NOVEMBER 2009

THE GREEN VISIONS PLAN

for 21st century southern california

23. Hydrology and Water Quality Modeling of the Santa Clara River Watershed

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Acknowledgements: This work was completed as part of the Green Visions Plan for 21st Century Southern California, which received funding from the San Gabriel and Lower Los Angeles Rivers and Mountains Conservancy, the County of Los Angeles, and the USC College of Letters, Arts & Sciences. The authors thank Travis Longcore and Jennifer Wolch for their comments and edits on this paper. The authors would also like to thank Eric Stein, Drew Ackerman, Ken Hoffman, Wing Tam, and Betty Dong for their timely advice and encouragement.

Prepared for: San Gabriel and Lower Los Angeles Rivers and Mountains Conservancy, 100 North Old Santa Clara Canyon Road, Azusa, CA 91702

Preferred Citation: Sheng, J., and Wilson, J.P., 2009. The Green Visions Plan for 21st Century Southern California: 23. Hydrology and Water Quality Modeling of the Santa Clara River Watershed. University of Southern California GIS Research Laboratory, Los Angeles, California.

This report was printed on recycled paper.

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THE GREEN VISIONS PLAN

for 21st century southern california

The mission of the Green Visions Plan for 21st Century Southern California is to offer a guide to habitat conservation, watershed health and recreational open space for the Los Angeles metropolitan region. The Plan will also provide decision support tools to nurture a living green matrix for southern California. Our goals are to protect and restore natural areas, restore natural hydrological function, promote equitable access to open space, and maximize support via multiple-use facilities. The Plan is a joint venture between the University of Southern California and the San Gabriel and lower Los Angeles Rivers and Mountains Conservancy, Santa Monica Mountains Conservancy, Coastal Conservancy, and Baldwin Hills Conservancy.

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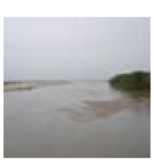

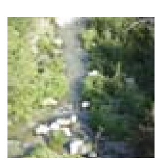

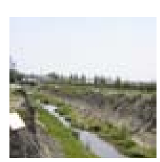

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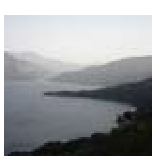
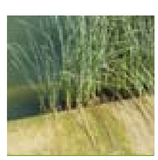
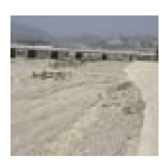

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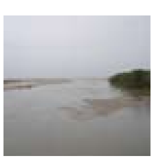
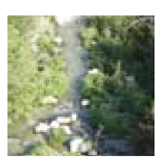
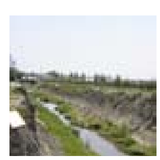

Executive Summary

The goal of the Green Visions Plan project's watershed health assessments, as described in the GVP framework, is to support and inform regional planning efforts from the perspective of habitat conservation, water protection, and recreational opportunities in southern California. In this report, hydrologic models of the Green Vision's Plan watersheds were developed for use as a tool for watershed planning, resource assessment, and ultimately, water quality management purposes. The modeling package selected for this application is the Danish Hydrology Institute's MIKE BASIN watershed model of hydrology and water quality, which includes modeling of both land surface and subsurface hydrologic and water quality processes. It was used to evaluate the current baseline hydrologic conditions and water quality and pollutant loadings in the GVP's five 8-digit HUC watersheds, namely, the Los Angeles River, San Gabriel River, Santa Monica Bay, Calleguas Creek, and Santa Clara River watersheds.

Land use, topography, hydrology, population, rainfall and meteorological data were used to develop the model segmentation and input, and detailed stream flow data were selected to conduct model calibration over a nine year period (10/1996 – 09/2005) and validation for additional stations. Both quantitative and qualitative comparisons were developed to support the model performance evaluation effort.

Statistical comparisons and model performance evaluation were performed at eight stream locations throughout the watershed, for annual runoff, daily and monthly stream flow and water balance components. The comparisons demonstrate conclusively that the model is a good representation of the water balance and hydrology for the Sespe, Piru and Hopper Creek, and upper Santa Clara River subwatersheds. Flow validation results were also reasonably good for the Santa Paula subwatershed and Santa Clara River near Piru. The flow simulation in the lower Santa Clara River was directly influenced by water diversions that resulted in over-predictions in low flow conditions.

The water quality simulation results were much less satisfactory. Graphically, some sampled concentrations were captured while others were missed in the pollutographs and MIKE BASIN did not always predict the temporal variability of the pollutograph. The modeled results demonstrated the spatial distribution of the nutrient flux and loads throughout the watershed. The highest NH4, NO3, and TP fluxes appear in the cities of Santa Clarita, Fillmore and Santa Paula, and on the coastal Oxnard Plain, where development and agricultural land uses are concentrated. Wastewater treatment plants are significant sources of nutrients to the surface waters as well.

1 Introduction

The hydrology and water quality simulation presented in this report is a part of the Green Visions Plan for 21st Century Southern California project. The primary focus of the Santa Clara River watershed water quality modeling is to determine the impact of pollutant sources entering the stream network and to what degree surface waters are subject to water quality impairments. A basin scale model, MIKE BASIN developed by the Danish Hydrology Institute (DHI; Portland, Oregon), was used to represent the hydrologic and water quality conditions in the Santa Clara River watershed. The MIKE BASIN model was implemented at the basin scale and offered the capability of representing both water availability and potential users of water, such that the results may assist with planning for future water developments within the GVP study area.

In general terms, MIKE BASIN offers a mathematical representation of the river basin encompassing the configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, and existing and potential demands on water. The MIKE BASIN Water Quality (WQ) module adds the capacity to conduct water quality simulations. MIKE BASIN is structured as a network model in which the rivers and their major tributaries are represented by a network comprising branches and nodes. The branches represent individual stream sections while the nodes represent confluences and locations where certain activities may occur. MIKE BASIN is an extension to ESRI's ArcView GIS (Environmental Systems Research Institute, Redlands, California), such that existing GIS information can be included in the water resources simulation. The network of rivers and nodes is also edited in ArcView. The concept of MIKE BASIN for water modeling is illustrated in Figure 1.

MIKE BASIN operates on the basis of a digitized river network. Figure 2 shows the schematic layout of this network. All information regarding the configuration of the river branch network, location of water users, channels for intakes and outlets to and from water users, and reservoirs are defined by on-screen editing. Basic input to the model consists of time series data of various types. Basically only time series of catchment rainfall is required to have a model setup that runs. Additional input files define reservoir characteristics and operation rules of each reservoir, meteorological time series and data pertinent to each water supply or irrigation scheme such as bifurcation requirements and other information describing return flows. Additional data describe hydraulic conditions in river reaches and channels, hydropower characteristics, groundwater characteristics, etc.

Often, several users may want to receive water from the same resource. Within the MIKE BASIN network model concept, such a situation is represented by several users connected to a single supply node. A very important feature in MIKE BASIN is a global set of rules and local algorithms that guide the allocation of surface waters. Rules affect at least the node they are attached to, and possibly a second node, the extraction point of the former. Multiple rules can be associated with a single water user. However, the implementation

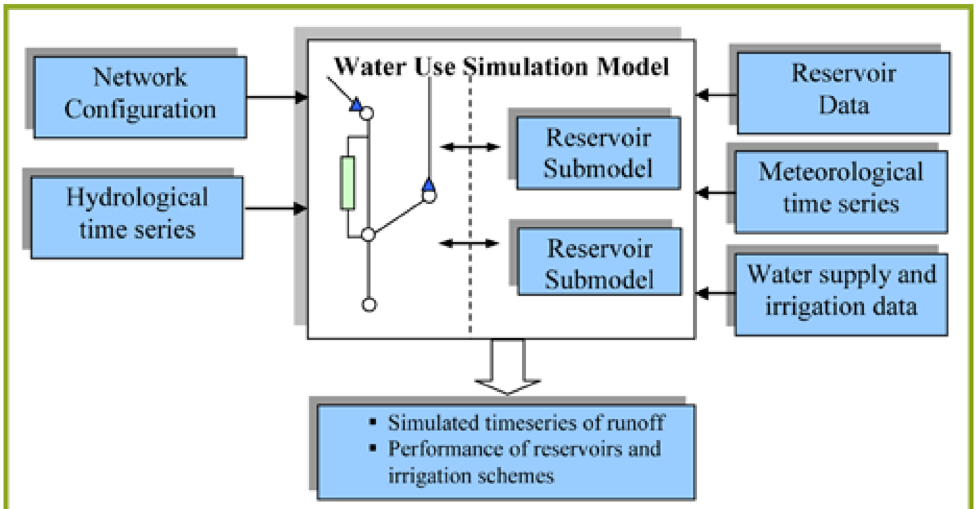

Figure 1 MIKE BASIN's water allocation modeling structure (DHI 2007)

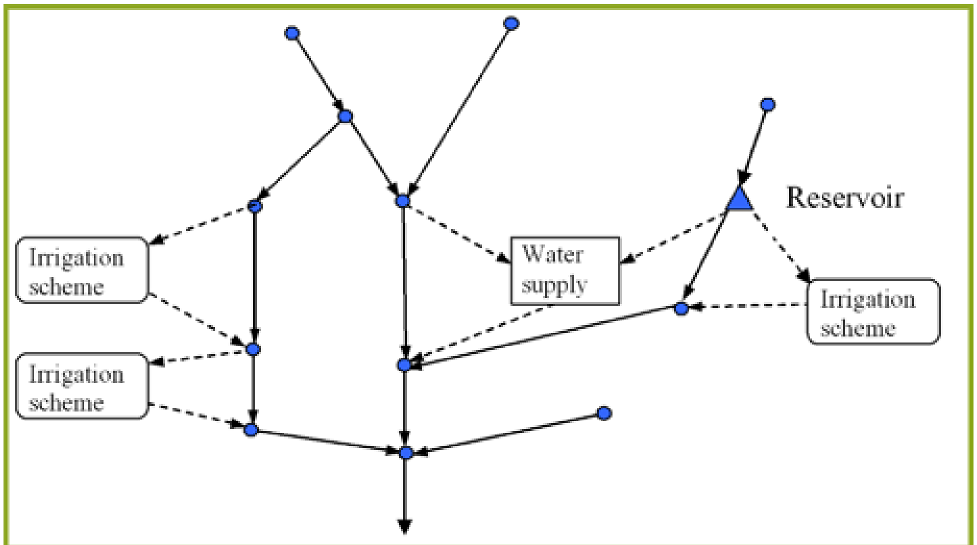

Figure 2 Schematic layout of MIKE BASIN's network modeling approach (DHI 2007)

of rules does not account for delays in flow routing, water quality pulses or dilution, and groundwater processes. The overall modeling concept in MIKE BASIN is to find stationary solutions for each time step. Accordingly, time series input and output are presumed to contain flux-averaged values for some period between two time stamps, not pulses at a time stamp (DHI 2007).

This report documents the hydrology and water quality simulation results produced with MIKE BASIN for the Santa Clara River watershed. It identifies and describes the types of data that were obtained and used for the model, and presents the procedures in establishing, calibrating and validating the model. Section 2 describes the hydrological, meteorological, and other data needed for the simulation; Sections 3 and 4 document the watershed segmentation based on multiple criteria and the calibration / validation procedures used for selected subwatersheds within the Santa Clara River watershed; Section 5 describes the model results; and Section 6 discusses model performance and offers some recommendations regarding the surface water impairments and contributing sources.

The Santa Clara River watershed is the largest watershed in southern California remaining in a relatively pristine state. The major tributaries include Castaic and San Francisquito Creeks in Los Angeles County, and Sespe, Piru and Santa Paula Creeks in Ventura County. The total length of the stream network is 4,024.5 miles, as reported in the 1999 National Hydrography Dataset (NHD), and the average channel elevation of the drainage system is 2,311 ft, much higher than that of the other four HUC-watersheds.

2 Data Needs for Watershed Hydrologic Modeling

Precipitation, potential evaportranspiration, air temperature, and streamflow time series data were acquired for the hydrologic modeling. Additional data such as point sources and diversions that define the inflow and outflow of water in the watershed were also obtained for the modeling. All time series data for the model are stored in DHI's own binary file format named DFS (Data File System), which is a format that can be read by DHI's numerical program suite. We used the Time Series Editor that comes with the MIKE BASIN package for the work reported herein. This program can read data in Excel or arbitrary flat file formats and import them into DFS, from which MIKE BASIN then reads its input data. The Temporal Analysis function provided by MIKE BASIN allows the user to perform a variety of data manipulation tasks, such as aggregation / disaggregation, gap filling and generation of graphical displays.

2.1 Precipitation

Meteorological data are a critical component of any hydrology model. MIKE BASIN requires appropriate representation of precipitation and potential evapotranspiration (ET). Daily precipitation data are sufficient to represent the hydrology and water quality in the model at the watershed scale. Within the Santa Clara River watershed, the Los Angeles County Department of Public Works (LADPW), Ventura County Water Protection District (VCWPD) and National Weather Service (NWS) maintain networks of precipitation stations, most of which have been continuously operated for 30 years or longer. Stations with daily records from 10/1995 to 09/2006 were selected for the model (Table 1). Their locations relative to the watershed are shown in Figure 3.

Table 1 Precipitation data records selected for the model

Station ID	Station Name	Elevation (ft)	Source	Latitude	Longitude
018/018A	Santa Paula-Limoneira Ranch	295	VCWPD	34.332	-119.130
25	Piru-Newhall Ranch	825	VCWPD	34.401	-118.723
39	Fillmore-Rancho Sespe	360	VCWPD	34.384	-118.963
152	Piedra Blanca Guard Station	3065	VCWPD	34.560	-119.166
160	Piru-Temescal Guard Station	1080	VCWPD	34.474	-118.760
167	Ventura-Hall Canyon	180	VCWPD	34.281	-119.258
171	Fillmore-Fish Hatchery	465	VCWPD	34.394	-118.884
172	Piru Canyon	1120	VCWPD	34.513	-118.757
175	Saticoy Fire Station	185	VCWPD	34.286	-119.155
189	Somis-Deboni	520	VCWPD	34.285	-119.072
191	Moorpark-Downing Ranch	1040	VCWPD	34.326	-118.895
199	Fillmore-County Fire Stat	435	VCWPD	34.403	-118.926
225	Wheeler Canyon	900	VCWPD	34.391	-119.145
231	El Rio-Riverpark	0	VCWPD	34.245	-119.183
238	South Mountain-Shell Oil	2240	VCWPD	34.331	-119.008
242	Tripas Canyon	2500	VCWPD	34.368	-118.764
244	Cuddy Valley-Cuddy Ranch	5500	VCWPD	34.840	-119.059
250	Moorpark-Happy Camp Canyon	1410	VCWPD	34.346	-118.850
261	Saticoy-Recharge Facility	145	VCWPD	34.279	-119.123
264	Wheeler Gorge	1900	VCWPD	34.515	-119.269
271	Lockwood Valley near Seymour Creek	5165	VCWPD	34.767	-119.045
372	San Francisquito Power House	1580	LA_OBSER	34.534	-118.524
1191	Bear Divide	2700	LA_OBSER	34.360	-118.394
1262	Saugus Reclamation Plant	1150	LA_OBSER	34.413	-118.540
1263	Valencia Reclamation Plant	1000	LA_OBSER	34.432	-118.620
036A	Piru-County Fire Station	700	VCWPD	34.413	-118.795
064B	Upper Ojai-Happy Valley	1320	VCWPD	34.437	-119.189
065/065A	Upper Ojai Summit-County	1560	VCWPD	34.437	-119.134
094B/094C	Fillmore-Fairview Ranch	640	VCWPD	34.389	-118.860
096A	Bardsdale-Lander Ranch	390	VCWPD	34.362	-118.950
1005B	Mint Canyon Fire Station	2300	LA_OBSER	34.51	-118.361
101A	Piru-Camulos Ranch	725	VCWPD	34.406	-118.756
130A	Chuchupate Ranger Station North	5260	NWS	34.808	-119.010
134B	Matilija Dam	1060	VCWPD	34.484	-119.305
163A/163B	Sulphur Mountain	2450	VCWPD	34.409	-119.174
173/173A	Santa Paula Canyon-Ferndale Ranch	1010	VCWPD	34.427	-119.086

Table 1 Precipitation data records selected for the model, continued

Station ID	Station Name	Elevation (ft)	Source	Latitude	Longitude
207B	Matilija Canyon	1450	VCWPD	34.503	-119.353
209A	Lockwood Valley-County Yard	5150	NWS	34.733	-119.103
216B	Ventura Marina-Port District	5	VCWPD	34.252	-119.266
222A	Ventura-County Government Center	280	VCWPD	34.267	-119.210
224A	Sespe-Westates	2840	VCWPD	34.479	-118.881
245/245A	Santa Paula-UWCD	300	VCWPD	34.353	-119.064
252C	Castaic Lake	1150	LA_OBSER	34.498	-118.615
405B	Soledad Canyon	2150	LA_OBSER	34.440	-118.293
409B	Pyramid Reservoir	2505	LA_OBSER	34.676	-118.780
801B	Magic Mountain	4720	LA_OBSER	34.398	-118.324
40014	ACTON FC261	2968	NCDC	34.500	-118.267
42516	DRY CANYON RESERVOIR	1456	NCDC	34.483	-118.533
46161	NEWHALL 5 NW	1765	NCDC	34.400	-118.600
46162	NEWHALL SOLEDAD FC32CE	1243	NCDC	34.383	-118.533
46165	NEWHALL	1401	NCDC	34.367	-118.567
46940	PIRU 2 ESE	731	NCDC	34.400	-118.750
47734	SANDBERG PATROL STN	4025	NCDC	34.750	-118.717
47735/23187	SANDBERG	4510	NCDC	34.750	-118.717
47957	SANTA PAULA	72	NCDC	34.317	-119.133
48014	SAUGUS POWER PLANT 1	2106	NCDC	34.583	-118.450

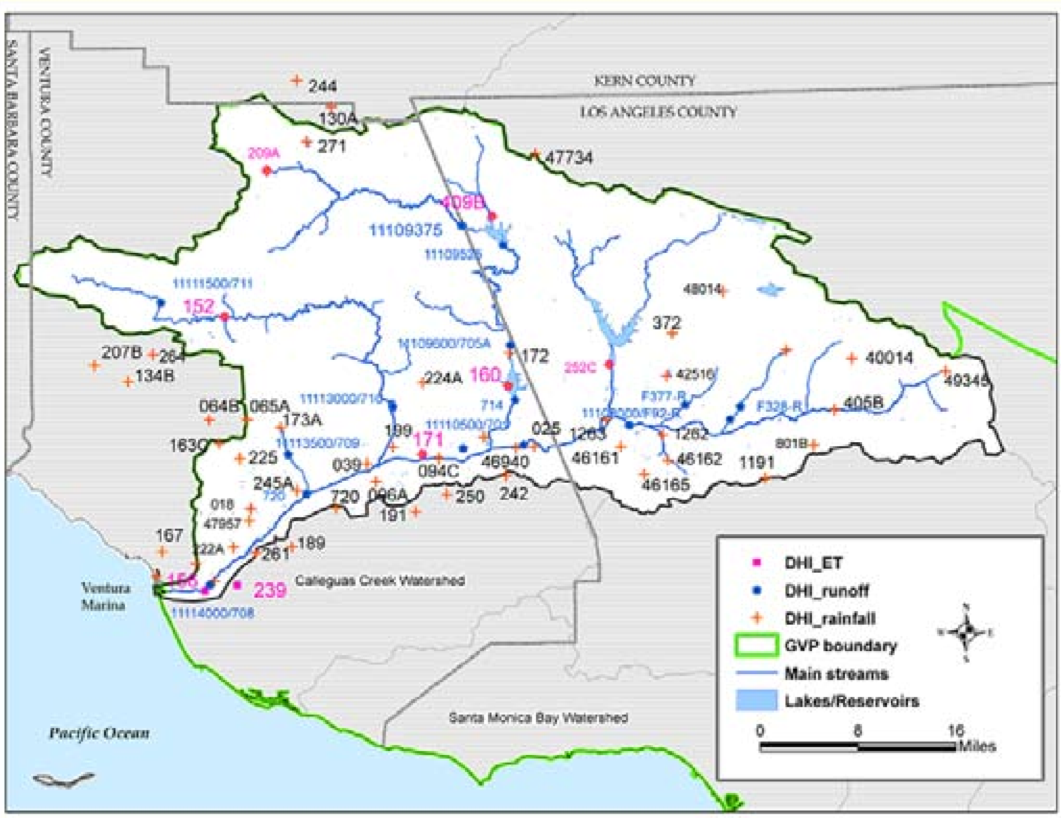

Figure 3 Precipitation, stream flow and evapotranspiration gauge locations in or near the Santa Clara River watershed

Table 2 Evaporation stations in or near the Santa Clara River watershed

Source	Evaporation ID/Name	Latitude	Longitude	Elevation (ft)	Annual average (in)
LADPW	252 C	34.498	-118.615	29.21	4.24
LADPW	409 B	34.676	-118.780	63.63	7.56
CIMIS	156	34.234	-119.197	1.22	3.68
VCWPD	152	34.560	-119.166	3065.00	4.95
VCWPD	160	34.474	-118.760	1080.00	5.22
VCWPD	171	34.394	-118.884	465.00	5.03
VCWPD/USGS	209/USGS0432	34.733	-119.103	5150.00	4.68
VCWPD	239	34.241	-119.151	105.00	5.13

Some of the calibration stations have missing data in the time series. The missing periods were filled using nearby stations with values weighted to the ratio of the annual averages over their common period record. The precipitation data were applied to the subwatersheds based on a Thiessen polygon approach using the selected gauges. A Thiessen polygon approach is a standard hydrologic technique to define the watershed area that will receive the rainfall recorded at the gauge; it constructs polygons around each gauge using perpendicular bisecting lines drawn at the midpoint of connecting lines between each gauge.

