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THE GREEN VISIONS PLAN

for 21st century southern california

21. Hydrology and Water Quality Modeling of the Calleguas Creek Watershed

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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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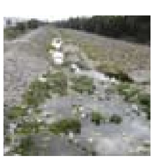

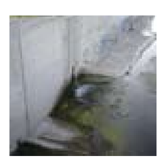

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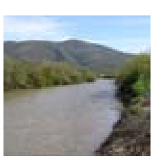
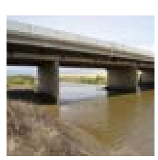
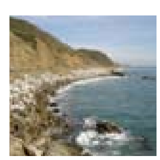

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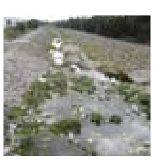

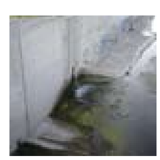

Executive Summary

The purpose of the Green Visions Plan watershed health assessments, as described in the GVP framework, are to support and inform region wide 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 (DHI) MIKE BASIN. MIKE BASIN is a 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 streamflow data were selected to conduct model calibration over a nine year period (10/1996 – 9/2005) and validation for additional stations. Both quantitative and qualitative comparisons were developed to support the model performance evaluation effort.

The calibration and validation results, based on the graphic comparison and error analyses described herein, demonstrate a fair to good representation of the observed flow data. Statistical comparisons and model performance evaluation were performed at eight stream locations throughout the watershed, for annual runoff, daily and monthly stream flow, water balance components, and annul water quality. For the five validated stations, the total stream water volumes were fairly well simulated with the exception of two sites at Beardsley Wash and Calleguas Creek at Camarillo. Very good validation results were achieved for simulating the 90th percentile high flows while the 10th percentile low flows are generally poorly simulated with over predictions at all sites. The overall validation results suggest that the model represented the dominant flow conditions in the watershed.

The water quality simulations are not satisfactory in reproducing the observed sample concentrations. The 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 it does not always predict the temporal variability of the pollutograph.

The simulation results for NO3 with relatively smaller errors were a little better than those for NH4 and TP. The load calculator had difficulties reproducing the extremely high and low concentration values in the pollutographs that resulted from instantaneous samples. This performance could limit the application of the results in TMDL or BMP designs, in which the exceedance of nutrient concentration over the predefined numeric targets need to be assessed more precisely. The resulted loading maps (Figures B-3, B-4 and B-5) demonstrate the spatial abundance of nutrients among subcatchments. The highest NH4 and NO3 loadings appear in the Camarillo Hills Drain and part of Beardsley Wash. The high Camarillo Hills Drain nitrogen concentrations may be due to the larger proportion of medium to high density residential areas or presence of groundwater. The highest TP concentrations were recorded in the Camarillo Hills Drain subwatershed and those containing the Simi Valley and Old Canyon wastewater treatment plants.

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 Calleguas Creek Watershed water quality modeling is to determine the pollutant concentration and loads entering the stream network and to what degree surface waters are subject to water quality impairments. Accurate simulation of hydrology and water quality in the study area is difficult due to the complexity of the hydrologic processes in the semi-arid environment and the severity of human modifications to the natural systems. Increased urbanization has been shown to result in increased runoff and pollutant loading to receiving waters (USEPA 1995, Schueler and Holland 2000, Davis et al. 2001, Sheng and Wilson 2008). The watershed asset assessment for the GVP study area shows that the higher levels of impervious surfaces associated with urban landscapes resulted in increased magnitude and frequency of surface runoff in the upper Arroyo Simi near Simi Valley and other urban areas (Sheng and Wilson 2008). This urban runoff also collects toxic compounds, such as heavy and trace metals and nutrients, which can result in downstream habitat impairment (Schueler and Holland 2000).

Previous studies have documented impairments to Calleguas Creek and its tributaries caused by chloride, total dissolved solids (TDS), sulfate, metals, nutrients, toxicity and bacteria. Models of various kinds (e.g. simple conceptual and spreadsheet models, TMDL mass balance models and EPA's HSPF model) have been developed and/or implemented for determining allowable loadings for the various sources and removing these impairments in the watershed (CRWQCB-LAR 2002a,b; Larry Walker Associates 2001, 2005a, b, 2006). Different from all these studies, this report focused on the simulation of hydrology and nutrient loads and concentrations for the entire Colleguas Creek watershed and demonstration of the spatial and temporal variation of constituent loadings within the watershed.

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 Calleguas Creek watershed. The MIKE BASIN model also offers the capability of representing water availability and potential users of water, which serves the planning purpose for future water developments within the GVP study area.

In general terms MIKE BASIN is 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 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

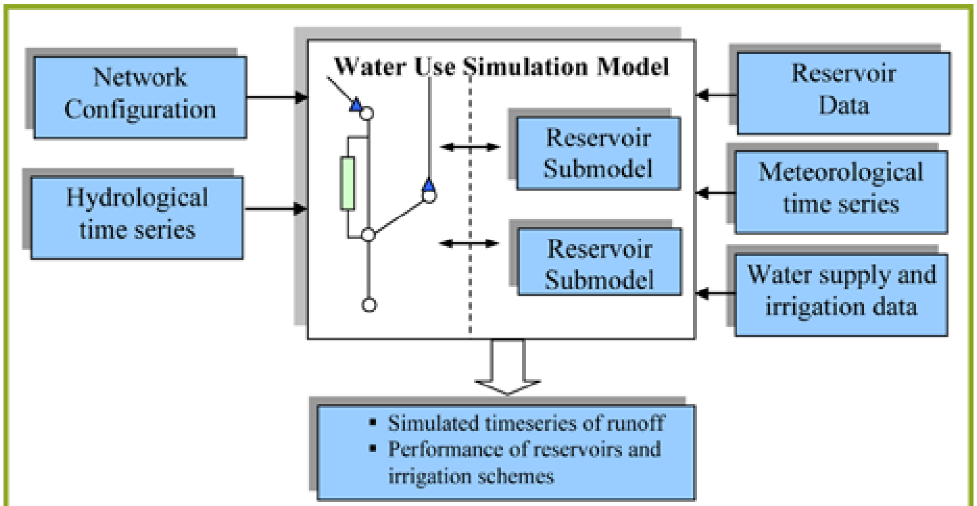

Figure 1 MIKE BASIN's water allocation modeling structure (DHI 2007)

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 of rules does not account for delays in flow routing, water quality pulse 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 Calleguas Creek watershed. It identifies and describes the types of data that were obtained and used for the model, and presents the procedures used 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 Calleguas Creek 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 Calleguas Creek watershed encompasses an area of 343 mi^2. Development is concentrated in the upper reaches of the creeks and arroyos, and 50,000 acres of irrigated agriculture in the middle and lower watershed. The current land use in the watershed is 26% agriculture, 24% urban, and 50% open space. Patches of high quality riparian habitat are present along the length of Calleguas Creek and its tributaries. The watershed is semi-arid, receiving an average of 15 inches of rainfall per year at

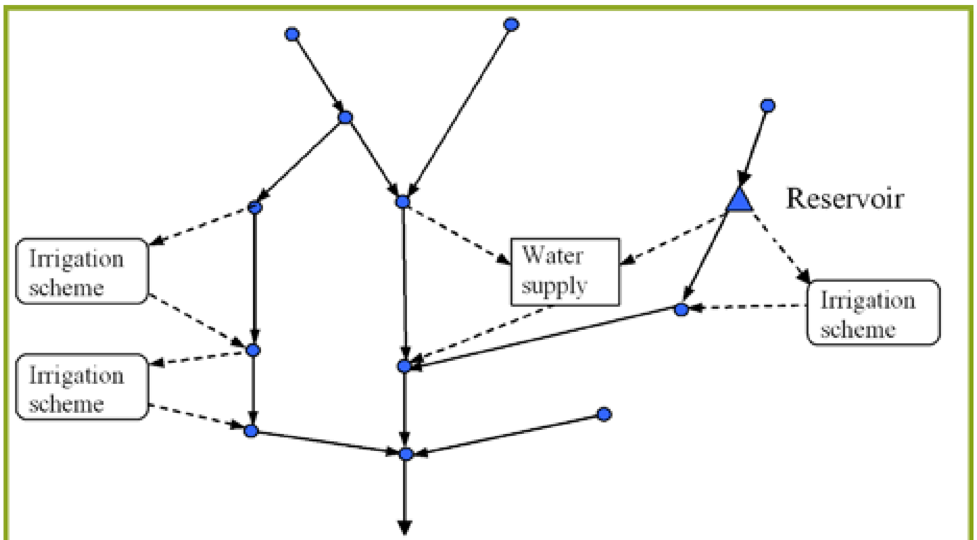

Figure 2 Schematic layout of MIKE BASIN's network modeling approach (DHI 2007)

Moorpark, CA with the majority occurring between November and March. The surface waters are primarily arroyos and creeks that have historically carried storm flows and post-storm flows from the upper watershed down to the alluvial valleys and it discharges into the Pacific Ocean at Mugu Lagoon. Prior to the effects of large-scale water management projects, these streams were ephemeral and only occasionally flowed from the upper watershed to the ocean (Hajas 2003). Urban water is principally supplied by imported water from the State Water Project, with some contributions from the Freeman Diversion on the Santa Clara River and groundwater wells. Agricultural water demands have been satisfied primarily by mining deep groundwater and importing surface water from the Santa Clara River watershed.

2 Data Needs for Watershed Hydrologic Modeling

Precipitation, potential evaportranspiration, air temperature, and streamflow time series data were acquired for the hydrologic modeling. For the Calleguas Creek watershed snow accumulation and melt are not significant, so that air temperature was not required for the hydrologic simulations. Additional data such as point sources, diversions, and irrigation practices 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 the 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 the hydrology model. MIKE BASIN requires appropriate representation of precipitation and potential evapotranspiration (ET). Daily precipitation data are sufficient to represent hydrologic and water quality in the model at the basin scale. Within the Calleguas Creek watershed, the Ventura County Water Protection District (VCWPD), Los Angeles County Department of Public Works (LACDPW) and the National Weather Service (NWS) each maintain networks of precipitation stations, most of which have been continuously operating for 30 years or longer. Stations with records at least spanning from 10/1996 to 09/2006 were selected for the model (Table 1). Their locations relative to the watershed are shown in Figure 3.

Some of the calibration stations have some 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 estimates of potential evapotranspiration required by MIKE BASIN. Pan evaporation data were obtained from the VCWPD and California Irrigation Management Information System (CIMIS) at several locations in and around the Calleguas Creek Watershed (Table 2). Several Class A stations provide long-term evaporation data coverage including Thousand Oaks in the south central portion of the watershed, Fillmore Fish Hatchery to the north and the El Rio UWCD Spreading Grounds at the east end of the watershed.

Table 1 Precipitation data records selected for the model

Station ID	Station Name	Elevation (ft)	Source	Latitude	Longitude
017C	Port Hueneme – Oxnard Sewer Plant	10	VCWPD	34.143	-119.186
049A	Santa Rosa Valley-Worthington Ranch	450	VCWPD	34.248	-118.940
154B	Simi-County Fire Station	1075	VCWPD	34.294	-118.709
169	Thousand Oaks-Weather Station	805	VCWPD	34.179	-118.851
177	Camarillo-Pacific Sod	20	VCWPD	34.157	-119.078
188A	Newbury Park-County Fire Station #35	640	VCWPD	34.186	-118.929
189	Somis-Deboni	520	VCWPD	34.285	-119.072
191	Moorpark-Downing Ranch	1040	VCWPD	34.326	-118.895
192A	Moorpark-Everett	680	VCWPD	34.251	-118.843
193A	Santa Susana	950	VCWPD	34.268	-118.709
196B	Tapo Canyon	1390	VCWPD	34.326	-118.719
215	Channel Islands Harbor	5	VCWPD	34.162	-119.222
227	Lake Bard	1010	VCWPD	34.242	-118.828
231	El Rio-County Yard	79	VCWPD	34.241	-119.177
234B	Las Llajas Canyon	1160	VCWPD	34.302	-118.689
250	Moorpark-Happy Camp Canyon	1410	VCWPD	34.346	-118.850
263A	Camarillo-Leisure Village	115	CIMIS	34.220	-118.991
032A	Oxnard Civic Center	53	VCWPD	34.200	-119.179
46569	Oxnard	15	NWS	34.200	-119.183

For model input, daily ET values are preferred. Unfortunately, only monthly data are currently available for the VCWPD stations. Daily data are available at two CIMIS stations but only for limited (i.e. recent) periods. Therefore, monthly 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 Stream Flow

To calibrate the model, simulated daily stream flow data were compared with observed daily flows. Daily flow records from 10/1996 to 09/30/2006 were obtained for eight stream gauges on the main stem and its tributaries (Figure 3). Several stream gauges have been moved over time for reasons including safety, accessibility, and accuracy. For calibration and validation purposes, the records from those gauges were combined into one continuous time series, if appropriate based on double-mass curve analyses to assess the continuity of the record. The records were combined at the paired gauges where no systematic difference is found between the pair. Five sets of stations that fell into this category are 11105850 and 803; 11106000, 806, and 806A; 11106400 and 800; 11106550 and 805; and 841 and 841A. Three gauges – VCWPD 802 Arroyo Simi at Royal Avenue Bridge, VCWPD 800 Conejo Creek above Highway 101, and VCWPD 776 Revolon Slough at Laguna Road – were selected for the primary calibration and flow data from five more gauges were used as consistency checks and further validation of the model (Table 3).

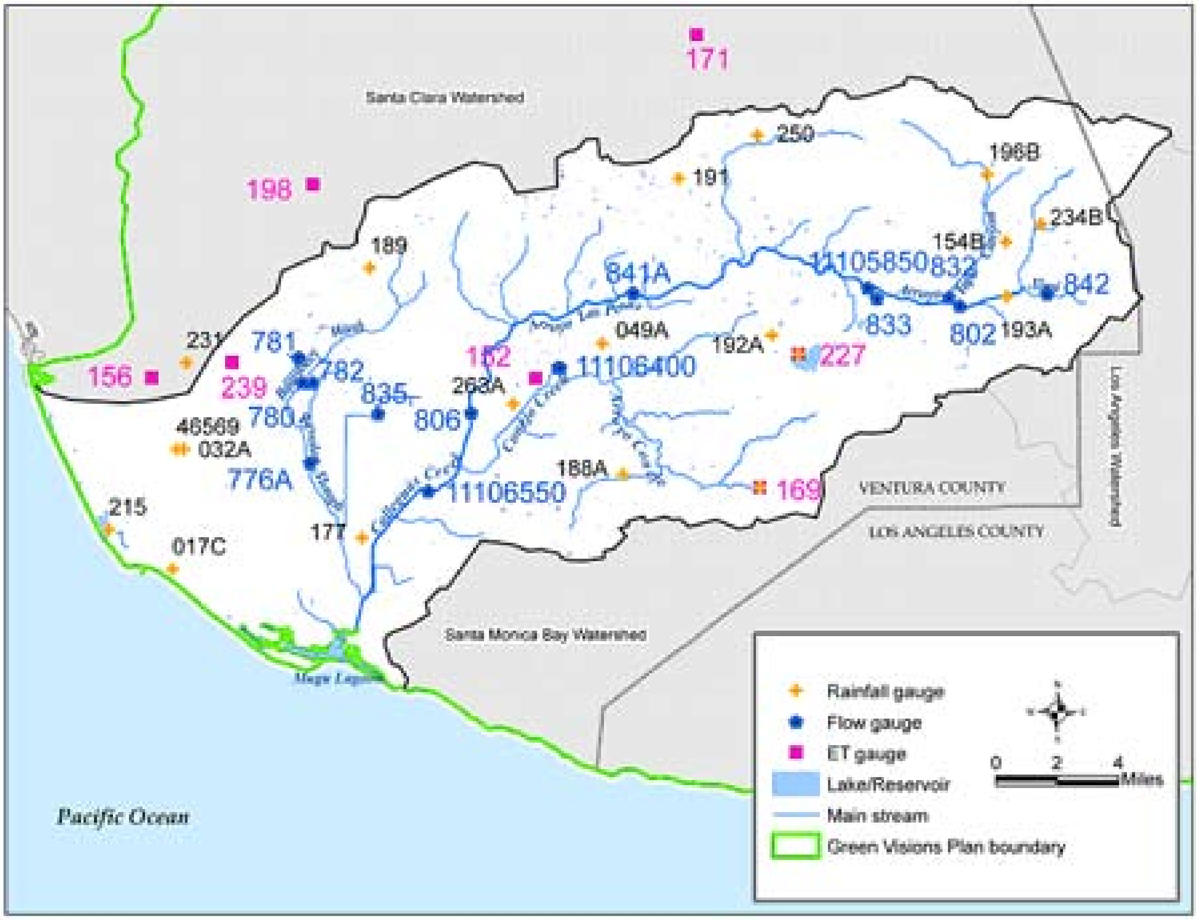

Figure 3 Precipitation, flow and evapotranspiration gauge locations in/near the Calleguas Creek watershed

