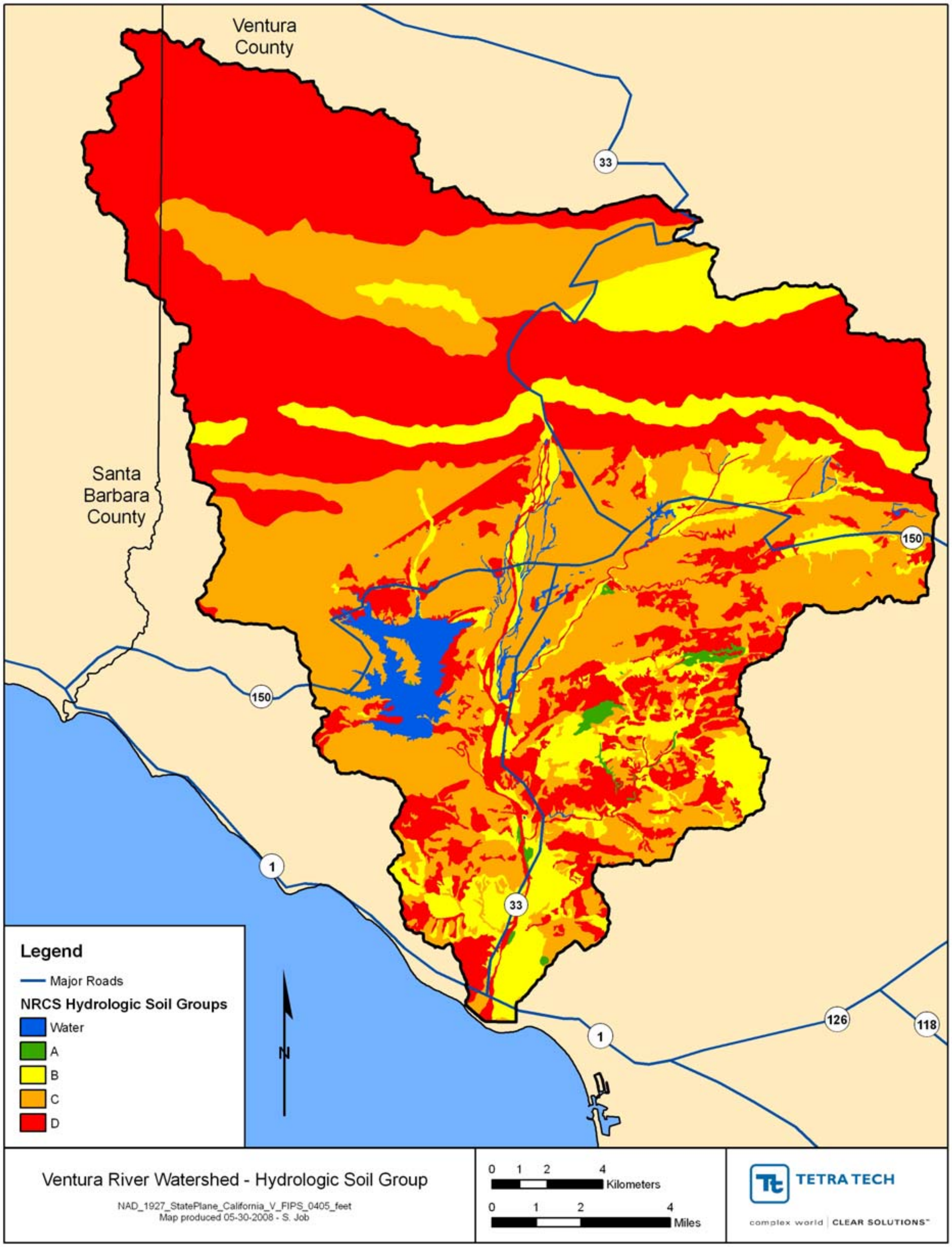

Figure 3-4. NRCS Hydrologic Soil Group Polygons in the Ventura River Watershed

Figure 3-5. Percent Slope (Less/Greater than 10 Percent) in the Ventura River Watershed Derived from GIS Analysis of 10 m USGS DEM

Soil type and slope are often strongly correlated. Given the level of detail in slope (even with two categories), a GIS file based on a union of land use/land cover, soil hydrologic group, and slope would have a very large number of polygons and become unmanageable. Where slope can be assigned to soil hydrologic group polygons, it reduces the complexity of the GIS file. This can be done in the southern portion of the watershed where the soils polygons are more detailed, but is not appropriate in the northern portion of the watershed where the soils polygons are large. Another observation is that development is almost entirely confined to areas with lower slope (<10 percent), so the low/high slope designation can be used exclusively in undeveloped areas.

3.4 Irrigation Water Supply

In the climate of Ventura County, irrigation of lawns and agricultural areas is necessary to sustain viable plants. To accurately simulate low flow hydrology, this additional supply of water must be considered. Since application rates are rarely known across the watershed, estimates of irrigation are required. In California, reference evapotranspiration rates are measured and, in combination with daily rainfall data, can be used estimate daily irrigation demand. Irrigation demand is adjusted with crop or grass coefficients specific to each land use, and external water is applied to model pervious land uses receiving irrigation. Applying this method typically results in simulation of base flows during the summer. Without accounting for irrigation and its effect on groundwater and baseflow, the simulated summer flows would be grossly underestimated.

In the Ventura River watershed, most irrigation is for orchard or lawn irrigation. Irrigation water is derived primarily from groundwater withdrawal or directly from municipal systems.

For the Calleguas Creek and Santa Clara River HSPF models, Aqua Terra (2005, 2008) developed a detailed approach for simulation of irrigation applications. This consists of two components: calculation of potential irrigation demand based on cropping data, cover coefficients, reference ET, and irrigation efficiency; and calculation of daily irrigation applications after accounting for rainfall contributions to crop and lawn demands. A similar approach was used for irrigation demand in the Ventura River model; however, improvements were made to the calculation of application rate.

3.4.1 Irrigation Demand

The Ventura River model accounts for irrigation applications on both agricultural and pervious urban land, which subsequently influences base flows in both major and minor tributaries within the watershed. Daily irrigation applications were calculated from precipitation data and reference crop and lawn ET demands determined by CIMIS (California Irrigation Management Information System) from either measured daily data (when available) or long-term monthly average ET demand values. Tetra Tech utilized the landscape coefficient method described in the WUCOLS III (Water Use Classifications of Landscape Species) manual in order to calculate the ET demands within the Ventura River Watershed. The equation to calculate ET Demand is:

$$\text{ET Demand} = \text{ETo} \cdot \text{Kc},$$

where ET Demand = Crop/lawn evapotranspiration demand (in.), ETo = Reference crop evapotranspiration (in.), and Kc = crop/lawn coefficient (dimensionless).

3.4.1.1 Reference Crop/Lawn Evapotranspiration (ETo)

Several CIMIS stations have operated in Ventura County, but none provides a long period of record through 2007. Active stations 152 (Camarillo), 156 (Oxnard) and Santa Paula (198) commenced in 2000, 2001, and 2005, respectively. Station 101 (Piru) commenced in 1991, but was discontinued in February

2005. To determine appropriate ETo values for the Ventura Watershed, GIS coverages of the ET zones were overlain on the watershed boundary (Figure 3-6). Note that three different ETo zones intersect near the center of the watershed. As a result, Tetra Tech simplified the watershed into two zones – the northern interior portion (represented by ETo zones 10 and 14), and the southern coastal part (ETo zone 3). ETo zones 10 and 14 were aggregated since their average elevations within the watershed are similar and the watershed is located on their boundary. Thus, the actual ETo values within the watershed were more likely an average of the average monthly values for the two CIMIS ETo zones. Due to lack of viable nearby CIMIS stations for the northern interior zone, Tetra Tech used the average of the long-term monthly average ETo values (Table 3-1) for CIMIS zones 10 and 14 in order to interpolate daily ETo values for each day in the model time period. Daily CIMIS data was available for the southern coastal zone from CIMIS stations 107 (Santa Barbara) and 94 (Goleta Foothills) with preference given to 107, which are located approximately 18 and 25 miles, respectively, from the Ventura watershed. Daily data available for the two CIMIS stations in Zone 3 covered the following date ranges:

- Station 107: 4/6/1993 - 9/31/2007
- Station 94: 7/7/1990 - 9/31/2007

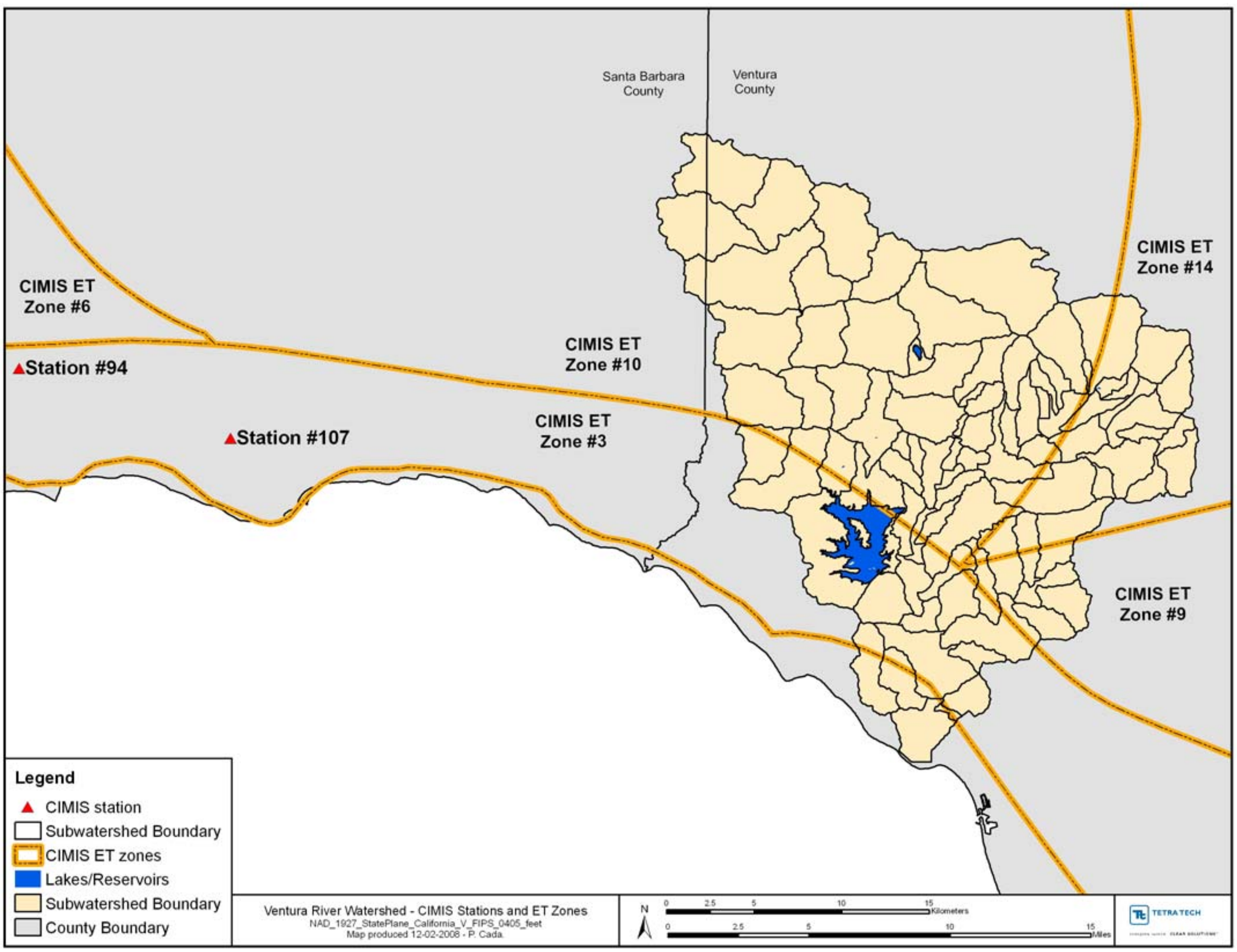

Figure 3-6. ET Zones for the Ventura Watershed

For the prior time period not covered by the two nearby CIMIS stations, daily ETo values were linearly interpolated from the monthly average values (Table 3-1).

Table 3-1. Monthly Reference Crop Evapotranspiration (ETo, in.)

Month	ETo Zone 3	ETo Zones 10 and 14 (average)
January	0.06	0.04
February	0.08	0.07
March	0.12	0.11
April	0.16	0.16
May	0.17	0.21
June	0.19	0.25
July	0.18	0.27
August	0.17	0.24
September	0.14	0.18
October	0.11	0.12
November	0.08	0.06
December	0.06	0.04

3.4.1.2 Crop Coefficient (Kc)

Irrigation demands were calculated separately for the major crop/lawn types in the watershed, Crop coefficient values, which are measured in the field for specific crop types, represent the fraction of water lost from a crop relative to its reference evapotranspiration (ETo). The Kc values are taken as a constant fraction of ETo, although in fact the ratio is likely to vary with growth stage.

The majority of the irrigated agriculture land within the Ventura Watershed includes citrus, avocado and fruit orchards, row/truck crops, and plant nurseries. SCAG land use data most accurately represents the extent of these coverages, but Dave Panaro from VCPWD did provide parcel-based GIS data that shows the proportions of these major agriculture types within Ventura County. The WUCOLS III manual provides crop coefficients for various crop and turf grasses. Where a high and low seasonal range was provided, the average value was used to calculate irrigation demand. Table 3-2 shows the selected Kc values used for the major crops in the Ventura Watershed, which also correspond with values used in the Calleguas and Santa Clara watershed models.

Table 3-2. Crop Irrigation Coefficients (Kc)

Land Use	Crop Type	Kc
Agriculture	Row/truck crops	0.75
	Orchards	0.70
Urban	Warm season turfgrass	0.6

3.4.1.3 Irrigation Efficiency

Since irrigation systems never perform 100 percent efficiently, additional water must be applied in order to meet the plant's beneficial use. Irrigation efficiency largely depends on the type of system (e.g., microjet, drip, sprinkler, and furrow), which is selected depending on intended crop/landscape type, soil and slope conditions, water source, and growth conditions. For urban irrigation systems, the WUCOLS III manual specifies a range of landscape irrigation efficiencies between 65 percent and 90 percent, where well designed and operated systems have an efficiency range of 80 percent to 90 percent while poorly performing systems can have irrigation efficiencies less than 50 percent. In the Ventura River watershed, the most common irrigation system used for household lawns and golf courses are sprinklers (personal communication, Brooks Engelhardt, VCRCD, 7/31/08). Although they are easy to maintain, their performance depends more on how they are designed and located and the time of day they are operated. Even with optimal design and operation, sprinkler irrigation systems can only attain efficiencies of 65 percent to 80 percent, depending on whether they are movable or in permanent locations (Solomon, 1988). According to Scott Holder (VCWPD, personal communication, 8/20/08), most residential and non-residential parcels have permanent systems installed or upgraded within the past 20 years, and movable sprinklers are rarely used. As a result, Tetra Tech assumed an efficiency value of 80 percent to calculate the urban irrigation demand.

Micro-drip irrigation is the most common system used for agriculture crops and orchards (personal communication, Brooks Engelhardt, VCRCD, 7/31/08) in the Ventura River watershed. These types of systems can achieve higher irrigation efficiencies than sprinkler or surface systems (75 percent - 90 percent), but their performance largely relies on how well they are maintained and operated; often yielding actual irrigation efficiencies as low as 60 percent. Tetra Tech used a 75 percent irrigation efficiency for agriculture crops, which is the same value used in both the Calleguas and Santa Clara studies.

3.4.2 Irrigation Application

Irrigation application rates were estimated external to the model and saved to the meteorology WDM. The fraction of land of a given class that is actually irrigated is specified in the External Sources block of the model input file and can be used as a calibration parameter.

Irrigation application is influenced by soil moisture storage from antecedent precipitation events, and it is not appropriate to calculate application rates based only on the difference between irrigation demand and same day precipitation. Instead, the application rate (or actual irrigation demand) should be calculated as the difference between the theoretical irrigation demand and the cumulated effective precipitation (P_e), where P_e is the fraction of precipitation that is stored in the soil and available to plants. USDA (1993) provides a method for estimating P_e (inches) on a monthly basis:

$$P_e = SF \cdot \left(0.70917\, P_t^{0.82416} - 0.11556\right) \cdot \left(10^{0.02426\, ET_c}\right), \text{ with}$$

$$SF = \left(0.531747 + 0.295164\ D - 0.057697\ D^2 + 0.003804\ D^3\right)$$

Here, P_t is the monthly total precipitation (in.), D is equal to 50 percent of the available water capacity of the soil (in.), and ET_c is the monthly crop evapotranspiration demand. The use of D helps account for the variability among different soil types. Following USDA (1993), the resulting value of P_e is then limited to the smaller of the value calculated above, monthly total precipitation, and monthly crop evapotranspiration demand.

This method was adapted to a daily basis by calculating values on a 30-day rolling basis. A precipitation depth of 0.2 inches was defined as a critical amount of rainfall that results in no irrigation on that day or the succeeding day. The daily evapotranspiration demand was then renormalized to the fraction of days in the previous 30-days on which irrigation is possible because the critical precipitation depth was not exceeded. Subtracting one-thirtieth of the calculated 30-day P_e then yields the daily irrigation application rate. Application rates are calculated separately for turf grass, row crops, and orchards.

3.5 Fire Impacts

Fire is a natural component of the southern California landscape which can significantly affect watershed hydrologic response. Some of the effects of fires in a watershed include (1) changes to vegetative cover, which reduce evapotranspiration, (2) the creation of hydrophobic materials which change runoff characteristics of the landscape by reducing infiltration and soil moisture storage capacities, (3) increased hydraulic roughness, and (4) increased erosion, which can be exacerbated by tree clearing associated with fire fighting activity, often resulting in intense mud and debris flows.

3.5.1 Simulation Approach for Burned Land

At a gross level, a landscape that has recently and intensely burned has hydrologic characteristics similar to an unpaved road. For the Lake Tahoe TMDL, the U.S. Forest Service used an "Equivalent Roaded Area" (ERA) method to simulate the impacts of burned areas by assigning parameters appropriate to unpaved roads.

Effects of fires vary with the intensity of the burn. The impacts are strongest in the season immediately following the fire, but can persist for several years as vegetative cover is gradually re-established. The impacts generally decrease quickly after the first year following an exponential decline, but full return to a pre-fire state can take from 3 to 10 years (Brown, 1972; Rowe et al., 1954; Wells, 1981).

Spatial burn severity information for fires from 1984 to present is available from the Monitoring Trends in Burn Severity (MTBS) web site (http://www.mtbs.gov/dataaccess.html). Similar information on severity of burns for fires prior to 1984 is difficult to obtain.

As part of the Santa Clara Study, Aqua Terra (2008) undertook a pilot effort to simulate potential impacts of the Ranch Fire of 2006. This effort adjusted HSPF parameters as follows:

- Reduce interception by 90 percent. This value is perhaps high, as Goodrich (2000) assigns a 50 percent reduction in cover to a high severity burn in a shrub-dominated area, with only a 15 percent reduction for a low severity burn.
- Reduce infiltration by 35 percent, as recommended in the LA Burn Methodology (Willardson and Walden, 2003).
- Reduce upper zone nominal soil moisture storage parameter (UZSN) by 50 percent.
- Reduce soil ET parameter (LZETP) by 70 percent.
- Reduce riparian ET (BASETP) to zero.

This approach provided a starting point for adjusting pervious land parameters to account for fire impacts, but is still in the pilot stage, with Aqua Terra reporting that they are pursuing ongoing research. Simulation in the Ventura River watershed suggests that these parameters work fairly well for simulation of burned land; however, the results are improved with the additional assumption for high-elevation watersheds that the effects of fire include a reduction in the fraction of active groundwater lost to deep storage. The physical reasons for this reduction are uncertain, but may include development of hydrophobic layers in the soil profile that enhance lateral flow.

Burn severity is accounted for by adjusting the area to which the burned parameters apply. The intensity information includes six classes, indicating (0) outside fire perimeter, (1) unburned to low severity, (2) low severity, (3) moderate severity, (4) high severity, and (5) "increased greenness" (greater vegetation cover than prior to the fire). Class 2 is assumed to be equivalent to 25 percent of the area converting to burned parameters, Class 3 to 50 percent of the area, and Class 4 to 100 percent of the area. Classes 0, 1, and 5 are assigned 0 percent. The mosaic of fire intensity is then used to determine the fraction of the underlying land use that is converted to burned parameters.

The effects of burned land can be significant, resulting in an increase in runoff for both dry and wet periods. Figure 3-7 shows the difference in monthly average flow for burned and unburned conditions in North Fork Matilija Creek. For these simulations, the burn extent/intensity is set to the conditions estimated for the 1985 Wheeler #2 fire and maintained throughout the simulation period. The percentage difference is greatest during dry conditions, when the suppressed vegetation leads to higher baseflows for burned conditions; however, flow peaks are also higher due to reduced infiltration.

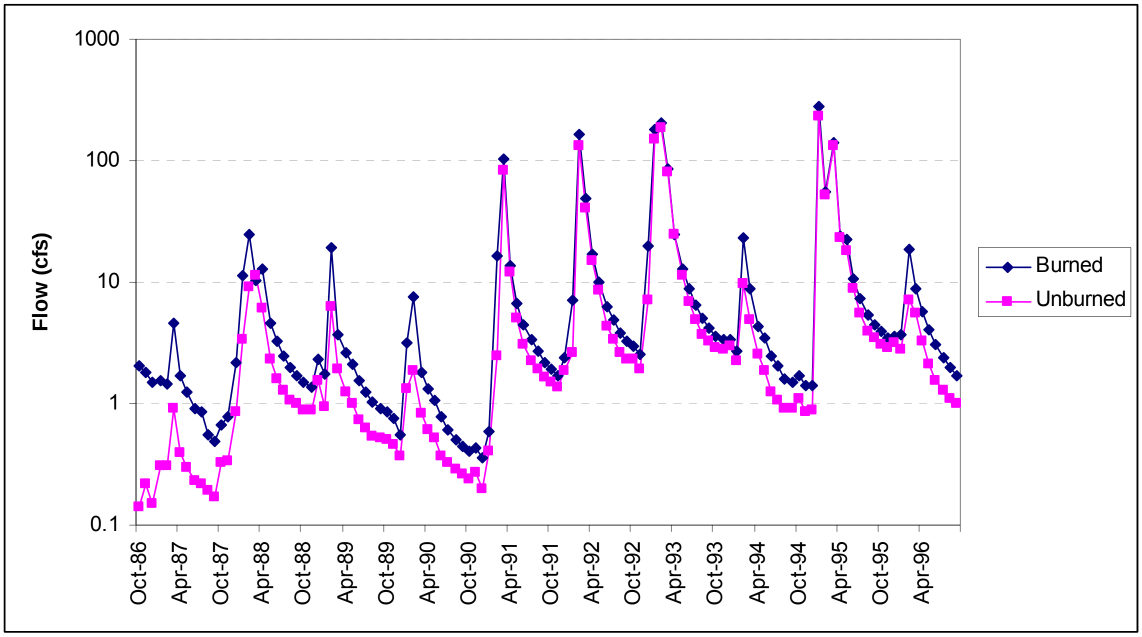

Figure 3-7. Simulation of Monthly Average Flow for Burned and Unburned Conditions, North Fork Matilija

Incorporation of the effects of fires into the model is complicated by the fact that HSPF uses static land use. While the simulation approach for the Ventura River model incorporates several land use change points, it is not possible to simulate the gradual re-establishment of vegetation over time. However, step changes in land use are simulated, and this process can include fire impacts. The division of the model into separate upland (HRU) components and reach simulation facilitates this by allowing the reach model to select appropriate upland inputs for a given year of the simulation. Accordingly, Tetra Tech incorporated the burned land use to represent runoff from burned areas for a two-year period following the date of a major fire. (Two years is selected as an approximation of the period of greatest impact during the estimated 3- to 10-year recovery period to fully vegetated conditions.)

Mudflows and debris flows associated with fires in steep terrain can also impact flood flow hydraulics by increasing the bulk density of the flow. Costa (1988) reports flows with 47 to 77 percent sediment concentration by weight. Elliott et al. (2005) modified HEC-HMS peak flow predictions for post-fire conditions in Colorado by incorporating a bulking factor (BF) equation based on the percent sediment concentration by volume (C_v), given as $BF = 1/(1 - C_v)$ (O'Brien and Fullerton, 1989). Effectively, a debris-laden flow increases the apparent volume of water relative to the amount of runoff by the magnitude of the bulking factor. Potentially the model may need to incorporate a bulking factor to reproduce observed flux from heavily burned areas.

HSPF hydraulic response is implemented via the FTables, which represent discharge as a function of volume. To account for sediment bulking in post-fire flows in steep terrain for a single reach, the apparent volume of water could simply be increased by multiplying times the bulking factor. This, however, would tend to overestimate flows downstream as the sediment load begins to settle out on flatter terrain. The appropriate bulking factor is likely to decrease as flow proceeds to higher order reaches with lower slope, or as incremental flow is added from non-burned areas. In theory, the bulking effect of debris flows could be incorporated into the model as follows:

- Determine appropriate bulking factor for a reach i, BF_i. This should likely reflect soils, slope, and burn severity.
- Increase the "apparent" volume of water entering the reach by multiplying times the bulking factor. This bulked volume would then be used by the FTable to determine the rate of outflow.
- In the model linkage that routes water to the next downstream reach (i+1), reduce the volume back to the true volume of water by dividing by the bulking factor, BF_i.
- If appropriate, account for bulking in the next downstream reach by multiplying by its bulking factor, BF_{i+1}.

Further research and discussion would be needed to evaluate appropriate factors and spatial applicability to implement the bulking factor approach for burned areas. This adjustment is not used in the current model calibration and validation exercises.

The use of a bulking factor may also be appropriate if the model is used to evaluate response to removal of Matilija Dam, which could result in downcutting and mobilization of sediment deposits currently stored within that impoundment, depending on the degree to which these deposits are stabilized. A bulking factor approach could also be used to evaluate response to specific storm events in which high concentration debris flows are documented to have occurred in response to factors other than fires.

3.5.2 Fire History

Despite the efficiencies gained by HRU simulation, implementation of land use change points in the model is still somewhat cumbersome. Therefore it is important to select only those change points related to fire at which sufficient burning occurred to have a potentially significant impact on hydrology.

Fire history was provided by VCWPD in a GIS shapefile providing area, date, and name for fires occurring in or near the Ventura River watershed. There are 406 recorded fires, having occurred between 1890 and 2002. (Burn intensity was not included.) Areas where fires took place prior to 1965 are expected to have had significant vegetative regrowth prior to the start of the anticipated model simulation period in the late 1960s and are therefore not considered further. There are 35 recorded fires after 1965 that had at least one percent of the burn area in the watershed (Table 3-3). The cumulative area burned between 1965 and 2007 is shown in Figure 3-8.

Table 3-3. Fires within Ventura River Watershed, 1965-2007

Fire Name	Date of Fire	Total Reported Acres	Percent within Watershed Area	Percent of Watershed Burned	UIDENT
Sulphur Mountain	09/01/1966	31	27%	0.01%	16VENT_CO
Shell	09/24/1968	60	96%	0.04%	58VENT_CO
Canada Larga	09/22/1968	241	100%	0.17%	163VENT_CO
Taylor	09/22/1968	295	100%	0.20%	8VENT_CO
Sycamore	07/01/1968	32	35%	0.01%	158VENT_CO
Foothill	07/01/1968	16	36%	0.01%	66VENT_CO
Foothill	09/25/1970	5,241	6%	0.22%	203VENT_CO
Bear	08/22/1972	17,327	1%	0.12%	LPNF19720082
Aliso Canyon	09/03/1975	1,250	8%	0.07%	162VENT_CO
Cozy Dell	09/25/1978	910	88%	0.56%	3VENT_CO
Creek Road	09/18/1979	32,000	68%	15.10%	47VENT_CO
Not designated	00/00/1979	490	100%	0.34%	LPNF19790002
Poplin	07/10/1983	194	100%	0.13%	64VENT_CO
Matilija	07/07/1983	4,706	100%	3.27%	LPNF19830019
Ferndale	10/14/1985	47,064	8%	2.61%	197VENT_CO
R. Colla	07/05/1985	160	60%	0.07%	122VENT_CO
Black Mountain	07/03/1985	1,324	100%	0.92%	185VENT_CO
Wheeler #2	07/01/1985	118,000	66%	54.04%	LPNF19850027
Girard Rx Burn	05/29/1985	506	66%	0.23%	15VENT_CO
Hall Canyon Rx-Burn	12/02/1986	644	7%	0.03%	182VENT_CO
Foothill	06/26/1990	569	100%	0.39%	131VENT_CO
Sulphur	10/23/1992	106	81%	0.06%	126VENT_CO
Larkspur	10/10/1992	20	100%	0.01%	118VENT_CO
Seneca	09/30/1992	510	69%	0.24%	11VENT_CO
Steckel	10/27/1993	27,088	13%	2.44%	187VENT_CO
Wheel	10/27/1993	1,475	100%	1.02%	LPX19930043H
Poli	10/25/1996	360	9%	0.02%	204VENT_CO
Dennison Park	04/17/1996	50	68%	0.02%	Rx-3-035-VNC
Sisar	10/22/1997	659	43%	0.20%	Rx-3-031-VNC
Sloan	01/25/2002	3,000	7%	0.15%	Rx-3-021-VNC

Fire Name	Date of Fire	Total Reported Acres	Percent within Watershed Area	Percent of Watershed Burned	UIDENT
Ranch Incident	12/21/1999	4,371	68%	2.06%	VNC99034249
Creek Incident	09/06/2000	80	97%	0.05%	VNC00023472
Kenewa Incident	08/23/2000	80	100%	0.06%	VNC00022152
Creek Incident	09/30/2001	28	100%	0.02%	VNC1052068
School Incident	11/20/2005	3,900	24%	0.65%	Not recorded

Figure 3-8. Cumulative Burned Area within Ventura River Watershed, 1965-2007

The northwestern side of the watershed was heavily burned in July 1985 by an individual fire that covered 54 percent of the watershed, known as Wheeler #2 (Figure 3-9). The southeastern portion of the watershed was also heavily impacted by a single fire in September 1979 that covered 15 percent of the watershed, known as the Creek Road Fire.

Figure 3-9. The Creek Road (1979) and Wheeler #2 (1985) Fire Areas

There were several other fires that burned at least five square miles of land within the watershed and are thus considered to be potentially significant for impacts on basin hydrology (Table 3-4). These include the two major fires occurring in 1979 and 1985, mentioned above, as well as major fires in 1983 and 1993. Figure 3-10 displays the total burned area coverage (major and minor fires) for these four years. To simplify model application, switchover to burned land uses is simulated at only the following dates: 10/1/1979, 8/1/1085, and 11/1/1993.

Table 3-4. Fires Covering More than Five Square Miles in Ventura River Watershed, 1965-2008

Fire Name	Date of Fire	Square Miles in Watershed	Percentage of Watershed Area Burned	UIDENT
Wheeler #2	07/01/1985	122.10	54%	LPNF19850027
Creek Road	09/18/1979	33.85	15%	47VENT_CO
Matilija	07/07/1983	7.35	3%	LPNF19830019
Ferndale	10/14/1985	5.65	3%	197VENT_CO
Steckel	10/27/1993	5.54	2%	187VENT_CO

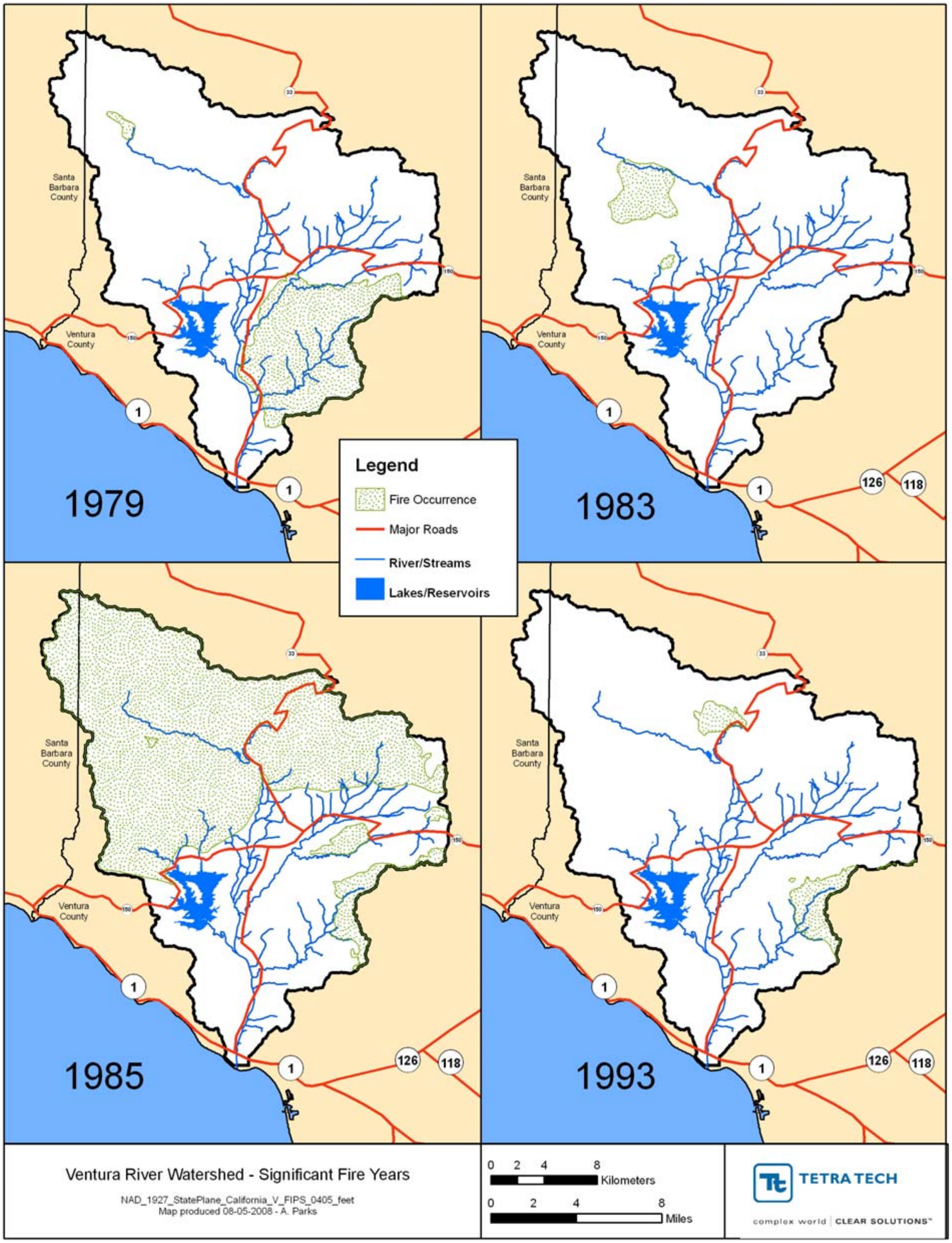

Figure 3-10. Significant Burn Areas in the Ventura River Watershed, 1965-2008

3.6 WATERSHED SEGMENTATION

VCWPD supplied Tetra Tech with a subwatershed boundary layer for the Ventura River watershed developed for preliminary HEC analysis of hydrology. This coverage contains 31 subwatersheds, and provides a starting point for model segmentation. The boundaries of these subwatersheds were already aligned to coincide with the locations of most long-term flow monitoring gages. Further refinement of subwatersheds was, however, needed to meet project goals including, in particular, the isolation of individual FEMA tributaries.

To ensure accurate representation of the runoff and streamflow routing throughout the Ventura River watershed, stream segmentation and watershed boundary delineation were performed using a 10-meter resolution digital elevation model (DEM), the highest available resolution. Post-processing of selected subwatershed boundaries/stream segments was performed using the LIDAR contour images provided by the Ventura County Watershed Protection District (VCWPD). The watershed boundary delineation and stream segmentation processes took into account several important features within the Ventura River watershed—FEMA tributaries, surface diversions, point sources, detention basins, dams, and monitoring gages. All of these features were considered along with the overall goal of creating watersheds with a reasonable range of areas. Each segment/watershed was assigned a unique identification number.

The 10-meter DEM was processed using the fill, flow direction (D8) and flow accumulation tools within the Terrain Analysis System program (TAS), version 2.0.9 (Lindsay, 2005). Because TAS allows one to create approximately equal-sized basins, it helped meet the requirement that even the smallest scale FEMA tributary within the Ventura River watershed have its own watershed/segment. Therefore, after several iterations of watershed delineation within TAS, the appropriate minimum basin size was identified as approximately 150 acres.

The subwatershed file created in TAS was exported into ArcGIS 9.2 for post-processing. First, the boundaries of the two major lakes (Matilija Lake and Lake Casitas) were “burned” into the watershed layer. At this stage, the subwatersheds were at the scale of the smallest FEMA tributary and were too numerous (small in size) for modeling the entire basin. These small scale subwatersheds were merged into larger watersheds to create a GIS layer with a reasonable range of subwatershed sizes, while still meeting the needs of all aforementioned features (Figure 3-11). Subwatershed boundaries and break points were determined using the following criteria, which are designed to optimize representation of hydrology in the HSPF model:

- Each FEMA tributary should have its own distinct segment/watershed (seen as colored segments in Figure 3-11)
- Placement of point sources should be at the top of a segment/watershed
- Diversions should be at the downstream end of a segment/watershed
- Flow gages and water quality sites should be at the downstream end of a segment/watershed
- Major urban and agricultural areas – potential sources of nonpoint pollution – are isolated to the extent practical within a limited set of subbasins
- The multiple temporal shifts of the Live Oak Creek diversions should be accounted for in the delineation

In areas of little topographic variation (like those seen on the main stem of the Ventura River downstream of the Robles Diversion) there were a few instances where watershed boundaries were modified using the provided LIDAR contours and 2005 aerials to better represent the hydrology of the area. Finally, all boundaries of the watersheds were inspected for topology errors (e.g., gaps, overlaps, etc.) and any errors were corrected.

Each subwatershed was given a unique identification number (Figure 3-11 and Table 3-5) that is based loosely on the watershed number (WSNUMBER in file's attribute table) in the watershed GIS file provided by VCWPD. The watershed number used by VCWPD is shown as "Parent Basin" in Table 3-5.

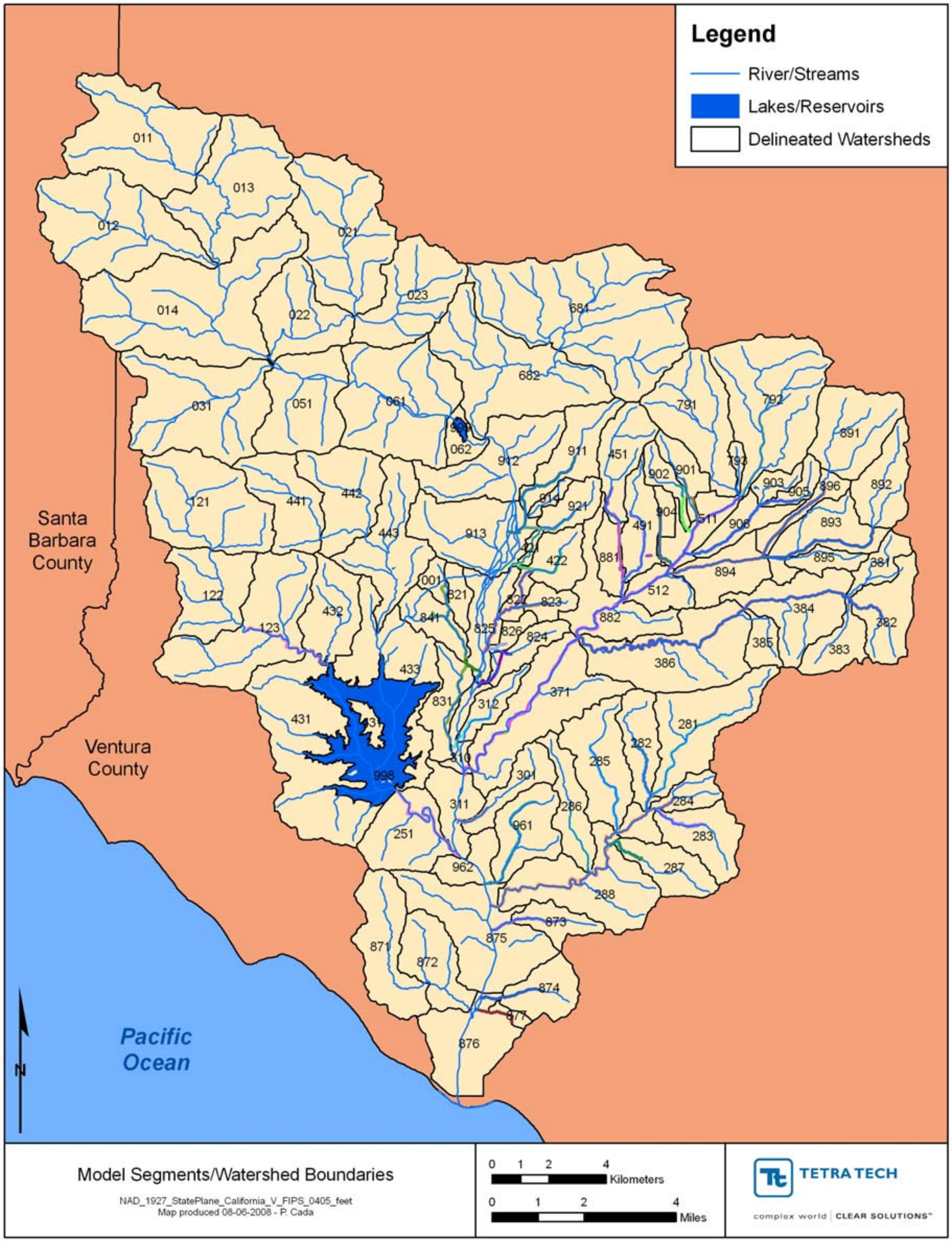

Figure 3-11. Subwatershed Delineation for the Ventura River

Table 3-5. Ventura River Subbasins for HSPF Modeling

Model Subbasin	Area (acres)	Parent Basin (VCWPD)	Notes
001	276	LOC01	Live Oak Creek. Diverted by Rancho Matilija Diversion to #825.
011	3738	MAT01	
012	3775	MAT01	
013	3429	MAT01	
014	5662	MAT01	FEMA Trib: Matilija Creek
021	3732	MAT02	
022	1896	MAT02	
023	2281	MAT02	
031	3789	MAT03	
051	2350	MAT05	FEMA Trib: Matilija Creek; Contains USGS flow gage (11114495)
061	3709	MAT06	FEMA Trib: Matilija Creek; Contains USGS flow and WQ gage (11114500)
062	402	MAT06	Direct drainage to Matilija and incremental drainage to gage, no reach
121	3178	1012	
122	1871	1012	
123	3328	1012	Coyote Creek; Contains USGS flow gage (11117600)
251	1689	425	FEMA Trib.: Coyote Creek; Contains USGS flow gage (11118000)
281	2268	428	Hammond Canyon
282	1089	428	Sulphur Canyon
283	1293	428	Verde Canyon
284	907	428	FEMA Trib.: Canada Larga; contains VCWPD gage (630)
285	1850	428	Coche Canyon

Model Subbasin	Area (acres)	Parent Basin (VCWPD)	Notes
286	1087	428	Canada de Aliso
287	1058	428	Leon Canyon
288	2683	428	FEMA Trib.: Canada Larga
301	839	VEN30	Fresno Canyon
310	438	1083	FEMA: Ventura mainstem above San Antonio
311	958	VEN31, 1083	FEMA: Ventura mainstem. Contains USGS flow gage (11118400) and flow and WQ gage at basin outlet (11118500). Contains Foster Park diversion.
312	590	VEN31	FEMA Trib.: Oak View Drain
371	2976	437	FEMA Trib.: San Antonio Creek; Contains USGS flow gage (11117500)
381	562	438	
382	1330	438	Lion Canyon
383	790	438	
384	1904	438	Lion Canyon
385	465	438	
386	3016	438	Lion Canyon
421	114	442	FEMA Trib.: McDonald Canyon Drain South; Prior to 1972 this area (Subbasin #421) drained McDonald Canyon Drain South (#921)
422	854	442	FEMA Trib.: Happy Valley Drain; Prior to 1973 this area (Subbasin #422) flowed into Happy Valley Drain South (#822), Post 1973 it drains to #825
431	4215	1043	Direct drainage to Casitas, no reach
432	1421	1043	Direct drainage to Casitas, no reach
433	2303	1043	Direct drainage to Casitas, no reach
441	1651	1044	

Model Subbasin	Area (acres)	Parent Basin (VCWPD)	Notes
442	1896	1044	
443	2171	1044	Contains USGS flow gage (11117800)
451	1233	1045	Stewart Canyon; Stewart Canyon Debris Basin Outlet
491	1024	449	FEMA Trib.: Fox Canyon Barranca; VCWPD Gage 631 located near outlet
511	852	451, 1090	FEMA Trib.: San Antonio Creek
512	722	451, 1090	FEMA Trib.: San Antonio Creek
681	6439	468	
682	3828	468	Contains USGS flow and WQ gage (11116000)
791	2336	1079	
792	3701	1079	Senior Canyon; San Antonio Creek Debris Basin Outlet
793	144	1079	
821	369	1082	Prior to 1983 this area (Subbasin #821) flowed into Live Oak Creek via Subbasin #841. After 1983 #821 flowed to #825.
822	280	1082	FEMA Trib.: Happy Valley Drain South; Prior to 1973 this area (Subbasin #822) drained Happy Valley Drain (#422)
823	430	1082	FEMA Trib.: Miramonte Drain
824	631	1082	FEMA Trib.: Skyline Drain
825	1072	1082	FEMA: Ventura mainstem
826	250	1082	FEMA Trib.: Mirror Lake Watershed
831	938	1083	Live Oak Creek.
841	782	1084	Live Oak Creek. Reach 001 disconnected late 2002. Originally flowed to #310. Starting in late (Nov?) 2002, #841 redirects any discharges ranging from 20-800 cfs to #310. Flows less than 20 cfs and greater than 800 cfs flow to #831.
871	1957	1087	

Model Subbasin	Area (acres)	Parent Basin (VCWPD)	Notes
872	1400	1087	
873	666	1087	FEMA Trib.: Manuel Canyon
874	1020	1087	FEMA Trib.: Canada de San Joaquin
875	2965	1087	FEMA: Ventura mainstem. Ojai WWTP located at upstream boundary
876	1992	1087	FEMA: Ventura mainstem.
877	134	1087	FEMA Trib.: Dent Drain
881	575	1088	FEMA Trib.: Stewart Canyon
882	1599	1088	FEMA Trib.: San Antonio Creek
891	1873	1089	
892	1228	1089	
893	1453	1089	FEMA Trib.: Reeves Creek
894	1200	1089	FEMA Trib.: Thacher Creek; VCWPD Gage 669 located near outlet
895	441	1089	
896	542	1089	FEMA Trib.: Thacher Creek
901	583	1090	Dron Creek
902	458	1090	Crooked Creek
903	339	1090	
904	249	1090	FEMA Trib.: East Ojai Drain; All flow drains to Grand Ave. via East Ojai Drain and storm sewer adjacent storm sewer. Lower flows enter 41" pipe and discharge to basin 511. Excess flows overflow to Grand Ave. sewer system and drain to basin 491.
905	351	1090	McNeill Creek
906	729	1090	FEMA Trib.: McNeill Creek
911	1341	1091	FEMA Trib.: Cozy Dell Canyon

Model Subbasin	Area (acres)	Parent Basin (VCWPD)	Notes
912	2290	1091	FEMA: Ventura mainstem. Robles Diversion downstream, contains inactive USGS flow gage upstream (11116500) and active flow gage downstream (11116550), CMPD Gage 610 at Robles Casitas Canal flume
913	2280	1091	FEMA: Ventura mainstem. VCWPD Gage 633 measures flow for Happy Valley Drain (422) and McDonald Canyon Drain South (421)
914	176	1091	
921	654	1092	McDonald Canyon Drain; Prior to 1972 this area (Subbasin #921) flowed into McDonald Canyon Drain South (#421). After 1972 flow was diverted to #913 via the Cozy Dell Canyon outlet
961	1416	1096	Weldon Canyon
962	696	1096	FEMA: Ventura mainstem.

3.7 Summary of the HRU Development Process

To summarize, the HSPF HRU development process is as follows:

1. Developed Areas
   a. Use SCAG developed area polygons
   b. IMPLND assessment
      i. Use NLCD 2001 impervious estimates in or near urban areas on a SCAG polygon basis
      ii. In rural areas with development, use average impervious values for SCAG polygons
      iii. Optionally, estimate road impervious area in undeveloped areas using either NLCD imperviousness or road length times assumed width
      iv. Adjust MIA to EIA as discussed in Section 0
   c. Agricultural uses – perform additional research to refine assignment to model HRUs
   d. “Oil and Gas Exploration” polygons – use spectral differences to distinguish barren land from vegetated areas
   e. Assume all developed PERLND slopes are in the low (0 to 10 percent) category, with the exception of the “Oil and Gas Exploration” polygons, nearly all of which have high slopes
   f. Tabulate soil hydrologic group area in each SCAG polygon on a percentage basis, and post-process with IMPLND area
2. Undeveloped Areas
   a. Use LANDFIRE EVT dataset, and combine land covers into barren land, grassland, chaparral/shrub, and forest polygons.
   b. Southern portion of the watershed with high soils detail
      i. Assign prevalent slope class to each soils polygon
      ii. Union with LANDFIRE EVT polygons
   c. Northern portion of the watershed lacking soils detail
      i. Create slope class polygon file
      ii. Union slope class polygon, soils, LANDFIRE EVT and polygons

The distribution of HRUs needed over time by the model varies to reflect changes in land use or occurrence of major fires. To facilitate the modeling process, implementation occurs through use of two separate model runs, one covering the upland simulation, with results stored in a WDM file, and one covering the instream reach simulation. In this way, the HRU upland simulation can be run continuously to build up a complete time series of unit area upland runoff. The reach model can then be run separately, with appropriate stop-start change points, to complete the simulation, selecting different mixes of upland HRUs as appropriate at different time points. While somewhat more complex to implement initially, no additional data is required, and this approach provides for greater flexibility and efficiency in final simulations. The development of the reach model is summarized in Section 4.

A dedicated UCI file for PERLND/IMPLND is used to generate and archive unit-area hydrographs for all possible weather-associated HRU combinations within HSPF operations limits. Table 3-6 presents a list of HRUs for the Ventura River watershed. For a given set of HRUs associated with a weather station; many of these combinations drop out of consideration either because they do not exist, or they compose a relatively insignificant amount of area.

Table 3-7 presents the indexing convention for the land simulation UCI file. The indexes are grouped in sets of 20, which is designed to allow for association of up to 20 unique meteorological forcing functions per HRU. Model parameters can be adjusted by HRU; however, the weather related responses are uniquely indexed using the convention presented below.

Table 3-6. List of HRUs for the Ventura River Watershed

HRU	Soil Hydrologic Group	Slope	Land Use
Burned_A	A	≤ 10%	Burned areas, post-fire (~ 2 years)
		> 10%	
Burned _B	B	≤ 10%	
		> 10%	
Burned _C	C	≤ 10%	
		> 10%	
Barren_A	A	≤ 10%	Bare soil, unpaved roads, harvested forest
		> 10%	
Barren_B	B	≤ 10%	
		> 10%	
Barren_C	C	≤ 10%	
		> 10%	
Grassland_A	A	≤ 10%	Grassland
		> 10%	
Grassland_B	B	≤ 10%	
		> 10%	
Grassland_C	C	≤ 10%	
		> 10%	
Chaparral/Shrub_A	A	≤ 10%	Shrubland
		> 10%	
Chaparral /Shrub_B	B	≤ 10%	
		> 10%	
Chaparral/Shrub_C	C	≤ 10%	
		> 10%	
Chaparral /Shrub_D	D	≤ 10%	
		> 10%	
Forest_A	A	≤ 10%	Forest, woods
		> 10%	
Forest_B	B	≤ 10%	
		> 10%	
Forest_C	C	≤ 10%	
		> 10%	
Forest_D	D	≤ 10%	
		> 10%	
Agriculture_A	A	≤ 10%	Agricultural land
Agriculture_B	B	≤ 10%	
Agriculture_C	C	≤ 10%	
Orchards_A	A	≤ 10%	Orchards
Orchards_B	B	≤ 10%	
Orchards_C	C	≤ 10%	
LD_Urban_Grass_A	A	≤ 10%	Developed Pervious Areas for Low Density Residential, Parks, etc. (lower irrigation use)
LD_Urban_Grass_B	B	≤ 10%	
LD_Urban_Grass_C	C	≤ 10%	
HD_Urban_Grass_A	A	≤ 10%	Developed Pervious Areas for High Density Residential, Commercial, etc. (higher irrigation use)
HD_Urban_Grass_B	B	≤ 10%	
HD_Urban_Grass_C	C	≤ 10%	
Rural_Imperv	Impervious	≤ 10%	Rural residential, other rural uses
Urban_Imperv	Impervious	≤ 10%	Commercial, industrial, institutional, High density residential
Transportation	Impervious	≤ 10%	Primary or secondary roads

Table 3-7. Block Numbering Convention to Capture Meteorological Variability

HRU	Operations Block	Minimum Index	Maximum Index
Burned_A	PERLND	1	20
Burned _B	PERLND	21	40
Burned _C	PERLND	41	60
Vegetated_A	PERLND	61	80
…	PERLND	…	…
Rural_Imperv	IMPLND	1	20
Urban_Imperv	IMPLND	21	40
Transportation	IMPLND	41	60

3.8 Assignment of Meteorology to HRUs

The final step of the HRU development process is to incorporate weather station assignments, with groups of HRUs assigned to a unique weather station. In terms of model structure, there is a need to preserve a high degree of spatial resolution. Analysis of precipitation data trends suggests that orographic relief noticeably influences observed weather patterns. Weather data are typically assigned according to spatially weighted methods such as the Thiessen Polygon method; however, due to the variable nature of the landscape in this watershed, and considering the relatively dense network of rainfall stations, an overlay of isohyetal rainfall contours and elevation provides better guidance on rainfall data assignments.

VCWPD provided spatial coverages of precipitation isohyetals for a 50-year, 24-hour storm, as well as isohyetals for normal precipitation over the period 1957 to 1992. These coverages aid in accounting for orographic effects when assigning gage information to model subbasins. Figure 3-12 shows the assignment of precipitation stations to HSPF watersheds. Starting with the original Thiessen polygons, assignments were modified to better honor average annual isohyetal lines, including providing a balance between areas likely to be over-estimated or under-estimated by a given precipitation gage.

Upon inspection, it was found that differences between precipitation amounts recorded at gages 254, 204, and 218 are generally small. Further, the hydrological properties of the Santa Ana Creek watershed appeared to be somewhat different from those in the surrounding area. As parameters are assigned to PERLNDs in groups corresponding to weather station assignments, the group of HRUs in this watershed were reassigned to a weighted mix of precipitation recorded at gages 204 (40 percent) and 207B (60 percent), while the remainder of the area surrounding gage 204 was assigned to the adjacent gages 254 and 218. The assignment of additional weather series by precipitation group is summarized in Table 3-8.

Other isohyetals could have been used to guide this process, such as the 100-yr 1-day values from VCWPD (2006), which have added topographical correction. However, it was deemed advisable to use average annual rainfall, rather than extreme events, to provide a representation of the full water balance. Little change in assignments of subwatersheds to precipitation gages would be expected from use of alternate isohyetals.

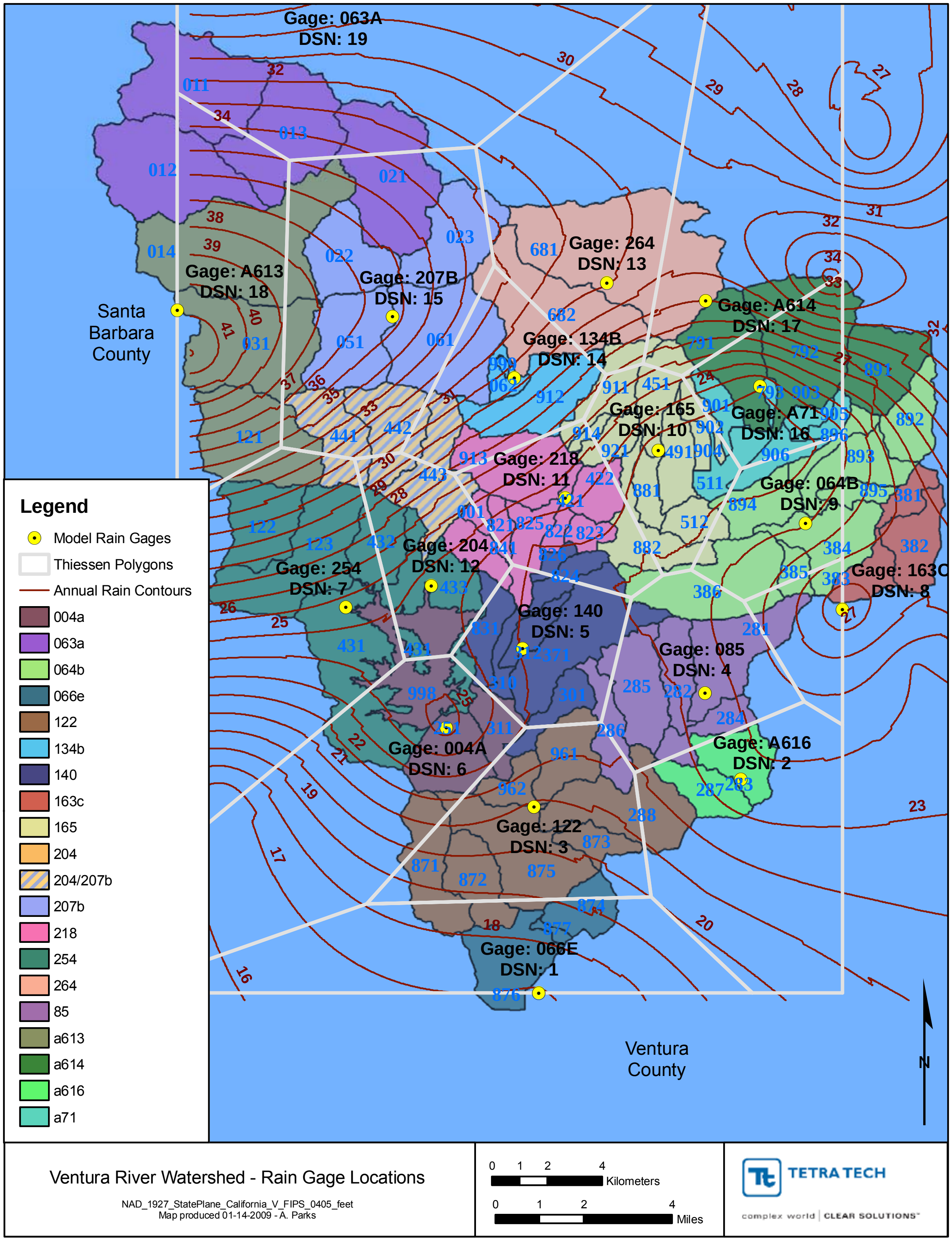

Figure 3-12. Precipitation Station Assignments for Ventura River Watershed

Table 3-8. Assignment of Meteorology to HRUs

Precipitation Index	Precipitation Station	PET station	Air Temperature Station	Mean Elevation (ft MSL)	PET Elevation (ft MSL)	Air Temp. Elevation (ft MSL)
1	Ventura-Downtown (Courthouse)	El Rio	Point Mugu	291	105	9.8
2	Canada Larga Alert	Matilija	Ojai	1,158	1,060	745
3	Ventura-Kingston Reservoir	Casitas	Casitas	638	335	335
4	Canada Larga	Matilija	Ojai	1,227	1,060	745
5	Oak View-County Fire Station	Matilija	Ojai	744	1,060	745
6	Casitas Dam	Casitas	Casitas	715	335	335
7	Casitas Station - Station Canyon	Casitas	Casitas	1,336	335	335
8	Sulphur Mountain	Matilija	Ojai	1,802	1,060	745
9	Upper Ojai-Happy Valley	Matilija	Ojai	1,626	1,060	745
10	Ojai-Stewart Canyon	Matilija	Ojai	1,456	1,060	745
11	Meiners Oaks-County Fire Station	Matilija	Ojai	812	1,060	745
12/15	Lake Casitas-Upper *with* Matilija Canyon	Matilija	Ojai	2,297	1,060	745
13	Wheeler Gorge	Piedra Blanca	Surrogate-3500	3,029	3,050	3500
14	Matilija Dam	Matilija	Ojai	1,693	1,060	745
15	Matilija Canyon	Matilija	Ojai	2,703	1,060	745
16	Senior Gridley Canyon Alert	Matilija	Ojai	1,342	1,060	745
17	Nordhoff Ridge Alert	Piedra Blanca	Surrogate-3500	3,221	3,050	3,500
18	Old Man Mountain Alert	Piedra Blanca	Surrogate-3500	3,274	3,050	3,500
19	Pine Mountain Inn	Piedra Blanca	Surrogate-3500	4,475	3,050	3,500

Note: See Section 2 for information on period of record and procedures used to fill in missing data.

4 Hydraulic Routing Network

Hydraulic routing of water in the Ventura River watershed includes both the natural drainage network and manmade water management. Management structures include dams, reservoirs, debris basins, and direct point source inflows. Human uses of water in the Ventura River watershed are primarily supplied by Lake Casitas and groundwater; there is not significant importation of water. This section describes the methodology for simulating natural and human influenced water management in the Ventura River watershed.

4.1 Stream Segmentation

Stream reach segmentation follows the boundaries of the subbasins described in Section 3.6, and stream segments are generally assigned the same number as the subbasin in which they fall. These watershed boundaries were selected to account for important aspects of the stream network, including FEMA tributaries, tributary junctions, dams, location of gages and water quality monitoring, and so on. The only significant point source discharge is the Ojai Valley WWTP, which is located at the head of reach 875.

An additional objective of channel segmentation is to specify reach lengths that are appropriate to obtaining desired model results. While HSPF is not itself a hydraulic model, the routing algorithms used by HSPF are, in general, related to storage routing and kinematic wave approaches. These algorithms are most accurate when flow time of the flood wave through individual reaches approximates the simulation time step. While the HSPF solution algorithm is designed to maintain stability, accuracy decays rapidly when reach length is shorter than half the celerity times the time step. (Celerity for these channels should be reasonably approximated by 5/3 V, where V is the average velocity evaluated at bankfull conditions.) If channel length is much greater than celerity times the time step, problems are less, but the solution will tend to spread out and reduce short-interval peaks.

For the routing (non-headwater) reaches, the bankfull celerity appears to be on the order of 5-8 ft/s based on existing HEC-RAS models. This suggests that most reaches should be greater than 1.4 miles in length, and all should be greater than 0.85 miles in length. The final model segmentation has a shortest reach length of about 1 mile (reach 421), with most other routing reaches in the 1.5-2 mile range. Therefore, the reach segmentation should be appropriate for obtaining an accurate simulation of channel flow.

Within HSPF it is also possible to set up routing reaches that do not themselves have contributing area. This is used to specify the water surface of the two reservoirs (Lake Casitas and Matilija Reservoir) and several detention basins, as well as to specify the routing of the Robles Diversion from the Ventura River mainstem to Lake Casitas, as the major drainages that intersect the Robles Diversion are piped under the canal or cross over the siphon portion of the canal (personal communication from Neil Cole, Casitas Water, July 16, 2008). No separate routing reaches are specified within individual subbasins; however, in various cases provision is made for multiple outlets from one reach to account for diversions and drains. The network routing is summarized in Table 4-1. The location of the reaches is the same as the watershed subbasins shown above in Figure 3-11.

Table 4-1. Model Reaches and Connectivity for Ventura River HSPF Model

Model Reach	Direct Drainage Subbasin	Upstream Reach(es)	Downstream Reach(es)	Notes
001	001	headwater	841, 825	Live Oak Creek; rerouted by Rancho Matilija Diversion from #841 to #825
011	011	headwater	013	
012	012	headwater	014	
013	013	011	014	
014	014	013, 012	051	FEMA Trib.: Matilija Creek
021	021	headwater	022	
022	022	021, 023	051	
023	023	headwater	022	
031	031	headwater	051	
051	051	014, 022, 031	061	FEMA Trib.: Matilija Creek; Contains active USGS flow gage (11114495)
061	061	051	999	FEMA Trib.: Matilija Creek; Contains active USGS flow and WQ gage (11114500)
121	121	headwater	122	
122	122	121	123	
123	123	122	998	Coyote Creek; Contains active USGS flow gage (11117600)
251	251	998	962	FEMA Trib.: Coyote Creek; Contains active USGS flow gage (11118000)
281	281	headwater	284	Hammond Canyon
282	282	headwater	284	Sulphur Canyon
283	283	headwater	284	Verde Canyon
284	284	281, 282, 283	288	FEMA Trib.: Canada Larga
285	285	headwater	288	Coche Canyon
286	286	headwater	288	Canada de Aliso

Model Reach	Direct Drainage Subbasin	Upstream Reach(es)	Downstream Reach(es)	Notes
287	287	headwater	288	Leon Canyon
288	288	284, 285, 286, 287	875	FEMA Trib.: Canada Larga
301	301	headwater	311	Fresno Canyon
310	310	824, 825, 994	311	FEMA: Ventura mainstem above San Antonio
311	311	301, 310, 311, 312, 371, 831	962, diversion	FEMA: Ventura mainstem. Contains active USGS flow gage (11118400) and active flow and WQ gage at basin outlet (11118500). Contains Foster Park diversion, which removes water from system.
312	312	headwater	311	FEMA Trib.: Oak View Drain
371	371	386, 882	311	FEMA Trib.: San Antonio Creek; Contains active USGS flow gage (11117500)
381	381	headwater	384	
382	382	headwater	384	Lion Canyon
383	383	headwater	384	
384	384	381, 382, 383	386	Lion Canyon
385	385	headwater	386	
386	386	384, 385	371	Lion Canyon
421	421	(921)	825	FEMA Trib.: McDonald Canyon Drain South; Prior to 1972 this area (Subbasin #421) drained McDonald Canyon Drain South (#921)
422	422	headwater	822, 825	FEMA Trib.: Happy Valley Drain; Prior to 1973 this area (Subbasin #422) flowed into Happy Valley Drain South (#822), Post 1973 it drains to #825
441	441	headwater	442	
442	442	441	443	
443	443	442	998	Contains active USGS flow gage (11117800)
451	451	headwater	996	Stewart Canyon; Stewart Canyon Debris Basin Outlet

Model Reach	Direct Drainage Subbasin	Upstream Reach(es)	Downstream Reach(es)	Notes
491	491	904	882	FEMA Trib.: Fox Canyon Barranca; VCWPD Gage 631 located near outlet
511	511	791, 792, 793, 901, 902, 904	512	FEMA Trib.: San Antonio Creek
512	512	511, 894, 906	882	FEMA Trib.: San Antonio Creek
681	681	headwater	682	
682	682	681	912	Contains active USGS flow and WQ gage (11116000)
791	791	headwater	511	
792	792	headwater	511	Senior Canyon; San Antonio Creek Debris Basin Outlet
793	793	headwater	511	
821	821	headwater	825, 841	Prior to 1983 this area (Subbasin #821) flowed into Live Oak Creek via Subbasin #841. After 1983 #821 flowed to #825.
822	822	823, (422)	825	FEMA Trib.: Happy Valley Drain South; Prior to 1973 this area (Subbasin #822) drained Happy Valley Drain (#422)
823	823	headwater	822	FEMA Trib.: Miramonte Drain
824	824	headwater	310	FEMA Trib.: Skyline Drain
825	825	001, 421, 422, 821, 822, 826, 913	310	FEMA: Ventura mainstem. Prior to 1983 Subbasin #821 flowed into Live Oak Creek via Subbasin #841. After 1983 #821 flowed to #825. Between 1983 and 2002 it is unknown how much flow came from Subbasin #001 into #821 versus to #841. Starting Late 2002 all flow from #001 was routed to #821, and thus to #825.
826	826	headwater	825	FEMA Trib.: Mirror Lake Watershed
831	831	841, 994	311	Live Oak Creek.
841	841	001, 821	831, 994	Live Oak Creek. Reach 001 disconnected late 2002. Originally flowed to #310. Starting in late (Nov?) 2002, #841 redirects any discharges ranging from 20-800 cfs to #310. Flows less than 20 cfs and greater than 800 cfs flow to #831.
871	871	headwater	872	
872	872	871	876	

Model Reach	Direct Drainage Subbasin	Upstream Reach(es)	Downstream Reach(es)	Notes
873	873	headwater	875	FEMA Trib.: Manuel Canyon
874	874	headwater	876	FEMA Trib.: Canada de San Joaquin
875	875	288, 873, 961, 962	876	FEMA: Ventura mainstem. Ojai WWTP located at upstream boundary
876	876	872, 874, 875, 877	Pacific Ocean	FEMA: Ventura mainstem.
877	877	headwater	876	FEMA Trib.: Dent Drain
881	881	996	882	FEMA Trib.: Stewart Canyon
882	882	512, 881, 491	371	FEMA Trib.: San Antonio Creek
891	891	headwater	896	
892	892	headwater	893	
893	893	892	894	FEMA Trib.: Reeves Creek
894	894	893, 895, 896	512	FEMA Trib.: Thacher Creek; VCWPD Gage 669 located near outlet
895	895	headwater	894	
896	896	891	894	FEMA Trib.: Thacher Creek
901	901	headwater	511	Dron Creek
902	902	headwater	511	Crooked Creek
903	903	headwater	906	
904	904	headwater	491, 511	FEMA Trib.: East Ojai Drain; All flow drains to Grand Ave. via East Ojai Drain and storm sewer adjacent storm sewer. Lower flows enter 41" pipe and discharge to basin 511. Excess flows overflow to Grand Ave. sewer system and drain to basin 491.
905	905	headwater	906	McNeill Creek
906	906	903, 905	512	FEMA Trib.: McNeill Creek
911	911	headwater	913	FEMA Trib.: Cozy Dell Canyon

Model Reach	Direct Drainage Subbasin	Upstream Reach(es)	Downstream Reach(es)	Notes
912	912	682, 999	913, 997	FEMA: Ventura mainstem. Robles Diversion downstream, contains inactive USGS flow gage upstream (11116500) and active flow gage downstream (11116550), CMPD Gage 610 at Robles Casitas Canal flume
913	913	911, 912, 914, 921, 995	825	FEMA: Ventura mainstem. VCWPD Gage 633 measures flow for Happy Valley Drain (422) and McDonald Canyon Drain South (421)
914	914	headwater	913	
921	921	headwater	421, 913, 995	McDonald Canyon Drain; Prior to 1972 this area (Subbasin #921) flowed into McDonald Canyon Drain South (#421). After 1972 flow was diverted to #913 via the Cozy Dell Canyon outlet
961	961	headwater	875	: Weldon Canyon
962	962	251, 311	875	FEMA: Ventura mainstem.
994	none	841	310, 831	Live Oak Diversion Basin (active WY 2003 on), reach only
995	none	921	913	McDonald Detention Basin, reach only
996	none	451	881	Stewart Canyon Debris Basin, reach only
997	none	912	998	Robles Diversion Channel, reach only
998	431, 432, 433	123, 423, 997	251	Lake Casitas (reach)
999	062	061	912	Matilija Reservoir, reach defined to active USGS flow gage (11115000) and USGS flow and WQ gage (11115500) in basin 062

4.2 Functional Representation of Hydraulics (FTables)

The modeled stream network is composed of natural streams, reservoirs, debris basins, and diversion structures. HSPF models hydrology, but does not directly simulate hydraulics. Rather, the hydraulic behavior of stream reaches is specified externally through Function Tables (FTables) that define stage-storage-discharge relationships. One useful source of this information is from a hydraulic stream channel model, such as HEC-RAS.