2.2 Potential Evapotranspiration

Pan evaporation data were used to derive the estimates of potential evapotranspiration required by MIKE BASIN. LADPW provided monthly pan evaporation data and the California Irrigation Management Information System (CIMIS) provided daily data at several locations in and around the Santa Clara River watershed. The sites are listed in Table 2 below.

For model input, daily ET values are preferred. Daily data are available at CIMIS stations but only for limited (i.e. recent) periods. Therefore, monthly ET data were used for calibration and validation in this study. The monthly data were then disaggregated to daily values using the disaggregation function in the Time Series Analysis module of the model, which distributed each monthly value at the given latitude in that month. Cloud cover was not considered when distributing monthly evaporation to daily values due to the lack of cloud cover data. The climatic map of the region shows an estimated pan coefficient of 0.70-0.75, and the value of 0.74 recommended by Aqua Terra Consultants (2004) was used to estimate potential evapotranspiration in the model runs.

2.3 Streamflow

To calibrate the model, records of measured daily streamflow data were compared with simulated values. The gauges selected for calibration and validation are listed in Table 3, and their locations appear in Figure 3. Daily records from 10/1/1996 to 09/30/2005 were obtained for these eight stream gauges on the main stem and its tributaries. Four gauges – USGS 11113000/710A, B, C, D Sespe Creek near Fillmore, CA; USGS 11110500/701 Hopper Creek near Piru, CA; USGS 11109375/716 Piru Creek below Buck Creek near Pyramid Lake, CA; and USGS 11108000/ LADPW F92-R Santa Clara River near Saugus, CA – were selected for the primary calibration with the daily data, and the other four gauges listed in Table 3 were used as consistency checks and for further validation of model performance.

2.4 Point Source Discharges

During model configuration, three major National Pollutant Discharge Elimination System (NPDES) dischargers were incorporated into the MIKE BASIN model as point sources of flow and nutrients due to their large associated loadings (Table 4). Each point source was included in the model as a time variable source

Table 3 Stream flow stations in the Santa Clara River watershed

Station ID	Station Name	Drainage Area (mi^2)	Elevation (ft)	Data From	Data To
11113000/710A,B,C, D	SESPE C NR FILLMORE	251	565	1911	Present
11110500/701	HOPPER CREEK NEAR PIRU CA	24	590	1930	Present
11109375/716	PIRU C BL BUCK C NR PYRAMID LK CA	198		1976	2003
11108000/F92-R	SANTA CLARA R NR SAUGUS CA	411	1,046	1929	Present
11113500/709/709A	SANTA PAULA C NR SANTA PAULA	38	619	1927	Present
11109600/705/705A	PIRU CREEK ABOVE LAKE PIRU CA	372	1059	1955	Present
11109000/707A	SANTA CLARA R NR PIRU CA	645	710	1927	2006
720	Santa Clara River at 12th Street	1509		2004	2007

of flow from 10/1996 to 09/2006. Complete daily discharge data were not available for the simulation period. Average design flow rates were used for each site to overcome the gaps in the time series.

The other major sources of flows to river system are scattered urban runoff discharge at stormwater outlets, particularly during the dry-weather seasons. Urban practices such as lawn irrigation and car washing, contribute to these inflows. The wet weather runoff volume accounts for the majority of the discharge and the dry weather runoff contributes very little to the annual total. The Santa Clara River watershed is the least urbanized watershed with the majority of land in a relatively pristine and undeveloped state, so the influence of dry-weather urban runoff is minimal compared to that experienced in the other more heavily urbanized watersheds in the GVP study area.

2.5 Water Regulation Data

Municipal water supplies within the watershed are obtained from local groundwater in aquifers located under the service area, imported water from the State Water Project and relatively small quantities of recycled water. There are two significant sources of imported water within the Santa Clara River watershed, the California and Los Angeles Aqueducts. The former, part of the State Water Project network, feeds the William E. Warner Power Plant located in the north central part of the watershed in Los Angeles County. From there, water is delivered to the Castaic Power Plant through the Angeles tunnel and then into Castaic Lake. Imported water transported through the Los Angeles Aqueducts supplies the Los Angeles Power Plant and Reservoir and is temporarily stored in Bouquet Reservoir, which lies in the Bouquet Creek upstream of the City of Santa Clarita. The local flow regime is affected during the interim by water inputs and extraction.

The Piru Reservoir, owned and operated by United Water Conservation District (UWCD), receives imported and natural water flow from the upstream State Water Project's Pyramid Reservoir. Water storage in the Piru Reservoir allows for strategic conservation releases aimed at recharging downstream groundwater basins and aquifers, which provide irrigation and drinking water and help to block saltwater intrusion

Table 4 NPDES permitted major dischargers and median concentrations of three constituents in the Santa Clara River watershed

POWT	Median flow (cfs)	Ammonia-N (mg/L)	Nitrate-N (mg/L)	Total Phosphorus (mg/L)
Valential WRP	17.9	16.0	4.5	10.0
Saugus WRP	8.14	10.2	1.9	8.48
Santa Paula WRP	3.5	19.0	4.1	9.0

on the Oxnard Plain (Aqua Terra Consultants 2004). Operation data are available for the Santa Felicia Reservoir and were utilized in the MIKE BASIN model runs. Unfortunately, no detailed data were obtained for the Castaic Lake and Pyramid Lake reservoirs.

There are also some diversions in the lower watershed. The Freeman Diversion was constructed in 1991 in place of its earthen dyke predecessor to increase the diversion capacity from approximately 375 to 460 cfs. The 60,000 acre-feet (AF) of water diverted annually by Freeman feeds the groundwater recharge facilities as well as supplies the Pleasant Valley and Pumping Trough Pipelines (UWCD 2001). Most artificial recharge at El Rio is pumped back through nearby extraction wells for irrigation or delivery to adjacent sub-basins. The pumping return rate is 44% historically (Aqua Terra Consultants 2004). A smaller diversion (approximately 6,000 AF/yr) located along Piru Creek at the confluence with the Santa Clara River feeds the Piru Spreading grounds located next to Piru Creek. Lastly, the Fillmore Fish Hatchery pumps approximately 12,000 AF of water annually from the Santa Clara River approximately 12 miles west of the Los Angeles / Ventura County boundary as well.

2.6 Water Quality Data

The Load Calculator in the model was used to determine pollution loads in individual subwatersheds. It calculated average mass fluxes of pollutants (e.g. kg/catchment/year) and then each individual estimate was transferred to the MIKE BASIN Water Quality module for estimating pollution loadings within the entire watershed. The Load Calculator in MIKE BASIN takes account of all point and non-point source contributions. Each source has a unique set of required input data, but the data input is very similar in many instances. There are nine wastewater treatment plants (WTPs) located in the Santa Clara River watershed. Eight of these have outfalls within the watershed, but only three discharge directly to the Santa Clara River (the Saugus, Valencia and Santa Paula WTPs). Time variable discharge data are available and were incorporated into the model as time variable point sources of pollutants due to their large associated loadings. Constituent concentrations for each point source were obtained from the Sanitation Districts of Los Angeles County (Table 4). The median concentrations were calculated from the time series data.

The variability of non-point source contributions is represented through dynamic representation of hydrology and land practices. Selected water quality constituent loading fluxes (e.g. nitrogen, phosphorus) associated with different land uses were obtained from research conducted by the LADPW and SCCWRP. Land use data were obtained from SCAG (2001). Event mean fluxes by land use were estimated by averaging a large number of water quality samples taken on specific land use classes (Table 5). The constituent flux from a given land use will vary from site to site and storm to storm. This variability is magnified when the area of interest is expanded from single land use areas to watersheds because of the complexity of runoff behavior. Our goal is to investigate long-term average loading to the receiving water; therefore, mean flux and other static pollutant sources were adequate to represent the spatial variations in constituent loading across the watershed. However, some additional knowledge of inter-storm and intra-site variability would be needed to estimate loads on shorter time scales.

Non-point sources from agriculture were also specified as properties of the catchment in the model. Agricultural lands introduce nutrients to waterways through both surface runoff and erosion during storms

Table 5 Event mean flux values by land use type for selected constituents

Flux (kg/km^2)	Agriculture	Commercial	Industrial	Open Space	Residential
Ammonia	49.9	94.1	74.5	1.83	56.5
Nitrate	271	275	287	50.8	219
Phosphate	20.9	103	83.1	14	76.1

Table 6 Calibrated treatment efficiency values

Zone	NH4	NO3	TP
Santa Clara River	0.95	0.95	0.95

and through shallow groundwater flows. The nutrient sources include fertilizers applied during cultivation; organic litter from the plants, grasses, or trees; erosion of the surface soils; waste accumulation from grazing animals; and soluble nutrients released during the decomposition and mineralization of plant litter and animal waste. Manure produced by horses, cattle, sheep, goats, birds, and other wildlife in the watershed contribute nutrients and bacteria as well. These loads can be introduced directly to the receiving waters in the case of waterfowl or cattle wading in streams, or they may occur as non-point sources during storm runoff.

Although some information exists about the different agricultural practices in the watershed and different nutrient removal rates by different crops, there is no information that allows for the adequate characterization of oxidized nitrogen and phosphate discharges from different types of agriculture. For this reason, general agricultural loading and removal rates were calibrated using the water quality sample data.

The sewer system is also a potential source of nutrients to surface waters by introducing nutrients to shallow groundwater that may eventually enter surface waters. Septic systems (onsite wastewater treatment systems) are used in areas where direct connection to sewer lines is not possible and have been used as a form of wastewater disposal in various parts of the Santa Clara River watershed for many decades.

In the MIKE BASIN Load Calculator, the impact of sewer systems on surface water quality can be configured as a function of population and treatment efficiencies. The treatment efficiencies vary between 0 and 1, with 0 representing no retention and 1 representing complete retention. Treatment efficiency values for various zones were obtained for three constituents during the calibration processes (Table 6). No pronounced spatial variation was found in the watershed and a single set of treatment efficiency values were applied in the model.

The population in each subwatershed was estimated using the 2001 LandScanTM Global Population Database (Bhaduri et al. 2002; see http://www.ornl.gov/landscan/ for additional details). The grid-based LandScan population density was generated by distributing best available census counts to 30” by 30” grid cells through a “smart” interpolation based on the relative likelihood of population occurrence in grid cells due to road proximity, slope, land cover, and nighttime lights (Bright 2002).

The total loadings in each subwatershed are the sum of the loadings from all sources and these are then specified as properties of the catchment in the model. The estimated concentrations were compared with the sample data for the graphic error analysis. Figure 4 shows the water quality monitoring sites including mass emission and land use sites in the watershed. Samples at land use sites were taken in very specific years and no reoccurring sample data are available at these sites. Table 7 lists sites that have water quality sample data.

Table 7 Water quality monitoring sites within the Santa Clara River watershed

Station ID	Station Name	Source	Data
RA/RB	Santa Clara River at Bouquet Canyon	UWCD	1991-2004
S29	Santa Clara River at Old Road	LADPW	1988-1995,2002-2006
RE	Santa Clara River at Castaic Creek	UWCD	1991-2004
P-R-3	Santa Clara River near Santa Paula	UWCD	1999-2004
ME-SCR	Santa Clara River Mass Emission Site	VCWPD	2001-2007
I-2	Ortega Street industrial land use site	VCWPD	Discontinued
R-1	Swan Street and Macaw Avenue residential land use site	VCWPD	Discontinued

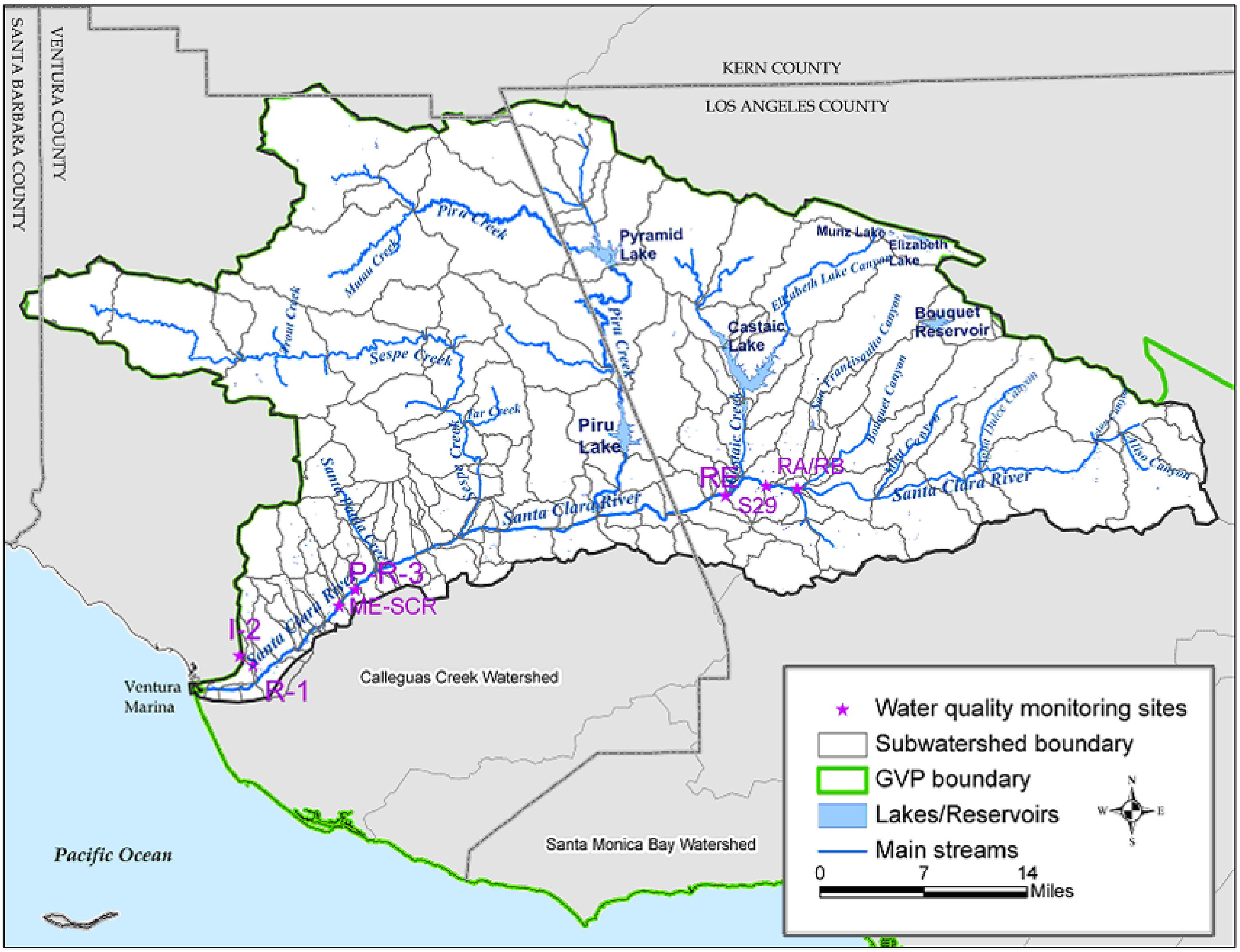

Figure 4 Watershed and stream segmentation

3 Subwatershed Delineation and Characterization

Similar to many other hydrologic and water quality models, MIKE BASIN requires the entire watershed to be segmented into a series of subwatersheds, a process also referred to as 'segmentation'. The individual subwatersheds are assumed to demonstrate relatively homogenous hydrologic, hydraulic and water quality behavior. This segmentation provides the basis for assigning similar or identical inputs and/or parameter values to the whole of the land area or channel length contained within a model subwatershed. Each subwatershed tends to simulate separate hydrologic and water quality conditions in response to storms and other driving forces and will be linked together using the model routing algorithm to represent the entire watershed area.

For the Santa Clara River watershed, this segmentation was primarily based on the stream networks, topographic variability, and secondarily on the location of flow and water quality monitoring stations, consistency of hydrologic and land use factors, and the existing catchment boundary layer. The stream network was generated from the 1:24K NHD dataset with minor revisions from various sources of aerial imagery, storm drainage data and topographic maps (Sheng et al. 2007). Catchment boundaries were delineated for each individual river segment using the improved

1:24K NHD dataset and the Nature Conservancy Tool (Fitzhugh 2001; Sheng et al. 2007). The highly segmented catchment units were accordingly lumped into larger subwatersheds based on the flow direction, stream network, drain network, land use map, and stream/water quality gauges. The entire watershed was aggregated into 146 subwatersheds for the MIKE BASIN model runs (Figure 4).