Table 2 Evaporation stations in/near the Calleguas Creek watershed

Source	Evaporation ID/Name	Latitude	Longitude	Elevation (ft)	Annual average (in)
CIMIS	152 Camarillo	34.232	-118.978	3.3	3.8
CIMIS	156 Oxnard	34.234	-119.197	1.2	3.7
VCWPD	169 Thousand Oaks	34.179	-118.851	805.0	4.3
VCWPD	198 Santa Paula	34.325	-119.104	5.4	3.9
VCWPD	171 Fillmore Fish Hatchery	34.394	-118.884	465.0	4.7
VCWPD	227 Lake Bard	34.242	-118.828	1010.0	4.5
VCWPD	239 El Rio-UWCD	34.241	-119.151	105.0	5.1

Table 3 Stream flow stations in the Calleguas Creek watershed

STA_ID	Station name	Drainage (mi^2)	Flow records	
			From	To
776	Revolon Slough at Laguna Rd	46.0	19791001	20050930
11106400/800	Conejo Creek ABOVE HW 101 CA	64.2	19721001	Present
VCWPD802	Arroyo Simi At Royal Ave Bridge	32.6	19681001	Present
780	Beardsley Wash at Central Ave		19940120	Present
11105850/803	Arroyo Simi NR Simi CA	70.6	19331001	Present
11106550/805	Calleguas C A Camarillo State Hospital	248	19681001	Present
841/841A	Arroyo Las Posas above Hitch Blvd		19901001	20051001
11106000/806/806A	Calleguas C AT Camarillo	168.7	19281001	Present

2.4 Point Source Discharges

Point sources to Calleguas Creek include discharges from wastewater treatment works, groundwater remediation projects and industrial plants. These discharges are regulated through a National Pollution Discharge Elimination System (NPDES) permit or Waste Discharge Requirements (WDRs). Non-point sources to Calleguas Creek include stormwater and dry weather runoff from urban, agricultural, and open areas. Because urban and stormwater runoff are regulated through the Ventura County Municipal Stormwater NPDES permit, they are addressed as point sources in the permit.

The largest point sources of ammonia and oxidized nitrogen to Calleguas Creek are Publicly Owned Treatment Works (POTWs). For all reaches except Revolon Slough, Beardsley Wash, and the upper watershed tributaries, the POTWs provide more than 85% of the flow to the Calleguas Creek watershed during dry weather. During model configuration, six plants were included in the model (Table 4). Although the Olsen Road plant is currently out of service, it was active during much of the calibration period, and therefore it was included in the model. The Camrosa and Moorpark Water Reclamation Plants reclaim most of their effluent for use in agriculture or infiltrate their discharge in percolation ponds. Only during wet, winter months does either of these plants discharge any effluent to the receiving waters. The Camarillo, Hill Canyon, Olsen Road and Simi Valley water treatment plants discharge year round to the Conejo, Arroyo Conejo, Arroyo Santa Rosa and Arroyo Simi, respectively (Table 4). Active point sources were included in the model as a time variable source of flow from 10/1996 to 9/2005. To overcome the unavailability of daily discharge data, average daily flows were determined using the available data for each site.

In addition, we need to point out that runoff associated with urban land uses during the was not represented in the current MIKE BASIN model setup due to the limits of the model conceptual design and unavailability of necessary data. The accuracy level provided by the model will still meet our project objectives since our primary goal was the estimation of the spatial distribution of various constituents and the average contributions to surface waters.

2.5 Flow Regulation Data

The flow regime in the Calleguas Creek watershed has undergone many alterations over the years due to the addition of storm water retention basins, reservoirs, flow augmentation and irrigation practices, and diversions. Some of these controls were incorporated into the model through basic configurations: this included several dam-reservoir complexes located along the upper reach of Beardsley Wash, Land Creek, Las Llajas Canyon, Runkle Canyon, and Sycamore Canyon. Spillway crest, minimum pool, water conservation

Table 4 NPDES permitted major discharges and median concentrations for the three constituents used in the Calleguas Creek model

WRP	Discharge	Mean flow (cfs)	Ammonia-N (mg/L)	Nitrate-N (mg/L)	Nitrite-N (mg/L)
Camrosa	Irrigation	0.91			
Camrosa	Stream	0.03			
Hill Canyon	Total	15.69	4.9	7.8	0.96
Camarillo	Total	6.25	1.99	28.5	0.18
Moorpark	Stream	0.38	27.6	0.18	0.045
Olsen Road*	Total	0.34	2.4	0.96	0.045
Simi Valley	Total	13.27	24.7	1.68	0.29

*Closed in 2002

pool, flood control levels, and height-discharge look-up tables for these structures were incorporated into the MIKE BASIN configuration. Dam regulation data for Las Llajas Canyon Dam, Sycamore Canyon Dam, Runkle Canyon Debris Basin and Lang Creek Dam were obtained from a recent debris and detention basin report (VCWPD 2005).

A large portion of the lower Calleguas watershed is comprised of irrigated agricultural land that uses groundwater (primary supply), imported water, surface stream water, and effluents from treatment plants delivered through local water companies. Growers in the Oxnard Plain, Pleasant Valley Plain and Santa Rosa Valley receive water from the Conejo Creek Division Project plus local groundwater and water imported from the Santa Clara River at the Freeman Diversion and Calleguas Municipal Water District. Water right appropriations prevent the diversion of water in Conejo and Calleguas Creeks for uses other than the Conejo Creek Diversion Project. The Conejo Creek Diversion Project water is blended before it is supplied to sensitive agricultural users (Larry Walker Associates 2006). The water rights application allows the diversion of an amount equal to Hill Canyon's effluent minus 4 cfs for in-stream uses and channel losses. An additional amount of water equal to the flow contributed by use of imported water in the region (estimated at 4 cfs) may be diverted when at least 6 cfs of water will remain in the stream downstream of the diversion point (SWRCB 1997).

2.6 Water Quality Data

The Load Calculator Module in the model was used to determine pollution loadings in individual catchments. It calculated average mass fluxes of pollutants for individual catchments in kg/catchment/year and these estimates were then used by the MIKE BASIN Water Quality model to estimate pollution loadings in 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. Six NPDES dischargers were incorporated in the model as time variable point sources of pollutants due to their large associated loadings. Median concentrations of three constituents for each point source were obtained from the TMDL report prepared for the California Regional Water Quality Control Board – Los Angeles Region (Larry Walker Associates 2001; CRWQCB 2002a). Concentrations of ammonia discharged from these treatment plants range from 0.6 to 32 mg/l based on data collected under the Calleguas Creek Characterization Study (CCCS). Table 4 summarizes the median concentrations calculated from the CCCS for each of the POTWs.

The variability of non-point source contributions is represented through dynamic representation of hydrology and land use practices. Selected water quality constituent loading fluxes (e.g. nitrogen, phosphorus) associated with different land uses were obtained from research conducted by SCCWRP and LADPW. Land use data were obtained from SCAG (2001). The event mean fluxes by land use provided by SCCWRP and the LADPW were estimated by averaging a large number of water quality samples taken on certain types of land use classes. Representative event mean fluxes for different land uses are summarized in Table 5. The constituent fluxes from a given land use will vary from site to site and storm to storm, and this variability is magnified when the area of interest is expanded from single land use areas to watersheds because of the complexity

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

Flux ($kg/km^2/yr$)	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

of runoff sources and behavior. Our goal was to investigate the long-term average loadings to receiving waters; therefore, mean flux and other static pollutant sources are adequate to represent the spatial variations in constituent loadings across the watershed.

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 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 are sources of both nutrients and bacteria. 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 connections to sewer lines are not possible and have been used as a form of wastewater disposal for many decades. In the Calleguas Creek Watershed, septic systems are most widely used in unincorporated areas of the watershed, in particular the Santa Rosa Valley and unincorporated parts of the Arroyo Las Posas and Arroyo Simi areas. It was estimated that about 25,000 persons are served by septic systems in the Santa Rosa Valley, an area not served by sanitary sewer utilities (CRWQCB – LAR 2002a). In the Arroyo Las Posas/Arroyo Simi area, approximately 1% of the residents are still served by septic systems, which suggests that there is currently about 1,000 septic systems in this pair of subwatersheds.

Table 6 Calibrated treatment efficiency values for different zones

	NH4	NO3	TP
Revolon Slough	0.9	0	0.5
others	1	1	1

Nitrogen is quite mobile in groundwater, while phosphorus has a tendency to be absorbed by the soil. However, the contributions of sewer systems to groundwater are not very well understood and even less is known about the contributions to surface waters from these sources. 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 of the system. The treatment efficiencies can be varied in space between 0 and 1, with 0 representing no retention and 1 representing complete retention. Treatment efficiency values for various zones were therefore obtained for three aforementioned constituents during the calibration processes (Table 6). The zone boundaries were designated in accordance with the upstream subwatersheds for each of the water quality calibration sites.

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

Table 7 Water quality monitoring sites within the Calleguas Creek watershed

Station Code	Location	Site Type	Drainage Area (acre)	Data
ME-CC	Camarillo-Adohr	Mass Emission	160640	2001-2007
W3	Somis-Bard @La Vista Rd	Receiving water	752	1997-2006
W4	Revolon Slough Oxnard Airport	Receiving water	28800	1997-2006
W1	Heywood St	Receiving water	2307	1995-1996
W2	Alamo St	Receiving water	1237	1996
I-1	Via Pescador and Avenida Acaso	Industrial LU	30	1993-1996
R-2	Lawrence Way and Hill Street	Residential LU	121	1993-1996
C-1	Via del Norte and Los Olivos	Commercial LU	62	1993-1996
A-1	Wood Road at Revolon Slough	Agriculture LU	350	1995-2005

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).

3 Subwatershed Delineation and Characterization

The total loading in each subwatershed is the sum of the loadings from all sources and 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 at very specific years and no reoccurring sample data are available at these sites. Table 7 lists sites that have water quality monitored by the VCWPD stormwater monitoring program. The mass emission site ME-CC and the receiving water site W-4 were selected and used for the calibration/validation process.

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 Calleguas Creek 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 has primarily been generated from the 1:24K NHD data set 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 and Mackay 2000; 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 162 subwatersheds in the final MIKE BASIN model runs (Figure 4).

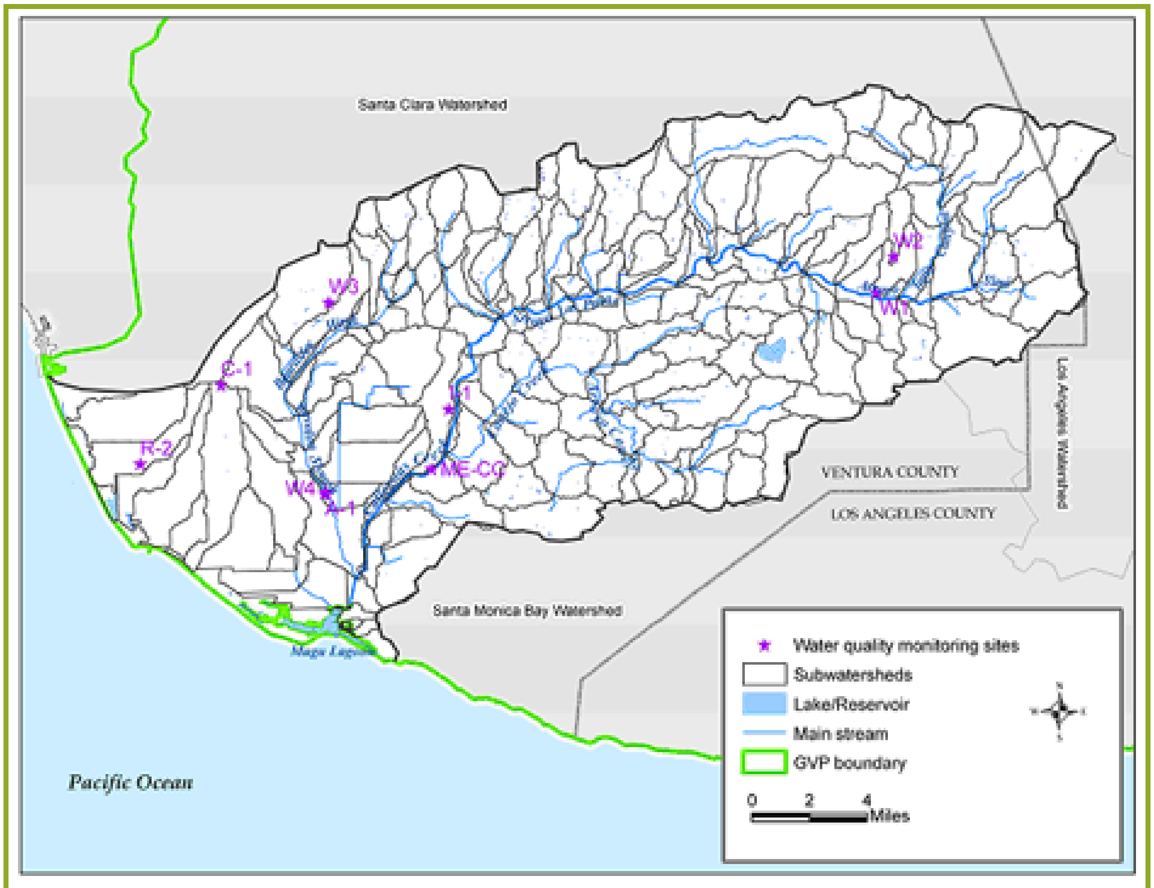

Figure 4 Watershed and stream segmentation

4 Model Calibration and Validation

4.1 MIKE BASIN Rainfall-runoff NAM Model Configuration

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 groundwater storage (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-3 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.

The NAM model requires stream flow, precipitation and evapotranspiration time series 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 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 subwatershed level that we delineated. As a result, no modification was performed on the precipitation observations and each subwatershed was assigned precipitation and evapotranspiration time series using the Thiessen polygon method.