4.2.1 Use of HEC Flood Elevation Models

HEC-RAS is a one-dimensional hydraulic model of water flowing through natural channels. Capable of modeling complex stream networks, dendritic systems or a single river reach, HEC-RAS is typically used for channel flow analysis and floodplain determination. HEC-RAS applications provide an excellent basis for creating the FTables at selected points within a stream network. The accuracy of the generated FTable is dependent upon the spacing and number of HEC-RAS cross sections throughout a stream network, as well as the accuracy of the measured flows used to correlate river stage to discharge. HEC-RAS can interpolate between cross sections if the gaps are relatively small, but large gaps can eliminate the usefulness of disconnected upstream sections for F-table generation. If several measured flows are provided with a HEC-RAS model (e.g., flows from the 10-, 50-, 100-, 500-year return periods), the HSPF modeler can interpolate additional flows using percent differences in order to complete enough points in an FTable. As previously mentioned, data from adjacent stream gages can also be used to establish flow profiles in HEC-RAS for a particular reach.

The available HEC models for the Ventura River were assembled and analyzed to determine their extents, connectivity, and relevance to the watershed model. VCWPD provided a HEC-RAS model of the Ventura River mainstem from Matilija Dam to the Pacific Ocean, along with two partial HEC-RAS models of San Antonio Creek. Tetra Tech used LIDAR data to complete the HEC-RAS model of San Antonio Creek from Ojai to the Ventura River for FTable generation purposes. (This model application does not include detailed surveys of bridges and other structures outside of the original partial HEC-RAS models, and so is not applicable to detailed flood elevation modeling. However, it does provide a strong basis for estimating reach-scale FTables.)

The Ventura mainstem HEC-RAS model included peak flows for seven return periods at various flow change points along the mainstem (Table 4-2). The partial models of San Antonio creek did not include a full set of peak flows, so these were generated with the HSPF model.

Table 4-2. HEC-RAS Peak Flows along Ventura River (cfs)

Return Period (yr)	Upstream Confluence w/ N. Fork Matilija Cr.	Downstream Confluence w/ N. Fork Matilija Cr.	Baldwin Rd.	Casitas Springs	Casitas Rd. Bridge	Shell Chemical Plant
2	3,060	3,250	3,380	4,130	4,520	5,080
5	7,090	7,580	7,910	9,820	11,060	12,250
10	12,500	15,000	16,000	35,200	36,400	41,300
20	15,200	18,800	19,800	44,400	46,400	52,700
50	18,800	24,000	24,800	56,600	59,700	67,900
100	21,600	27,100	28,300	66,600	69,700	78,900
500	27,900	35,200	36,700	89,000	93,100	105,500

To use HEC-RAS to generate FTables, additional flow profiles are created for every flow change point along a modeled reach in order to account for lower flows and improve FTable accuracy. Most HEC models already contain several observed flow profiles for various flood return periods (e.g., 10-, 50-, 100-, 500-yr storms); however, more flow profiles are needed to create an FTable, and Tetra Tech developed additional flow profiles (ranging between base flow and the 500-yr event peak flow) starting with the most upstream cross section. Finally, downstream flows are calculated for each flow change point and flow profile using the mean percent flow change values.

For each flow profile, HEC-RAS models provide the following water surface profile outputs for FTable generation:

- Q Total – total flow in cross section (cfs)
- Length Wt – weighted cross section reach length based on flow distribution (ft)
- Max Chl Dpth – maximum main channel depth (ft)
- SA Total – cumulative surface area for entire cross section from the bottom of the reach (acres)
- Volume – cumulative volume of water in the direction of computation (acre-ft)

Each point (or flow profile) representing the discharge-storage-surface area relationship by computed FTable is thus a weighted average of channel stage and discharge that is based on the weighted cross section reach length within the entire modeled reach. Also included for each flow profile in the FTable are the cumulative surface area and water volume between the reaches' upstream and downstream cross section.

4.2.2 Regional Curve Fitting

The majority of the delineated subbasins within the Ventura River watershed lack stream gage stations and existing hydraulic models to formulate FTables. However, the availability of high resolution topographical data (LIDAR) for 27 of the 88 non-lake subbasins provides Tetra Tech an alternative approach for FTable generation in lieu of using generic regional FTables. In general, hydraulic geometry data (i.e., historic bank height, top width, bottom width, floodplain width and side slope) can be measured at selected subbasin outlets, as well as the corresponding upstream drainage area. A trapezoidal channel is used to approximate the observed channel geometry, as illustrated in Figure 4-1.

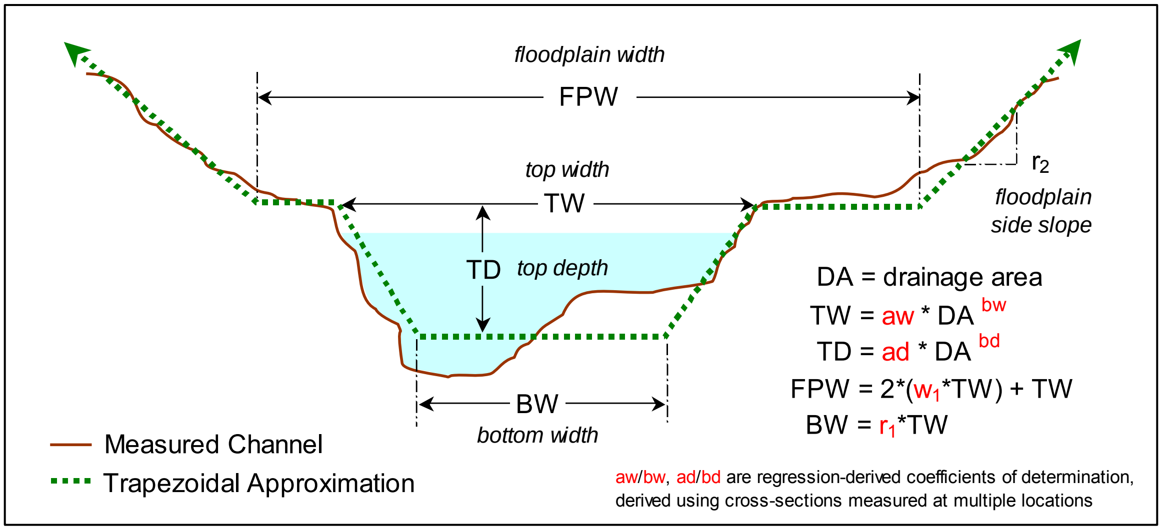

Figure 4-1. Trapezoidal Cross-section Estimate of a Measured Channel

Channel geometry from multiple ungaged locations in the Ventura River watershed was used to derive two power function regression equations for top width and top depth as follows:

$$\text{TW} = aw \cdot \text{DA}^{bw}$$

$$\text{TD} = ad \cdot \text{DA}^{bd}$$

TW and TD are historic channel top width and top depth (average depth based on average trapezoidal cross-section area), DA represents the cumulative drainage area, and *aw/bw* and *ad/bd* are the derived coefficients of determination for width and depth, respectively.

The sample set of 23 subbasins was classified and group the subbasins as either "urban" or "rural" in order to improve the regressions. Figure 4-2 shows an example of the fitted power functions for the rural subbasins.

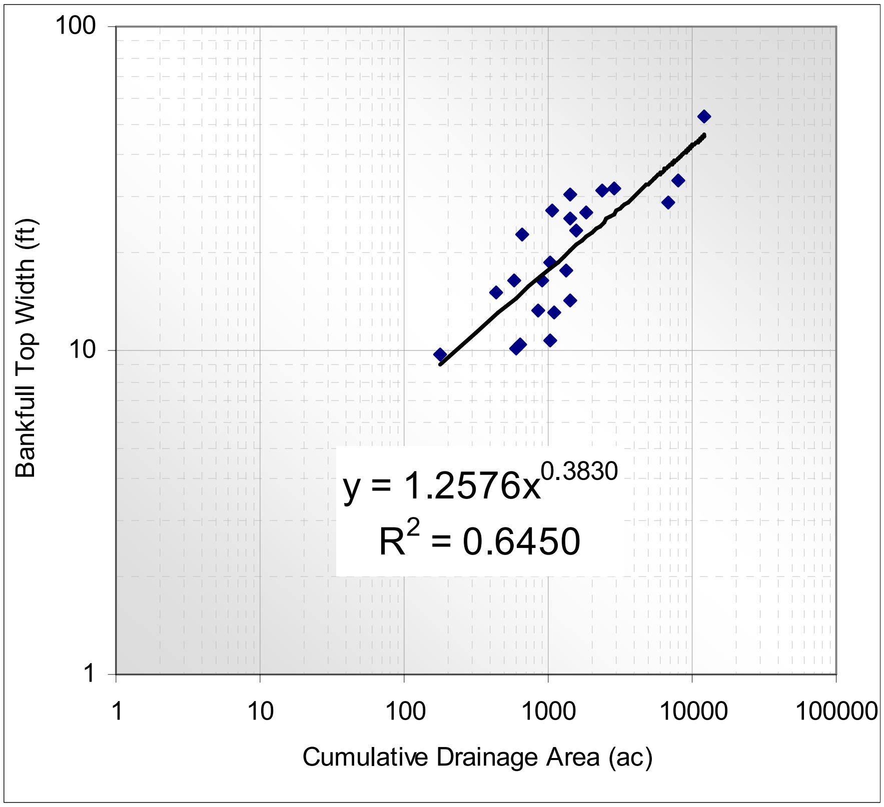

Figure 4-2. Fit for Bankfull Top Width in Rural Subbasins

After deriving the parameters for the power function curves, Tetra Tech used these Ventura River regional relationships to approximate trapezoidal geometry for the remaining reach outlets not measured directly from LIDAR data using their associated upstream drainage area.

The estimated FTables were based on the predicted channel geometry at the centroid of each subbasin. An average stage-storage and stage-surface area relationships for the subbasin was subsequently developed for all the subbasins. Measured floodplain geometry was also approximated and related to top width as illustrated in Figure 4-1. The r_1, r_2, and w_1 terms in the diagram represent scaling factors which are used to estimate bottom width, floodplain side slope, and floodplain width, respectively for a trapezoidal channel. These terms are derived independently using the observed channel geometry and applied directly to the regression results to complete the rest of the trapezoidal channel geometry. For various stages within the main channel and floodplain, weighted storage and weighted surface area are calculated by multiplying the average cross-section area and the average top width, respectively, by the total stream length within the subbasin. While stage-discharge rating tables can easily be created for subbasins with USGS or VCWPD gages near their outlets that contain sufficient peak flow data, Manning's equation was used to calculate stream discharges at varying depths for the non-gaged subbasins.

FTables derived using regional regressions are subject to considerable uncertainty and are less reliable than those developed using HEC models. This impacts the shape of the hydrograph, but generally has only a moderate effect on flood peaks, which are determined primarily by rainfall intensity. Accurate FTables are most important for future sediment simulation, as channel scour processes are very sensitive to hydrograph shape. It is clear, however, that the accuracy of flood peak predictions will be less using the regional regression than in reaches for which HEC models are available.

4.3 Reservoirs

Several approaches can be taken to incorporate the dams and reservoirs into an HSPF model: (1) Represent outflow by a functional stage-storage-discharge relationship, derived from rating curves or a weir equation; (2) Represent outflows by measured demand time series (potentially with a correction to maintain proper storage); or (3) Use a combination approach with demand time series for water released through the outlet works and stage-storage-discharge relationships for uncontrolled flow over the spillway. Where the primary interest is in accurate prediction of flows downstream of the dams, it is preferable to use approach (2) or (3). The disadvantage is that these approaches require data.

The watershed contains two significant dams and associated reservoirs: Lake Casitas and Matilija Reservoir (Figure 4-3).

Lake Casitas, completed in 1959, is part of the U.S. Bureau of Reclamation Ventura River Project and supplies the majority of water for human use in the watershed. Casitas Dam impounds Coyote Creek, and Santa Ana Creek; however, the major source of water for the reservoir is a diversion from the Ventura River mainstem via the Robles Diversion. Lake Casitas has an active capacity of 251,000 acre-feet (AF) and a storage capacity of 254,000 AF. Lake Casitas provides irrigation, municipal, and industrial water to urban and suburban areas with the Casitas Municipal Water District.

Casitas Water provided daily information on storage and releases in Lake Casitas from 1998 to present, with monthly data available prior to 1998. Elevations in Lake Casitas did not approach storage capacity until about 1970. Water leaves Lake Casitas primarily via the water treatment plant and conveyance system. There have also been controlled releases and spillage downstream; however, the controlled releases generally ceased in 1996, while flow over the spillway occurs infrequently (Figure 4-4).

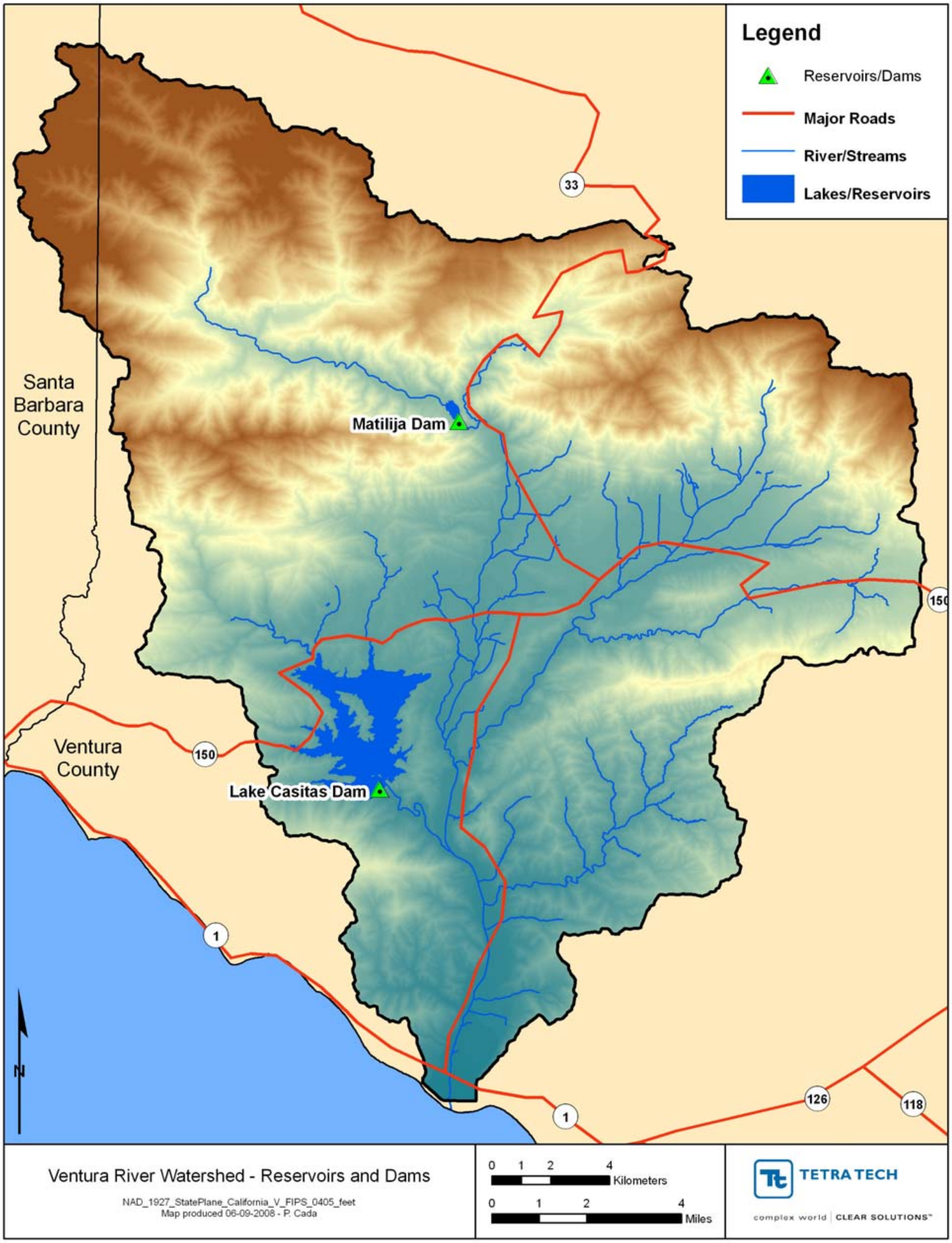

Figure 4-3. Reservoirs in the Ventura River Watershed

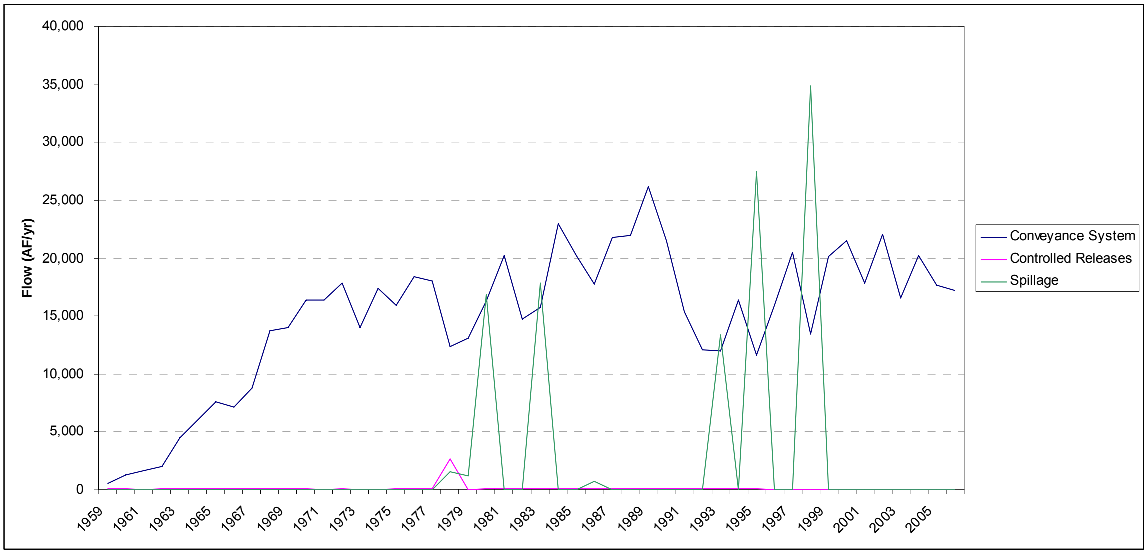

Figure 4-4. Annual Outflow of Water from Lake Casitas

Although infrequent, the model needs to account for spillage from Lake Casitas during wetter periods. Daily data are not available for the historic period in which spills have occurred. Flow over the spillway can be predicted using an appropriate stage-storage-discharge curve, reflecting spillway characteristics, available from Casitas Water. However, prediction of spills requires accurate accounting of inflow, evaporation and other losses (e.g., to groundwater), and consumptive use, all of which are subject to uncertainty. To help minimize error during model calibration and validation, Tetra Tech used HSPF SPECIAL ACTIONS to reset the storage volume in Lake Casitas to measured values at the start of each month.

Within the model, Lake Casitas is simulated with three outlets. Outlet 1 is flow over the spillway, described via a rating curve incorporated in the FTable; Outlet 2 is consumptive use, specified as an external demand time series; and Outlet 3 is controlled releases, also specified as an external demand time series. Only Outlets 1 and 3 are routed to the downstream reach.

Matilija Dam was constructed in 1947 by the Ventura County Flood Control District as both a flood control and water supply facility. The dam originally provided 7,018 AF of storage. The available storage volume was, however, rapidly depleted by sedimentation. The concrete in the dam also experienced corrosion, and the dam was lowered by cutting a 285-ft wide notch in 1965, reducing the nominal capacity (without accounting for sedimentation) to 65 percent of the original. In 1978, the notch was widened to 385 ft, with no additional change in elevation. As of 2004, the dam was estimated to provide only 500 remaining AF of surface water storage (Greimann, 2006).

The effective storage in Matilija Reservoir appears to be much greater than 500 AF, however, as the reservoir is able to discharge much more than 500 AF in excess of estimated inflows after the cessation of spring floods. We theorize that the material that has infilled the reservoir is largely unconsolidated with high porosity, providing a significant volume of shallow groundwater storage that can be slowly drained. A series of model sensitivity tests for the 1996-2007 period suggests that the total effective storage of both surface and ground water in Matilija Reservoir is around 3200 AF, or around 2/3 of the expected original storage volume of 4561 AF after the dam was notched. The amount of water available for outflow appears to be greater than is explained by concurrent baseflow discharge for the upstream watershed.

The available records for Matilija Reservoir consist of water elevations and notes on percent opening of various outflow valves. Controlled releases are apparently cycled through the day to optimize inflow into the Robles diversion. Water elevations are reported only on weekdays, and are only available in hardcopy prior to 2001. The lack of data on storage and discharge presents a challenge for simulation, which is compounded by the evidently rapid decline in storage capacity.

Fortunately, flow has been gaged since 1927 a short distance downstream of Matilija Reservoir (gages 602 and 602A), including daily average flows and event peaks. The best option for simulating Matilija Reservoir during the calibration/validation runs is thus to represent outflow as a demand time series representing the downstream gaging and independent of simulation storage. Because Matilija Dam is effectively simulated "as if" located coincident with the gage, the subbasin boundary has been extended to the gage, rather than ending exactly at Matilija Dam.

Because the gage downstream of Matilija does not report sub-daily flows on a regular basis, the gage record is not sufficient to represent flood peaks that overtop Matilija Dam. Accordingly, the following approach is taken to estimate effective releases from Matilija:

1. Recorded daily gage flow below Matilija (gage 602) up to a maximum of 500 cfs (the approximate magnitude of flow that can be released via the various outlet works) is assigned as a demand outflow time series.
2. When the total effective storage is exceeded, releases of excess water are estimated using an FTable based on a weir equation representing overtopping of the dam crest.
3. Sub-daily release rates from Matilija are estimated as the maximum of the rates obtained from (1) and (2).

Runoff from the steep, high-elevation watersheds upstream of Matilija appears to have significant losses to deep groundwater, based on calibration to the gage above Matilija. It is likely that much of this stored water can eventually discharge into Matilija Reservoir when head in the reservoir is low, as is suggested by the fact that releases from Matilija are maintained even during extended drought periods. Therefore, HSPF SPECIAL ACTIONS were used to assign an inflow from groundwater to Matilija, estimated, based on trial and error, as 3 cfs when the storage volume in Matilija is less than 1/3 of full pool. A constant inflow of 3 cfs from groundwater upwelling is also supplied at all times.

This ad hoc approach is able to reproduce the complete series of observed daily flows below Matilija with a high degree of accuracy, while also providing a reasonable estimate of transient flood peak flows across the dam. However, the uncertainties inherent in the approach, including, in particular, accurate estimates of the storage capacity of Matilija Reservoir over time, do limit the accuracy of estimated flood peaks leaving Matilija, which in turn limits the potential accuracy of predicted flood peaks throughout the Ventura River mainstem.

4.4 Debris and Detention Basins

The steep headwaters of the Ventura River watershed present a risk of flash floods and debris flows. To address these risks, several debris basins have been constructed in the watershed. In terms of the flow of water, these function as dry detention basins. Four such dry detention/debris basins are located in the watershed (Figure 4-5):

1. McDonald Detention Basin
2. San Antonio Creek Debris Basin (not represented in model; see below)
3. Stewart Canyon Debris Basin
4. Dent Debris Basin (not represented in model; see below)

In addition, the Live Oak diversion is operated by means of a detention basin that is also explicitly represented in the model.

Of the four existing debris basins, Dent Debris Basin is located in a headwater region with a drainage area of only 19 acres. At the recommendation of VCWPD, this basin is not explicitly represented in the model. There was also a historic debris basin constructed on the main channel of San Antonio Creek to control sediment flow following a fire in the 1980s. This basin was not maintained and has since filled in to the point where it is unrecognizable. While there are as-built plans, there is no information on the rate of filling of this basin, which is believed to have occurred quickly. Given the lack of data on the filling of this basin, it is not represented in the model.

The debris basins are represented in the model using stage-storage-discharge relationships that describe outflow through the two exits provided by the riser and the spillway. The most detailed data regarding the detention basins are included in the VCWPD's Debris Basin Report. This report includes stage-storage and stage-discharge curves, watershed areas, and basin and primary outlet structure dimensions. The information appears to be sufficient to set up an accurate representation in the model. It should be noted, however, that the model does not account for sediment accumulation in the debris basins and associated impacts on storage capacity.

4.5 Diversions and Withdrawals

Four major on-stream diversion structures and conveyances have been identified in the Ventura River watershed. Three diversions are represented spatially in the GIS; the fourth (Foster Park) is shown only as a point. In addition, there have been a number of minor withdrawals by irrigators, domestic users, and industrial users. In 1981, there were apparently a total of 45 minor withdrawals, as noted in the Data Report (Tetra Tech, 2008).

Water stored in Casitas Reservoir is in large part derived from the Ventura River via the Robles Diversion Dam and the Casitas-Robles Canal. Gage records are available for the Robles Diversion, including monthly data from 1959-2007 and daily flows for 2001-2006. This diversion is represented as a demand time series, one of two outlets from reach 912.

Prior to 2001, daily flows into the Robles diversion are estimated based on a regression equation relating daily inflow into the Robles diversion to flows at gage 602 below Matilija Dam, capped at a flow of 500 cfs, the capacity of the diversion. The regression (based on upstream flows less than 450 cfs) has a slope of 0.989 and an R^2 of 91 percent. However, because the actual operation of the diversion is subject to human intervention, estimates of the flow proceeding downstream are less accurate prior to 2001.

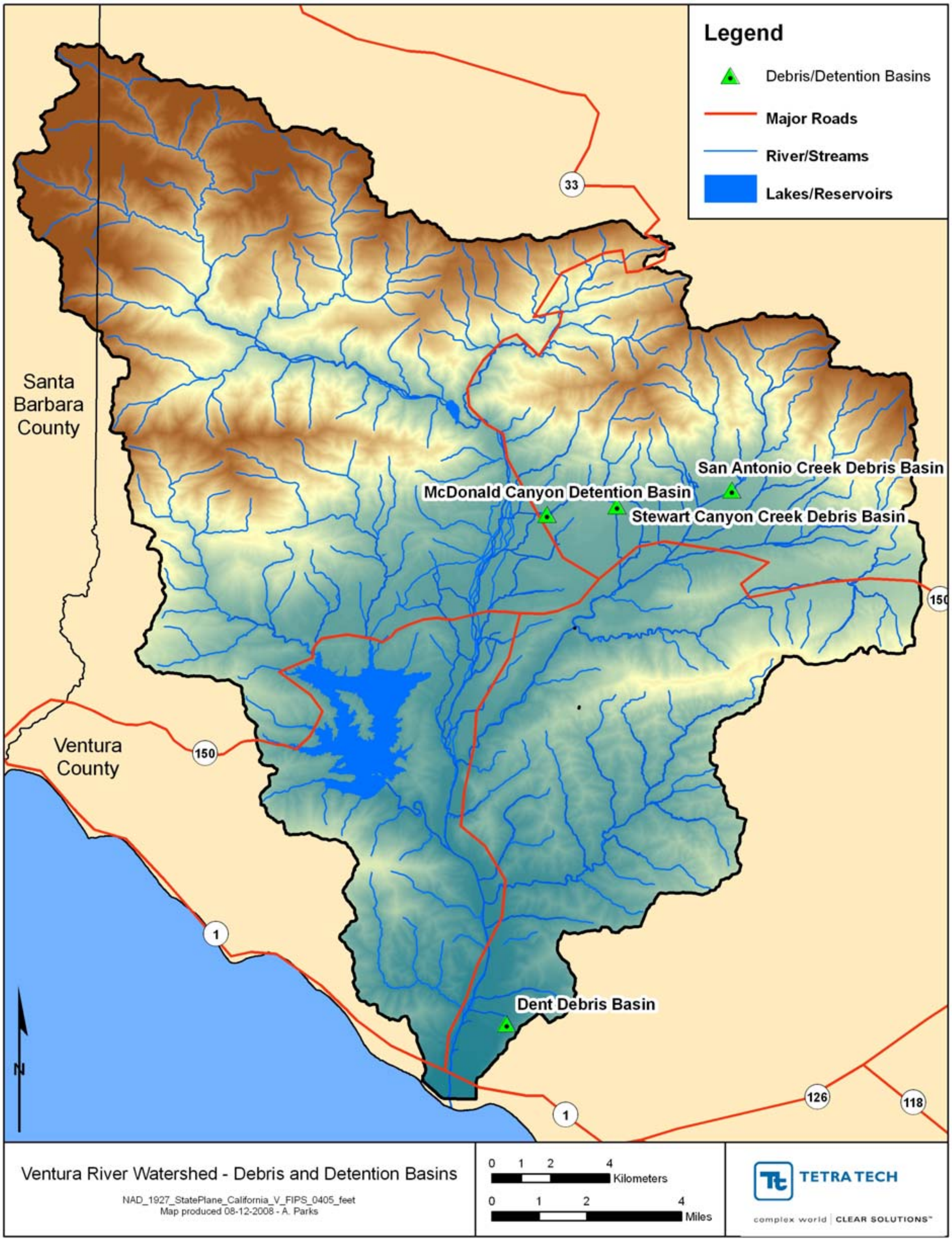

Figure 4-5. Location of Functioning Debris Basins in the Ventura River Watershed

The Foster Park diversion on the Ventura River mainstem (reach 311) supplies water to the City of San Buenaventura. The diversion is apparently via a pipe embedded in the alluvium, and so may include both surface and shallow subsurface flow – but these flow types are difficult to separate in this stretch of the river, which has high storage capacity in the alluvium. Therefore, the diversion is represented as a second flow outlet from the mainstem reach. Daily gaged flows for the Foster Park diversion are available through September 2007 from USGS gage 11118400.[1] Sensitivity analyses suggest an assumption that 50 percent of the Foster Park diversion is derived from surface flows provides reasonable results.

The other two mapped diversions – Live Oak and Rancho Matilija –function primarily to reroute flow in upper Live Oak Creek (Figure 4-6). Through 1985 there were also diversions from Matilija Reservoir to percolation basins on San Antonio Creek. Details of this diversion have not been obtained; however, it ceased operation prior to the model calibration and validation periods.

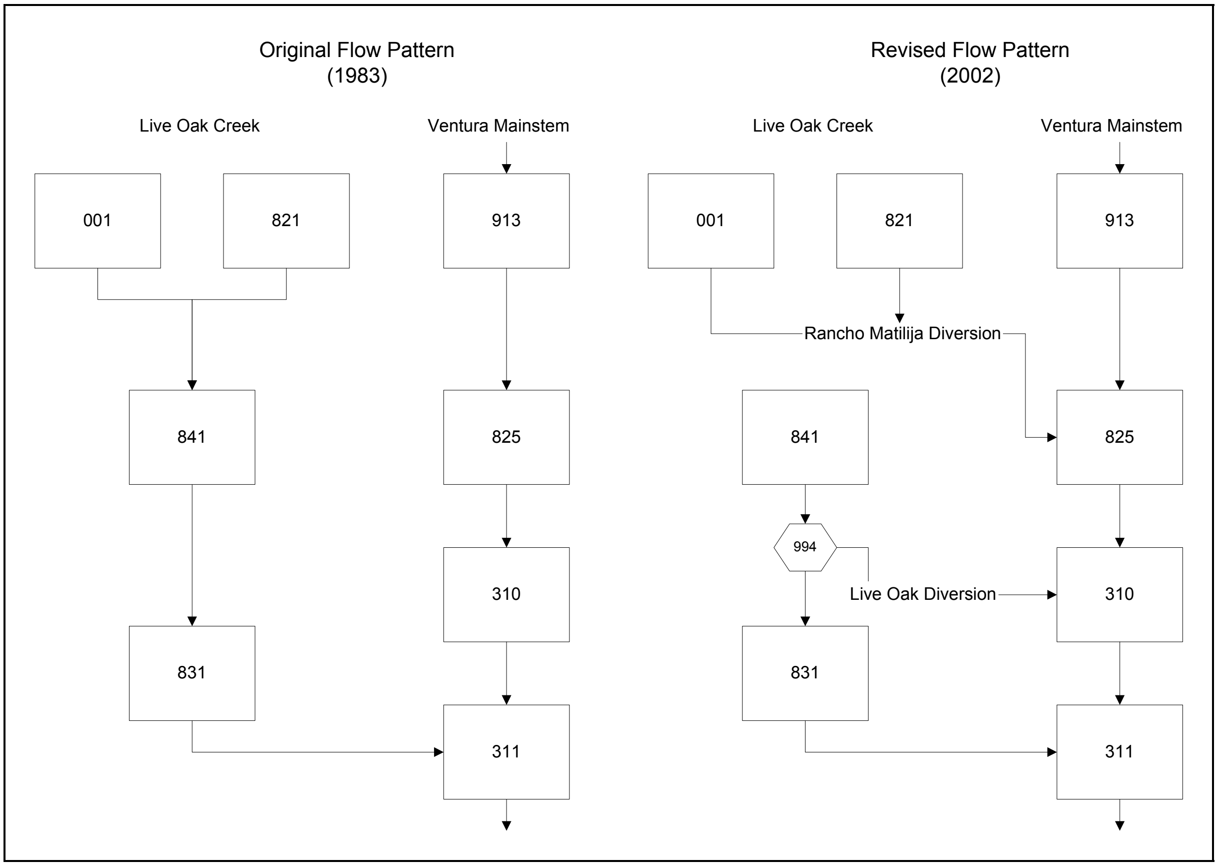

Figure 4-6. Reorganization of Flow in Live Oak Creek

While no gaging data are available, the time periods for which subareas drained to these diversions were provided. Prior to 1983, all flow in Live Oak Creek (subbasins 001, 821, 831, and 841) flowed down the natural channel, joining the Ventura River mainstem in reach 311. Following the initial construction of the Rancho Matilija Diversion in 1983, subbasin 821 was diverted to the Ventura River at reach 825.

[1] USGS recently ceased operation of this gage. Extension of the model beyond September 2007 will require alternate estimates of diverted flows, which can presumably be supplied by the City.

Between 1983 and completion of the Rancho Matilija Diversion in 2002, it is unknown how much flow was diverted from subbasin 001; however, after 2002, all flow from subbasin 001 is known to have been diverted to the Ventura River at reach 825 via the Rancho Matilija Diversion. The model represents this change as having occurred at the beginning of water year 1984. (Because of the small size of subbasin 001, any errors introduced by this assumption are small.)

Starting in late (Nov?) 2002, the Live Oak Diversion redirected flows ranging from 20 to 800 cfs to the Ventura River mainstem at reach 310 via a detention basin (Reach 994). Flows less than 20 cfs and greater than 800 cfs continue to flow to reach 831. The Debris Basin Manual provides all the stage-storage-discharge-surface area curves necessary to describe the flow through the Live Oak Creek Diversion (plus the low-flow to Live Oak Creek).

Changing patterns of diversions over time are live-linked in the model by setting up FTables that contain multiple outlets representing all possible configurations of the diversions. Column indices (COLINDs) are assigned as time series in the EXTERNAL SOURCES block of the model to indicate which columns of the FTables should be used at which points in time.

Given the lack of data and apparent small significance to the total water balance, additional minor private withdrawals of surface water from the stream network are not explicitly represented in the model. The effect of such withdrawals may be implicitly included as part of the accounting of exchanges with groundwater.

4.6 Stream Reach Interactions with Groundwater

Calibration of a hydrologic model requires that all portions of the water balance be accounted for. In addition to the surface runoff component, the flow in a stream channel may also discharge to or be recharged by the shallow groundwater zone. In some cases, water is “lost” from the system by percolation to deep aquifers. The interactions of streams and groundwater are influenced by the amount and timing of precipitation, soil characteristics, and land use/land cover. Underground fault lines within the watershed also have an impact on the interactions between ground and surface water.

In coastal California, groundwater aquifers are typically insignificant in upland areas, but play a major role in lowland alluvial areas. Tetra Tech obtained a GIS layer showing all the major underground fault lines, major groundwater basins, and locations of the major upwelling and downwelling sites. VCWPD also provided a GIS layer of all the groundwater wells within the watershed. Tetra Tech expects no further spatial data regarding this topic at this time.

The four major groundwater basins within the Ventura River watershed are the Ojai Valley Basin, the Upper Ojai Basin, the Upper Ventura Basin, and the Lower Ventura Basin (Figure 4-7). The hydrogeology of all four basins is described in the *Ventura County Water Resources Management Study, Geohydrology of the Ventura River System: Ground Water Hydrology* (Ventura County Flood Control District, 1971). More recent hydrogeologic information regarding the Ojai Valley Groundwater Basin is described in the following reports:

- *Ojai Valley Basin Ground Water Management Plan* (OBGMA, 2007)
- *Hydrologic Assessment: San Antonio Creek Sub-Watershed* (Stephens and Associates, 2007)
- *Hydrogeology of the Ojai Groundwater Basin: Storativity and Confinement, Ventura County, CA* (Kear, 2005)

Most of the recharge to the Ojai Basin occurs where Thacher Creek, San Antonio Creek, and Reeves Creek enter the basin at alluvial fan heads. All three exit the basin as the near-perennial San Antonio Creek, fed by effluent groundwater from the Ojai Basin, which has a storage volume of up to 85,000 AF. Significant losses from the stream to ground water occur in the Ojai Basin (Stephens and Associates, 2007). Up until 1985, water was diverted from Matilija Reservoir to the San Antonio Creek spreading grounds, located downstream of the confluence of Gridley Canyon and Senior Canyon creeks, and used to recharge the ground water basin. (No records of these diversions have been obtained.) Use of the spreading grounds was discontinued following the 1985 fires and construction of a temporary debris basin on San Antonio Creek that destroyed most of the percolation basins (OBGMA, 2007); however, rehabilitation of the percolation basins has been proposed.

Groundwater is typically withdrawn from shallow wells in alluvial basins. Due to the porous nature of the alluvium, surface and groundwater are closely linked. The most substantial withdrawals on the mainstem in 2001 were as follows (Entrix, 2001):

- Meiners Oaks County Water District operates two wells about 1 mile downstream of Matilija Dam and two wells in the vicinity of Meiners Oaks. As of 2001, about 1,300 AF/yr was produced by these wells.
- Ventura River County Water District operates three wells between Meiners Oaks and the Highway 150 crossing, producing about 1,200 AF/yr as of 2001.
- City of San Buenaventura operates four wells in the Foster Park area, producing about 3,900 AF/yr as of 2001.

Annual groundwater extraction volumes between 2004 and 2007 were also provided to Tetra Tech for approximately 115 of the wells located in the Ojai Groundwater Basin. However, no groundwater simulation models have been developed for the watershed. Groundwater use between 1981 and 2005 averaged approximately 5,170 acre-feet per year, of which 35 percent was pumped by Golden State Water Company for domestic and municipal supply (OBGMA, 2007).

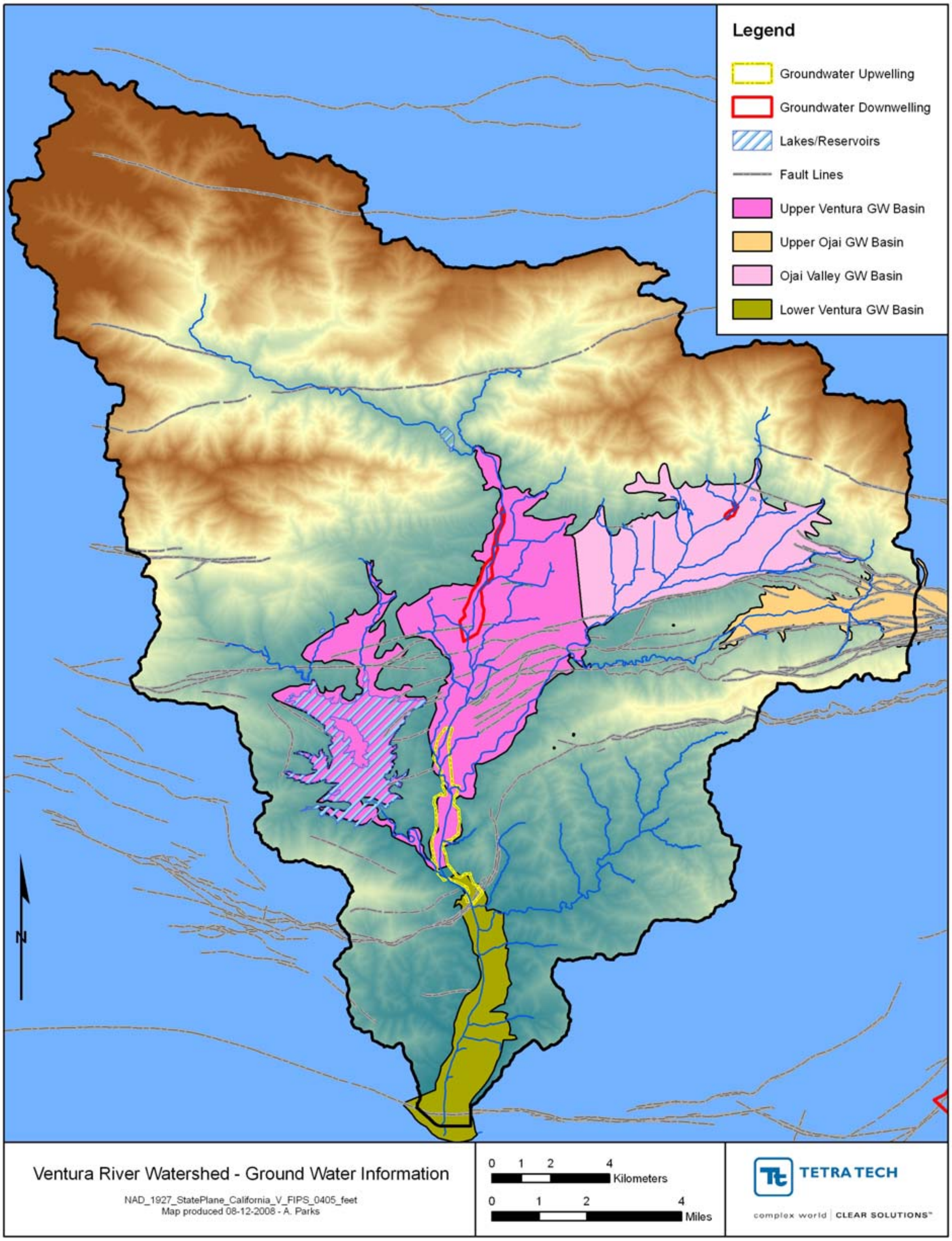

Figure 4-7. Groundwater Basins, Upwelling and Downwelling Areas, and Fault Lines

As there is not a groundwater model available, and primarily qualitative information is available on surface-groundwater interactions, the model treats groundwater interactions in an approximate manner, with some adjustments during calibration. The following assumptions are made:

1. Interactions between reaches and groundwater other than those simulated directly by the HSPF model are applied only within the major identified groundwater basins (see Figure 4-7).
2. Losses from stream reaches to groundwater are assigned only in those reaches identified as "groundwater downwelling" areas (including the San Antonio Creek spreading grounds) or where major well fields are known to be located in the alluvial aquifer adjacent to the stream.
3. Loss rates in losing reaches are specified as a second demand outflow from the reach. The original plan was to estimate these losses as a function of flow so as to be able to account for impacts of changes in runoff in response to changes in land use, but without the necessity of a full groundwater balance, for which the U.S. Bureau of Reclamation's simplified empirical Moritz formula (Moritz, 1913, 1915) was proposed. This approach, which estimates channel loss as a function of discharge, was found to perform adequately in the Santa Clara watershed (Aqua Terra, 2008). However, the Moritz approach did not provide useful results in the Ventura River. This is because the approach is designed for losses from unlined canals that do not intercept the water table. In the Ventura alluvial valleys the water table appears to vary seasonally, and some reaches both gain and lose water at different times of the year. Loss rates may be smallest in the wettest periods, when the water table is elevated, and may be higher during dry periods when the water table is lowered and groundwater extraction is at a maximum – exactly the opposite of what the Moritz equation would predict. Therefore, the approach was revised to specify seasonal patterns of groundwater losses. Initial constant patterns were then modified to improve low flow fit to gage records.
4. Loss rates to groundwater from Lake Casitas are treated implicitly by restricting storage to observed levels, as described above. Matilija Reservoir is located outside the area of significant alluvial groundwater basins, so no groundwater loss is represented for this reservoir, although some groundwater gains are simulated, as noted above.
5. Within defined "upwelling" reaches (see Figure 4-7) an evaluation was made of the need to specify additional inflow based on water balance analysis after upstream reaches were calibrated.

Groundwater interactions are a major influence on average and low flows in the Ventura River system, and must be accounted for to obtain a reasonable flow balance. The approach taken is largely empirical, but appears to be the best available without creation of a groundwater model for the basin. While a current focus of the model is on peak flow prediction, for which the importance of low flow interactions with groundwater is of minor importance, future uses of the model may include water quality simulation, for which simulation of average and lower flows will be key. For such uses of the model development of a better-constrained groundwater flow balance would be an important improvement.

The representation of groundwater interactions in the model is summarized in Table 4-3.

Table 4-3. Summary of Representation of Groundwater Interactions

Model Reach	Name	Representation
310	Ventura River above San Antonio Creek	Upwelling (DSN 3050), set to seasonal pattern (May-September), averaging 992 AF/yr after 1992. Prior to 1993 this source is largely turned off to reflect lower water table associated with increased withdrawals at Foster Park.
311	Ventura River at Foster Park	Outflow demand series (DSN 3001), set to 50% of reported Foster Park diversion withdrawals. These withdrawals range from a high of 7770 AF/yr in 1986 to less than 1 AF in 2000.
511	San Antonio Creek	Outflow demand series (DSN 3002) set to constant value of 192 AF/mo.
825	Ventura River at Hwy. 150	Outflow demand series (DSN 3003) set to constant seasonal pattern (July-Sept.) totaling 2210 AF/yr.
882	San Antonio Creek, near Ojai	Outflow demand representing Ojai area wells (DSN 500) specified as variable monthly pattern, peaking in July and August, averaging 1.5 cfs. Upwelling (DSN 3052) set to constant pattern of 60 AF/mo in June and July.
893	Reeves Creek	Outflow demand series (DSN 3004) set to constant value of 39.6 AF/mo.
894	Thacher Creek	Outflow demand series (DSN 3005) set to constant value of 126 AF/mo.
912	Ventura River nr. Meiners Oaks	Outflow demand series (DSN 3006) set to balance flow records of Matilija Creek (gage 602), North Fork Matilija Creek (604), Ventura River at Robles Diversion (607), and Robles Diversion. Averages 3345 AF/yr, representing significant well withdrawals.
998	Lake Casitas	Groundwater exchanges implicitly accounted for via monthly reset of storage volume to observed levels using Special Actions.
999	Matilija Reservoir	Upwelling (DSN 3055) set to constant 3 cfs. An additional 3 cfs is added using Special Actions when storage is below 1/3 of total.

4.7 Point Source Inputs

Permitted point source discharges provide direct inputs of flow and pollutants to a stream; any that provide significant flow should be explicitly represented by time series in the hydrologic model. There is only one major point source discharge in the Ventura River watershed. This is the Ojai Valley Wastewater Treatment Plant (NPDES permit CA 0053961), which has a permitted discharge flow rate of 3 MGD to the Ventura River. The WWTP is owned by the Ojai Valley Sanitary District, which provides sanitary sewer service for about 20,000 residents of the City of Ojai and the unincorporated Ojai Valley area.

Daily discharge records for Ojai Valley WWTP were provided for January 1982 to present and are stored in the WDM (DSN 3054) and added to Reach 875. During the calibration period (10/96 – 9/07) this discharge averaged 208 AF/mo. For model simulations prior to 1982 (used solely for evaluation of peak flow frequency) monthly average discharges from the later records are entered into the model.

4.8 FINAL REACH MODELS

Separate HSPF model input (UCI) files containing the detailed hydrography, reservoirs, debris basins, and diversions were developed for each land use period. These UCI files access the archived unit-area HRU response time series from the land simulation and route flows through the stream network.

There are several key advantages to dividing the model into separate upland and reach simulation components. First, it allows more flexibility in the spatial resolution of both land and reach connectivity. In the case where stop-start changes are required for representing dynamic land use, it can be isolated to the land portion only where it is needed, and save redundancy in the stream segments. Second, since land blocks are removed from the hydrographic UCI file, it allows for flexibility in reach segmentation, without the risk of exceeding HSPF operations limits.

The following reach models are defined for the validation and calibration periods.

Model	Time Period	Notes
Rch86	10/1/1986 – 9/30/1987	Represents period to 2 years after 1985 Wheeler fire, combined with 1990 SCAG land use
Rch87	10/1/1987 – 9/30/1991	Uses 1990 SCAG land use
Rch91	10/1/1991 – 10/31/1993	Uses 1993 SCAG land use
Rch93	11/1/1993 – 9/30/1995	Period following 1993 fire
Rch95	10/1/1995 – 9/30/1996	Uses 1993 SCAG land use
Rch01	10/1/1996 – 9/30/2003	Uses 2001 SCAG land use
Rch05	10/1/2003 – 9/30/2007	Uses 2005 SCAG land use

5 Hydrologic Model Calibration and Validation Approach

5.1 Hydrologic and Hydraulic Calibration Procedures

This section describes the calibration of the hydrologic and hydraulic components of the watershed model. The hydrologic calibration is performed after configuring the watershed model. It is an iterative procedure of parameter evaluation and refinement as a result of comparing simulated and observed values of interest. It is required for parameters that cannot be deterministically and uniquely evaluated from topographic, climatic, and physical information of the watershed.

Hydrologic calibration was generally conducted in accordance with established recommendations for HSPF simulation (USEPA, 2000). Some modifications to the general calibration procedures were made to address specific study questions of interest to the Ventura River project.

5.1.1 HSPF Hydrology Algorithms

The HSPF hydrology algorithms follow conservation of mass principles, with various compartments available to represent different aspects of the hydrologic cycle. The sources of water to the land surface are direct precipitation and snowmelt.

Some of the water supplied by precipitation is intercepted by the vegetation canopy, manmade structures, or other means. The interception is represented in the model as a land use-specific reservoir that must be filled before any excess water is allowed to overflow to the land surface. The water in the reservoir is also subject to evaporation. The size (in inches per unit of area) of this reservoir can be varied monthly to represent the level of each compartment (above and below the land surface).

Water that is not intercepted is placed in surface detention storage. If the land segment is impervious, no subsurface processes are modeled, and the only pathway to the stream reach is through direct surface runoff. If the land segment is pervious, the water in the surface detention storage can infiltrate, be categorized as potential direct runoff, or be divided between runoff and infiltration. This partitioning is made during simulation as a function of soil moisture and infiltration rate. The water that is categorized as potential direct runoff is partitioned into surface storage/runoff or interflow, or kept in the upper-zone storage. The amount of surface runoff that flows out of the land segment depends on the land slope and roughness and on the distance it has to travel to a stream. Interflow outflow recedes based on a user-defined parameter.

Water that does not become runoff or interflow or is not lost to evaporation from the upper-zone storage infiltrates. This water becomes part of the lower-zone soil storage or active groundwater storage, or it is lost to the deep/inactive groundwater. Groundwater is stored and released based on the specified groundwater recession rates, which can be made to vary nonlinearly.

The model attempts to meet the evapotranspiration demand by evaporation of water from base flow (groundwater seepage into the stream channel), interception storage, upper-zone storage, active groundwater, and lower-zone storage. How much of the evapotranspiration demand may be met from the lower-zone storage is determined by a monthly-variable parameter (LZETP). Finally, water can exit the system in three ways—through evapotranspiration, through loss to deep/inactive groundwater, or by entering the stream channel. The water that enters the stream channel can come from direct overland runoff, interflow outflow, and groundwater outflow.

Although snowfall and snowmelt is not expected to have a large impact on hydrology in the Ventura River watershed, snow occurs in the higher elevations of the watershed, and modeling and calibrating snow is required for a successful and hydrologically accurate model. HSPF applications have typically used an energy balance approach for simulating snow. In this approach, the HSPF SNOW module uses the meteorological forcing information to determine whether precipitation falls as rain or snow, how long the snowpack remains, and when snowpack melting occurs. Heat is transferred into or out of the snowpack through net radiation heat, convection of sensible heat from the air, latent heat transfer by moist air condensation on the snowpack, rain, and conduction from the ground beneath the snowpack. The snowpack essentially acts like a reservoir that has specific thermodynamic rules for how water is released. Melting occurs when the liquid portion of the snowpack exceeds the snowpack's holding capacity; melted snow is added to the hydrologic cycle. With version 12, HSPF provides an option for a simpler, degree-day approach to the simulation of snowmelt, depending only on air temperature. In contrast, the energy balance approach also requires wind movement, relative humidity, and solar radiation for the calculation of snowmelt. Given that snow plays a relatively minor role in the overall hydrology of the watershed, while some of the input data for the energy balance simulation of snowmelt are available for only limited recent time periods, the energy balance approach was selected for the Ventura River watershed model.

While HSPF represents storage and release of shallow groundwater, it does not provide a detailed simulation of groundwater flow, and is not designed to automatically simulate losses to or gains from groundwater in stream reaches. Interactions between stream reaches and groundwater are important in certain sections of the Ventura River watershed and are, of necessity, specified externally, using best available information (see Section 4.6).

5.1.2 Parameter Inference from Data

A number of the parameters used in HSPF reflect properties of soils and slopes. These parameters can be derived from, or related to, reported soil characteristics. This approach has two important advantages: First, it reduces the number of unconstrained or "free" parameters that must be addressed in calibration. Second, it helps to ensure that variability in parameter values between basins is systematic and based on physical evidence.

Upland areas of the model are described using an HRU approach, as described in Section 3, which includes a cross-tabulation of cover, soil hydrologic group, and slope. The HRU approach facilitates relating appropriate parameters to soil and slope characteristics.

For the simulation of hydrology, parameters for infiltration rate index (INFILT; in/hr) and nominal lower zone soil storage (LZSN; in) can be related to soil characteristics. Infiltration estimates in soils coverages are based on ring infiltrometers under dry conditions, and do not reflect actual infiltration rates during storm events, when surface sealing may occur. Further, the INFILT parameter used in HSPF is not a direct measure of infiltration rate, but rather an infiltration index, which cannot be measured directly. Similarly, LZSN should be related to soil available water capacity (AWC) over the rooting depth, but is an index that is not equivalent to measured AWC. The best approach for these parameters is generally as follows:

1. Perform GIS analysis to evaluate area-weighted reported values of infiltration and AWC by HRU.
2. Set initial values to recommended ranges for HSPF (USEPA, 2000).
3. Adjust values during calibration using a global scaling factor on each hydrologic group, with local adjustments to reflect spatial variability in reported infiltration and AWC.

Other parameters associated with soil hydrologic group and slope include: surface slope, slope length, surface roughness, interflow inflow, and recession rates. These parameters are initially set based on soil/slope characteristics of an HRU and varied locally only when there is compelling evidence in gage data.

Other HSPF parameters are primarily associated with cover (and associated management), and are set based on the cover component of the HRU. These include parameters such as upper zone soil storage capacity, and the various monthly ET factors.

5.1.3 Calibration Process

The calibration period, calibration locations, and performance criteria for the evaluation of calibration should be specified prior to the start of the calibration process. Performance criteria are discussed below in Section 5.2.

5.1.3.1 Calibration and Validation Time Periods

The calibration time period should represent a period in which accurate, continuous information is available for both meteorological forcings and stream flow gaging. Generally, at least 5 years should be used. It is also advantageous to choose a period for which a range of conditions (e.g., both wet and dry years) are present. In general, the most accurate precipitation data are available for the most recent period, where ALERT station records are available to assist in extrapolation to the headwaters portion of the watershed where regular rain gauges are not present. Therefore, water years 1997-2006 are specified for general calibration (with model start of 10/1/1995 to allow for spin-up). This time period contains both wet and dry years and is consistent with the validation period selected for the Santa Clara model (1997-2005). Model validation is then undertaken for water years 1987-1995. Subsequent continuous model applications are extended back to 1968 to obtain a wider range of meteorological conditions for evaluation of event peaks.

Specification of the validation period prior to the calibration period is somewhat unusual, but does not present problems. Both the calibration period and validation period commence at the start of the water year (October 1 of the antecedent calendar year) following a relatively dry prior year, so soil moisture stores are low, except in irrigated areas, and the impact of initial conditions is lessened.

The availability of observed high flow events for calibration/validation was evaluated by examining annual event peaks at gage 604 (North Fork Matilija Creek), 605 (San Antonio Creek at Highway 33) and 608 (Ventura River near Ventura, at Foster Park) from 1934-2007. Preliminary Log Pearson III fits to gages 604 and 605 were used to sort for events that appeared to have a greater than 5-year recurrence interval at one or both of these gages. (Initial examination suggests that a good Log Pearson III fit cannot be obtained for the annual peak series at gage 608, probably because of the large changes in storage capacity in Matilija Reservoir over time. The Log Pearson III estimates presented here are preliminary and provided for a relative comparison of event magnitude only.) Results are shown in Table 5-1. Several moderately large events occurred during both the calibration period (1998, 2005) and the validation period (1992, 1995). The 1978 event (which was particularly high on the Ventura River at gage 608, but not at gages 604 and 605), along with the 1969 event, may be useful for additional tests on prediction of high flow events.

Table 5-1. Peak Flow Events, 1934-2007

Event Date	604: North Fork Matilija Creek		605: San Antonio Creek at Highway 33		608: Ventura River near Ventura
	Peak Flow (cfs)	Recurrence (yrs)	Peak Flow (cfs)	Recurrence (yrs)	Peak Flow (cfs)
3/3/1938	5,580	16.2	No Data	No Data	39,200
4/3/1958	4,530	11.7	5,240	5.5	18,700
1/25/1969	2,900	6.5	6,800	7.3	11,200
2/24/1969	9,440	44.4	11,500	14.0	40,000
2/6/1973	4,110	10.2	1,570	2.1	3,940
2/10/1978	5,050	13.8	13,900	18.1	63,600
3/4/1978	5,780	17.2	9,530	10.9	No Data
2/12/1992	7,860	30.2	8,700	9.8	45,800
1/18/1993	966	2.5	10,050	11.7	12,500
1/10/1995	5,040	13.8	14,400	19.1	43,700
3/10/1995	4,170	10.4	12,700	16.0	No Data
2/3/1998	1,780	3.9	13,100	16.7	No Data
2/23/1998	7,230	25.7	13,700	17.8	38,800
1/10/2005	5,010	13.6	24,000	41.8	41,000

Note: Recurrence intervals are estimated from a preliminary Log Pearson III fit to report annual maxima.

5.1.3.2 Simulation Time Step

Model accuracy for high flow events can be improved through use of a short time step in the reach simulation as long as celerity constraints are not violated (see Section 4.1). Therefore, the model is run at a 15-minute time step. The original plan called for using 15-minute precipitation to drive the model; however, many stations have only hourly data, particularly for earlier time periods and the spatial coverage of 15-minute data is not sufficient to drive the full model. In addition, use of 15-minute point rainfall data can introduce another sort of error into the simulation, as sub-periods of the most intense precipitation are implicitly assumed to occur simultaneously on all land areas covered by a given precipitation gauge – whereas, in fact storms typically move across the watershed, resulting in progressive offsets in the exact timing of maximum precipitation, leading to an over estimate of the magnitude of flood peaks. To compensate for this effect and enable the application of the model to areas and times for which only hour data are available, precipitation is assigned as 1-hour totals,, and these totals are divided by the model into equal amounts over each quarter hour.

5.1.3.3 Calibration Locations

Stream gages available for the calibration and validation time periods (excluding gages on diversions) are summarized in Table 5-2 and Figure 5-1. Tetra Tech reviewed station records to select those stations with reliable and relatively complete records for both the calibration and validation period as primary calibration sites. In general, gages 600 through 608 meet these criteria. However, gage 602 is used to drive the simulation of releases from Matilija Reservoir, and so cannot be used as a primary calibration site. Gages 630, 631, 633, and 669 primarily report event peak data and were not used directly for calibration; however, observed and predicted peaks are compared.

Table 5-2. Stream Gaging Data Available for Ventura River Watershed Calibration Period (1997-2006)

ID	USGS ID	Name	Resolution	Start	Stop	Years	Agencies	Notes
600	11117600	Coyote Creek near Oak View	Daily	10/1/1958	10/1/2007	49	USGS, CAS	
600A			Event Peaks	2/16/1959	1/11/2001	42	USGS, CAS	
602	11115500	Matilija Creek below Dam	Daily	10/1/1927	10/1/2007	80	USGS, CAS	
602A		Matilija Creek at Matilija Hot Springs	Event Peaks	1/20/1933	4/4/2006	73	USGS, CAS	
603A	11114495	Matilija Creek above Reservoir	Daily	10/1/2001	10/1/2006	5	USGS	Seasonal for WY 2002, 2003
			Event Peaks	3/16/2003	4/5/2006	4	USGS	
			High-Res Flow	2/14/2002	10/1/2006	4	USGS	
604	11116000	North Fork Matilija Creek	Daily	10/1/1928	10/1/2007	78	VCWPD, USGS	No data for 1933
			Event Peaks	1/1/1934	1/28/2007	73	VCWPD, USGS	
			High-Res Flow	2/4/1976	10/1/2007	31	VCWPD	
605	11117500	San Antonio Creek at Highway 33	Daily	10/1/1949	1/28/2007	58	VCWPD, USGS	
			Event Peaks	2/6/1950	10/1/2007	58	VCWPD, USGS	
			High-Res Flow	10/29/1982	10/1/2007	25	VCWPD	Additional data from 1970-1982 can be entered
606	11117800	Santa Ana Creek near Oak View	Daily	10/1/1958	10/1/2007	49	USGS, CAS	
606A			Event Peaks	3/3/1938	2/21/2006	68	USGS, CAS	Casitas only has limited peaks, Peak for 1938 flood, data start 1959
607	11116550	Ventura River at Robles Diversion	Daily	10/1/1959	10/1/2007	47	USGS, CAS	No data available for 1980, large flows may be missing or estimated.
			Annual Peaks	2/2/1960	3/1/1988	23	USGS	Scattered peaks by USGS, site captures low flow only.

ID	USGS ID	Name	Resolution	Start	Stop	Years	Agencies	Notes
608	11118500	Ventura River near Ventura	Daily	10/1/1929	10/1/2007	78	USGS, VCWPD	
			Annual Peaks	1/20/1933	4/4/2006	73	USGS	USGS only provide max peaks after WY 1973
			High-Res Flow	9/30/1988	5/24/2007	19	USGS	
630		Canada Larga at Ventura Ave	Event Peaks	12/19/1970	10/1/2007	37	VCWPD	Annual Peaks only for 1976-1986
			High-Res Flow (Discontinuous)	10/1/2004	10/1/2007	3	VCWPD	Global available from 1999 but must re-comp record
631		Fox Canyon Drain below Highway 150	Event peaks	3/9/1968	12/9/2006	39	VCWPD	
			High-Res Flow (Discontinuous)	10/1/2004	10/1/2007	3	VCWPD	Global available from 2000 but must re-compile record.
633		Happy Valley Drain at Rice Road	Event Peaks	12/4/1974	1/28/2007	33	VCWPD	
			High-Res Flow (Discontinuous)	10/1/2004	10/1/2007	3	VCWPD	Global available from 1999 but must re-compile record.
669		Thacher Creek at Boardman	Event Peaks	10/1/2002	10/1/2006	4	VCWPD	ALERT gage, not quality assured.

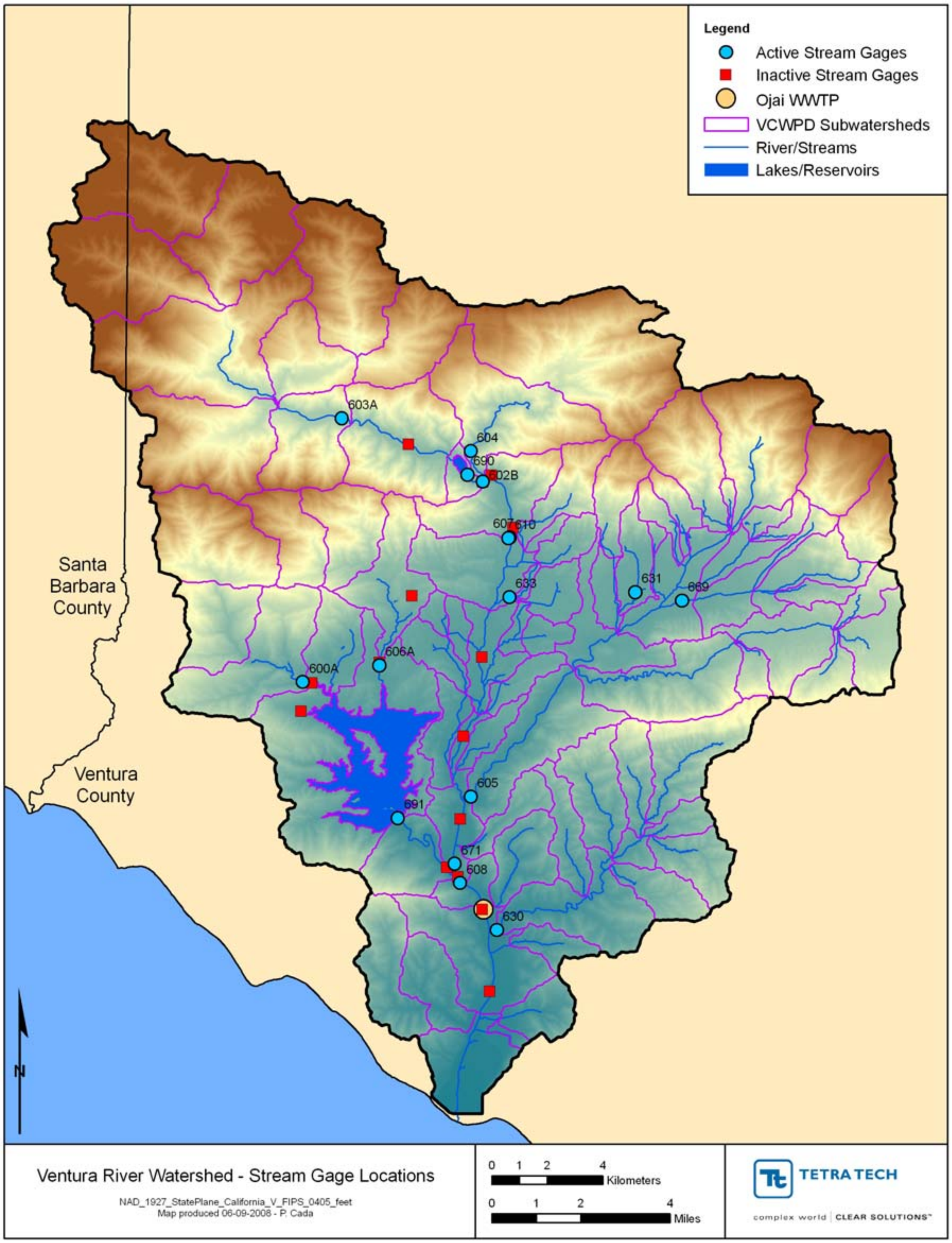

Figure 5-1. Location of Stream Gages in the Ventura River Watershed

5.1.3.4 Calibration Approach

Hydrologic calibration uses the standard operating procedures for the HSPF model described in Donigian et al. (1984), Lumb et al. (1994), and USEPA (2000). During hydrology calibration, land segment hydrology parameters were adjusted iteratively to achieve agreement between simulated and observed stream flows at specified locations throughout the basin. Agreement between observed and simulated stream flow data was first evaluated on an annual and seasonal basis using quantitative and qualitative measures. Specifically, annual water balance, groundwater volumes and recession rates, and surface runoff and interflow volumes and timing were evaluated, along with composite comparisons (e.g., average monthly stream flow values over the period of record).

Hydrologic predictions from the model are most sensitive to external forcing by precipitation, followed by PET. These weather inputs are typically not adjusted during calibration. Within the model, the annual water balance is usually most sensitive to the specification of the lower zone nominal storage (LZSN) and the lower zone ET factor (LZETP), both of which control the amount of water lost to evapotranspiration. The distribution of runoff between storm and non-storm conditions is usually most sensitive to the infiltration index (INFILT) and groundwater recession rate (AGWRC).