4 Model Calibration and Validation

4.1 MIKE BASIN Rainfall-runoff NAM Model Configuration

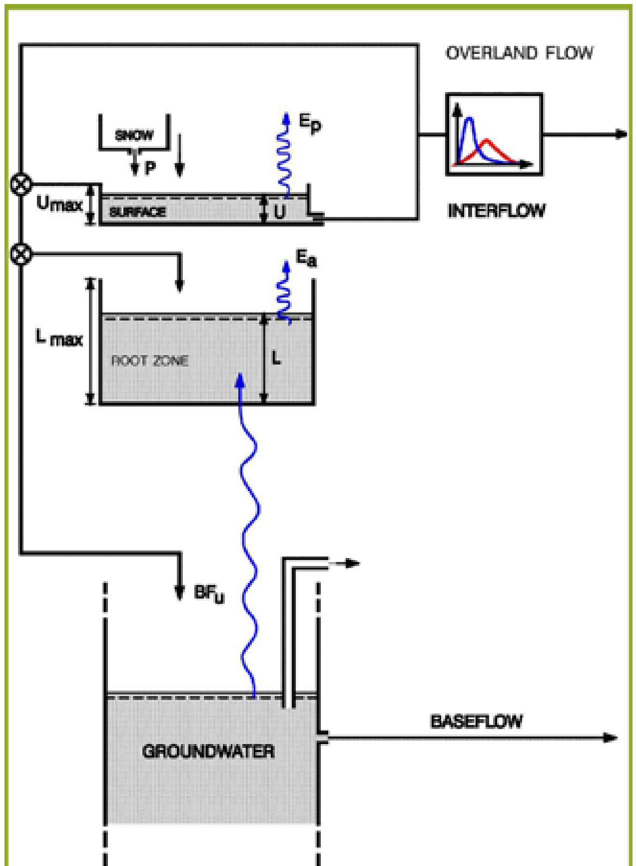

Figure 5 NAM model schematic

In MIKE BASIN, the NAM Rainfall-Runoff model is used to link rainfall and runoff. The NAM model is a deterministic, lumped and conceptual rainfall-runoff model accounting for the water content in up to four different storages representing the surface zone, root zone and the ground water storages (Figure 5). The NAM model was prepared with nine parameters representing four default storages. These eight parameters were specified for each representative subwatershed (Table 8). Parameter values were derived from the rainfall-runoff calibration implemented in several representative subwatersheds (see Figures A-1 through A-4 for additional details). Initial values of overland flow, interflow, baseflow, groundwater and snow storage were also specified for each of the MIKE BASIN subwatersheds that required rainfall-runoff modeling.

Table 8 Main NAM parameters

Symbol	Definition	Usual Value	Implications
Umax	Maximum contents of surface storage	10-25 mm	Evaporation; small peaks
Lmax	Maximum contents of rootzone storage	50-250 mm	Evaporation; water balance
CQof	Overland flow coefficient	0.01 - 0.99	Divides excess rainfall in runoff and infiltration
TOF	Rootzone threshold value for overland flow	0.0 - 0.7	Delays overland flow at the beginning of a wet season
TG	Root zone threshold value for recharge	0.0 - 0.7	Delays groundwater recharge at the beginning of a wet season
CKBF	Time constant for routing baseflow	500 - 5000 hours	Determines shape of baseflow hydrograph
CK1,2	Time constant for routing overland flow	3-48 hours	Determines shape of peaks

The NAM model requires precipitation and evapotranspirration input data. The Thiessen polygon method was used to determine precipitation time series for each subwatershed by assigning precipitation from a meteorological station to a computed polygon representing that station's data. The influence of storm pattern and elevation on the precipitation was evaluated by comparing the annual average precipitation in depth derived from the ANUSPLIN (Hutchinson 1995) simulated precipitation surface with the annual observations. The comparisons implied that current precipitation observations are spatially adequate in representing precipitation distribution for the sub-catchment level that we delineated. As a result, no modification was performed on the precipitation observations and each sub-catchment was assigned precipitation and evapotranspiration time series using the Thiessen polygon method.

The Santa Felicia reservoir-dam system was also simulated in MIKE BASIN. The specified operating policies were simulated using associated operating rule curves generated from the operation data provided by the county. These define the desired storage volumes, water levels and releases at any time as a function of existing water level, time of the year, demand for water and expected inflows.

4.2 Hydrology Calibration and Validation

After the model was configured, model calibration and validation were carried out. This is generally a two-phase process, with hydrology calibration and validation completed before conducting the same process for the water quality simulation. Upon completion of the calibration and validation at selected locations, a calibrated dataset containing parameter values for rainfall runoff simulation for each selected subwatershed was developed. Calibration is the adjustment or fine-tuning of rainfall-runoff modeling parameters to reproduce observations. The calibration was performed on the four selected subwatersheds from 10/1/1996 to 9/30/2005 and the values were extrapolated for all ungauged subwatersheds exhibiting similar physical, meteorological, and land use characteristics. Subsequently, more validation runs were performed to test the calibrated parameters at four more locations for the same time period without further adjustment.

Hydrology is the first model component calibrated because estimation of pollutant loadings relies heavily on flow prediction. The hydrology calibration involves a comparison of model results to flow observations at selected locations. After comparing the results, key hydrologic parameters were adjusted and additional model simulations were performed. This iterative process was repeated until the simulation results represented the hydrological behavior of the catchment as closely as possible and reproduced observed flow patterns and magnitudes. This process was automated using the MIKE 11 Autocalibration module. For modeling the rainfall–runoff process at the catchment scale, normally the only available information for evaluating this objective is the total catchment runoff. Thus, the amount of information provides certain limitations on how to evaluate the calibration objective.

The calibration scheme used by the MIKE 11 Autocalibration module includes optimization of multiple objectives that measure different aspects of the hydrograph: (1) overall water balance, (2) overall shape of the hydrograph, (3) peak flows, and (4) low flows. In order to obtain a successful calibration by using automatic optimization routines, four numerical performance measures are formulated to reflect the aforementioned calibration objectives as follows: (1) overall volume error, (2) overall root mean square error (RMSE), (3) average RMSE of peak flow events, and (4) average RMSE of low flow events. The detailed formulas can be obtained from Madsen (2000).

It is very important to note that, in general, trade-offs exist between the different objectives. For instance, one may find a set of parameters that provide a very good simulation of peak flows but a poor simulation of low flows, and vice versa.

The model's performance was evaluated through time-variable plots and regression analyses for each station on both a daily and seasonal basis. Some general

Table 9 General calibration/validation targets or tolerances for assessing model performance (Aqua Terra Consultants 2004)

R^2	0.6	0.7	0.8	0.9
Daily flows	Poor	Fair	Good	Very good
Monthly flows	Poor	Fair	Good	Very good

guidance used by EPA's HSPF model users over the past decade (e.g. Donigian 2000) was adopted to help assess MIKE BASIN model accuracy (Table 9). Table 10 also presents the range of coefficient of determination (R2) values that may be appropriate for judging how well the model is performing based on the daily and monthly simulations. To supplement the model accuracy assessment, relative errors of model-simulated water volumes with various hydrologic and time-variable considerations were determined to assess the model performance for each calibration and validation analysis.

Table 10 R2 value ranges for model assessment (Aqua Terra Consultants 2004)

	% difference between simulated and observed values			
	Very good	Good	Fair	Poor
Hydrology/Flow	<10	10 - 15	15 -25	>25
Water Quality/Nutrients	<15	15 - 25	25 -35	>35

4.2.1 Hydrology Calibration Results

Figure A-1 shows the calibration results for USGS 11113000/710A,B,C,D Sespe Creek near Fillmore, CA gauging station. The table in Figure A-1 summarizes the calibrated parameters. A nine-year time series plot of modeled and observed daily flows is presented here along with a mass curve showing cumulative simulated and observed runoff volumes versus time. The time series plot shows that the model picked up seven annual storm peaks but missed the small storm peaks on the plot. These kinds of outcomes were also observed in the other calibration cases. Regression analyses were performed for both daily and monthly values. The graphs at the bottom of Figure A-1 show that the model performs better in reproducing average monthly values than daily values given much higher coefficient of determination (R2) values for monthly data (R2=0.95 versus R2= 0.83 for daily data). Table A-1 presents the error analysis performed on the predicted volumes. The volume comparisons indicate that the model satisfactorily reproduces high flows, total, fall and winter flow volume but does fairly poor predicting low flow periods (the total low flow volume was over-estimated). Both the time-variable plots and volume comparisons indicate that the model reproduced the calibration observation data for this minimally controlled headwater subwatershed reasonably well.

The USGS 11109375/716 Piru Creek below Buck Creek near Pyramid Lake CA gauging is another site selected for the calibration that represents a natural undeveloped headwater subwatershed that has data covering the period from 10/1993 to 10/2003. The regression lines between the observed and simulated flows show fairly acceptable calibration results in this headwater area with particularly good performance in generating summer flows (Figure A-2), which is not observed in any other subwatersheds selected for calibration. The model under-estimated flow regimes during the most time of the year (Table A-2).

Calibration was also performed for a subwatershed that is impacted by the agricultural water diversion at the USGS 11110500/701 at Hopper Creek near Piru CA gauging station. Only winter flow conditions were closely reproduced. The model had difficulty reproducing total stream volume and low flow volumes probably because it under-estimated agricultural water diverted from the creek (Table A-3).

The calibration results for the USGS 11108000/F92-R at Santa Clara River near Saugus CA gauging station show that the simulated flows reproduced observed flows reasonably well (Figure A-4). The model performed very satisfactorily in reproducing high flows, winter flows and even the 10th percentile low flows at this gauging station (Table A-4).

4.2.2 Hydrology Validation Results

After calibrating hydrology, the model was implemented using calibrated hydrologic parameters at four more locations along the main stem and tributaries for the period of 10/1996 to 09/2005. Validation results were assessed through time-variable plots and regression analyses for the USGS 11113500/709/709A, USGS 11109600/705/705A, USGS 11109000/707A and 720 Santa Clara River at 12th Street gauging stations as shown in Figures A-5 through A-8. Table 11 summarizes the results from these validation assessments.

For the four validated stations, the total stream water volumes were very well simulated with the exception of the Piru Creek above Lake Piru site. Very good validation results were achieved for simulating the 90th percentile high flows while the 10th percentile low flows were over-predicted and therefore simulated with less accuracy. The overall validation results suggest a satisfactory model performance and that the model adequately represented the baseline flow conditions in the watershed.

Model results for USGS 11113500/709/709A at Santa Paula Creek near Santa Paula CA were similar to the aforementioned located on Sespe Creek. Figure A-5 shows the time-variable plots and volume error analyses, respectively, for Santa Paula Creek. The graphic comparisons show that the model was very good in reproducing the observed flow pattern at this location. Specifically, an analysis of the error indicates that the model predicts total volume and high flow regimes reasonably well while slightly under-estimating the 10th percentile low flows.

Validation results for the lower Santa Clara River are directly influenced by the water diversion off the creek and the main stream. Over-predictions in low flows might be overcome by incorporating agricultural diversion data with a finer temporal resolution in the model.

4.3 Water Quality Calibration and Validation

MIKE BASIN can simulate water quality in surface and groundwater, with solute inputs from non-point and/or point sources. The water quality module then simulates the reactive steady-state transport of these substances. In general, first-order rate laws are assumed for all default substances predefined in the model including ammonium-nitrogen, nitrate-nitrogen, DO, BOD, total phosphorous, and E-coli, and the steady-state approach is consistent with MIKE BASIN's solution to the water allocation problem. Thus, advection cannot be modeled properly with MIKE BASIN, so that pulses of solute entering the stream do not travel downstream as simulation time advances. Specific routing approaches can be defined (e.g. linear, Muskingum, wave translation) in the individual reaches, such that the residence time and the effects of mixing between reach storage and inflows can be properly specified in the model.

Table 11 Model validation results summary

Sites	Overall assessment	Simulated High flows	Simulated low flows	Monthly R^2
USGS 11113500/709/709A Santa Paula near Santa Paula	Very good	Good	Good	0.93
USGS 11109600/705/705A Piru Creek above Lake Piru	Poor	Poor	Poor	0.67
USGS 11109000/707A Santa Clara River near Piru	Very good	Very good	Fair	0.86
VCWPD 720 Santa Clara River at 12th Street	Good	Very good	Poor	0.98

After the model was calibrated and validated for hydrology, water quality simulations were performed from 10/1996 through 09/2005. The water quality load calculator was calibrated by comparing model output with pollutographs for NH3-N, NO3-N, and TP observed at four locations in the Santa Clara River watershed. After comparing the results, key water quality parameters such as pollutant treatment coefficients were adjusted and additional model simulation runs were performed. This iterative process was repeated until the simulation results closely reproduced observed pollutographs. Different runoff coefficients and treatment coefficients for three constituents resulted from the calibration processes.

To assess the predictive capability of the model, the final output was graphically compared to observed data. Figures B-1 and B-4 present the time-series plots of model results and observed data at four monitoring sites. The LADPW monitors a mass emission station (S29 at Santa Clara River at Old Road) about 1.8 miles downstream from the confluence of San Francisquito Canyon with the Santa Clara River. The UWCD and VCWPD monitor several other water quality sites as well, and NH4, NO3, TP and other constituents are analyzed periodically for selected storm events. The graphic comparisons and quantitative analyses were performed based on small numbers of storm event-based water quality samples.

During the water quality simulation, we found that the total discharge to several nodes of the stream network was close to zero for a couple of simulations, which led to the extremely high concentrations of the three constituents. Therefore, the results from this time periods (10/1996-12/1996) were ignored in the output pollutographs and all subsequent analysis.

The water quality simulations were not satisfactory in reproducing the observed sample concentrations. Many predictions of constituent concentrations fell outside the range of fair criteria that were used for the water quality assessment. Graphically, some sample concentrations were captured while others were missed in the pollutographs and they did not always predict the temporal variability of the pollutograph. The mean values of the modeled and observed time series without the outlier values in the sample time series are summarized in Table 12. The simulation results for NO3 were slightly better than those for NH4 and TP in terms of error percentages and could be considered to represent fair performance based on the predetermined water quality model performance criteria.

Figure B-1 presents modeled and observed pollutographs for NH4 and NO3 for the RA/RB site, located at the intersection of Bouquet Canyon and the Santa Clara River. NH4 concentrations were underestimated by an average 35% at this site but followed the temporal variation well, which indicates the influence of the Saugus WRP on the in-stream constituent loadings. The

Table 12 Summary of modeled and observed water quality at selected sites

Sites		NH4 [mg/l]	NO3 [mg/l]	TP [mg/l]
RA/RB	Modeled	7.31	2.62	No data
	Observed	11.3	2.86	/
	Error (%)	-35.3	-8.4	/
S29	Modeled	No data	No data	0.53
	Observed	/	/	0.37
	Error (%)	/	/	43.2
RE	Modeled	10.36	2.76	No data
	Observed	5.51	4.15	/
	Error (%)	88.0	-33.5	/
ME-SCR	Modeled	1.15	0.75	0.16
	Observed	0.31	1.45	1.67
	Error (%)	271.0	-48.3	-90.4

Saugus WRP provides tertiary level treatment for seven million gallons of wastewater per day and discharges to the Santa Clara River. There are approximately 270 and 40 kg per day of NH4 and NO3, respectively discharged to the surface water as well. The magnitude and temporal variation of NO3 concentrations at this site seem to be reasonably well reproduced.

The LADPW operates the S29 mass emission station about 3.5 miles downstream from the RA/RB site. The model roughly reproduced the TP pollutographs during the simulation period from 2002 to 2005 at this site (Figure B-2). The low modeled TP concentration since 2001 is associated with the large reduction in the total phosphate concentration released from the Saugus WRP and missing records for the Valencia WRP.

The RE mass emission site is located about two miles downstream from the S29 mass emission site and above the confluence of Castaic Creek and the Santa Clara River. Predictions of the nitrogen concentrations were impacted by the small agricultural land use present near the stream bank, which was not represented in the model because of the dominant natural land use in the predefined subcatchment unit. The high NO3 concentrations in this local agricultural runoff to the monitored receiving waters can be expected to overwhelm the resultant NO3 pollutograph and result in the underestimated NO3 curve at the RE site (Figure B-3).

The P-R-3 and ME-SCR mass emission sites are only 1.5 miles apart. The measurements for NO3 and NH4 were highly correlated and very similar at the two sites. Observed and modeled constituent pollutographs for ME-SCR are plotted in Figure B-4. It seemed that the model was not able to predict the constituent concentrations for a certain time period during the simulation. The impacts of the WRP discharges on the downstream concentration were not dealt well by the model, as illustrated by the over-estimates of NH4 concentrations in 2002.

5 Results

The spatial-temporal variations of flow and water quality in the Santa Clara River watershed are characterized based on the model simulation results. Figure 6 depicts a time-series plot of modeled monthly flows in acre feet (AF) and as a percentage of the corresponding annual flow volumes at the outlet to the ocean.

Average monthly in-stream flow in the Santa Clara River at the outlet was about 45,000 AF during the simulation period. This average was lower than might be expected because of the extremely low flow conditions that occurred in the 2003 water year. The monthly flows are highly variable with discharge varying by several orders of magnitude. The flow discharge varied from 830,000 AF in February 1998 to the lows of about 10 AF that occurred in many dry months. The monthly flows varied from 0.1 to 41% when expressed as percentages of annual discharges. The winter flows contribute the

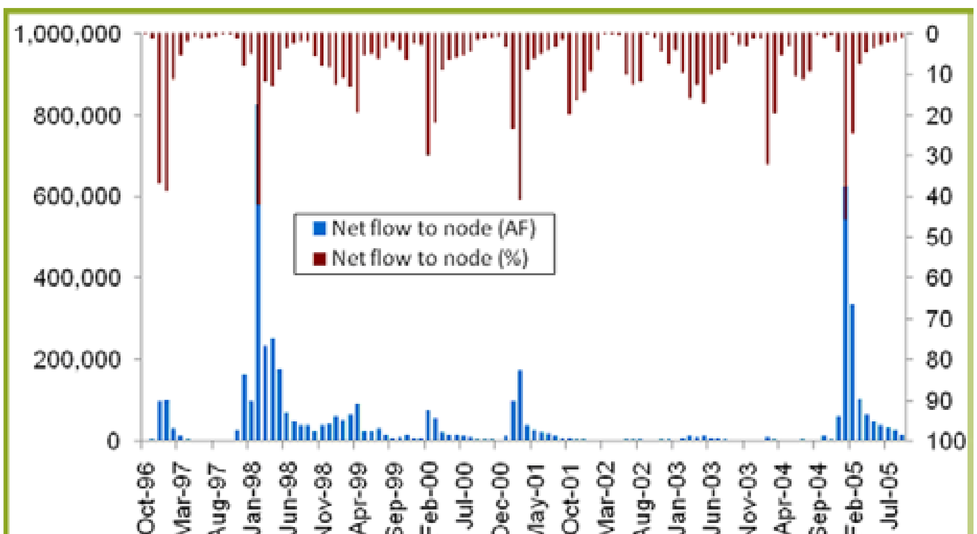

Figure 6 Flow volumes in acre-feet and as a percentage of annual flows for the Santa Clara River at the outlet

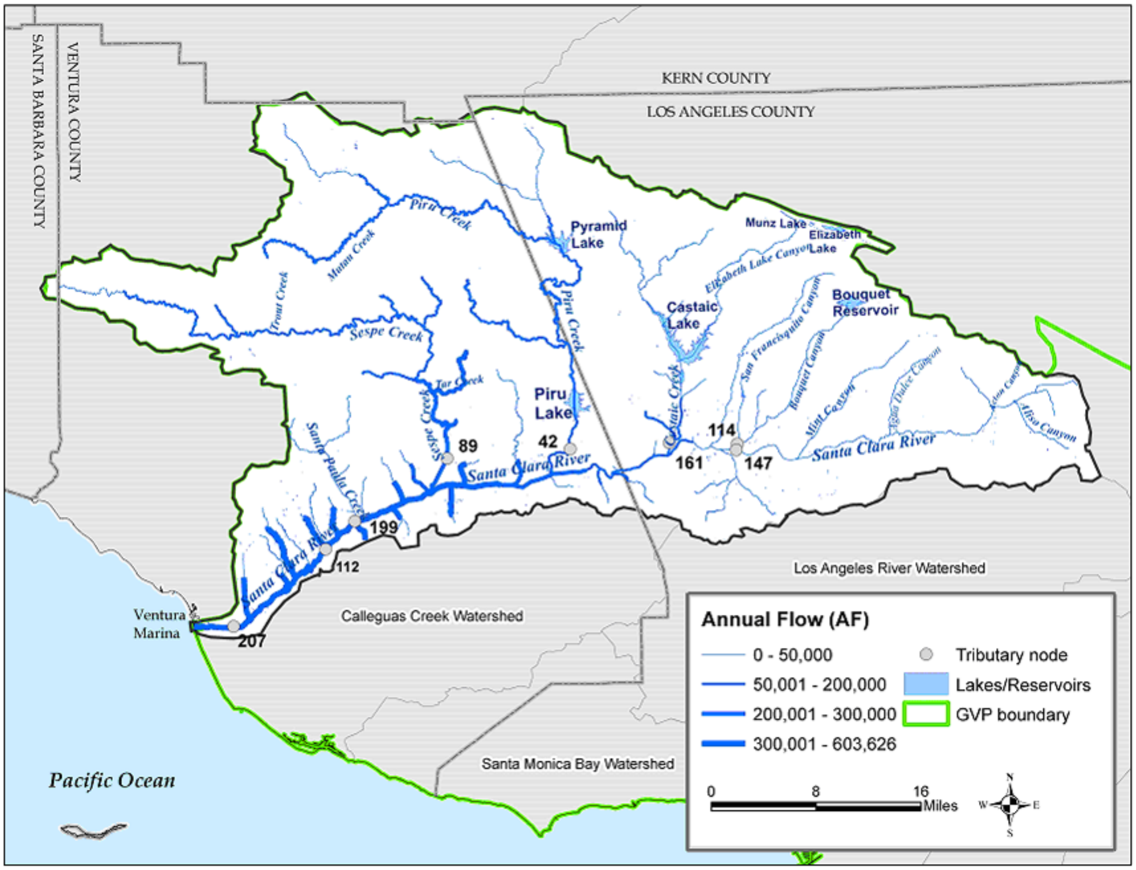

Figure 7 Cumulative flow discharges along the stream network

majority of the annual flow to the ocean. The flows are significantly lower and less variable during the dry weather period. From 1996 to 2005, dry-weather flows (May to October) accounted for just 19% of the annual discharge from the Santa Clara River.