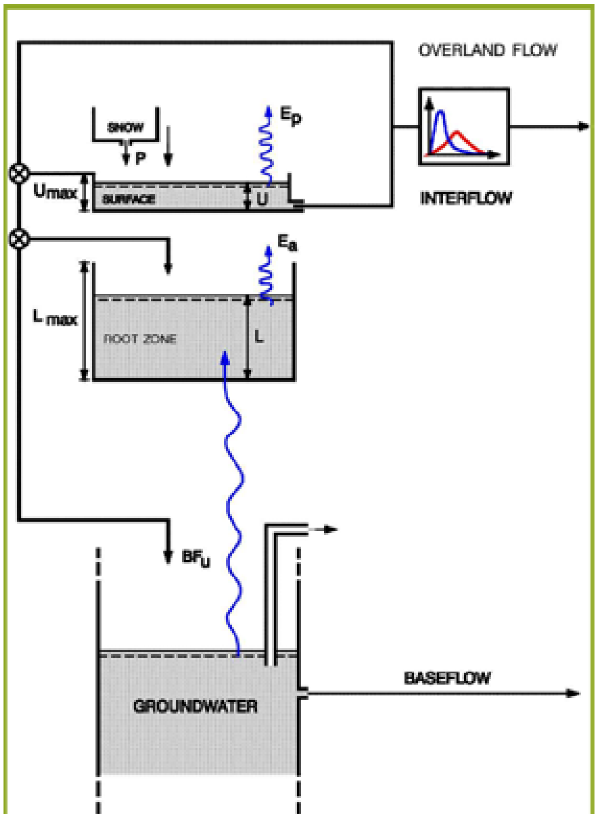

Figure 5 NAM model schematic

Multiple reservoir-dam systems were incorporated in the MIKE BASIN model runs. The performance of specified operating policies was simulated using associated operating rule curves generated from the dam and reservoir operation data provided by Ventura 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 possibly the anticipated or expected inflows. A reservoir can be located anywhere on a river represented by individual nodes on the stream network.

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 water quality simulation. Calibration is the adjustment or fine-tuning of rainfall-runoff modeling parameters to reproduce observations. To ensure that the model results are as current as possible and to provide for a range of hydrologic conditions, the period from 1 September 1996 to 30 August 2005 was selected as the hydrology/water quality simulation period. The calibration was performed on four selected subwatersheds and calibrated datasets containing parameter values for rainfall-runoff simulation were extrapolated for all ungauged catchments exhibiting similar physical, meteorological, and land use characteristics. Subsequently, validation runs were performed to test the calibrated parameters at ten more locations for the simulation period from 10/1/1996 to 9/30/2005, without further adjustment.

Hydrology is the first model component calibrated because estimation of pollutants loading relies heavily on flow prediction. The hydrology calibration involves a comparison of model results to in-stream flow observations at selected locations. After comparing the results, key hydrologic parameters were adjusted

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

Table 9 General calibration/validation targets or tolerances for assessing model performance (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

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 magnitude. This process was automated using the MIKE 11 autocalibration module. For modeling the rainfall-runoff process at the catchment scale, the total catchment runoff often constitutes the only available information for evaluating this objective. 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 optimisation 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 abovementioned 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 a seasonal basis. Some general guidance used by EPA's HSPF model users over the past decade was adopted to help assess the MIKE BASIN model accuracy (e.g. Donigian 2000) (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.

4.2.1 Hydrology Calibration Results

Figure A-1 shows the calibration results for the VCWPD 802 at Arroyo Simi gauging station. The Arroyo Simi subwatershed is located in the headwaters and is 30% urban, 60% forest, and 10% agricultural. The table included in Figure A-1 summarizes the calibrated parameters. The graph below the table shows a nine-year time series plot of modeled and observed daily flows. A mass curve showing cumulative stream runoff volume versus time is plotted for both observation and simulation data. The two time series plots provide a good overview of the entire calibration period. To provide a measure of model accuracy, regression analyses were performed for both daily and monthly values. Graphs at the bottom of the Figure A-1 show that the model performs better in reproducing average monthly values than daily values given the higher coefficient of determination (R2) associated with monthly values (R2=0.95) compared to daily values (R2= 0.59). The volume comparisons in Table A-1 indicate that the

Table 10 R2 value ranges for model assessment (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

model performs fairly well during winters but fairly poor during the other seasons. All seven annually occurring winter storm events were reflected on the prediction curve.

Model results for the VCWPD 800 at Conejo Creek gauging station were different in terms of both the dominant flow regimes and land use patterns. Figure A-2 and Table A-2 show the time-variable plots and volume error analyses, respectively, for Conejo Creek. The graphic comparisons show that the model provided fairly good results in terms of reproducing the observed flow pattern at this location. Specifically, an analysis of the error associated with volumes indicates that the model closely predicts high flow regimes while substantially under-estimating low flows, which is likely due to the presence of return flows through agricultural irrigation systems that receive water from imports and groundwater basins.

Calibration was also performed for the Revolon Slough agricultural subwatershed using the VCWPD 776 at Revolon Slough gauging station. The majority of the upstream land is used for growing strawberries, lemons and various row crops. The model predicts the overall flow volume and high flows reasonably well considering the complexity of agricultural irrigation representation in the model (Table A-3). But the model behaves poorly for low flow conditions, given that the model tends to under-estimate the flow pattern that is influenced by agricultural irrigation using imported water from outside the subwatershed (Table A-3).

4.2.2 Hydrology Validation Results

After calibrating hydrology, the model was implemented using calibrated hydrologic parameters at five more locations along Calleguas Creek and its major tributaries for the period 10/1/1996 to 9/30/2005. Calibrated parameters obtained from the Arroyo Simi subwatershed were applied to all natural forested or minimally developed catchments. Agricultural catchments were configured using the calibrated parameters for the Revolon Slough subwatershed. The Conejo Creek parameter set was applied to the remainder of the catchments. Validation results were assessed through time-variable plots and regression analyses for the VCWPD 780, 803, 841, USGS11106000/806/806A and 805 stations shown in Figures A-4 through A-8. Table 11 summarizes the overall results from the validation process.

For the five validated stations, the total stream water volumes were fairly well simulated with the exception of two sites at Beardsley Wash and Calleguas Creek at Camarillo. Very good validation results were even achieved for simulating the 90th percentile high flows while the 10th percentile low flows are poorly simulated with over-predictions at all sites. Major annually occurring winter storm events were reflected on the predicted hydrographs (Figures A-4 through A-8) with varying levels of under- estimation. The overall validation results suggest fair model performance and that the model does represent the dominant flow conditions in the watershed.

Table 11 Model validation results summary

Sites	Overall assessment	Simulated High flows	Simulated low flows	Monthly R^2
VCWPD 780 at Beardsley Wash at Central Ave	Poor	Fair	Poor	0.88
VCWPD 803 at Arroyo Simi near Simi CA	Fair	Very good	Poor	0.96
VCWPD 841 at Arroyo Las Posas above Hitch Blvd	Fair	Very good	Fair	0.93
USGS11106000/806/806A Calleguas Cr at Camarillo	Poor	Fair	Poor	0.93
VCWPD 805 at Calleguas Creek at Camarillo	Fair	Very good	Good	0.92

Validation results for the 780 and USGS11106000/806/806A gauging stations are not satisfactory in reproducing observed flows according to the recommended criteria. All flow conditions were over-predicted, which are very likely caused by the low accuracy data on the flow channel loss and agriculture irrigation water diverted from the surface water. An examination of historical flows in Calleguas Creek showed that Arroyo Las Posas does not generally provide surface flow to Calleguas Creek during dry periods. Conejo Creek provides the majority of the flow in Calleguas Creek (CRWQCB 2002a). Consequently, an artificial user was added to the model to represent the flow channel loss that actually improved the validation results in estimating total flow volume and flow volumes during all seasons at the VCWPD 805 at Calleguas Creek near Camarillo gauging station.

4.3 Water Quality Calibration and Validation

MIKE BASIN can simulate water quality in surface and ground waters, 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 pre-defined 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 individual reaches such that the residence time and the effects of mixing between reach storage and inflows can be properly specified in the model.

After the model was calibrated and validated for hydrology, water quality simulations were performed from 10/1996 through 9/2005. The water quality load calculator was calibrated by comparing model output with pollutographs for NH3-N, NO3-N, and TP observed for two water quality monitoring sites (W4 and ME-CC). After comparing the results, key parameters in configuring the load calculator such as pollutant treatment coefficients and runoff coefficients were adjusted accordingly. This iterative process was repeated until the "best fit" was estimated between the simulated pollutographs and observations. Different runoff and treatment coefficient values were assigned for the aforementioned constituents for different zones during the calibration process.

To assess the predictive capability of the model, the final output was graphically compared to observed data. Figures B-1 and B-2 present the time-series plots of model results and observed data at the ME-CC and W4 monitoring sites operated by the Ventura Countywide Stormwater Quality Management Program. The ME-CC site on Calleguas Creek monitors the water quality of the entire watershed, approximate six miles before the creek enters the lagoon (Photo 1, VCWPD 2004).

Photos 1 and 2

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

Sites		NH4 [mg/l]	NO3 [mg/l]	Total P [mg/l]
W4 Revolon Slough	Modeled	0.26	13.18	1.83
	Observed	0.51	11.72	2.36
	Error (%)	-49.0	12.5	-22.6
ME-CC Calleguas Creek	Modeled	0.15	6.30	1.87
	Observed	0.24	7.66	3.12
	Error (%)	-37.5	-17.8	-40.1

The W4 site at Revolon Slough drains the agricultural lands in the western portion of the watershed (Photo 2, VCWPD 2004). The slough does not pass through any urban areas, but does receive drainage from tributaries that drain urban areas. NH4, NO3, TP and other constituents were analyzed periodically for selected storm events. The graphic comparisons and quantitative analyses were performed based on relatively few 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 period (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 pollutographs. The water quality model had difficulties in reproducing the extreme high or low concentrations in the pollutographs (Figures B-1 and B-2) because it relied on a daily time stamp. This daily time stamp might have smoothed out the in-stream water quality pulse or the dilution that likely occurs over very short time periods. At the ME-CC site for example, a very high TP concentration value of 27.7 mg/l was reported on 10/16/2004, which was about 15 times of the median concentration reported at this site. This sample was not included in the subsequent analysis and it was not predicted by the model either. The mean values of the modeled and observed time series without the outliers are summarized in Table 12.

5 Results

The variations of flow and water quality in the Calleguas Creek watershed are characterized based on the model simulation results. Figure 6 shows the total flow discharge simulated for Calleguas Creek near the outlet (N167). Figure 6 depicts time-series plots of modeled monthly flows in acre-feet and as a percentage of the corresponding annual flows The simulation results for NO3 were slightly better than those for NH4 and TP based on the error percentages and offered fair performance using the previously specified water quality model assessment criteria.

Average monthly in-stream flow in Calleguas Creek at the outlet was about 6,000 AF during the simulation period. The monthly flows are highly variable with discharge varying by several orders of magnitude. Calleguas Creek used to be an ephemeral creek flowing only during the wet season near the outlet. During the storm high flow season, the channel would wander freely across the Oxnard Plain without direct discharge into the Mugu Lagoon, with such changes in course recorded as recently as 1884. The flow discharge varied from 100,000 AF in February 1998 to the low flows of approximately 50 AF the occurred in many of the

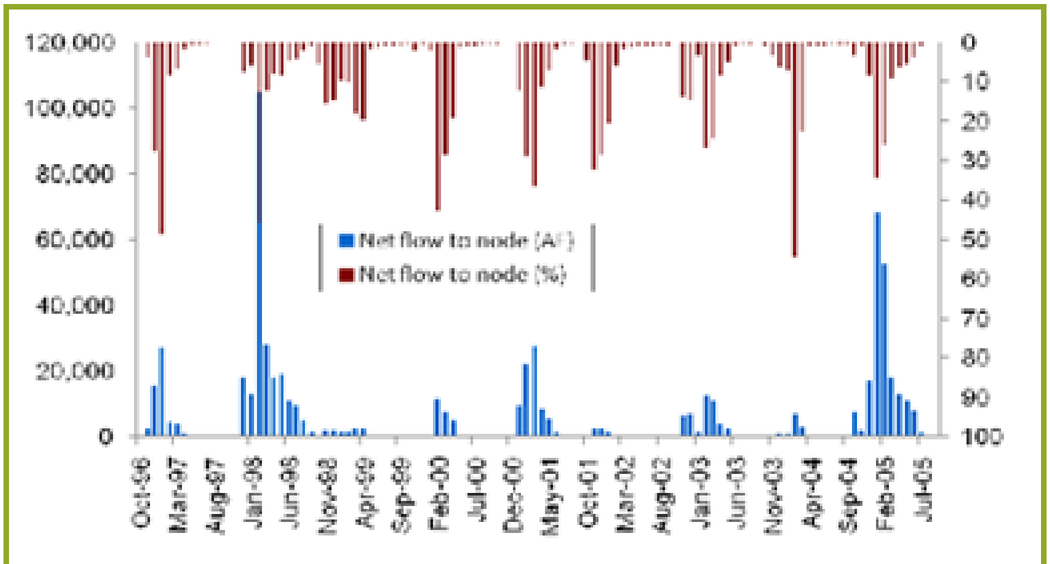

Figure 6 Flow volumes in acre feet (AF) and as a percentage of annual flows for Calleguas Creek near the outlet

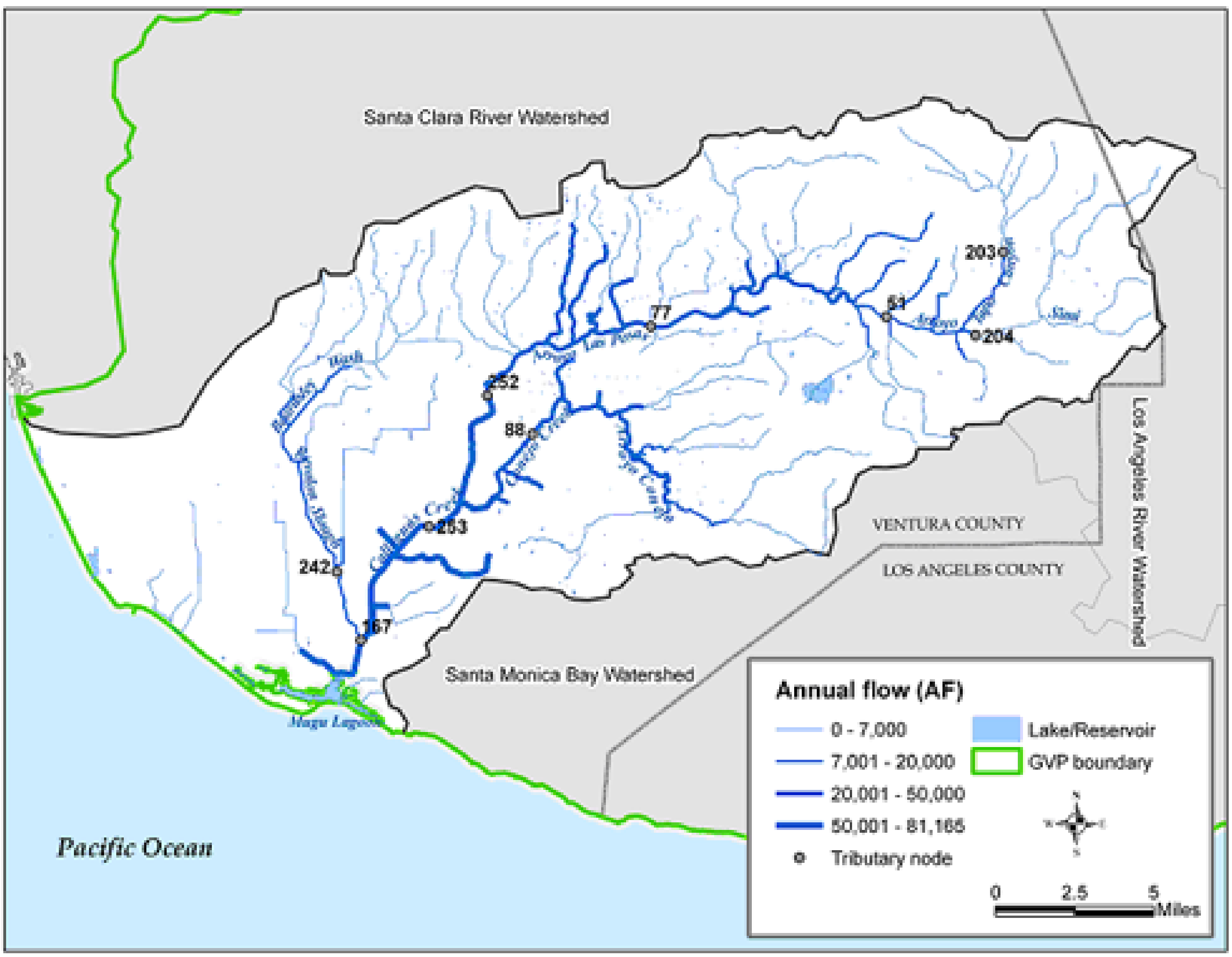

Figure 7 Cumulative flow discharges along the stream network

Table 13 Annual discharges and percent to the ocean at major tributaries

Reach name	Node ID	Annual Q [AF]	Q to the ocean (%)	Area (%)
Calleguas Creek outlet	N167	76,433	100.0	100.0
Arroyo Tapo	N203	4,041	5.3	5.5
Arroyo Simi At Royal Ave Bridge	N204	5,258	6.9	10.2
Revolon Slough at Pleasant Valley Road	N242	16,448	21.5	19.8
Calleguas Creek at Hwy 101	N252	36,374	47.6	52.1
Calleguas Creek at CSUCI	N253	65,734	86.0	53.6
Arroyo Simi near Simi at Madera Rd Bridge	N51	12,473	16.3	22.0
Arroyo Las Posas above Hitch Blvd	N77	38,440	50.3	40.0
Conejo Creek abv Hwy 101	N88	38,085	49.8	19.1

dry months. The percent of monthly discharge to the annual total varied from 46% to 0.5%. 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 13.7% of the annual discharge from Calleguas Creek.