The hydrologic model was calibrated by first adjusting model parameters until the simulated and observed annual and seasonal water budgets are in good agreement. Then, the intensity and arrival time of individual events was calibrated. This iterative process was repeated until the simulated results closely represent the system and reproduce observed flow patterns and magnitudes. Sensitivity analyses for model input parameters helped guide this effort (see Section 5.3). Below is a more detailed description of the step-by-step process.

1. **Annual water balance**. In this step, the total average annual simulated flow volume is compared with the observed data. The input precipitation and evaporation data set, along with the calibration parameters LZSN (lower zone nominal storage), LZETP (lower zone ET parameter), and INFILT (infiltration index) are the main factors influencing the annual water balance. Other factors include anthropogenic water inputs and outputs, and groundwater exchanges.
2. **Low flow/high flow distribution**. The low flows are usually matched first by adjusting the INFILT and AGWRC (groundwater recession) parameters. Low flows are also dependent on the accurate representation of point source discharges, irrigation applications, water withdrawals, and groundwater exchanges.
3. **Seasonal adjustments**. Adjustments related to seasonal differences can be made to CEPSC (vegetal interception), LZETP, and UZSN. Updates to KVARY (variable groundwater recession) and BASETP are also possible.
4. **Storm peaks and hydrograph shape**. Simulated storm event peaks are compared to available storm hydrograph and storm peak data for selected storms. The stormflow is largely dependent on surface runoff and interflow volumes and timing. Changes can be made to the INFILT (infiltration), UZSN (upper zone storage), INTFW (interflow parameter), IRC (interflow recession), and the overland flow parameters (LSUR, NSUR, and SLSUR), among other upland parameters. Storm hydrographs are also sensitive to the reach FTables, which may need to be re-evaluated to reproduce observed hydrographs.

In addition to the general process described above, the intended uses of the model by VCWPD require a good match to Q100 design flows. Events of this magnitude are, by definition, rarely observed, and gaging during such events may be inaccurate even if they are observed. Therefore, estimates of Q100 obtained by extrapolating observed maxima at gages using Log Pearson III analysis are compared to model results using simulated storm events for a range of return frequencies.

For each calibration location, a full analysis of model performance relative to performance criteria (Section 5.2) is provided. These are accompanied by standardized graphical comparisons of gaged and predicted flow generated by Tetra Tech's HydroCal spreadsheet system. Hydrologic Validation Procedures

After the model is adequately calibrated, the quality of the calibration was evaluated through validation tests on separate data. This helps to ensure that the calibration is robust, and that the quality of the calibration is not an artifact of over-fitting to a specific set of observations, which can occur due to the persistence of the impacts of high-precipitation events on water storage in the model. Validation also provides a direct measure of the degree of uncertainty that may be expected when the model is applied to conditions outside of the calibration series.

5.2 Performance Criteria

Performance criteria for the model are specified prior to the commencement of calibration and are used to help evaluate the quality of the model calibration and validation. The HSPF tolerance targets for simulation of the water balance components are summarized in Table 5-3.

Table 5-3. Tolerance Targets for Hydrologic Water Balance Simulation

Model Component	Acceptable Tolerance
1. Error in total volume	± 10%
2. Error in 50% lowest flow volumes	± 10%
3. Error in 10% highest flow volumes	± 15%
4. Error in storm volume	± 15%
5. Winter volume error	± 30%
6. Spring volume error	± 30%
7. Summer volume error	± 30%
8. Fall volume error	± 30%
9. Storm peak error	± 50%
10. Design flow frequency error	(see text)

It is important to clarify that the tolerance ranges are intended to be applied to mean values, and that individual events or observations may show larger differences and still be acceptable (Donigian, 2000).

Tolerance targets 1 through 9 are commonly applied in HSPF modeling applications and acceptable levels are well established. Item 10 (design flow frequency error) is not a typical calibration target for HSPF, but is added to reflect the intended uses of the model to evaluate storm design flows at ungaged locations. VCWPD recently noted (personal communication from Sergio Vargas to Mark Bandurraga, VCWPD, April 2, 2008) that the Santa Clara model predictions of Q100 flows did not provide a good match to estimates derived from streamflow measurements at many gage locations. Obtaining these estimates using Bulletin 17B (Log Pearson III) methods requires accurate estimation of annual maxima that are unbiased for both dry and wet years. The metrics used for calibration of the Santa Clara model included the *average* percent difference in peaks from selected storms, along with a variety of other measures, but did not include the model's ability to predict annual maxima or any potential bias in the prediction of peak relative to the magnitude of that peak. Therefore, the design flow frequency error is added to ensure that the Ventura River model is suitable to intended uses. The associated tolerance target of ±10 percent is noted as "tentative" because it is not as well established a target for HSPF applications as the others listed in the table.

For tolerance target 10, the comparison between the model and data-based estimates of flow frequency error takes into account the uncertainty bounds in the Log Pearson III regression line. A goal of 10 percent is desirable, but an error in central estimates of Q100 greater than 10 percent is indeed acceptable *if* the two estimates are not significantly different from one another at the 95 percent confidence level (as might occur, for instance, at a gage with limited peak data for which extrapolation to Q100 is highly uncertain).

Several additional statistics are provided to assess components of the predictive ability of the model, but are not assigned specific tolerances. These are:

- Coefficient of determination between observed and predicted flow at the daily and monthly scale
- Nash-Sutcliffe coefficient of model fit efficiency, which measures the predictive ability of the model on individual observations

While the tolerance targets specified above (for items 1 through 9) are typically attainable in HSPF applications, there are cases where some cannot be met – for example if the quality of the meteorological time series is not adequate. If the model did not meet a tolerance criterion, Tetra Tech first directed efforts to bring the model into compliance. If, after such efforts, the model still failed to meet a tolerance criterion, a thorough exposition of the problem and potential corrective actions (e.g., additional data collection or modification of model code) is provided.

5.3 Sensitivity and Uncertainty Analyses

5.3.1 Sensitivity Analysis

Sensitivity analysis is used to determine how the uncertainty in the output of the model is related to external inputs and parameters. HSPF is a large and complex model, with many input parameters, and a comprehensive sensitivity analysis using Monte Carlo or variance propagation methods is typically impractical. Sensitivity to individual inputs/parameters will therefore be evaluated using normalized sensitivity coefficients, which represent the percentage change in a response variable associated with a 1 percent change in an input variable. In general, inputs are perturbed by plus or minus 10 percent to evaluate normalized sensitivity coefficients.

5.3.2 Uncertainty Analysis

From a decision context, the primary function of the calibrated model is to predict the response of flow characteristics that can be used to assess attainment of management goals under existing and various future scenarios. An important input to the decision-making process is information on the degree of uncertainty that is associated with model predictions. In some cases, the risks or "costs" of exceeding a target value may be substantially greater than the costs of over-protection, creating an asymmetric decision problem in which there is a strong motivation for risk avoidance. Further, if two scenarios produce equivalent predicted results, the scenario that has the smaller uncertainty is often preferable. Therefore, an uncertainty analysis of model predictions is essential in good modeling practice.

The major sources of model output uncertainty include the following:

- **Mathematical Formulation**. A real water system is too complex for a mathematical model to represent all the dynamics, therefore, no matter how sophisticated a mathematical water quality model is, it is based on a simplified mathematical formulation. The simplifications, in general, neglect processes that are considered to be insignificant, thus the model can capture the general trend of the real system. In other words, a mathematical model is designed to represent the trend, rather than provide exact replication of the real system. Thus, uncertainty exists when those neglected factors start to play some detectable roles.

- **Data Uncertainty**. Site-specific data are the basis for developing a simulation model for a specific waterbody, and a model requires data from different sources and for a large number of parameters. Many of these data are subjected to either systematic or random errors, which propagate through the model. For hydrology, the estimation of areal rainfall based on point gages is often the most significant source of error.
- **Parameter Specification**. In a water quality model, parameters quantify the relationships in the major dynamic processes. The values of parameters are generally obtained through the model calibration process while constrained by a range of reasonable values documented in literature. Inadequate calibration may result in a parameter specification that is sub-optimal and contributes to output uncertainty.

All three sources of output uncertainty are present in any watershed model, but often vary in importance.

Results of model validation can be used to provide a direct, integrated measure of the level of uncertainty associated with model predictions outside the calibration time period. In addition to the performance statistics described in Section 5.2, the following measures of model prediction uncertainty are provided:

- RMSE (Root Mean Squared Error): the square root of the average of the squared differences between observed and simulated concentrations.
- AAE (Average Absolute Error): the average of the absolute value of the differences between observed and simulated concentrations.
- RAE (Relative Absolute Error): the average absolute error expressed as a percentage of the average observed concentration
- NMSE (Normalized Mean Squared Error): the average of the squared differences between observed and simulated concentrations divided by the variance of the observed data. This measure is recommended by CREM (2003) for comparison between fit of different model outputs.

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6 Hydrologic Calibration and Validation Results

6.1 Calibrated Parameters

Hydrologic calibration took as its starting point the guidance provided in USEPA (2000) and the results of the successful calibration for the Santa Clara River (Aqua Terra, 2008). In-depth sensitivity analyses were conducted on subset small watersheds, corresponding to gages 600A, 603A, 604, 605, and 606A and used to obtain satisfactory calibrations at these gages. These results were then taken to the full model, with extension of calibrated parameters to apparently similar areas. Final adjustments were then made to achieve satisfactory model fit at the Ventura River mainstem gages.

Model parameters are assigned in a spreadsheet to individual HRUs based on the intersection of soil hydrologic group, weather station group, and land use. First, base values of infiltration (INFILT) and groundwater recession (AGWRC) are assigned by soil hydrologic group (Table 6-1).

Table 6-1. Parameter Assignments by Hydrologic Soil Group

Hydrologic Soil Group	INFILT Base Value	AGWRC Base Value
B	0.36	0.995
C	0.087	0.995
D	0.06	0.991

Base values for LZSN and DEEPFR are assigned by weather station group. In addition, the base values for AGWRC, INFILT, and KVARY are modified by multipliers based on weather station group (Table 6-2).

Table 6-2. Parameter Assignments by Weather Station Group

Weather Station	LZSN	DEEPFR	AGWRC Multiplier (B,C Soils)	AGWRC Multiplier (D Soils)	INFILT Multiplier (B, C Soils)	INFILT multiplier (D Soils)	KVARY Multiplier
1	11	0.21	1.00	1.00	1.00	1.00	1.00
2	5	0.05	1.00	1.00	0.80	0.17	1.00
3	5	0.21	1.00	1.00	0.80	0.17	1.00
4	5	0.05	1.00	1.00	0.80	0.17	1.00
5	11	0.45	1.00	1.00	1.00	0.67	1.00
6	11	0.21	1.00	1.00	1.00	0.67	1.00
7	5	0.21	1.00	1.00	0.80	0.17	1.00
8	8	0.45	0.98	0.98	1.00	0.67	1.33
9	11	0.45	1.00	1.00	1.38	1.33	0.00
10	11	0.45	1.00	1.00	1.00	0.67	1.00

Weather Station	LZSN	DEEPFR	AGWRC Multiplier (B,C Soils)	AGWRC Multiplier (D Soils)	INFILT Multiplier (B, C Soils)	INFILT multiplier (D Soils)	KVARY Multiplier
11	11	0.35	1.00	1.00	1.00	0.67	1.00
12	8	0.21	0.99	0.99	0.80	0.80	1.00
13	10	0.22	1.00	1.00	1.05	1.05	1.00
14	11	0.21	1.00	1.00	1.00	1.00	1.00
15	11	0.18	1.00	0.99	1.38	1.33	0.00
16	11	0.35	1.00	1.00	1.00	0.67	1.00
17	11	0.21	1.00	1.00	1.00	0.67	1.00
18	11	0.18	1.00	0.99	1.38	1.33	0.00
19	11	0.18	1.00	0.99	1.38	1.33	0.00

Finally, certain parameter base values and multipliers are assigned by land use (Table 6-3). Certain other minor parameters, including INTFW, NSUR, and IRC are also varied to a small degree by land use. The full set of parameters may be seen in the UCI files.

Table 6-3. Parameter Assignment by Land Use/Cover

Land Use/Cover	KVARY base	LZSN multiplier	INFILT multiplier
Burned	0.3	0.933	0.650
Barren	0.3	0.933	0.857
Grassland	0.3	1.0	1.0
Chaparral	0.3	1.0	1.0
Forest	0.3	1.067	1.0
Agriculture	0.3	1.0	1.0
Orchard	0.3	1.0	1.0
LD Developed	0.5	0.933	0.857
HD Developed	0.5	0.933	0.857

Another important modification during calibration concerns irrigation application rates. Irrigation rates (Section 3.4.2) are initially estimated as the optimum application rate for crop type after considering effective precipitation and typical fractions of the land cover irrigated. This assumes that most lands identified as in cover types that demand irrigation are actually irrigated. Clearly, this is not always the case. For agricultural lands, farmers may allow some fields or orchards to lie fallow during certain years. For developed lands, not all homeowners or businesses will meet optimal irrigation demands of their lawns, and, increasingly, some are turning to xeriscaped yards. In addition, the model assumes that irrigation supply is met with “new” water that does not effect the baseflow discharge to streams (either because it is derived from reservoirs or from deep groundwater separate from stream interactions), whereas some of the demand is actually met from surface water diversions and shallow wells. Thus, the effective rate of irrigation application with new water is likely to be significantly less than the irrigation rate identified in Section 3.4.2, as was also found for the Santa Clara model (Aqua Terra, 2008).

During model calibration it appeared clear that the irrigation assumptions described in Section 3.4.2 resulted in an overestimate of baseflow in streams. Accordingly, the fraction of potential area irrigated with "new" water was reduced by approximately one third, to 30 percent for row crops, 40 percent for orchards, 50 percent for low density development, and 70 percent for high density development. Because the base series is calculated externally, this assumption can be readily modified for future applications of the model.

6.2 Model Calibration Summary

Detailed results of model calibration are provided in Section 6.4. This section provides a summary overview of the results. Performance of the model relative to calibration targets and metrics is summarized in Table 6-4.

For most stations, the model performs very well, meeting all or most tolerance criteria. Notable exceptions are the gages on Coyote Creek (600A) and Santa Ana Creek (606), where many criteria are not met. These two gages, both tributary to Lake Casitas, are maintained by Casitas Water District, which took over the gages from USGS in the 1980s. Records of both gages are suspect. No quality assurance data are available for these gages, and there is no record that the gage rating curves have been updated on a regular basis. (The mobile gravel bed streams of the Ventura watershed demand frequent rating curve updates to maintain accuracy.) Further, it appears evident that these gage records contain periods in which gage malfunctions are reported as zero flows, as well as other periods in which reported peak flows may have been clipped by modification of the channel (see Sections 6.5.7 and 6.5.8 for details). These inferences are bolstered by the observation that the model provides a better fit during the earlier validation period, when the gage records were likely in better accordance with actual flows due to earlier maintenance by USGS.

Of the other gages, Gage 602A (Matilija Creek below Matilija Reservoir near Meiners Oaks) should not be considered a proper calibration test, as the records from this gage are used (in part) to drive estimated releases from Matilija Reservoir. As a result, the model replicates flows exactly during low flow periods, but encounters some problems during the highest flows when flood waves from the upper watershed pass over Matilija Dam. Predictions for these periods depend on the accounting of storage in Matilija Reservoir – which is problematic as Matilija's storage capacity has changed over time and is not well documented.

For Matilija Creek above Matilija Reservoir (Gage 603A, maintained by USGS), only four years of continuous gaging is available. The relatively large errors in predicted storm volume are primarily driven by the results of the Winter 2004-2005 storms, for which limited precipitation measurements in the upper watershed may not be accurate.

Some potential problems in low flow simulation are also seen in San Antonio Creek (gage 605), where low flows, particularly in the Fall, appear to be over-estimated. The predicted baseflow at the gage is quite small (median 2.5 cfs), so a large percentage error results from a small absolute error. Much of the predicted baseflow at this gage results from groundwater discharge in lower San Antonio Creek. No groundwater withdrawals are simulated in this area, which was not identified as a losing reach in Section Figure 4-6. The over-prediction of low flows in this reach could result from not representing groundwater withdrawals in this area, or from other causes, such as an overestimation of the extent of irrigated land. Detailed station analysis reports for this gage are prepared every year by VCWPD, and for most of the calibration period (1996 to 4/9/2007) the discharge records are stated as being of only fair quality, with a need for frequent recalibration of the rating curves and period of estimated data due to transducer malfunctions or siltation in 1998, 1999, 2001, 2002, and 2007. More importantly, the reports note that "water wells 100 feet upstream of the gage probably affect summer low flow." Withdrawals by these irrigation wells are not represented in the model and are the most likely cause of the low flow discrepancies.

Instantaneous storm peaks are predicted well, on average, at all gages. Not all individual events are predicted correctly, however, as is discussed further in Section 7.

In general, the model performs well during the calibration period, with high values for the Nash-Sutcliffe E coefficient and low values for normalized mean square error – with results for Coyote Creek (gage 600A) being a notable exception.

Table 6-4. Summary of Model Calibration Results

Gage	600A	602	603A	604	605	606	607	608	Tolerance Criterion
Error in Total Volume	53.45%	13.13%	0.47%	1.67%	3.73%	-4.29%	7.24%	3.08%	±10%
Error in 50% Lowest Flow	9.80%	-0.42%	-9.81%	-0.70%	18.85%	291.86%	3.47%	6.43%	±10%
Error in 10% Highest Flow	80.86%	16.83%	-1.79%	3.77%	1.53%	-56.47%	10.28%	-0.25%	±15%
Error in Storm Volume	82.51%	9.36%	33.64%	-2.34%	1.94%	-50.36%	-1.77%	-8.01%	±15%
Winter Volume Error	102.81%	19.36%	-6.39%	6.86%	0.35%	5.92%	8.88%	1.01%	±30%
Spring Volume Error	1.12%	0.03%	14.10%	-10.58%	12.51%	-26.54%	5.07%	7.36%	±30%
Summer Volume Error	-44.42%	-4.14%	-1.77%	4.87%	-3.59%	-56.47%	1.69%	4.98%	±30%
Fall Volume Error	-2.03%	14.74%	47.22%	-6.22%	27.77%	-26.97%	-0.20%	17.52%	±30%
Storm Peak Volume Error	-24.85%	12.39%	49.44%	-9.13%	-14.85%	ND	ND	-13.54%	±50%
R^2 (Daily)	35.18%	86.37%	88.00%	91.13%	93.45%	79.87%	88.13%	89.47%	Maximize
R^2 (Monthly)	57.40%	93.44%	94.12%	95.63%	96.74%	93.41%	99.19%	98.98%	Maximize
RMSE (cfs)	36.20	87.38	111.23	25.30	68.87	24.75	130.44	280.94	Minimize
AAE (cfs)	6.47	9.78	19.74	4.34	10.64	4.70	17.25	39.84	Minimize
RAE	0.86	0.23	0.36	0.34	0.40	0.55	0.36	0.42	Minimize
NMSE	0.83	0.15	0.13	0.10	0.09	0.20	0.13	0.14	Minimize
Nash-Sutcliffe E	-0.687	0.849	0.869	0.903	0.905	0.799	0.869	0.860	Maximize

6.3 Model Validation Summary

Model validation tests – using the parameters derived during model calibration – were run for the period of October 1986 to September 1995. Results for validation would generally be expected to be somewhat poorer than for the calibration period, with the differences representing (in part) the degree to which the model is over-calibrated to the specific conditions of the calibration period. However, the validation period also suffers due to less precise forcing information, including potentially less precise rainfall gauging and uncertainties in water abstractions via the Robles and Foster Park diversions.

Detailed results of model calibration are provided in Section 6.6. This section provides a summary overview of the results.

Encouragingly, the results for the two problem gages upstream of Lake Casitas (600A: Coyote Creek and 606: Santa Ana Creek) are much improved for the validation period, although still exhibiting some relatively large percent errors. As noted for the calibration period, no quality assurance data are available for these gages

For the North Fork of Matilija Creek (gage 604) there are relatively large errors in 50 percent low flows, storm volumes, and storm peaks during the validation period. Station analysis reports from VCWPD indicate that discharge records for this gage are of good quality throughout the validation period, with concrete control. Errors related to low flows are mostly associated with conditions prior to 1992, and could reflect some change in condition of the watershed relative to the calibration period. The errors related to storm peaks are driven primarily by an overestimation of the response in February 1992, where the precipitation monitoring may not be representative of total rainfall on the watershed. Finally, discrepancies in predicted storm peaks at this gage might reflect inadequacies in the FTable representation of peak flow response. The FTables for this reach are derived from the regional regression and subsequently adjusted by hand, as no HEC models have been completed, and LIDAR was not available. The gage is located on the downstream side of the Hwy. 33 bridge, and the influence of this structure (for which survey information was not available) on flows has not been incorporated into the FTable.

Validation results for San Antonio Creek (gage 605) show some discrepancies at both high and low flows. Volumetric errors in high flow prediction are mostly due to individual events in February 1993 and January 1995 and could reflect unrepresentative precipitation assignments. Discharge records during this period are noted as being of only fair quality. Further, for the period of 2/10-3/31/1993 communication with the gage is noted as having been lost and daily flows are estimated values from weekly totals. Low flow errors are primarily associated with the Fall period prior to 1992 and may be due to withdrawals from shallow irrigation wells that are noted in the station analysis reports as being located within 100 feet upstream of the gage, but not included in the model. Model performance at this gage could likely be improved through explicit representation of the irrigation wells in this reach.

Ventura River near Ventura (gage 608) also shows over-prediction in low flows and summer-fall volumes. As noted previously, percentage errors during these low flow periods are amplified by the small volume of flow present: during many of these periods, predicted flow is less than 1 cfs, while the gage reported flow is 0, resulting in large percentage errors but small absolute errors. This gage is maintained by USGS, and VCWPD does not provide annual station analyses. USGS states that the flow discharge record at this gage is of fair quality, with many periods of estimated data. Field measurements at this station frequently report heavy debris. It is noteworthy that USGS has conducted frequent measurements at this gage (multiple times per month during the wet season) since February of 1991, many of which results in shifts to the rating curve. From 1986 to 1990, only 14 field measurements are reported, so records from the earlier part of the validation period are likely of less accuracy

Despite occasional discrepancies, the fit for all stations is generally good, with R^2 values (on daily flows) greater than 84 percent and Nash-Sutcliffe E coefficients greater than 0.8. Storm peak volume estimates are also within criteria at all stations except for Gage 604. Therefore, the model validation tests are judged to be successful.

Instantaneous storm peaks are also predicted well, on average, at most gages. Not all individual events are predicted correctly, however, as is discussed further in Section 7. The one station where the peak predictions are least satisfactory is gage 604, North Fork Matilija Creek, where peaks appear to be over-estimated on a fairly consistent basis – despite the fact that the 10 percent high flow volume is underestimated. As noted in the calibration section, some of this discrepancy could be due to use of an unrepresentative FTable to represent hydraulic response (there being no HEC model for this segment), and there could also be issues with the application of rain gauge 264 to this subwatershed. It does appear, however, that the North Fork Matilija Creek submodel might benefit from additional calibration adjustment efforts.

Table 6-5. Summary of Model Validation Results

Gage	600	602	603A	604	605	606	607	608	Tolerance Criterion
Error in Total Volume	-0.02%	-10.48%	ND	-7.96%	16.55%	11.56%	-6.13%	1.22%	±10%
Error in 50% Lowest Flow	13.82%	0.09%	ND	-26.84%	44.10%	183.45%	8.38%	167.63%	±10%
Error in 10% Highest Flow	-1.96%	-10.65%	ND	-3.22%	18.62%	12.47%	-7.28%	-2.44%	±15%
Error in Storm Volume	41.20%	-11.44%	ND	22.21%	34.70%	-3.67%	-1.04%	8.72%	±15%
Winter Volume Error	-0.71%	-9.23%	ND	-2.13%	22.46%	13.24%	-5.28%	1.50%	±30%
Spring Volume Error	3.99%	-17.54%	ND	-29.51%	-20.71%	-6.43%	-15.55%	-10.08%	±30%
Summer Volume Error	32.14%	-13.39%	ND	-9.93%	-0.37%	-8.94%	19.15%	62.46%	±30%
Fall Volume Error	-15.78%	-1.41%	ND	-29.51%	25.34%	31.67%	-0.56%	58.58%	±30%
Storm Peak Volume Error	34.04%	-1.45%	ND	63.82%	32.28%	35.84%	ND	-22.84%	±50%
R^2 (Daily)	84.43%	86.63%	ND	91.00%	91.38%	89.41%	88.36%	91.84%	Maximize
R^2 (Monthly)	96.47%	98.09%	ND	97.45%	95.27%	98.75%	97.72%	98.26%	Maximize
RMSE (cfs)	20.12	84.25	ND	22.79	52.67	15.47	91.83	143.81	Minimize
AAE (cfs)	3.20	10.75	ND	4.39	8.55	2.57	12.93	25.29	Minimize
RAE	0.39	0.21	ND	0.34	0.41	0.39	0.29	0.32	Minimize
NMSE	0.16	0.14	ND	0.15	0.17	0.11	0.12	0.08	Minimize
Nash-Sutcliffe E	0.843	0.864	ND	0.851	0.831	0.893	0.883	0.918	Maximize

6.4 Water Balance Summary

The water balance predicted by the model for water years 1997 to 2007 is summarized in Table 6-6 through Table 6-10 for the entire watershed and for four subareas (Coyote Creek/Lake Casitas drainage; Ventura River upstream of the Robles Diversion, including Matilija Reservoir, San Antonio Creek drainage, and the mainstem, including all additional contributing areas).

Each table first shows the upland balance, including land surface runoff, soil moisture, and shallow ground water. Inputs are predominantly precipitation, although some water is also added by irrigation and by depletion of soil and shallow groundwater storage. About 60 percent of this input is returned to the atmosphere via evapotranspiration, and one-third becomes runoff, while the residual enters deep ground water. This deep ground water is a source of irrigation water, and also interacts with the stream; however, a complete water balance of the ground water component is not possible because a ground water model has not been completed.

The waterbody balance has a number of inputs, beginning with runoff from the land surface, but also including upwelling ground water, point sources, and direct precipitation (the tables show net precipitation, the difference between precipitation and evaporation, which is an input for some reaches and an output for others). The subwatershed balances may also include input from diversions or upstream segments and outputs to diversions to other subwatersheds (e.g., the Robles diversion) and outputs downstream. There are no significant diversions of outside water into the Ventura River watershed.

Output from the stream reaches and reservoirs includes downstream flow, diversions (including diversions for consumptive use from Lake Casitas), evaporation, and losses to ground water. Downstream flow to the Pacific Ocean constitutes 69 percent of the water entering stream reaches or about 25 percent of precipitation on the watershed. About 16 percent of the surface water flow is diverted for consumption, while the remainder is lost to ground water or evaporation.

Table 6-6. Water Balance Summary for Entire Ventura River Watershed, Water Years 1997-2007

		AF/yr	Percent
Upland Balance			
Input			
	Precipitation	3,542,087	93.31%
	Irrigation	157,839	4.16%
	Change in storage	95,950	2.53%
	Total Input	3,795,877	
Land Surface Output			
	Evapotranspiration	2,369,553	62.42%
	To Stream	1,246,021	32.83%
	To Deep Ground Water	180,303	4.75%
	Total Output	3,795,877	
Waterbody Balance			
Input			
	Runoff	1,246,021	94.23%
	Diversions in	0	0.00%
	Upstream in	0	0.00%
	Ground Water in	46,771	3.54%
	Point Source	27,402	2.07%
	Net Precipitation	2,183	0.17%
	Total Input	1,322,376	
Output			
	Downstream out	933,677	70.61%
	Diversions out	216,605	16.38%
	Stream to Ground Water	81,123	6.13%
	Net Reach and Reservoir Loss	90,972	6.88%
	Total Output	1,322,376	

Note: The net reach and reservoir loss term includes evaporation from streams and lakes and losses to ground water from reservoirs.

Table 6-7. Water Balance Summary for Coyote Creek/Lake Casitas Drainage, Water Years 1997-2007

		AF/yr	Percent
Upland Balance			
Input			
	Precipitation	582,627	93.23%
	Irrigation	1,338	0.21%
	Change in storage	40,985	6.56%
	Total Input	624,950	
Land Surface Output			
	Evapotranspiration	367,448	58.80%
	To Stream	235,899	37.75%
	To Deep Ground Water	21,603	3.46%
	Total Output	624,950	
Waterbody Balance			
Input			
	Runoff	235,899	73.70%
	Diversions in	84,197	26.30%
	Upstream in	0	0.00%
	Ground Water in*	0	0.00%
	Point Source	0	0.00%
	Net Precipitation*	<0*	
	Total Input	320,097	
Output			
	Downstream out	52,553	16.42%
	Diversions out	206,870	64.63%
	Reach to Ground Water*	0	0.00%
	Net Reservoir Loss*	60,674	18.95%
	Total Output	320,097	

Note: * For Lake Casitas, the net precipitation balance along with any ground water exchanges from the lake are included with the net reservoir loss term.

Table 6-8. Water Balance Summary for Ventura River above Robles Diversion, Water Years 1997-2007

	AF/yr	Percent
Upland Balance		
Input		
Precipitation	1,377,238	99.03%
Irrigation	4,603	0.33%
Change in storage	8,864	0.64%
Total Input	1,390,705	
Land Surface Output		
Evapotranspiration	840,785	60.46%
To Stream	497,579	35.78%
To Deep Ground Water	52,340	3.76%
Total Output	1,390,705	
Waterbody Balance		
Input		
Runoff	497,579	94.20%
Diversions in	0	0.00%
Upstream in	0	0.00%
Ground Water in	30,662	5.80%
Point Source	0	0.00%
Net Precipitation	<0*	0.00%
Total Input	528,241	
Output		
Downstream out	376,292	71.23%
Diversions out	84,197	15.94%
Reach to Ground Water	40,035	7.58%
Net Reservoir Loss	27,717	5.25%
Total Output	528,241	

Note: * For Matilija Reservoir (Robles), the net precipitation balance is included with the net reservoir loss term.

Table 6-9. Water Balance Summary for San Antonio Creek, Water Years 1997-2007

	AF/yr	Percent
Upland Balance		
Input		
Precipitation	790,396	87.39%
Irrigation	91,434	10.11%
Change in storage	22,614	2.50%
Total Input	904,444	
Land Surface Output		
Evapotranspiration	598,075	66.13%
To Stream	237,394	26.25%
To Deep Ground Water	68,975	7.63%
Total Output	904,444	
Waterbody Balance		
Input		
Runoff	237,394	98.41%
Diversions in	0	0.00%
Upstream in	0	0.00%
Ground Water in	3,840	1.59%
Point Source	0	0.00%
Net Precipitation	<0	0.00%
Total Input	241,234	
Output		
Downstream out	210,570	87.29%
Diversions out	0	0.00%
Reach to Ground Water	28,083	11.64%
Net Reach Evaporation	2,581	1.07%
Total Output	241,234	

Table 6-10. Water Balance Summary for Ventura River Mainstem, Water Years 1997-2007

		AF/yr	Percent
Upland Balance			
Input			
	Precipitation	791,826	90.41%
	Irrigation	60,464	6.90%
	Change in storage	23,488	2.68%
	Total Input	875,778	
Land Surface Output			
	Evapotranspiration	563,245	64.31%
	To Stream	275,148	31.42%
	To Deep Ground Water	37,385	4.27%
	Total Output	875,778	
Waterbody Balance			
Input			
	Runoff	275,148	28.77%
	Diversions in	0	0.00%
	Upstream in	639,415	66.86%
	Ground Water in	12,269	1.28%
	Point Source	27,402	2.87%
	Net Precipitation	2,183	0.23%
	Total Input	956,416	
Output			
	Downstream out	933,677	97.62%
	Diversions out	9,735	1.02%
	Reach to Ground Water	13,005	1.36%
	Net Reach Evaporation	<0	0%
	Total Output	956,416	

6.5 DETAILED CALIBRATION RESULTS

This section provides detailed graphical and tabular analyses of the calibration results at each gage, using a standard format. Most of the results are based on daily flows, while event peaks are addressed separately in Section 7. It should be noted that model results for daily flows are by default arithmetic averages over the day and will tend to be somewhat lower than the integrated averages reported from the gages for storm events.

6.5.1 Matilija Creek above Reservoir (603A)

Note that the continuous period of continuous record begins in October 2003. Some intermittent records are also available starting in October 2001.

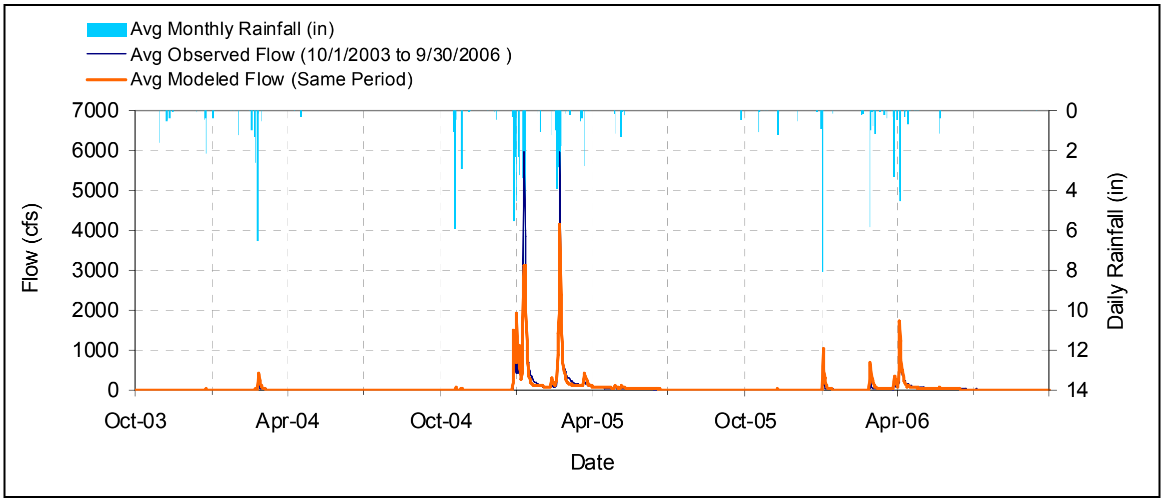

Figure 6-1. Mean Daily Flow: Model vs. USGS 11114495 Matilija Creek abv Res

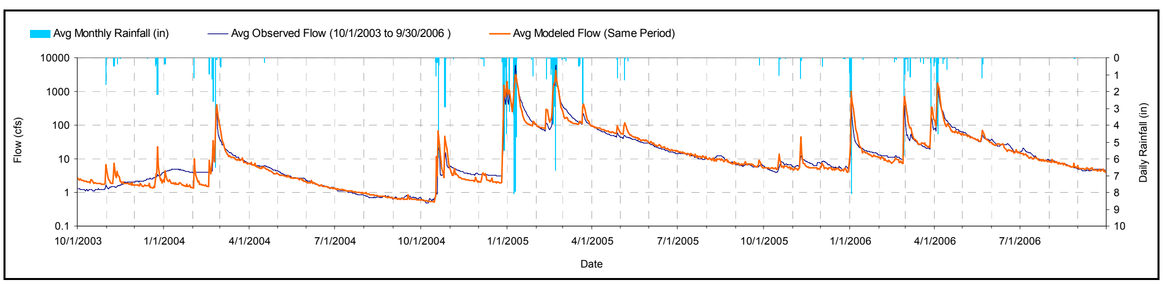

Figure 6-2. Mean Daily Flow: Model vs. USGS 11114495 Matilija Creek abv Res

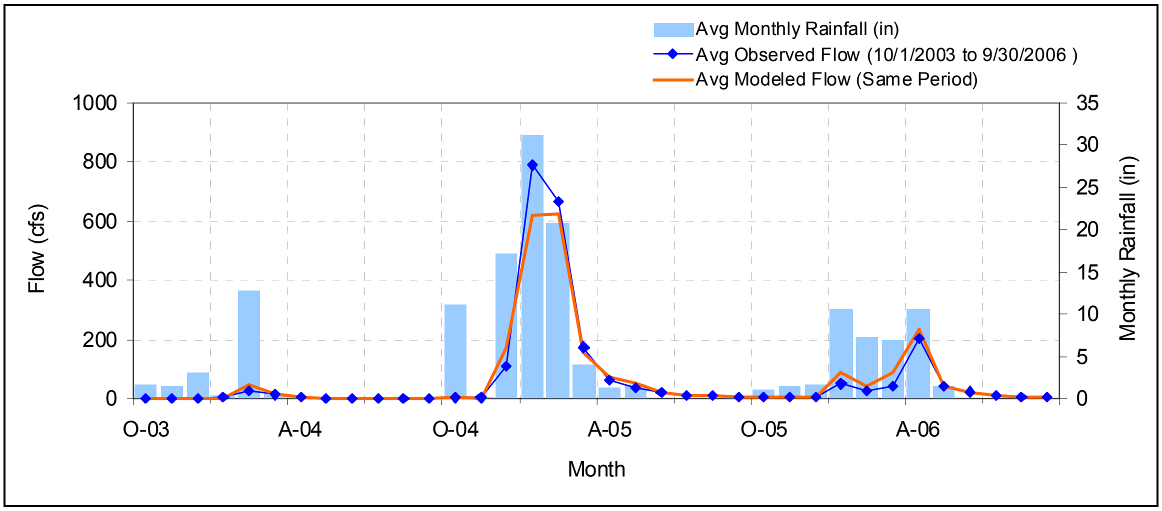

Figure 6-3. Mean Monthly Flow: Model vs. USGS 11114495 Matilija Creek abv Res

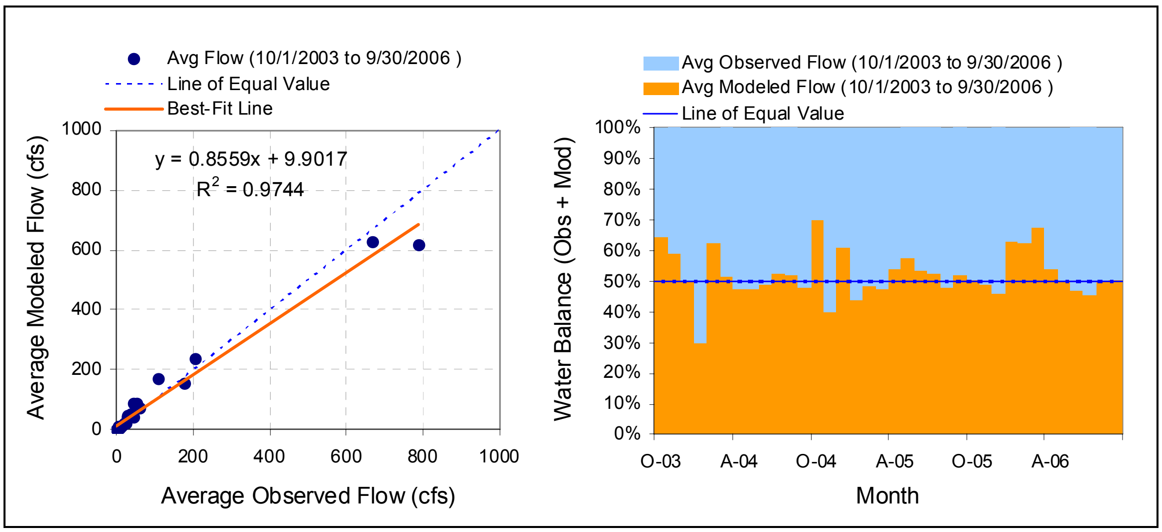

Figure 6-4. Monthly Flow Regression and Temporal Variation: Model vs. USGS 11114495 Matilija Creek abv Res

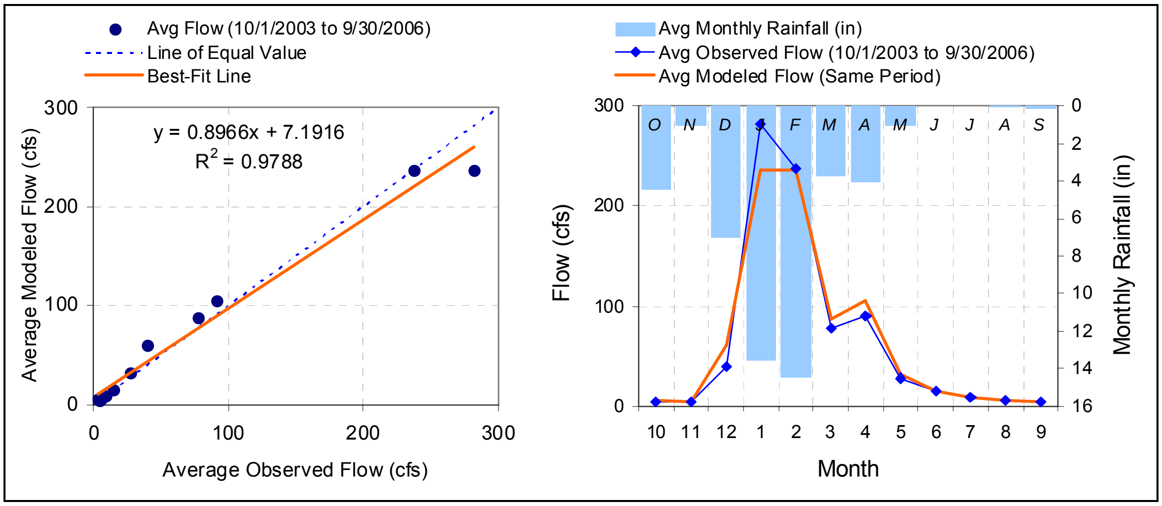

Figure 6-5. Annual Flow Regression and Monthly Aggregate: Model vs. USGS 11114495 Matilija Creek abv Res

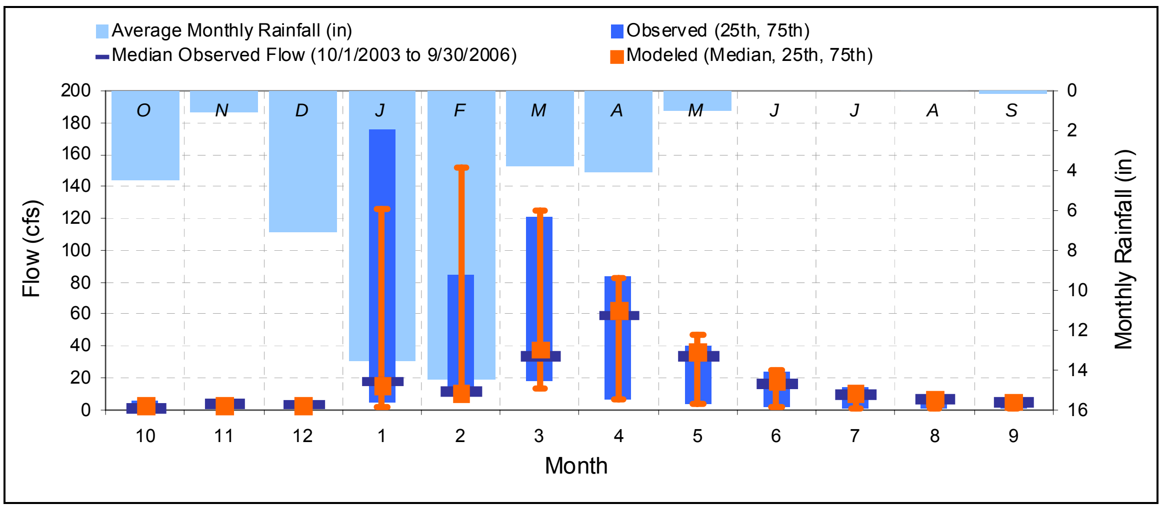

Figure 6-6. Seasonal Medians and Ranges: Model vs. USGS 11114495 Matilija Creek abv Res

Table 6-11. Seasonal Summary: Model vs. USGS 11114495 Matilija Creek abv Res

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	3.58	1.30	1.20	5.60	5.63	2.75	1.85	5.49
Nov	4.48	3.90	2.03	6.28	4.16	2.90	2.20	5.21
Dec	39.60	3.40	2.90	5.60	60.29	2.64	1.95	4.99
Jan	281.51	18.00	4.90	176.00	236.29	15.00	1.98	126.00
Feb	237.57	12.00	8.30	85.00	236.12	10.20	7.81	152.00
Mar	77.77	34.00	18.00	121.00	87.44	37.60	13.60	125.00
Apr	90.60	59.50	6.45	83.75	105.16	62.55	6.20	82.65
May	27.71	34.00	3.40	40.00	31.94	36.50	3.17	46.80
Jun	15.22	16.50	1.95	24.00	15.25	17.80	1.90	24.58
Jul	8.66	9.90	1.10	14.00	8.41	10.30	1.21	12.80
Aug	5.84	7.00	0.77	9.10	5.60	6.88	0.86	8.41
Sep	3.91	4.80	0.73	5.95	4.08	4.85	0.65	6.23

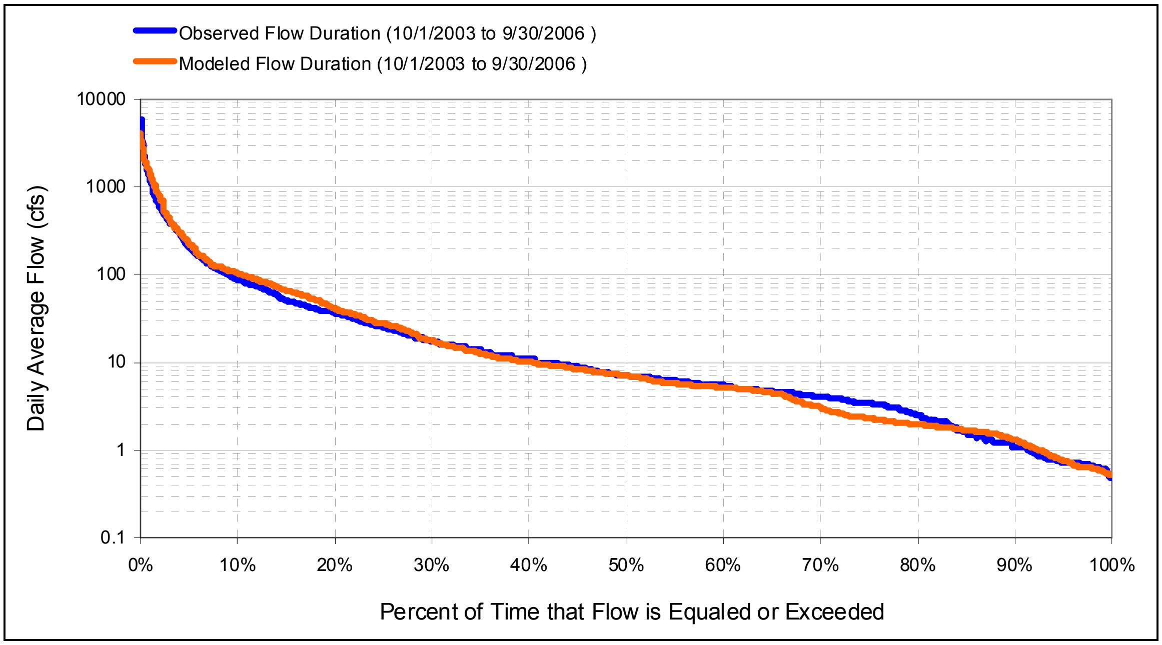

Figure 6-7. Flow Exceedence: Model vs. USGS 11114495 Matilija Creek abv Res

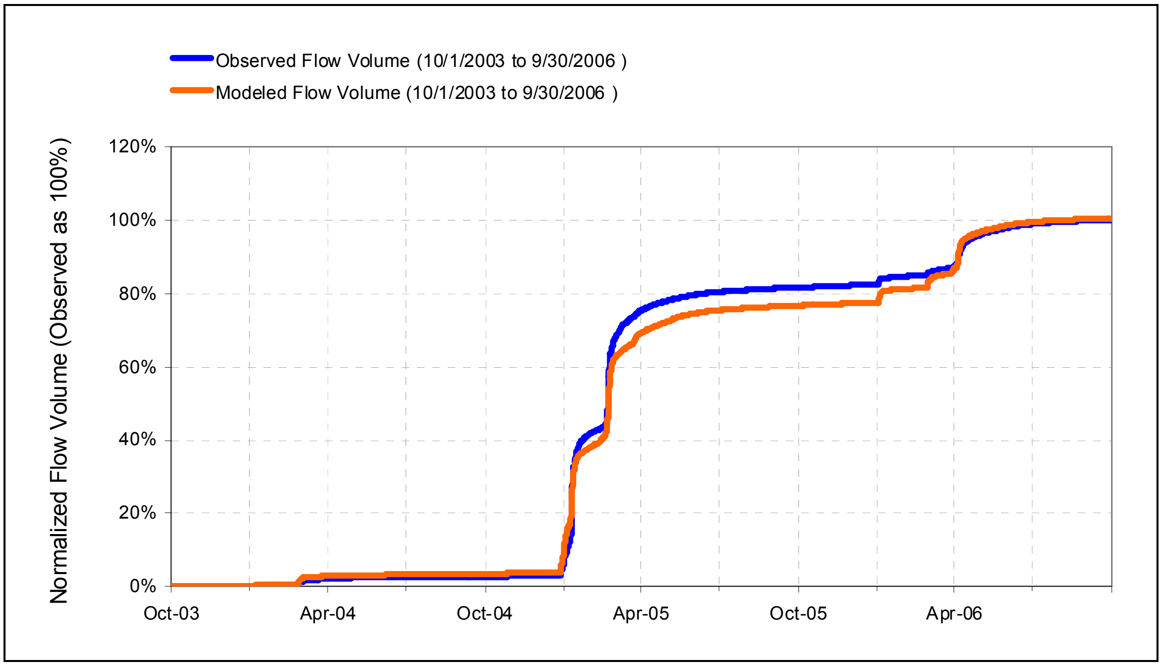

Figure 6-8. Flow Accumulation: Model vs. USGS 11114495 Matilija Creek abv Res

Table 6-12. Summary Statistics: Model vs. USGS 11114495 Matilija Creek abv Res

HSPF Simulated Flow		**Observed Flow Gage**	
REACH OUTFLOW FROM SUBBASIN 51 3-Year Analysis Period: 10/1/2003 - 9/30/2006 Flow volumes are (inches/year) for upstream drainage area **Gage 603A** **DSN 5002** **12/3/2008 15:12**		**USGS 11114495 Matilija Creek abv Res** Hydrologic Unit Code: 18070101 Latitude: 34.35222038 Longitude: -119.3084466 Drainage Area (sq-mi): 188	
Total Simulated In-stream Flow:	**25.19**	Total Observed In-stream Flow:	**25.08**
Total of simulated highest 10% flows:	**20.11**	Total of Observed highest 10% flows:	**20.48**
Total of Simulated lowest 50% flows:	**0.58**	Total of Observed Lowest 50% flows:	**0.64**
Simulated Summer Flow Volume (months 7-9):	**0.58**	Observed Summer Flow Volume (7-9):	**0.59**
Simulated Fall Flow Volume (months 10-12):	**2.27**	Observed Fall Flow Volume (10-12):	**1.54**
Simulated Winter Flow Volume (months 1-3):	**17.52**	Observed Winter Flow Volume (1-3):	**18.71**
Simulated Spring Flow Volume (months 4-6):	**4.82**	Observed Spring Flow Volume (4-6):	**4.22**
Total Simulated Storm Volume:	**10.92**	Total Observed Storm Volume:	**10.50**
Simulated Summer Storm Volume (7-9):	**0.04**	Observed Summer Storm Volume (7-9):	**0.03**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	0.47	10	
Error in 50% lowest flows:	-9.81	10	
Error in 10% highest flows:	-1.79	15	
Seasonal volume error - Summer:	-1.77	30	
Seasonal volume error - Fall:	**47.22**	**30**	
Seasonal volume error - Winter:	-6.39	30	
Seasonal volume error - Spring:	14.10	30	
Error in storm volumes:	4.02	20	
Error in summer storm volumes:	33.63	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.869	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.770	as E or E' approaches 1.0	

6.5.2 Matilija Creek below Dam (602/602A)

This gage record is used to estimate daily releases from Matilija Dam, as described in Section 4.3. Therefore, the results for this gage are not a proper calibration test, and only a graphical summary is provided here. Summary statistics are, however, reported above in Table 6-4.

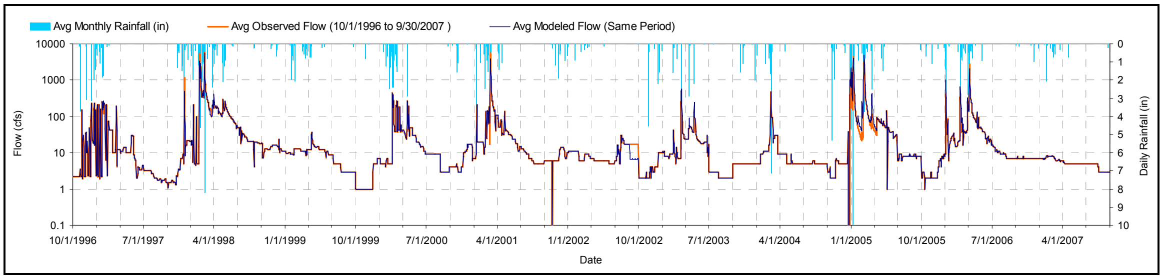

Figure 6-9. Mean Daily Flow: Model Outlet 999 vs. Gage 602/602A Matilija Creek below Dam

6.5.3 North Fork Matilija (604)

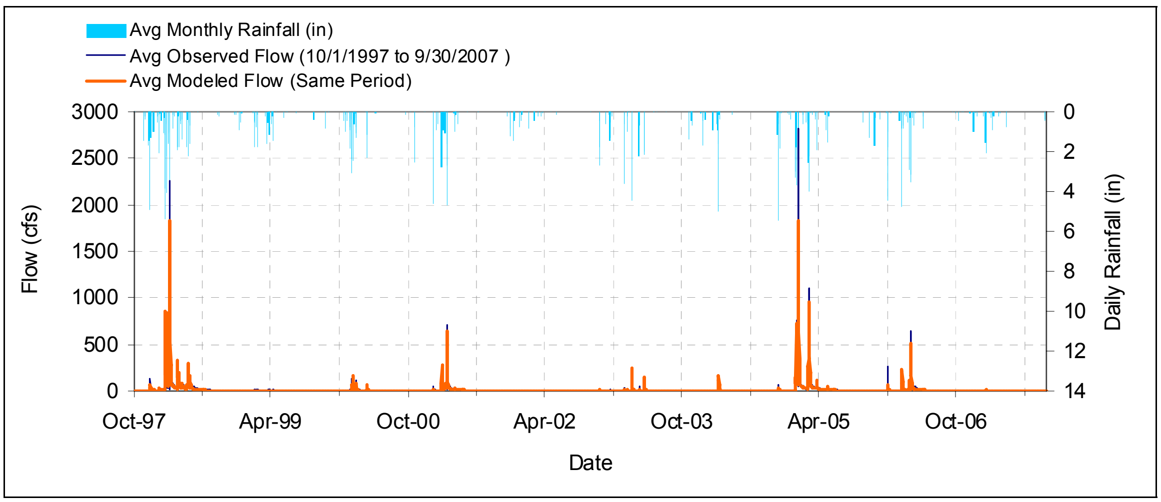

Figure 6-10. Mean Daily Flow: Model vs. USGS 11116000 North Fork Matilija Cr

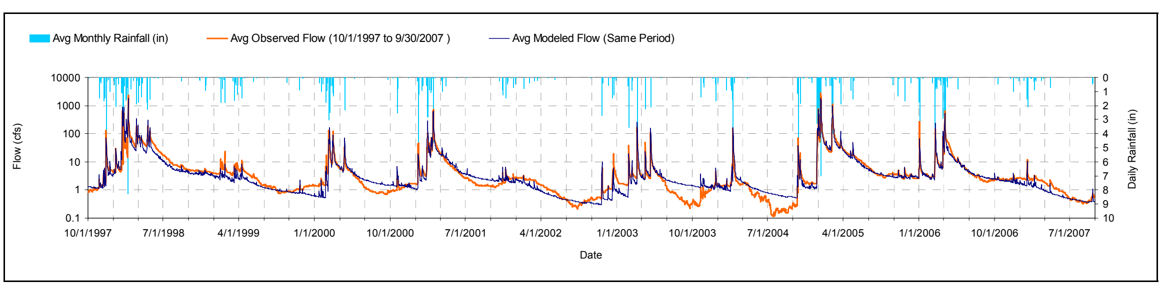

Figure 6-11. Mean Daily Flow: Model vs. USGS 11116000 North Fork Matilija Cr

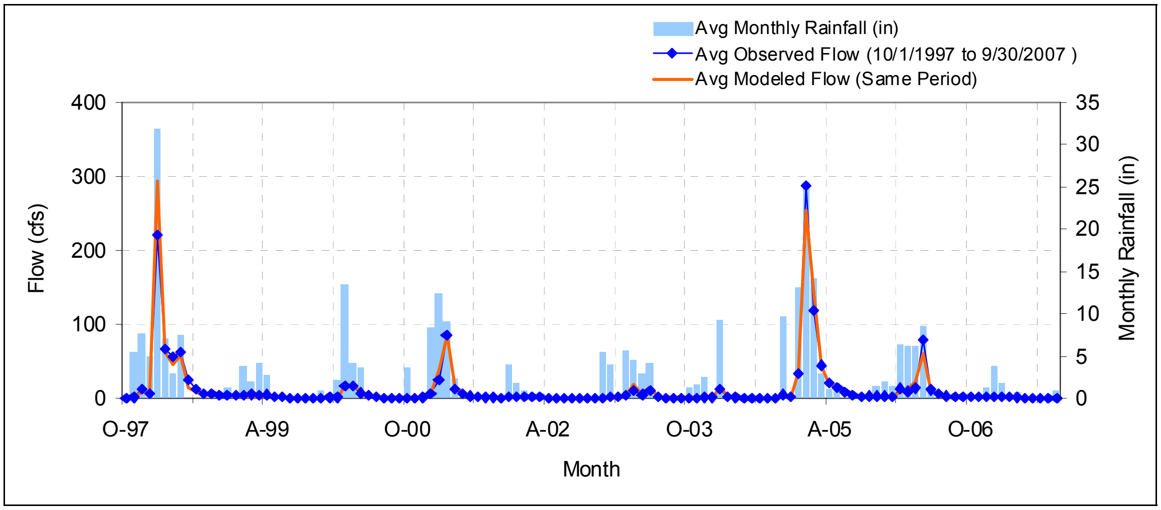

Figure 6-12. Mean Monthly Flow: Model vs. USGS 11116000 North Fork Matilija Cr

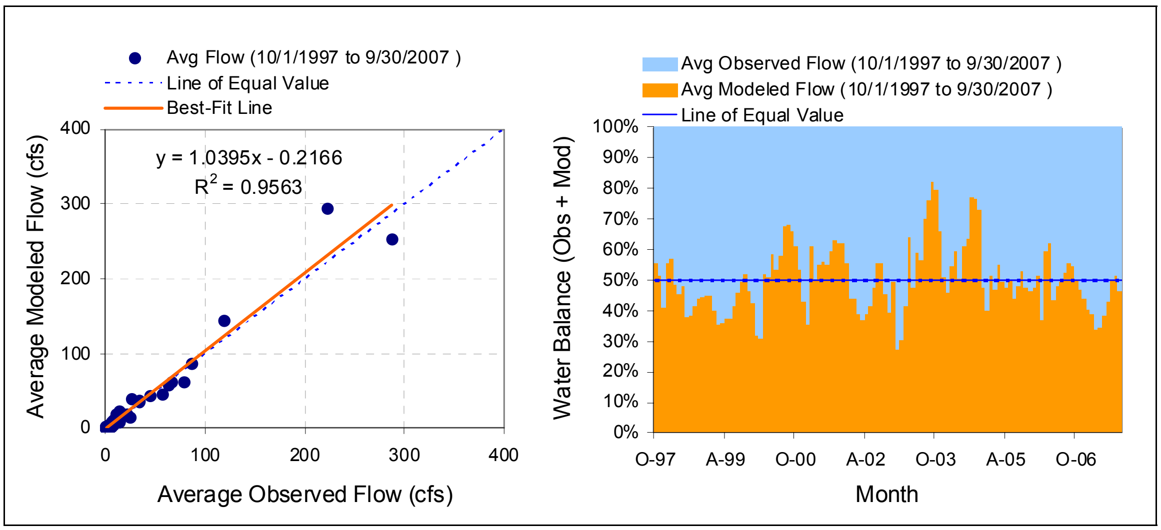

Figure 6-13. Monthly Flow Regression and Temporal Variation: Model vs. USGS 11116000 North Fork Matilija Cr

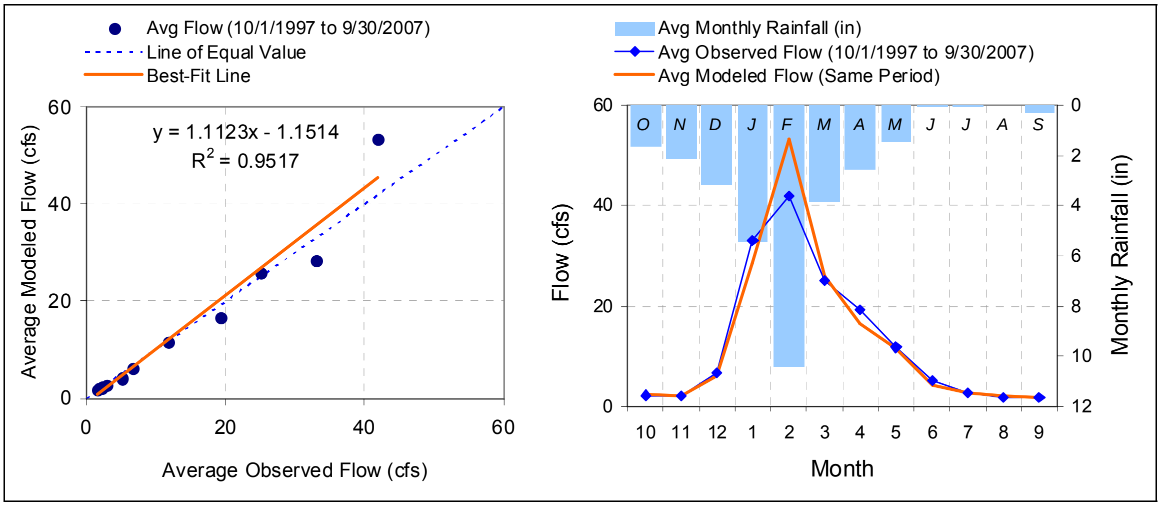

Figure 6-14. Annual Flow Regression and Monthly Aggregate: Model vs. USGS 11116000 North Fork Matilija Cr

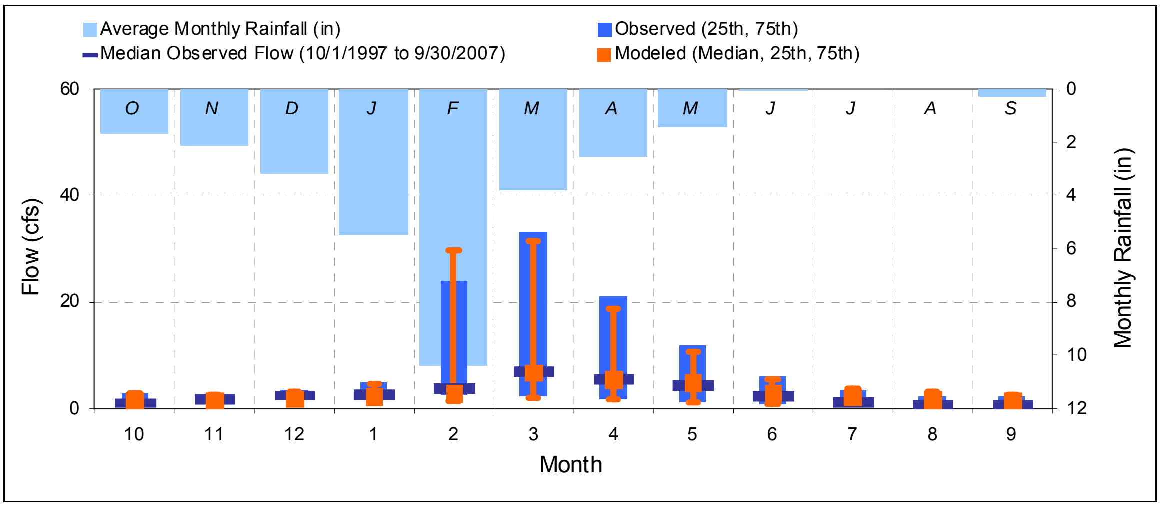

Figure 6-15. Seasonal Medians and Ranges: Model vs. USGS 11116000 North Fork Matilija Cr

Table 6-13. Seasonal Summary: Model vs. USGS 11116000 North Fork Matilija Cr

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	2.17	1.10	0.80	2.70	2.22	1.45	0.93	2.75
Nov	2.04	1.70	1.08	2.60	1.95	1.54	1.20	2.60
Dec	6.71	2.50	1.63	3.38	6.07	1.75	1.17	3.06
Jan	33.13	2.70	1.70	4.78	28.47	2.22	1.14	4.50
Feb	41.95	3.80	2.40	23.75	53.34	2.75	1.49	29.83
Mar	25.04	6.95	2.30	33.00	25.95	6.71	2.01	31.45
Apr	19.32	5.50	1.80	21.00	16.56	5.43	1.59	18.70
May	11.72	4.40	1.10	11.75	11.62	4.81	1.12	10.58
Jun	5.10	2.30	0.74	5.95	4.11	2.68	0.86	5.48
Jul	2.78	1.20	0.46	3.30	2.66	2.05	0.73	3.72
Aug	1.78	0.83	0.39	2.30	2.02	1.68	0.62	3.00
Sep	1.62	0.83	0.40	2.20	1.80	1.51	0.58	2.55

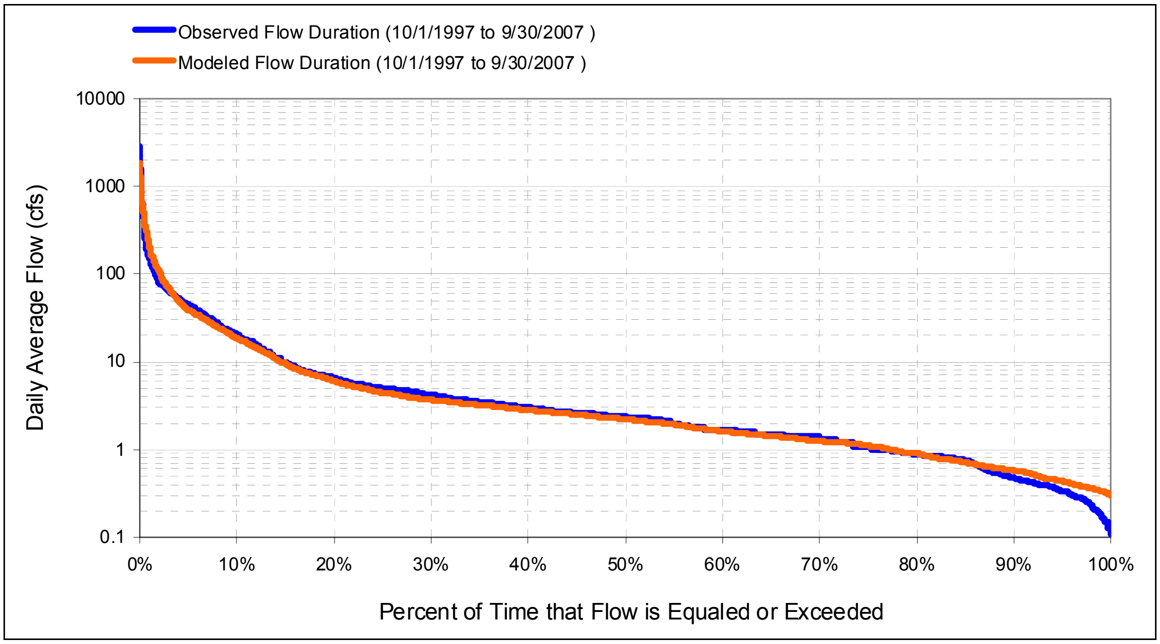

Figure 6-16. Flow Exceedence: Model vs. USGS 11116000 North Fork Matilija Cr

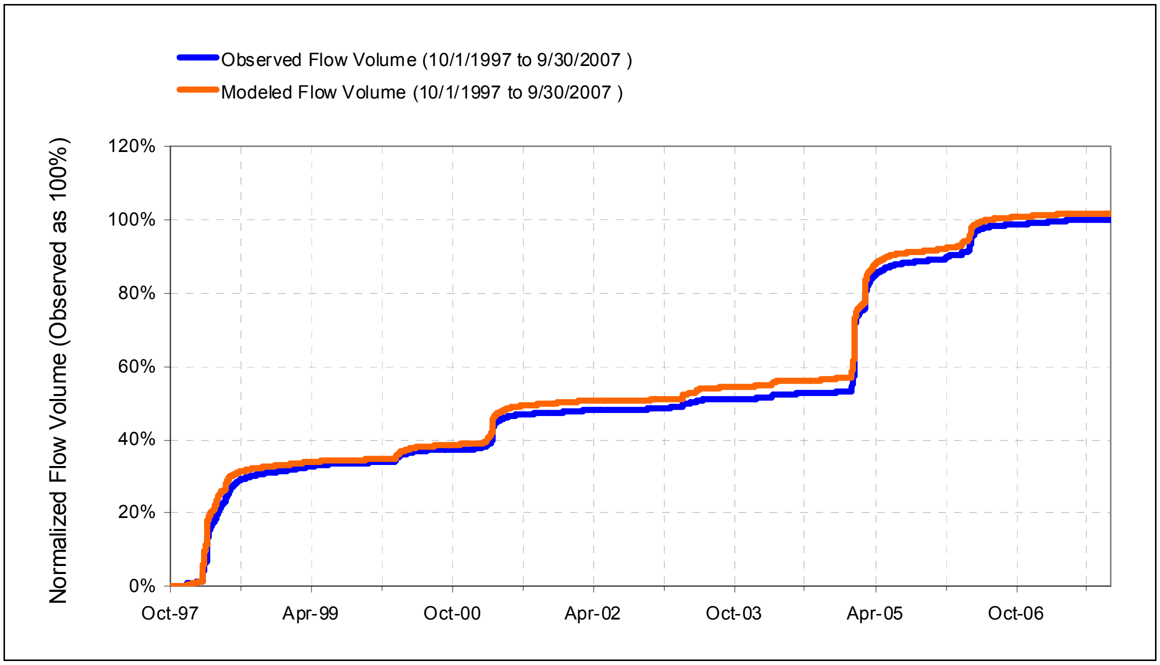

Figure 6-17. Flow Accumulation: Model vs. USGS 11116000 North Fork Matilija Cr

Table 6-14. Summary Statistics: Model vs. USGS 11116000 North Fork Matilija Cr

HSPF Simulated Flow		**Observed Flow Gage**	
REACH OUTFLOW FROM SUBBASIN 682 10-Year Analysis Period: 10/1/1997 - 9/30/2007 Flow volumes are (inches/year) for upstream drainage area **Gage 604** **DSN 5003** **7/17/2009 11:04**		**USGS 11116000 North Fork Matilija Cr** Hydrologic Unit Code: 4040003 Latitude: 43.10001159 Longitude: -87.9089745 Drainage Area (sq-mi): 696	
Total Simulated In-stream Flow:	**10.97**	Total Observed In-stream Flow:	**10.79**
Total of simulated highest 10% flows:	**8.71**	Total of Observed highest 10% flows:	**8.39**
Total of Simulated lowest 50% flows:	**0.48**	Total of Observed Lowest 50% flows:	**0.48**
Simulated Summer Flow Volume (months 7-9):	**0.47**	Observed Summer Flow Volume (7-9):	**0.44**
Simulated Fall Flow Volume (months 10-12):	**0.74**	Observed Fall Flow Volume (10-12):	**0.79**
Simulated Winter Flow Volume (months 1-3):	**7.47**	Observed Winter Flow Volume (1-3):	**6.99**
Simulated Spring Flow Volume (months 4-6):	**2.29**	Observed Spring Flow Volume (4-6):	**2.57**
Total Simulated Storm Volume:	**2.80**	Total Observed Storm Volume:	**2.86**
Simulated Summer Storm Volume (7-9):	**0.01**	Observed Summer Storm Volume (7-9):	**0.01**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	1.67	10	
Error in 50% lowest flows:	-0.70	10	
Error in 10% highest flows:	3.77	15	
Seasonal volume error - Summer:	4.87	30	
Seasonal volume error - Fall:	-6.22	30	
Seasonal volume error - Winter:	6.86	30	
Seasonal volume error - Spring:	-10.58	30	
Error in storm volumes:	-2.34	20	
Error in summer storm volumes:	35.76	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.903	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.750	as E or E' approaches 1.0	