The discharges of the various tributaries vary substantially (Figure 7). Table 13 summarizes the average inflows from several major tributaries to the main stem and shows that Sespe Creek contributes 40.5% of the total flow at the outlet on average. Sespe Creek is the only stream in Southern California designated as a California Wild and Scenic River (Federal Register 2002), and supports many riparian species that are not found in abundance elsewhere on the southern or central coast of California (USDA 2003). The Freeman Diversion, located between the N207 and N112 gauging stations, diverts approximately 60,000 AF of water annually to

Table 13 Annual discharges from the main channel and tributaries and fractions of flow reaching the ocean

Reach name	Node ID	Annual Q [AF]	Q to the ocean (%)	Area (%)
Bouquet Canyon	N114	4,571	0.8	4.4
Upper SCR at Bouquet Canyon	N147	18,778	3.2	14.6
Castaic Creek	N161	51,491	8.9	12.5
Santa Paula	N199	33,017	5.7	2.5
Piru Creek	N42	192,937	33.2	26.9
Sespe Creek	N89	235,111	40.5	16.1
ME-SCR site	N112	600,422	103.3	95.1
Santa Clara River outlet	N207	581,142	100.0	100.0

feed the groundwater recharge facilities as well as supply the Pleasant valley and Pumping Trough Pipelines (UWCD 2001), which causes smaller flow volumes at the lower of the two gauging stations (N207).

The water quality simulation results are used to characterize the spatial distribution of nutrient abundance associated with catchments and cumulative nutrient loads along the stream network. Figure 8 shows the total nutrient loads simulated for Santa Clara River at the bottom of the watershed as a time-series plot of modeled monthly loads and as a fraction of the corresponding annual loads. Monthly average in-stream loads in the Santa Clara River at the outlet were about 14,000, 19,000 and 5,000 kg for NH4, NO3 and TP, respectively, during the simulation period. Temporal variations in nutrient loads are relatively similar between the three nutrients. The large variation occurs in the storm seasons (e.g. December through February) while significantly lower and less variable monthly loads are predicted during the non-storm season. Larger fractions (%) of the total loads associated with winter storms make it to the ocean than those from the three other seasons. For example, the NO3 loads ranged from 410,000 kg in February 1998 (62% of the annual load) to 600 kg (≤ 2% of the annual load) in many of the dry months. The wet-weather flows (November to the following April) accounted for 81% of the annual NO3 loads from the Santa Clara River from 1996 to 2005.

Nutrients loads generally increase moving downstream. The average annual loads from several major tributaries

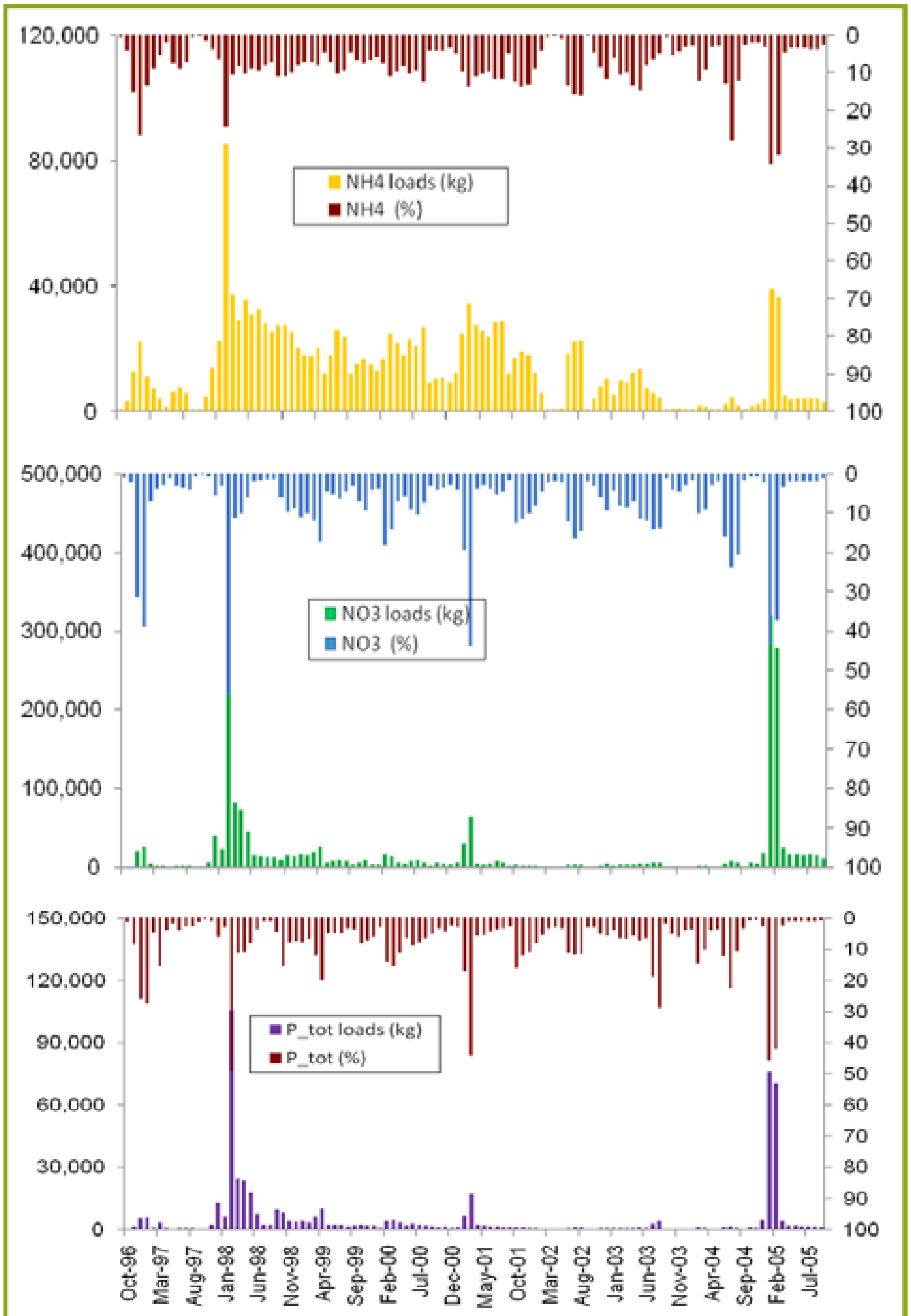

Figure 8 Monthly nutrients loads in kg and percentages for the Santa Clara River at the outlet

Table 14 Annual nutrient loads from main channel and tributaries and fractions reaching the ocean

Reach Name	Node ID	NH4(kg)	NH4 % to the ocean	NO3 (kg)	NO3 % to the ocean	TP (kg)	TP % to the ocean	Area (%)
Bouquet Canyon	N114	5,525	**3.1**	15,605	**6.3**	5,271	**7.9**	4.4
Upper SCR at Bouquet Canyon	N147	83,221	**46.8**	50,503	**20.4**	15,699	**23.6**	14.6
Castaic Creek	N161	3,800	**2.1**	21,921	**8.8**	6,517	**9.8**	12.5
Santa Paula	N199	2,581	**1.5**	4,770	**1.9**	2,054	**3.1**	2.5
Piru Creek	N42	2,897	**1.6**	48,787	**19.7**	13,263	**20.0**	26.9
Sespe Creek	N89	1,109	**0.6**	23,326	**9.4**	6,214	**9.4**	16.1
ME-SCR site	N112	243,345	**136.9**	261,788	**105.7**	69,118	**104.1**	95.1
SCR Outlet	N207	177,817	**100.0**	247,769	**100.0**	66,394	**100.0**	100.0