The contributions of the inland tributaries and discharges of the various tributaries to Callegaus Creek vary substantially (Figure 7). Conejo Creek contributes roughly 50% of the total inflow to the outlet on average and therefore has a substantial impact on flow conditions in the lower reaches of Calleguas Creek (Table 13). Historically, both Conejo Creek and Arroyo Las Posas were ephemeral. However, the increasing agricultural, municipal wastewater and urban non-storm water discharges turned both into perennial streams and the contributions from Arroyo Conejo have led to increasing flows in the portion of Calleguas Creek near the junction with Conejo Creek since the 1970s.

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 Calleguas Creek at the bottom of the watershed as time-series plots of modeled monthly loads and as a fraction of the corresponding annual loads.

Monthly average in-stream loads in Calleguas Creek at the outlet were about 1,200, 45,500 and 9,000 kg for NH4, NO3 and TP, respectively during the simulation period. Temporal variations in nutrient loads are relatively similar between the three nutrients. The largest variations occur in the storm season (e.g. December through February), while significantly lower and less variable monthly loads are predicted during the non-storm seasons. Much higher fractions of the total loads associated with winter storms reach the ocean than in the other three seasons as well. The highest NO3 load of 890,000 kg was predicted in February 1998 and can be contrasted with the 7,000 kg loads predicted in many dry months. The November to April wet weather loads accounted for 87% of the annual NO3 loads from Calleguas Creek during the period 1996-2005 for example.

Nutrient loads generally moving downstream. The average annual loads from several selected major tributaries summarized in Table 14. Figure 9 shows the spatial distribution of the nutrient loads along the stream network. Approximately 50% of the nutrient loads are contributed by the Revolon Slough subwatershed. Agriculture is the major land use in the subwatershed. A very high NH4 load was predicted at the Arroyo Las Posas above Hitch Boulevard (N77) monitoring station, which even exceeds the total NH4 load predicted at the outlet. The Moorpark and Simi Valley WRPs discharged large loads to the reach above the N77 monitoring station. Very high TP loads of 63,000 kg (about 60% of the total loads from Calleguas Creek) were predicted at the Conejo Creek above Hwy 101 (N88) monitoring station.

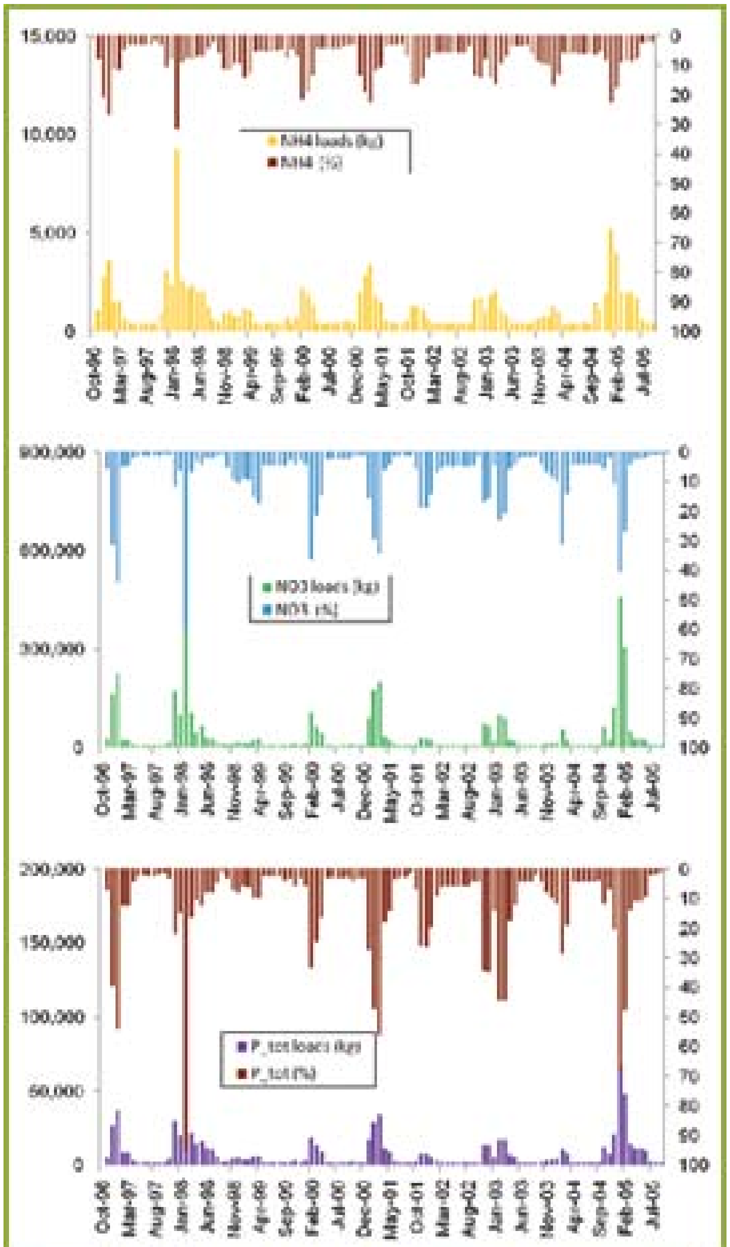

Figure 8 Monthly nutrient loads in kilograms and percentages for Calleguas Creek at the outlet

Figure 10 demonstrates the spatial distribution of nutrient flux (i.e. sources) in each catchment. High NH4, NO3 and TP fluxes are observed in the catchments where the Simi Valley, Hill Canyon, and Moorpark wastewater treatment plants are located. The highest annual fluxes estimated for NH4, NO3 and TP were 1,500, 36,000 and 28,000 kg/sq km, respectively, in the catchment where the Hill Canyon WRP is situated. Relatively high NH4 and NO3 loadings occur in the Camarillo Hills Drain, the lower Conejo Creek and part of Beardsley Wash as well. Relatively high phosphorous concentrations were predicted in the Camarillo Hills Drain and lower Conejo Creek areas.

The earlier studies pointed to 30 separate pollutants that had been listed in the Clean Water Act, Section 303(d) list of impaired waters in the Calleguas Creek watershed. For each of these pollutants, the Basin Plan has identified water quality objectives and adopted standards to address the listings (CRWQCB-LAR 1994). The Basin Plan states that surface water shall not exceed 10 mg/L nitrogen as nitrate- and nitrite-nitrogen, 45 mg/L as nitrate, 10 mg/L as nitrate-nitrogen or 1 mg/L as nitrite-nitrogen (CRWQCB-LAR 1994). The nitrate and nitrite targets for TMDLs on the numeric objectives in the Basin Plan are specified as 30-day average concentrations.

The simulated results were used for estimating the total loads and assessing the degree of water quality impairment for surface waters in a time and location specific way based on the Basin Plan that has been adopted by the California Water Quality Control Board. Figures B-1 and B-2 show that the target of 10mg/L for nitrate-nitrogen was exceeded at both the ME-CC and W4 sites during certain times, although not simultaneously. Figure 11 uses the simulated daily flow volume and NO3 concentration to estimate the daily NO3 load for the ME-CC (N253) mass emission site for example.