6.5.4 Ventura River near Meiners Oaks (at Robles Diversion) (607)

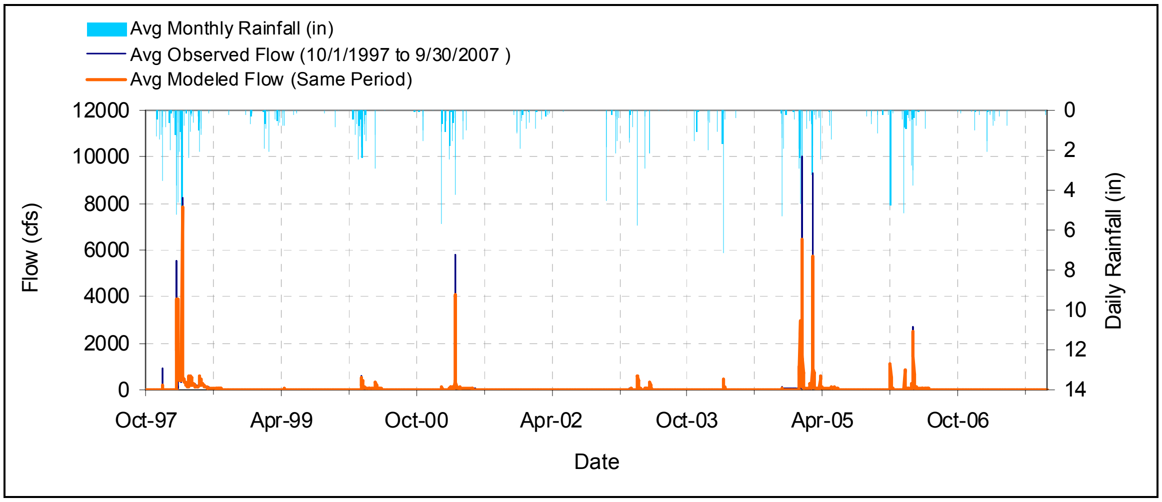

Figure 6-18. Mean Daily Flow: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA

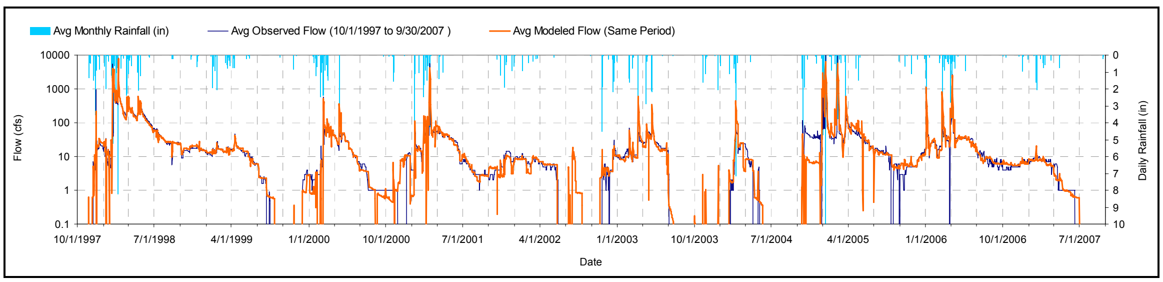

Figure 6-19. Mean Daily Flow: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA

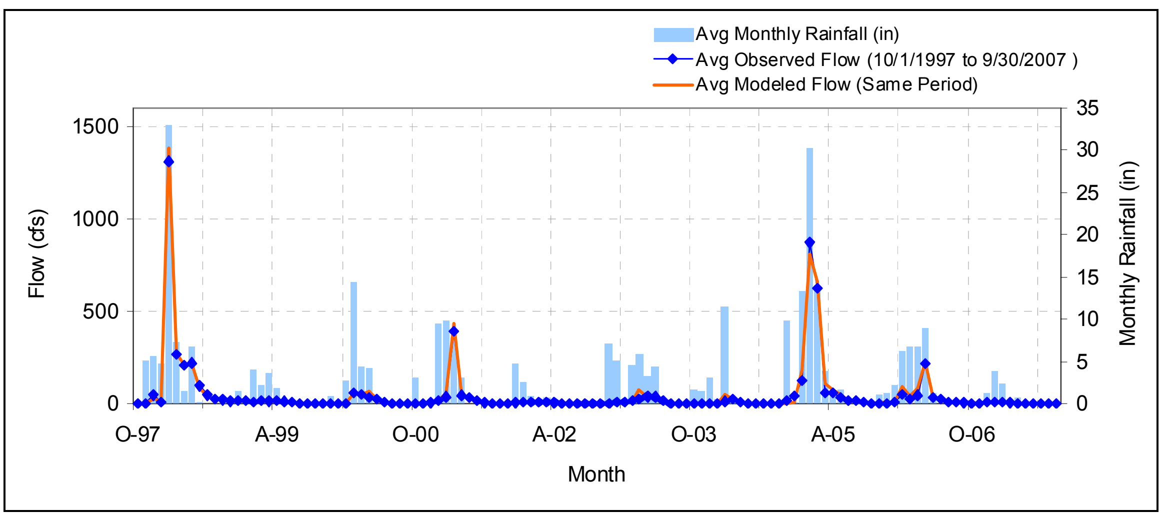

Figure 6-20. Mean Monthly Flow: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA

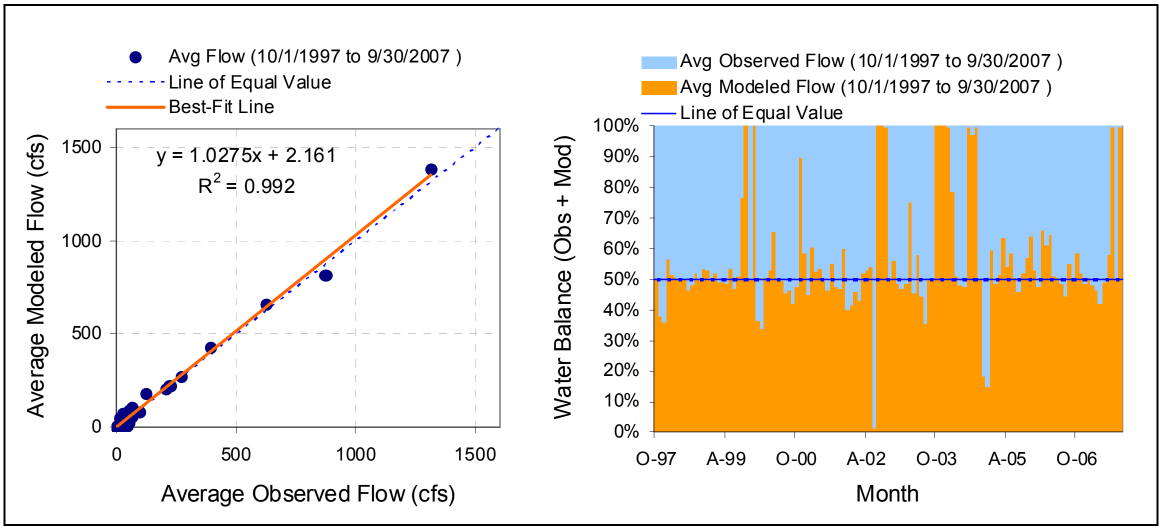

Figure 6-21. Monthly Flow Regression and Temporal Variation: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA

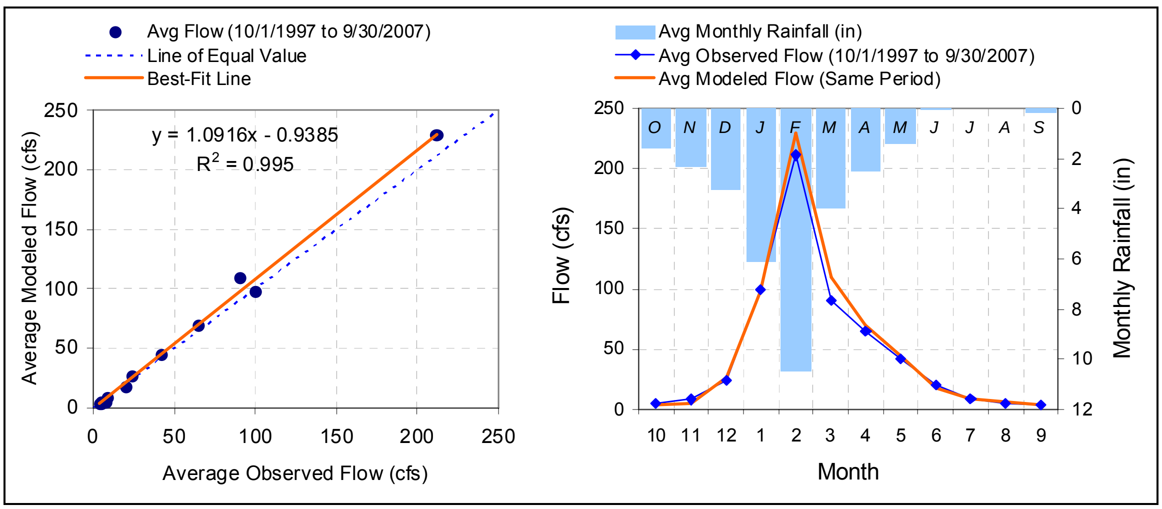

Figure 6-22. Annual Flow Regression and Monthly Aggregate: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA

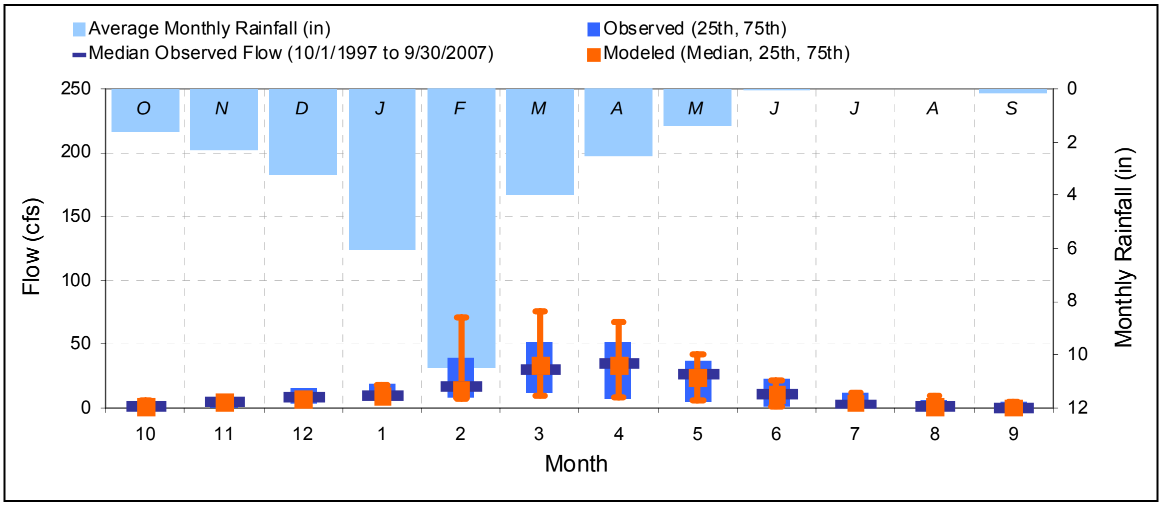

Figure 6-23. Seasonal Medians and Ranges: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA

Table 6-15. Seasonal Summary: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	4.47	1.00	0.00	4.00	3.86	0.49	0.00	5.73
Nov	7.95	5.00	0.00	6.00	5.02	4.32	0.20	6.46
Dec	23.47	9.00	3.00	15.00	26.84	7.17	3.26	11.00
Jan	99.45	10.00	5.70	19.00	98.00	9.49	6.91	17.18
Feb	211.58	17.00	8.00	39.00	229.57	14.35	7.55	70.05
Mar	90.07	30.00	12.25	52.00	109.08	33.45	9.56	74.88
Apr	64.51	35.00	7.00	52.00	69.80	33.05	8.03	66.95
May	41.76	27.00	5.00	36.75	44.89	23.55	5.75	42.35
Jun	19.90	11.00	1.00	22.00	17.84	10.25	0.63	21.20
Jul	8.94	3.00	0.00	12.00	8.55	3.81	0.00	11.28
Aug	4.83	1.00	0.00	6.00	5.45	1.05	0.00	8.86
Sep	3.73	0.00	0.00	4.00	3.81	0.33	0.00	4.77

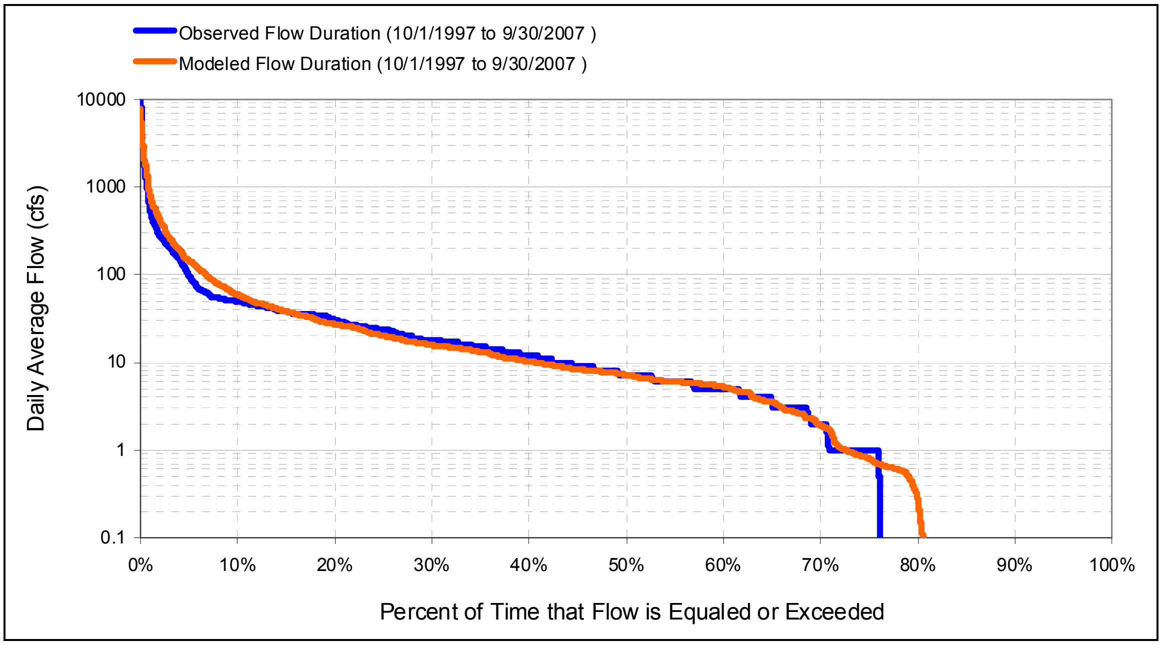

Figure 6-24. Flow Exceedence: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA

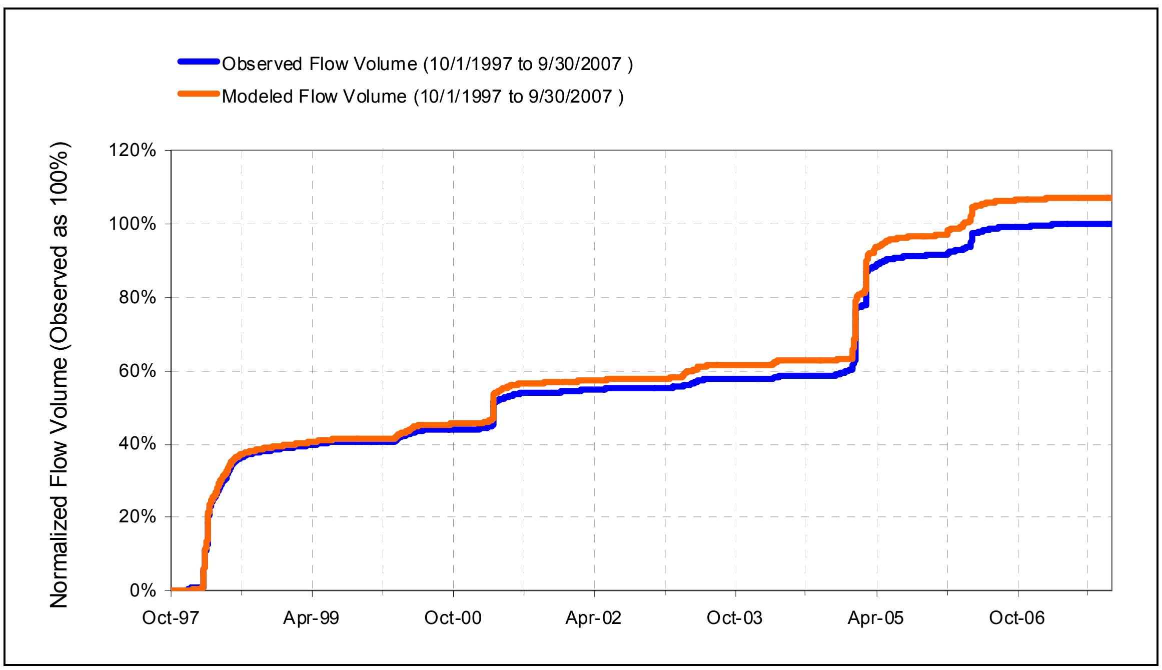

Figure 6-25. Flow Accumulation: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA

Table 6-16. Summary Statistics: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA

HSPF Simulated Flow		**Observed Flow Gage**		
REACH OUTFLOW FROM SUBBASIN 912 10-Year Analysis Period: 10/1/1997 - 9/30/2007 Flow volumes are (inches/year) for upstream drainage area **Gage 607** **DSN 5006** **12/3/2008 15:04**		**USGS 11116550 VENTURA R NR MEINERS OAKS CA** Hydrologic Unit Code: 4040003 Latitude: 43.10001159 Longitude: -87.9089745 Drainage Area (sq-mi): 696		
Total Simulated In-stream Flow:	**9.04**	Total Observed In-stream Flow:		**8.43**
Total of simulated highest 10% flows:	**7.40**	Total of Observed highest 10% flows:		**6.71**
Total of Simulated lowest 50% flows:	**0.19**	Total of Observed Lowest 50% flows:		**0.18**
Simulated Summer Flow Volume (months 7-9):	**0.27**	Observed Summer Flow Volume (7-9):		**0.26**
Simulated Fall Flow Volume (months 10-12):	**0.54**	Observed Fall Flow Volume (10-12):		**0.54**
Simulated Winter Flow Volume (months 1-3):	**6.28**	Observed Winter Flow Volume (1-3):		**5.77**
Simulated Spring Flow Volume (months 4-6):	**1.96**	Observed Spring Flow Volume (4-6):		**1.86**
Total Simulated Storm Volume:	**4.37**	Total Observed Storm Volume:		**4.45**
Simulated Summer Storm Volume (7-9):	**0.02**	Observed Summer Storm Volume (7-9):		**0.03**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	7.24	10		
Error in 50% lowest flows:	3.47	10		
Error in 10% highest flows:	10.28	15		
Seasonal volume error - Summer:	1.69	30		
Seasonal volume error - Fall:	-0.20	30		
Seasonal volume error - Winter:	8.88	30		
Seasonal volume error - Spring:	5.07	30		
Error in storm volumes:	-1.77	20		
Error in summer storm volumes:	-15.89	50		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.869	Model accuracy increases		
Baseline adjusted coefficient (Garrick), E':	0.739	as E or E' approaches 1.0		

6.5.5 San Antonio Creek at Hwy. 33 (605)

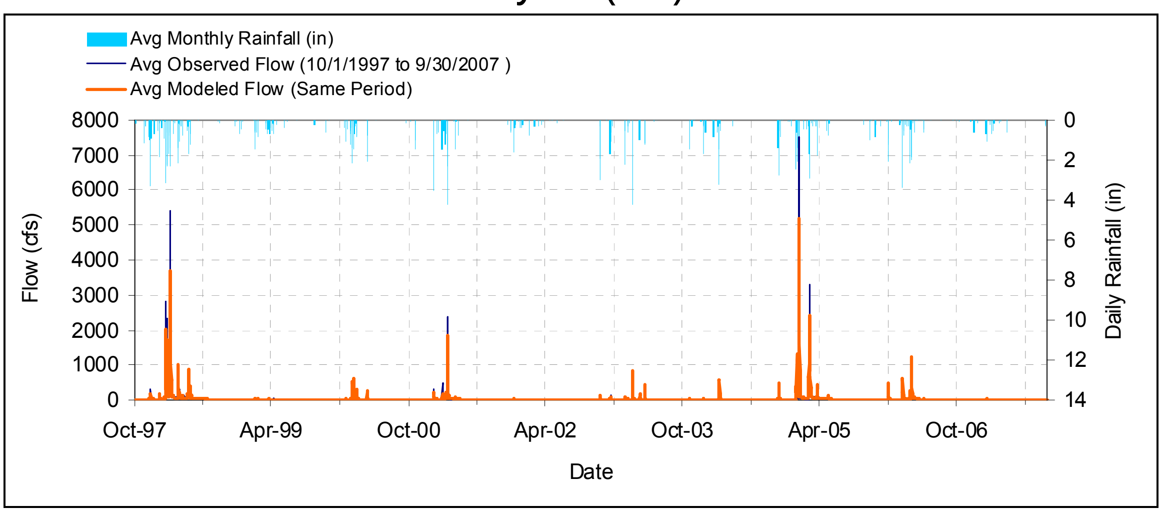

Figure 6-26. Mean Daily Flow: Model vs. USGS 11117500 San Antonio Cr at Hwy 33

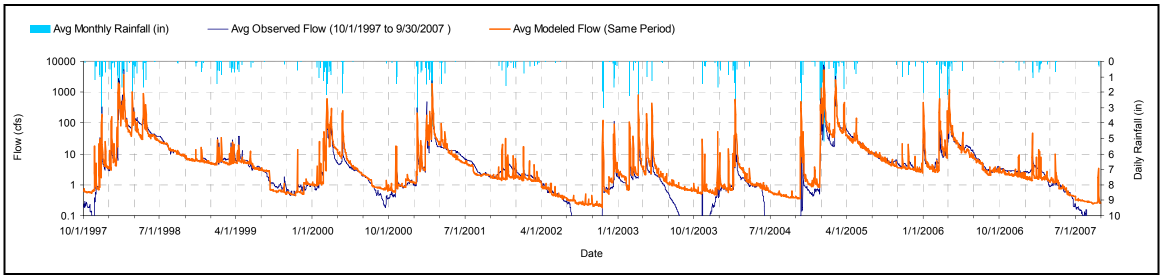

Figure 6-27. Mean Daily Flow: Model vs. USGS 11117500 San Antonio Cr at Hwy 33

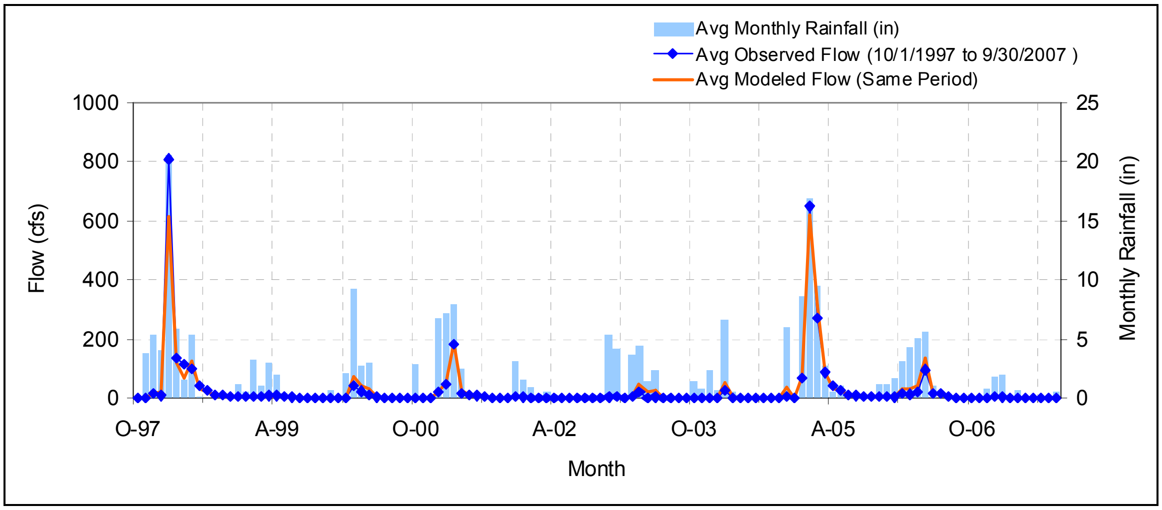

Figure 6-28. Mean Monthly Flow: Model vs. USGS 11117500 San Antonio Cr at Hwy 33

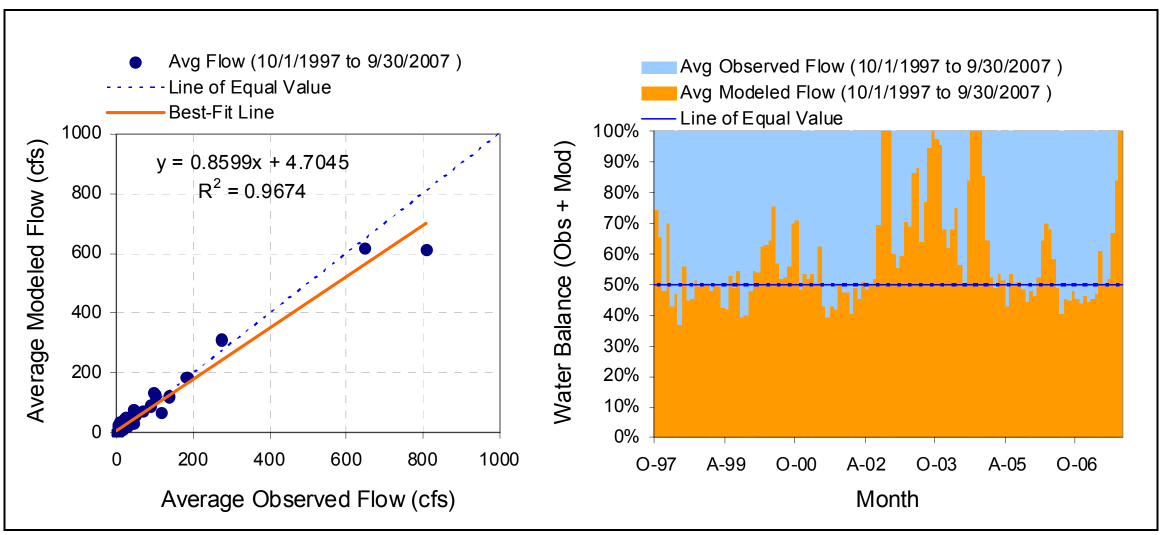

Figure 6-29. Monthly Flow Regression and Temporal Variation: Model vs. USGS 11117500 San Antonio Cr at Hwy 33

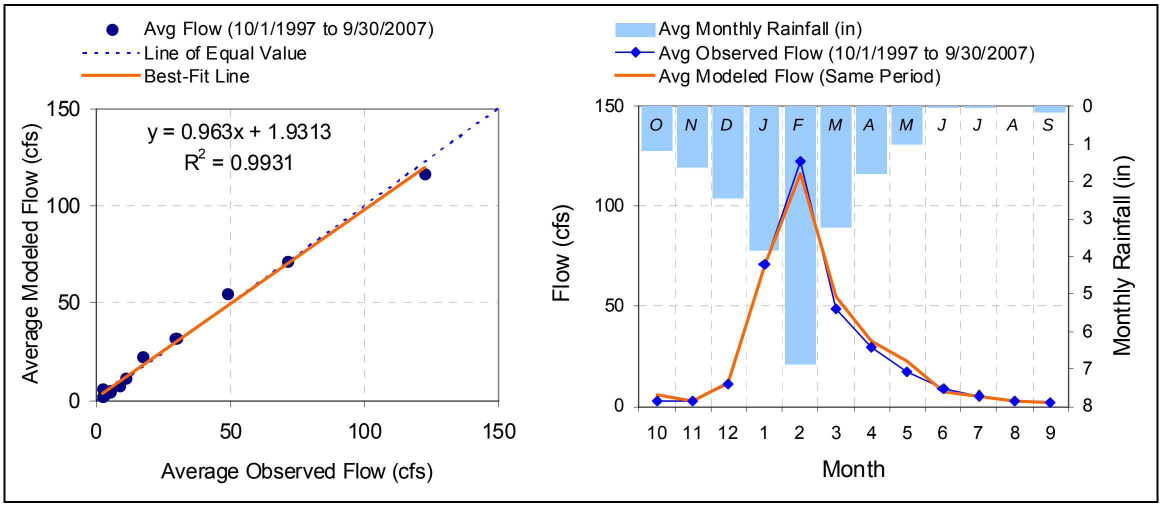

Figure 6-30. Annual Flow Regression and Monthly Aggregate: Model vs. USGS 11117500 San Antonio Cr at Hwy 33

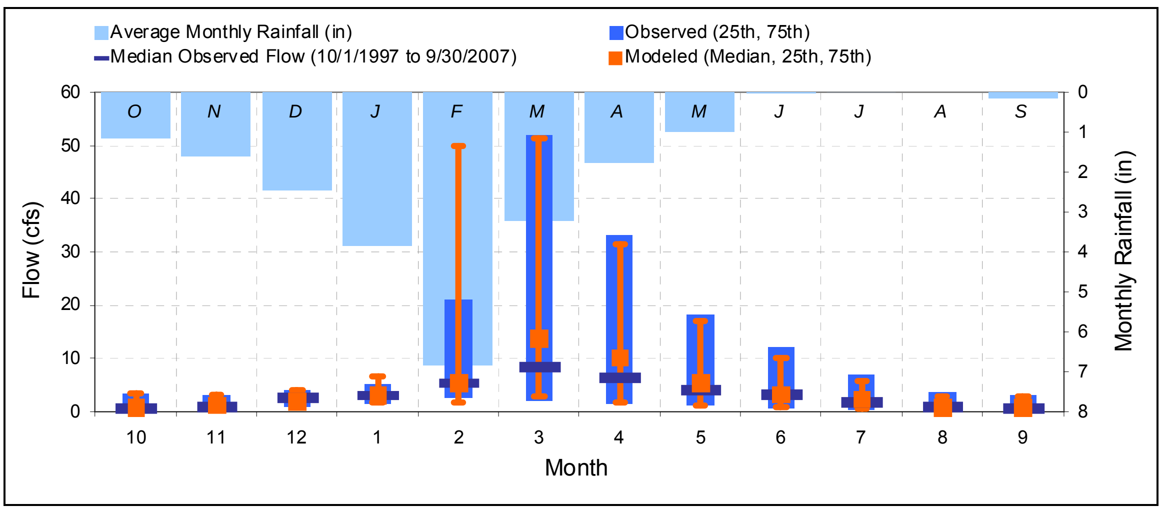

Figure 6-31. Seasonal Medians and Ranges: Model vs. USGS 11117500 San Antonio Cr at Hwy 33

Table 6-17. Seasonal Summary: Model vs. USGS 11117500 San Antonio Cr at Hwy 33

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	2.47	0.58	0.03	3.28	5.84	0.74	0.55	3.50
Nov	2.67	0.97	0.63	3.20	3.07	1.16	0.69	3.14
Dec	11.03	2.60	0.88	3.98	11.74	1.84	1.17	3.90
Jan	71.39	3.05	1.30	5.10	71.32	3.15	1.56	6.59
Feb	122.41	5.35	2.40	21.00	116.37	5.34	1.69	49.95
Mar	48.79	8.45	2.00	52.00	55.16	13.75	2.96	51.25
Apr	29.65	6.45	1.28	33.25	32.45	10.15	1.56	31.50
May	17.09	4.15	0.97	18.00	22.50	5.35	0.97	17.10
Jun	8.71	3.15	0.54	12.00	7.32	3.20	0.71	10.13
Jul	5.36	1.80	0.19	6.80	4.91	2.41	0.52	5.81
Aug	2.73	0.88	0.00	3.70	2.77	0.83	0.45	2.81
Sep	2.19	0.57	0.00	3.10	2.23	0.71	0.40	2.87

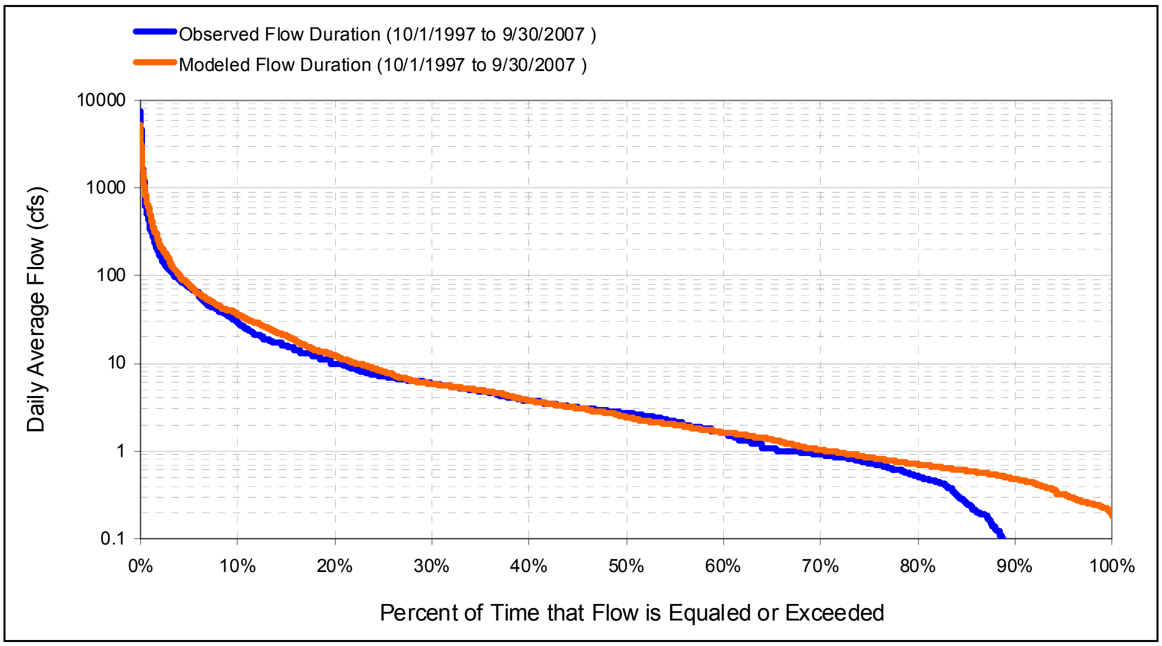

Figure 6-32. Flow Exceedence: Model vs. USGS 11117500 San Antonio Cr at Hwy 33

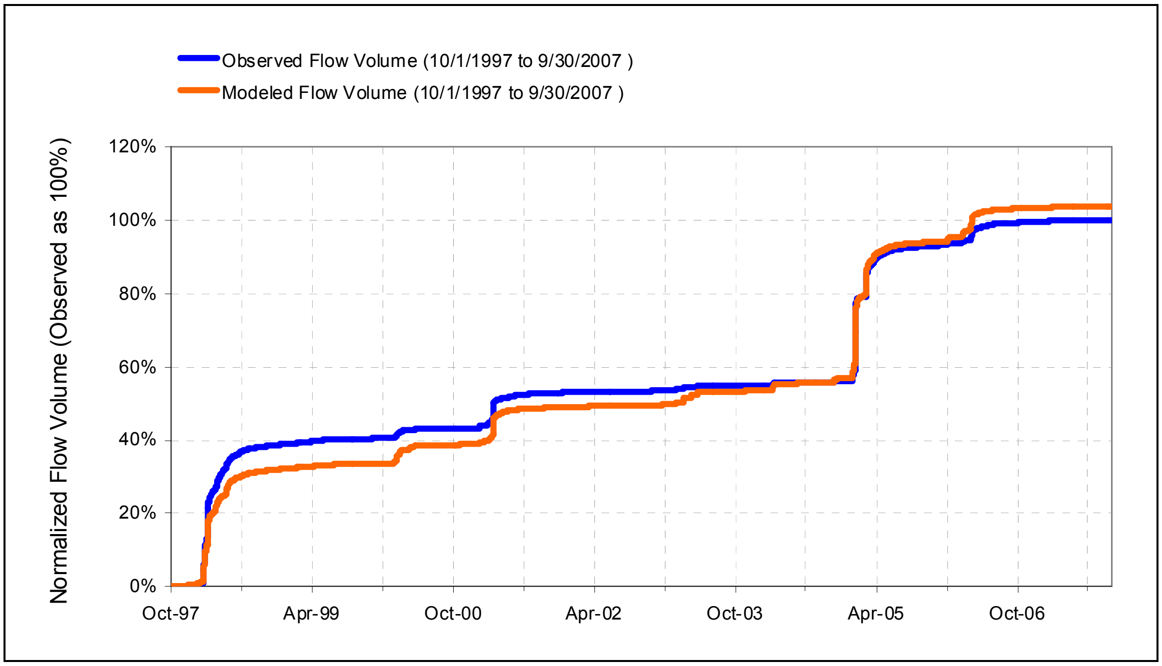

Figure 6-33. Flow Accumulation: Model vs. USGS 11117500 San Antonio Cr at Hwy 33

Table 6-18. Summary Statistics: Model vs. USGS 11117500 San Antonio Cr at Hwy 33

HSPF Simulated Flow		**Observed Flow Gage**		
REACH OUTFLOW FROM SUBBASIN 371 10-Year Analysis Period: 10/1/1997 - 9/30/2007 Flow volumes are (inches/year) for upstream drainage area **Gage 605** **DSN 5004** **12/3/2008 15:09**		**USGS 11117500 San Antonio Cr at Hwy 33** Hydrologic Unit Code: 4040003 Latitude: 43.10001159 Longitude: -87.9089745 Drainage Area (sq-mi): 696		
Total Simulated In-stream Flow:	**7.53**	Total Observed In-stream Flow:		**7.26**
Total of simulated highest 10% flows:	**6.36**	Total of Observed highest 10% flows:		**6.27**
Total of Simulated lowest 50% flows:	**0.14**	Total of Observed Lowest 50% flows:		**0.12**
Simulated Summer Flow Volume (months 7-9):	**0.23**	Observed Summer Flow Volume (7-9):		**0.24**
Simulated Fall Flow Volume (months 10-12):	**0.48**	Observed Fall Flow Volume (10-12):		**0.37**
Simulated Winter Flow Volume (months 1-3):	**5.41**	Observed Winter Flow Volume (1-3):		**5.39**
Simulated Spring Flow Volume (months 4-6):	**1.42**	Observed Spring Flow Volume (4-6):		**1.26**
Total Simulated Storm Volume:	**4.32**	Total Observed Storm Volume:		**4.23**
Simulated Summer Storm Volume (7-9):	**0.01**	Observed Summer Storm Volume (7-9):		**0.01**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	3.74	10		
Error in 50% lowest flows:	**18.85**	**10**		
Error in 10% highest flows:	1.53	15		
Seasonal volume error - Summer:	-3.59	30		
Seasonal volume error - Fall:	27.77	30		
Seasonal volume error - Winter:	0.35	30		
Seasonal volume error - Spring:	12.51	30		
Error in storm volumes:	1.94	20		
Error in summer storm volumes:	20.38	50		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.905	Model accuracy increases		
Baseline adjusted coefficient (Garrick), E':	0.737	as E or E' approaches 1.0		

6.5.6 Ventura River near Ventura (at Foster Park) (608)

Observed flows at this station are strongly influenced by groundwater pumping and withdrawals from alluvium at Foster Park.

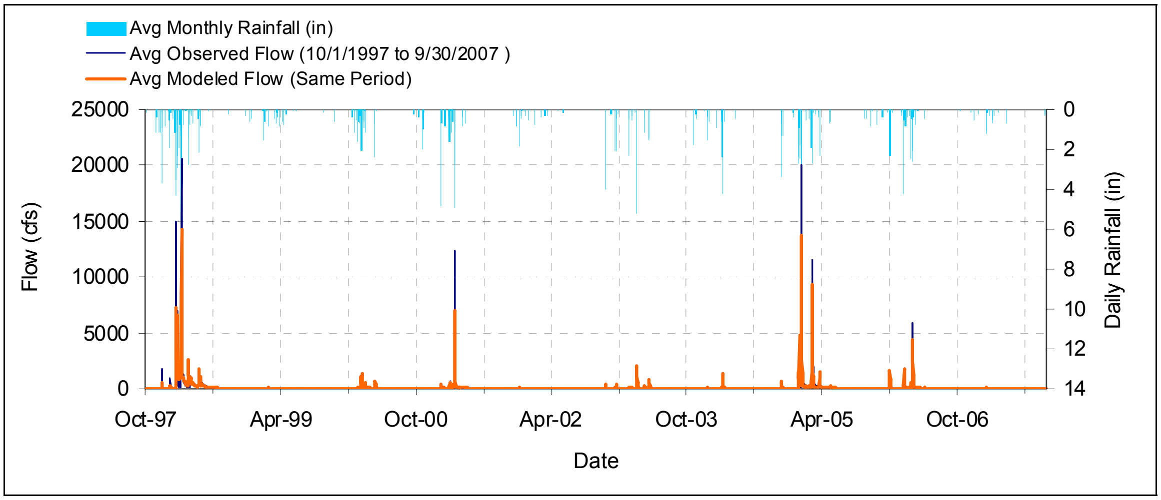

Figure 6-34. Mean Daily Flow: Model vs. USGS 11118500 Ventura R nr Ventura

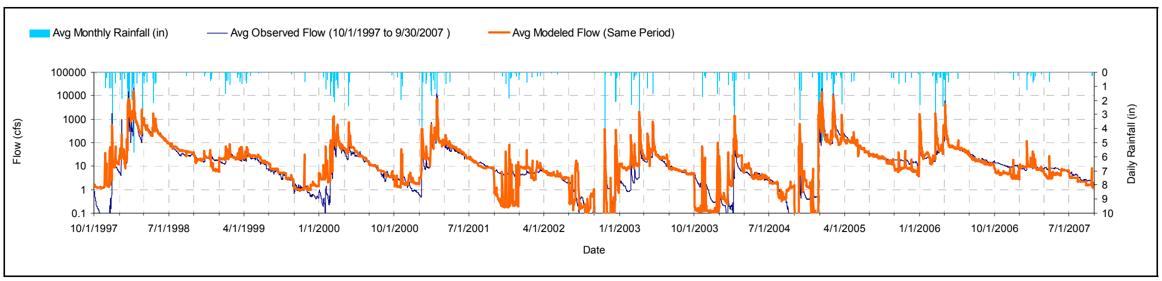

Figure 6-35. Mean Daily Flow: Model vs. USGS 11118500 Ventura R nr Ventura

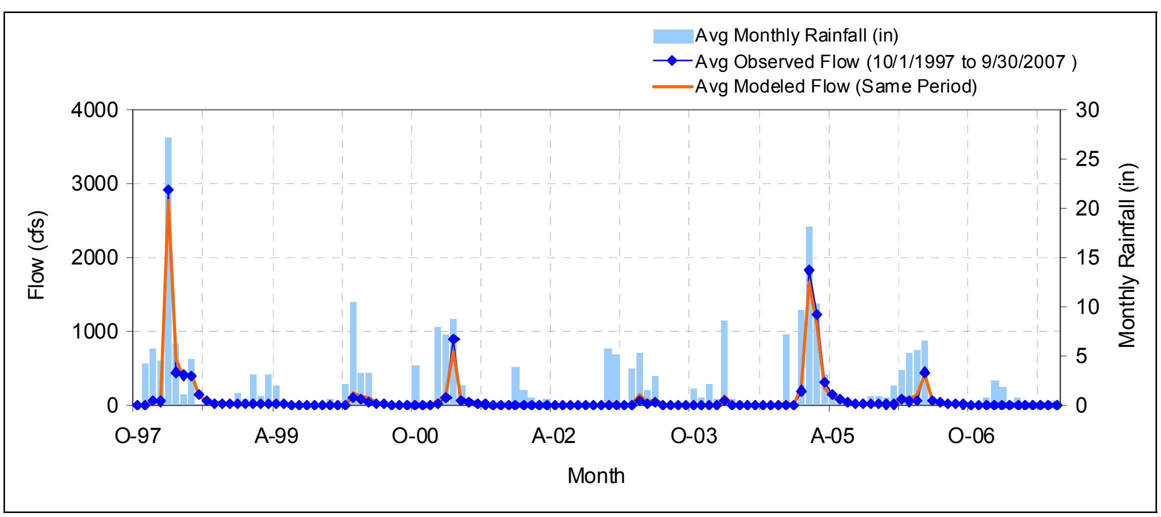

Figure 6-36. Mean Monthly Flow: Model vs. USGS 11118500 Ventura R nr Ventura

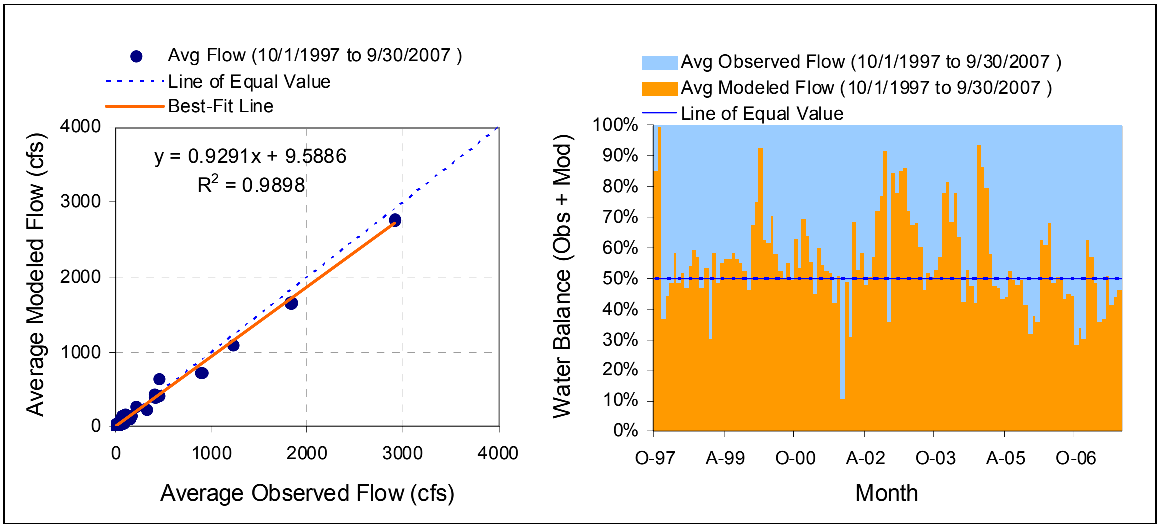

Figure 6-37. Monthly Flow Regression and Temporal Variation: Model vs. USGS 11118500 Ventura R nr Ventura

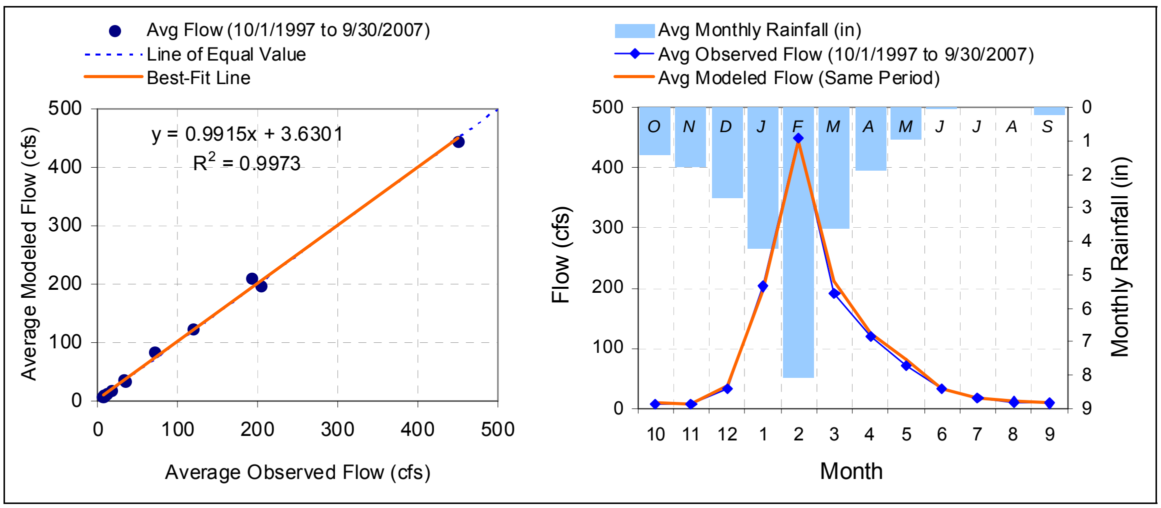

Figure 6-38. Annual Flow Regression and Monthly Aggregate: Model vs. USGS 11118500 Ventura R nr Ventura

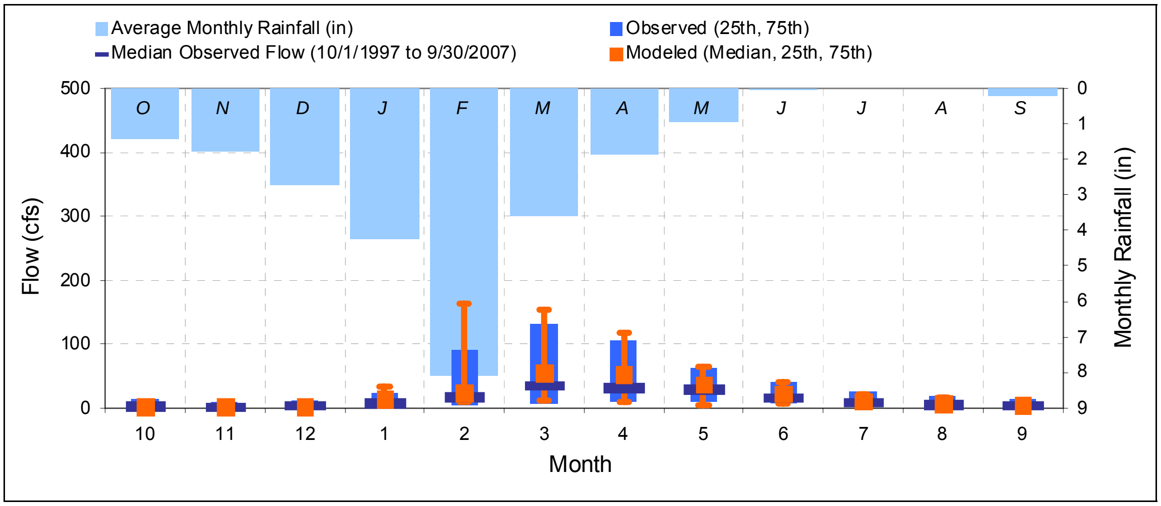

Figure 6-39. Seasonal Medians and Ranges: Model vs. USGS 11118500 Ventura R nr Ventura

Table 6-19. Seasonal Summary: Model vs. USGS 11118500 Ventura R nr Ventura

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	7.41	2.80	0.50	14.00	9.82	1.26	0.24	6.61
Nov	6.18	1.70	0.75	10.00	8.01	1.71	1.01	7.58
Dec	32.91	3.65	0.52	11.00	36.84	2.22	0.30	6.56
Jan	203.09	7.50	1.40	23.00	196.46	13.55	8.16	32.18
Feb	450.41	17.00	5.00	90.00	445.26	23.35	9.31	162.75
Mar	191.55	35.50	7.60	131.00	210.97	55.00	11.98	152.75
Apr	118.86	31.00	8.30	105.50	123.79	51.70	8.61	117.00
May	70.82	30.00	8.00	62.00	82.06	36.80	4.67	65.38
Jun	33.41	16.00	6.80	41.00	33.46	21.90	6.73	39.93
Jul	17.20	9.45	4.30	26.00	17.70	10.35	3.19	20.93
Aug	10.56	5.80	2.60	18.00	11.58	6.37	2.24	15.50
Sep	8.48	4.40	2.30	15.00	8.76	4.53	1.65	11.93

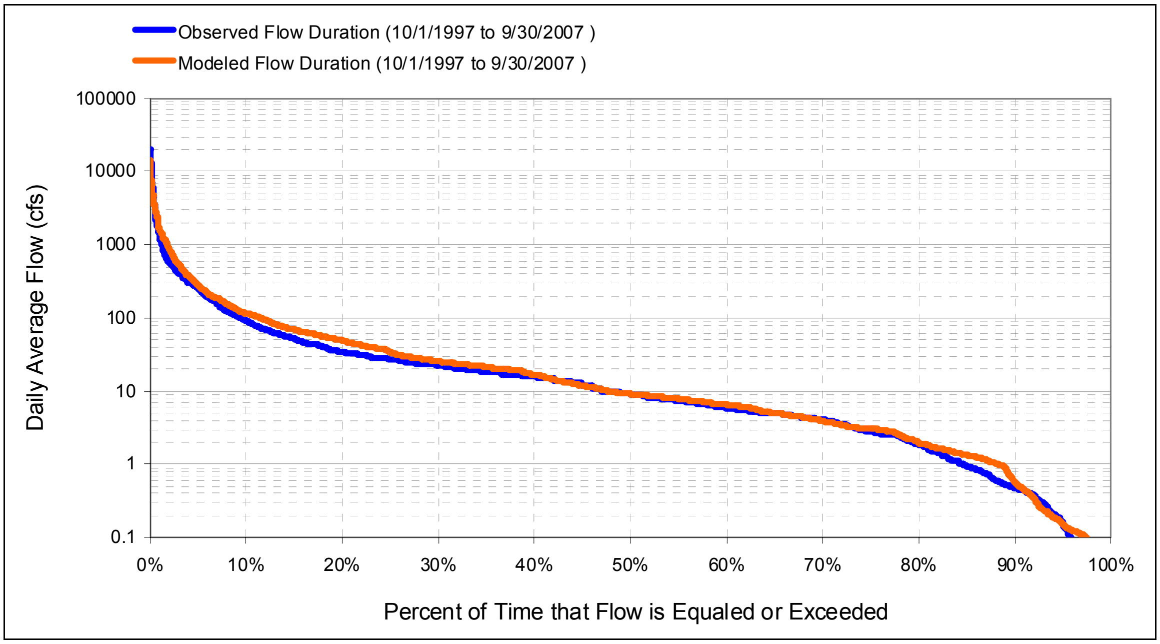

Figure 6-40. Flow Exceedence: Model vs. USGS 11118500 Ventura R nr Ventura

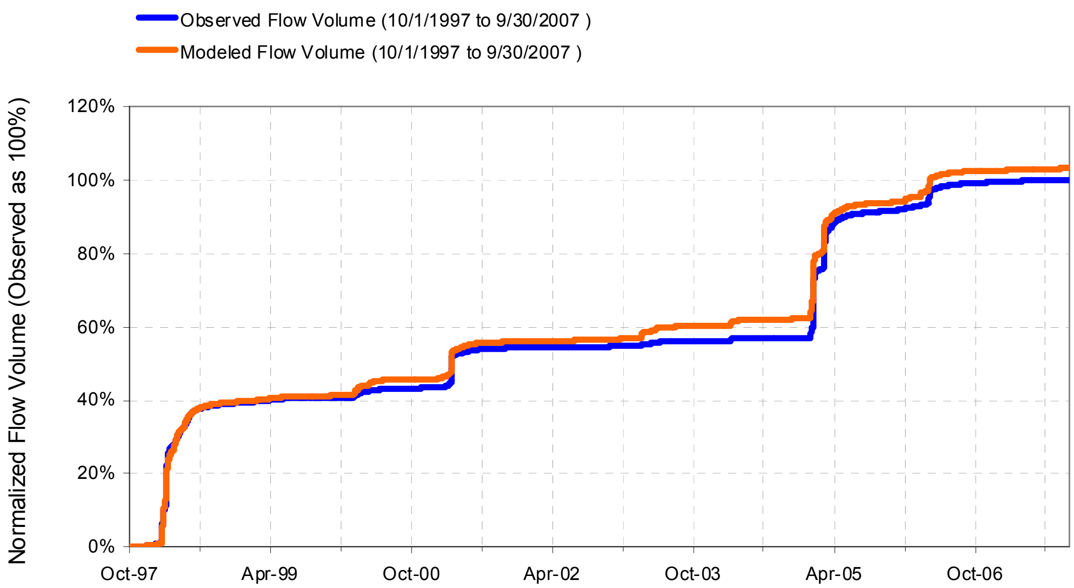

Figure 6-41. Flow Accumulation: Model vs. USGS 11118500 Ventura R nr Ventura

Table 6-20. Summary Statistics: Model vs. USGS 11118500 Ventura R nr Ventura

HSPF Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 311 10-Year Analysis Period: 10/1/1997 - 9/30/2007 Flow volumes are (inches/year) for upstream drainage area **Gage 608** **DSN 5007** **7/22/2009 9:57**		USGS 11118500 VENTURA R NR VENTURA Hydrologic Unit Code: 18070101 Latitude: 34.35222038 Longitude: -119.3084466 Drainage Area (sq-mi): 188		
Total Simulated In-stream Flow:	**6.99**	Total Observed In-stream Flow:		**6.78**
Total of simulated highest 10% flows:	**5.83**	Total of Observed highest 10% flows:		**5.84**
Total of Simulated lowest 50% flows:	**0.13**	Total of Observed Lowest 50% flows:		**0.12**
Simulated Summer Flow Volume (months 7-9):	**0.23**	Observed Summer Flow Volume (7-9):		**0.22**
Simulated Fall Flow Volume (months 10-12):	**0.33**	Observed Fall Flow Volume (10-12):		**0.28**
Simulated Winter Flow Volume (months 1-3):	**4.98**	Observed Winter Flow Volume (1-3):		**4.93**
Simulated Spring Flow Volume (months 4-6):	**1.44**	Observed Spring Flow Volume (4-6):		**1.34**
Total Simulated Storm Volume:	**3.50**	Total Observed Storm Volume:		**3.81**
Simulated Summer Storm Volume (7-9):	**0.02**	Observed Summer Storm Volume (7-9):		**0.01**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	3.08	10		
Error in 50% lowest flows:	6.43	10		
Error in 10% highest flows:	-0.25	15		
Seasonal volume error - Summer:	4.98	30		
Seasonal volume error - Fall:	17.52	30		
Seasonal volume error - Winter:	1.01	30		
Seasonal volume error - Spring:	7.36	30		
Error in storm volumes:	-8.01	20		
Error in summer storm volumes:	**64.92**	**50**		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.860	Model accuracy increases		
Baseline adjusted coefficient (Garrick), E':	0.721	as E or E' approaches 1.0		

6.5.7 Coyote Creek near Oak View (600)

The quality of gage record for this station appears poor, but no quality assurance information is available. Some periods of reported zero flow appear to actually be missing records.