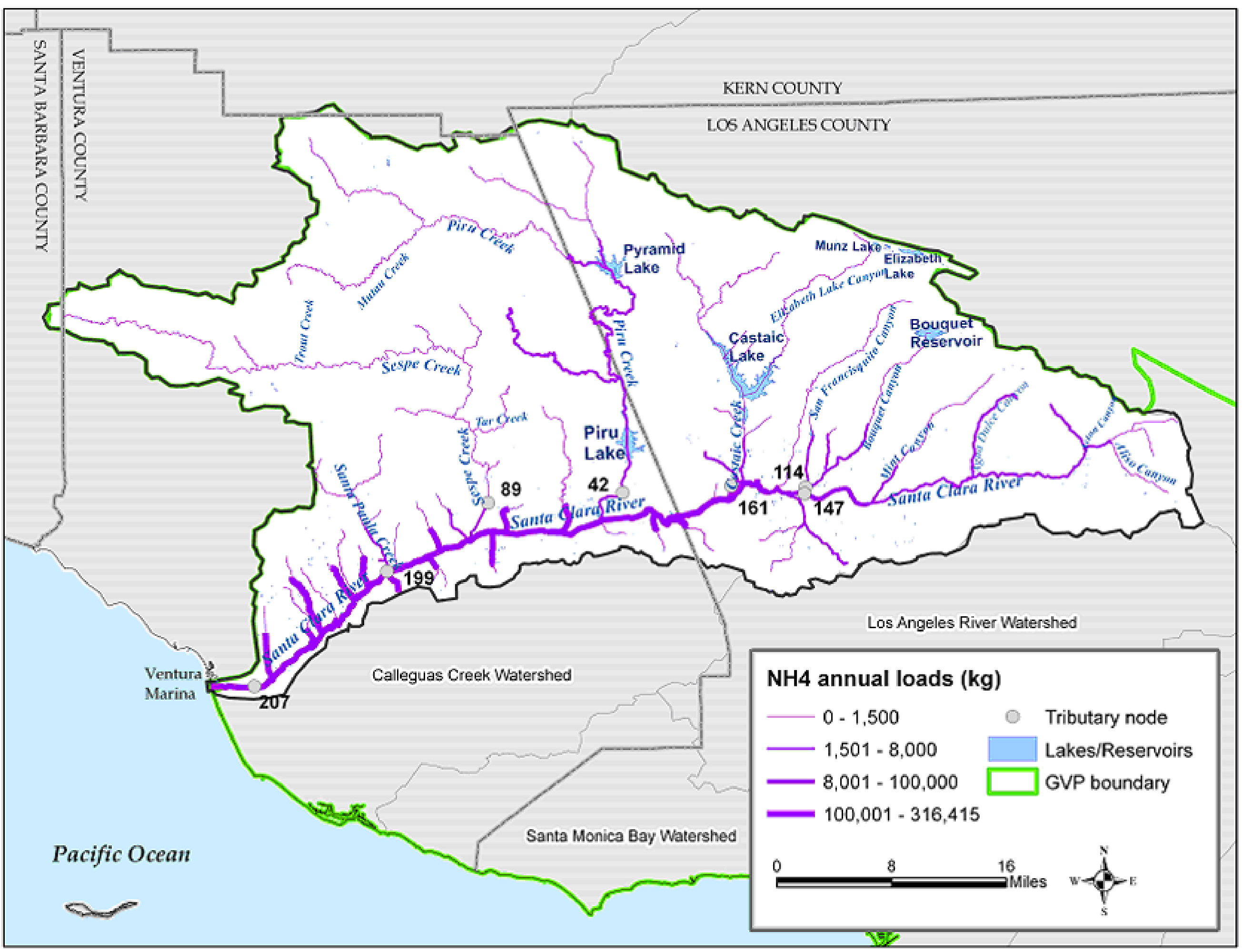

Figure 9a NH4 loads along the stream network

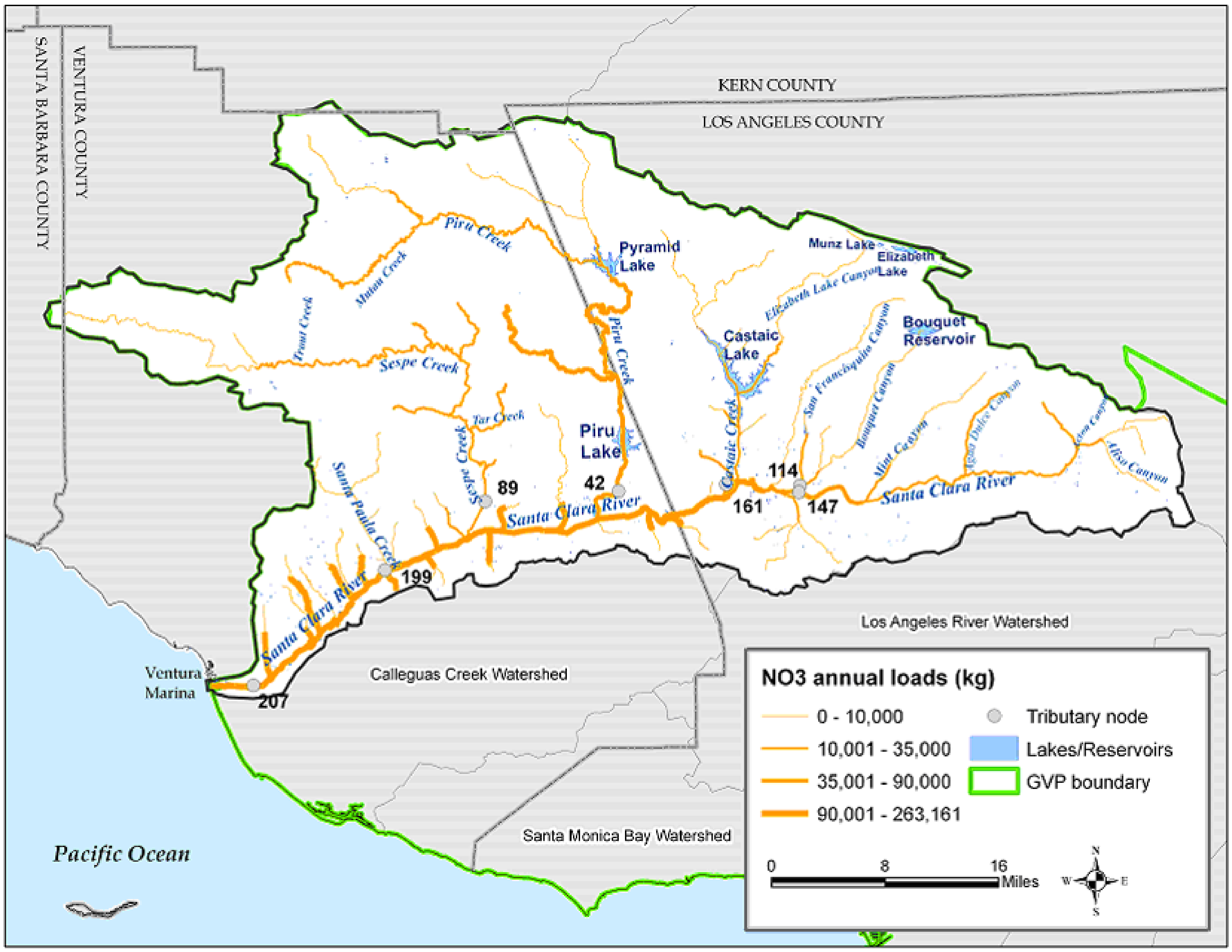

Figure 9b NO3 nutrients loads along the stream network

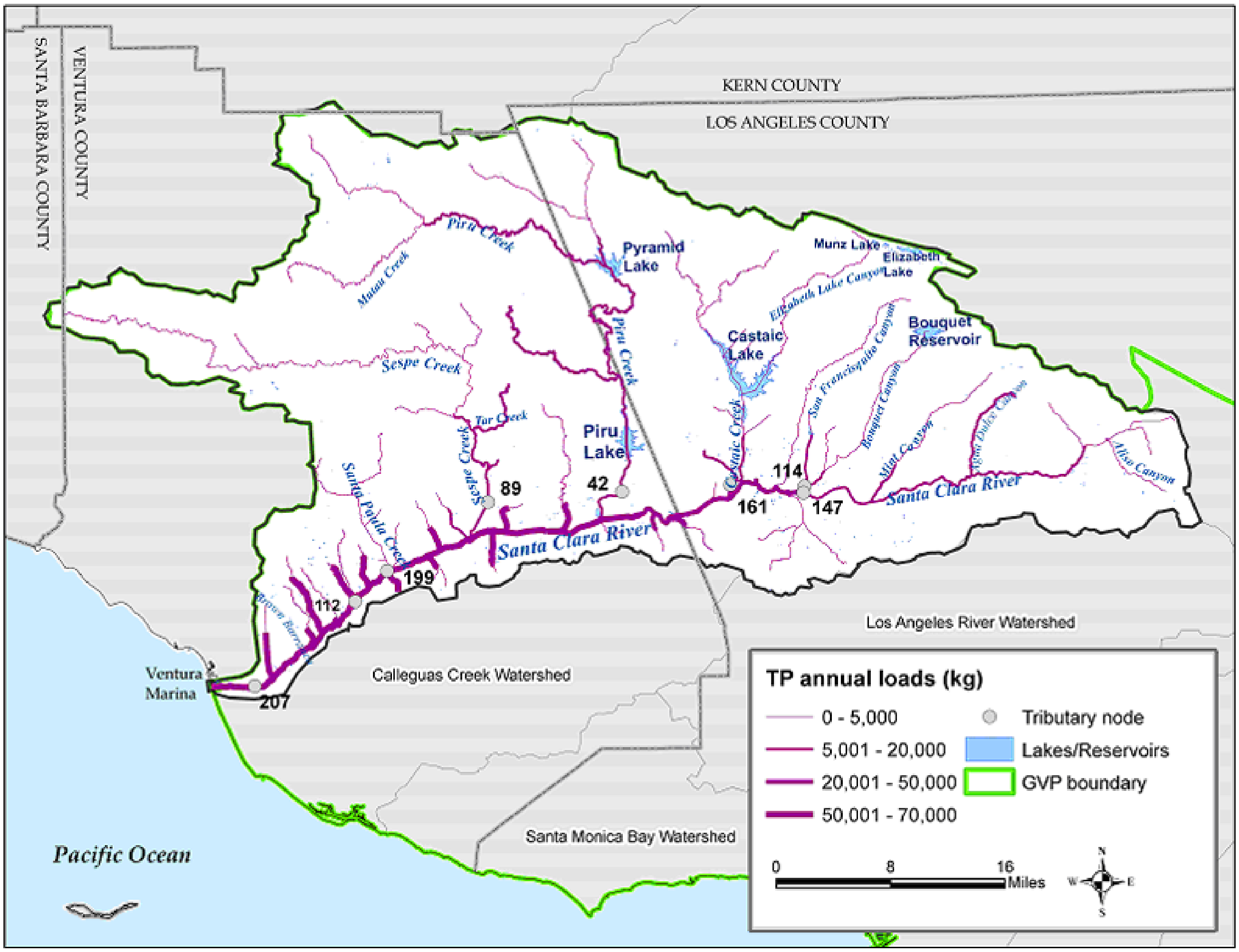

Figure 9c TP nutrients loads along the stream network

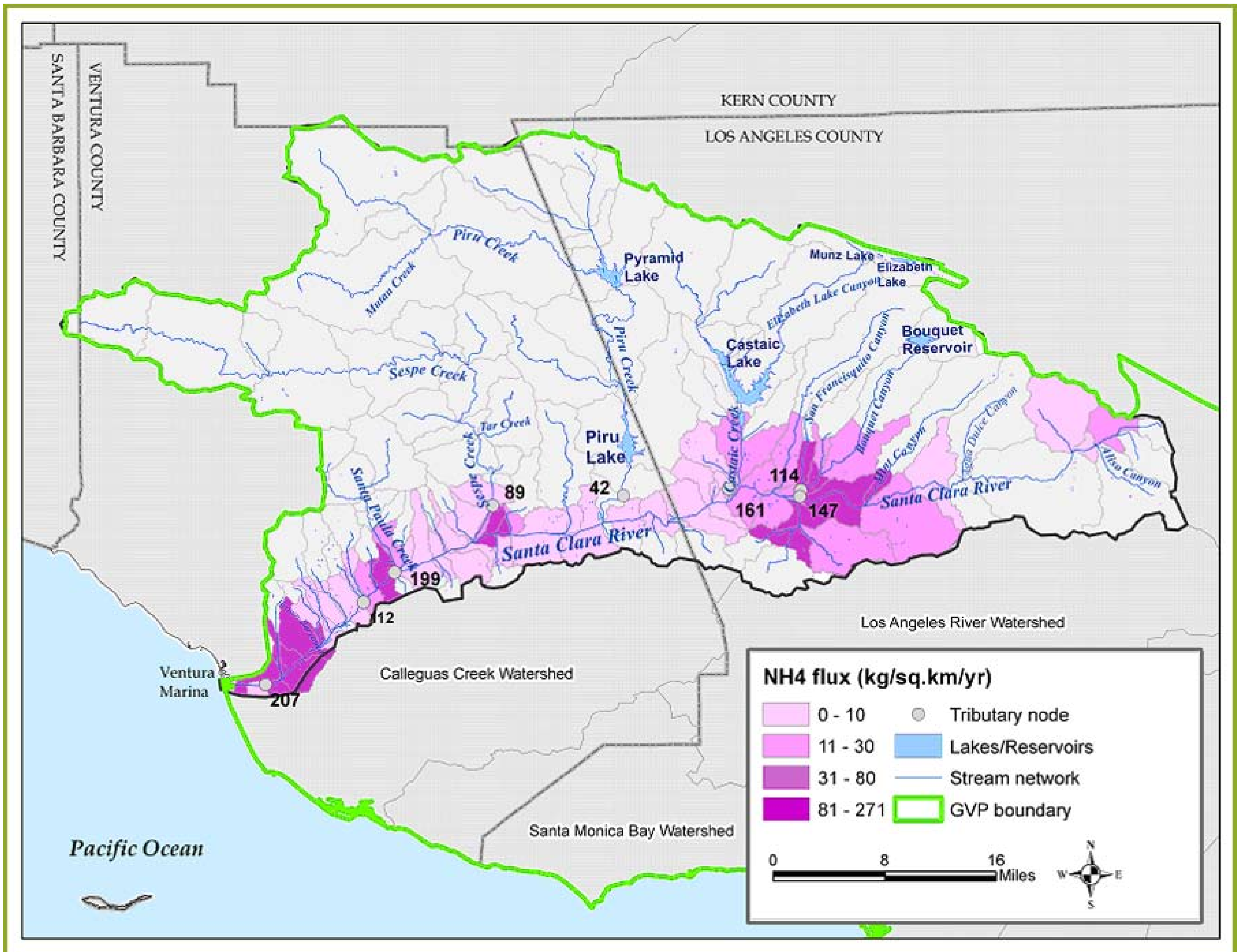

Figure 10a NH4 flux associated with each subcatchment

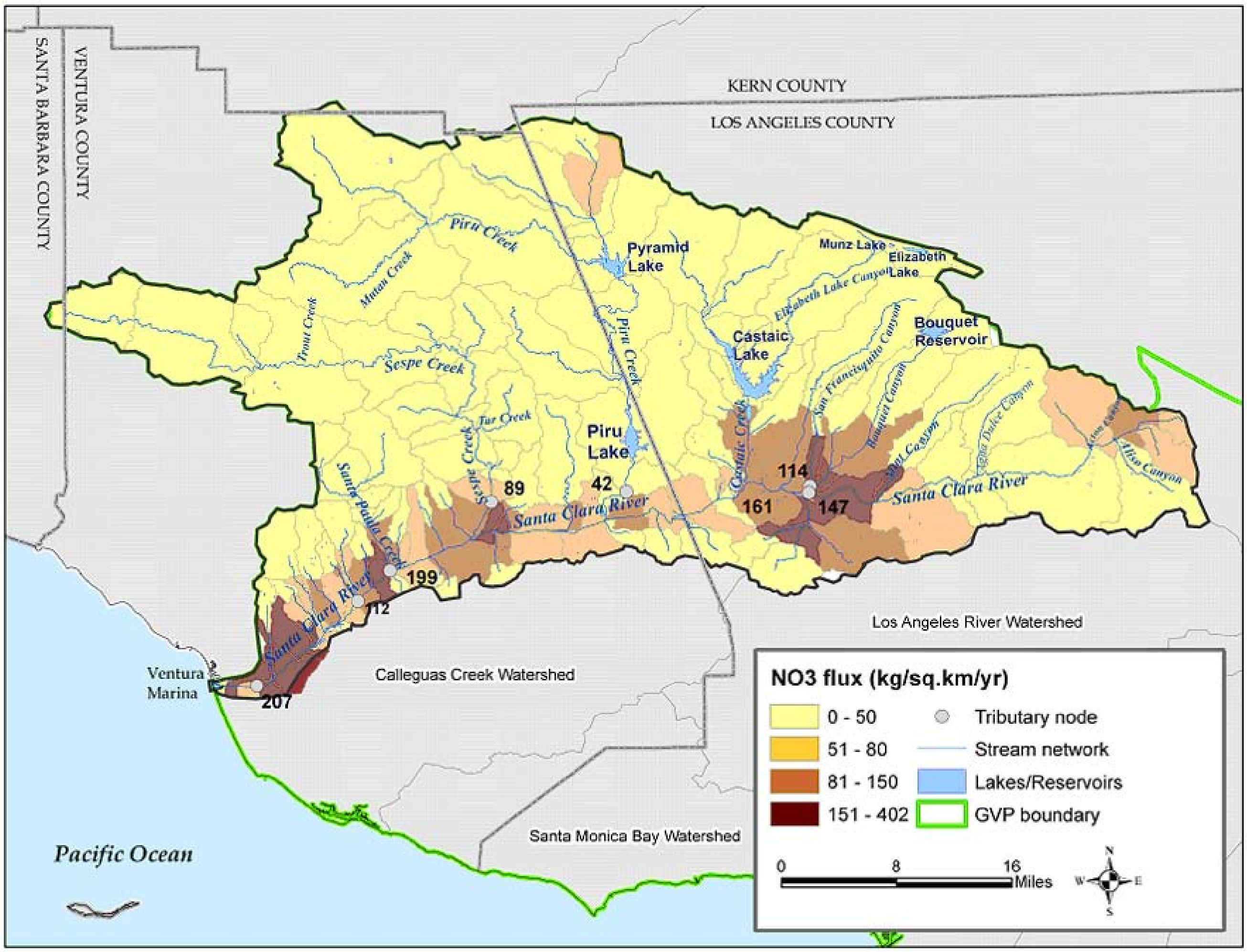

Figure 10b NO3 flux associated with each subcatchment

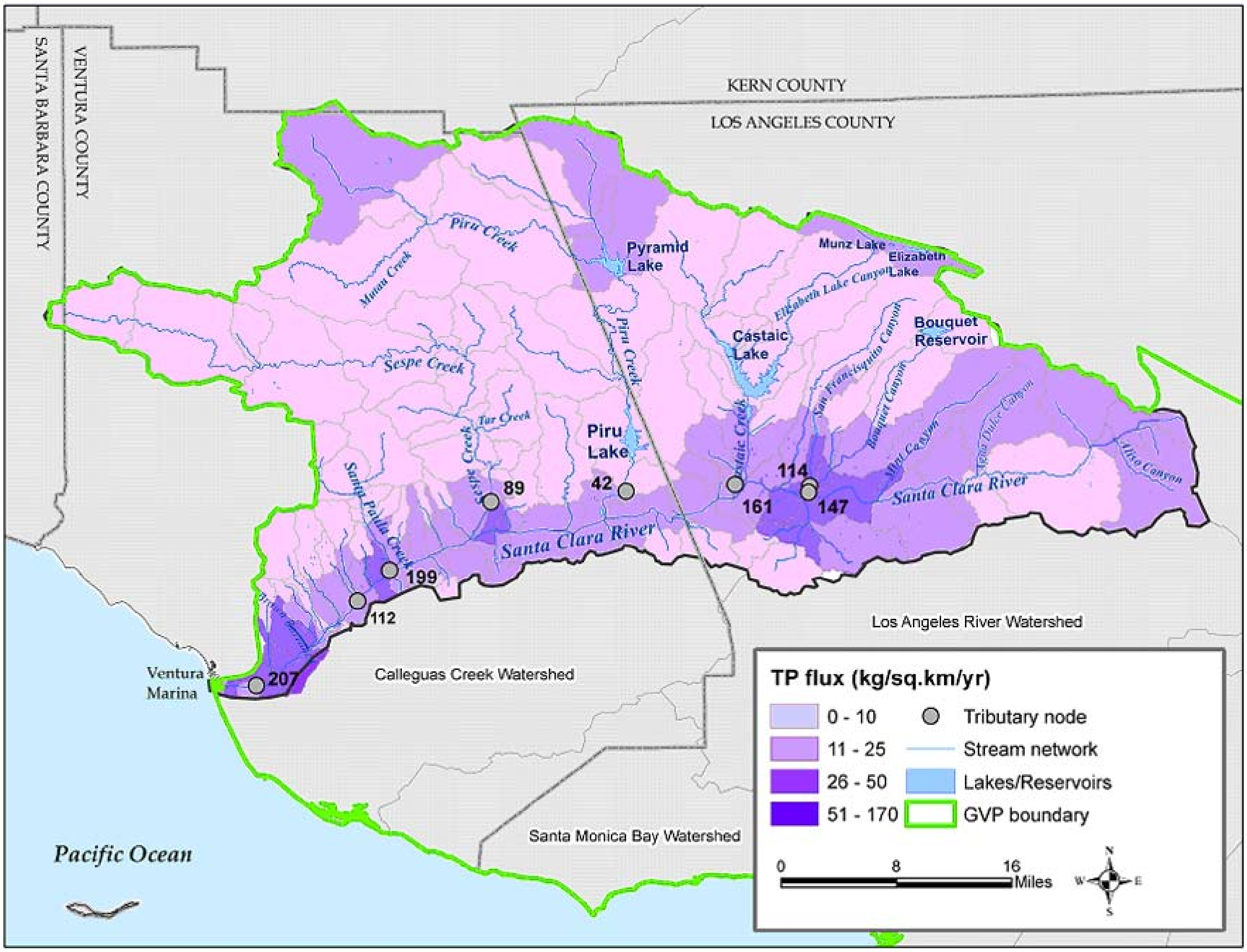

Figure 10c TP fluxes associated with each subcatchment

to the watershed total loads are summarized in Table 14. Figure 9 shows the spatial distribution of the nutrients loads along the stream network and indicates that a substantial fraction of the nutrients loads are added to the upper Santa Clara River at Bouquet Canyon (N147), which provides approximately 47, 20 and 24% of the total NH4, NO3 and TP loads, respectively, to the Santa Clara River.

Figure 10 demonstrates the spatial distribution of nutrient flux (i.e. sources) in each catchment. The spatial patterns are similar for the three nutrients. The high NH4, NO3 and TP fluxes occur in the catchments where the river and/or the tributaries pass through urban areas (Acton, Santa Clarita, Fillmore, Piru and Santa Paula) and the river traverses the Oxnard Coastal Plain. The highest annual fluxes for NH4, NO3 and TP of 271, 402, and 167 kg/sq.km, respectively, were predicted in the catchments where Mint Canyon and San Francisquito Canyon merge with the Santa Clara River (Figure 10).

Portions of the streams including Brown Barranca and Mint Canyons were listed on the Clean Water Act Section 303(d) list of impaired waters for nutrients. To address the listings, the Basin Plan states that surface water shall not exceed 10 mg/L nitrogen as nitrate-nitrogen plus nitrite-nitrogen, 45 mg/L as nitrate, 10 mg/L as nitrate-nitrogen or 1 mg/L as nitrite-nitrogen (CWQCB-LAR 1994). The nitrate and nitrite targets for are specified as 30-day average concentrations. The simulated results were used to assess the degree of water impairment for surface waters in a time- and location-specific way similar to the Basin Plan that has been adopted by the California Water Quality Control Board. Figure 11 demonstrates an example that uses simulated daily flow volumes and NO3 concentrations to estimate the daily NO3 concentrations and loads for the ME-SCR mass emission site (N112).

6 Discussion and Conclusions

MIKE BASIN combines the power of ArcGIS with comprehensive hydrologic modeling and was implemented in the Santa Clara River watershed to address water resource and water quality issues. For hydrologic simulations, MIKE BASIN builds on a network model in which branches represent individual stream reaches and the nodes represent confluences, diversions, reservoirs, or water users. The ArcGIS interface has been expanded accordingly, e.g. such that the network elements can be edited by simple right-clicking. Technically, MIKE BASIN is a quasi-steady-state mass balance model which supports routed river flows. The water quality solution assumes purely advective transport, although decay during transport can also be modeled. Daily simulations were generated for the Santa Clara River watershed based on water availability and utilization using hydrological data from 1996 through 2005.

Key inputs to the model included the digitized river system layout, withdrawal and reservoir locations, a time series of water demand, the groundwater abstraction (represented as a percentage), the return flow ratio, a linear routing coefficient (irrigation only), the unit naturalized runoff time series, the initial groundwater elevation, a linear reservoir time constant, the groundwater recharge time series, the initial reservoir water level, operational rule curves, the stage-area-volume curve, time series of rainfall and evaporation, linkages to users and delivery priority rules, linkages to upstream nodes, and water quality rate parameters, temperature, non-point loads, a weir constant for re-aeration, transport times and the water depth or Q-h relationship, and the effluent concentrations. Key outputs include mass balances, detailed flow descriptions throughout the water system, water diversions, and descriptions of various water quality constituents.

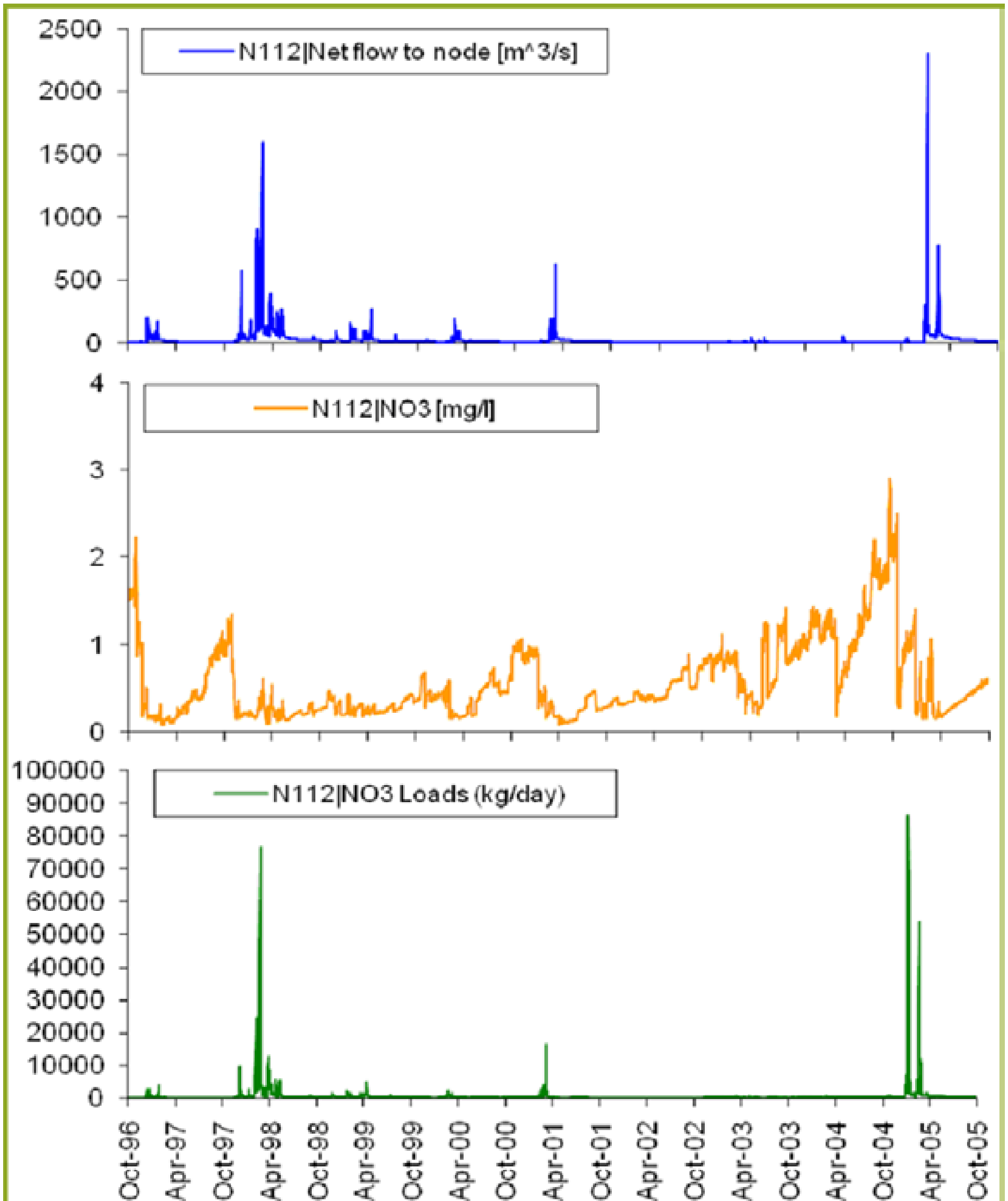

Figure 11 NO3 load calculation using the simulated flow volume and NO3 concentration for the ME-SCR mass emission site (N112)

The average monthly flow in the Santa Clara River at the outlet was about 45,000 AF during the simulation period. The extremely low flow conditions that occurred in the 2003 water year contributed to this relatively low average volume. The monthly flows are highly variable with discharge varying by several orders of magnitude: from 830,000 AF in February 1998 to just 10 AF in numerous dry months. The winter flows contribute the majority of the annual flow to the ocean. The flows are significantly lower and less variable during the dry weather period. From 1996 to 2005, dry-weather flows (May to October) accounted for 19% of the annual discharge from the Santa Clara River. Substantial tributary inflows occur at Sespe Creek, which contributes 40.5% of the total inflow to the ocean on average.