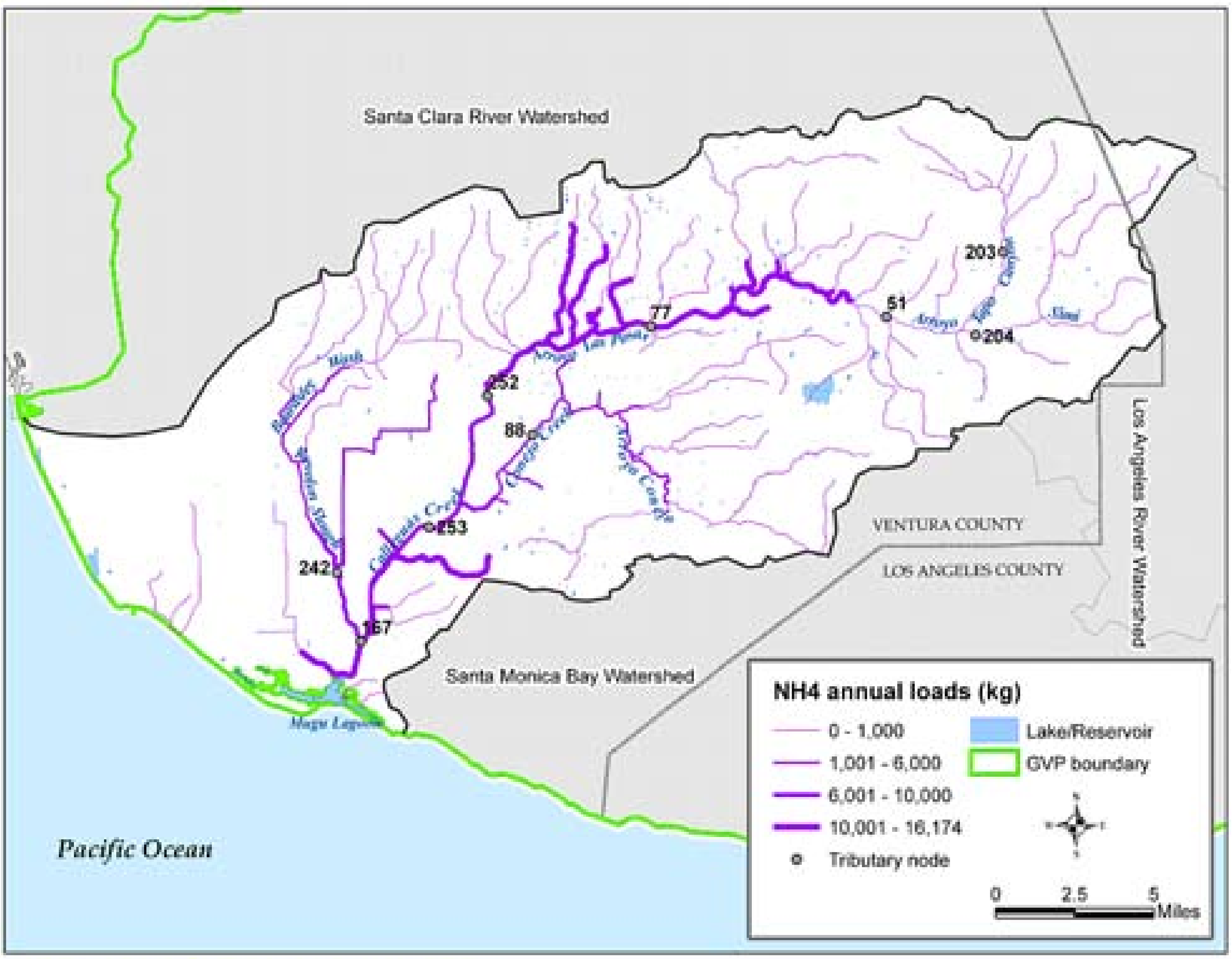

Figure 9a NH4 loads along the stream network

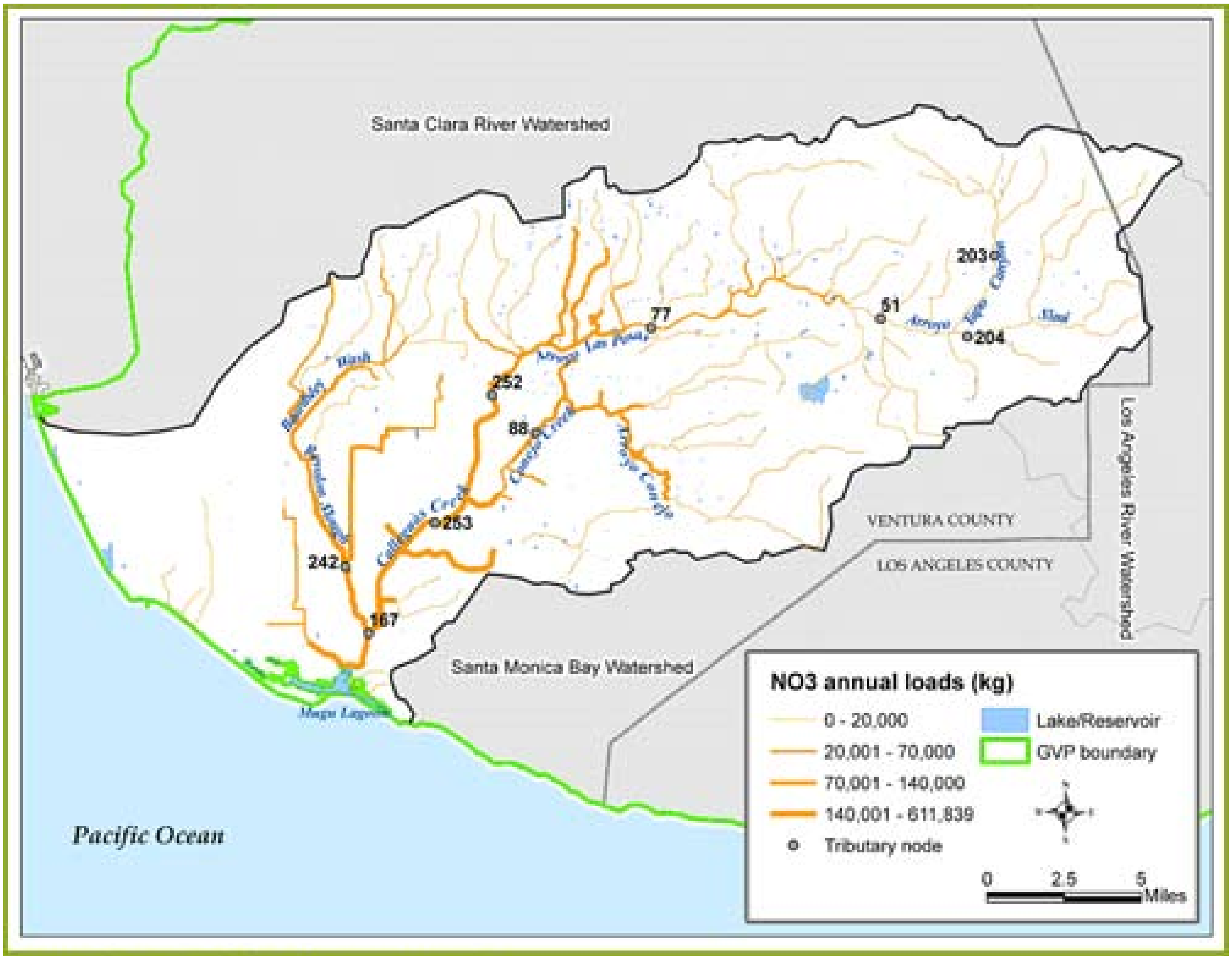

Figure 9b NO3 loads along the stream network

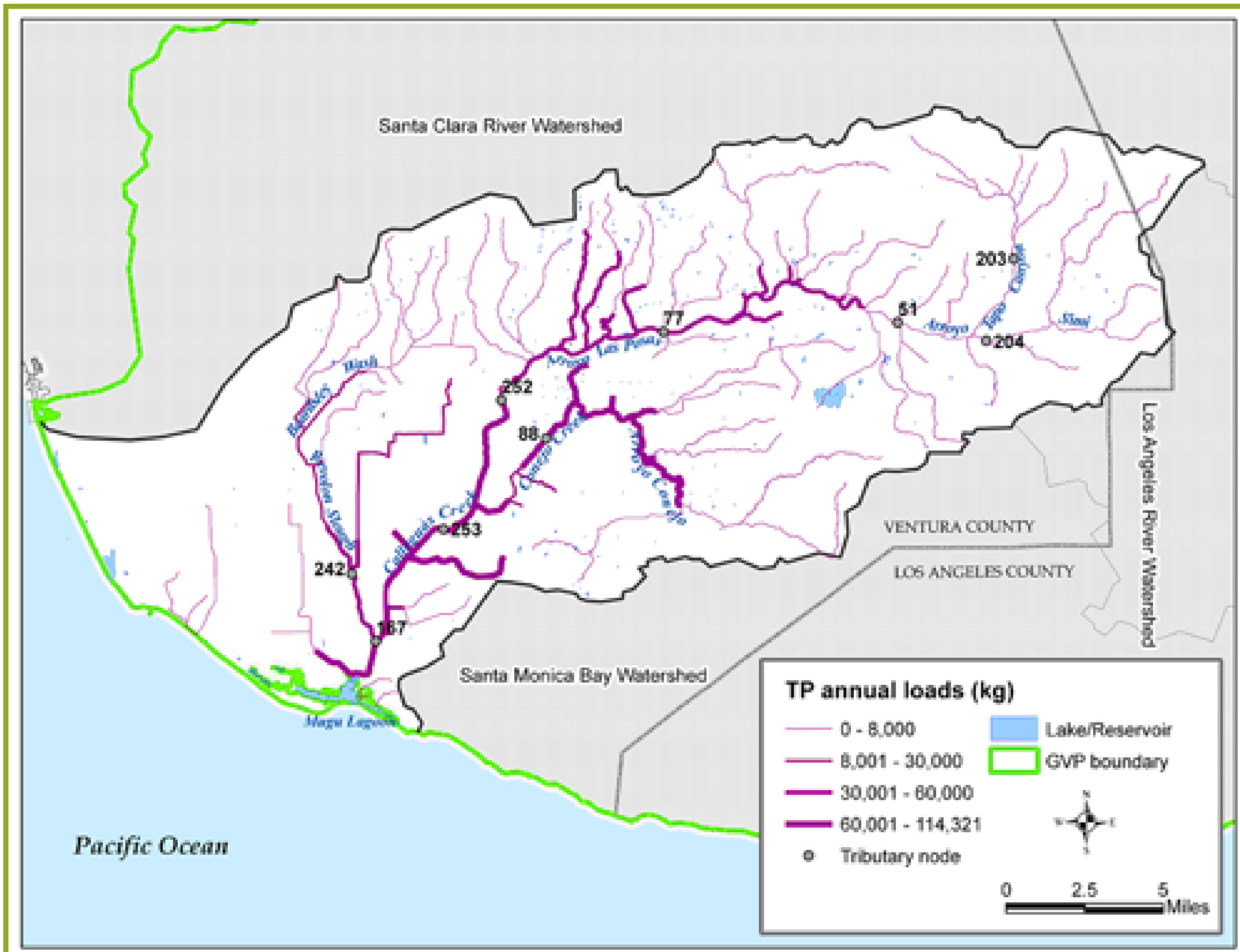

Figure 9c TP loads along the stream network

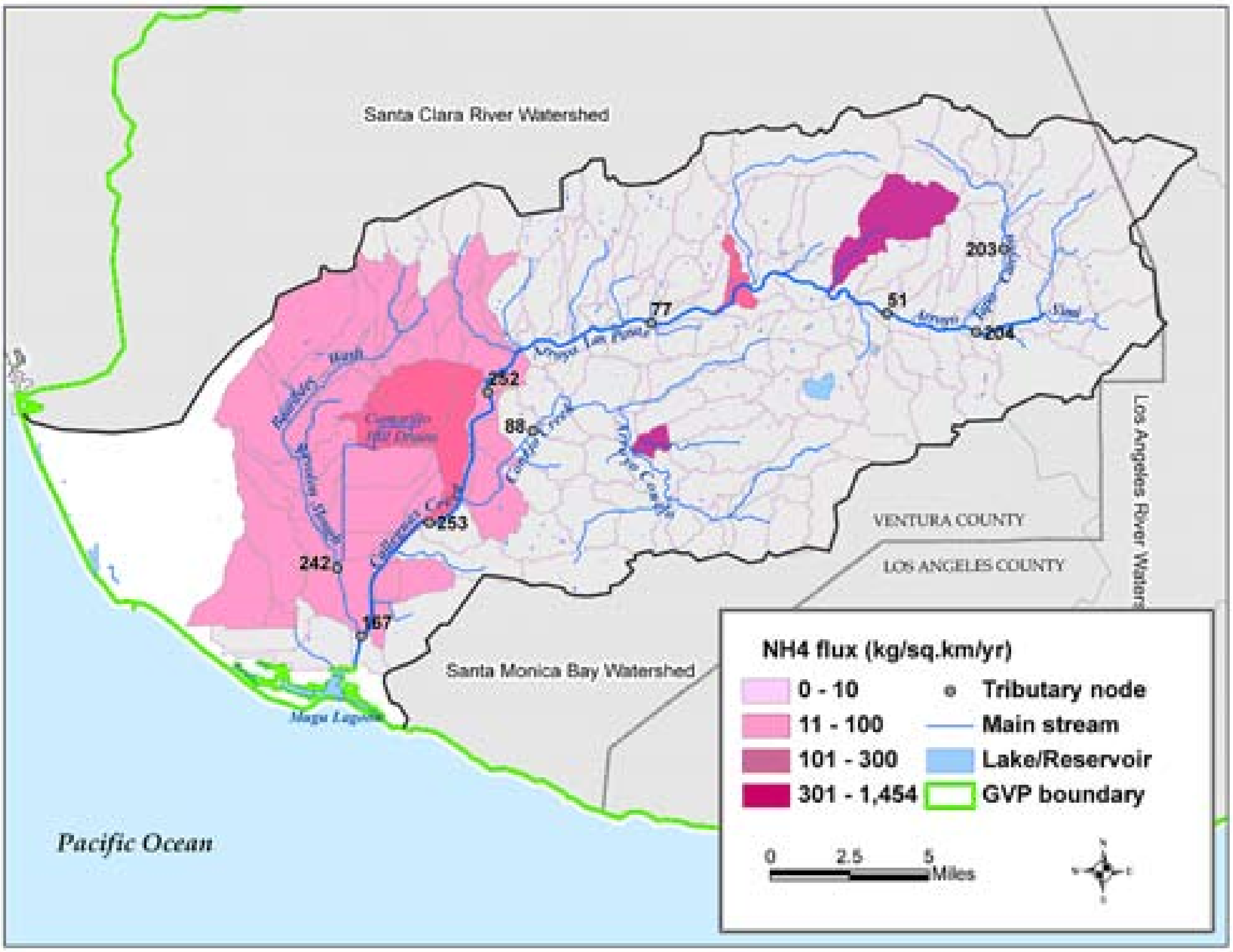

Figure 10a NH4 flux associated with each subcatchment

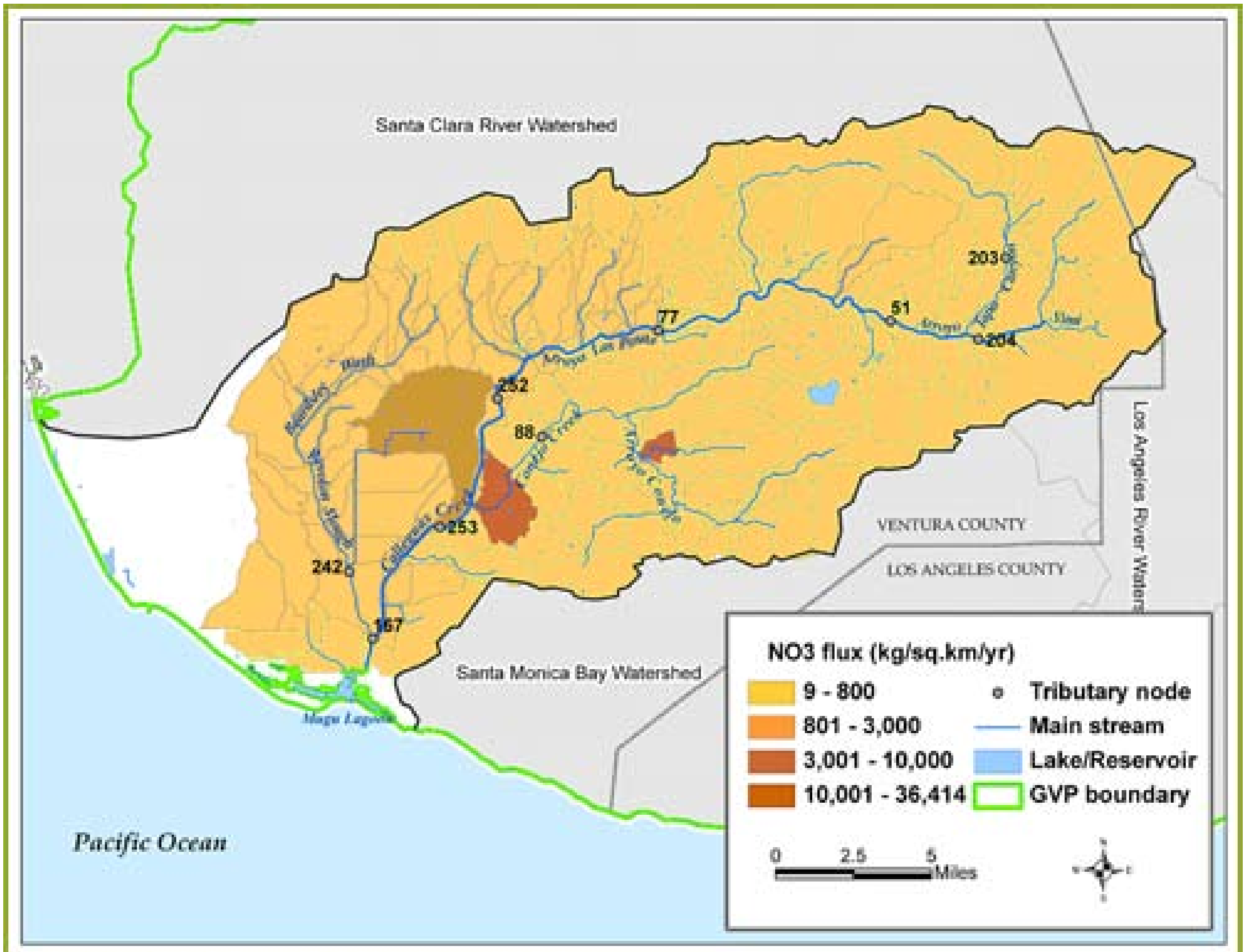

Figure 10b NO3 flux associated with each subcatchment

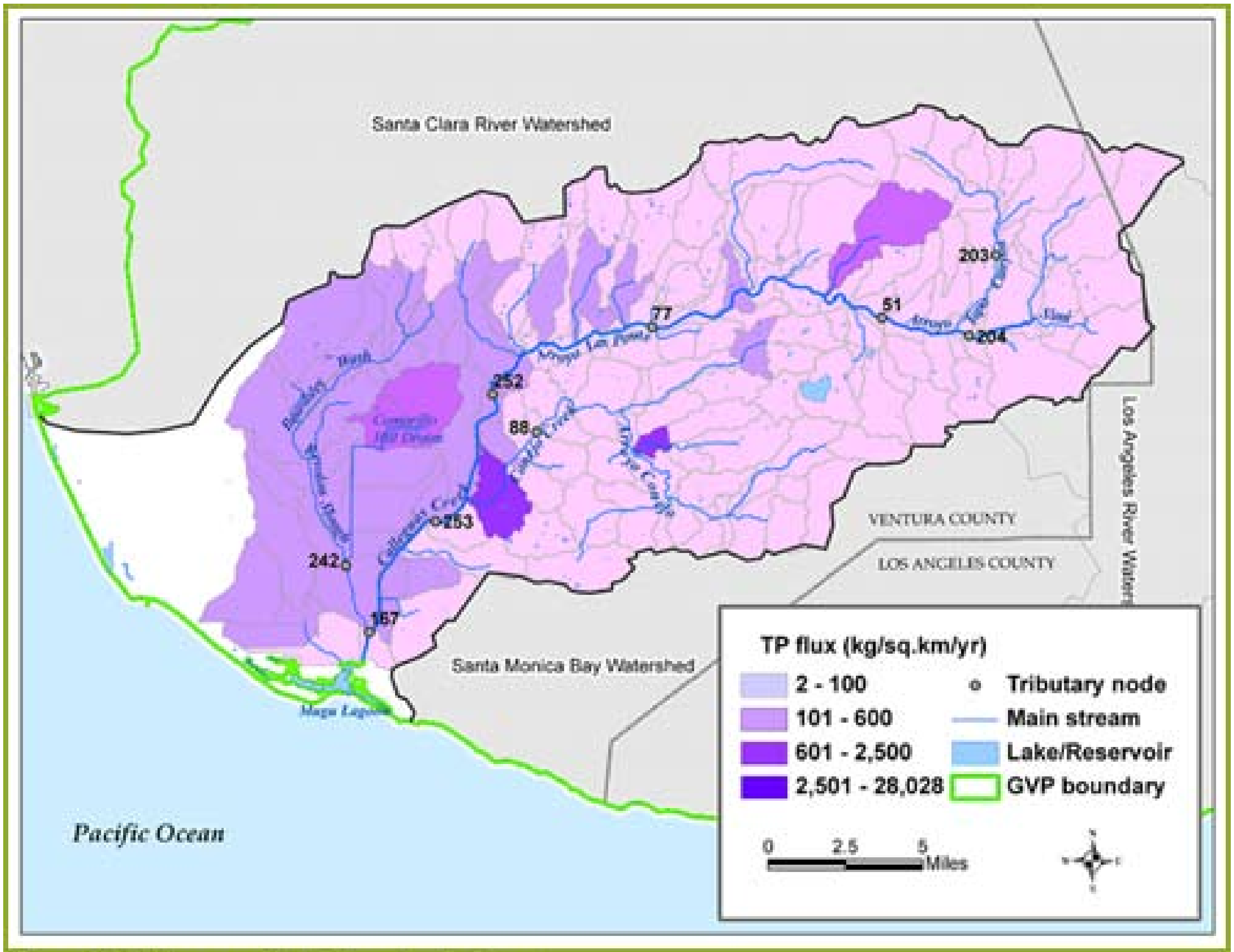

Figure 10c TP flux associated with each subcatchment

Table 14 Annual nutrient loads from major 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 (%)
Calleguas Creek outlet	N167	14,200	100.0	549,830	100.0	105,468	100.0	100.0
Arroyo Tapo	N203	0	0.0	7,005	1.3	860	0.8	5.5
Arroyo Simi At Royal Ave Bridge	N204	0	0.0	5,232	1.0	1,037	1.0	10.2
Revolon Slough at Pleasant Valley Road	N242	7,914	55.7	272,106	49.5	45,734	43.4	19.8
Calleguas Creek at Hwy 101	N252	7,499	52.8	117,632	21.4	29,932	28.4	52.1
Calleguas Creek at CSUCI	N253	9,295	65.5	289,041	52.6	79,105	75.0	53.6
Arroyo Simi near Simi at Madera Rd Bridge	N51	0	0.0	15,365	2.8	2,606	2.5	22.0
Arroyo Las Posas above Hitch Blvd	N77	15,965	112.4	50,428	9.2	41,822	39.7	40.0
Conejo Creek abv Hwy 101	N88	3,143	22.1	98,180	17.9	63,002	59.7	19.1