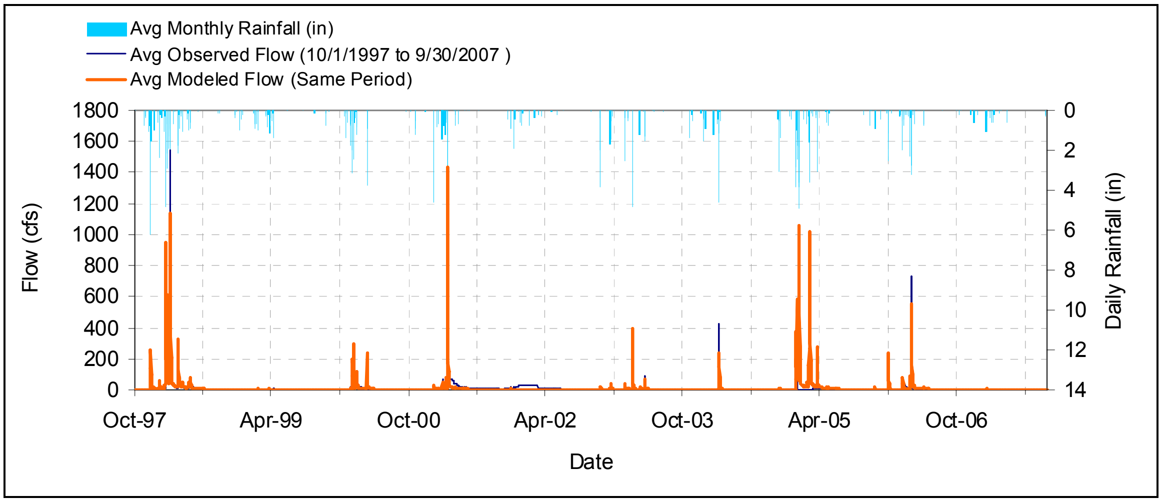

Figure 6-42. Mean Daily Flow: Model vs. USGS 11117600 Coyote Creek near Oak View

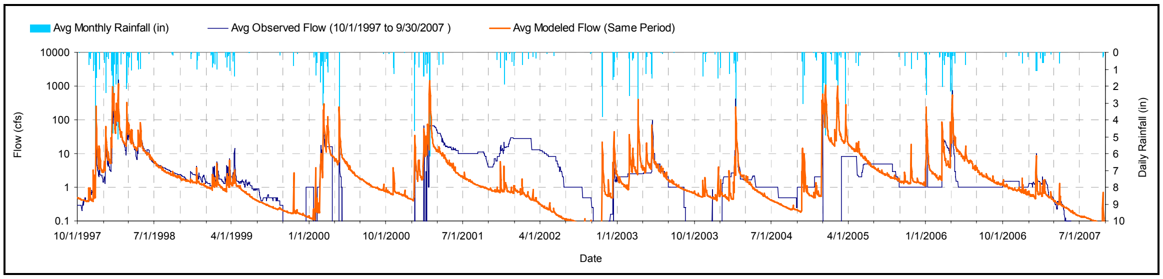

Figure 6-43. Mean Daily Flow: Model vs. USGS 11117600 Coyote Creek near Oak View

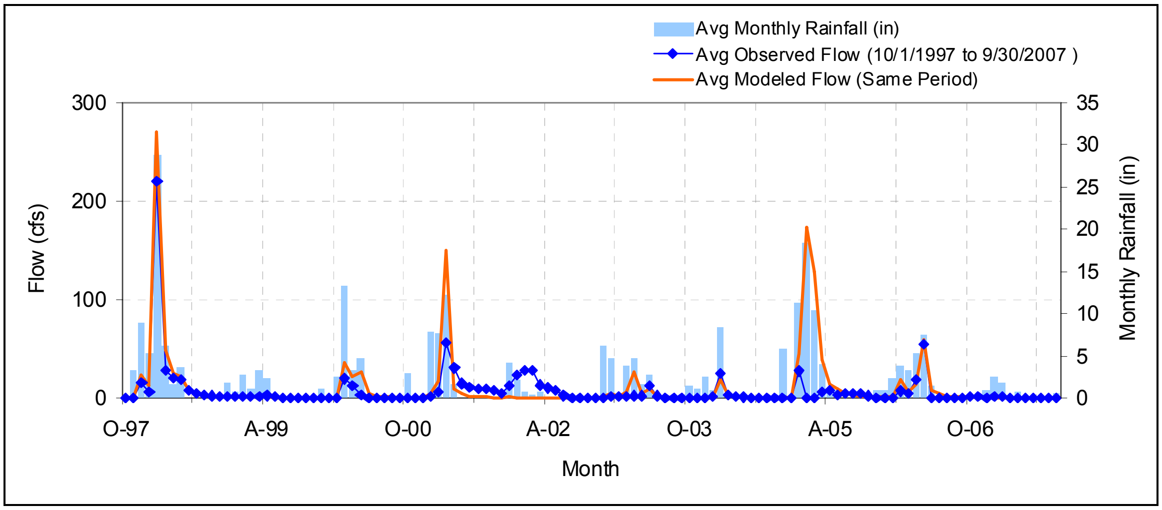

Figure 6-44. Mean Monthly Flow: Model vs. USGS 11117600 Coyote Creek near Oak View

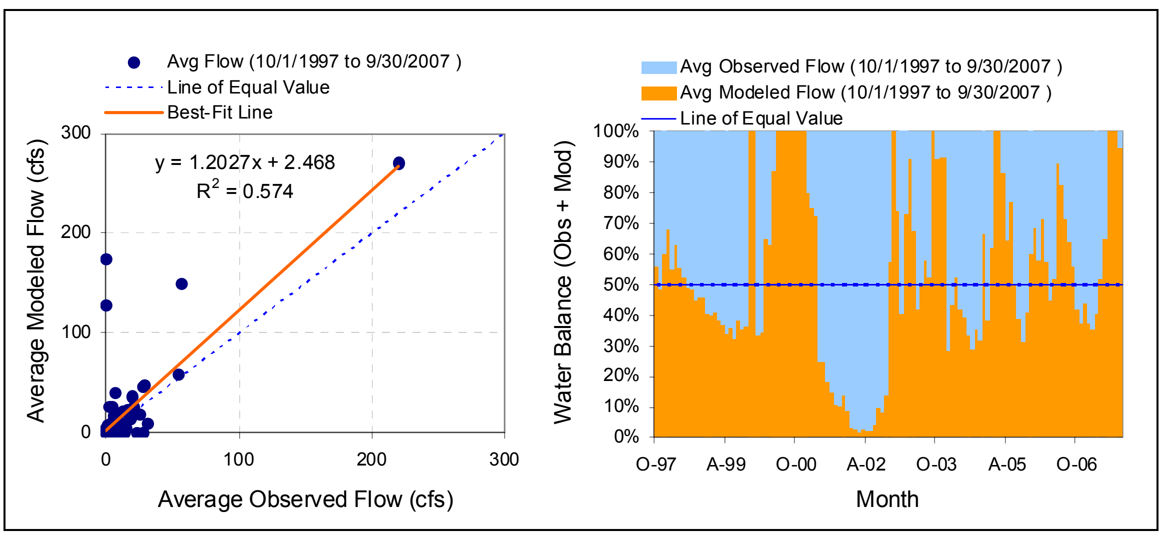

Figure 6-45. Monthly Flow Regression and Temporal Variation: Model vs. USGS 11117600 Coyote Creek near Oak View

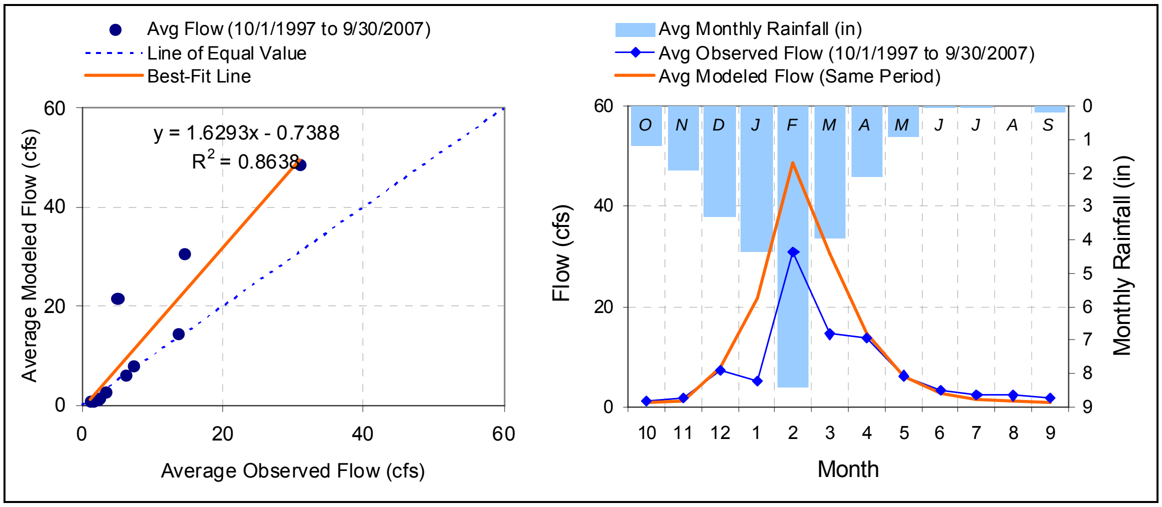

Figure 6-46. Annual Flow Regression and Monthly Aggregate: Model vs. USGS 11117600 Coyote Creek near Oak View

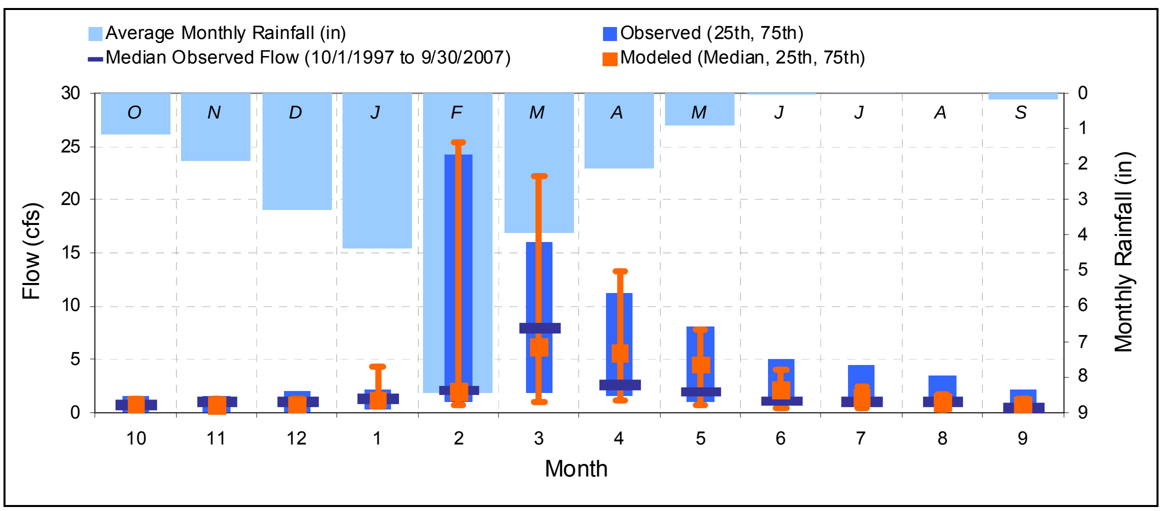

Figure 6-47. Seasonal Medians and Ranges: Model vs. USGS 11117600 Coyote Creek near Oak View

Table 6-21. Seasonal Summary: Model vs. USGS 11117600 Coyote Creek near Oak View

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	1.10	0.75	0.00	1.50	0.93	0.72	0.26	1.31
Nov	1.87	1.00	0.00	1.50	1.10	0.71	0.54	1.32
Dec	7.27	1.00	0.02	2.00	7.97	0.77	0.51	1.33
Jan	5.02	1.30	0.25	2.10	21.63	1.17	0.58	4.34
Feb	30.91	2.10	1.00	24.25	48.66	2.00	0.76	25.33
Mar	14.52	8.00	1.80	16.00	30.73	6.20	1.00	22.20
Apr	13.59	2.60	1.50	11.25	14.50	5.57	1.09	13.33
May	6.17	2.00	1.00	8.00	6.16	4.49	0.68	7.82
Jun	3.31	1.10	0.90	5.00	2.66	2.16	0.44	4.02
Jul	2.40	1.00	0.50	4.50	1.56	1.44	0.34	2.38
Aug	2.25	1.00	0.50	3.40	1.08	1.00	0.26	1.75
Sep	1.62	0.50	0.00	2.10	0.85	0.78	0.22	1.27

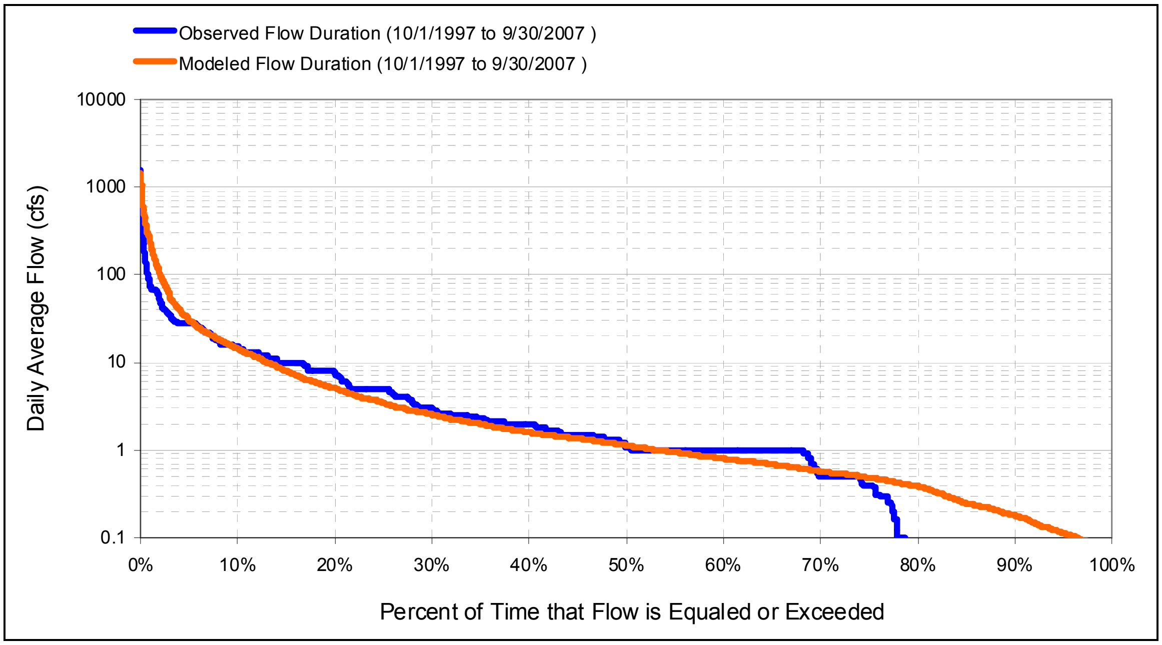

Figure 6-48. Flow Exceedence: Model vs. USGS 11117600 Coyote Creek near Oak View

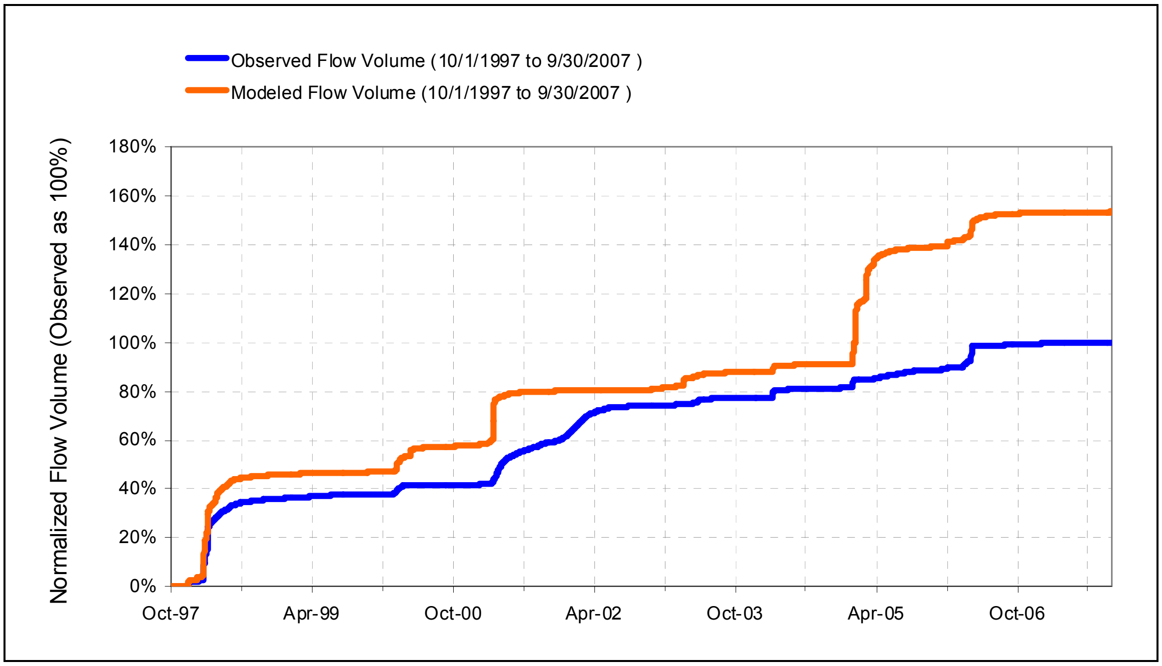

Figure 6-49. Flow Accumulation: Model vs. USGS 11117600 Coyote Creek near Oak View

Table 6-22. Summary Statistics: Model vs. USGS 11117600 Coyote Creek near Oak View

HSPF Simulated Flow		**Observed Flow Gage**	
REACH OUTFLOW FROM SUBBASIN 123 10-Year Analysis Period: 10/1/1986 - 9/30/1996 Flow volumes are (inches/year) for upstream drainage area **Gage 603A** **DSN 5001** **7/17/2009 13:11**		**USGS 11117600 Coyote Creek near Oak View** Hydrologic Unit Code: 18070101 Latitude: 34.35222038 Longitude: -119.3084466 Drainage Area (sq-mi): 188	
Total Simulated In-stream Flow:	**8.60**	Total Observed In-stream Flow:	**8.60**
Total of simulated highest 10% flows:	**7.24**	Total of Observed highest 10% flows:	**7.38**
Total of Simulated lowest 50% flows:	**0.22**	Total of Observed Lowest 50% flows:	**0.19**
Simulated Summer Flow Volume (months 7-9):	**0.23**	Observed Summer Flow Volume (7-9):	**0.17**
Simulated Fall Flow Volume (months 10-12):	**0.23**	Observed Fall Flow Volume (10-12):	**0.27**
Simulated Winter Flow Volume (months 1-3):	**7.20**	Observed Winter Flow Volume (1-3):	**7.25**
Simulated Spring Flow Volume (months 4-6):	**0.95**	Observed Spring Flow Volume (4-6):	**0.91**
Total Simulated Storm Volume:	**2.33**	Total Observed Storm Volume:	**2.74**
Simulated Summer Storm Volume (7-9):	**0.00**	Observed Summer Storm Volume (7-9):	**0.00**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-0.02	10	
Error in 50% lowest flows:	**13.82**	**10**	
Error in 10% highest flows:	-1.96	15	
Seasonal volume error - Summer:	**32.14**	**30**	
Seasonal volume error - Fall:	-15.78	30	
Seasonal volume error - Winter:	-0.71	30	
Seasonal volume error - Spring:	3.99	30	
Error in storm volumes:	-15.11	20	
Error in summer storm volumes:	41.20	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.843	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.746	as E or E' approaches 1.0	

Note: Summary statistics are likely not valid due to unflagged gaps in the gage record.

6.5.8 Santa Ana Creek near Oak View (606A)

The quality of gage records appears poor for this station, but no quality assurance information is available.

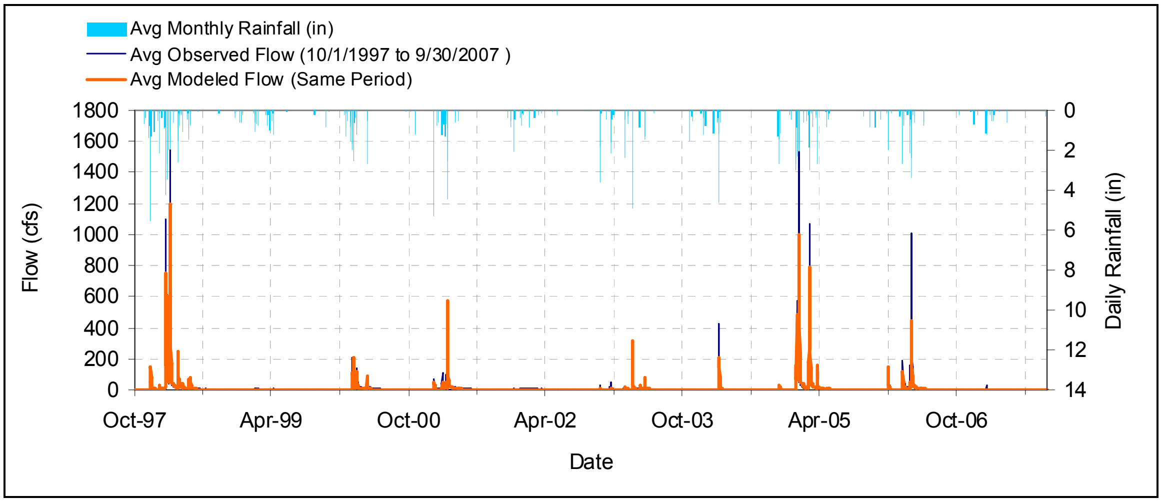

Figure 6-50. Mean Daily Flow: Model vs. USGS 11117800 Santa Ana Cr nr Oak View

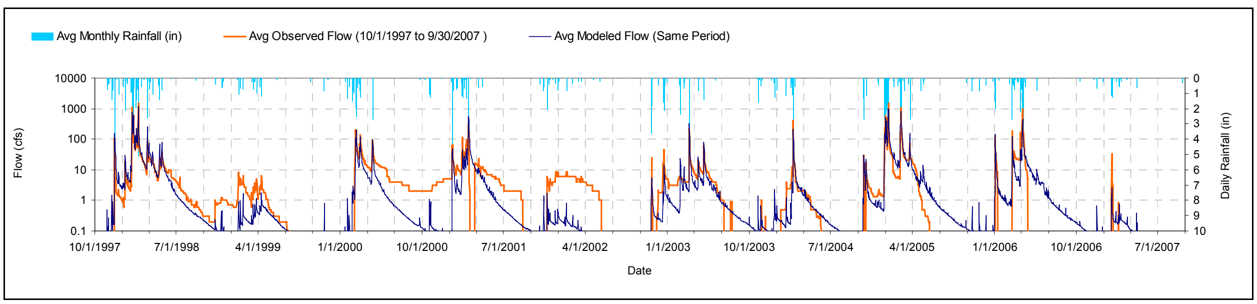

Figure 6-51. Mean Daily Flow: Model vs. USGS 11117800 Santa Ana Cr nr Oak View

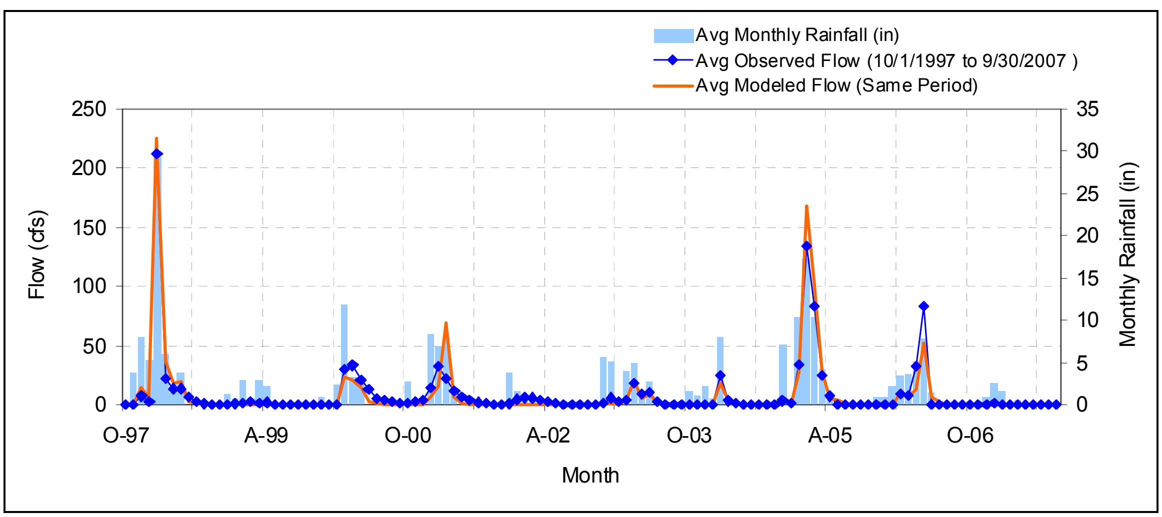

Figure 6-52. Mean Monthly Flow: Model vs. USGS 11117800 Santa Ana Cr nr Oak View

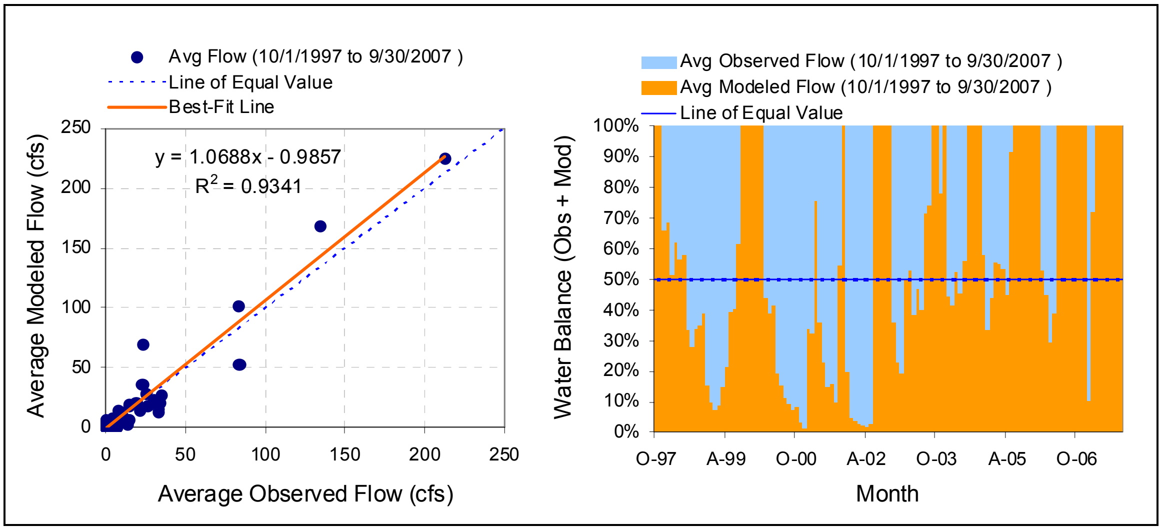

Figure 6-53. Monthly Flow Regression and Temporal Variation: Model vs. USGS 11117800 Santa Ana Cr nr Oak View

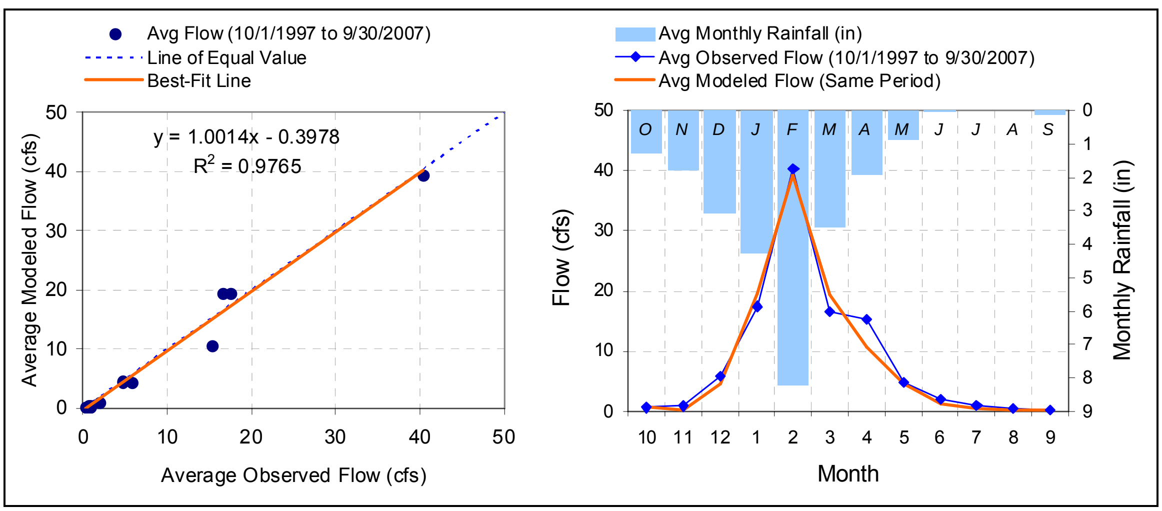

Figure 6-54. Annual Flow Regression and Monthly Aggregate: Model vs. USGS 11117800 Santa Ana Cr nr Oak View

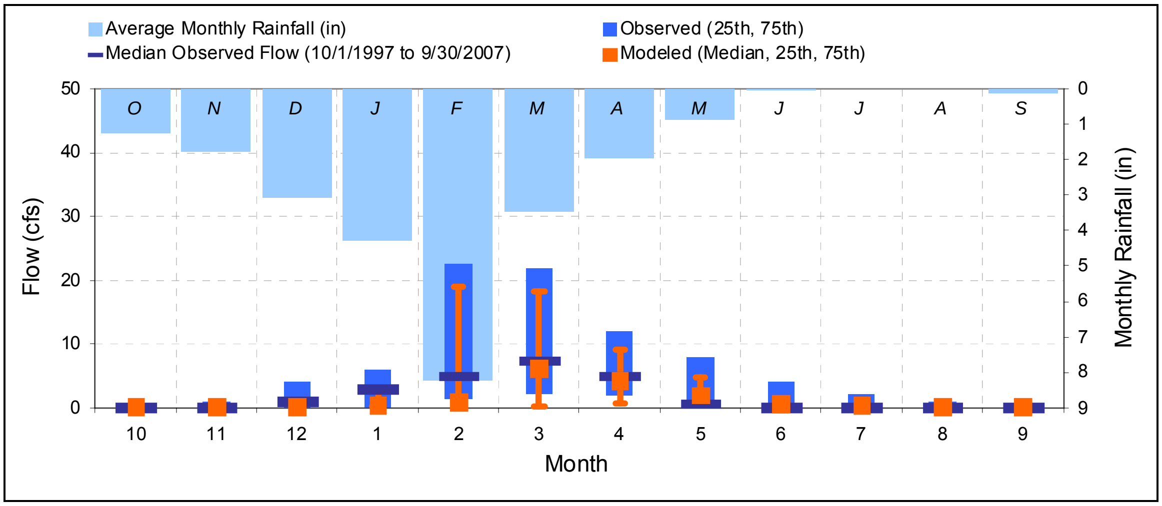

Figure 6-55. Seasonal Medians and Ranges: Model vs. USGS 11117800 Santa Ana Cr nr Oak View

Table 6-23. Seasonal Summary: Model vs. USGS 11117800 Santa Ana Cr nr Oak View

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	0.58	0.00	0.00	0.00	0.58	0.09	0.03	0.13
Nov	0.84	0.00	0.00	1.00	0.28	0.10	0.07	0.20
Dec	5.84	1.00	0.00	4.00	4.44	0.09	0.06	0.46
Jan	17.44	3.00	0.00	6.00	19.53	0.47	0.06	2.84
Feb	40.42	5.00	1.40	22.50	39.44	0.84	0.20	18.88
Mar	16.50	7.35	2.00	21.75	19.49	6.26	0.29	18.23
Apr	15.32	5.00	1.75	12.00	10.60	4.20	0.58	9.00
May	4.71	0.60	0.16	8.00	4.48	2.00	0.31	4.84
Jun	1.93	0.10	0.00	4.00	1.08	0.72	0.15	1.47
Jul	0.88	0.00	0.00	2.00	0.40	0.38	0.09	0.60
Aug	0.55	0.00	0.00	0.90	0.21	0.21	0.05	0.32
Sep	0.26	0.00	0.00	0.00	0.12	0.13	0.04	0.19

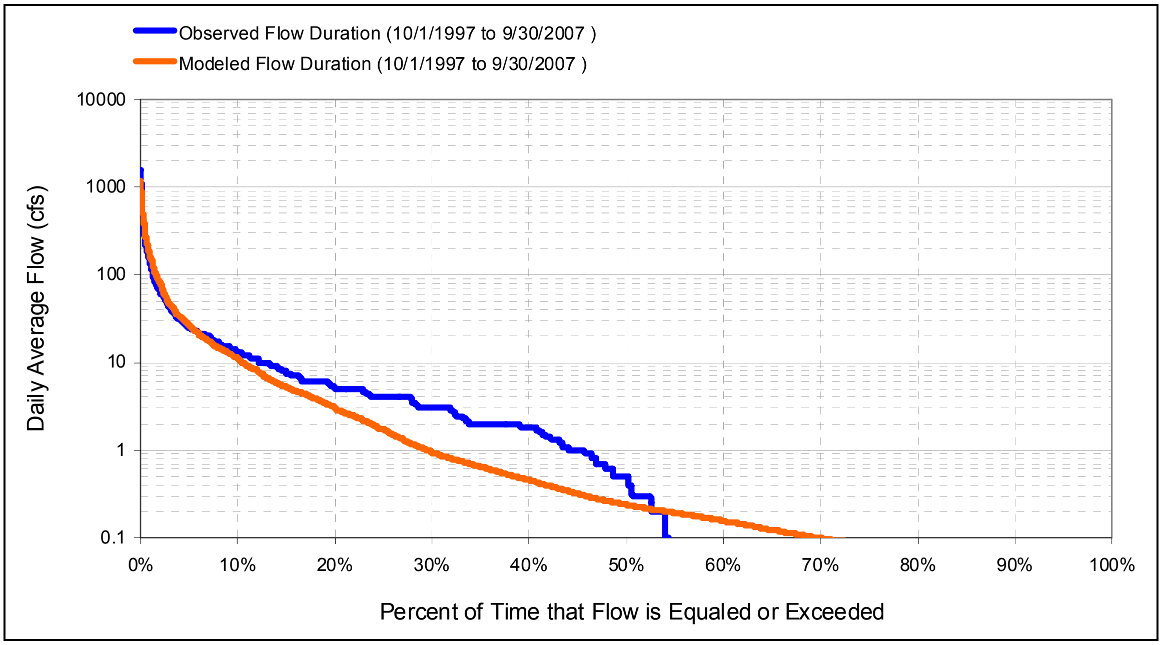

Figure 6-56. Flow Exceedence: Model vs. USGS 11117800 Santa Ana Cr nr Oak View

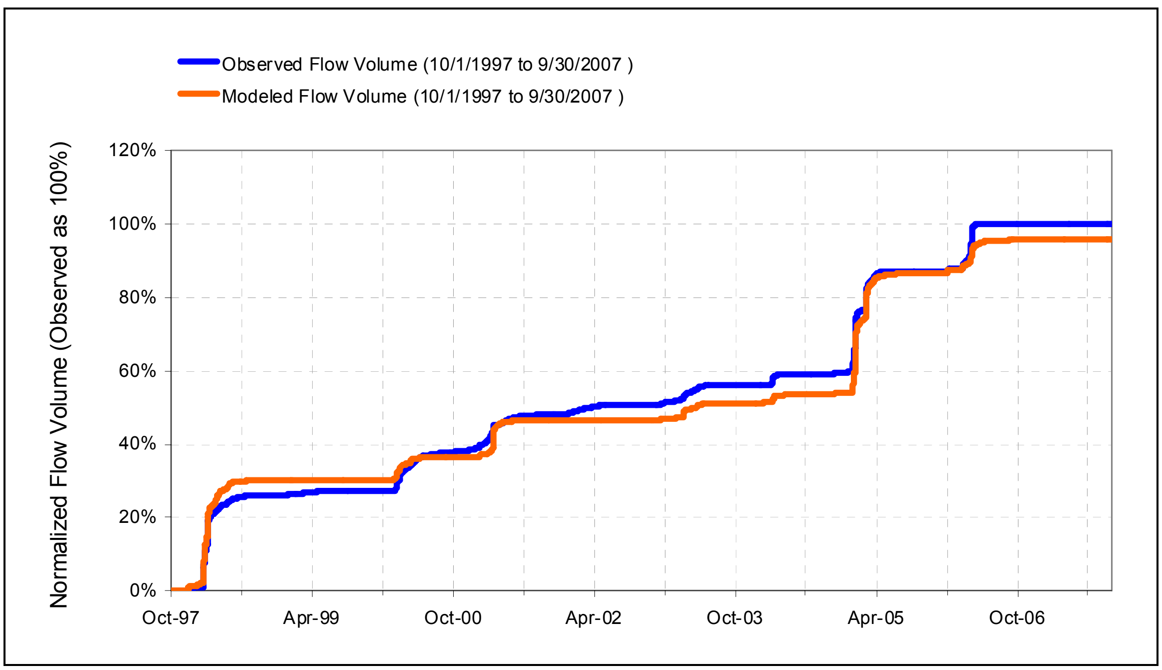

Figure 6-57. Flow Accumulation: Model vs. USGS 11117800 Santa Ana Cr nr Oak View

Table 6-24. Summary Statistics: Model vs. USGS 11117800 Santa Ana Cr nr Oak View

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 443 10-Year Analysis Period: 10/1/1997 - 9/30/2007 Flow volumes are (inches/year) for upstream drainage area **Gage 606** **DSN 5005** **11/20/2008 14:57**		USGS 11117800 Santa Ana Cr nr Oak View Hydrologic Unit Code: 4040003 Latitude: 43.10001159 Longitude: -87.9089745 Drainage Area (sq-mi): 696	
Total Simulated In-stream Flow:	**12.40**	Total Observed In-stream Flow:	**12.96**
Total of simulated highest 10% flows:	**11.04**	Total of Observed highest 10% flows:	**10.57**
Total of Simulated lowest 50% flows:	**0.07**	Total of Observed Lowest 50% flows:	**0.02**
Simulated Summer Flow Volume (months 7-9):	**0.09**	Observed Summer Flow Volume (7-9):	**0.22**
Simulated Fall Flow Volume (months 10-12):	**0.68**	Observed Fall Flow Volume (10-12):	**0.93**
Simulated Winter Flow Volume (months 1-3):	**9.61**	Observed Winter Flow Volume (1-3):	**9.07**
Simulated Spring Flow Volume (months 4-6):	**2.02**	Observed Spring Flow Volume (4-6):	**2.75**
Total Simulated Storm Volume:	**3.62**	Total Observed Storm Volume:	**4.47**
Simulated Summer Storm Volume (7-9):	**0.00**	Observed Summer Storm Volume (7-9):	**0.01**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-4.29	10	
Error in 50% lowest flows:	**291.86**	**10**	
Error in 10% highest flows:	4.46	15	
Seasonal volume error - Summer:	**-56.47**	**30**	
Seasonal volume error - Fall:	-26.97	30	
Seasonal volume error - Winter:	5.92	30	
Seasonal volume error - Spring:	-26.24	30	
Error in storm volumes:	-18.97	20	
Error in summer storm volumes:	**-50.36**	**50**	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.799	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.622	as E or E' approaches 1.0	

6.6 Detailed Validation Results

This section provides detailed results for the model validation period (10/1986-9/1996). As with the calibration results, daily and cumulative results for each gage are summarized in a standard format, while event peak results are summarized in Section 7. No results are available for gage 603 during the validation period.

6.6.1 Matilija Creek below Dam (602/602A)

This gage record is used to estimate daily releases from Matilija Dam, as described in Section Figure 4-3. Therefore, the results for this gage are not a proper calibration test, and only a graphical summary is provided here. Summary statistics are, however, reported above in Table 6-5.

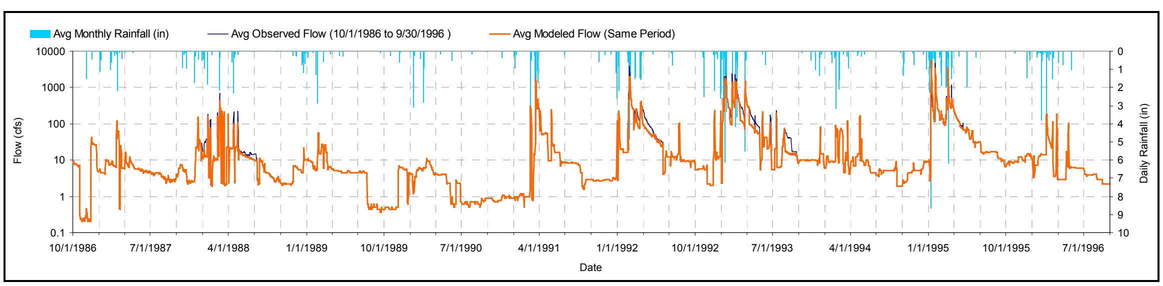

Figure 6-58. Mean Daily Flow: Model Outlet 999 vs. Gage 602/602A Matilija Creek below Dam (Validation Period)

6.6.2 North Fork Matilija (604)

Results for North Fork Matilija are shown in the following figures and tables. It is worth noting the apparent discontinuity (sudden drop in flow) that occurs on 10/1/1987 in Figure 6-61. The model simulates continuously through this date; however 10/1/1987 is the date on which a switch is made from post-fire to normal land use condition, and shows that the smaller amounts of vegetation on burned land result in higher base flows. The observed flows suggest that recovery from the burn may be represented as occurring several months too early.

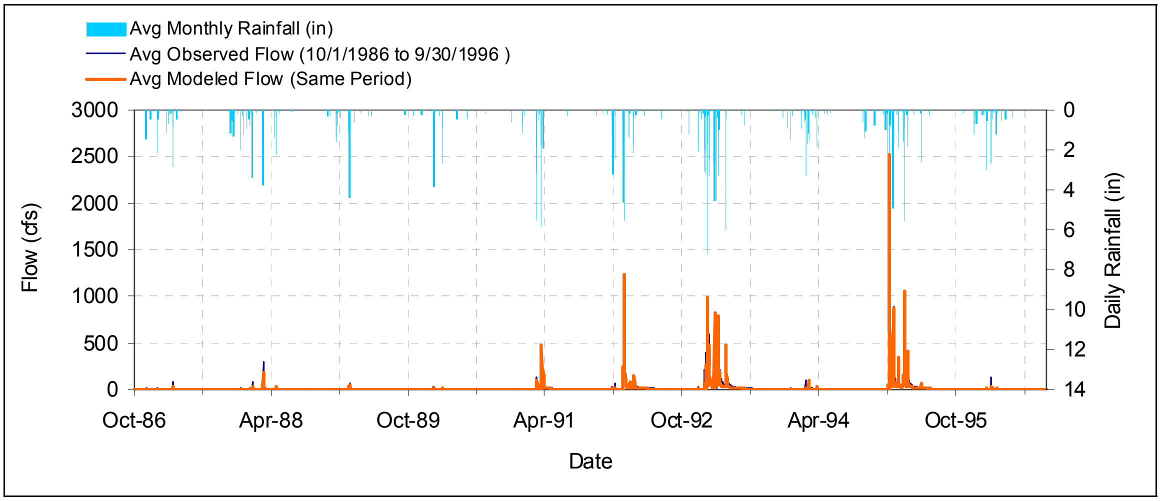

Figure 6-59. Mean Daily Flow: Model vs. USGS 11116000 North Fork Matilija Cr (Validation Period)

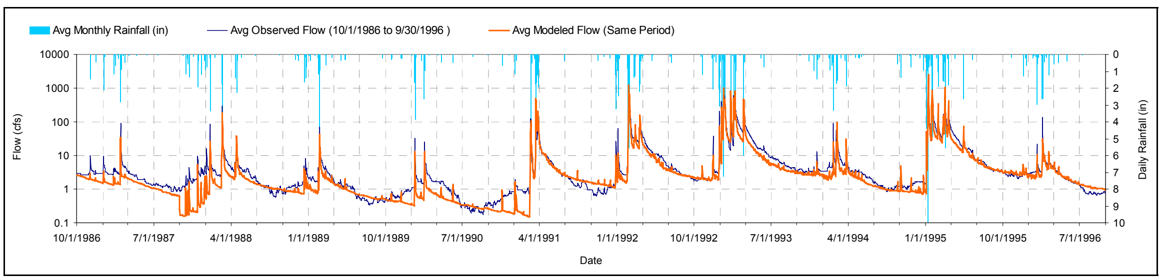

Figure 6-60. Mean Daily Flow: Model vs. USGS 11116000 North Fork Matilija Cr (Validation Period)

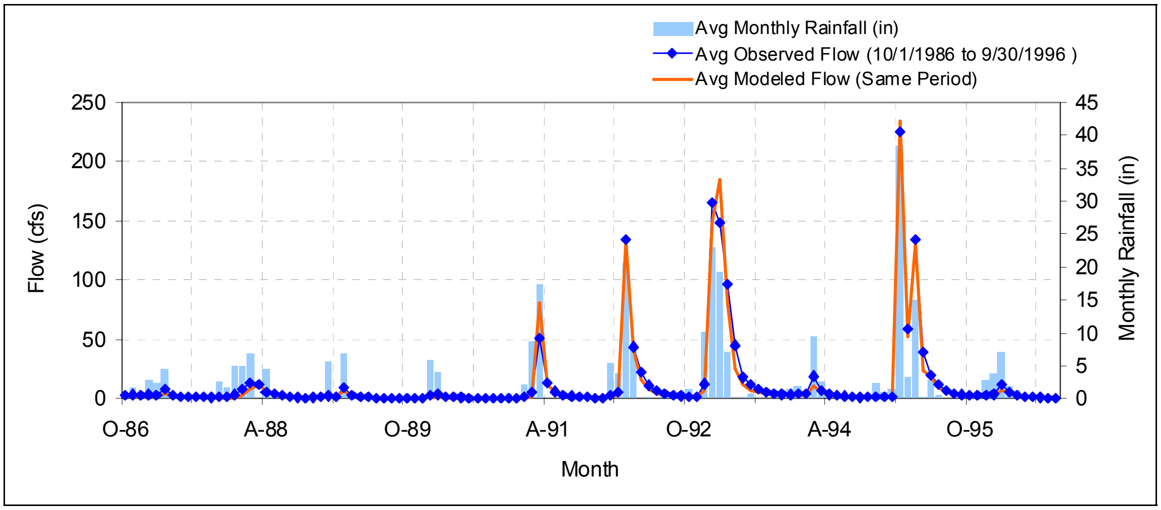

Figure 6-61. Mean Monthly Flow: Model vs. USGS 11116000 North Fork Matilija Cr (Validation Period)

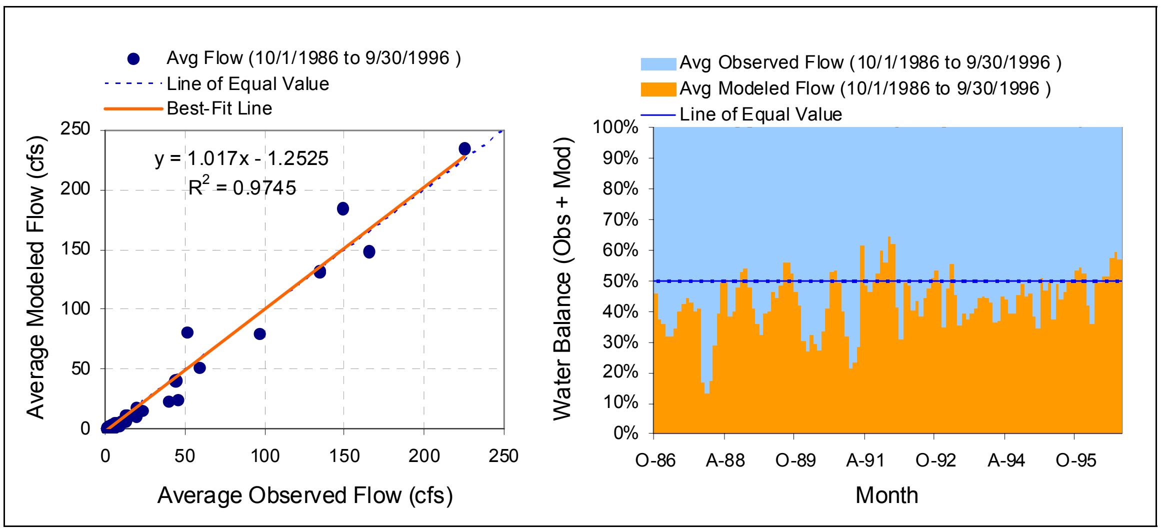

Figure 6-62. Monthly Flow Regression and Temporal Variation: Model vs. USGS 11116000 North Fork Matilija Cr (Validation Period)

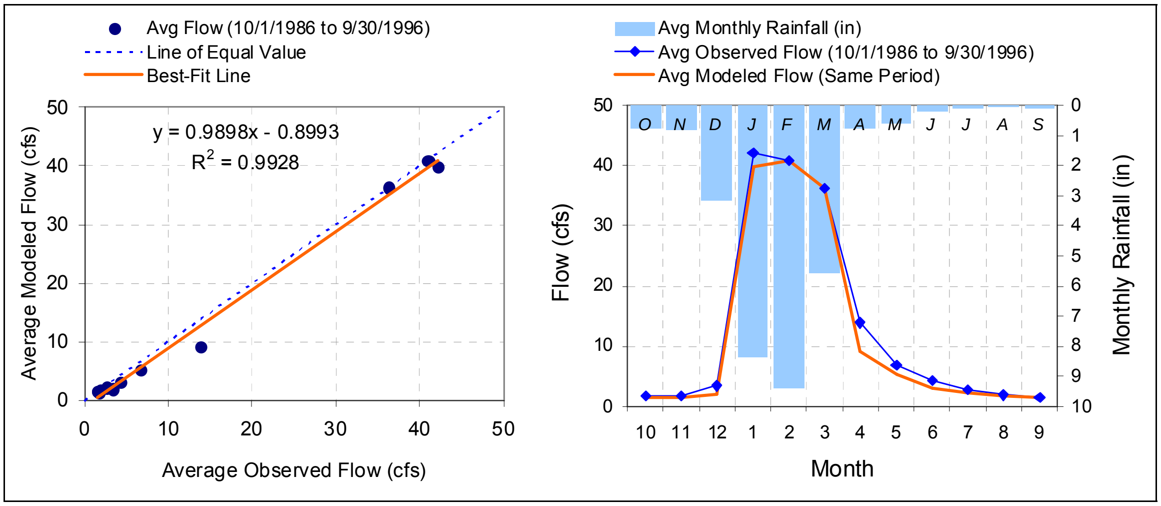

Figure 6-63. Annual Flow Regression and Monthly Aggregate: Model vs. USGS 11116000 North Fork Matilija Cr (Validation Period)

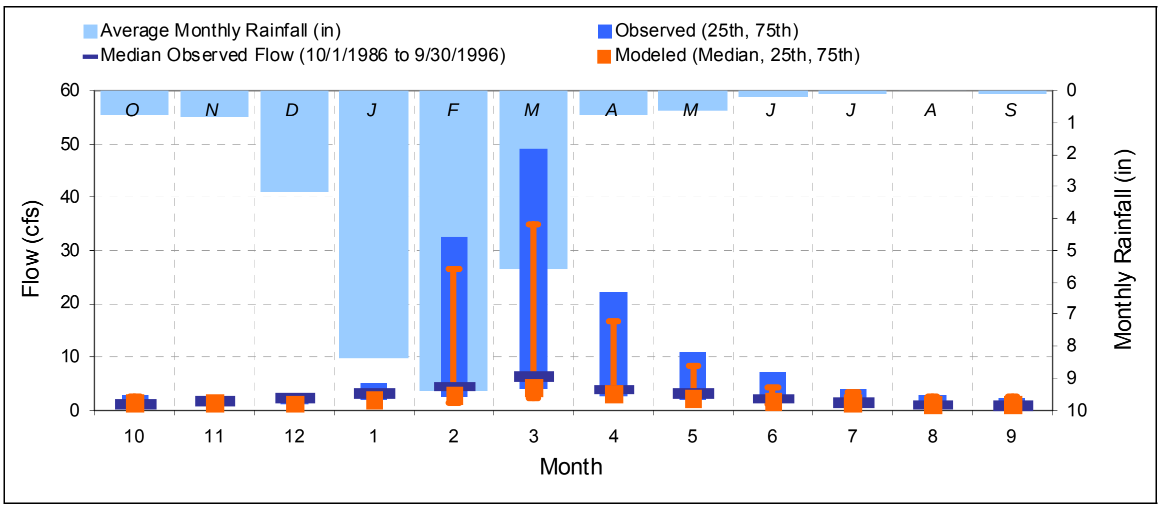

Figure 6-64. Seasonal Medians and Ranges: Model vs. USGS 11116000 North Fork Matilija Cr (Validation Period)

Table 6-25. Seasonal Summary: Model vs. USGS 11116000 North Fork Matilija Cr (Validation Period)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	1.64	1.20	0.75	2.70	1.52	1.43	0.47	2.51
Nov	1.80	1.70	0.80	2.60	1.39	1.27	0.43	2.05
Dec	3.38	2.40	1.20	3.10	1.97	1.23	0.40	2.52
Jan	42.18	3.20	2.00	5.10	39.79	1.87	0.84	2.78
Feb	40.97	4.50	2.65	32.50	40.78	2.82	1.32	26.55
Mar	36.23	6.40	4.03	49.00	36.31	4.17	2.29	34.98
Apr	13.88	3.90	2.60	22.25	9.12	3.17	1.83	16.63
May	6.74	3.30	1.90	11.00	5.35	2.23	1.46	8.20
Jun	4.29	2.20	1.40	7.03	3.08	1.63	1.16	4.21
Jul	2.68	1.40	0.94	4.00	2.24	1.29	1.00	3.28
Aug	1.86	1.10	0.73	2.78	1.74	1.10	0.80	2.63
Sep	1.57	0.98	0.73	2.33	1.53	1.02	0.67	2.39

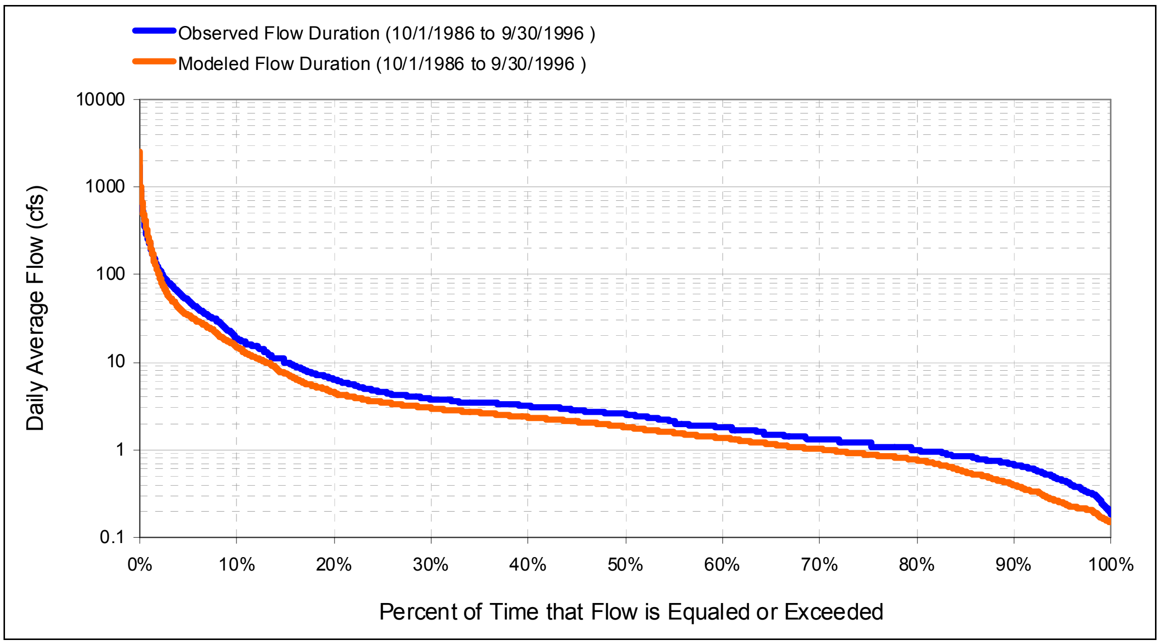

Figure 6-65. Flow Exceedence: Model vs. USGS 11116000 North Fork Matilija Cr (Validation Period)

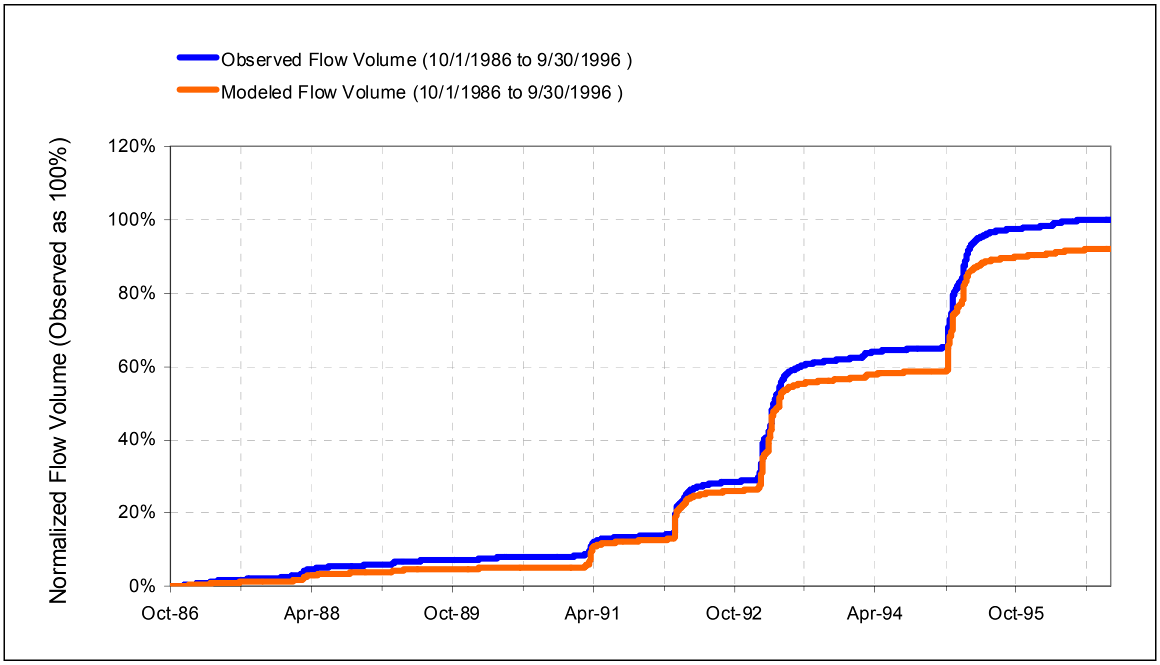

Figure 6-66. Flow Accumulation: Model vs. USGS 11116000 North Fork Matilija Cr (Validation Period)

Table 6-26. Summary Statistics: Model vs. USGS 11116000 North Fork Matilija Cr (Validation Period)

HSPF Simulated Flow		**Observed Flow Gage**		
REACH OUTFLOW FROM SUBBASIN 682 10-Year Analysis Period: 10/1/1986 - 9/30/1996 Flow volumes are (inches/year) for upstream drainage area **Gage 604** **DSN 5003** **7/17/2009 13:09**		**USGS 11116000 North Fork Matilija Cr** Hydrologic Unit Code: 4040003 Latitude: 43.10001159 Longitude: -87.9089745 Drainage Area (sq-mi): 696		
Total Simulated In-stream Flow:	**10.21**	Total Observed In-stream Flow:		**11.10**
Total of simulated highest 10% flows:	**8.42**	Total of Observed highest 10% flows:		**8.70**
Total of Simulated lowest 50% flows:	**0.38**	Total of Observed Lowest 50% flows:		**0.52**
Simulated Summer Flow Volume (months 7-9):	**0.40**	Observed Summer Flow Volume (7-9):		**0.44**
Simulated Fall Flow Volume (months 10-12):	**0.35**	Observed Fall Flow Volume (10-12):		**0.49**
Simulated Winter Flow Volume (months 1-3):	**8.22**	Observed Winter Flow Volume (1-3):		**8.40**
Simulated Spring Flow Volume (months 4-6):	**1.24**	Observed Spring Flow Volume (4-6):		**1.76**
Total Simulated Storm Volume:	**2.98**	Total Observed Storm Volume:		**2.43**
Simulated Summer Storm Volume (7-9):	**0.01**	Observed Summer Storm Volume (7-9):		**0.01**
Errors (Simulated-Observed)	*Error Statistics*			
Error in total volume:	-7.96	10		
Error in 50% lowest flows:	**-26.84**	**10**		
Error in 10% highest flows:	-3.22	15		
Seasonal volume error - Summer:	-9.93	30		
Seasonal volume error - Fall:	-28.51	30		
Seasonal volume error - Winter:	-2.13	30		
Seasonal volume error - Spring:	-29.51	30		
Error in storm volumes:	**22.21**	**20**		
Error in summer storm volumes:	6.07	50		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.851	Model accuracy increases		
Baseline adjusted coefficient (Garrick), E':	0.755	as E or E' approaches 1.0		

6.6.3 Ventura River near Meiners Oaks (at Robles Diversion) (607)

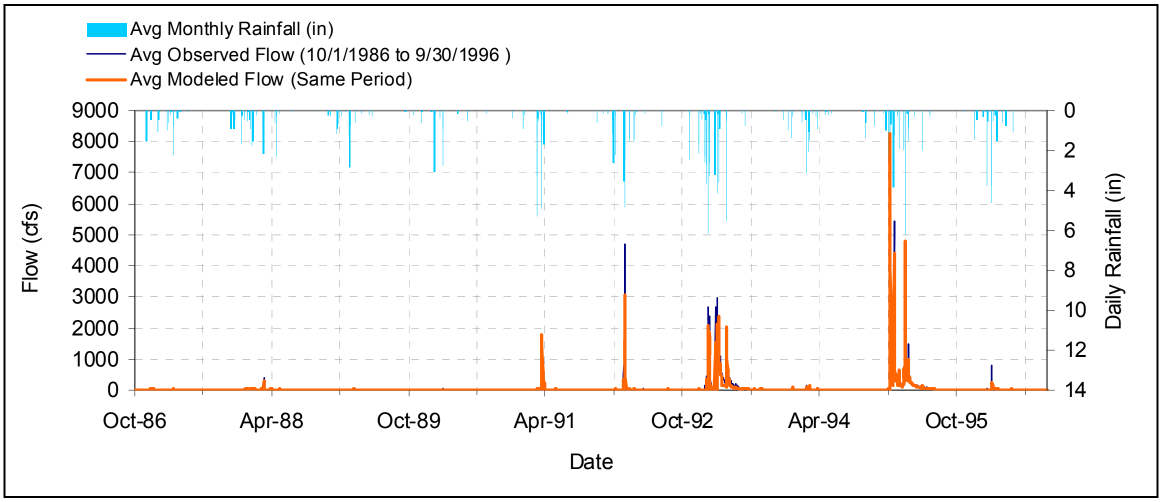

Figure 6-67. Mean Daily Flow: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA (Validation Period)

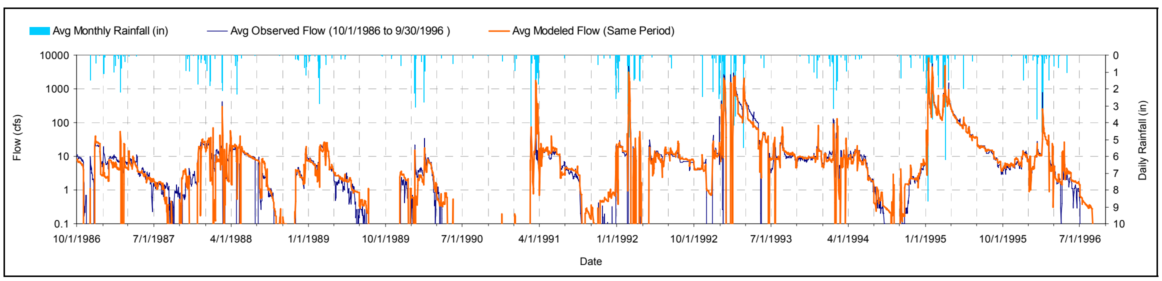

Figure 6-68. Mean Daily Flow: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA (Validation Period)

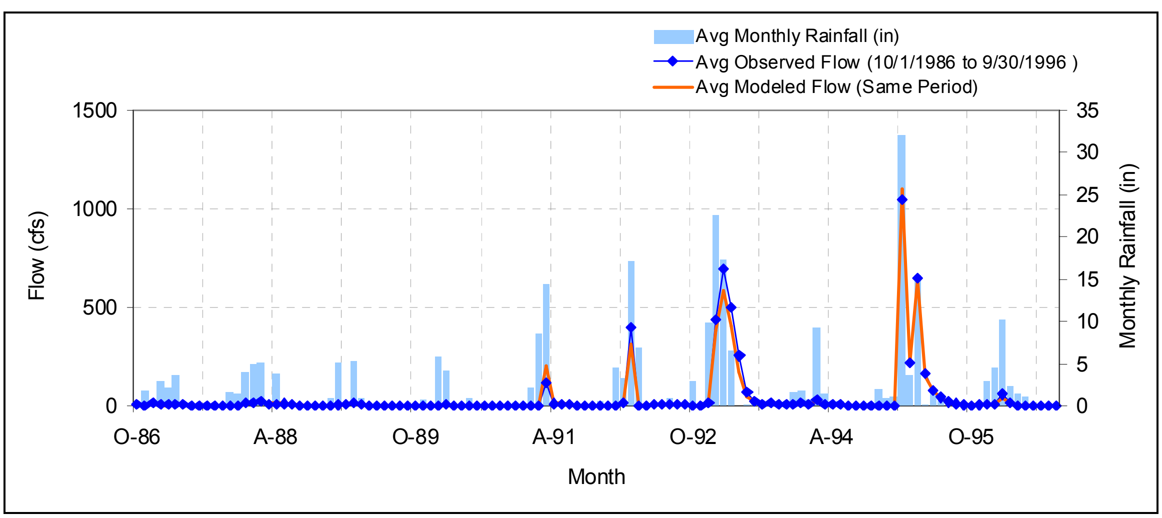

Figure 6-69. Mean Monthly Flow: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA (Validation Period)

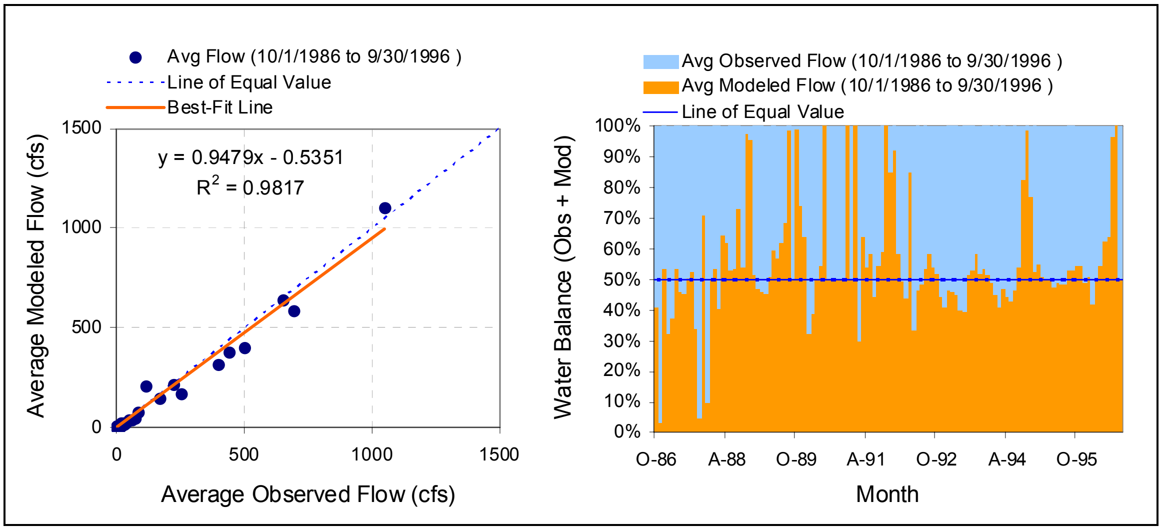

Figure 6-70. Monthly Flow Regression and Temporal Variation: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA (Validation Period)

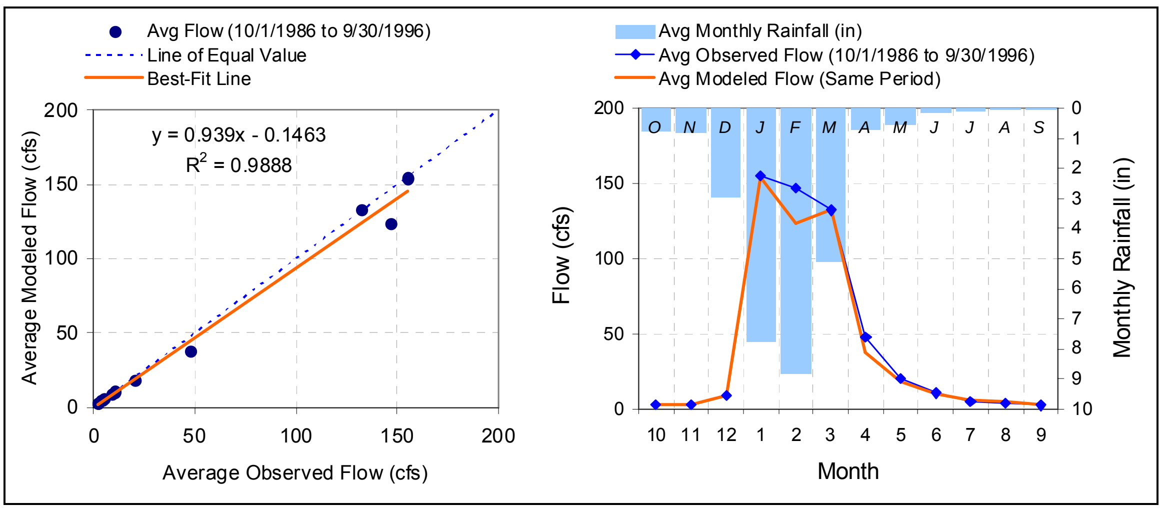

Figure 6-71. Annual Flow Regression and Monthly Aggregate: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA (Validation Period)

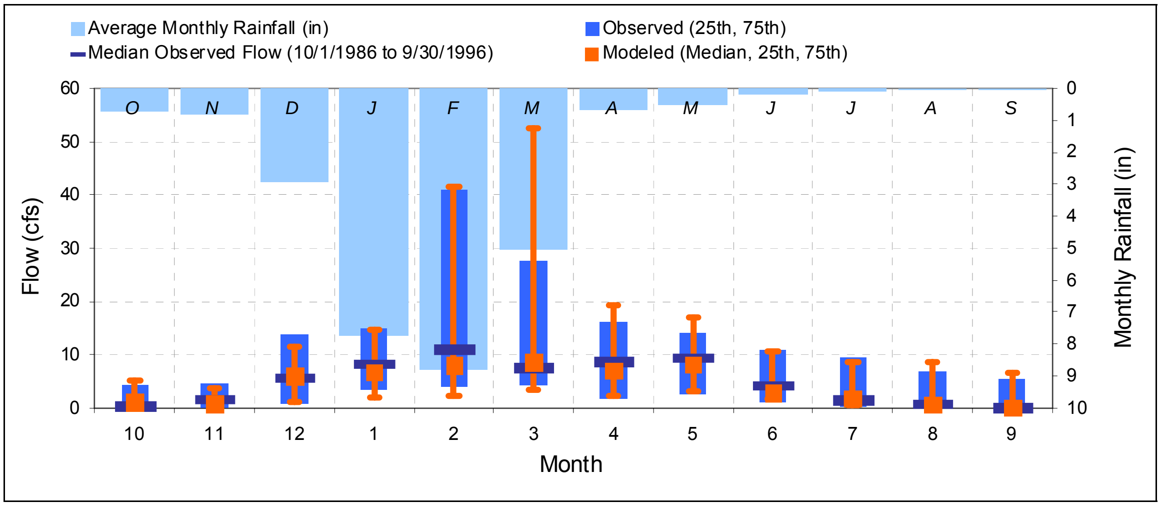

Figure 6-72. Seasonal Medians and Ranges: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA (Validation Period)

Table 6-27. Seasonal Summary: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA (Validation Period)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	2.48	0.30	0.00	4.20	2.72	1.12	0.00	5.15
Nov	2.50	1.60	0.00	4.43	2.39	0.71	0.00	3.78
Dec	8.71	5.65	0.91	13.75	8.46	5.95	1.11	11.50
Jan	155.44	8.30	3.53	15.00	154.17	6.74	1.98	14.60
Feb	147.06	11.00	3.95	41.00	123.22	7.95	2.13	41.60
Mar	132.29	7.60	4.20	27.75	133.00	8.52	3.51	53.08
Apr	47.52	8.65	1.60	16.25	37.67	6.99	2.08	19.25
May	20.55	9.40	2.50	14.00	18.27	8.08	3.05	16.88
Jun	10.50	4.20	1.00	11.00	10.37	2.81	1.68	10.70
Jul	5.07	1.50	0.11	9.43	5.77	1.74	0.44	8.49
Aug	4.04	0.77	0.00	7.00	5.24	0.62	0.00	8.68
Sep	2.27	0.00	0.00	5.40	2.54	0.00	0.00	6.56

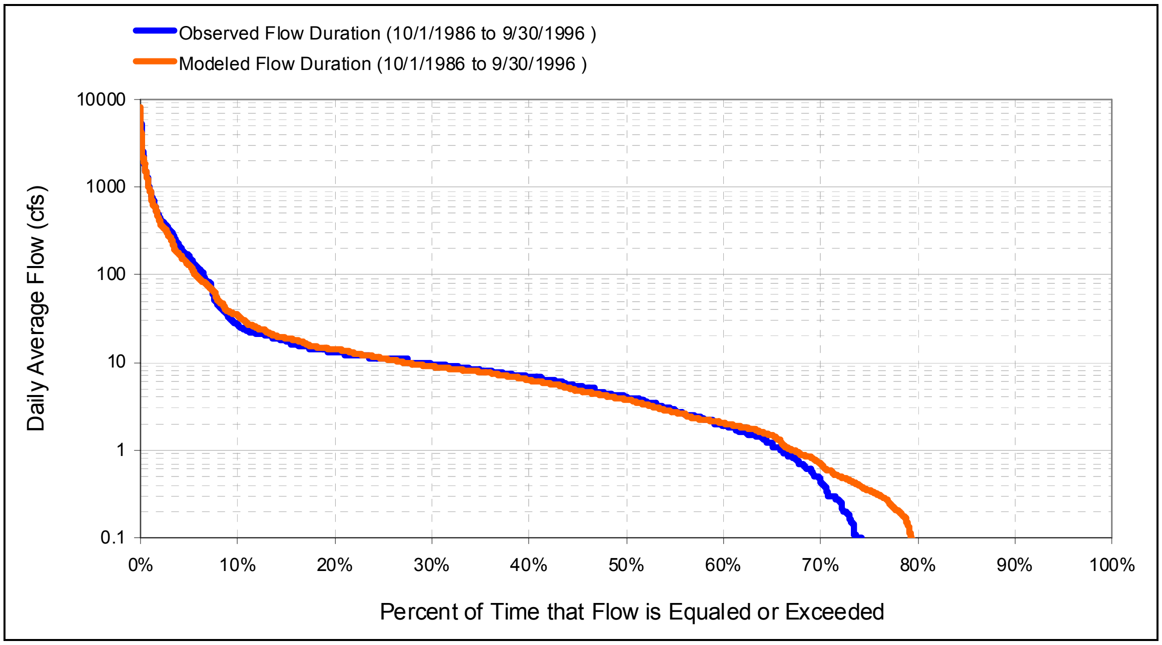

Figure 6-73. Flow Exceedence: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA (Validation Period)

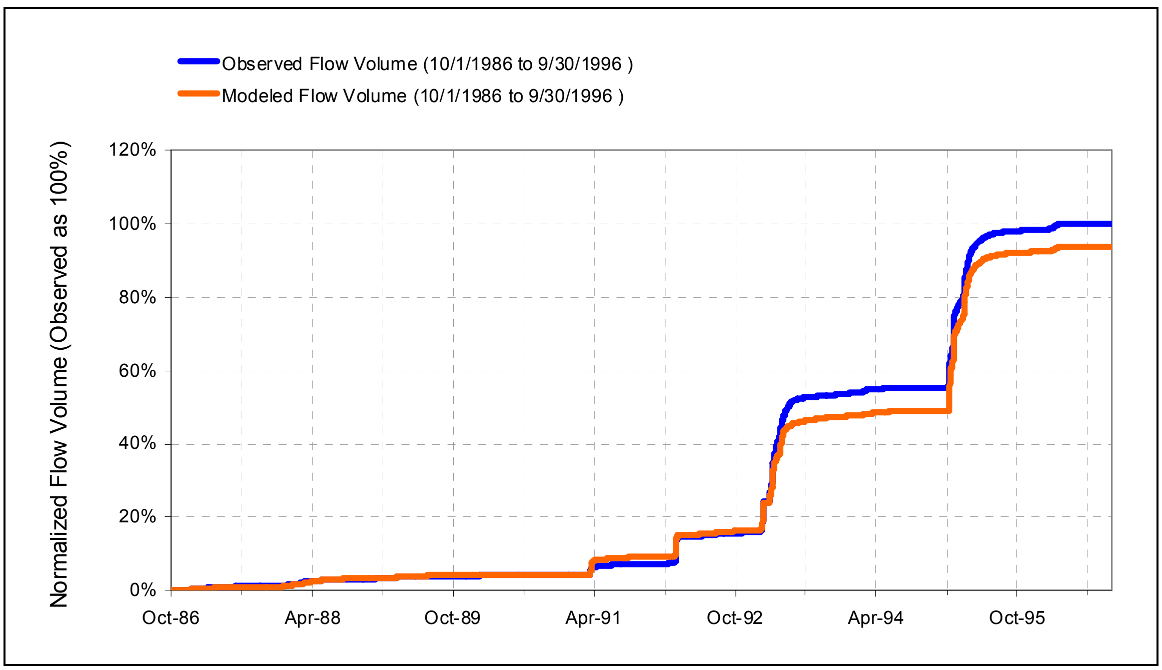

Figure 6-74. Flow Accumulation: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA (Validation Period)