Monthly average in-stream loads in Santa Clara River at the outlet were about 14,000, 19,000 and 5,000 kg for NH4, NO3 and TP, respectively, during the simulation period. Temporal variations in nutrient loads are relatively similar and the loads associated with winter storms generally contribute much higher fractions of the contributions to the ocean than those from the other seasons: from 1996 to 2005, wet-weather flows (November to the following April) accounted for 81% of the annual NO3 loads from the Santa Clara River for example. Large nutrients loads are produced in the upper Santa Clara River above the Bouquet Canyon (N147) gauging station, contributing 47%, 20 and 24% of the total NH4, NO3, and TP loads, respectively, predicted for the Santa Clara River. The highest nutrient fluxes for NH4, NO3 and TP were predicted in subwatersheds passing through Acton, Santa Clarita, Fillmore, Piru, and Santa Paula and where the main channel traversed the Oxnard Coastal Plain. This pattern meant that high flux catchments were distributed along the main stem of the Santa Clara River and near the confluences of the Mint Canyon, San Francisquito, Bouquet Canyon, Santa Paula, and Brown Barranca tributaries.

Overall, the modeled results should provide users with simple, intuitive and yet in-depth insights when exploring basin-scale planning and management solutions. The MIKE BASIN simulation results can be visualized in both space and time, making it the perfect tool for building understanding and consensus. As shown in Figures A-1 through A-4, the model simulates the hydrology for the selected subwatersheds in a reasonable manner.

In addition, the simulation of the water quality components of NH4, NO3, and TP were less satisfactory due to the errors in the hydrologic simulations and our limited understanding of the generation, transportation and degradation dynamics on land surface and in streams for these pollutants. The use of mean fluxes for land use classes is an approximate method for estimating the average water quality conditions. Temporal variations in the stream concentrations are significant but not represented in the input parameters, which might have negatively impacted the estimates of nutrient loadings. Large volumes of agricultural runoff with high concentrations of pollutants may find their way into the Santa Clara River and its tributaries in certain time periods and not during other periods. Such variations in in-river concentration and flows can easily cause the large errors in the predictions because these temporal variations were not incorporated or anticipated in the model parameterization.

Two other issues of broad concern warrant a brief mention as well. First, a large portion of the nutrient loads in the Santa Clara River watershed are derived from sources beyond the control of dischargers, especially atmospheric deposition. Direct air deposition to water bodies was treated as a nonpoint source from the Los Angeles and Padres National Forests. Air deposition that entered the stream network via the land surface is included in the event mean flux values for each land use category. Secondly, the current model configuration was not set up to treat urban storm runoff and scattered agricultural discharges separately, which would be the preferred approach given adequate input data (not possible at present) and a focus on TMDL compliance.

This report has focused on assessing the sources and average loads of nutrients to the surface water and the relative impairment of surface water quality in the watershed. It is a great challenge to obtain time series flow and water quality data for hundreds and thousands of industrial and urban runoff dischargers that are scattered across the entire region. However, the simulated water quality time series at each of the node points of the stream network offer some understanding of the spatio-temporal variability of the nutrient loads and concentrations at the basin scale while being inadequate for site-specific projects. Actual data values should be used with further validation and site- specific data for applications such as BMP capacity design.

The results do nevertheless identify the parts of the watershed and times of the year that further research should focus on if we are to improve our management of the water supply and quality issues that affect the streams and subwatersheds that drain into the Santa Clara River.

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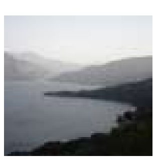
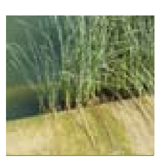
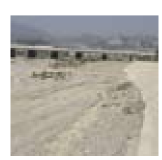
Appendix A
Hydrology Calibration and Validation
Graphs and Tables

Rainfall-Runoff Results

USGS 11113000/710A,B,C, D Catchment Area = 650.1 km2

Parameter	Description	Value	Units	*Observations*
Umax	Maximum water content in surface storage	16.8	in	Forest
Lmax	Maximum water content in root zone storage	170	in	
CGOF	Overland flow runoff coefficient	0.527		
CKIF	Time contstant for routing interflow	652.9	hrs	
CK1,2	Time constant for routing overland flow	11.1	hrs	
TOF	Root zone threshold value for overland flow	0.823		
TIF	Root zone threshold value for interflow	0.891		
Tg	Root zone threshold value for GW recharge	0.827		
CKBF	Time constant for routing baseflow	1589	hrs	
Carea	Ratio of GW-area to catchment area	1		

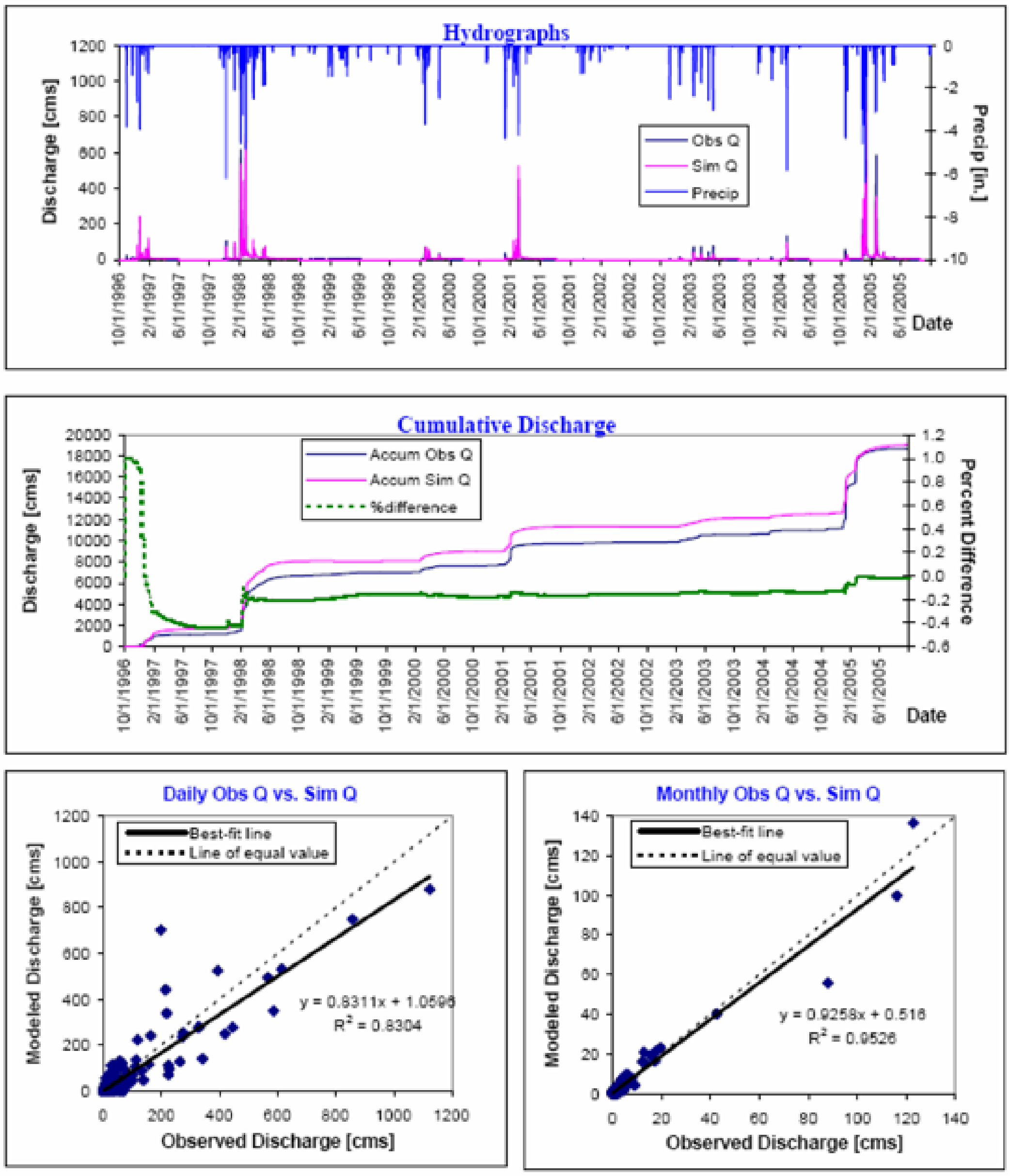


Figure A-1 Calibration results for USGS 11113000/710A, B, C, D Sespe Creek near Fillmore, CA gauging station

Table A-1 Calibration error analysis for USGS 11113000/710A,B,C,D Sespe Creek near Fillmore, CA gauging station

6-year analysis period : 10/1/1996 - 9/30/2005

Flow volumes are (cubic meter per second) for upstream drainage area

Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	9.12	7.40
Lowest 50% cutoff value	0.46	0.54
Total in-stream flow	19030.16	18705.71
Total of the highest 10% flows	15168.62	15795.99
Total of the lowest 50% flows	165.49	304.46
Summer flow volume (months 7-9)	545.60	285.80
Fall flow volume (months 10-12)	1685.40	1652.40
Winter flow volume (months 1-3)	13816.71	14504.59
Spring flow volume (months 4-6)	2982.09	2262.39
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	1.73	Very good
Error in 10% highest flows	-3.97	Very good
Error in 50% lowest flows	-45.65	Poor
Volume error - Summer	90.91	Poor
Volume error - Fall	2.00	Very good
Volume error - Winter	-4.74	Very good
Volume error - Spring	31.81	Fair

Rainfall-Runoff Results

USGS 11108000/F92-R Santa Clara River near Saugus CA Catchment Area = 1064.5 km2

Parameter	Description	Value	Units	*Observations*
Umax	Maximum water content in surface storage	16.8	in	forest dominates
Lmax	Maximum water content in root zone storage	298	in	
CGOF	Overland flow runoff coefficient	0.26		
CKIF	Time contstant for routing interflow	994.6	hrs	
CK1,2	Time constant for routing overland flow	10.2	hrs	
TOF	Root zone threshold value for overland flow	0.762		
TIF	Root zone threshold value for interflow	0.508		
Tg	Root zone threshold value for GW recharge	0.932		
CKBF	Time constant for routing baseflow	2041	hrs	
Carea	Ratio of GW-area to catchment area	1		

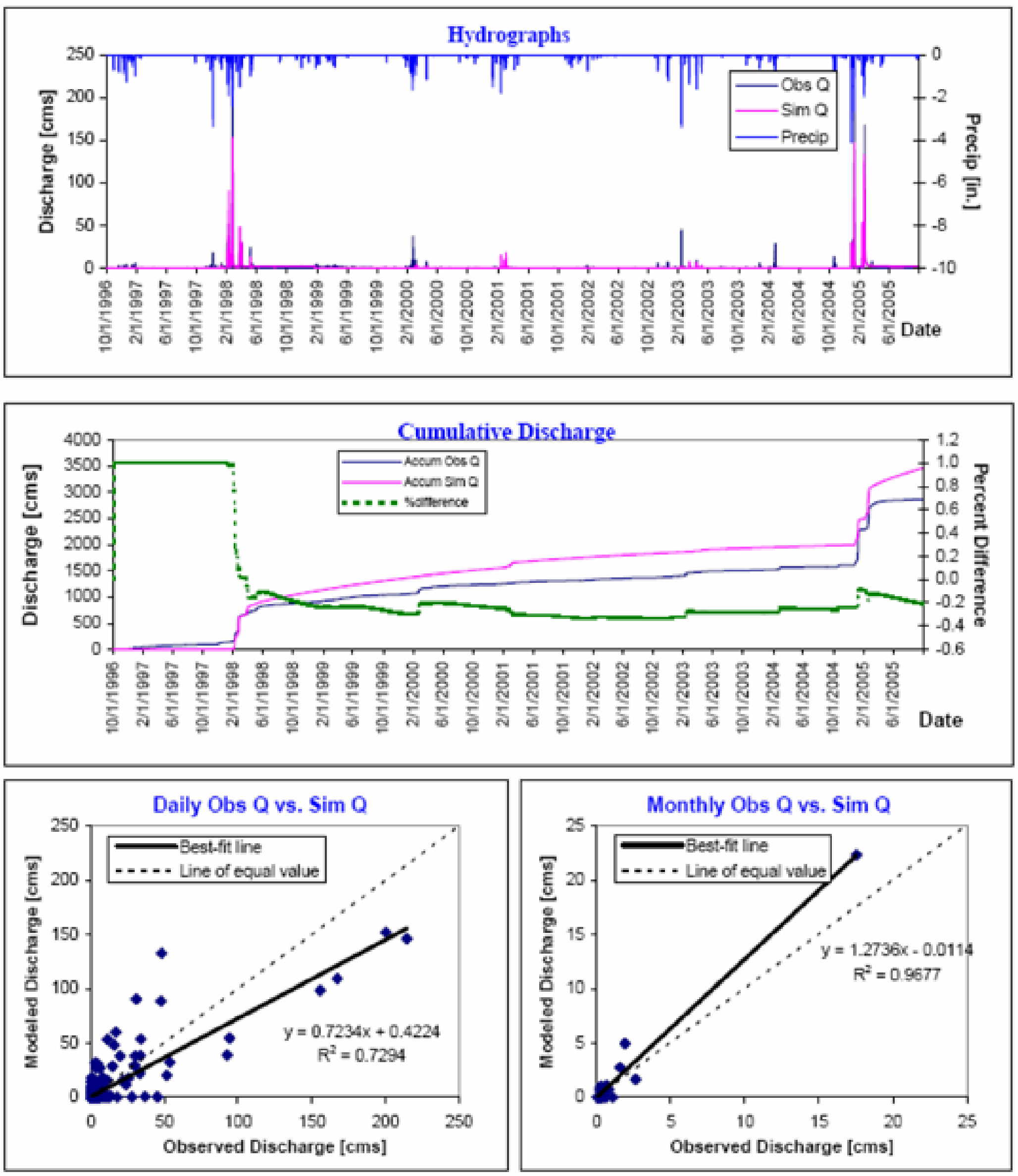


Figure A-2 Calibration results for USGS 11108000/F92-R Santa Clara River near Saugus CA gauging station

Table A-2 Calibration error analysis for USGS 11108000/F92-R Santa Clara River near Saugus CA gauging station

6-year analysis period : 10/1/1996 - 9/30/2005

Flow volumes are (cubic meter per second) for upstream drainage area

Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	1.37	0.65
Lowest 50% cutoff value	0.32	0.18
Total in-stream flow	3460.08	2863.62
Total of the highest 10% flows	2387.77	2293.72
Total of the lowest 50% flows	230.09	167.51
Summer flow volume (months 7-9)	404.49	127.08
Fall flow volume (months 10-12)	319.74	259.63
Winter flow volume (months 1-3)	2191.53	2112.44
Spring flow volume (months 4-6)	542.96	364.30
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	20.83	Fair
Error in 10% highest flows	4.10	Very good
Error in 50% lowest flows	37.36	Poor
Volume error - Summer	218.31	Poor
Volume error – Fall	23.15	Fair
Volume error – Winter	3.74	Very good
Volume error – Spring	49.04	Poor

Rainfall-Runoff Results

USGS 11110500/701 HOPPER CREEK NEAR PIRU CA Catchment Area = 61.1 km2

Parameter	Description	Value	Units	*Observations*
Umax	Maximum water content in surface storage	19.3	in	subject to agricultural irrigation
Lmax	Maximum water content in root zone storage	293	in	
CGOF	Overland flow runoff coefficient	0.819		
CKIF	Time contstant for routing interflow	495.3	hrs	
CK1,2	Time constant for routing overland flow	10.2	hrs	
TOF	Root zone threshold value for overland flow	0.9		
TIF	Root zone threshold value for interflow	0.48		
Tg	Root zone threshold value for GW recharge	0.555		
CKBF	Time constant for routing baseflow	2402	hrs	
Carea	Ratio of GW-area to catchment area	1		

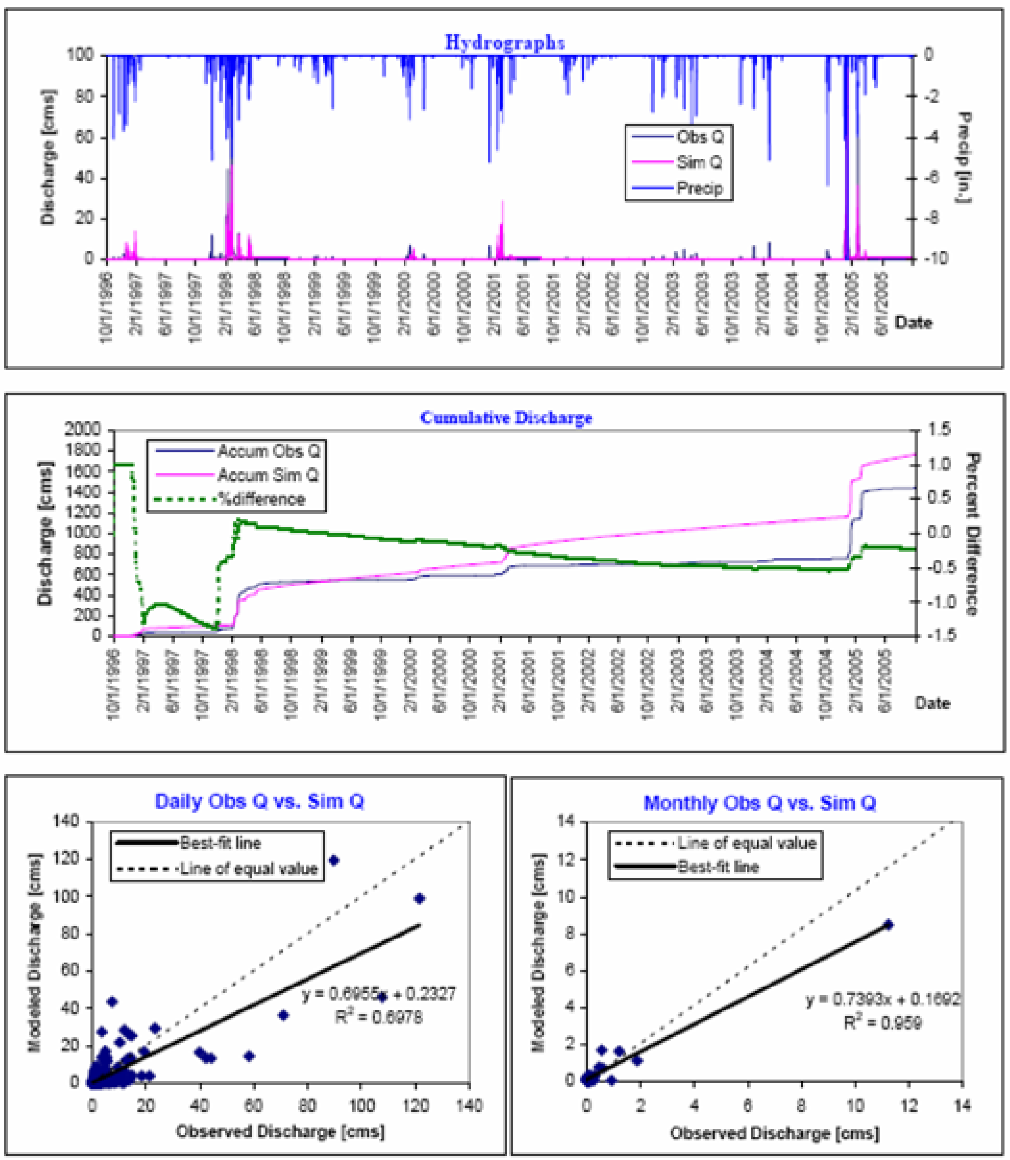


Figure A-3 Calibration results for USGS 11110500/701 at Hopper Creek near Piru CA gauging station