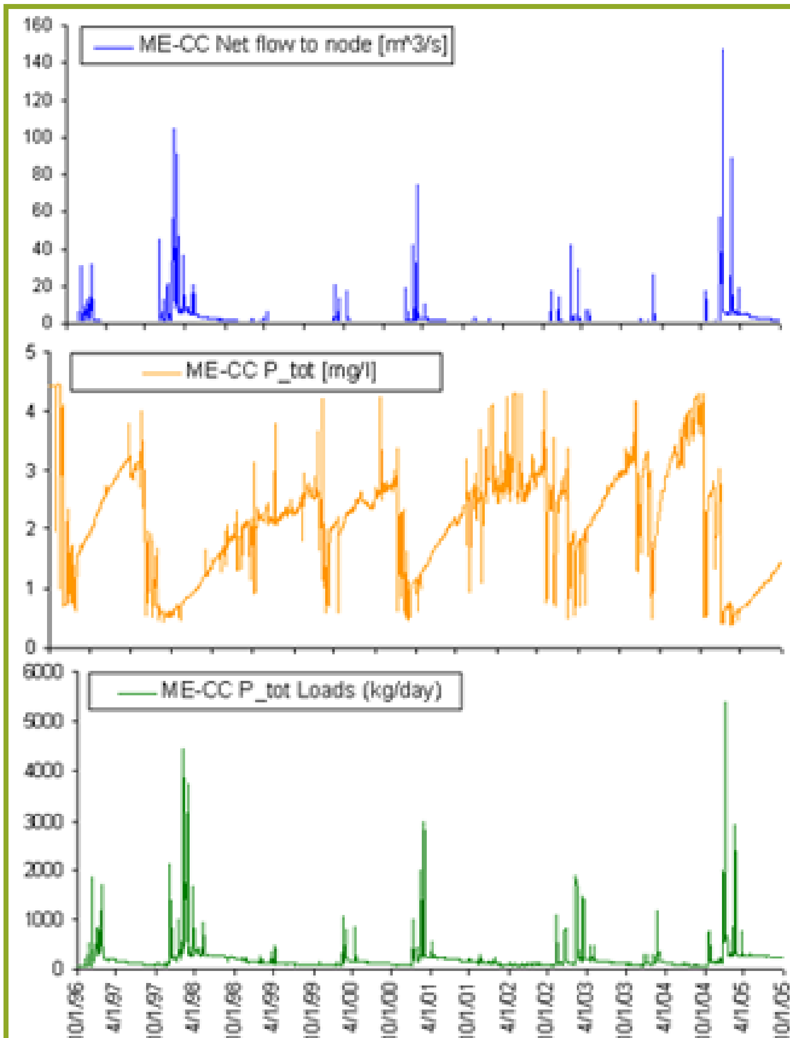

Figure 11 NO3 load calculation using the simulated flow volume and NO3 concentration for the ME-CC (N253) mass emission site

6 Discussion and Conclusions

MIKE BASIN combines the power of ArcGIS with comprehensive hydrologic modeling and was implemented in the Callegaus Creek 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 sections 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 Callegaus Creek watershed based on water availability and utilization using hydrological data from 10/1996 through 09/2005.

Key inputs to the model included the digitized river system layout, withdrawal and reservoir locations, a time series of water demand, the ground water abstraction (expressed 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 user's delivery priorities and upstream nodes, water quality rate parameters, temperature, non-point loads, weir constant for re-aeration, transport time and water depth (or the Q-h relationship), and the concentrations in effluent. Key outputs included mass balances, detailed flow descriptions throughout the water system, water diversions, and descriptions of various water quality constituents.

The spatio-temporal variations of flow and water quality in the Calleguas Creek watershed were characterized based on the model simulation results. Monthly average in-stream flow in Calleguas Creek at the outlet was about 6,000 AF during the simulation period. The monthly flows are highly variable with discharge varying by several orders of magnitude. Calleguas Creek used to be an ephemeral creek flowing only during the wet season near its outlet. The winter flows contribute the majority of the annual flow to the ocean. The flows are significantly lower and less variable during dry weather. From 1996 to 2005, dry-weather flows (May to October) accounted for 13.7% of the annual discharge from Calleguas Creek. Conejo Creek contributes roughly 50% of the total inflow to the outlet on average and therefore affects flow conditions in the lower reaches of Calleguas Creek. The Arroyo Las Posas does not generally provide surface flow to Calleguas Creek during dry periods.

Monthly average in-stream loads in Calleguas Creek at the outlet were about 1,200, 45,500 and 9,000 kg for NH4, NO3 and TP, respectively during the simulation period. Temporal variations in nutrient loads for the three constituents are relatively similar. The large variations occur in the storm season (e.g. December through February) with substantially lower and less variable monthly loads during the non-storm seasons. The total loads associated with winter storms generally contribute the much higher fractions to the ocean as well. From 1996 to 2005, wet-weather flows (November to the following April) accounted for 87% of the annual NO3 loads from Calleguas Creek for example. Nearly 50% of the nutrient loadings come from the Revolon Slough subwatershed (N242 mass emission site). The NH4 load predicted at Arroyo Las Posas above Hitch Boulevard (N77), which sits below the reach into which the Moorpark and Simi Valley WRPs discharge, exceeded the loading predicted at the outlet. Conejo Creek above Hwy 101(N88 mass emission site) yielded very high TP loads of 63,000 kg that constituted about 60% of the total loads from Calleguas Creek. The highest NH4, NO3 and TP fluxes were observed in the catchments where the Simi Valley, Hill Canyon and Moorpark wastewater treatment plants are located. The highest annual fluxes for NH4, NO3 and TP of 1,500 36,000, 28,000 kg/sq.km, respectively were estimated in the catchment where Hill Canyon WRP is situated.

The results can also be used for estimating the total loads and assessing the degree of water impairment for predefined stream sections of the stream network based on the Basin Plan implemented by the California Water Quality Control Board. It was shown that the target of 10mg/L for nitrate-nitrogen was exceeded at both the ME-CC and W4 mass emission sites during certain time periods of the simulation although not simultaneously.

Overall, the model results should provide users with simple, intuitive and in-depth insight to support basin-scale planning and management. In MIKE BASIN, the flow and water quality constituents can be visualized in both space and time, making it the perfect tool for building understanding and consensus. As shown in Figures A-4 through A-8, the model appears to be simulating the total stream water volumes fairly well with the exception of the 780 Beardsley Wash and 806 Calleguas Creek at Camarillo validation stations. Very good validation results were even achieved for simulating the 90th percentile high flows while the 10th percentile low flows were poorly simulated with over-predictions at all sites. All flow conditions were over-predicted, which are very likely caused by the low accuracy data on the flow channel loss and agriculture irrigation water diverted from the surface water. Consequently, artificial users that represent the flow channel loss were added to the model and the modeled flow results were actually improved for all seasons at VCWPD 805 at Calleguas Creek near Camarillo.

However, the water quality simulations are not satisfactory in reproducing the observed sample concentrations. The 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 it does not always predict the temporal variability of the pollutograph.

Several issues of concern can be noted as well. A certain portion of nutrient loads in the watershed derives from sources beyond the control of dischargers, especially atmospheric deposition. Direct air deposition to water bodies is treated as a non-point source of the pollutant from the Santa Monica Mountains and given its own concentrations labeled "open space" to account for non-point source loads. Air deposition that enters the water body through the land surface is included in the event mean flux values for each land use category.

Secondly, flow conditions during the wet- and dry-weather periods are significantly different. Flows during the wet-weather periods are generated by storm runoff in the watershed. Stormwater runoff in the sewered urban areas of the watershed is carried to the river through a system of storm drains. During the dry-weather periods the flows are extremely low and less variable, which are provided by point source discharges, urban runoff, and groundwater baseflow. Simulation of these two different flow regimes using different approaches is preferred assuming adequate input data (Larry Walker Associates 2005). However, wet- and dry- weather nutrient simulations are not differentiated in the MIKE BASIN package, which may limit applications of the model results to TMDL compliance and/or BMP design studies, which require estimates at finer time steps than the annual loads reported and discussed herein. This report and the work on which it was based has focused on assessing the sources and base loading 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 whose activities are scattered across the entire region. Lastly, the simulated water quality time series at each of the node points on the stream network offers some understanding of spatio-temporal variability of nutrient loads and concentrations at the basin scale. The results do identify those 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 affecting the Callegaus Creek watershed.

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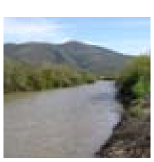
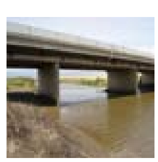
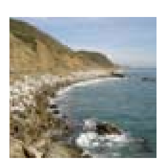
Appendix A
Hydrology Calibration and Validation
Graphs and Tables

VCWPD station 802 at Arroyo Simi Catchment Area = 84.4 sq km

Parameter	Description	Value	Units	*Observations*
Umax	Maximum water content in surface storage	11.6	in	mix
Lmax	Maximum water content in root zone storage	296	in	
CGOF	Overland flow runoff coefficient	0.385		
CKIF	Time contstant for routing interflow	510.8	hrs	
CK1,2	Time constant for routing overland flow	11.8	hrs	
TOF	Root zone threshold value for overland flow	0.00593		
TIF	Root zone threshold value for interflow	0.909		
Tg	Root zone threshold value for GW recharge	0.934		
CKBF	Time constant for routing baseflow	3847	hrs	
Carea	Ratio of GW-area to catchment area	1		

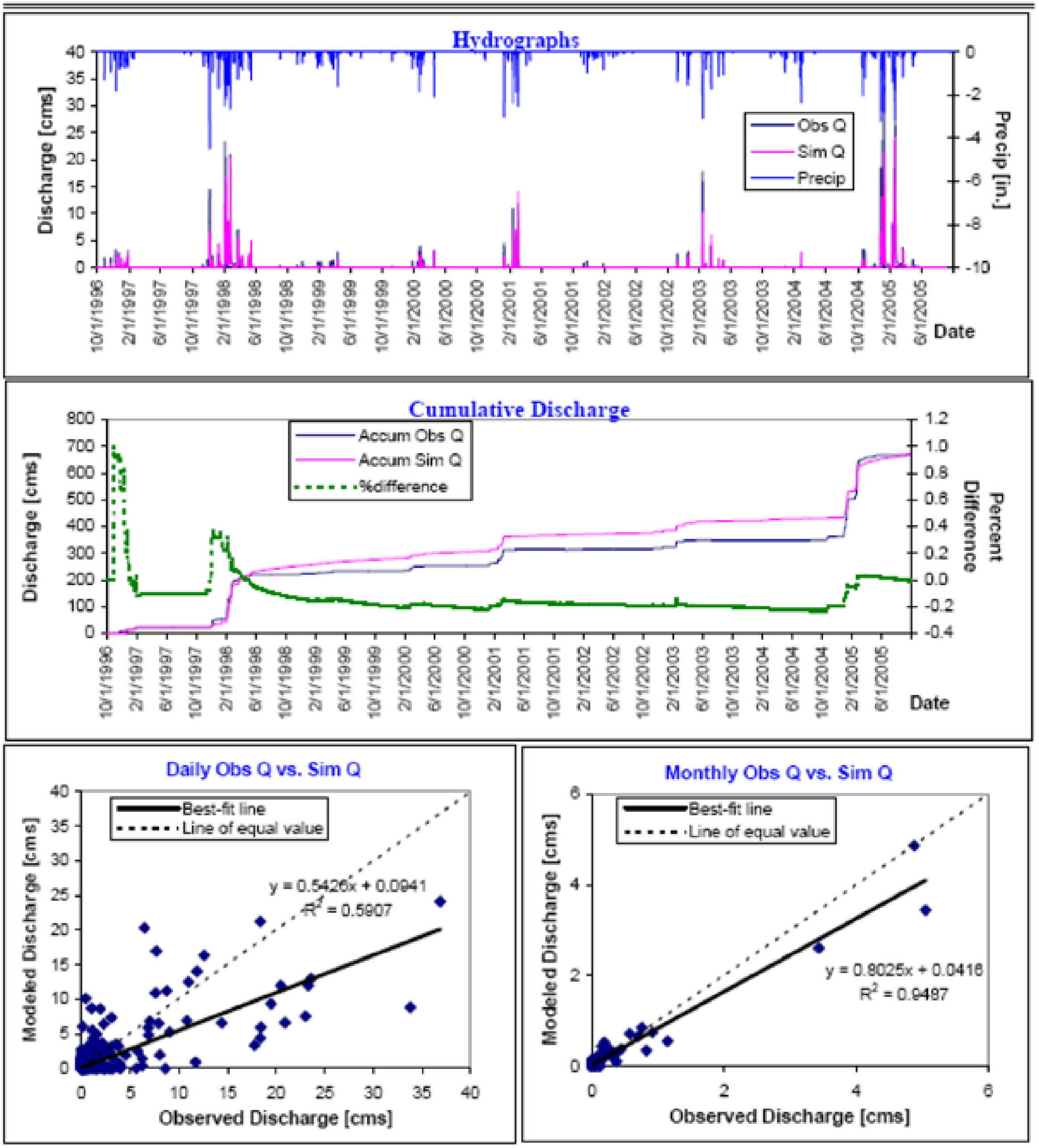


Figure A-1 Calibration results for VCWPD 802 at Arroyo Simi at Royal Ave Bridge

Table A-1 Calibration Error Analysis for VCWPD 802 at Arroyo Simi at Royal Ave Bridge

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	0.19	0.02
Lowest 50% cutoff value	0.03	0.00
Total in-stream flow	671.14	666.68
Total of the highest 10% flows	545.80	665.44
Total of the lowest 50% flows	23.61	0.00
Summer flow volume (months 7-9)	39.56	1.08
Fall flow volume (months 10-12)	73.30	102.07
Winter flow volume (months 1-3)	478.41	535.80
Spring flow volume (months 4-6)	79.74	27.73
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	0.67	Very good
Error in 10% highest flows	-17.98	Fair
Error in 50% lowest flows	-	-
Volume error - Summer	3565.75	Poor
Volume error - Fall	-28.19	Fair
Volume error - Winter	-10.71	Very good
Volume error - Spring	187.61	Poor

VCWPD station 800 at Conejo Creek Catchment Area = 166.3 sq km

Parameter	Description	Value	Units	Observations
Umax	Maximum water content in surface storage	10.3	in	
Lmax	Maximum water content in root zone storage	109	in	
CGOF	Overland flow runoff coefficient	0.352		
CKIF	Time contstant for routing interflow	285.5	hrs	
CK1,2	Time constant for routing overland flow	10.5	hrs	
TOF	Root zone threshold value for overland flow	0.0995		
TIF	Root zone threshold value for interflow	0.0721		
Tg	Root zone threshold value for GW recharge	0.00449		
CKBF	Time constant for routing baseflow	3312	hrs	
Carea	Ratio of GW-area to catchment area	1		