Table 6-28. Summary Statistics: Model vs. USGS 11116550 Ventura R nr Meiners Oaks CA (Validation Period)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 912 10-Year Analysis Period: 10/1/1986 - 9/30/1996 Flow volumes are (inches/year) for upstream drainage area **Gage 607** **DSN 5006** **7/17/2009 13:10**		USGS 11116550 VENTURA R NR MEINERS OAKS CA Hydrologic Unit Code: 4040003 Latitude: 43.10001159 Longitude: -87.9089745 Drainage Area (sq-mi): 696	
Total Simulated In-stream Flow:	**7.42**	Total Observed In-stream Flow:	**7.90**
Total of simulated highest 10% flows:	**6.55**	Total of Observed highest 10% flows:	**7.07**
Total of Simulated lowest 50% flows:	**0.08**	Total of Observed Lowest 50% flows:	**0.07**
Simulated Summer Flow Volume (months 7-9):	**0.20**	Observed Summer Flow Volume (7-9):	**0.17**
Simulated Fall Flow Volume (months 10-12):	**0.20**	Observed Fall Flow Volume (10-12):	**0.21**
Simulated Winter Flow Volume (months 1-3):	**6.03**	Observed Winter Flow Volume (1-3):	**6.37**
Simulated Spring Flow Volume (months 4-6):	**0.98**	Observed Spring Flow Volume (4-6):	**1.16**
Total Simulated Storm Volume:	**3.62**	Total Observed Storm Volume:	**3.66**
Simulated Summer Storm Volume (7-9):	**0.03**	Observed Summer Storm Volume (7-9):	**0.02**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-6.13	10	
Error in 50% lowest flows:	8.38	10	
Error in 10% highest flows:	-7.28	15	
Seasonal volume error - Summer:	19.15	30	
Seasonal volume error - Fall:	-0.56	30	
Seasonal volume error - Winter:	-5.28	30	
Seasonal volume error - Spring:	-15.55	30	
Error in storm volumes:	-1.04	20	
Error in summer storm volumes:	**50.24**	**50**	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.883	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.818	as E or E' approaches 1.0	

6.6.4 San Antonio Creek at Hwy. 33 (605)

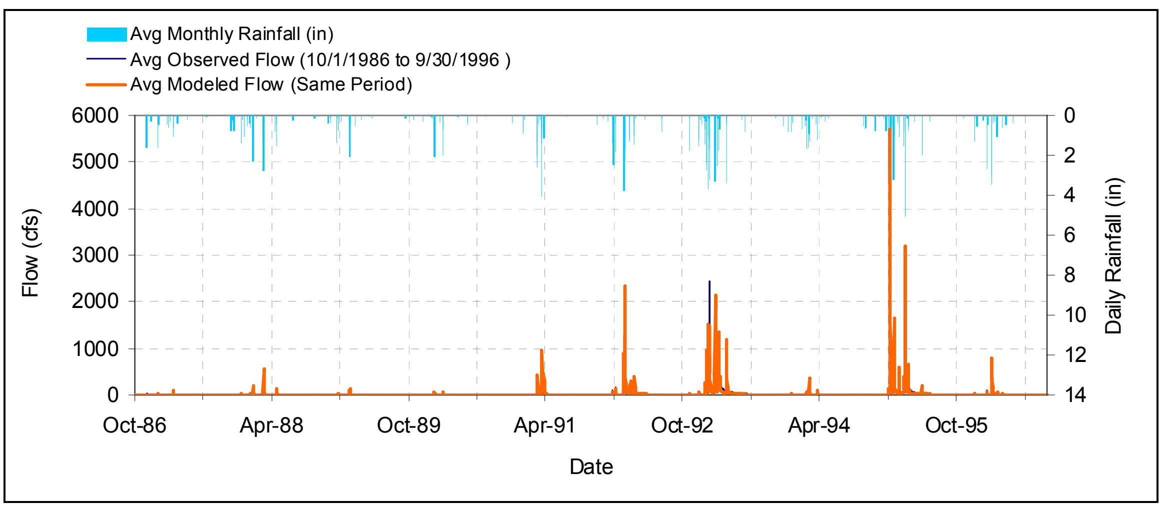

Figure 6-75. Mean Daily Flow: Model vs. USGS 11117500 San Antonio Cr at Hwy 33 (Validation Period)

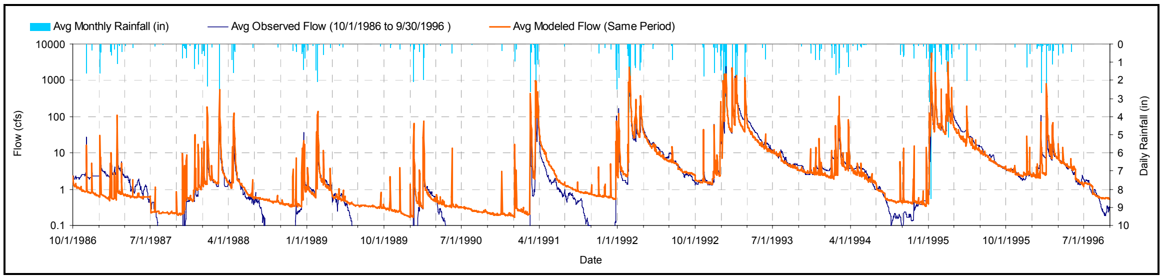

Figure 6-76. Mean Daily Flow: Model vs. USGS 11117500 San Antonio Cr at Hwy 33 (Validation Period)

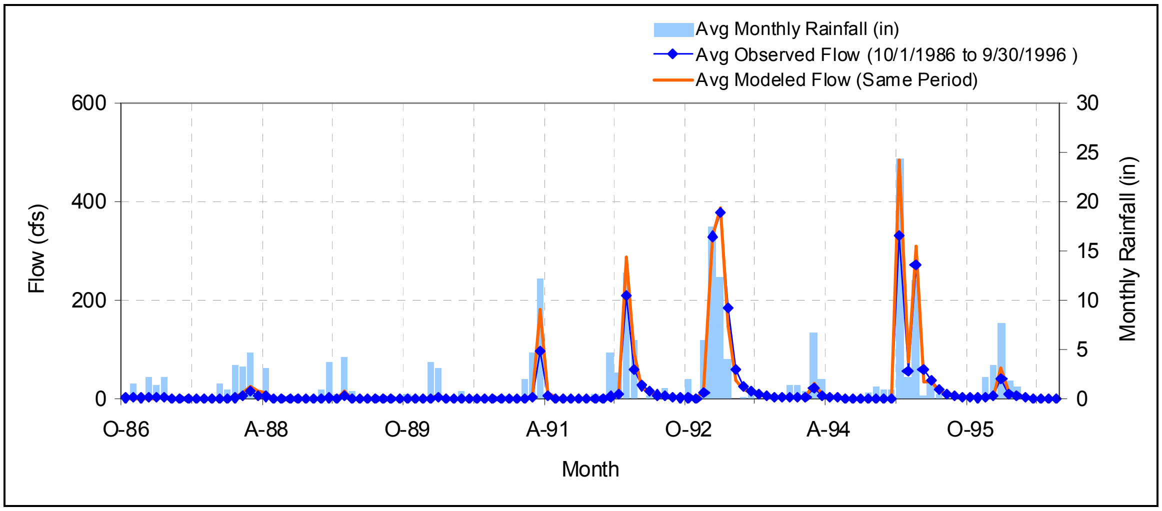

Figure 6-77. Mean Monthly Flow: Model vs. USGS 11117500 San Antonio Cr at Hwy 33 (Validation Period)

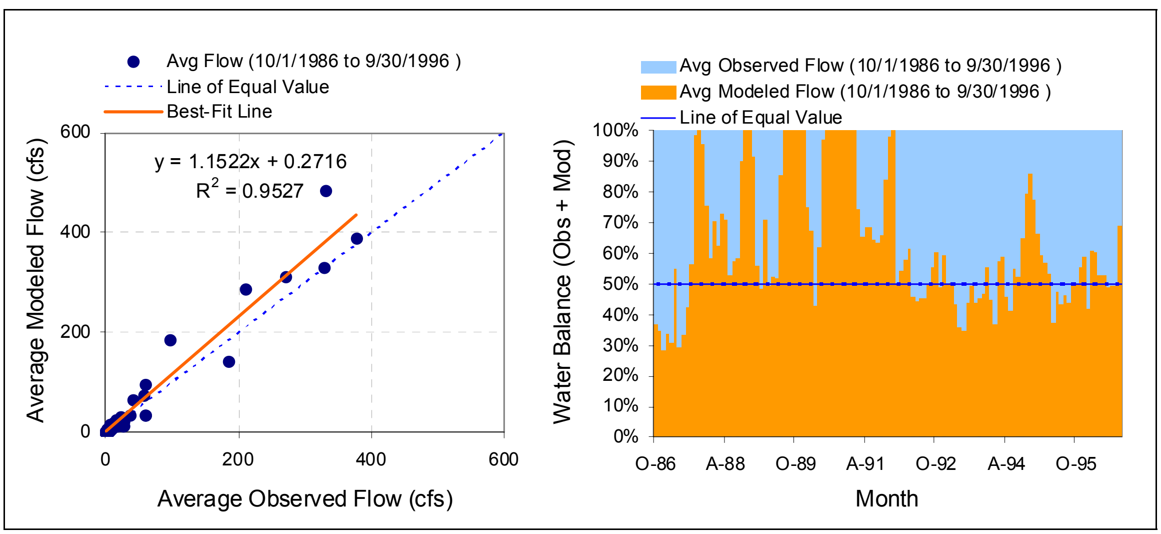

Figure 6-78. Monthly Flow Regression and Temporal Variation: Model vs. USGS 11117500 San Antonio Cr at Hwy 33 (Validation Period)

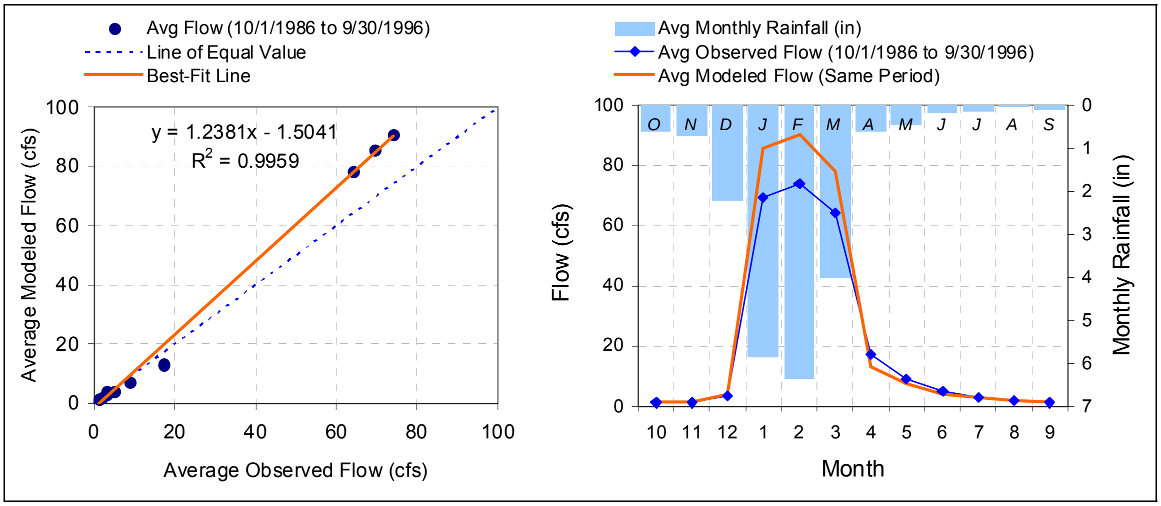

Figure 6-79. Annual Flow Regression and Monthly Aggregate: Model vs. USGS 11117500 San Antonio Cr at Hwy 33 (Validation Period)

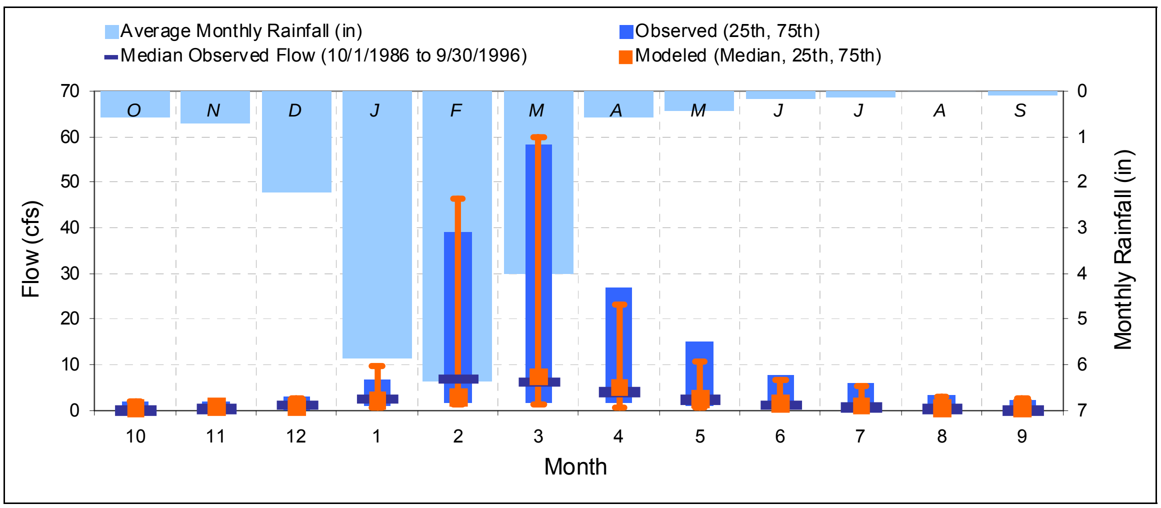

Figure 6-80. Seasonal Medians and Ranges: Model vs. USGS 11117500 San Antonio Cr at Hwy 33 (Validation Period)

Table 6-29. Seasonal Summary: Model vs. USGS 11117500 San Antonio Cr at Hwy 33 (Validation Period)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	1.15	0.09	0.00	2.10	1.49	0.66	0.30	2.07
Nov	1.13	0.40	0.00	2.10	1.47	0.86	0.36	1.61
Dec	3.24	1.25	0.03	2.88	3.95	0.81	0.38	2.61
Jan	69.38	2.60	1.03	6.55	85.64	2.19	0.72	9.52
Feb	74.05	7.00	1.50	39.00	90.68	2.85	1.14	46.25
Mar	64.28	6.30	1.70	58.25	78.04	7.45	1.11	59.75
Apr	17.11	4.20	1.50	27.00	13.13	5.17	0.67	23.30
May	9.05	2.40	0.90	15.00	7.36	2.67	0.61	10.75
Jun	4.98	1.20	0.53	7.70	4.20	1.57	0.61	6.78
Jul	3.12	0.75	0.22	5.98	2.97	1.07	0.36	5.45
Aug	1.86	0.41	0.00	3.15	1.76	0.58	0.34	3.12
Sep	1.17	0.16	0.00	2.30	1.40	0.55	0.32	2.72

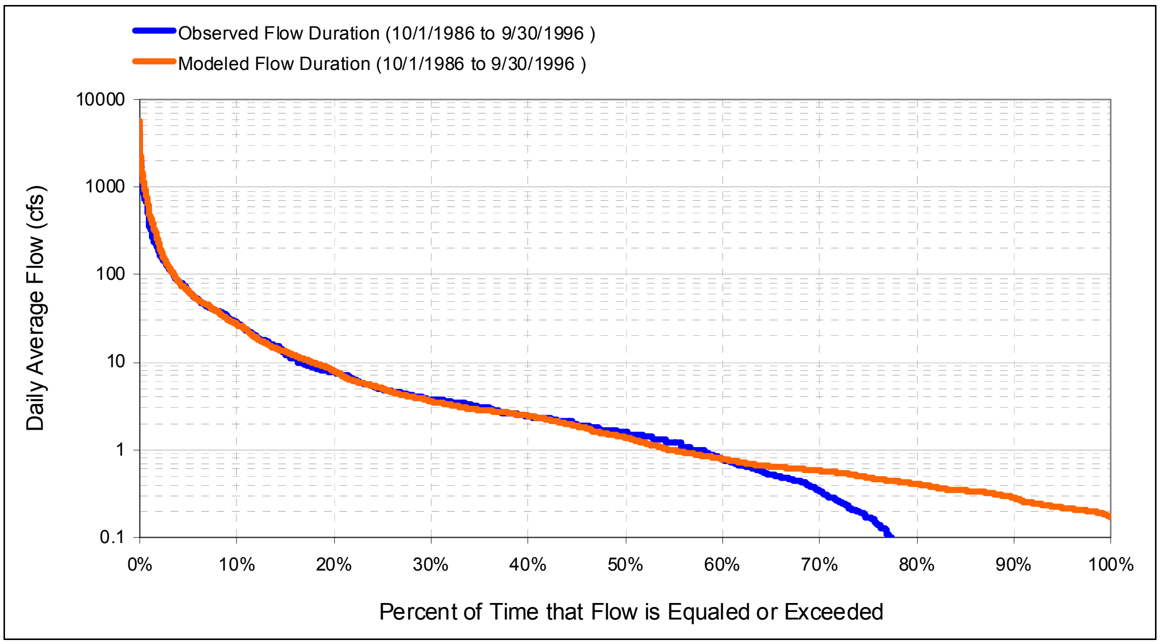

Figure 6-81. Flow Exceedence: Model vs. USGS 11117500 San Antonio Cr at Hwy 33 (Validation Period)

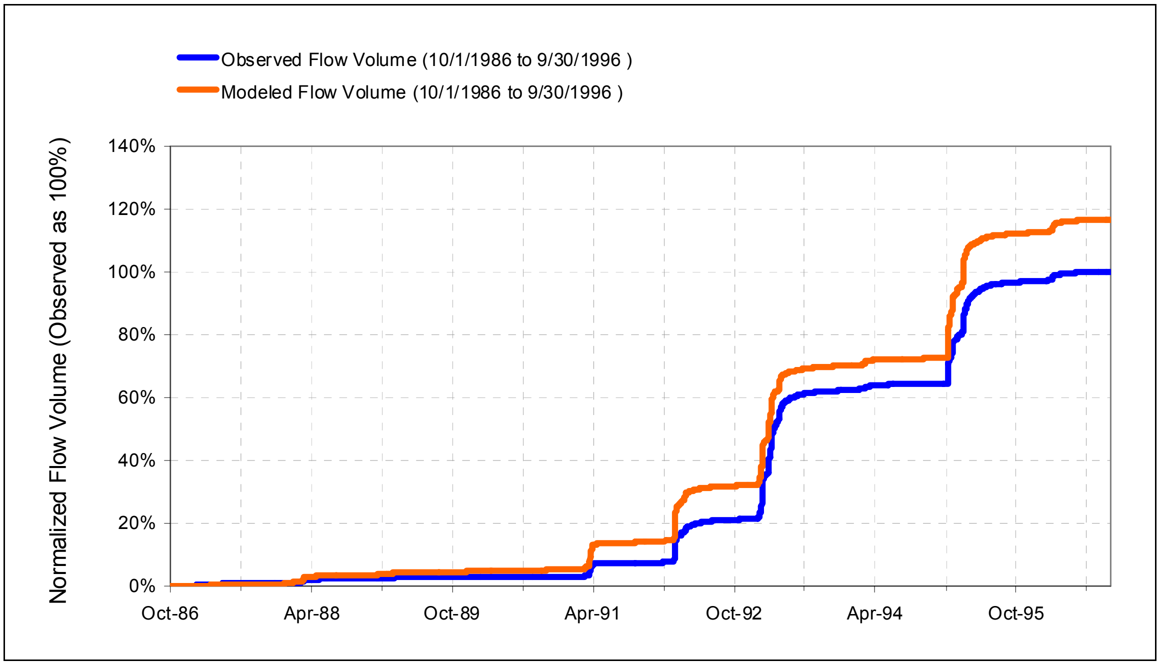

Figure 6-82. Flow Accumulation: Model vs. USGS 11117500 San Antonio Cr at Hwy 33 (Validation Period)

Table 6-30. Summary Statistics: Model vs. USGS 11117500 San Antonio Cr at Hwy 33 (Validation Period)

HSPF Simulated Flow		**Observed Flow Gage**	
REACH OUTFLOW FROM SUBBASIN 371 10-Year Analysis Period: 10/1/1986 - 9/30/1996 Flow volumes are (inches/year) for upstream drainage area **Gage 605** **DSN 5004** **7/17/2009 13:10**		**USGS 11117500 San Antonio Cr at Hwy 33** Hydrologic Unit Code: 4040003 Latitude: 43.10001159 Longitude: -87.9089745 Drainage Area (sq-mi): 696	
Total Simulated In-stream Flow:	**6.60**	Total Observed In-stream Flow:	**5.66**
Total of simulated highest 10% flows:	**5.86**	Total of Observed highest 10% flows:	**4.94**
Total of Simulated lowest 50% flows:	**0.08**	Total of Observed Lowest 50% flows:	**0.05**
Simulated Summer Flow Volume (months 7-9):	**0.14**	Observed Summer Flow Volume (7-9):	**0.14**
Simulated Fall Flow Volume (months 10-12):	**0.16**	Observed Fall Flow Volume (10-12):	**0.13**
Simulated Winter Flow Volume (months 1-3):	**5.73**	Observed Winter Flow Volume (1-3):	**4.68**
Simulated Spring Flow Volume (months 4-6):	**0.56**	Observed Spring Flow Volume (4-6):	**0.71**
Total Simulated Storm Volume:	**3.96**	Total Observed Storm Volume:	**2.94**
Simulated Summer Storm Volume (7-9):	**0.01**	Observed Summer Storm Volume (7-9):	**0.01**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	**16.55**	**10**	
Error in 50% lowest flows:	**44.10**	**10**	
Error in 10% highest flows:	**18.62**	**15**	
Seasonal volume error - Summer:	-0.37	30	
Seasonal volume error - Fall:	25.34	30	
Seasonal volume error - Winter:	22.46	30	
Seasonal volume error - Spring:	-20.71	30	
Error in storm volumes:	**34.70**	**20**	
Error in summer storm volumes:	-11.29	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.831	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.733	as E or E' approaches 1.0	

6.6.5 Ventura River near Ventura (at Foster Park) (608)

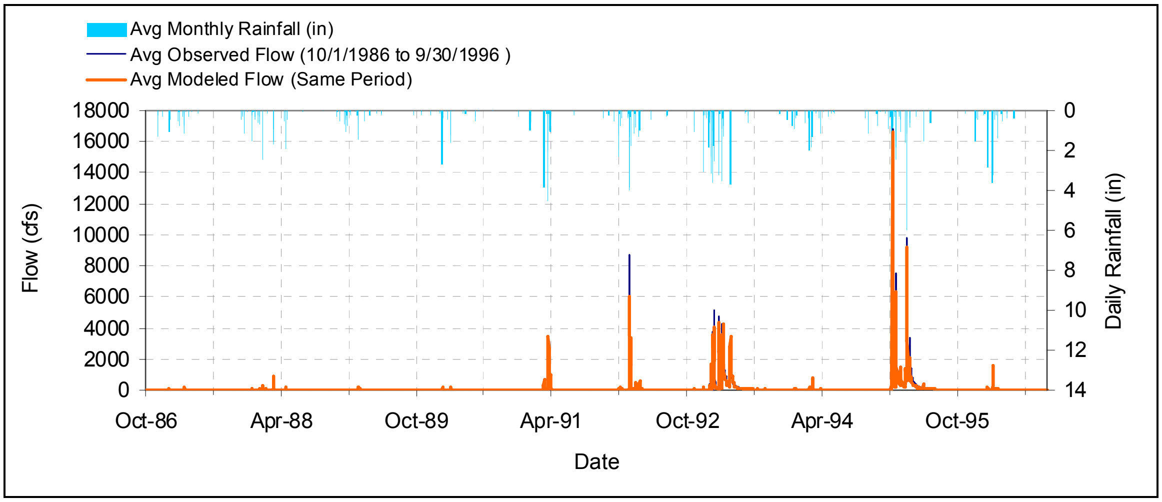

Figure 6-83. Mean daily flow: Model vs. USGS 11118500 Ventura R nr Ventura (Validation Period)

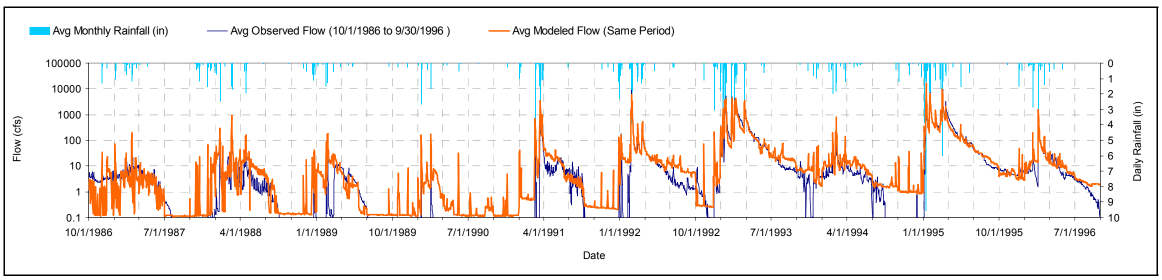

Figure 6-84. Mean daily flow: Model vs. USGS 11118500 Ventura R nr Ventura (Validation Period)

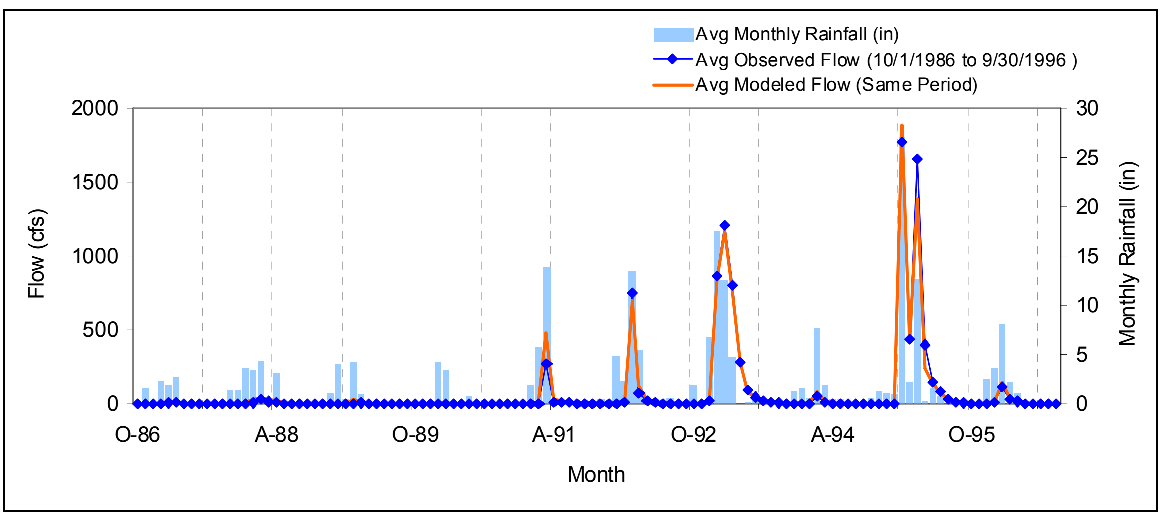

Figure 6-85. Mean monthly flow: Model vs. USGS 11118500 Ventura R nr Ventura (Validation Period)

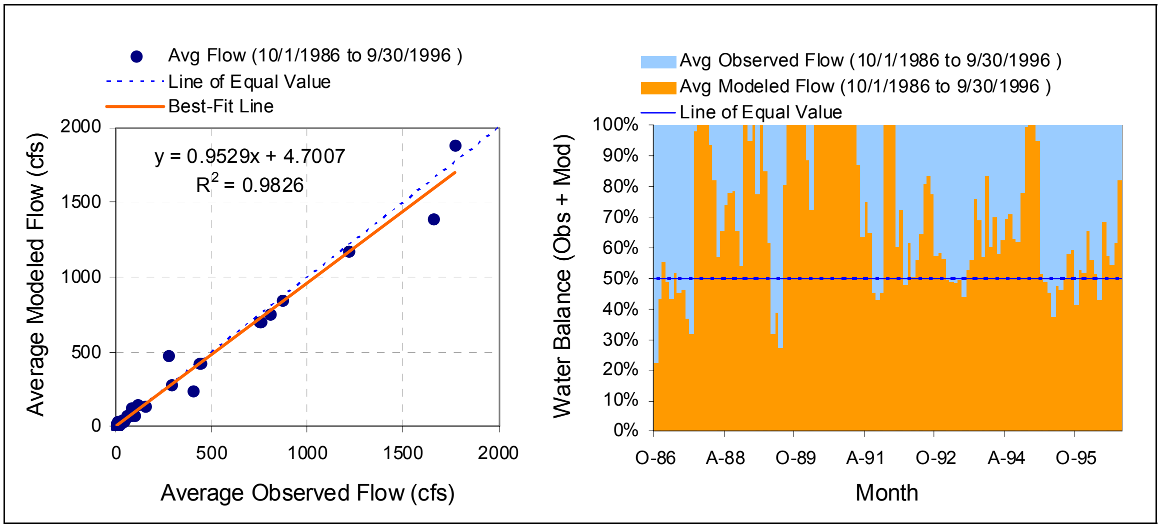

Figure 6-86. Monthly Flow Regression and Temporal Variation: Model vs. USGS 11118500 Ventura R nr Ventura (Validation Period)

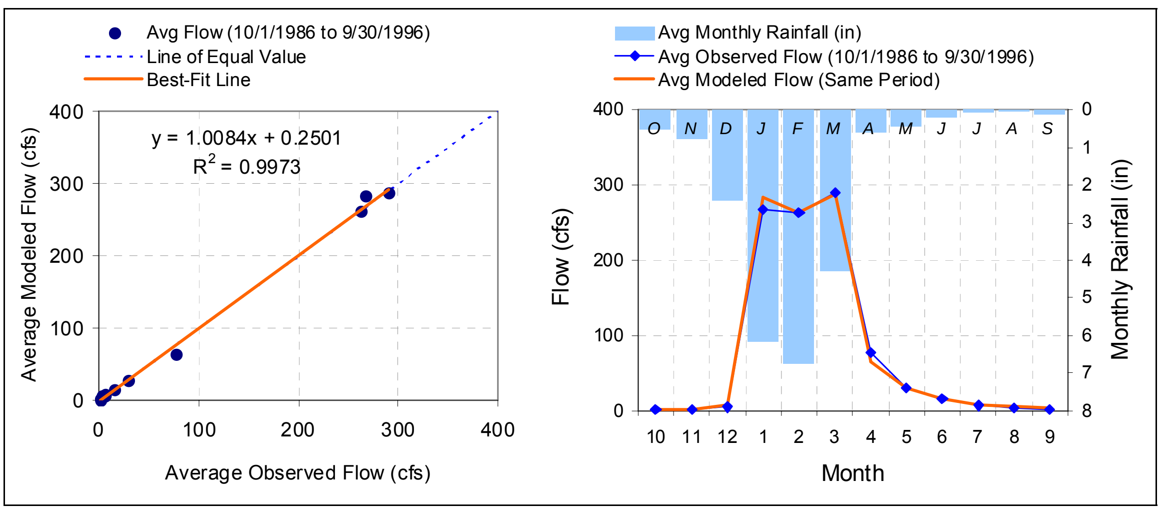

Figure 6-87. Annual Flow Regression and Monthly Aggregate: Model vs. USGS 11118500 Ventura R nr Ventura (Validation Period)

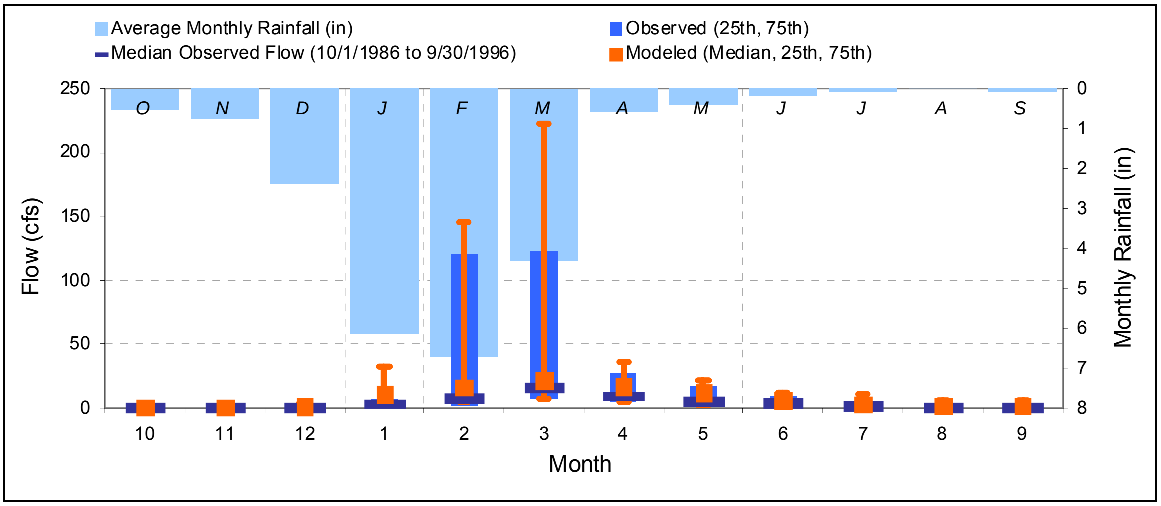

Figure 6-88. Seasonal Medians and Ranges: Model vs. USGS 11118500 Ventura R nr Ventura (Validation Period)

Table 6-31. Seasonal Summary: Model vs. USGS 11118500 Ventura R nr Ventura (Validation Period)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	1.77	0.00	0.00	3.28	2.02	0.29	0.13	2.30
Nov	1.05	0.00	0.00	1.43	2.39	0.26	0.13	1.63
Dec	4.47	0.09	0.00	3.60	7.17	1.01	0.14	3.72
Jan	267.96	3.30	0.00	7.38	283.50	10.30	2.59	32.35
Feb	263.22	7.60	0.30	120.50	262.79	15.90	4.04	145.50
Mar	290.10	16.00	7.13	123.00	286.96	21.30	7.04	222.25
Apr	76.98	9.10	4.50	27.25	64.16	16.55	4.45	36.25
May	29.35	5.30	2.70	16.00	29.26	11.55	2.43	21.40
Jun	15.55	3.70	0.93	8.73	16.08	5.27	0.57	12.33
Jul	6.72	1.60	0.23	4.10	8.32	2.48	0.13	10.53
Aug	3.02	0.44	0.00	2.20	6.47	1.58	0.13	6.10
Sep	1.77	0.00	0.00	1.43	3.94	1.43	0.14	5.62

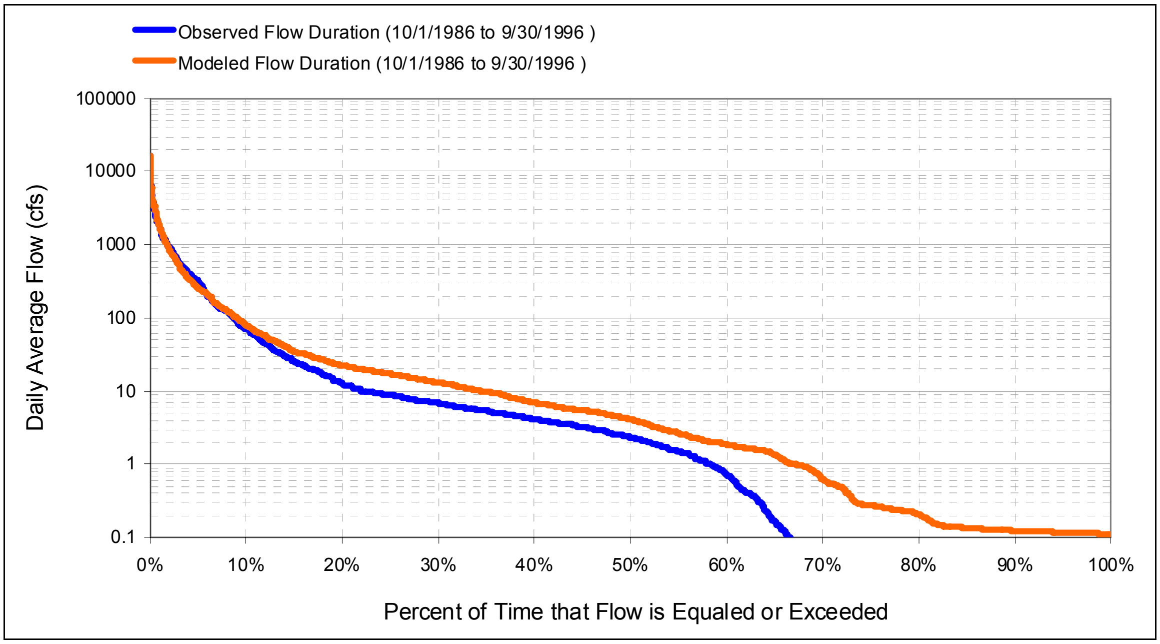

Figure 6-89. Flow Exceedence: Model vs. USGS 11118500 Ventura R nr Ventura (Validation Period)

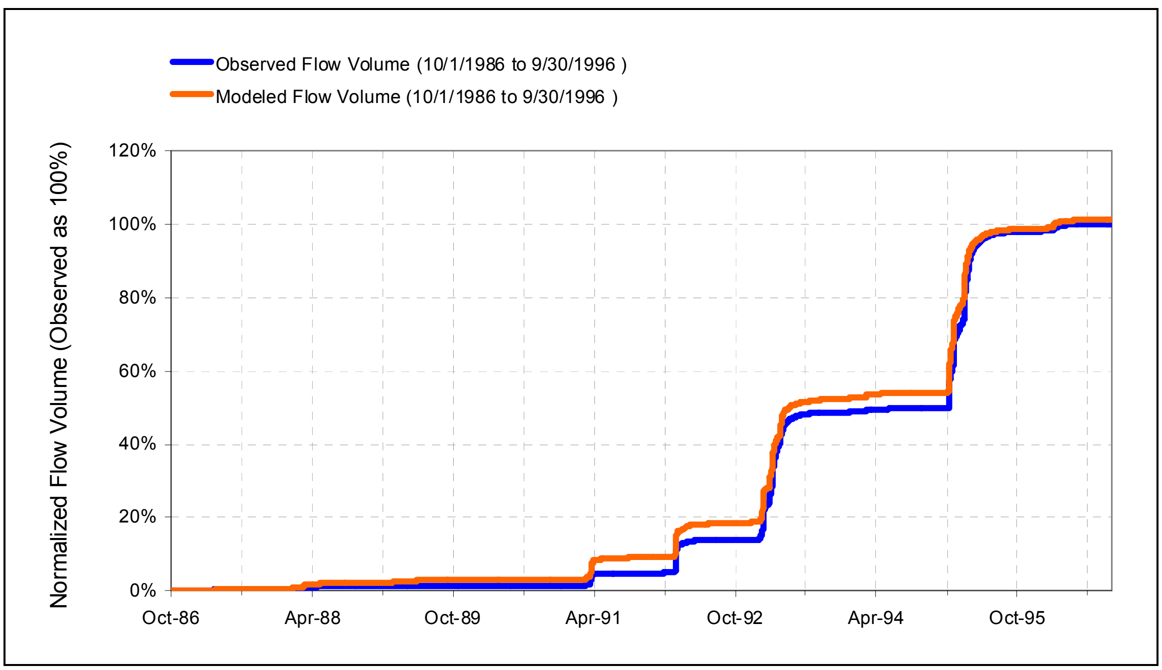

Figure 6-90. Flow Accumulation: Model vs. USGS 11118500 Ventura R nr Ventura (Validation Period)

Table 6-32. Summary Statistics: Model vs. USGS 11118500 Ventura R nr Ventura (Validation Period)

HSPF Simulated Flow		**Observed Flow Gage**	
REACH OUTFLOW FROM SUBBASIN 311 10-Year Analysis Period: 10/1/1986 - 9/30/1996 Flow volumes are (inches/year) for upstream drainage area **Gage 608** **DSN 5007** **7/17/2009 13:11**		USGS 11118500 VENTURA R NR VENTURA Hydrologic Unit Code: 18070101 Latitude: 34.35222038 Longitude: -119.3084466 Drainage Area (sq-mi): 188	
Total Simulated In-stream Flow:	**5.81**	Total Observed In-stream Flow:	**5.74**
Total of simulated highest 10% flows:	**5.25**	Total of Observed highest 10% flows:	**5.38**
Total of Simulated lowest 50% flows:	**0.03**	Total of Observed Lowest 50% flows:	**0.01**
Simulated Summer Flow Volume (months 7-9):	**0.11**	Observed Summer Flow Volume (7-9):	**0.07**
Simulated Fall Flow Volume (months 10-12):	**0.07**	Observed Fall Flow Volume (10-12):	**0.04**
Simulated Winter Flow Volume (months 1-3):	**4.97**	Observed Winter Flow Volume (1-3):	**4.90**
Simulated Spring Flow Volume (months 4-6):	**0.66**	Observed Spring Flow Volume (4-6):	**0.73**
Total Simulated Storm Volume:	**2.99**	Total Observed Storm Volume:	**2.75**
Simulated Summer Storm Volume (7-9):	**0.01**	Observed Summer Storm Volume (7-9):	**0.01**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*
Error in total volume:	1.22	10
Error in 50% lowest flows:	**167.63**	**10**
Error in 10% highest flows:	-2.44	15
Seasonal volume error - Summer:	**62.46**	**30**
Seasonal volume error - Fall:	**58.58**	**30**
Seasonal volume error - Winter:	1.50	30
Seasonal volume error - Spring:	-10.08	30
Error in storm volumes:	8.72	20
Error in summer storm volumes:	**96.49**	**50**
Nash-Sutcliffe Coefficient of Efficiency, E:	0.918	Model accuracy increases
Baseline adjusted coefficient (Garrick), E':	0.810	as E or E' approaches 1.0

6.6.6 Coyote Creek near Oak View (600A)

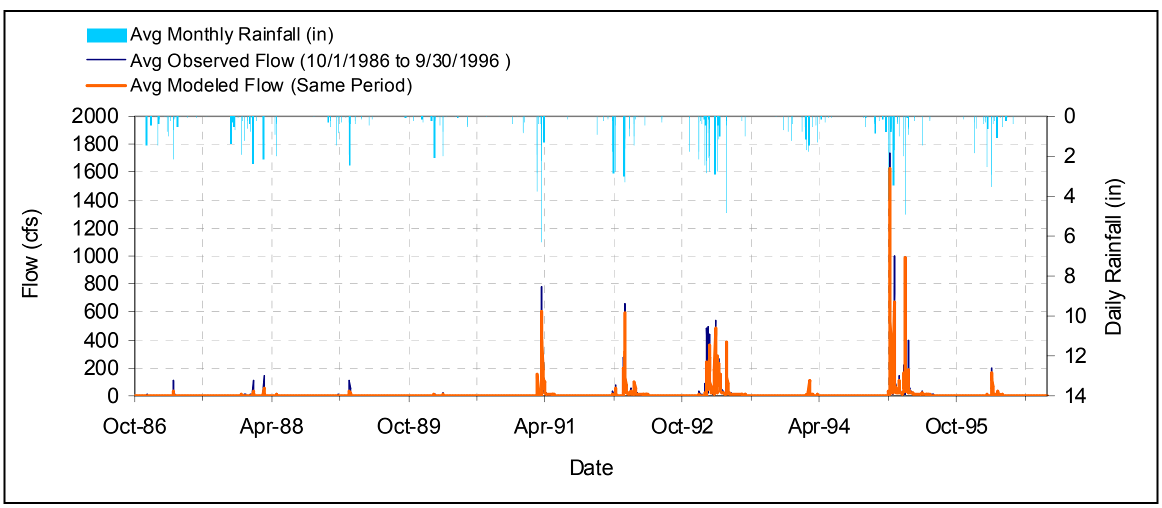

Figure 6-91. Mean Daily Flow: Model vs. USGS 11117600 Coyote Creek near Oak View (Validation Period)

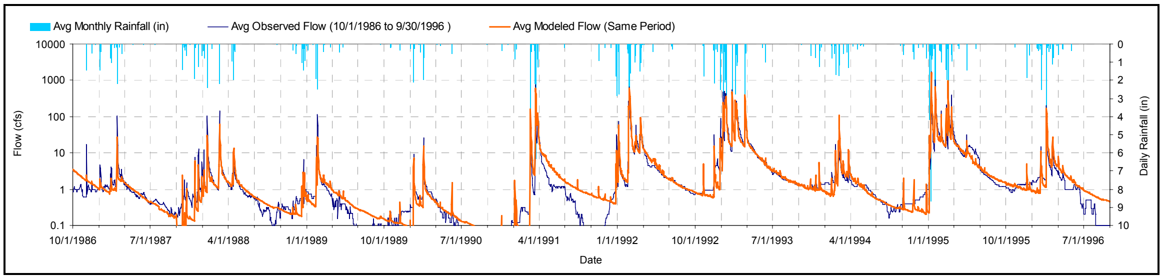

Figure 6-92. Mean Daily Flow: Model vs. USGS 11117600 Coyote Creek near Oak View (Validation Period)

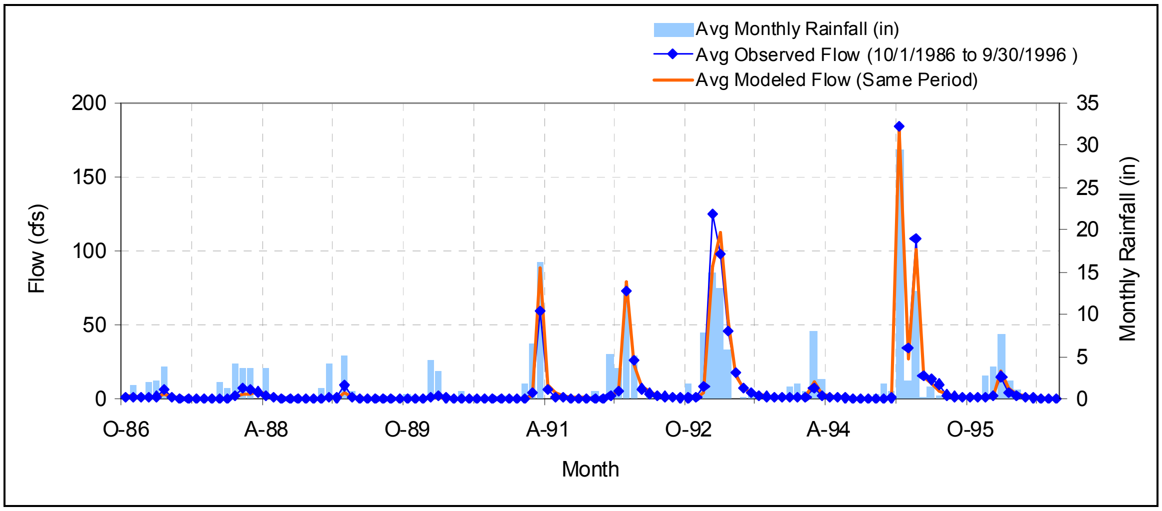

Figure 6-93. Mean Monthly Flow: Model vs. USGS 11117600 Coyote Creek near Oak View (Validation Period)

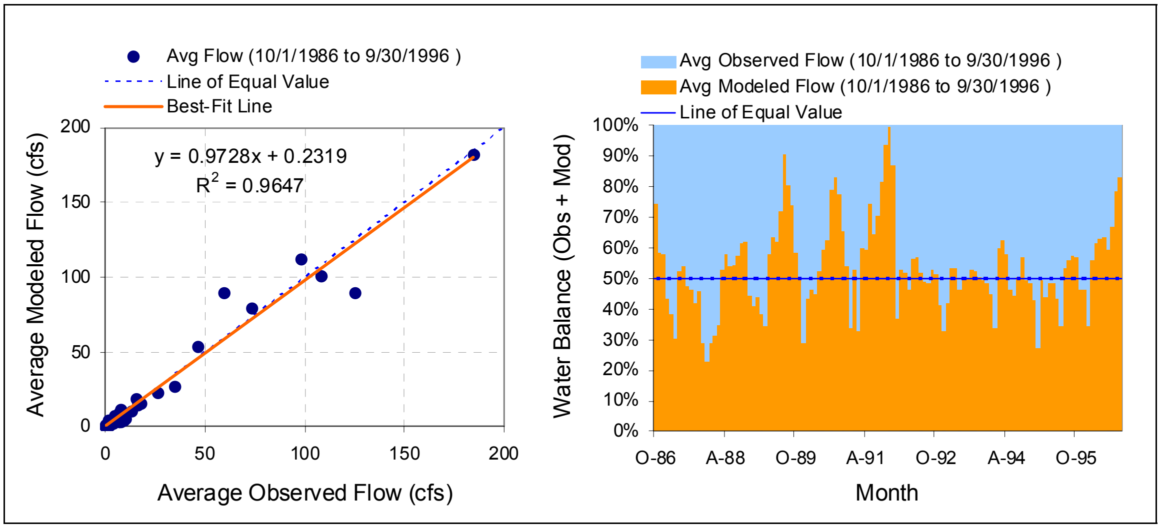

Figure 6-94. Monthly Flow Regression and Temporal Variation: Model vs. USGS 11117600 Coyote Creek near Oak View (Validation Period)

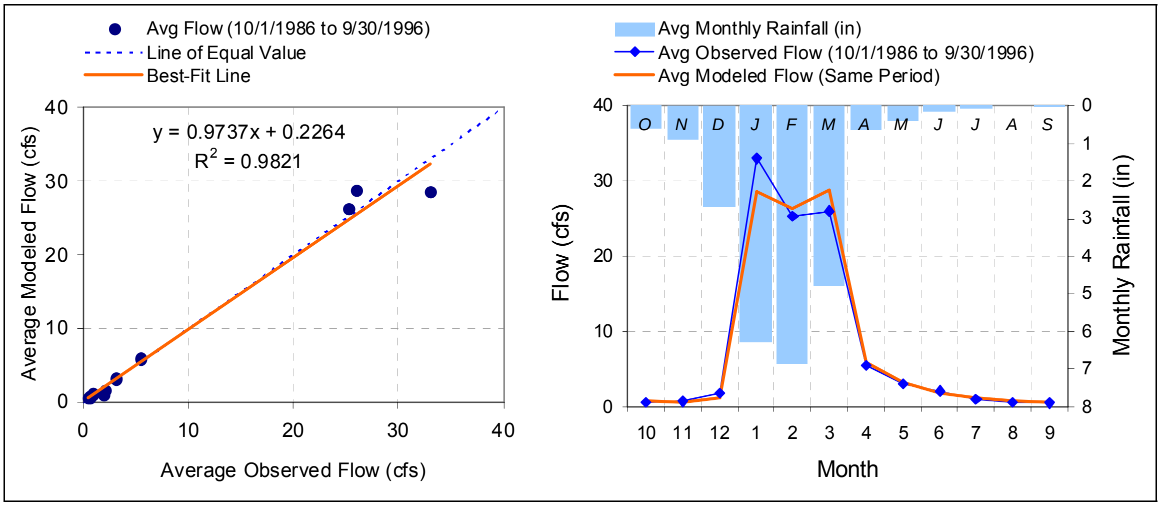

Figure 6-95. Annual Flow Regression and Monthly Aggregate: Model vs. USGS 11117600 Coyote Creek near Oak View (Validation Period)

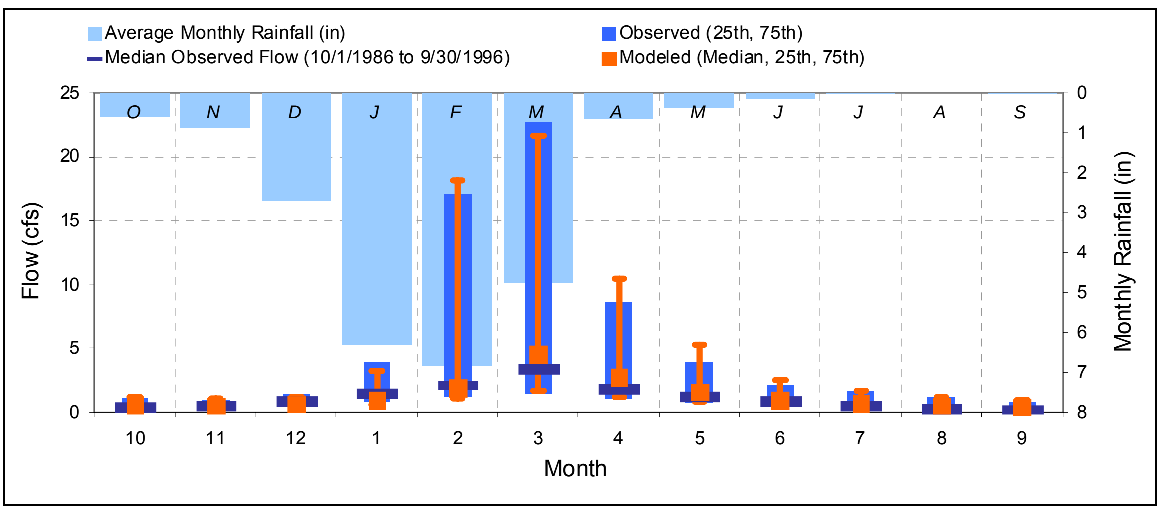

Figure 6-96. Seasonal Medians and Ranges: Model vs. USGS 11117600 Coyote Creek near Oak View (Validation Period)

Table 6-33. Seasonal Summary: Model vs. USGS 11117600 Coyote Creek near Oak View (Validation Period)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	0.54	0.40	0.10	1.00	0.81	0.58	0.14	1.24
Nov	0.66	0.50	0.16	0.97	0.64	0.48	0.16	1.02
Dec	1.86	0.88	0.45	1.40	1.11	0.60	0.20	1.14
Jan	33.01	1.50	0.84	4.00	28.65	0.93	0.52	3.18
Feb	25.28	2.10	1.20	17.00	26.35	1.90	1.01	18.20
Mar	26.03	3.35	1.43	22.75	28.82	4.49	1.70	21.70
Apr	5.45	1.80	1.00	8.60	5.96	2.75	1.19	10.50
May	3.04	1.20	0.68	3.90	3.25	1.58	0.81	5.23
Jun	2.07	0.86	0.41	2.10	1.76	0.92	0.53	2.53
Jul	0.93	0.50	0.26	1.70	1.16	0.65	0.40	1.60
Aug	0.60	0.27	0.10	1.20	0.81	0.49	0.26	1.15
Sep	0.45	0.20	0.06	0.77	0.64	0.39	0.19	0.93

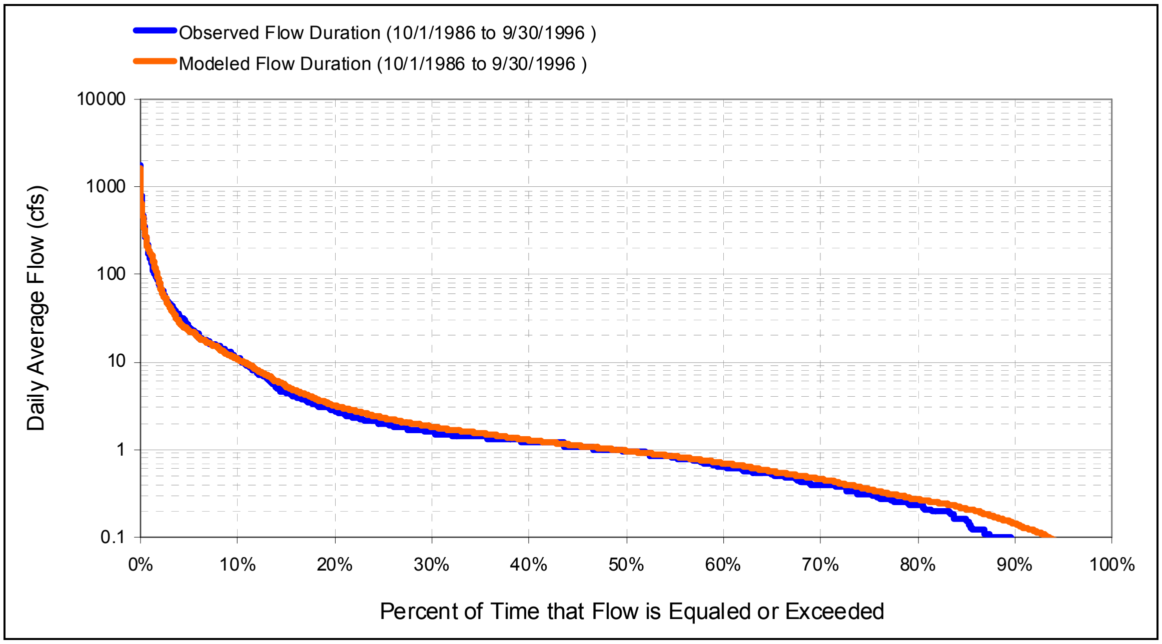

Figure 6-97. Flow Exceedence: Model vs. USGS 11117600 Coyote Creek near Oak View (Validation Period)

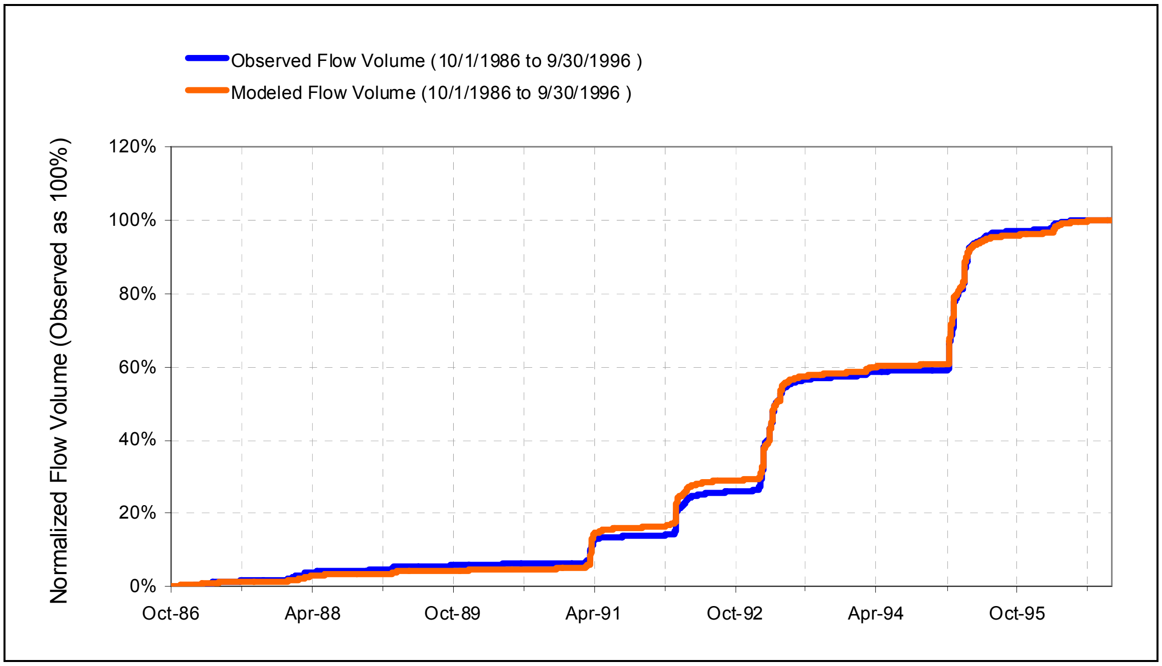

Figure 6-98. Flow Accumulation: Model vs. USGS 11117600 Coyote Creek near Oak View (Validation Period)

Table 6-34. Summary Statistics: Model vs. USGS 11117600 Coyote Creek near Oak View (Validation Period)

HSPF Simulated Flow		**Observed Flow Gage**	
REACH OUTFLOW FROM SUBBASIN 123 10-Year Analysis Period: 10/1/1986 - 9/30/1996 Flow volumes are (inches/year) for upstream drainage area **Gage 603A** **DSN 5001** **7/17/2009 13:11**		**USGS 11117600 Coyote Creek near Oak View** Hydrologic Unit Code: 18070101 Latitude: 34.35222038 Longitude: -119.3084466 Drainage Area (sq-mi): 188	
Total Simulated In-stream Flow:	**8.60**	Total Observed In-stream Flow:	**8.60**
Total of simulated highest 10% flows:	**7.24**	Total of Observed highest 10% flows:	**7.38**
Total of Simulated lowest 50% flows:	**0.22**	Total of Observed Lowest 50% flows:	**0.19**
Simulated Summer Flow Volume (months 7-9):	**0.23**	Observed Summer Flow Volume (7-9):	**0.17**
Simulated Fall Flow Volume (months 10-12):	**0.23**	Observed Fall Flow Volume (10-12):	**0.27**
Simulated Winter Flow Volume (months 1-3):	**7.20**	Observed Winter Flow Volume (1-3):	**7.25**
Simulated Spring Flow Volume (months 4-6):	**0.95**	Observed Spring Flow Volume (4-6):	**0.91**
Total Simulated Storm Volume:	**2.33**	Total Observed Storm Volume:	**2.74**
Simulated Summer Storm Volume (7-9):	**0.00**	Observed Summer Storm Volume (7-9):	**0.00**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-0.02	10	
Error in 50% lowest flows:	**13.82**	**10**	
Error in 10% highest flows:	-1.96	15	
Seasonal volume error - Summer:	**32.14**	**30**	
Seasonal volume error - Fall:	-15.78	30	
Seasonal volume error - Winter:	-0.71	30	
Seasonal volume error - Spring:	3.99	30	
Error in storm volumes:	-15.11	20	
Error in summer storm volumes:	41.20	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.843	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.746	as E or E' approaches 1.0	

6.6.7 Santa Ana Creek nr Oak View (606)

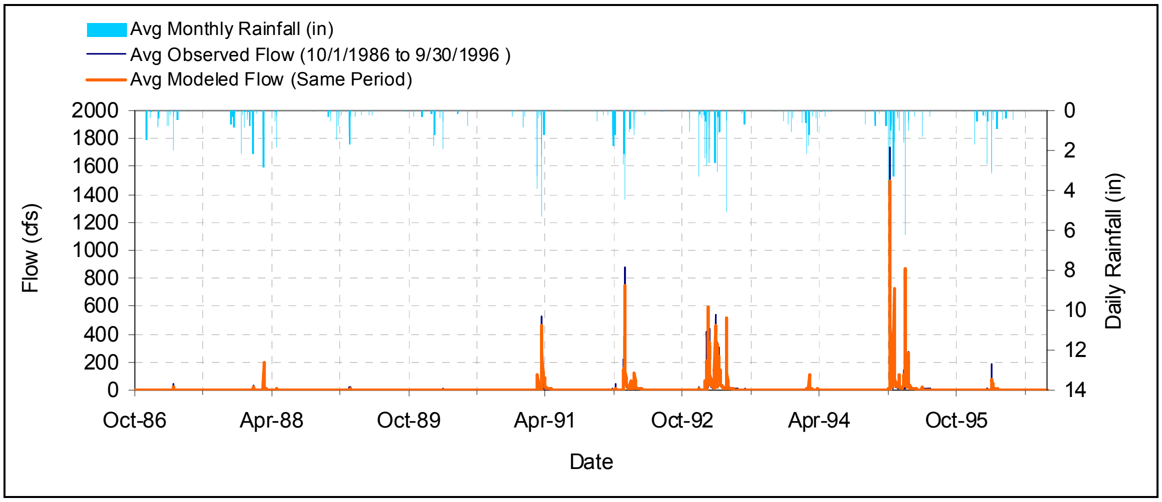

Figure 6-99. Mean Daily Flow: Model vs. USGS 11117800 Santa Ana Cr nr Oak View (Validation Period)

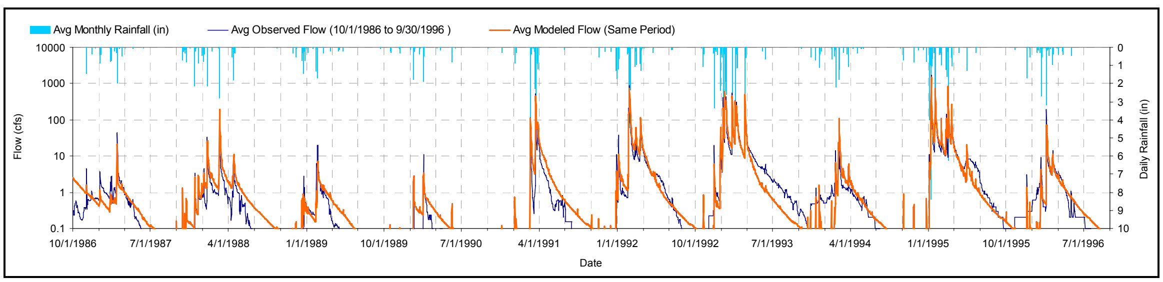

Figure 6-100. Mean Daily Flow: Model vs. USGS 11117800 Santa Ana Cr nr Oak View (Validation Period)

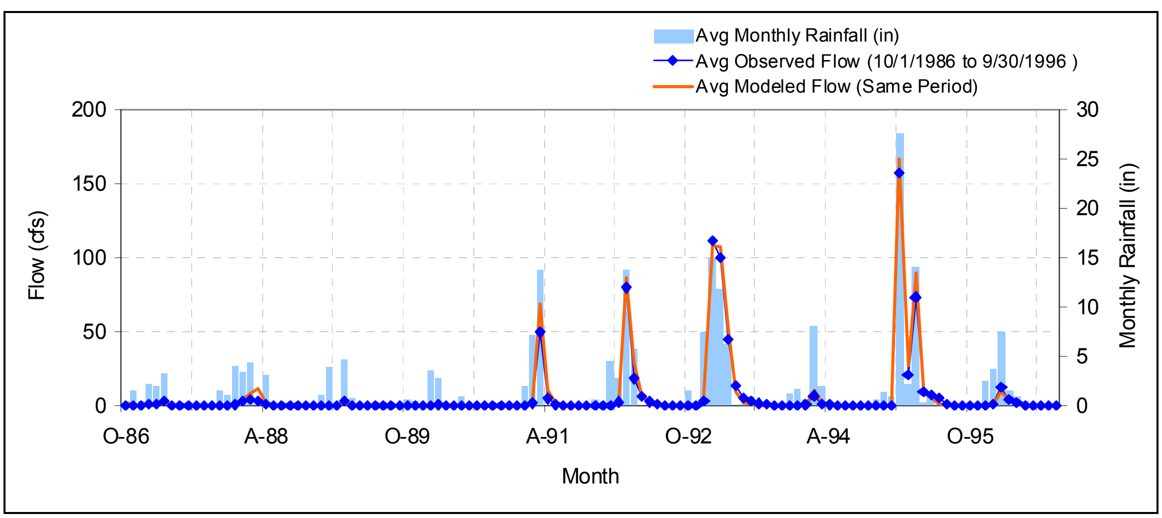

Figure 6-101. Mean monthly flow: Model vs. USGS 11117800 Santa Ana Cr nr Oak View (Validation Period)

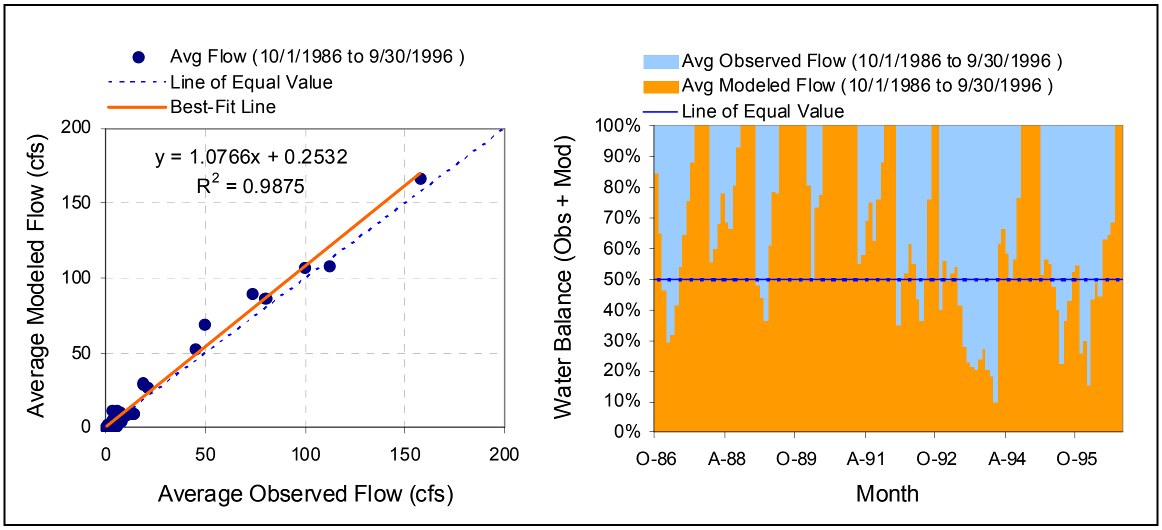

Figure 6-102. Monthly Flow Regression and Temporal Variation: Model vs. USGS 11117800 Santa Ana Cr nr Oak View (Validation Period)