Table A-3 Calibration error analysis for USGS 11110500/701 at Hopper Creek near Piru CA gauging station

6-year analysis period : 10/1/1996 - 9/30/2005

Flow volumes are (cubic meter per second) for upstream drainage area

Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	0.45	0.31
Lowest 50% cutoff value	0.22	0.02
Total in-stream flow	1765.96	1439.39
Total of the highest 10% flows	1125.88	574.55
Total of the lowest 50% flows	264.83	9.62
Summer flow volume (months 7-9)	198.31	13.30
Fall flow volume (months 10-12)	190.62	128.81
Winter flow volume (months 1-3)	1105.04	1184.99
Spring flow volume (months 4-6)	271.58	112.28
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	22.69	Fair
Error in 10% highest flows	95.96	Poor
Error in 50% lowest flows	2652.92	Poor
Volume error – Summer	1391.21	Poor
Volume error – Fall	47.99	Poor
Volume error – Winter	-6.75	Very good
Volume error – Spring	141.87	Poor

Rainfall-Runoff Results

USGS 11109375/716 PIRU C BL BUCK C NR PYRAMID LK CA Catchment Area =253.8

Parameter	Description	Value	Units	*Observations*
Umax	Maximum water content in surface storage	18.3	in	1993-2003 data for calib
Lmax	Maximum water content in root zone storage	176	in	
CGOF	Overland flow runoff coefficient	0.883		
CKIF	Time contstant for routing interflow	798.8	hrs	
CK1,2	Time constant for routing overland flow	10.4	hrs	
TOF	Root zone threshold value for overland flow	0.912		
TIF	Root zone threshold value for interflow	0.321		
Tg	Root zone threshold value for GW recharge	0.568		
CKBF	Time constant for routing baseflow	3131	hrs	
Carea	Ratio of GW-area to catchment area	1		

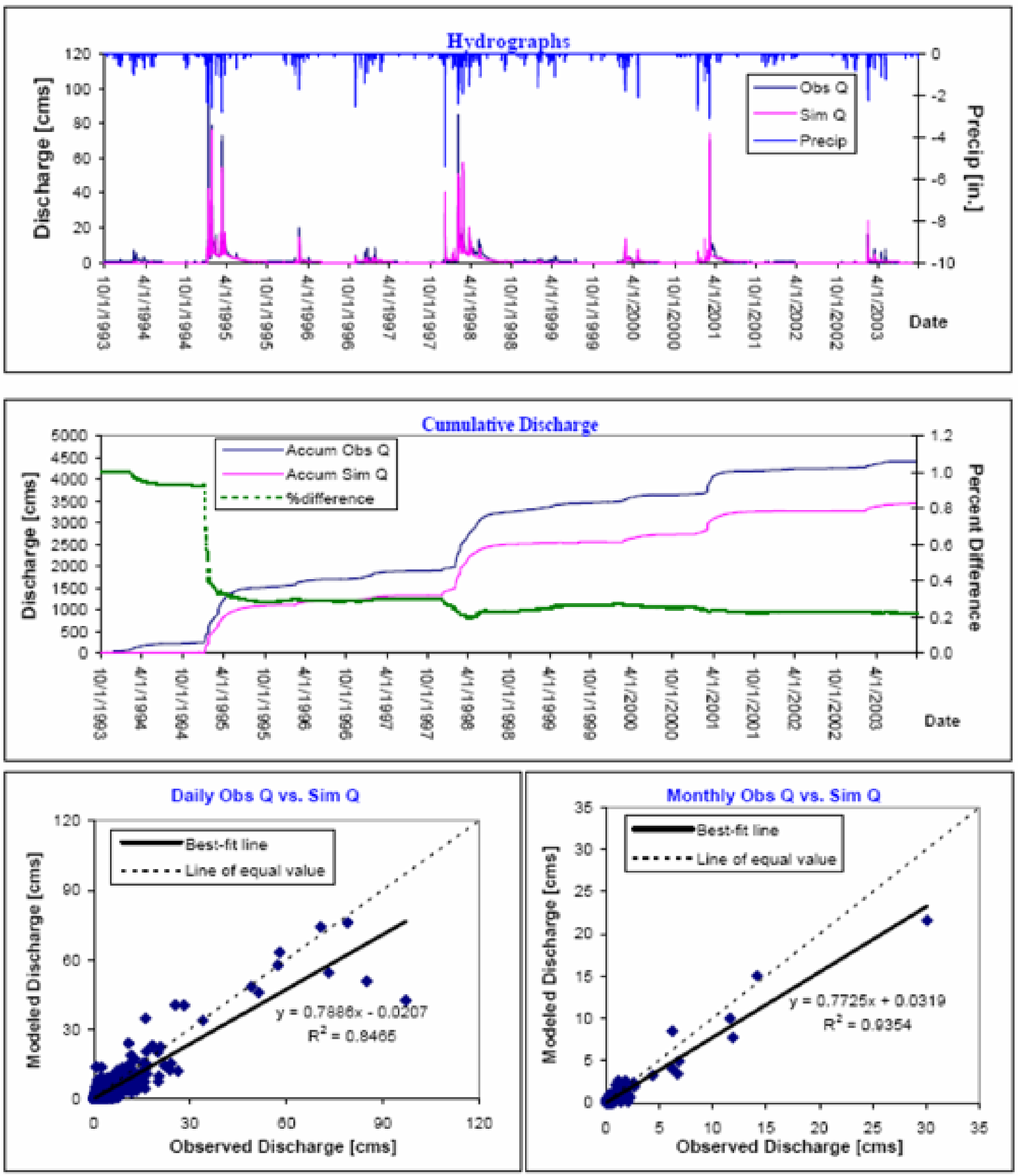


Figure A-4 Calibration results for USGS 11109375/716 Piru Creek below Buck Creek near Pyramid Lake CA gauging station

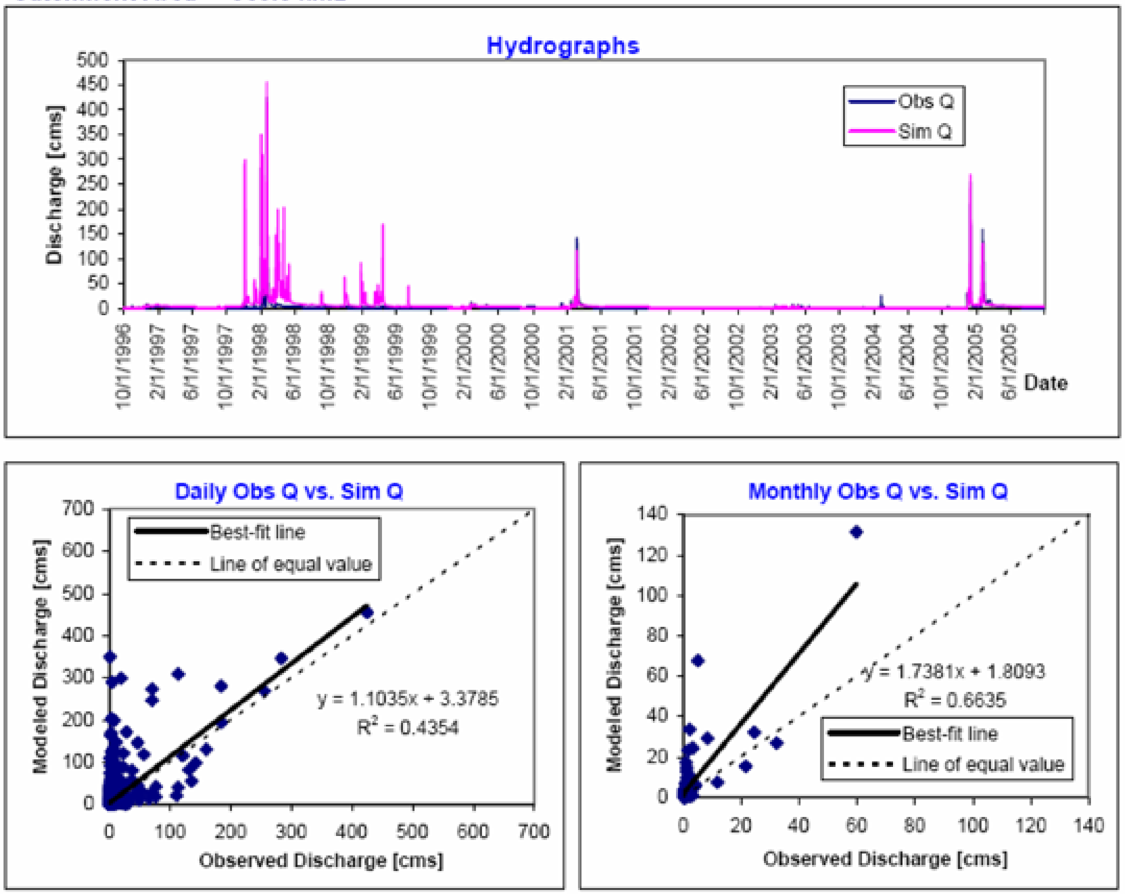
Table A-4 Calibration Error Analysis for USGS 11109375/716 Piru Creek below Buck Creek near Pyramid Lake CA gauging station

10-year analysis period : 10/1/1993 - 9/30/2003

Flow volumes are (cubic meter per second) for upstream drainage area

Summary	***MIKE BASIN Simulated Flows***	***Observed Flows***
Highest 10% flow	2.00	2.63
Lowest 50% flow	0.13	0.31
Total in-stream flow	3445.16	4749.33
Total of the highest 10% flows	2485.13	3364.21
Total of the lowest 50% flows	49.56	180.36
Summer flow volume (months 7-9)	187.59	175.59
Fall flow volume (months 10-12)	189.44	348.23
Winter flow volume (months 1-3)	2252.07	3081.38
Spring flow volume (months 4-6)	816.07	1144.14
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	-27.46	Fair
Error in 10% highest flows	-26.13	Fair
Error in 50% lowest flows	-72.52	Poor
Volume error - Summer	6.84	Very Good
Volume error - Fall	-45.60	Poor
Volume error - Winter	-26.91	Fair
Volume error - Spring	-28.67	Fair

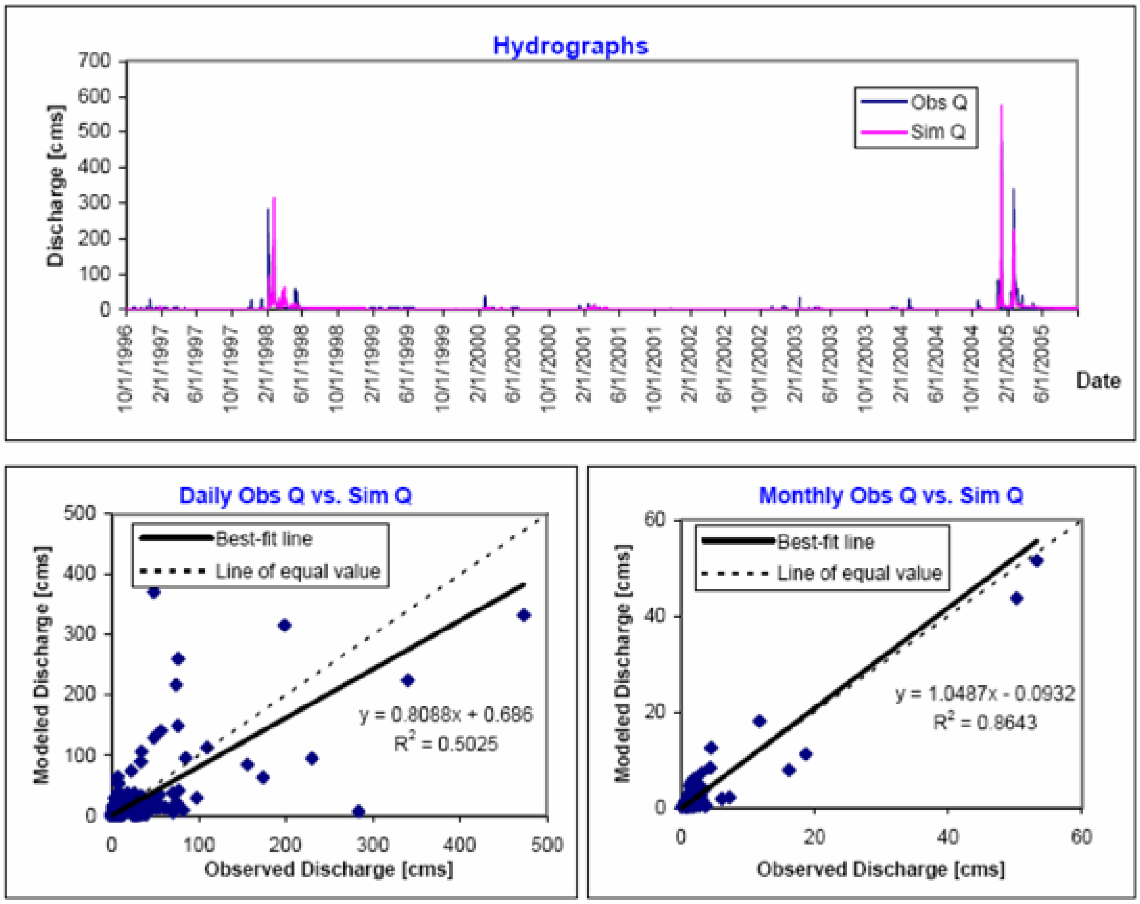
USGS 11109600/705/705A PIRU CREEK ABOVE LAKE PIRU CA
Catchment Area = 963.5 km2



6-year analysis period : 10/1/1996 - 9/30/2005 Flow volumes are cms		
Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	8.25	3.49
Lowest 50% cutoff value	1.85	0.71
Total in-stream flow	19951.36	8063.71
Total of the highest 10% flows	13241.77	5548.06
Total of the lowest 50% flows	1276.23	666.36
Summer flow volume (months 7-9)	1965.98	656.62
Fall flow volume (months 10-12)	2651.84	613.20
Winter flow volume (months 1-3)	9862.71	5445.90
Spring flow volume (months 4-6)	5470.83	1347.57
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	147.42	Poor
Error in 10% highest flows	138.67	Poor
Error in 50% lowest flows	91.52	Poor
Volume error - Summer	199.41	Poor
Volume error - Fall	332.46	Poor
Volume error - Winter	81.10	Poor
Volume error - Spring	305.98	Poor

Figure A-5 Validation results for USGS 11109600/705/705A Piru Creek above Lake Piru, CA gauging station

USGS 11109000/707A SANTA CLARA R NR PIRU CA
Catchment Area = 1670.5 km2

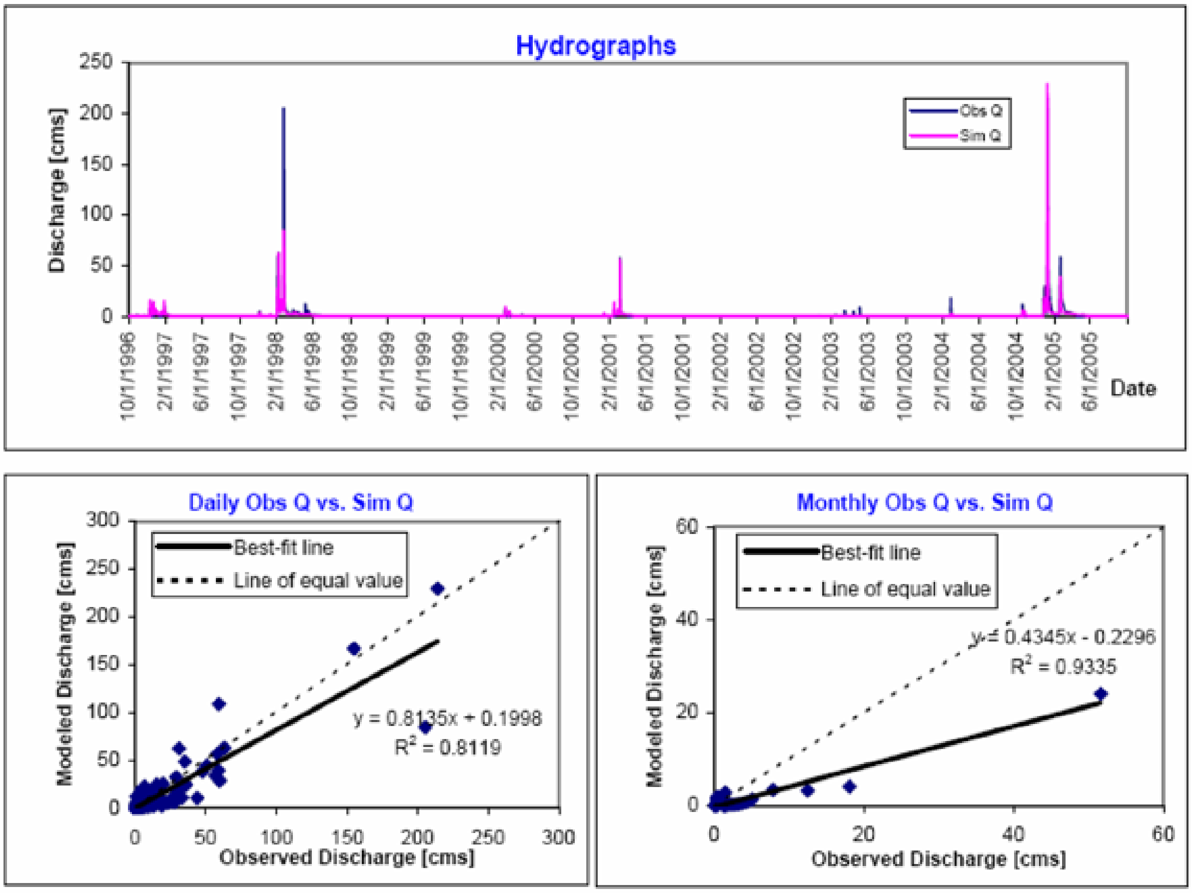


6-year analysis period : 10/1/1996 - 9/30/2005 Flow volumes are cms		
Summary	***MIKE BASIN Simulated Flows***	***Observed Flows***
Highest 10% cutoff value	5.41	3.31
Lowest 50% cutoff value	1.03	1.19
Total in-stream flow	10674.79	10427.08
Total of the highest 10% flows	7058.81	6795.45
Total of the lowest 50% flows	953.23	1343.15
Summer flow volume (months 7-9)	1316.07	688.77
Fall flow volume (months 10-12)	825.99	1301.42
Winter flow volume (months 1-3)	6439.85	6565.26
Spring flow volume (months 4-6)	2092.87	1871.63
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	2.38	Very good
Error in 10% highest flows	3.88	Very good
Error in 50% lowest flows	-29.03	Fair
Volume error - Summer	91.08	Poor
Volume error - Fall	-36.53	Poor
Volume error - Winter	-1.91	Very good
Volume error - Spring	11.82	Good