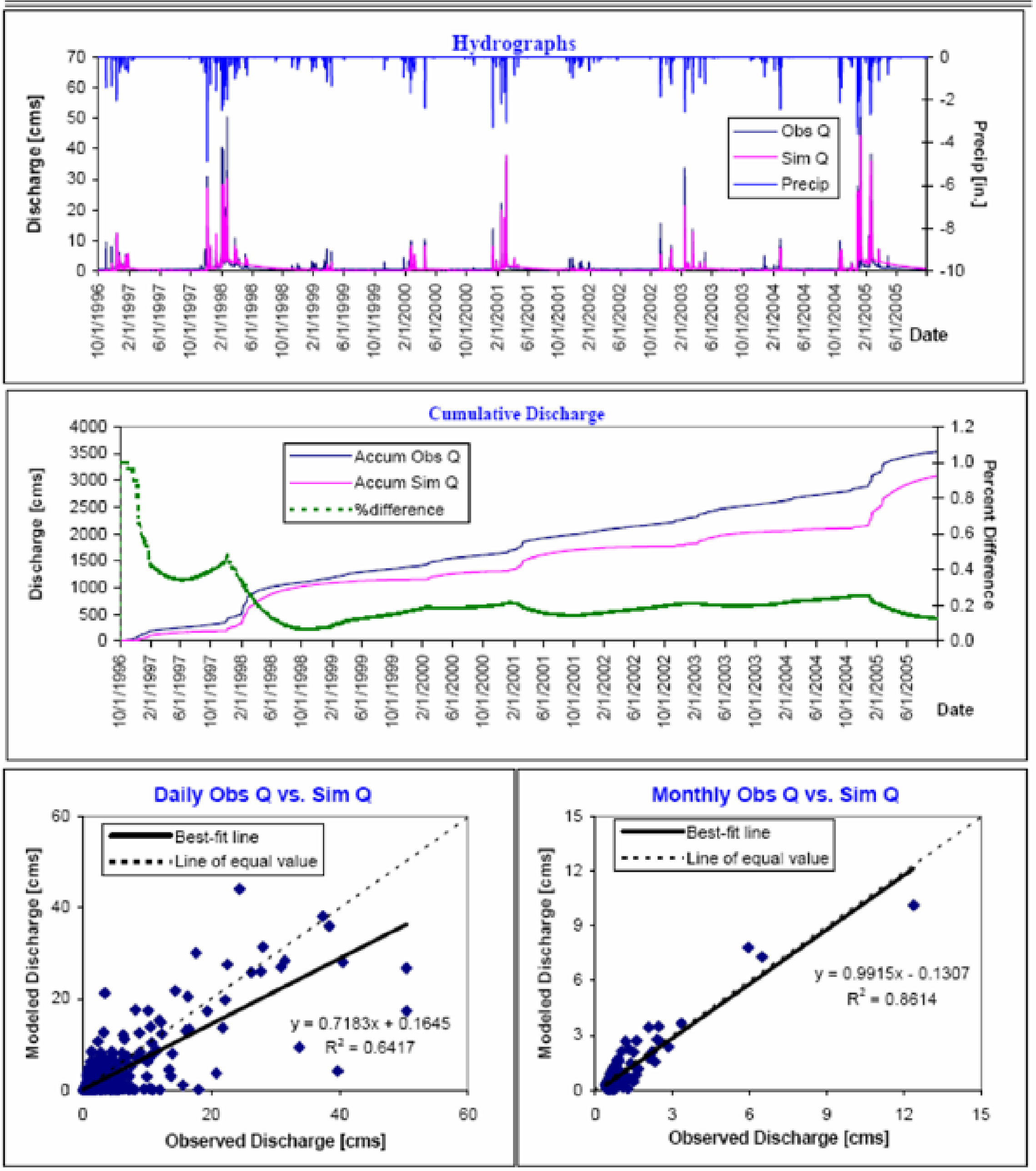


Figure A-2 Calibration results for USGS 11106400/800 at Conejo Creek above HW 101 CA

Table A-2 Calibration Error Analysis for USGS 11106400/800 at Conejo Creek above HW 101

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	2.09	1.24
Lowest 50% cutoff value	0.33	0.59
Total in-stream flow	3081.21	3536.58
Total of the highest 10% flows	1727.17	1692.87
Total of the lowest 50% flows	261.06	749.67
Summer flow volume (months 7-9)	357.24	454.88
Fall flow volume (months 10-12)	424.48	796.35
Winter flow volume (months 1-3)	1589.08	1669.46
Spring flow volume (months 4-6)	710.42	615.90
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	-12.88	Good
Error in 10% highest flows	2.03	Very good
Error in 50% lowest flows	-65.18	Poor
Volume error - Summer	-21.47	Fair
Volume error - Fall	-46.70	Poor
Volume error - Winter	-4.81	Very good
Volume error - Spring	15.35	Good

VCWPD station 776 at Revolon Slough Catchment Area = 119.1 sq km

Parameter	Description	Value	Units	Observations
Umax	Maximum water content in surface storage	10.2	in	Agricultural sub waters
Lmax	Maximum water content in root zone storage	101	in	
CGOF	Overland flow runoff coefficient	0.501		
CKIF	Time contstant for routing interflow	306.4	hrs	
CK1,2	Time constant for routing overland flow	10.5	hrs	
TOF	Root zone threshold value for overland flow	0.058		
TIF	Root zone threshold value for interflow	0.0441		
Tg	Root zone threshold value for GW recharge	0.0507		
CKBF	Time constant for routing baseflow	2662	hrs	
Carea	Ratio of GW-area to catchment area	1		

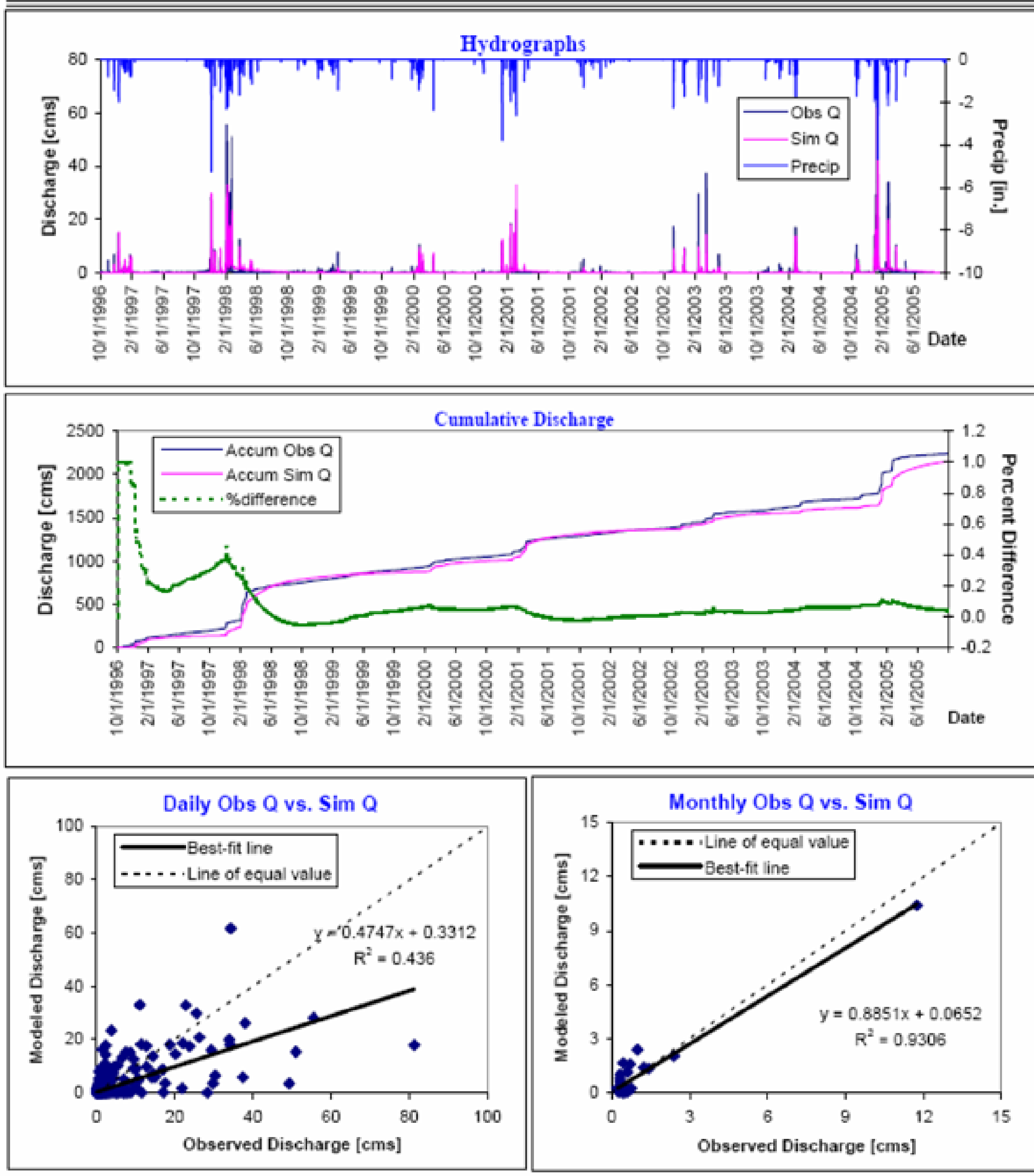


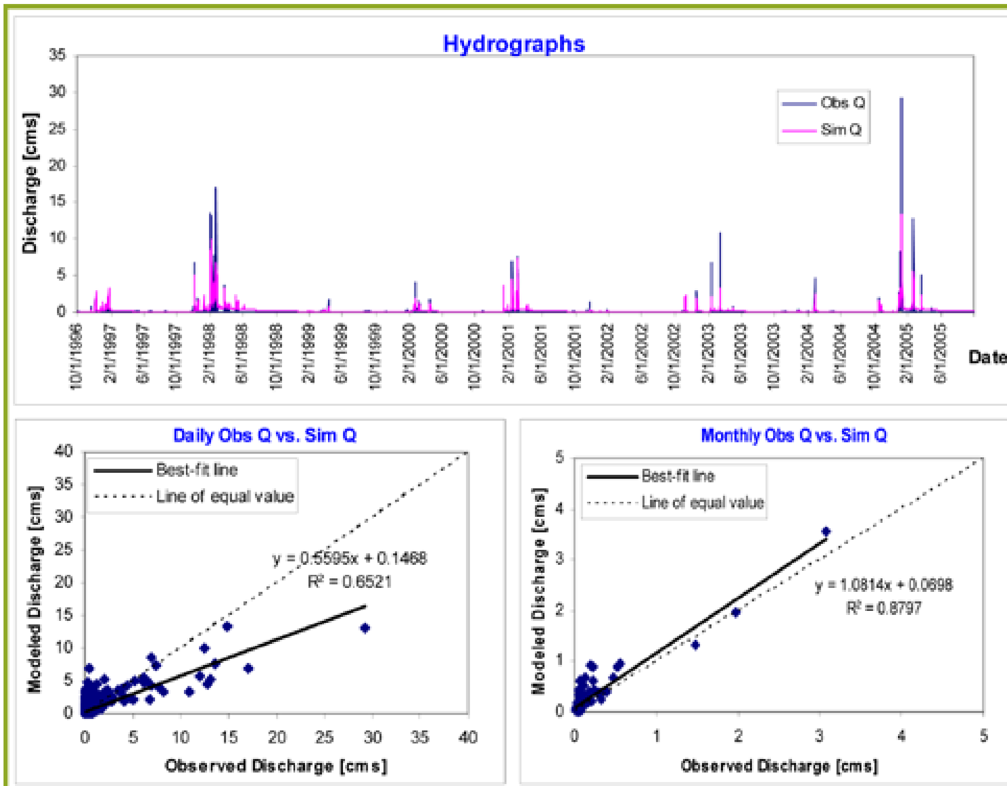
Figure A-3 Calibration results for VCWPD776 at Revolon Slough at Laguna Rd

Table A-3 Calibration Error Analysis for VCWPD776 at Revolon Slough at Laguna Rd

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

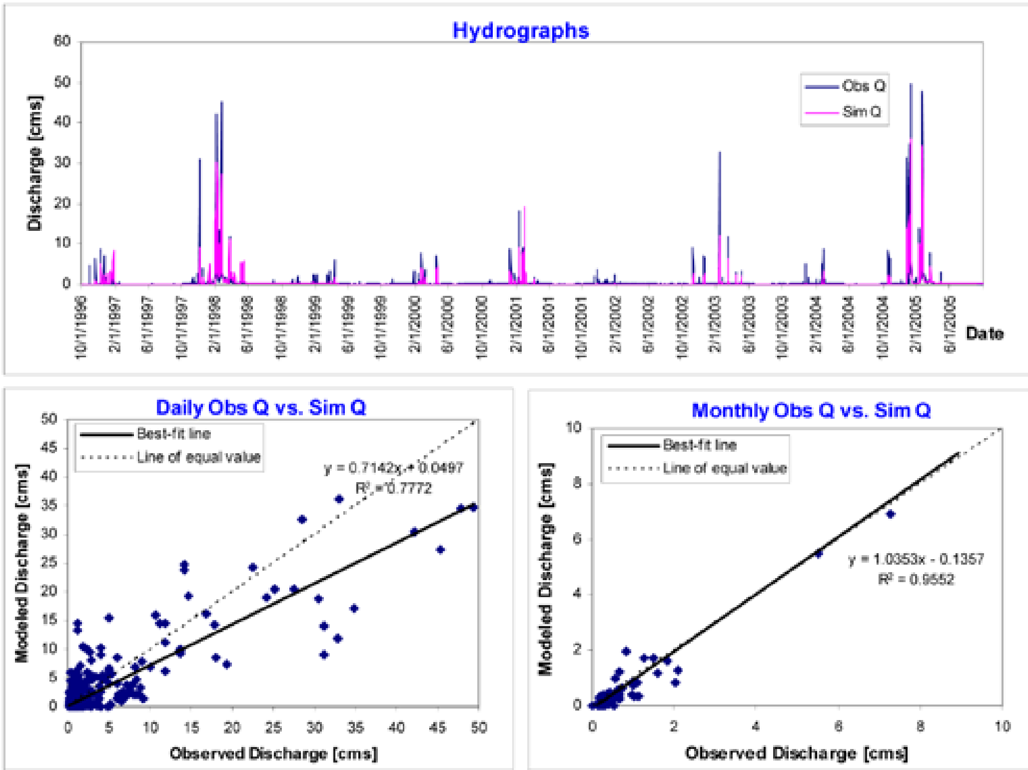
Flow volumes are (cubic meter per second) for upstream drainage area

Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	1.17	0.57
Lowest 50% cutoff value	0.21	0.27
Total in-stream flow	2152.66	2241.36
Total of the highest 10% flows	1340.90	1439.41
Total of the lowest 50% flows	182.47	312.57
Summer flow volume (months 7-9)	200.99	181.84
Fall flow volume (months 10-12)	298.66	507.72
Winter flow volume (months 1-3)	1237.03	1279.25
Spring flow volume (months 4-6)	415.98	272.55
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	-3.96	Very good
Error in 10% highest flows	-6.84	Very good
Error in 50% lowest flows	-41.62	Poor
Volume error - Summer	10.53	Very good
Volume error - Fall	-41.18	Poor
Volume error - Winter	-3.30	Very good
Volume error - Spring	52.63	Poor