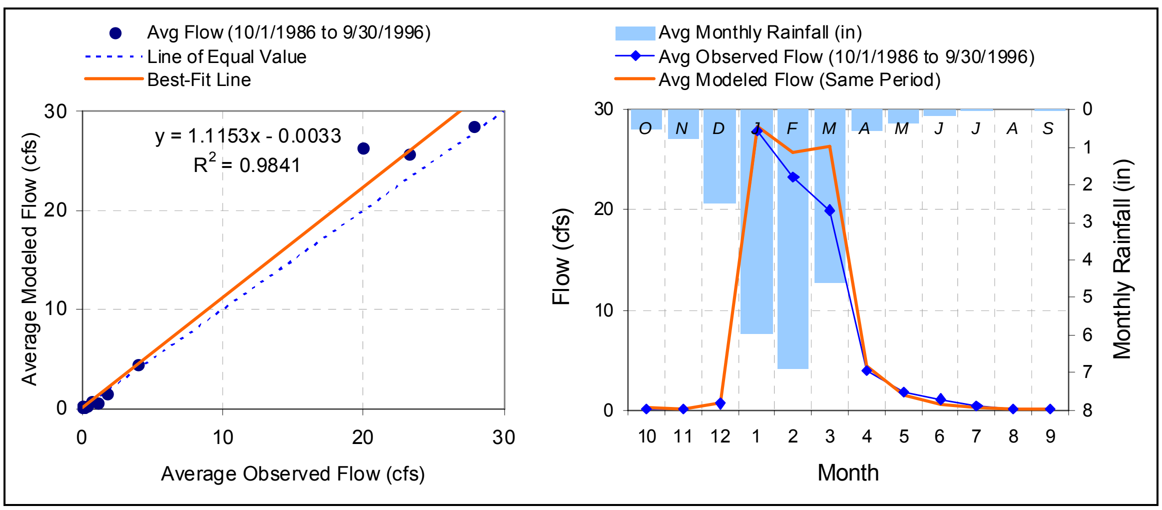

Figure 6-103. Annual Flow Regression and Monthly Aggregate: Model vs. USGS 11117800 Santa Ana Cr nr Oak View (Validation Period)

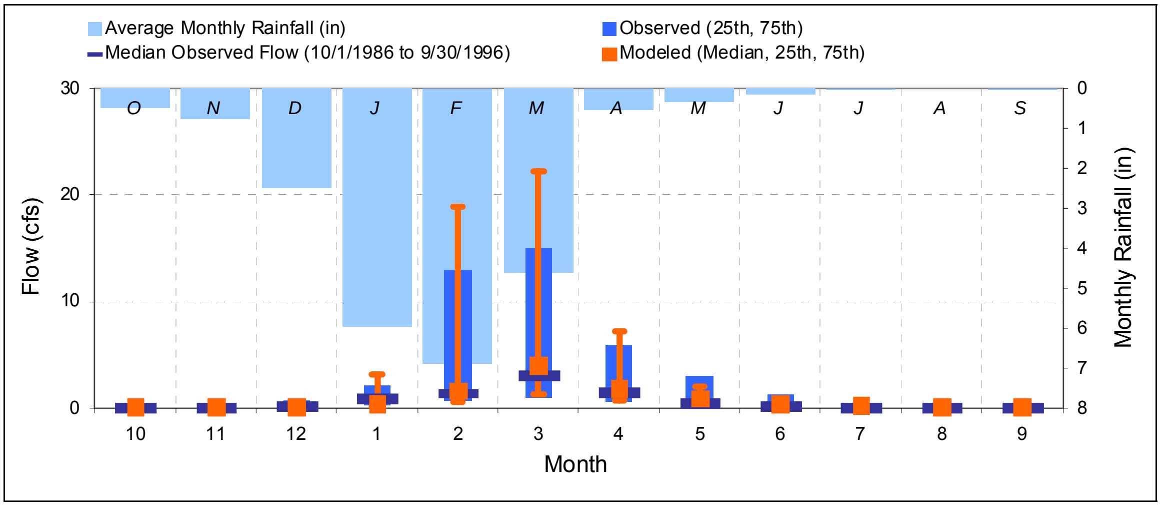

Figure 6-104. Seasonal Medians and Ranges: Model vs. USGS 11117800 Santa Ana Cr nr Oak View (Validation Period)

Table 6-35. Seasonal summary: Model vs. USGS 11117800 Santa Ana Cr nr Oak View (Validation Period)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	0.07	0.00	0.00	0.10	0.27	0.07	0.03	0.10
Nov	0.12	0.00	0.00	0.20	0.17	0.06	0.04	0.08
Dec	0.67	0.20	0.00	0.64	0.68	0.08	0.03	0.47
Jan	27.87	0.86	0.28	2.10	28.43	0.44	0.08	3.10
Feb	23.24	1.40	0.70	13.00	25.70	1.63	0.53	18.90
Mar	19.99	3.05	0.97	15.00	26.34	3.97	1.32	22.20
Apr	3.99	1.50	0.50	5.95	4.43	1.86	0.66	7.24
May	1.82	0.48	0.17	3.00	1.48	0.91	0.34	1.97
Jun	1.09	0.20	0.05	1.23	0.56	0.43	0.16	0.83
Jul	0.36	0.06	0.00	0.38	0.28	0.24	0.10	0.42
Aug	0.15	0.00	0.00	0.05	0.15	0.14	0.06	0.22
Sep	0.06	0.00	0.00	0.00	0.09	0.08	0.04	0.13

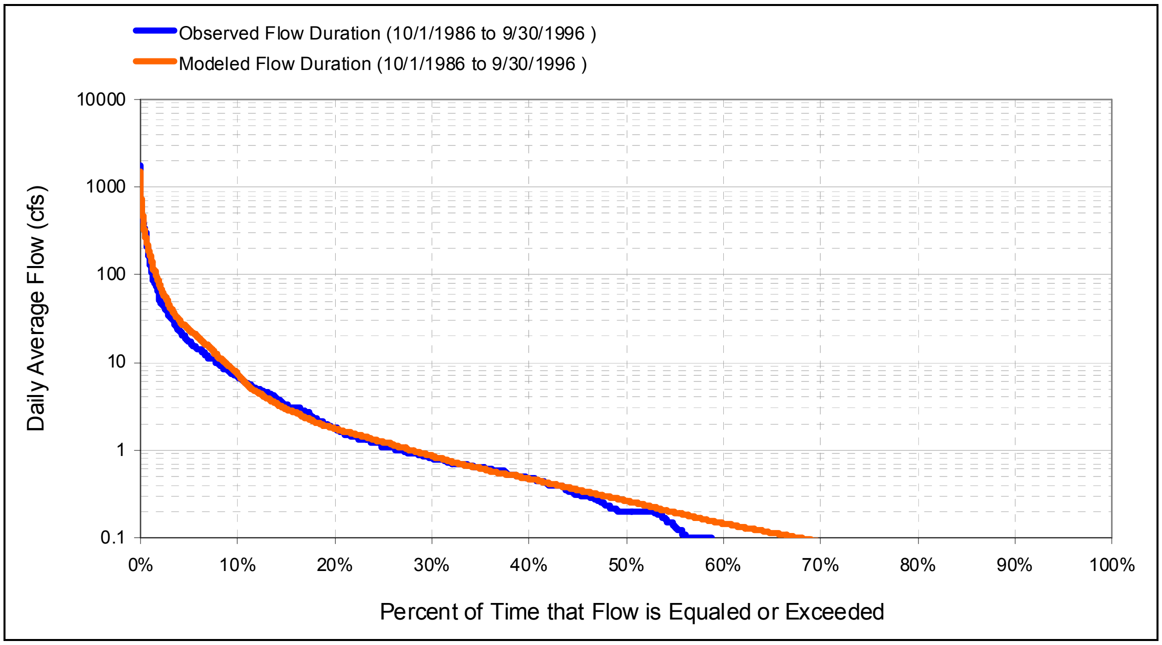

Figure 6-105. Flow Exceedence: Model vs. USGS 11117800 Santa Ana Cr nr Oak View (Validation Period)

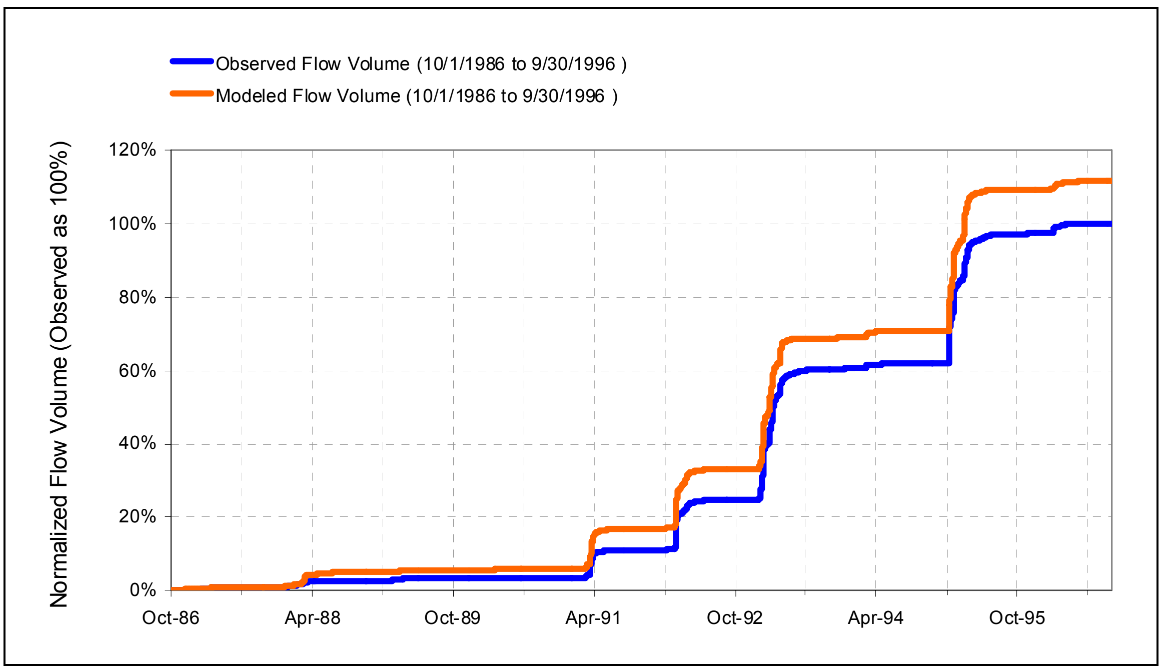

Figure 6-106. Flow Accumulation: Model vs. USGS 11117800 Santa Ana Cr nr Oak View (Validation Period)

Table 6-36. Summary Statistics: Model vs. USGS 11117800 Santa Ana Cr nr Oak View (Validation Period)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 443 10-Year Analysis Period: 10/1/1986 - 9/30/1996 Flow volumes are (inches/year) for upstream drainage area **Gage 606** **DSN 5005** **7/17/2009 13:11**		USGS 11117800 Santa Ana Cr nr Oak View Hydrologic Unit Code: 4040003 Latitude: 43.10001159 Longitude: -87.9089745 Drainage Area (sq-mi): 696	
Total Simulated In-stream Flow:	**11.05**	Total Observed In-stream Flow:	**9.90**
Total of simulated highest 10% flows:	**10.13**	Total of Observed highest 10% flows:	**9.01**
Total of Simulated lowest 50% flows:	**0.07**	Total of Observed Lowest 50% flows:	**0.02**
Simulated Summer Flow Volume (months 7-9):	**0.07**	Observed Summer Flow Volume (7-9):	**0.07**
Simulated Fall Flow Volume (months 10-12):	**0.14**	Observed Fall Flow Volume (10-12):	**0.11**
Simulated Winter Flow Volume (months 1-3):	**10.03**	Observed Winter Flow Volume (1-3):	**8.86**
Simulated Spring Flow Volume (months 4-6):	**0.81**	Observed Spring Flow Volume (4-6):	**0.86**
Total Simulated Storm Volume:	**3.42**	Total Observed Storm Volume:	**3.55**
Simulated Summer Storm Volume (7-9):	**0.00**	Observed Summer Storm Volume (7-9):	**0.00**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*
Error in total volume:	**11.56**	**10**
Error in 50% lowest flows:	**183.45**	**10**
Error in 10% highest flows:	12.47	15
Seasonal volume error - Summer:	-8.94	30
Seasonal volume error - Fall:	**31.67**	**30**
Seasonal volume error - Winter:	13.24	30
Seasonal volume error - Spring:	-6.43	30
Error in storm volumes:	-3.67	20
Error in summer storm volumes:	**-55.73**	**50**
Nash-Sutcliffe Coefficient of Efficiency, E:	0.893	Model accuracy increases
Baseline adjusted coefficient (Garrick), E':	0.757	as E or E' approaches 1.0

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7 Prediction of Flood Event Peaks

Prediction of extreme events is a primary objective of this phase of the modeling. Extreme events are, however, by their nature difficult to simulate accurately. This is primarily due to the heterogeneous nature of rainfall processes. Extreme high flow events occur in response to intense rainfall events, but such events often show a large amount of spatial variability, due both to systematic elevation effects and stochastic variability in storm tracks and the intensity of fine-scale convective cells within a storm. Rain gages, which measure precipitation at a point, may not be representative of the average rainfall intensity across a model subbasin – as can be inferred by the large differences often seen between gages at similar elevation separated by only a few miles. Greater precision can only be attained through use of techniques such as Doppler radar interpretation to produce areal, rather than point estimates of precipitation.

Extreme event prediction is also influenced by the relative timing of events. A storm that drops an inch of rain in 10 minutes will have a greater impact than one that drops an inch of rain in an hour; however, the peak intensity of a storm typically moves across a watershed. Response is greater if the intense rainfall occurs everywhere at the same instant than if it moves gradually across a drainage area.

This section summarizes and analyzes model skill at predicting storm event peaks. First, an overall evaluation is made of event peaks for the calibration and validation periods. Then, a comparative analysis of the ability to predict low-frequency, high-volume events is made by comparing estimates of long return period runoff derived from gaged and modeled data, using a longer, 40-year period of simulation.

7.1 Overall Prediction of Storm Event Peaks

7.1.1 Event Peaks (Calibration Period)

The fit to instantaneous storm event peaks is summarized in Table 7-1 as the error in the volumetric sum of all reported peaks. Individual events are plotted in Figure 7-1.

Table 7-1. Volume Error in Instantaneous Storm Event Peaks (Calibration Period)

Gage	Name	Count	Volume Error
600a	Coyote Creek	4	-24.85%
602	Matilija below Dam	10	12.39%
603a	Matilija Creek above Reservoir	8	49.44%
604	North Fork Matilija Creek	58	-9.13%
605	San Antonio Creek at Hwy 33	81	-14.85%
606	Santa Ana Creek	0	ND
608	Ventura River near Ventura (Foster Park)	10	-13.54%
630	Canada Larga	58	-26.03%
631	Fox Canyon Drain	94	-10.56%
633	Happy Valley Drain	79	9.37%
669	Thacher Creek	2	152.50%

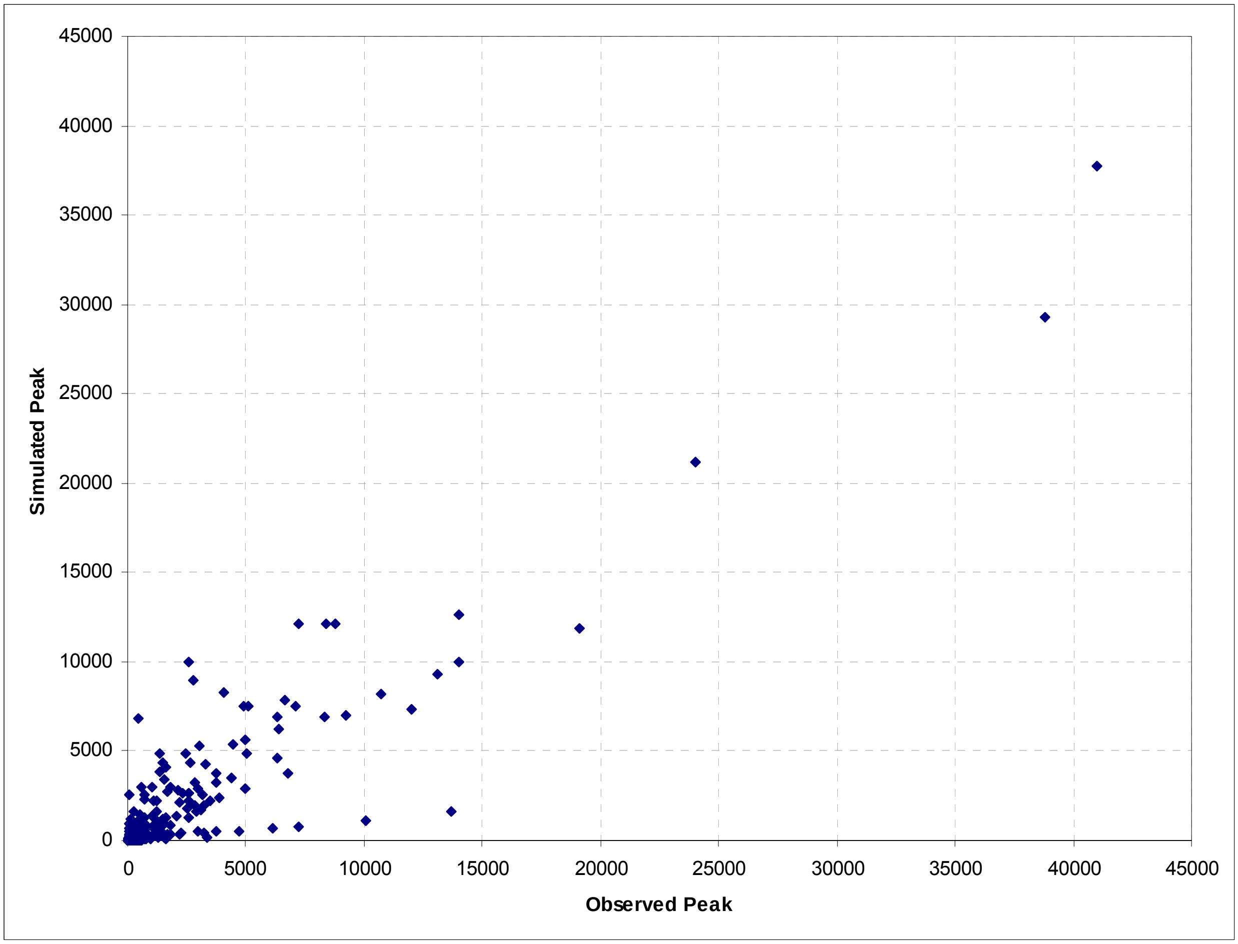

Figure 7-1. Observed versus Simulated Peak Flows (Calibration Period)

7.1.2 Event Peaks (Validation Period)

The fit to instantaneous storm event peaks is summarized in Table 7-2 as the error in the volumetric sum of all reported peaks. Individual events are plotted in Figure 7-1. The figure shows one extreme outlier associated with the reported flow of 45,800 cfs in the Ventura River near Ventura on 2/12/1992, which the model under predicts by 50 percent.

Table 7-2. Volume Error in Instantaneous Storm Event Peaks (Validation Period)

Gage	Name	Count	Volume Error
600a	Coyote Creek	8	34.04%
602	Matilija below Dam	8	-1.45%
603a	Matilija Creek above Reservoir	0	ND
604	North Fork Matilija Creek	49	63.82%
605	San Antonio Creek at Hwy 33	67	32.28%

Gage	Name	Count	Volume Error
606	Santa Ana Creek	5	35.84%
608	Ventura River near Ventura	10	-22.84%
630	Canada Larga	37	-19.11%
631	Fox Canyon Drain	87	1.00%
633a	Happy Valley Drain	58	3.95%
669	Thacher Creek	0	ND

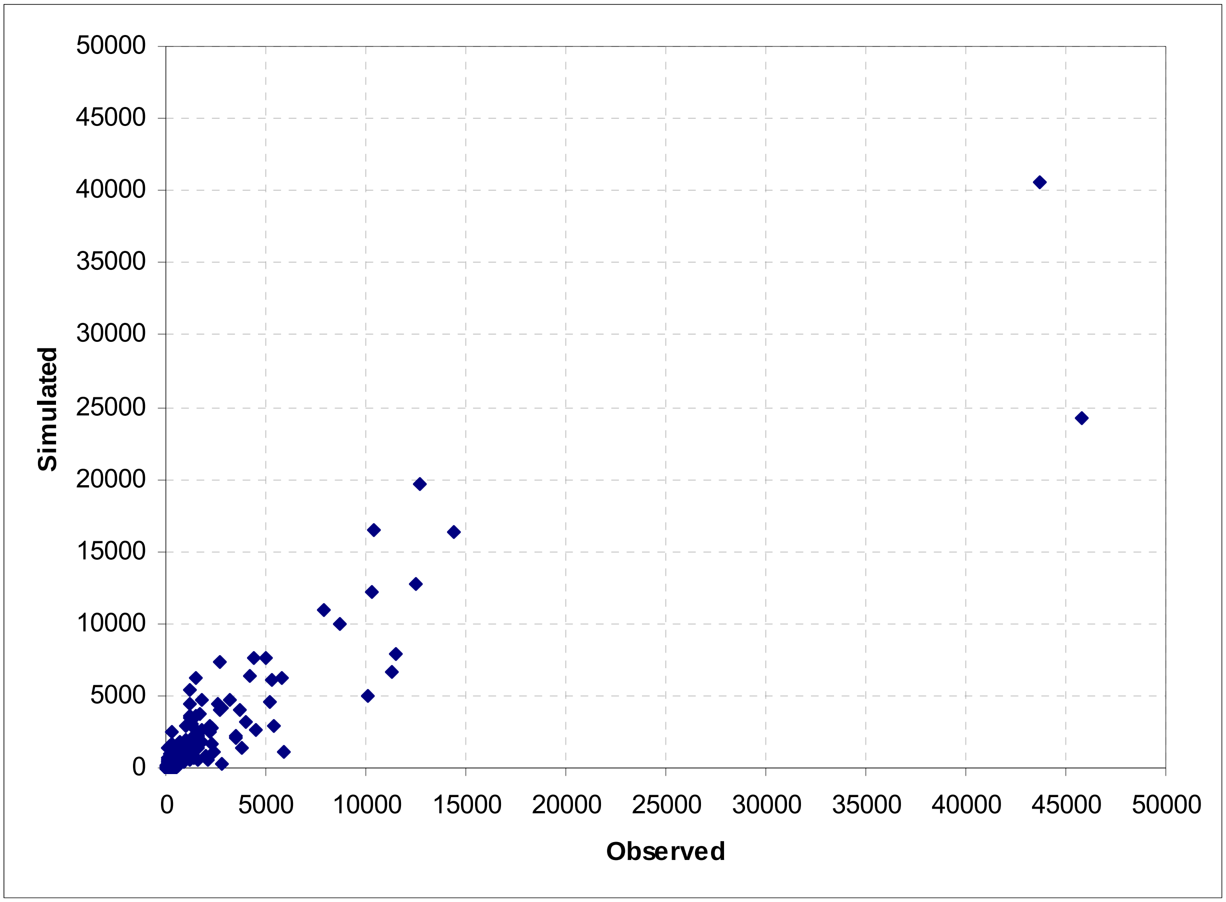

Figure 7-2. Simulated vs. Observed Event Peaks, 1986-1996 (Validation Period)

7.2 Flood Frequency Analysis

The Ventura River HSPF watershed model has been calibrated and validated to continuous flow gage data for October 1986 through September 2007. The ability of the model to estimate flood peaks is one area of particular interest. To evaluate this issue further, the model was run over the period from October 1967 through September 2007, providing 40 water years for analysis. Long records of observed peaks are available for eight gages, and are also limited to the water year 1968-2007 period to provide a common basis for comparison.

This longer model run extends back for an additional 19 years prior to the calibration and validation periods. While some of the model inputs are not as well known for this earlier period, their effect on extreme events is expected to be small. Land use for the earlier period was approximated as described in Section 3.1, and approximates 1978 conditions. The reach portions of the model were implemented in the following increments for the earlier period:

10/1/1967 – 9/18/1979, using the 1978 baseline land use

9/19/1979 – 9/30/1981, using the 1978 baseline land use modified for the 1979 Creek Road fire

10/1/1981 – 6/30/1985, using the 1978 baseline land use

7/1/1985 – 9/30/1986, using the 1990 baseline land use modified for the 1985 Wheeler fire

The USGS PeakFQ program provides flood-frequency analyses according to Bulletin 17-B methodology (USGS, 1982). This analysis was applied to both observed and simulated annual peak series. The results presented in this memo focus on the flow peak comparison for the 100-year flood event (Q100), which is the design flow of interest for the intended floodplain applications in the Ventura watershed.

It should be noted that it is not the purpose of the Model Calibration report to produce final estimates of peak flows, but rather to document and assure the proper performance of the model. The Bulletin 17-B methodology estimates flood peaks using a Log Pearson III curve fit. Bullard (2002) noted that low outliers are present in the Ventura River peak flow records. When the Bulletin 17-B procedure is used to fit all of the data, including the low outliers, the resulting log-mean, log standard-deviation, and log-skew values are such that the fitted Log Pearson III curve may become inflated on the high end of the data set, resulting in over-estimation of the magnitude of extreme flood events. To address this issue, Bullard recommended use of a top end fitting procedure. In this type of analysis the peak flows and plotting positions, or the equivalent return period, are fit with a curve by a least squares analysis procedure. The resulting regression equation is then used to determine the peak flow for the desired return periods. Bullard suggested that fitting the top seven peak events was sufficient for extrapolation.

For assessing model calibration, the Bulletin 17-B procedure is applied to the complete annual peak series over the 1968-2007 model run period, including any low outliers. Results are then compared to determine the consistency between the simulated and observed data. Final estimation of peak flows for floodplain mapping or flood insurance purposes must take into account the potential biases introduced by using Log Pearson III analysis on series with low outliers. If the model is shown to be consistent with observed event peak series it may be appropriate to apply top end fitting to the top seven peak events predicted by the model to estimate long return period peak flows for ungaged reaches in the watershed.

Event peak simulations are considered to be excellent if the Q100 peaks calculated from the model are within 10 percent of those calculated from observed data, and are considered to be acceptable if the Q100 from the model peaks falls within the 95 percent confidence bounds of the Q100 peak predicted from observed data using the Bulletin 17-B approach.

Table 7-3 summarizes the results of the analysis, including percent difference between Q100 from observed and simulated peaks and an analysis of the quality of results. Detailed figures for each station follow.

Table 7-3. 100-Year Flood Peak Flow Comparison (WY 1968-2007; Bulletin 17-B Procedure)

Station Name	Gage ID	Number of Observed Peaks	Q100 from Observed Peaks	Station Skew for Observed Data	Q100 from Simulated Peaks	Assumed Regional Skew	HSPF Station Skew	Percent Difference in Q100	Analysis
Coyote Cr near Oak View	600/ 600A	30	17,480 (9,106 - 45,070)	-0.055	19,090 (10,220 - 44,720)	-0.25	-0.608	**9.2%**	**Excellent**
North Fork Matilija Cr	604	40	19,130 (9,964 - 46,640)	-0.412	43,760 (19,900 – 128,900)	-0.25	-0.265	**128.8%**	**Out of Tolerance**
San Antonio Creek at Highway 33	605	40	43,570 (23,900 - 99,840)	0.073	43,190 (24,090 - 95,900)	-0.25	-0.460	**-0.9%**	**Excellent**
Santa Ana Cr near Oak View	606	24	19,640 (9,374 - 60,980)	0.218	39,330 (16,980 - 123,600)	-0.25	-0.546	**100.3%**	**Acceptable**
Ventura River near Ventura (at Foster Park)	608	39	183,300 (87,030 - 512,000)	-0.210	128,700 (67,220 - 314,000)	-0.25	-0.193	**-29.8%**	**Acceptable**
Canada Larga at Ventura Ave	630	32	23,290 (11,920 - 60,620)	-0.704	20,720 (11,230 - 47,440)	-0.25	-0.921	**-11.0%**	**Acceptable**
Fox Canyon Drain	631	39	1,435 (976 - 2,464)	0.677	1,753 (1,154 - 3,134)	-0.25	0.379	**22.2%**	**Acceptable**
Happy Valley Drain	633	33	1,445 (1,011 - 2,401)	-0.209	2,879 (1,754 – 5,682)	-0.25	-0.260	**99.2%**	**Out of Tolerance**

Notes: 95% confidence limits shown in parentheses.

Disclaimer: The estimates provided in this table are generated from application to a limited data set for the purposes of comparing observed and modeled flood peaks during the model simulation period. Therefore, these numbers are not official design or FEMA Flood Insurance Study estimates.