Figure A-6 Validation results for USGS 11109000/707A Santa Clara River near Piru, CA gauging station

USGS 11113500/709/709A SANTA PAULA C NR SANTA PAULA

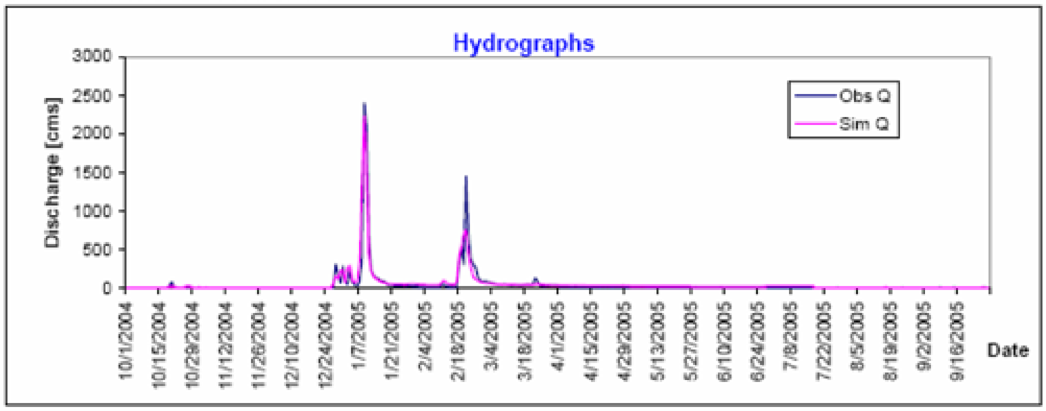
Catchment Area = 99.5 km2

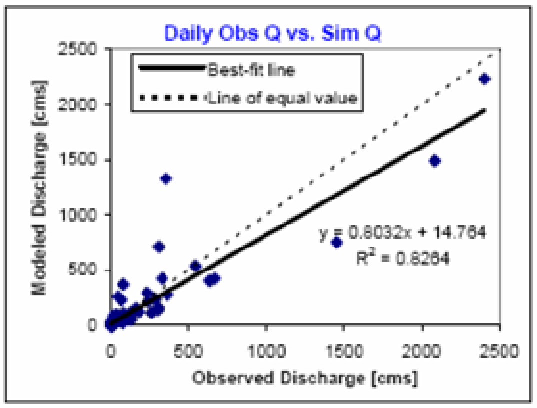


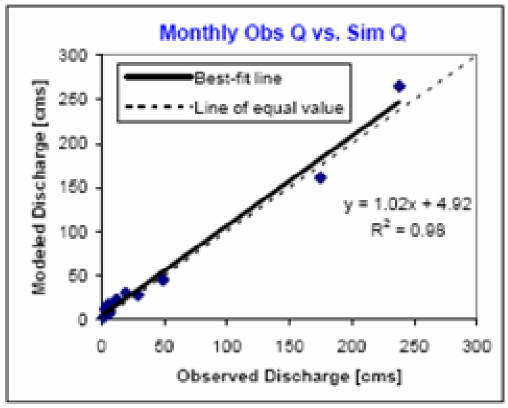
6-year analysis period : 10/1/1996 - 9/30/2005 Flow volumes are cms		
Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	1.88	1.76
Lowest 50% cutoff value	0.29	0.19
Total in-stream flow	3682.74	3723.57
Total of the highest 10% flows	2453.68	2894.97
Total of the lowest 50% flows	175.44	154.60
Summer flow volume (months 7-9)	197.05	139.80
Fall flow volume (months 10-12)	421.71	283.59
Winter flow volume (months 1-3)	2443.43	2723.57
Spring flow volume (months 4-6)	620.55	576.61
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	-1.10	Very good
Error in 10% highest flows	-15.24	Good
Error in 50% lowest flows	13.48	Good
Volume error - Summer	40.95	Poor
Volume error - Fall	48.71	Poor
Volume error - Winter	-10.29	Very good
Volume error - Spring	7.62	Very good

Figure A-7 Validation results for USGS 11113500/709/709A Santa Paula near Santa Paula, CA gauging station

720 Santa Clara River at 12th Street
Catchment Area = 3908.5 km2







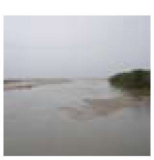
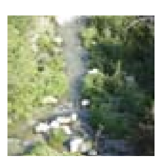
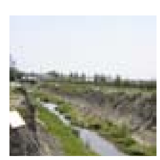
6-year analysis period : 10/1/1996 - 9/30/2005 Flow volumes are cms		
Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	63.89	64.00
Lowest 50% cutoff value	16.46	6.09
Total in-stream flow	18561.60	16419.58
Total of the highest 10% flows	12216.14	12860.14
Total of the lowest 50% flows	1501.87	541.74
Summer flow volume (months 7-9)	1096.40	408.01
Fall flow volume (months 10-12)	1184.77	1116.60
Winter flow volume (months 1-3)	14134.23	13799.04
Spring flow volume (months 4-6)	2146.20	1095.92
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	13.05	Good
Error in 10% highest flows	-5.01	Very Good
Error in 50% lowest flows	177.23	Poor
Volume error - Summer	168.72	Poor
Volume error - Fall	6.10	Very good
Volume error - Winter	2.43	Very good
Volume error - Spring	95.84	Poor

Observations

the lower SCC. This site was established during Water Year 2005 as a replacement for the Santa Clara River at Saticoy (Montalvo). The site at Santa Clara River at Freeman Diversion served as a interim location for the entire 2005 Water Year. The 12th Street gage was installed in January 2005. For Water Year 2005 the record prior to the January gage installation was estimated from the data recorded at the Freeman Diversion site. Currently the record for this site is not being checked or published by the USGS.

Figure A-8 Validation results for 720 Santa Clara River at 12th Street gauging station

Appendix B
Water Quality Calibration and Validation Graphs and Tables

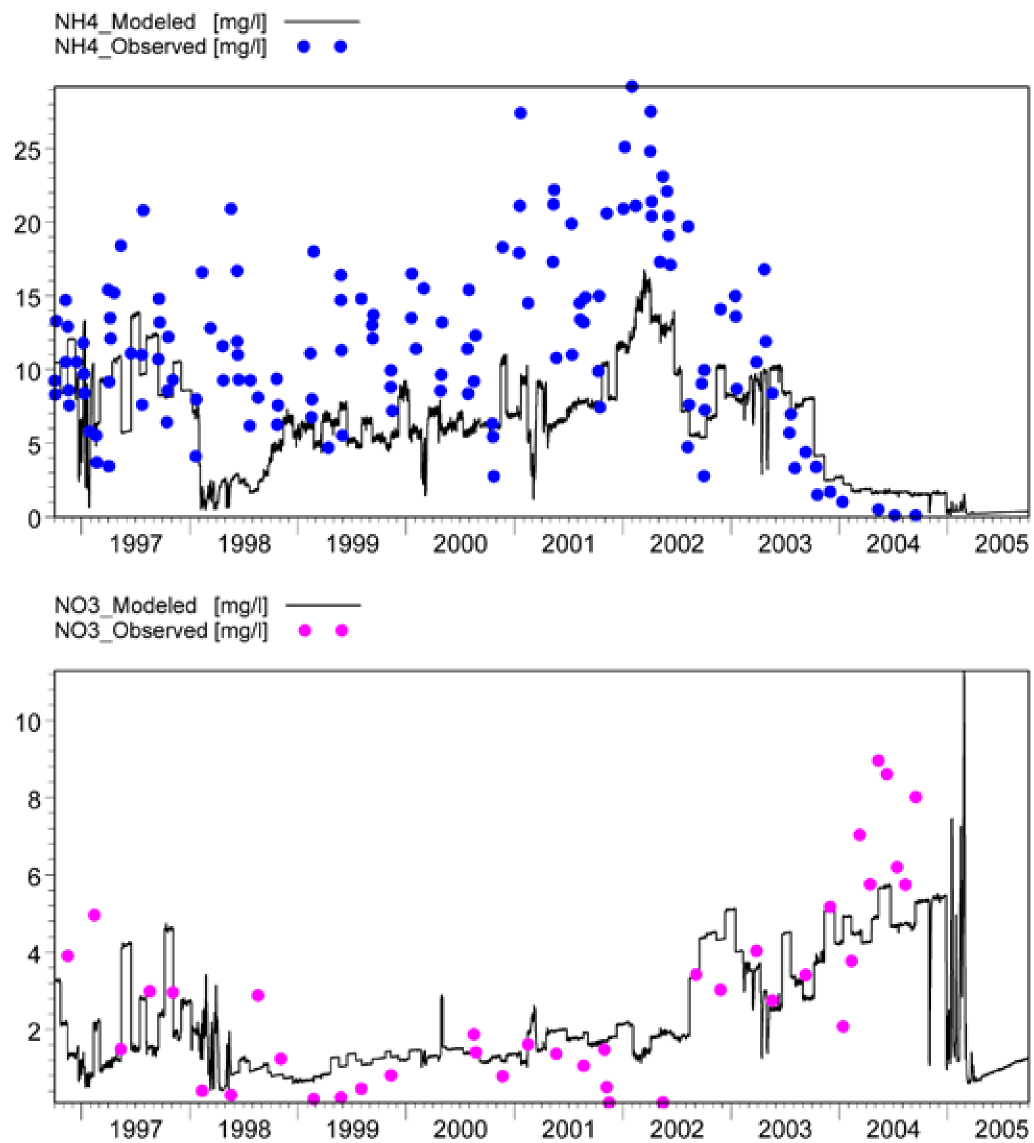


Figure B-1 Time series comparison of modeled and observed NH4 and NO3 at the RA/RB mass emission site

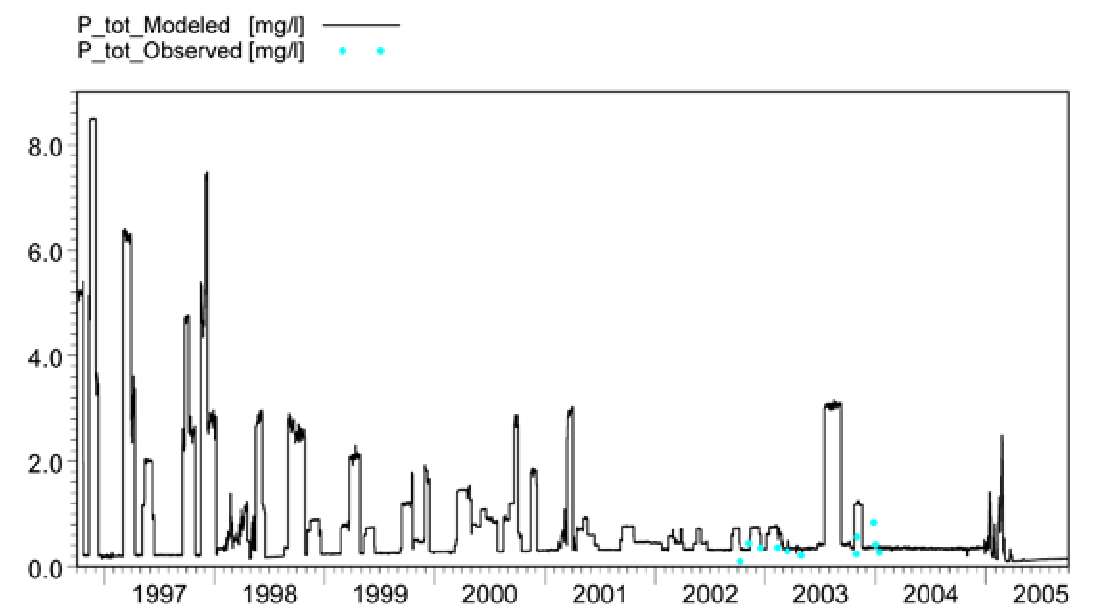


Figure B-2 Time Series comparison of modeled and observed TP concentrations at the S29 mass emission site

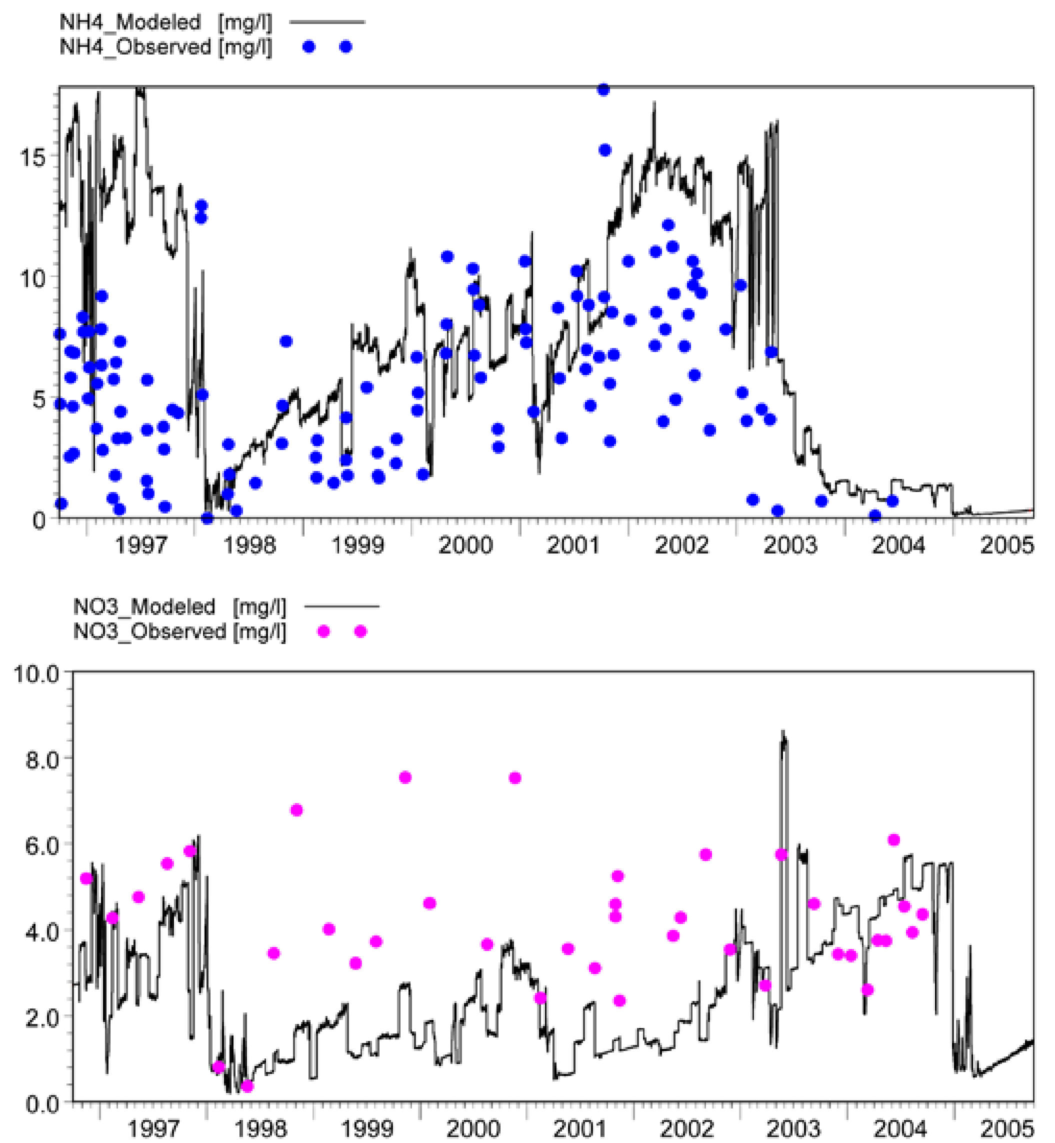


Figure B-3 Time Series comparison of modeled and observed NH4 and NO3 at the RE mass emission site

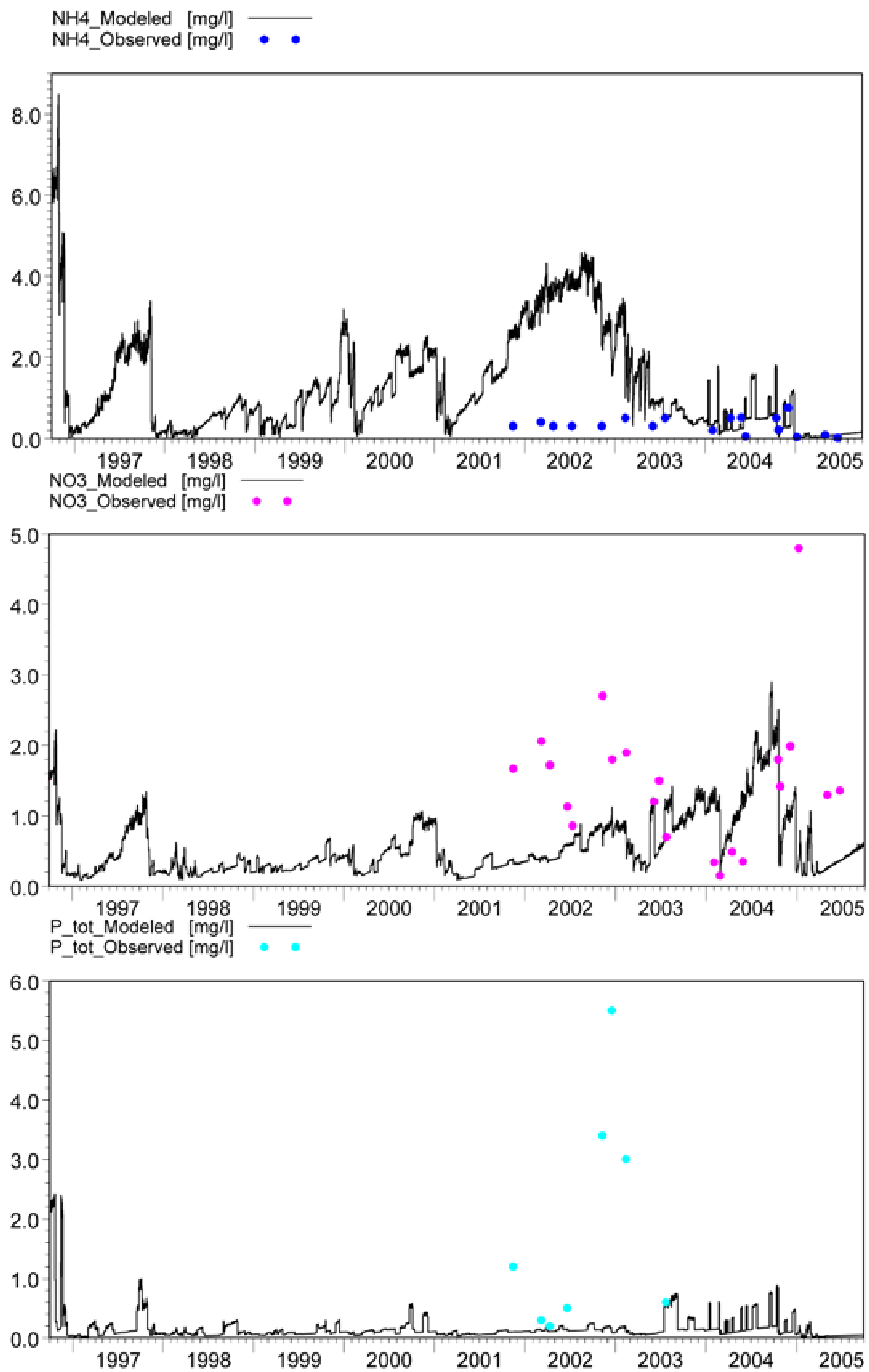


Figure B-4 Time Series comparison of modeled and observed NH4, NO3 and TP at the ME-SCR mass emission site