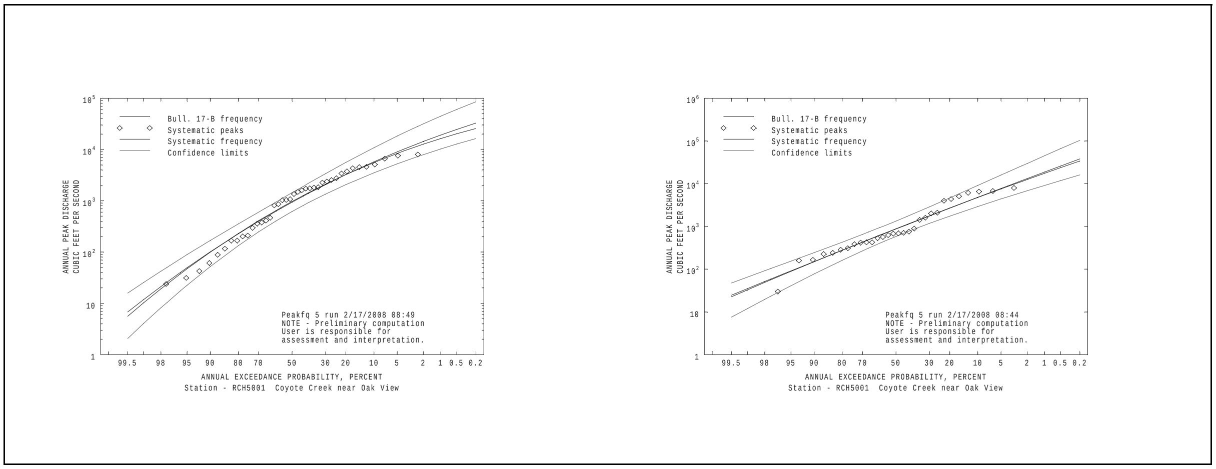

Figure 7-3. Coyote Creek PeakFQ Output, HSPF and Observed

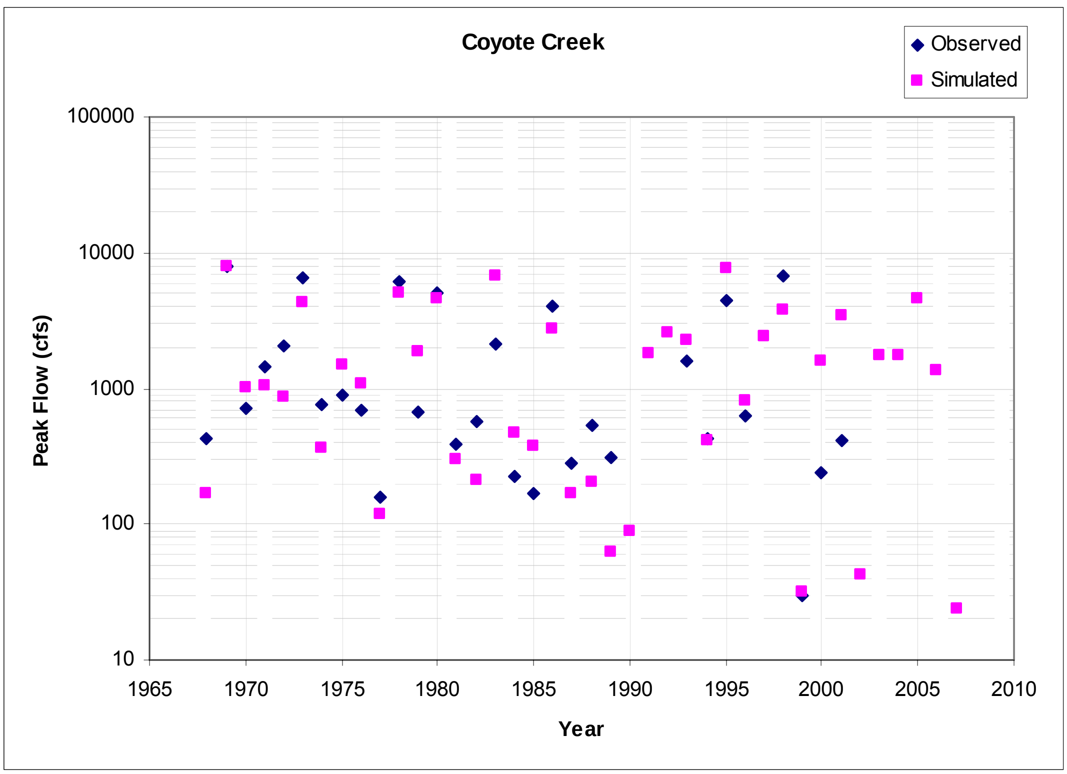

Figure 7-4. Peak Flow versus Year at Coyote Creek

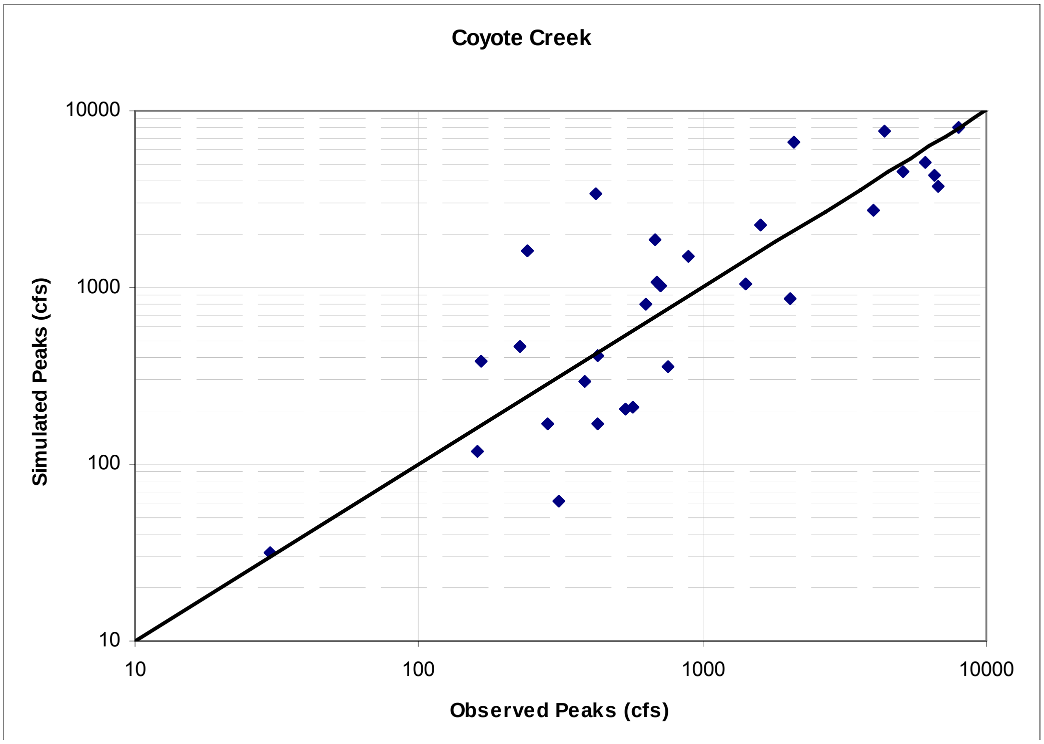

Figure 7-5. Simulated versus Observed Peak Flows at Coyote Creek

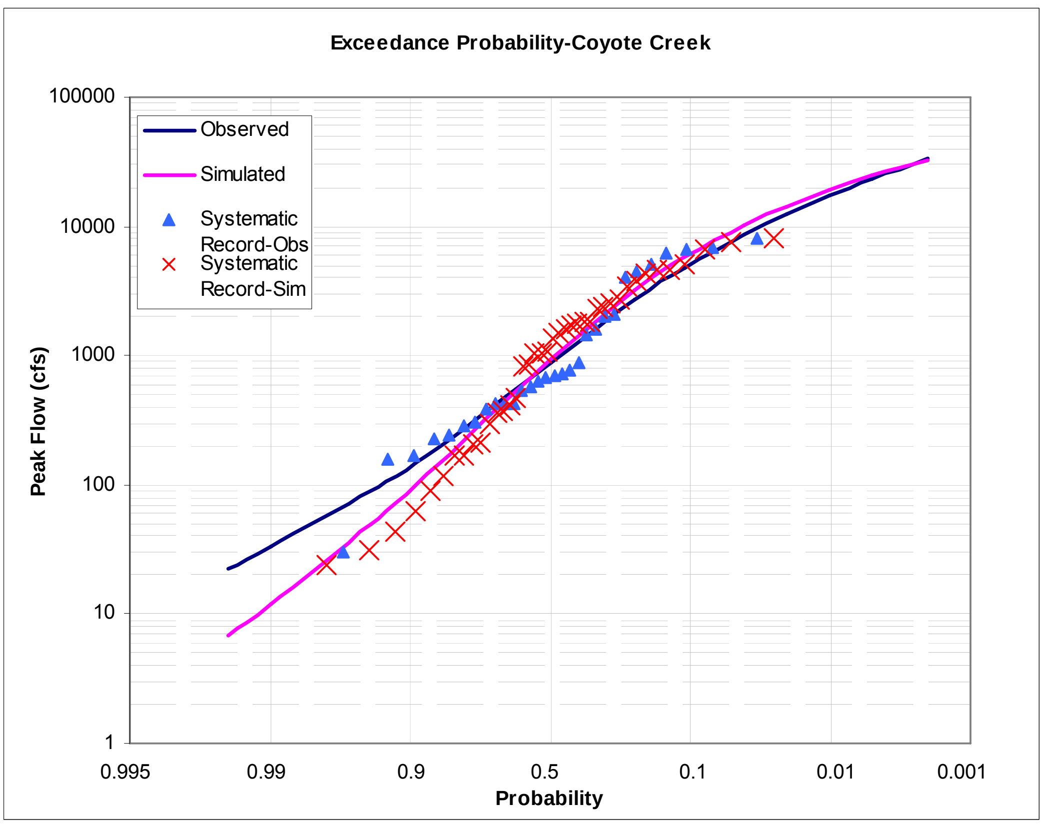

Figure 7-6. Exceedance Probability at Coyote Creek

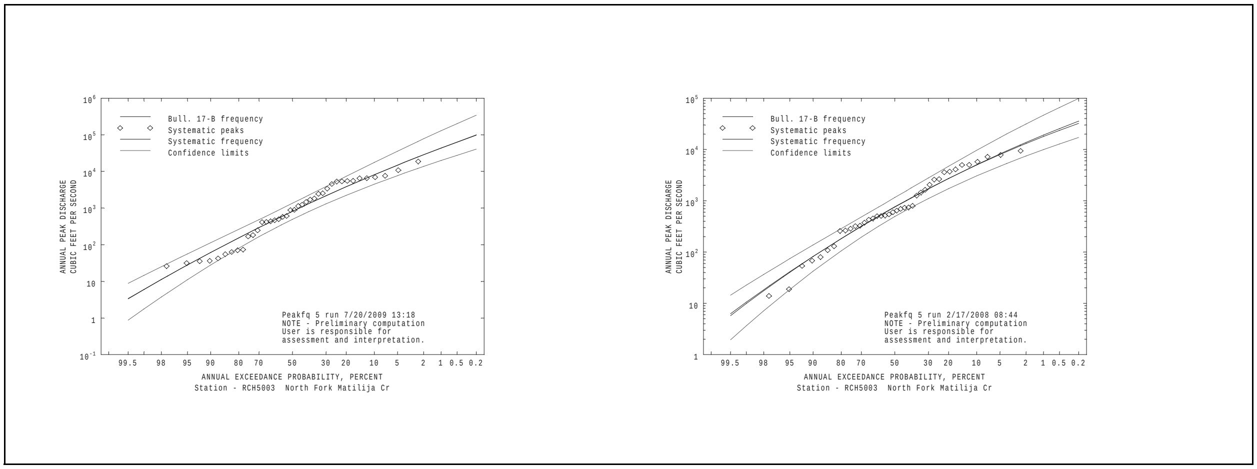

Figure 7-7. North Fork Matilija PeakFQ Output, HSPF and Observed

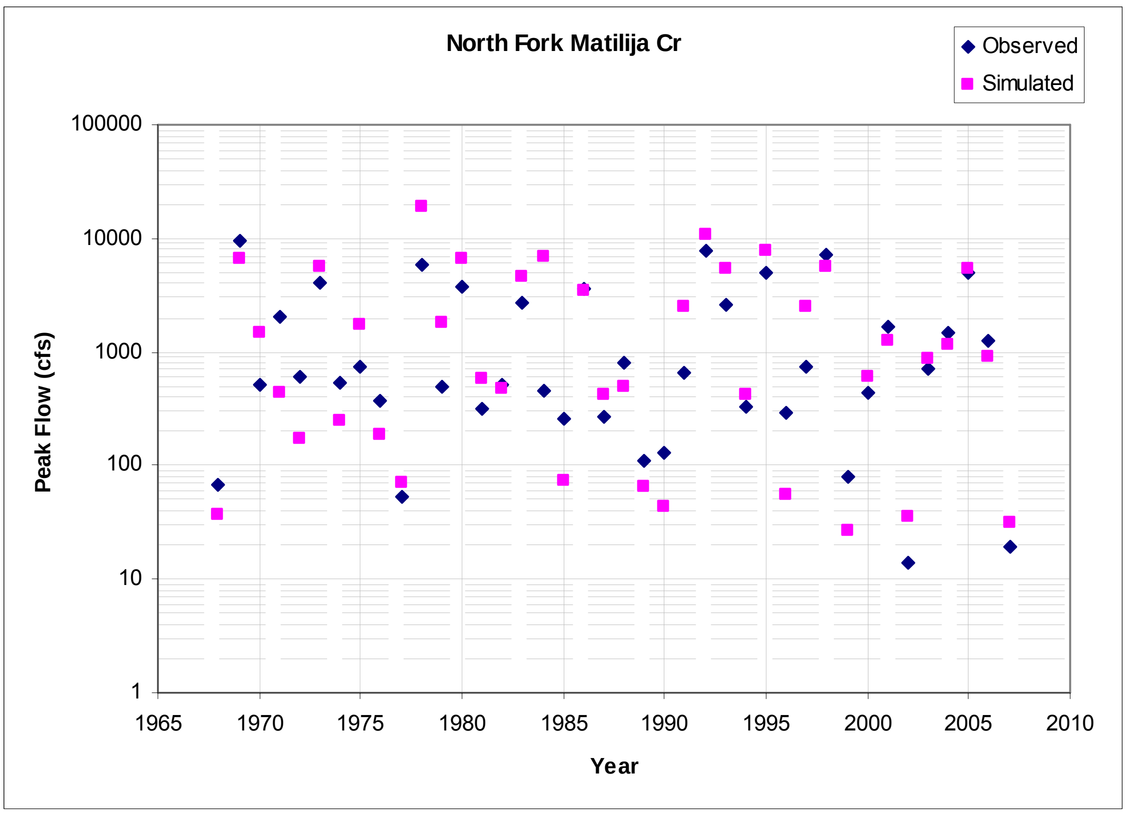

Figure 7-8. Peak Flow versus Year at North Fork Matilija Creek

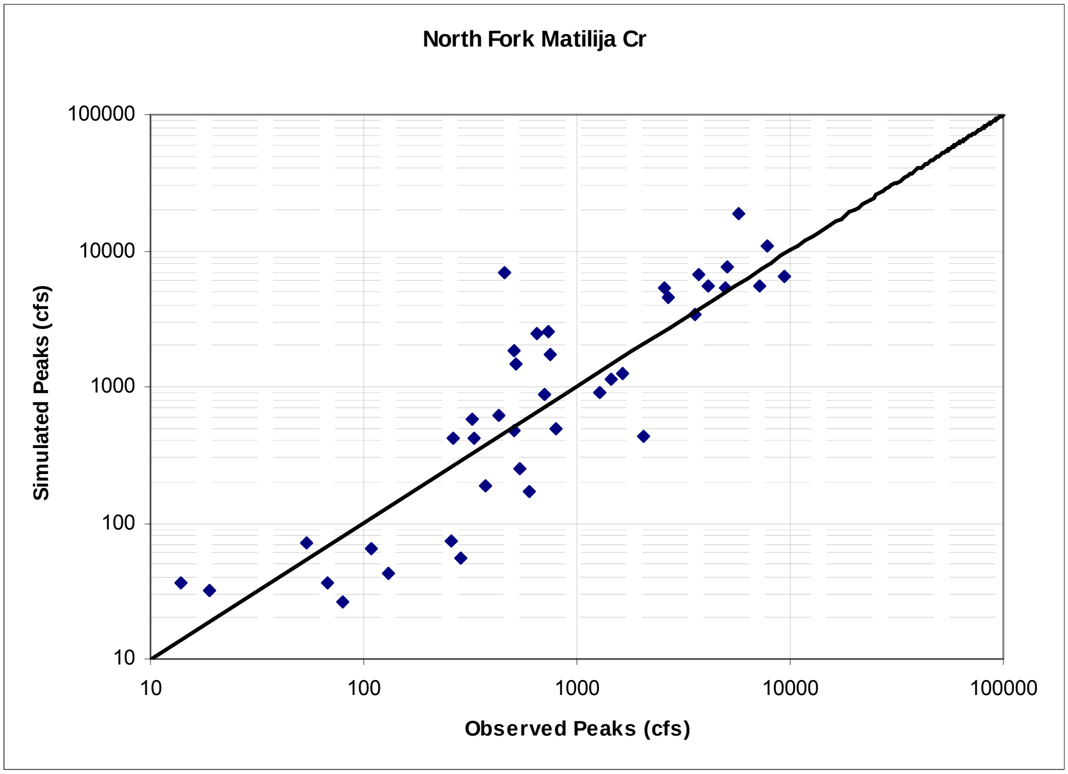

Figure 7-9. Simulated versus Observed Peak Flows at North Fork Matilija Creek

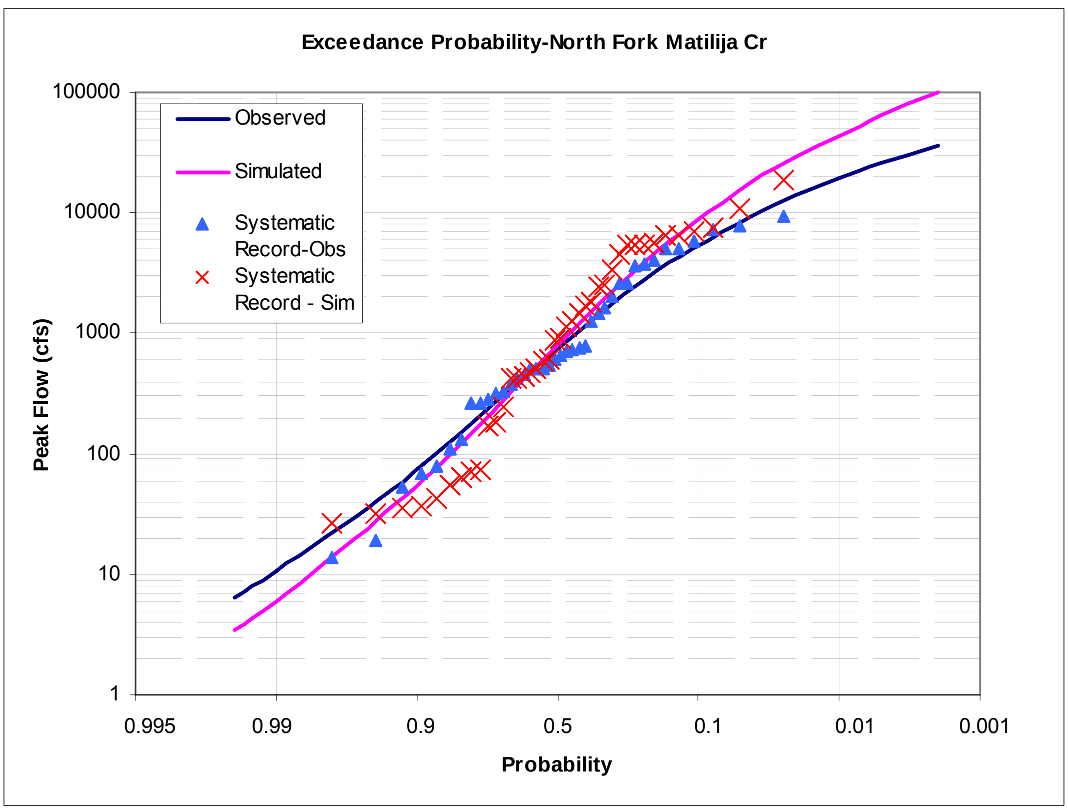

Figure 7-10. Exceedance Probability at North Fork Matilija Creek

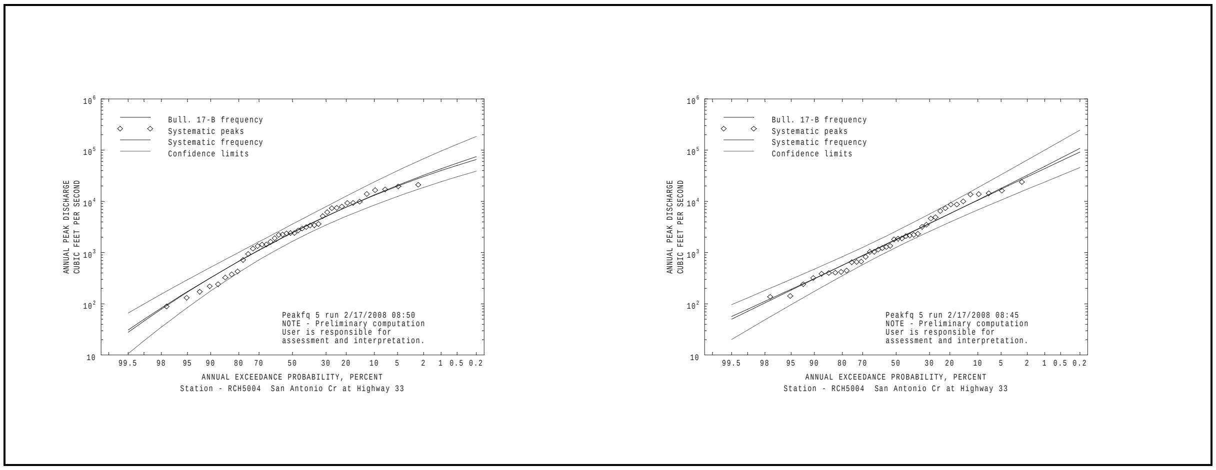

Figure 7-11. San Antonio Creek PeakFQ Output, HSPF and Observed

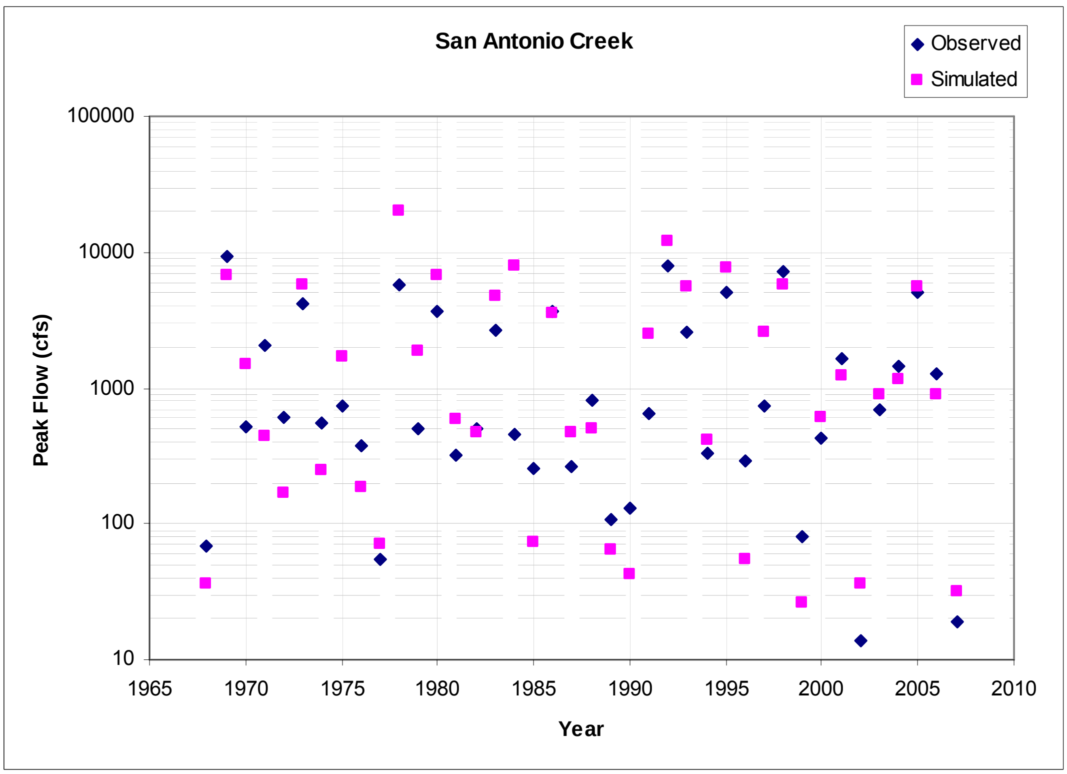

Figure 7-12. Peak Flow versus Year at San Antonio Creek

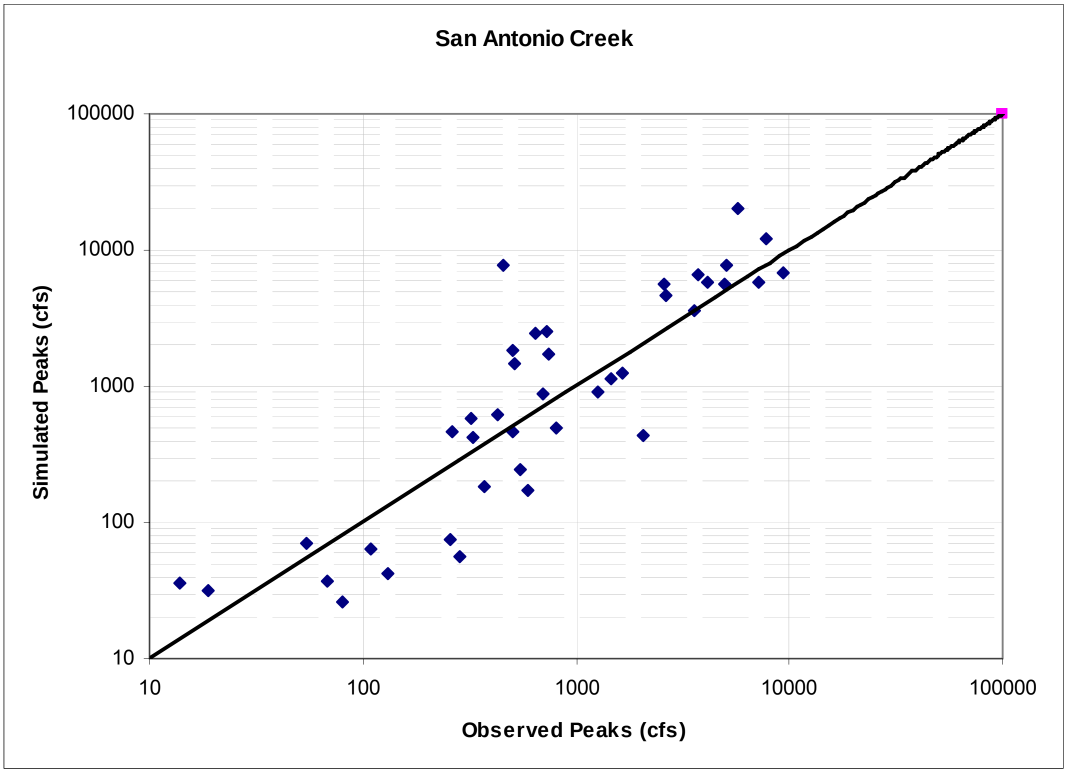

Figure 7-13. Simulated versus Observed Peak Flows at San Antonio Creek

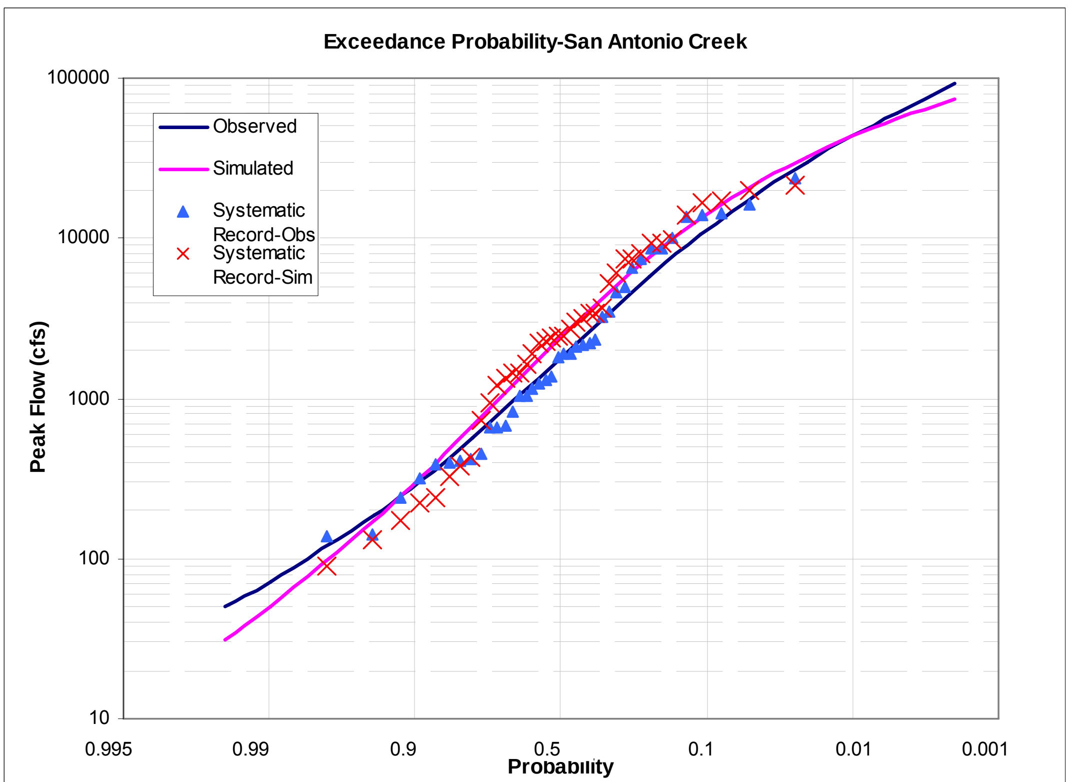

Figure 7-14. Exceedance Probability at San Antonio Creek

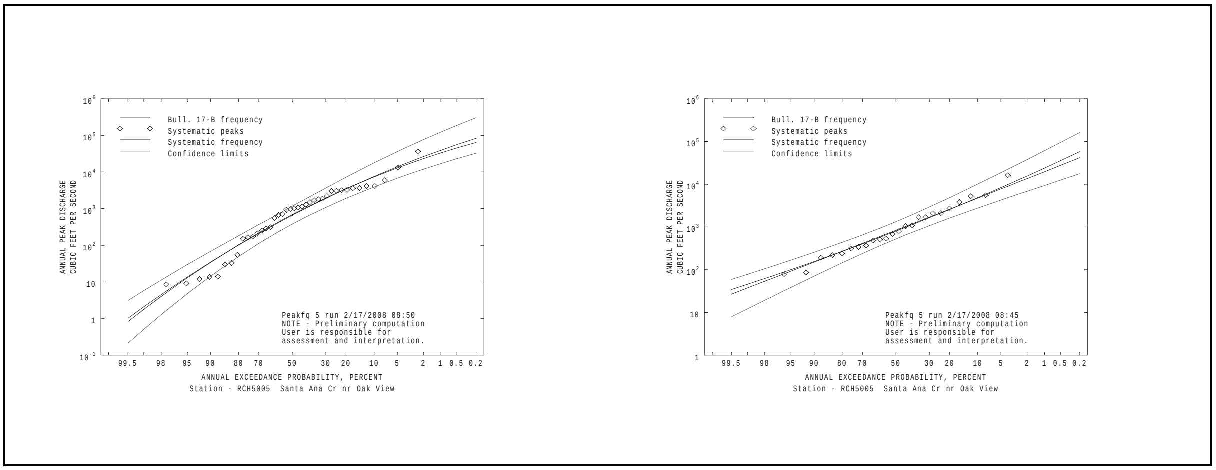

Figure 7-15. Santa Ana Creek PeakFQ Output, HSPF and Observed

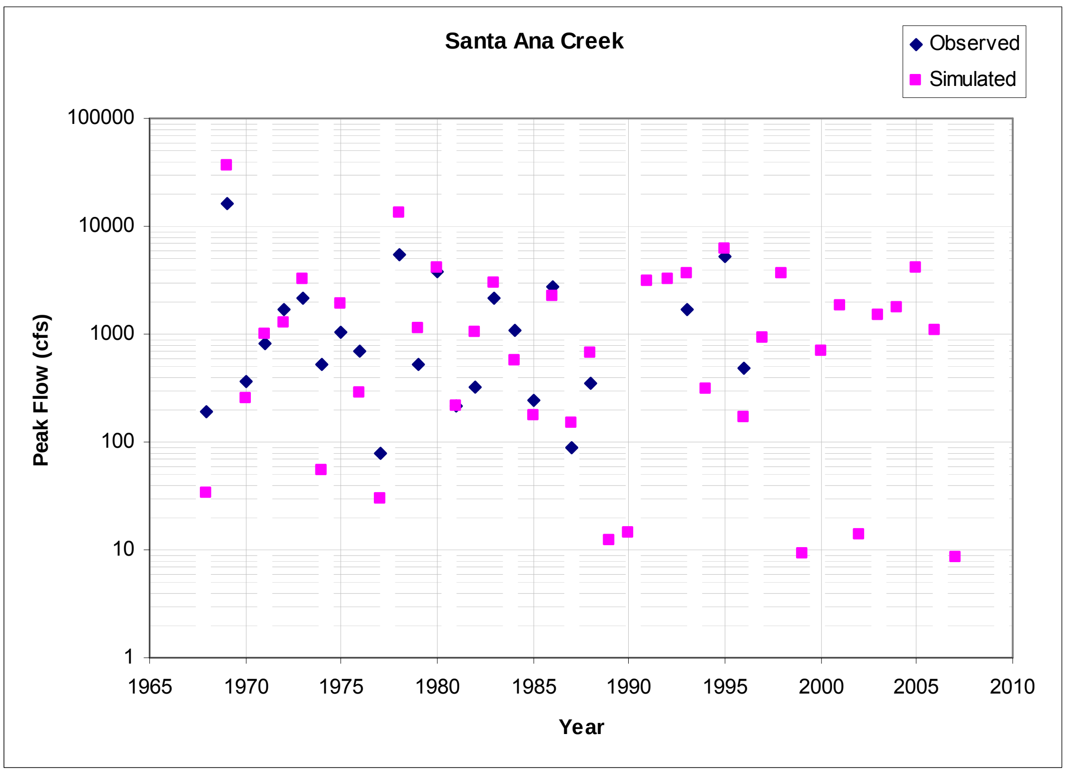

Figure 7-16. Peak Flow versus Year at Santa Ana Creek

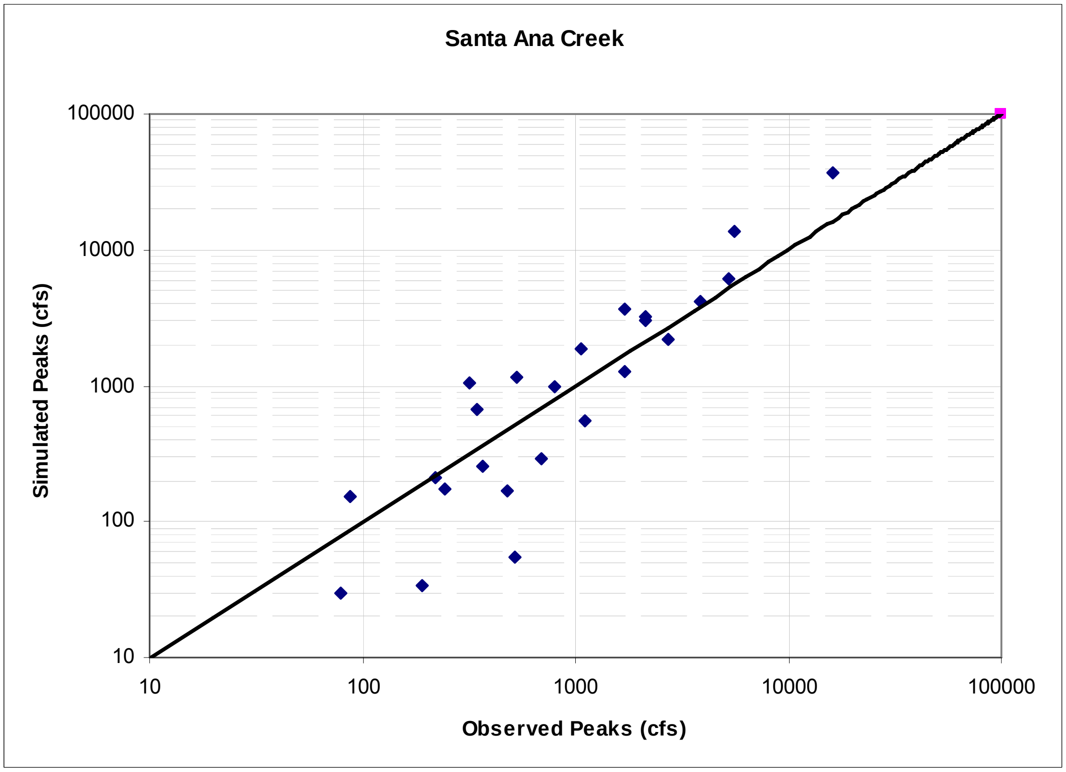

Figure 7-17. Simulated versus Observed Peak Flows at Santa Ana Creek

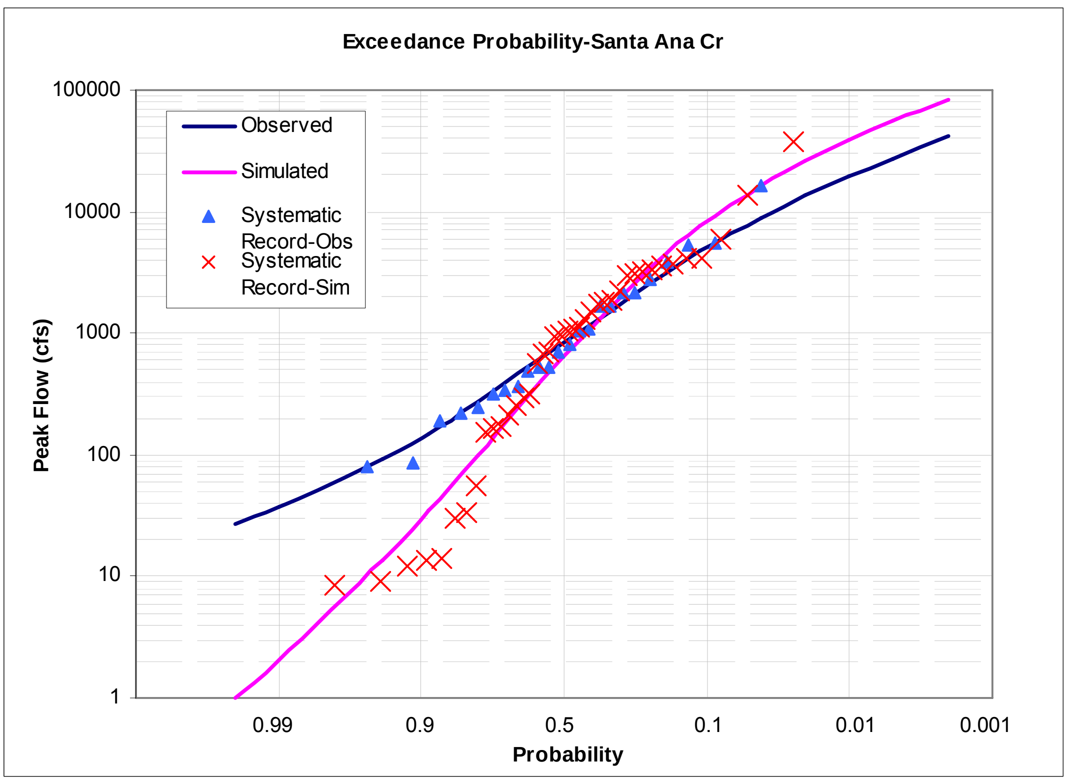

Figure 7-18. Exceedance Probability at Santa Ana Creek

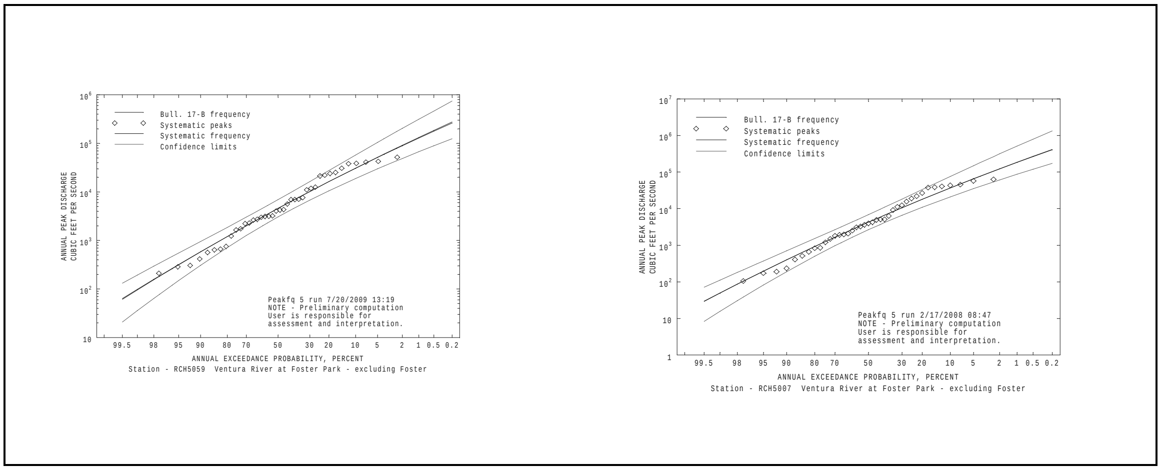

Figure 7-19. Ventura River near Ventura PeakFQ Output, HSPF and Observed

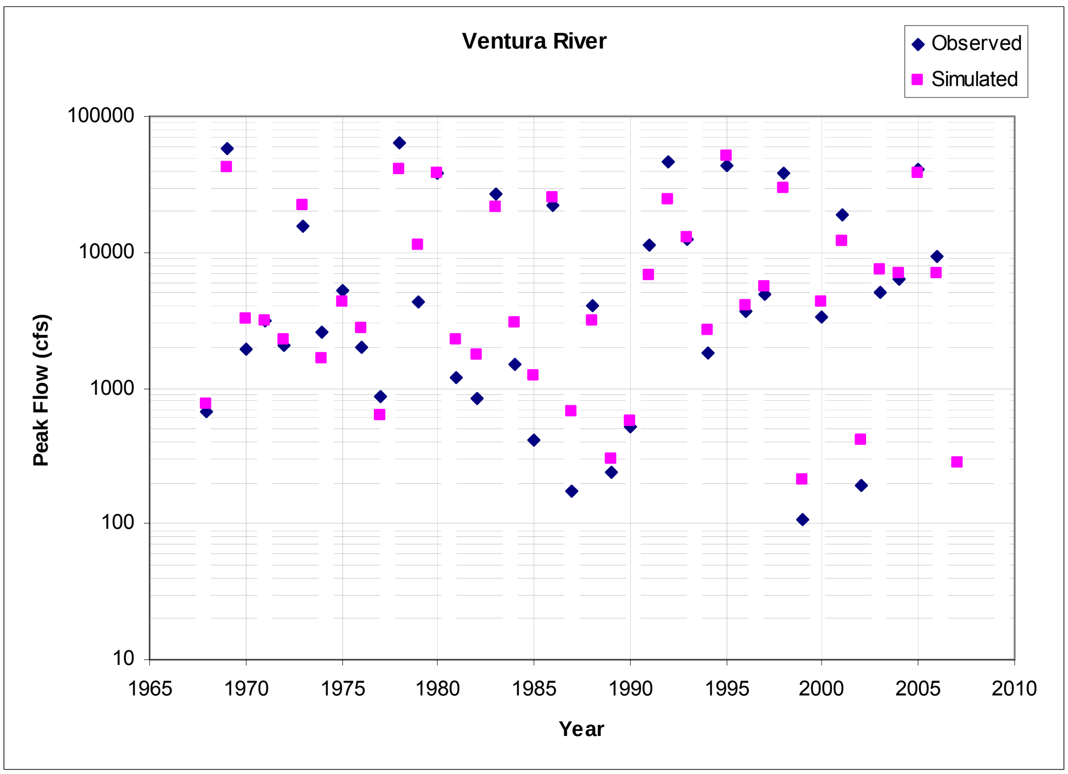

Figure 7-20. Peak Flow versus Year at Ventura River near Ventura

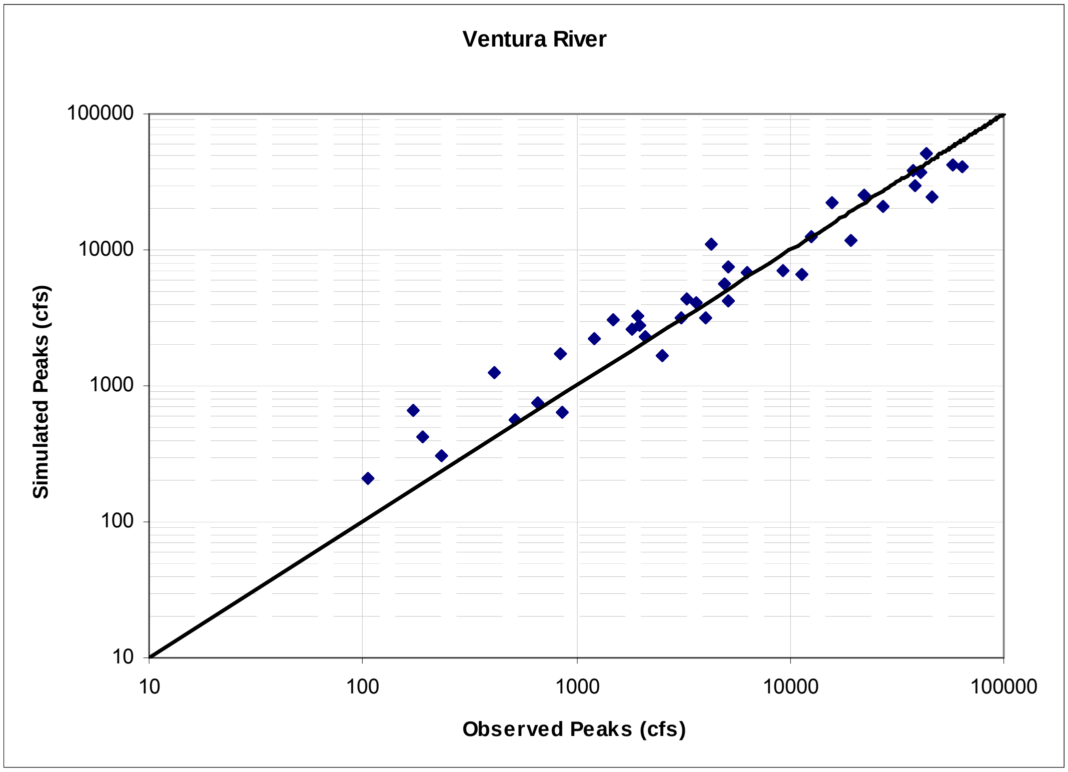

Figure 7-21. Simulated versus Observed Peak Flows at Ventura River near Ventura

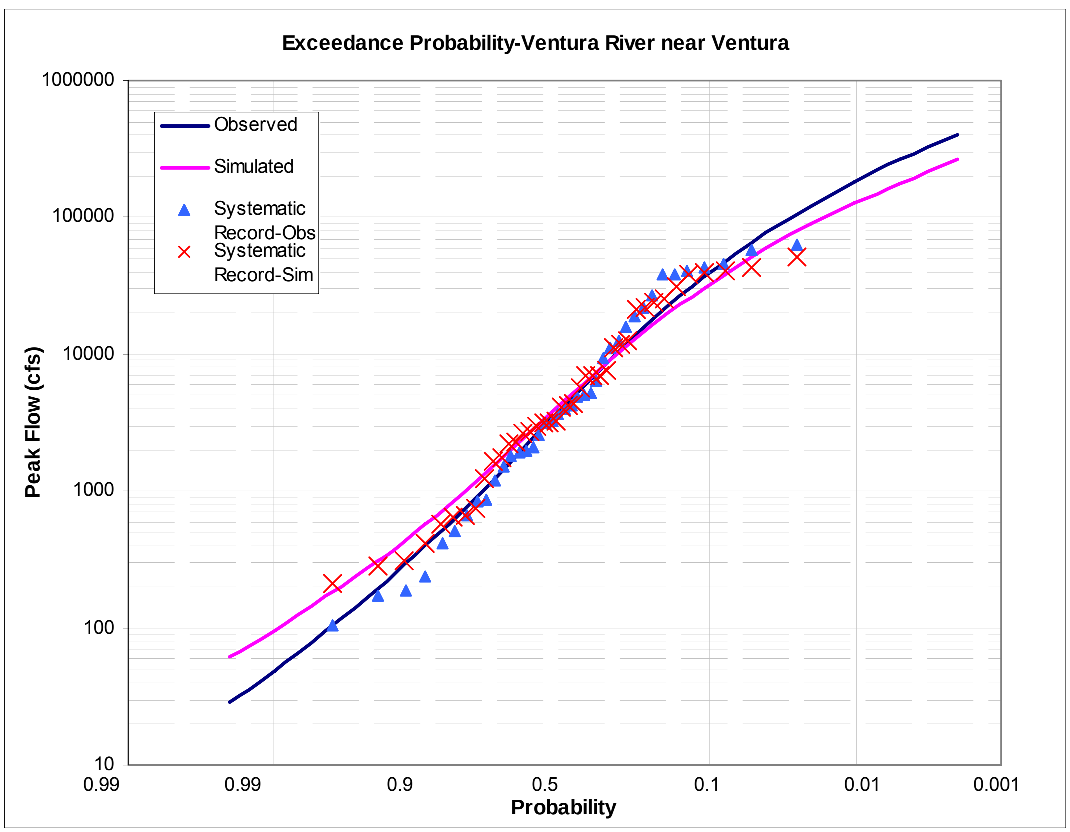

Figure 7-22. Exceedance Probability at Ventura River near Ventura

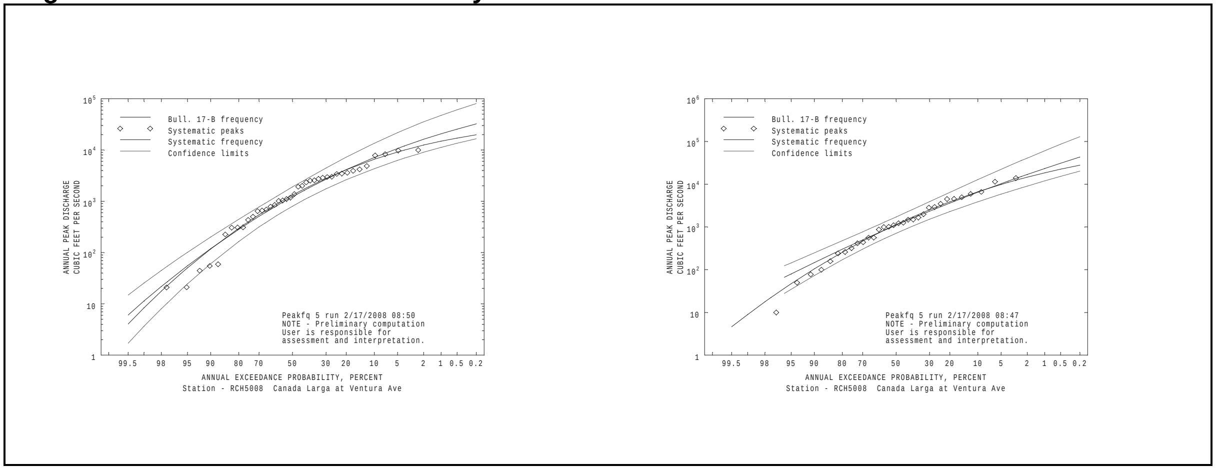

Figure 7-23. Canada Larga PeakFQ Output, HSPF and Observed

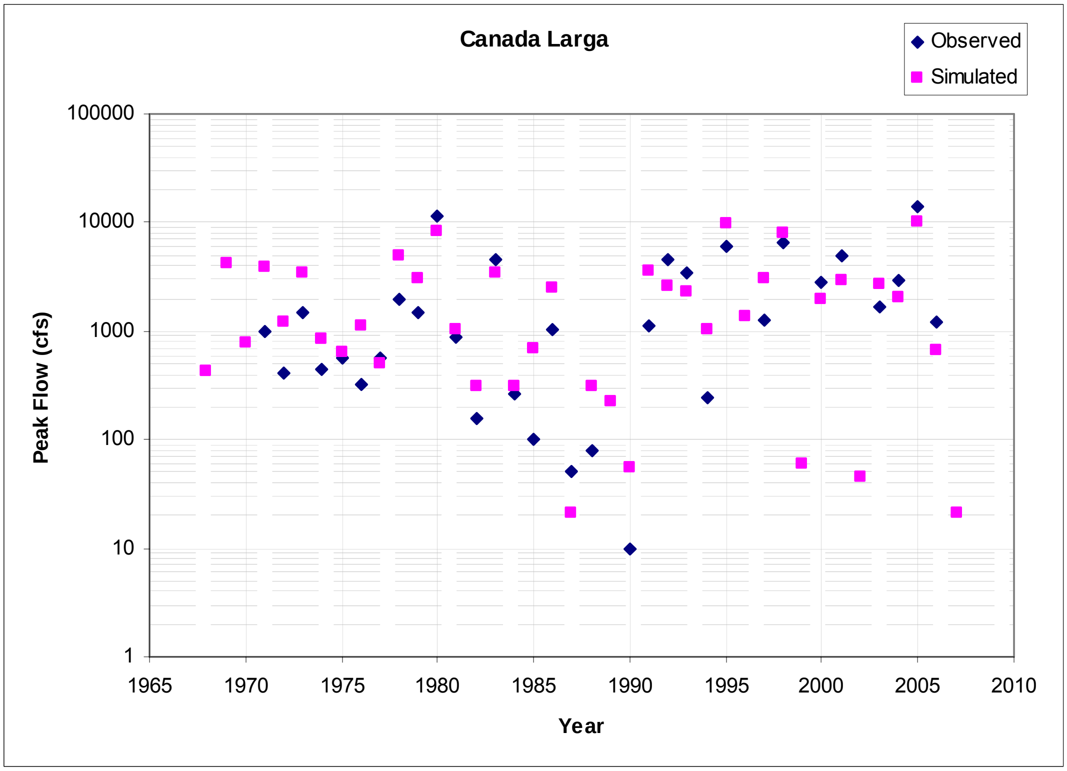

Figure 7-24. Peak Flow versus Year at Canada Larga

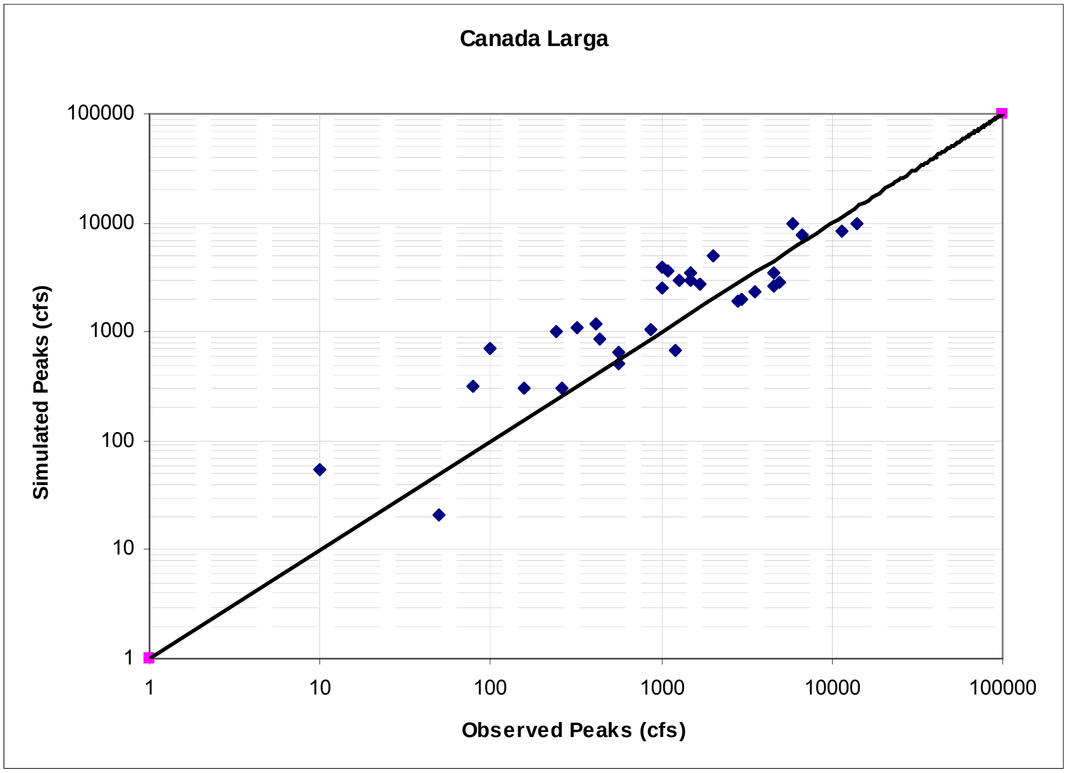

Figure 7-25. Simulated versus Observed Peak Flows at Canada Larga

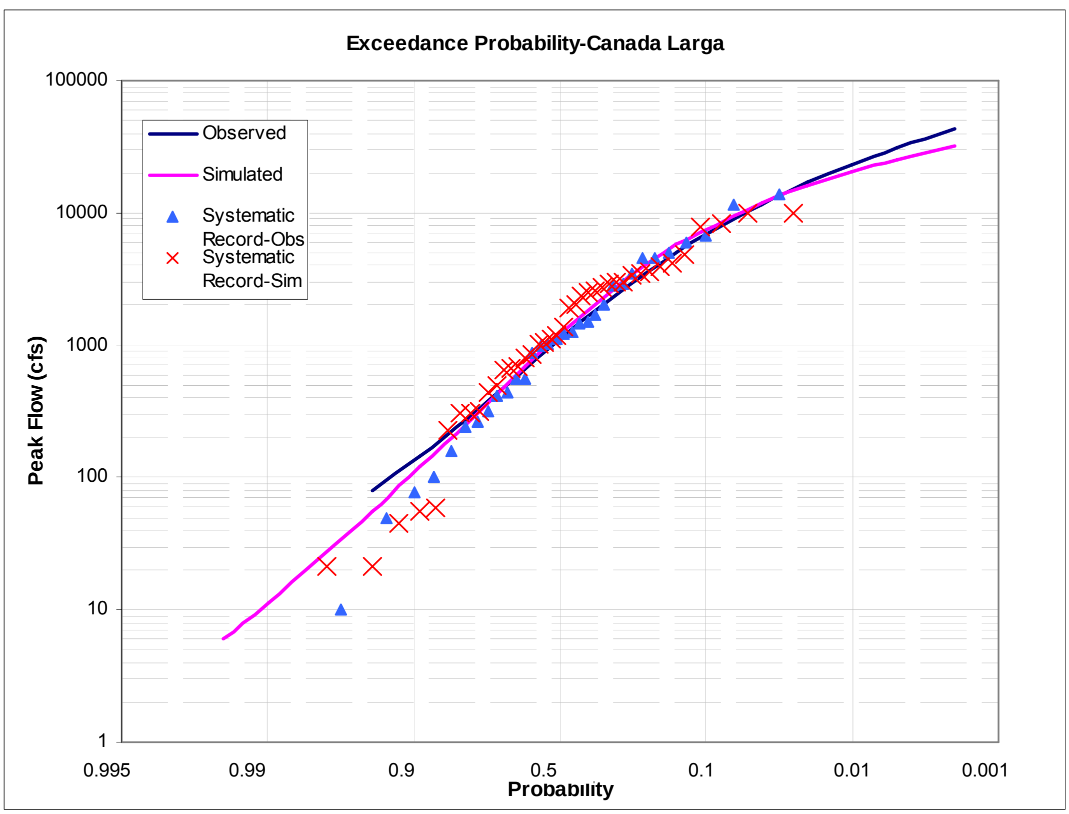

Figure 7-26. Exceedance Probability at Canada Larga

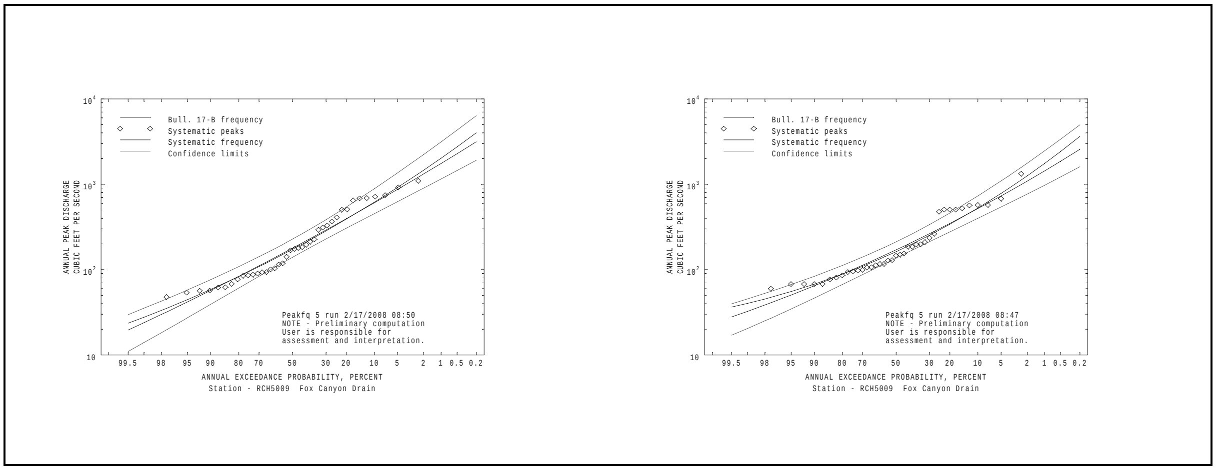

Figure 7-27. Fox Canyon Drain PeakFQ Output, HSPF and Observed

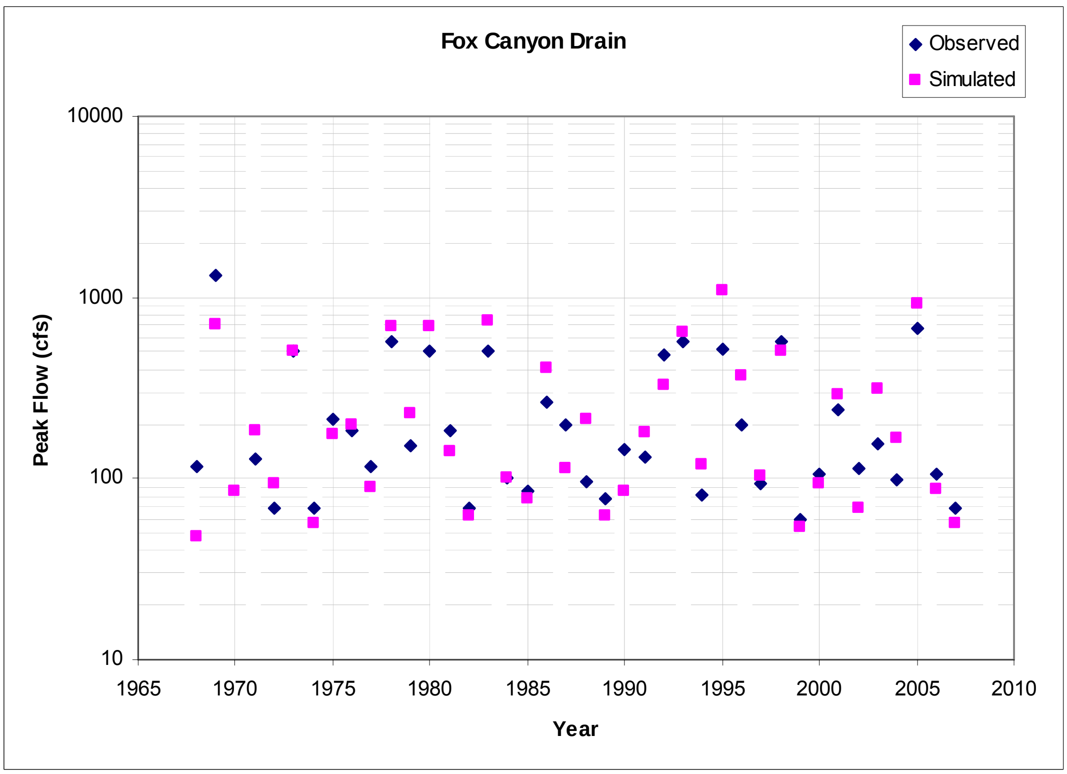

Figure 7-28. Peak Flow versus Year at Fox Canyon Drain

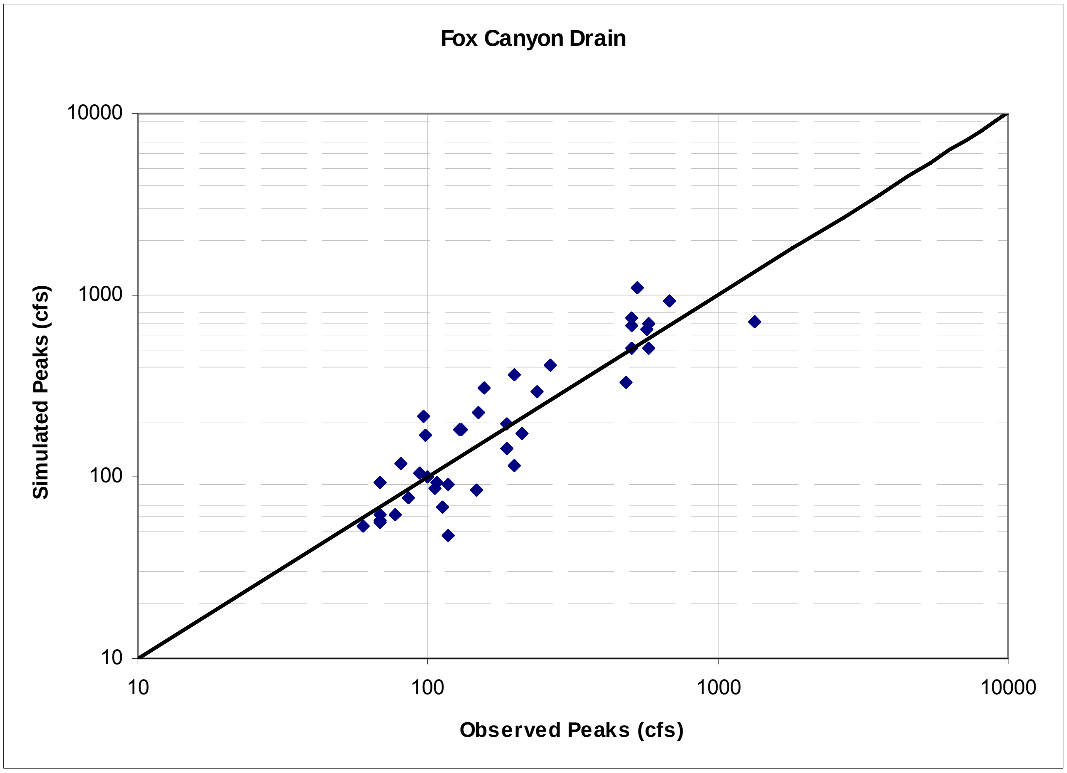

Figure 7-29. Simulated versus Observed Peak Flows at Fox Canyon Drain

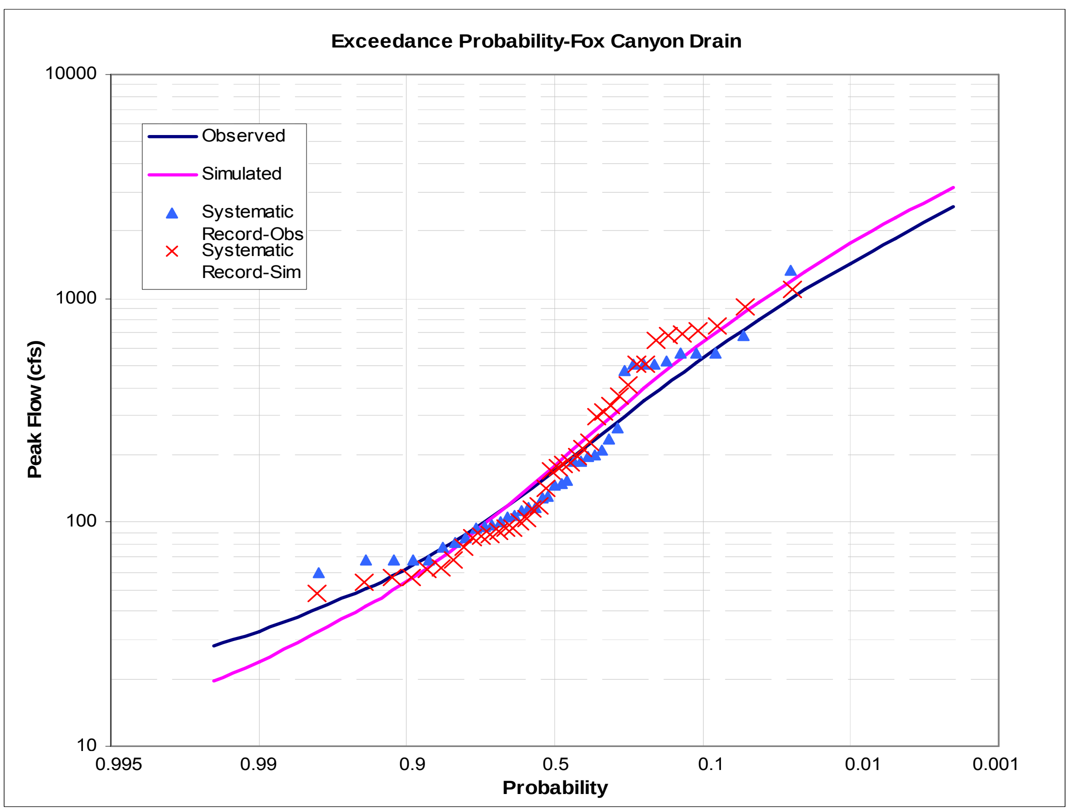

Figure 7-30. Exceedance Probability at Fox Canyon Drain

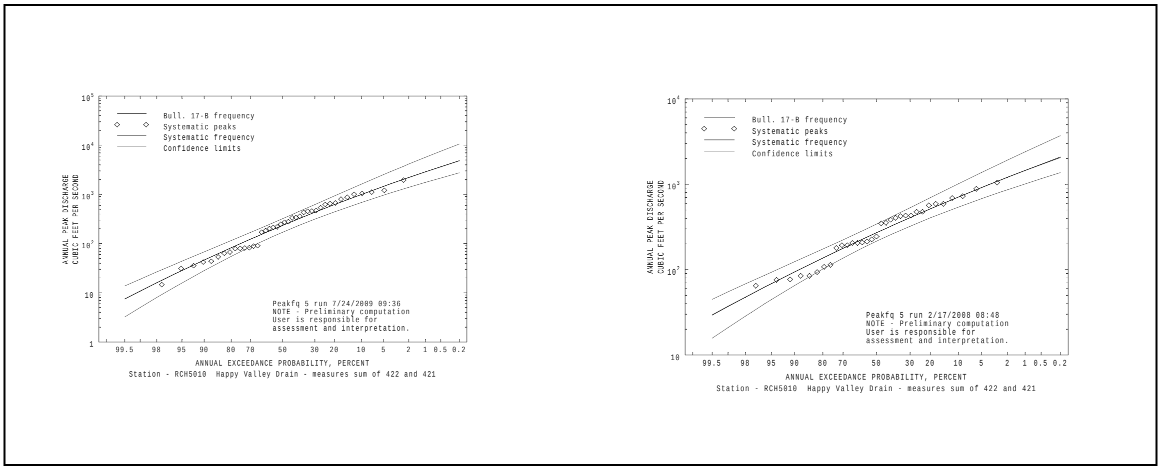

Figure 7-31. Happy Valley Drain PeakFQ Output, HSPF and Observed

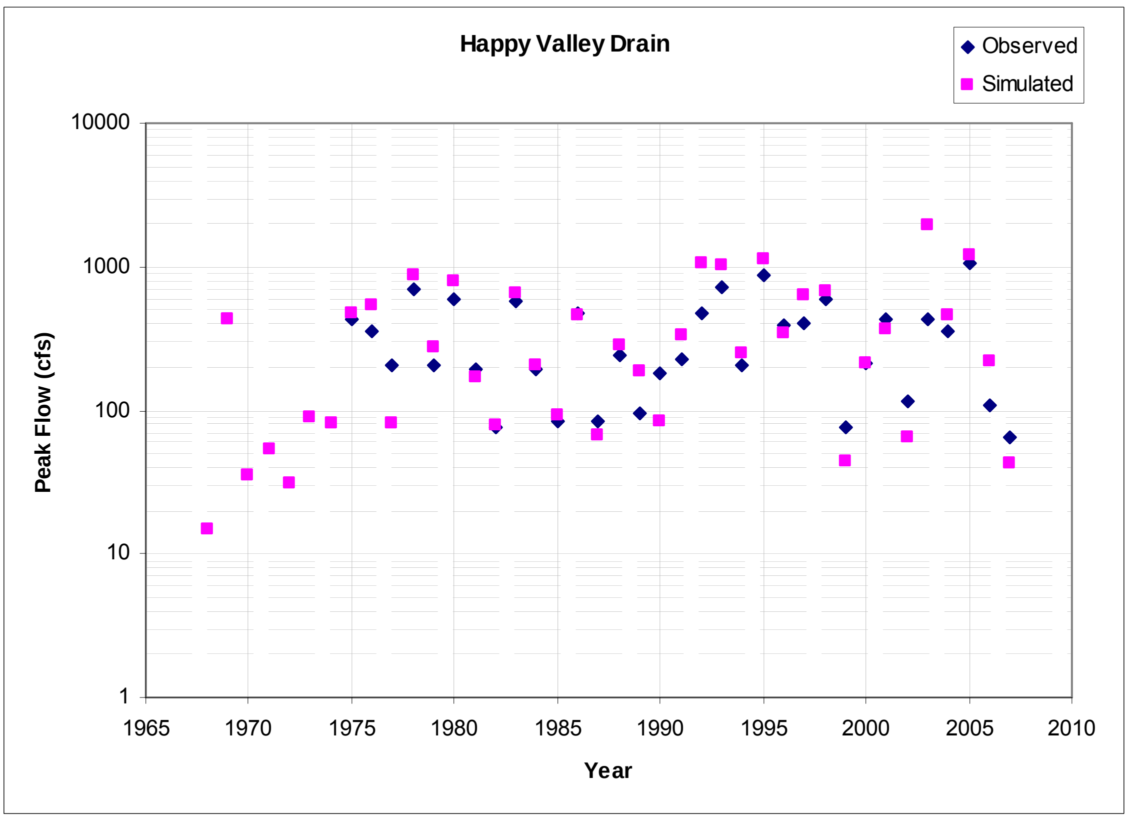

Figure 7-32. Peak Flow versus Year at Happy Valley Drain

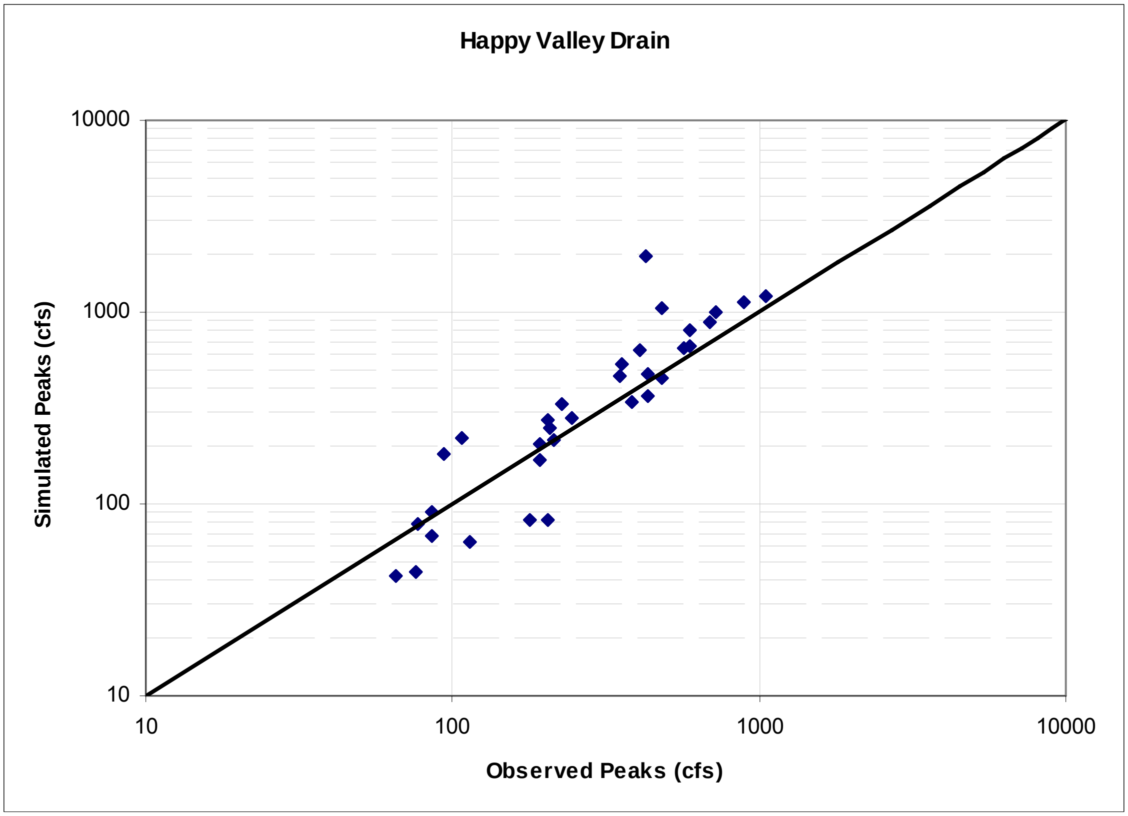

Figure 7-33. Simulated versus Observed Peak Flows at Happy Valley Drain

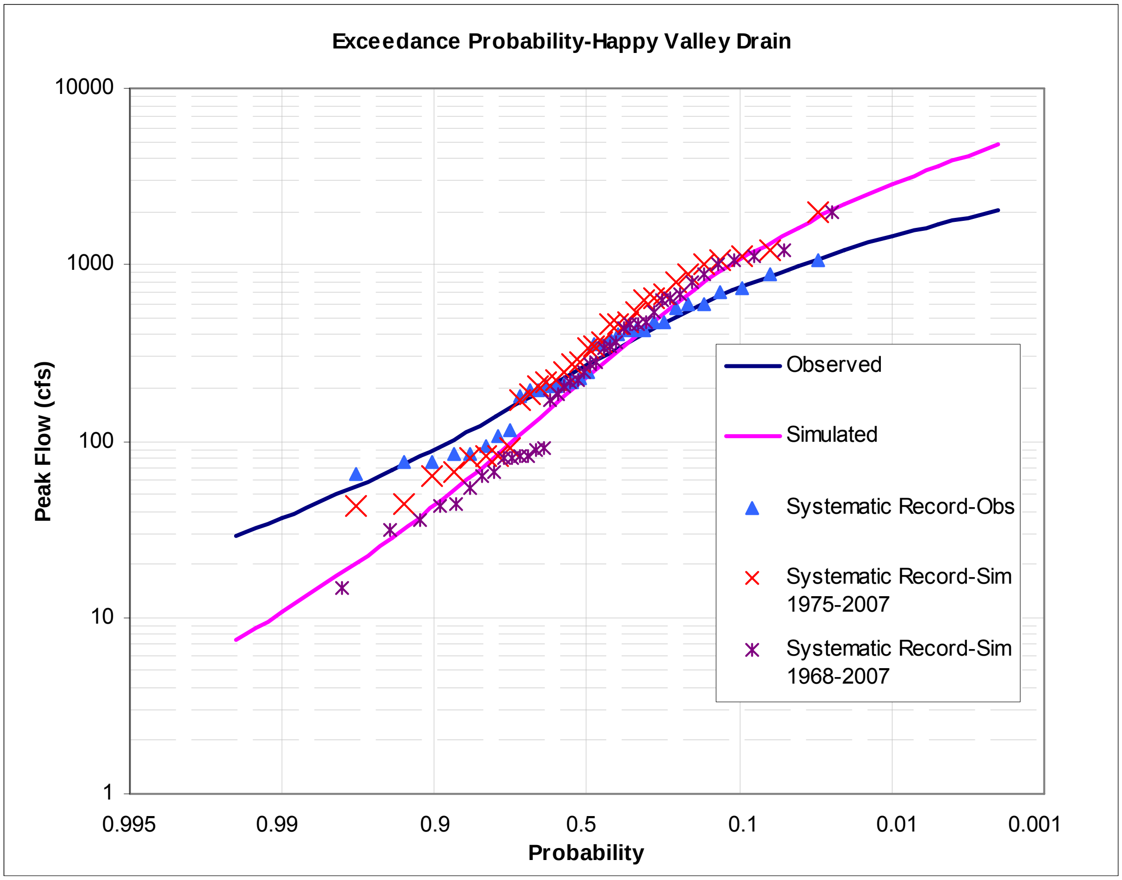

Figure 7-34. Exceedance Probability at Happy Valley Drain

7.3 Discussion of Flood Frequency Analysis Results

The Q100 fit is excellent at two of the eight gages, and acceptable at four additional gages. Results for Santa Ana Creek are assessed as acceptable despite the fact that the simulated Q100 is twice the observed Q100 due to the large confidence limits on the Q100 from observed peaks associated with the relatively small sample size. It should be noted that the reporting of observed peaks at this station largely ceased after 1988 (with the exception of 1993, 1995, and 1996). No peaks are reported for the dry years of 1990, 1999, 2002, and 2007. Inspection of the figures shows that the difference in Q100 predictions is largely due to differences in the smaller, high probability peaks, which, as they are lower, in the simulated data series, serve to steepen the regression line. This phenomenon is likely due in part to the omission of dry weather peaks from the gage record. However, results from 1968 and 1974 suggest that the deviation between model and gage during dry years may be real. This likely suggests a need to reduce the value of LZSN in the Santa Ana submodel.

The Q100 results do not meet tolerance criteria at two of the eight gages (604 and 633). For North Fork Matilija (gage 604), most peaks are fit relatively well; however, the model deviates above observations for the largest peaks, resulting in a different slope to the regression line and a higher prediction of Q100. As discussed in Section 6.3, the FTable for this reach (derived from the regional regression) may overestimate the flood flow capacity of the channel. However, a series of sensitivity analyses undertaken to investigate this issue did not result in any significant improvement in the fit for peak storm events. This suggests it is more likely that the precipitation record applied to this area may overestimate total areal precipitation for large events.

Figure 7-35 and Figure 7-36 show detailed 15-minute hydrograph results for two large storm events on North Fork Matilija. For January-February 2005, the model fits well; in contrast, discrepancies are evident for the February 1992 event.

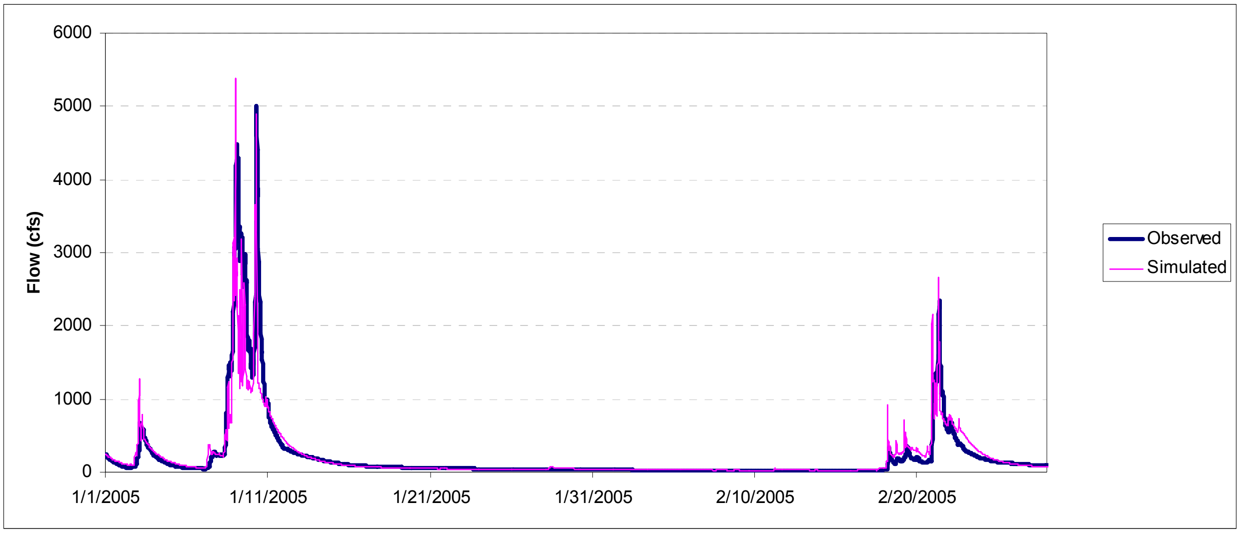

Figure 7-35. Observed and Simulated Hydrograph for North Fork Matilija Creek, January-February 2005

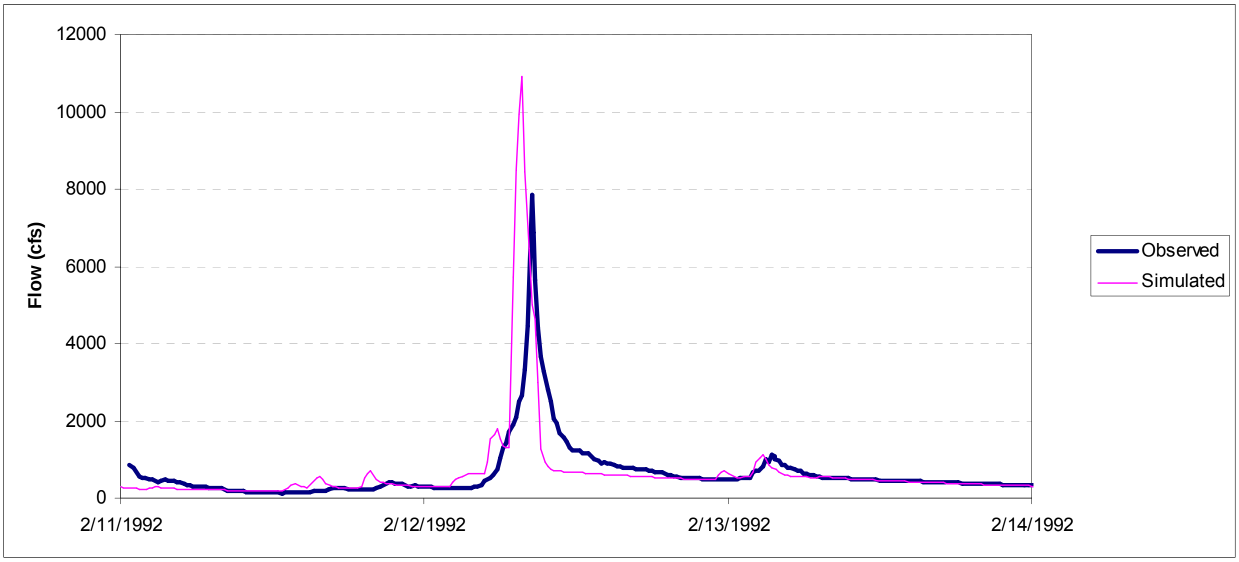

Figure 7-36. Observed and Simulated Hydrograph for North Fork Matilija Creek, February 1992

The lack of fit in February 1992 appears to be related to precipitation gauging. The North Fork of Matilija drains model subbasins 681 and 682. Precipitation gage 264 (Wheeler Gorge) is near the center of this area and is used for the simulation (see Figure 2-1). However, gages 134B and A614 are located only a few miles away, at the boundary of the North Fork subbasin. During the 2/12/1992 event precipitation amounts at gages 134B and A614 were both less than that reported at 264 (Figure 7-37). Thus the amount reported at gage 264 may overestimate the total areal precipitation over the drainage area, leading to an overestimate of the peak flow. In addition, the peak is predicted as occurring at 7:49 a.m., approximately 45 minutes before it was recorded at the gage (8:29 a.m.), but the timing of the simulated peak is consistent with the reported hourly rainfall, which reached a maximum between 7 and

8 a.m. This shift appears to be due to the subhourly timing of the rainfall, as the 15-minute precipitation record for this event shows maximum precipitation occurring between 7:45 and 8:00 a.m.

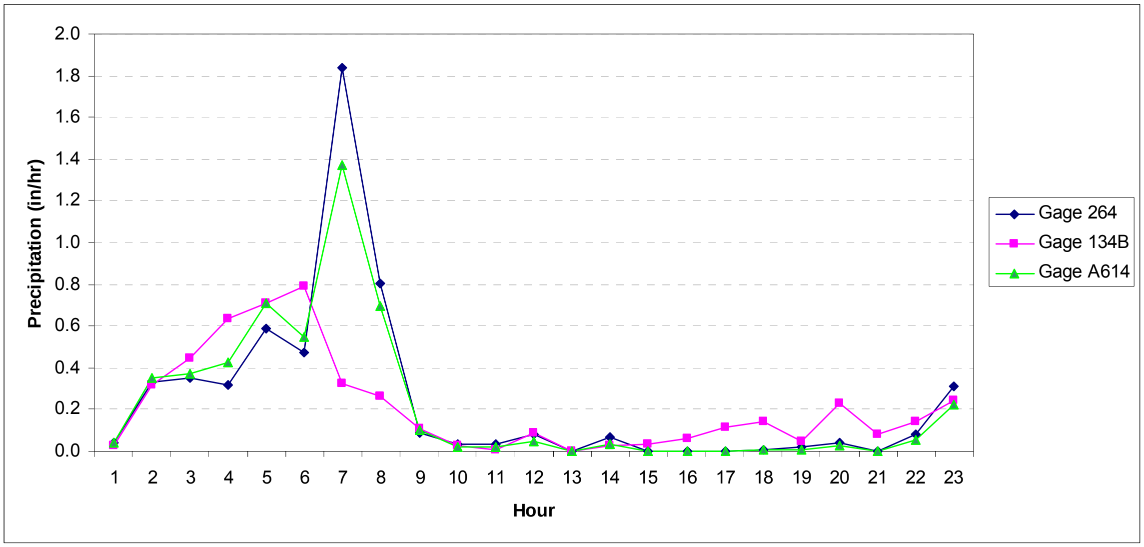

Figure 7-37. Precipitation Patterns for Event of 2/12/1992

Another type of behavior is seen for the very large event of 2/9/1978, with a peak rainfall intensity of 2.66 in/hr at gage 264 (Figure 7-38). A similar peak intensity was recorded at gage 134B, but shifted an hour earlier, while the peak at gage A614 was only about one-third of that at gage 264. Not surprisingly, the model – which uses the gage with the maximum intensity and assumes that this amount of rainfall fell at the same time over the entire watershed of North Fork Matilija – provides an estimated peak of 20,400 cfs that is much greater than the observed peak of 5,780 cfs.

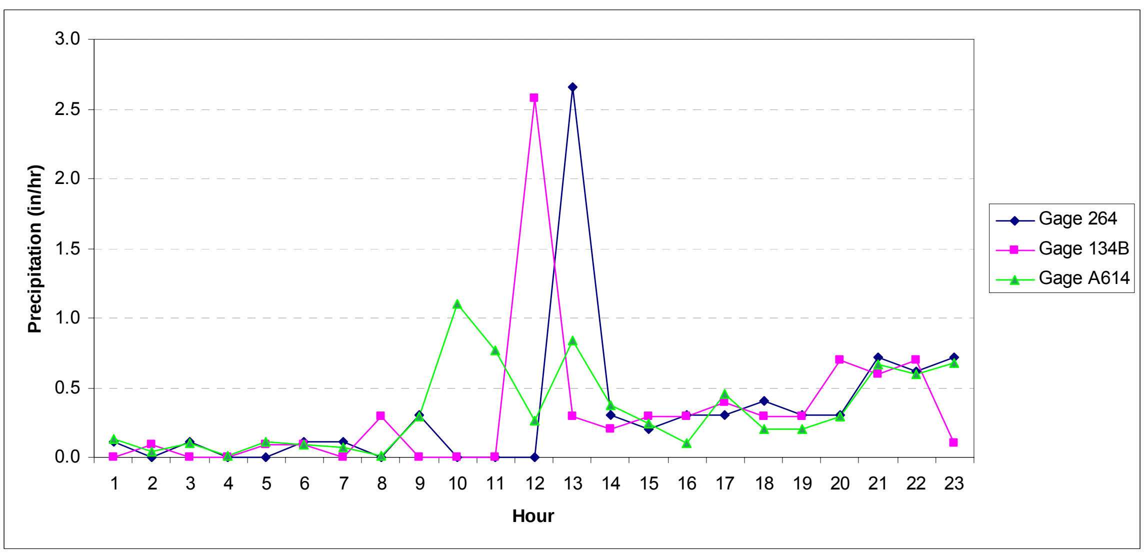

Figure 7-38. Precipitation Patterns for Event of 2/9/1978

Results for Happy Valley Drain (gage 633) are also out of tolerance, primarily due to apparent over-prediction at the high end of the curve. In addition, observed peaks are available only from Water Year 1975 on, and inclusion of the lower peaks from 1968-1974 in the Bulletin 17-B fit drags the lower tail of the distribution down (the systematic record based on simulation results for 1968-2007 and 1975-2007 are both plotted on Figure 7-34). The hydrology in this area is somewhat complicated, with two diversions rerouting water in the 1970s; however, on review, the representation in the model appears to be correct. Detailed efforts to revise the FTable to reflect the reported characteristics of the concrete diversion channel have provided only small improvements. It should be noted that PERLND parameters have not been specifically calibrated for this gage, as it reports peaks only.

In sum, the peak flow analysis is generally acceptable. Problems with predictions in North Fork Matilija might be resolved through obtaining channel cross sections and building a HEC-RAS model to refine FTables. Some additional detailed investigations of contributing area, water retention, and water routing might also be needed to improve model fit for the Happy Valley Drain area.

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8 Conclusions and Recommendations

The performance of a model is judged by a weight of evidence approach, recognizing that some discrepancies are likely to be unavoidable at specific locations and times. The Ventura River Watershed Model performs well across a variety of measures and is judged ready for use, despite certain caveats: During the calibration period, it was evident that there are problems with the flow gage records for Coyote Creek and Santa Ana Creek, neither of which appear to have been measured and calibrated during the last decade. Excluding these gages, 92 percent of the pre-specified performance criteria for the various components of the water balance are met. In addition, the coefficient of determination (R^2) between observed and predicted daily flows are high, ranging from 86.4 to 93.5 percent.

Performance during the validation period is also good, although some degradation in fit is noted (and is expected due to less precise information on high-elevation precipitation, diversions, and withdrawals). On the other hand, discrepancies are not present relative to the Coyote and Santa Ana Creek gage records during most of this period when the gage rating tables originally developed by USGS were likely a closer representation of actual conditions. The R^2 values between observed and predicted daily flows range from 84.4 to 91.4 percent during the validation period.

Model prediction of storm event peaks is also generally good. Some individual events are not well predicted, presumably because the available point rainfall measurements do not accurately reflect the total rainfall across the upstream watershed.

Tetra Tech’s conclusion is that the model is fully usable; however, it will be important to consider the range of uncertainty revealed in the model validation relative to specific uses of the model.

The following areas are provided as suggestions of where the model might be further improved through continuing effort:

- There is uncertainty regarding the model’s ability to accurately predict high flow peaks at the North Fork Matilija and Happy Valley Drain stream gages. Some improvement could likely be attained by refining the channel hydraulic representation through development of HEC-RAS models for these subwatersheds, which would require assembly of additional information on channel dimensions and structures.
- Simulation of event peaks in Happy Valley Drain appears particularly problematic. The hydrology in this area is complex, including a diversion and a concrete channel. A detailed survey and small scale modeling of this area might reveal ways in which the model representation could be improved.
- Model fit to the Santa Ana and Coyote Creek gages is uncertain due to the lack of information on gage accuracy and bias. New rating tables have apparently not been developed for these gages in a number of years, and adjustments are likely needed to reflect changes in channel dimensions. Measurements to develop a current-day rating curve would assist in interpretation of records from earlier in this decade.

The following recommendations are made for improving data collection for future maintenance and refinement of the model:

- As noted above, the quality of gage records for Coyote Creek and Santa Ana Creek is uncertain. These gages are useful for providing a broad basis to evaluate model performance. Tetra Tech suggests that field measurements be made on a regular schedule (at least annually) to provide a basis for calibrating and adjusting the Coyote Creek and Santa Ana Creek rating tables.
- No current gaging exists in the southernmost portion of the watershed, downstream of Foster Park. As a result, this portion of the model cannot be directly calibrated. Tetra Tech suggests

that a mainstem gage should be installed at an appropriate location near the outlet of the Ventura River. In addition, the Canada Larga peak flow gage should be operated to provide continuous flow records.

- The present-day precipitation monitoring network appears to provide generally good coverage of the watershed. However, quality assurance can likely be improved for the high elevation ALERT gages. In addition, there are fundamental difficulties in extrapolating from point rainfall measurements to total areal precipitation, particularly in regions of high relief. There is a potential to improve total rainfall estimates through use of integrative techniques, such as Doppler radar interpretation.
- Evapotranspiration is a major part of the overall water balance, and is, of necessity, estimated from a small number of stations (many of which report only monthly totals) for the calibration and validation periods. The recently activated CIMIS stations within the watershed provide an opportunity to develop better estimates of potential evapotranspiration in the future. Use of these stations would also provide better estimates of irrigation demand.

In addition, there are a number of research-oriented issues that might lead to significant improvements in the model, but could not be addressed within the current scope;

- The most significant limitation on simulation of the water balance is the lack of a detailed groundwater model of the basin. As described in this report, there are portions of the stream network that both lose to and gain from groundwater. Pumping in the alluvial aquifers also provides a significant influence on low flows in San Antonio Creek and portions of the Ventura River mainstem. Ideally, a dynamic groundwater flow model (e.g., MODFLOW) would be developed and could be linked to provide the reach losses and deep groundwater discharge time series to the HSPF model. Developing such a model represents a considerable effort. In the absence of funding to develop a dynamic model, a simpler mass balance accounting of inputs and outputs to the alluvial aquifers would also be useful for constraining and improving the surface water model.
- During model calibration it was necessary to reduce the default assumptions of irrigation application rates. This should be investigated further, starting with a survey to better determine the extent of irrigated lands and actual irrigation rates. As much of the irrigation supply in the basin comes from groundwater, this could best be done in conjunction with development of a groundwater model or mass balance accounting.
- As part of the current work, a method was developed to account for the potential effects of high sediment concentrations on runoff volumes and flow values using a sediment bulking approach. The validity of this method has not been tested in the Ventura River watershed. Further investigations and fine-tuning of the sediment bulking approach could be pursued if and when data are available to document extremely high sediment concentrations during specific peak runoff events.
- The current work also developed and incorporated a method to account for the hydrologic effects of severe wildfires, which reduce interception, infiltration, and evapotranspiration, leading to increases in both high flows and low flows. These effects were assumed to persist for two years after a major fire. The method appears to perform adequately in general, in particular providing an improved fit to observed flows following the 1979 and 1985 fires. However, some of the gage data (e.g., North Fork Matilija) suggest that the fire impacts persist for somewhat longer than two years. Some adjustments to the approach – in particular the period of application – may thus be warranted.

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Appendix A. Response to Comments

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southwest Region
501 West Ocean Boulevard, Suite 4200
Long Beach, California 90802-4213
10014SWR2009PR00125

March 9, 2009

Scott Holder
Ventura County Watershed Protection District
800 South Victoria Ave.
Ventura, CA 93009-1600

Dear Mr. Holder:

Under the authority of the U. S. Endangered Species Act, NOAA's National Marine Fisheries Service (NMFS) is mandated to conserve endangered steelhead (*Oncorhynchus mykiss*) throughout waterways in southern California, including the Ventura River watershed. The growth and survival this species are inextricably connected to the pattern and magnitude of river discharge. Consequently, understanding the natural hydrology of the Ventura River watershed and how anthropogenic activities have altered the natural condition are crucial to inform programs that are intended to conserve this species. To this end, the following comments are offered on the hydrology model under development for the Ventura River watershed.

With regard to the behavior and ecology of endangered steelhead, high flows in the watershed during winter and spring allows migration of the species to spawning and rearing areas and the ocean. Low-flow hydrology, typically observed during the dry season or extended periods of below-normal precipitation, can limit growth, survival, and movement of juvenile steelhead and adult steelhead that remain in the watershed after spawning. Accordingly, if the hydrology model is to have utility for informing conservation programs for endangered steelhead, the model should consider high and low-flow hydrology representing natural conditions and recent baseline conditions reflecting effects of past and ongoing anthropogenic activities. In particular, the model should possess the capability to generate reliable estimates of the natural or unimpaired hydrology, and estimates of how anthropogenic activities have lead to recent hydrological conditions, i.e., baseline conditions.

Natural and baseline conditions should be clearly defined and distinguished in the model documentation and output. Simulating natural conditions should require an assumption that all anthropogenic water storage, diversion, withdrawals, and applications are not present. The assumptions on which the simulations are based should be disclosed.

The hydrology model should possess the capability to estimate specific characteristics of river discharge. The timing, duration, magnitude, frequency, and rate-of-change of high-flow events are particularly important to the migratory behavior and ecology of steelhead. Estimates of how anthropogenic activities have altered these discharge characteristics and led to recent conditions are critically important, as is the capability to forecast impacts of future proposed activities and projected climate change, and the cumulative effects due to baseline conditions and future activities and climate.

The capability to disentangle the effects of specific individual or aggregate anthropogenic activities (past, ongoing, and future activities) on characteristics of the natural flow regime, including low-flow hydrology, would be an important feature to instill in the model. The ability to generate estimates of hydrology at discrete geographic locations or spatial scales within the watershed would be valuable as well.

NMFS appreciates the opportunity to comment on the hydrology model. Please call Anthony Spina at (562) 980-4045 if you have a question concerning this letter or if you would like additional information.

Sincerely,

for Rodney R. McInnis
Regional Administrator

cc: Mary Larson, California Department of Fish and Game

Surfrider Foundation

Ventura County Chapter – Matilija Coalition

PO Box 1028, Ventura, CA 93002

(805) 667-2222 **www.matilija-coalition.org**

March 17, 2009

Scott Holder
Hydrologist - Storm Operations
Ventura County Watershed Protection District
800 South Victoria Ave
Ventura, CA 93009-1600

RE: Comments on Ventura HSPF model

We have reviewed the *Ventura River Model Baseline Report of February 12, 2009,* and have the following comments:

The model as formulated will provide an excellent tool for modeling wet season hydrology and flood risk as well evaluating changes in hydrology due to land use (i.e. hydromodification.) The latter is significant in that hydromodification has negative impact on watershed function and water quality, and may provide a tool for evaluating the feasibility of restoring watershed function through LID (Low Impact Development) and Green Infrastructure.

However, it appears that the model shows limited accuracy for low flows. This limits the usefulness of the model for water quality modeling. In particular, it seems the assumption that irrigation is an added source of surface water is flawed. In most cases, the sources of irrigation water within the Ventura River watershed are groundwater wells. The model as formulated does not account for the impacts of aquifer depletion on base flows, and in fact assumes that irrigation is a benefit to instream flows. Since this is a critical issue in relation to water quality and steelhead habitat, it is recommended that additional work be done to model the interaction of groundwater and surface water especially in the critical reaches of San Antonia Creek and the main stem of the Ventura River.

Sincerely,

A. Paul Jenkin, M.S.

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Environmental Director, Surfrider Foundation, Ventura County Chapter
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MEMORANDUM

To: Scott Holder, Ventura County Watershed Protection District

From: Jonathan Butcher, Ph.D., P.H.

Cc: Gerard Kapuscik, Sergio Vargas, Steve Carter

Date: 24 March 2009

Subject: Response to Comments

On 12 February 2009 Tetra Tech submitted to VCWPD the *Baseline Model Calibration and Validation Report, Ventura River Watershed Hydrology Model*. This describes the development, calibration, and validation of an HSPF surface-water hydrology model of the watershed. VCWPD distributed the report for stakeholder comment. As of the end of the comment period two written comment letters had been received. It is Tetra Tech's opinion that neither comment letter necessitates modifications to the model or report; however, additional clarification is warranted and is provided in this response to comments.

NMFS Comments

Rodney R. McInnis, Regional Administrator for the National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NMFS) provided comments relative to the NMFS mandate to conserve endangered steelhead in waterways of southern California, including the Ventura River watershed. These comments note that both high and low-flow hydrology are important to steelhead survival, and states that "the model should consider high and low-flow hydrology representing natural conditions and recent baseline conditions reflecting effects of past and ongoing anthropogenic activities."

Tetra Tech notes that the Ventura River watershed HSPF model is a continuous simulation model, operating at a time step of 15-minutes and applied over a 40-year simulation period, that has been successfully calibrated and validated and provides a good representation of the entire flow regime under existing (baseline) conditions. We agree that it is important to provide information on how past and ongoing anthropogenic conditions have altered natural hydrology in the system. That topic, however, was not intended to be addressed within the scope of the calibration and validation report, the purpose of which is primarily to document the development of the model and establish its credibility through the calibration and validation process. Tetra Tech's scope calls for the development and documentation of a natural conditions run for the Ventura River watershed following approval of the calibration and validation report. Comparison of the results of the natural condition run to the baseline run will provide a direct basis for evaluating the cumulative impacts of anthropogenic activities in the watershed. The natural conditions run will indeed assume that all anthropogenic water storage, diversion, withdrawals, and applications are removed, as well as reversion of developed and agricultural land uses to natural land cover. The model can also be used to investigate impacts of specific anthropogenic activities, such as individual dams, on watershed hydrology.

The NMFS comments note that the model should possess the capability to estimate specific characateristics of river discharge, such as the timing, duration, magnitude, frequency, and rate-of-change of high-flow events, and should be able to generate hydrologic output at discrete geographic locations. Tetra Tech wishes to assure NMFS that the Ventura River Watershed Model does indeed provide these capabilities. As noted above, the model operates at a sub-hourly time step and is capable of resolving the details of storm-event hydrographs. Model calibration addressed a full range of spatial and temporal scales, ranging from the overall water balance to the prediction of individual event peaks. In addition, the model divides the stream network into 94 discrete stream reaches and output (for up to 40-years at a 15-minute time step) can be generated at any one of these locations.

In sum, we are confident that the Ventura River Watershed Model will provide a useful tool for supporting NMFS' activities and mandates relative to the Ventura River.

Surfrider Foundation

A brief comment letter was provided by A. Paul Jenkin, M.S., Coordinator, Matilija Coalition, and Environmental Director, Surfrider Foundation, Ventura County Chapter. This letter first states that "the model as formulated will provide an excellent tool for modeling wet season hydrology and flood risk as well as evaluating changes in hydrology due to land use…" The letter then goes on to question the ability of the model to represent low flows: "…it appears that the model shows limited accuracy for low flows. This limits the usefulness of the model for water quality modeling. In particular, it seems the assumption that irrigation is an added source of surface water is flawed. In most cases, the sources of irrigation water within the Ventura River watershed are groundwater wells. The model as formulated does not account for the impacts of aquifer depletion on base flows, and in fact assumes that irrigation is a benefit to instream flows. Since this is a critical issue in relation to water quality and steelhead habitat, it is recommended that additional work be done to model the interaction of groundwater and surface water…"

Tetra Tech readily acknowledges the difficulties and data limitations present for evaluating surface and ground water interactions in the Ventura River watershed. It is important to note that the scope of the current project does not include development of a comprehensive groundwater simulation model of the aquifers underlying the Ventura River watershed, and no such model is currently available. The HSPF watershed model is primarily a surface water model, but does incorporate shallow ground water and baseflow returns to streams. However, the model is not capable of providing a complete simulation of deep ground water storage, extraction, and interaction with stream reaches. Therefore, these facets of the overall water balance have had to be addressed approximately, as explained further below.

Tetra Tech does disagree with a number of the specific assertions made by Mr. Jenkin regarding the low flow simulation and offers the following clarifications and suggestions:

- Whether or not the "model shows limited accuracy for low flows" is a matter of opinion. In our experience, the representation of low flows attained for the Ventura River is actually quite good for this type of model in this type of physical setting. For low flows in arid regions, the relative model uncertainty can appear quite large, even though the absolute uncertainty is small. For instance, if the model predicts a flow of 2 cfs relative to an actual flow of 1 cfs, the relative error is 100 percent, but the absolute error is only 1 cfs. (Note that the use of log-scale plots tends to over-emphasize deviations at low flows.) Further, low-flow discrepancies tend to be persistent. That is, if the soil moisture storage accumulated over a given winter is not precisely estimated (because, for instance, the rain fall gauging network does not provide an accurate estimate of areal average precipitation totals) then the flows for the entire succeeding summer may deviate in a consistent direction from observations. In most cases, the match between observed and predicted flow duration curves and monthly average flows is good, suggesting that the model provides a reasonable representation of the low flow regime over time. It is likely, however, that occasional discrepancies do arise because rates of pumping from alluvial wells are not fully known.

- Tetra Tech believes that the model will be useful for water quality modeling. Mass transport is primarily driven by high flow events, whereas instream water quality mostly reflects low flow conditions. As long as the model provides a good approximation of the magnitude and sources of flow during dry weather it will provide a firm basis for water quality evaluations even if not all individual observations are precisely matched.
- It is not entirely correct to state that the model regards irrigation “as an added source of surface water.” Tetra Tech agrees that the sources of most irrigation water are groundwater wells, which draw both from the alluvium along stream channels and from deeper groundwater basins. While our ability to simulate a complete groundwater balance is limited by the fact that a full groundwater model is not available, the model does account for the depletion of stream flow by pumping for irrigation by assigning a seasonally varying channel depletion rate in those areas where pumping from shallow wells is present. Other portions of irrigation water are supplied from deeper groundwater storage. While the deeper groundwater basins are not directly simulated (and cannot be fully represented within the framework of HSPF), the model does represent a loss from shallow to deep groundwater that approximately balances the apparent rate of withdrawal from deep groundwater stores over time.
- The presence of irrigation does help support baseflows during dry periods; however, it is incorrect to say that the model only represents irrigation as “a benefit” to instream flows. This is because the irrigation application is balanced by losses from stream reaches that are caused by alluvial pumping. Simulation of natural conditions would require removing both the irrigation application *and* the channel losses that are due to pumping to support irrigation. Under many conditions, the presence of both irrigation and stream losses from irrigation pumping likely constitute a net detriment to instream flows. Tetra Tech does acknowledge, however, that the lack of a full groundwater model will result in uncertainties in making this determination.
- Tetra Tech fully agrees that it would be desirable to undertake additional work to model the interaction of groundwater and surface water, particularly along San Antonio Creek and the Ventura River mainstem where most of the irrigation wells and irrigated land are located. Indeed, we have specifically recommended this to VCWPD, on p. 192 of the report: “Ideally, a dynamic groundwater flow model (e.g., MODFLOW) would be developed and could be linked to provide the reach losses and deep groundwater discharge time series to the HSPF model.” Unfortunately, construction, calibration, and testing of such a model is a time-consuming and expensive effort for which funding is not currently available. If possible, such work should be pursued in the future to support development of a comprehensive water management strategy for the Ventura River watershed.