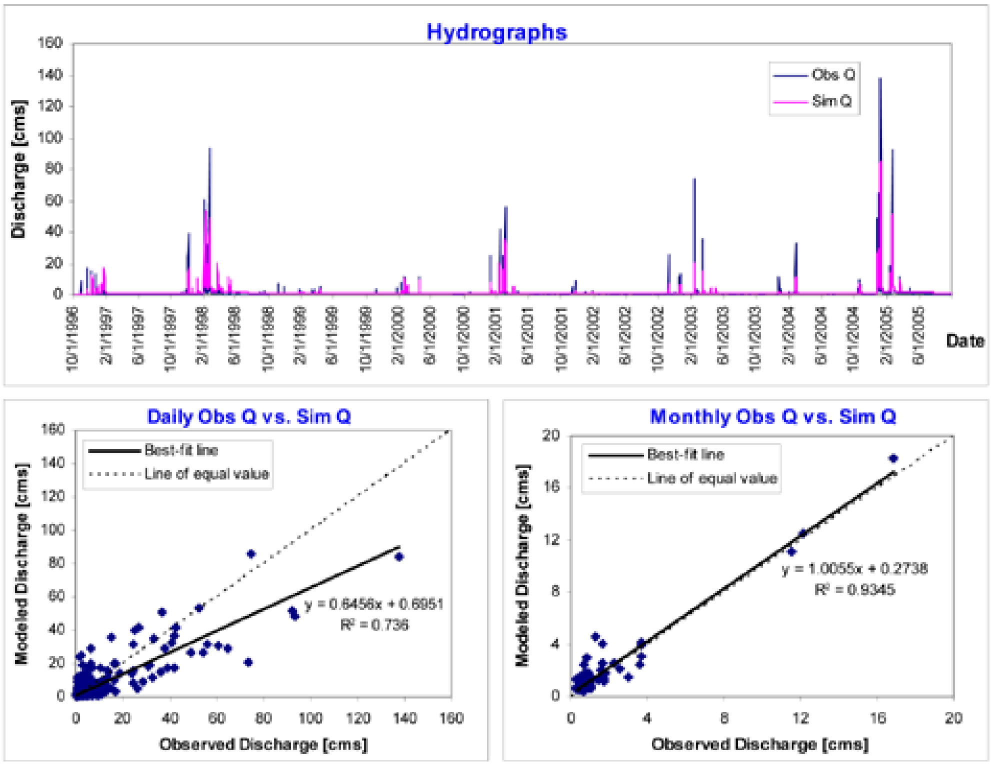
6-year analysis period : 10/1/1996 - 9/30/2005 Flow volumes are cms		
Summary	***MIKE BASIN Simulated Flows***	***Observed Flows***
Highest 10% cutoff value	0.43	0.09
Lowest 50% cutoff value	0.08	0.04
Total in-stream flow	753.07	483.36
Total of the highest 10% flows	459.68	353.38
Total of the lowest 50% flows	71.74	48.66
Summer flow volume (months 7-9)	69.24	37.62
Fall flow volume (months 10-12)	101.93	78.62
Winter flow volume (months 1-3)	433.48	314.66
Spring flow volume (months 4-6)	148.42	52.46
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	55.80	Poor
Error in 10% highest flows	30.08	Fair
Error in 50% lowest flows	47.43	Poor
Volume error - Summer	84.05	Poor
Volume error - Fall	29.65	Fair
Volume error - Winter	37.76	Poor
Volume error - Spring	182.95	Poor

Figure A-4 Validation results for VCWPD 780 at Beardsley Wash at Central Ave



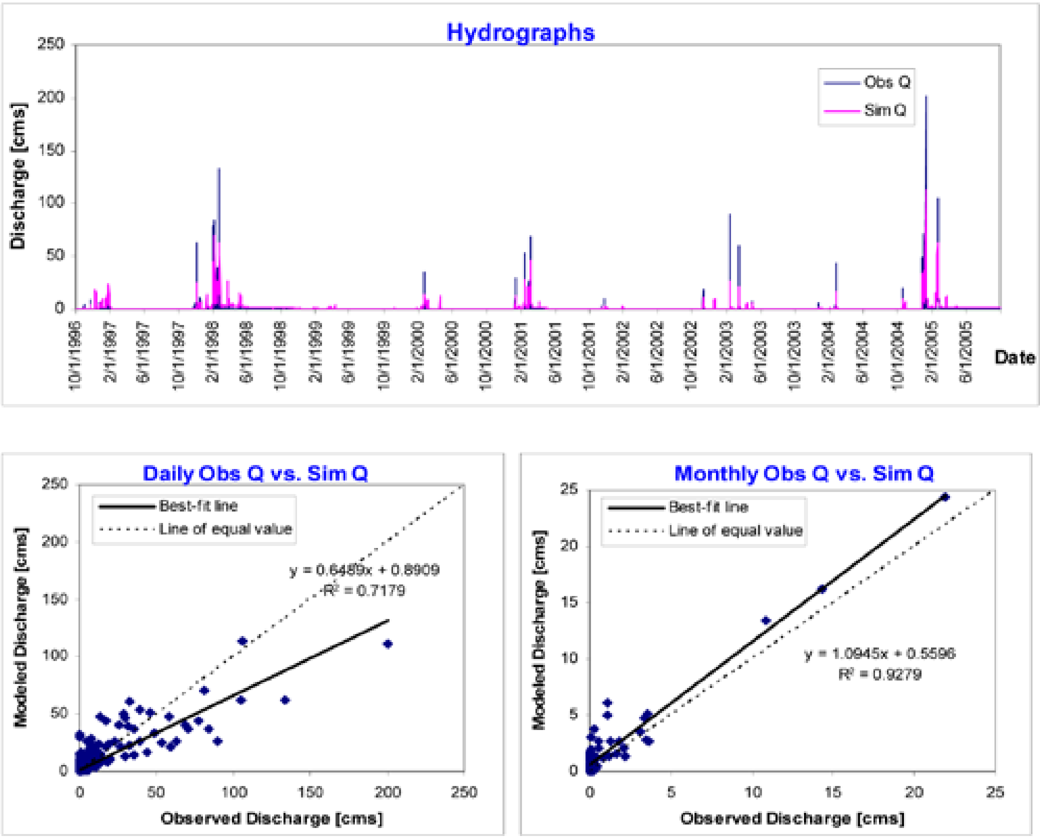
6-year analysis period : 10/1/1996 - 9/30/2005 Flow volumes are cms		
Summary	***MIKE BASIN Simulated Flows***	***Observed Flows***
Highest 10% cutoff value	0.47	0.43
Lowest 50% cutoff value	0.09	0.20
Total in-stream flow	1514.23	1892.78
Total of the highest 10% flows	1178.88	1295.52
Total of the lowest 50% flows	75.15	274.10
Summer flow volume (months 7-9)	98.89	143.14
Fall flow volume (months 10-12)	177.93	405.02
Winter flow volume (months 1-3)	1046.26	1113.75
Spring flow volume (months 4-6)	191.14	230.86
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	-20.00	Fair
Error in 10% highest flows	-9.00	Very good
Error in 50% lowest flows	-72.58	Poor
Volume error - Summer	-30.91	Fair
Volume error - Fall	-56.07	Poor
Volume error - Winter	-6.06	Very good
Volume error - Spring	-17.21	Fair

Figure A-5 Validation results for USGS11105850/803 at Arroyo Simi near Simi CA



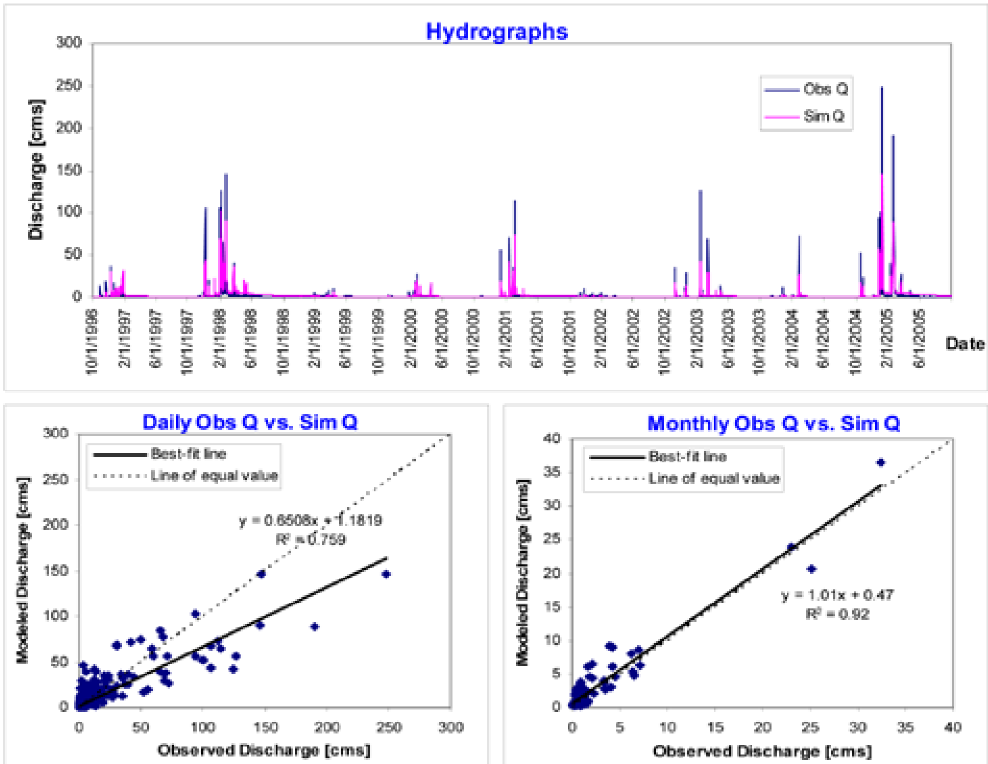
6-year analysis period : 10/1/1996 - 9/30/2005 Flow volumes are cms		
Summary	***MIKE BASIN Simulated Flows***	***Observed Flows***
Highest 10% cutoff value	1.73	0.82
Lowest 50% cutoff value	0.73	0.51
Total in-stream flow	4762.62	3837.62
Total of the highest 10% flows	2462.10	2374.34
Total of the lowest 50% flows	981.16	754.30
Summer flow volume (months 7-9)	649.59	367.16
Fall flow volume (months 10-12)	800.56	786.37
Winter flow volume (months 1-3)	2458.92	2196.98
Spring flow volume (months 4-6)	853.55	487.11
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	24.10	Fair
Error in 10% highest flows	3.70	Very good
Error in 50% lowest flows	30.08	Fair
Volume error - Summer	76.92	Poor
Volume error - Fall	1.80	Very good
Volume error - Winter	11.92	Good
Volume error - Spring	75.23	Poor

Figure A-6 Validation results for VCWPD station 841/841A at Arroyo Las Posas above Hitch Blvd



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	1.87	0.00
Lowest 50% cutoff value	0.35	0.00
Total in-stream flow	4505.11	2429.74
Total of the highest 10% flows	3158.71	2412.75
Total of the lowest 50% flows	299.05	10.66
Summer flow volume (months 7-9)	404.92	0.00
Fall flow volume (months 10-12)	597.55	366.69
Winter flow volume (months 1-3)	2816.86	2023.33
Spring flow volume (months 4-6)	685.78	39.72
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	85.42	Poor
Error in 10% highest flows	30.92	Fair
Error in 50% lowest flows	2705.05	Poor
Volume error - Summer	/	/
Volume error - Fall	62.96	Poor
Volume error - Winter	39.22	Poor
Volume error - Spring	1626.55	Poor

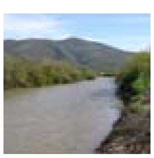
Figure A-7 Validation results for USGS11106000/806/806A Calleguas Cr at Camarillo

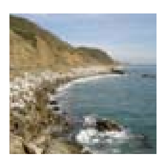


6-year analysis period : 10/1/1996 - 9/30/2005 Flow volumes are cms		
Summary	***MIKE BASIN Simulated Flows***	***Observed Flows***
Highest 10% cutoff value	4.45	1.67
Lowest 50% cutoff value	0.75	0.62
Total in-stream flow	8088.30	6494.70
Total of the highest 10% flows	4987.77	4659.36
Total of the lowest 50% flows	781.78	700.03
Summer flow volume (months 7-9)	827.07	355.90
Fall flow volume (months 10-12)	1127.31	1289.96
Winter flow volume (months 1-3)	4638.82	4145.78
Spring flow volume (months 4-6)	1495.09	703.05
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	24.54	Fair
Error in 10% highest flows	7.05	Very good
Error in 50% lowest flows	11.68	Good
Volume error - Summer	132.39	Poor
Volume error - Fall	-12.61	Good
Volume error - Winter	11.89	Good
Volume error - Spring	112.66	Poor

Figure A-8 Validation results for VCWPD 805 at CALLEGUAS C A CAMARILLO STATE HOSPITAL CA

Appendix B
Water Quality Calibration and Validation Graphs and Tables





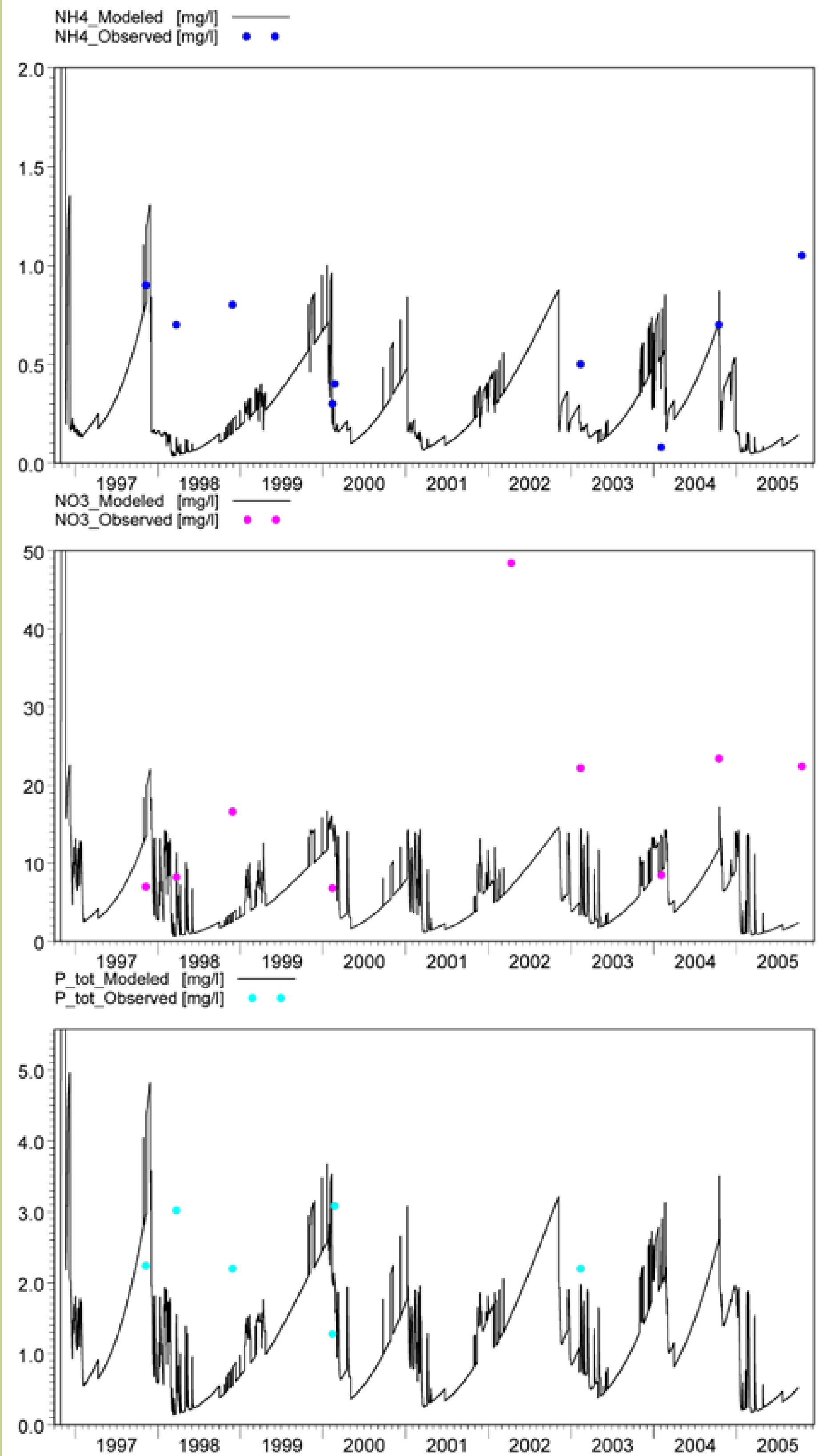


Figure B-1 Time series comparison of modeled and observed NH4, NO3 and total P at the W4 Revolon Slough Oxnard Airport site

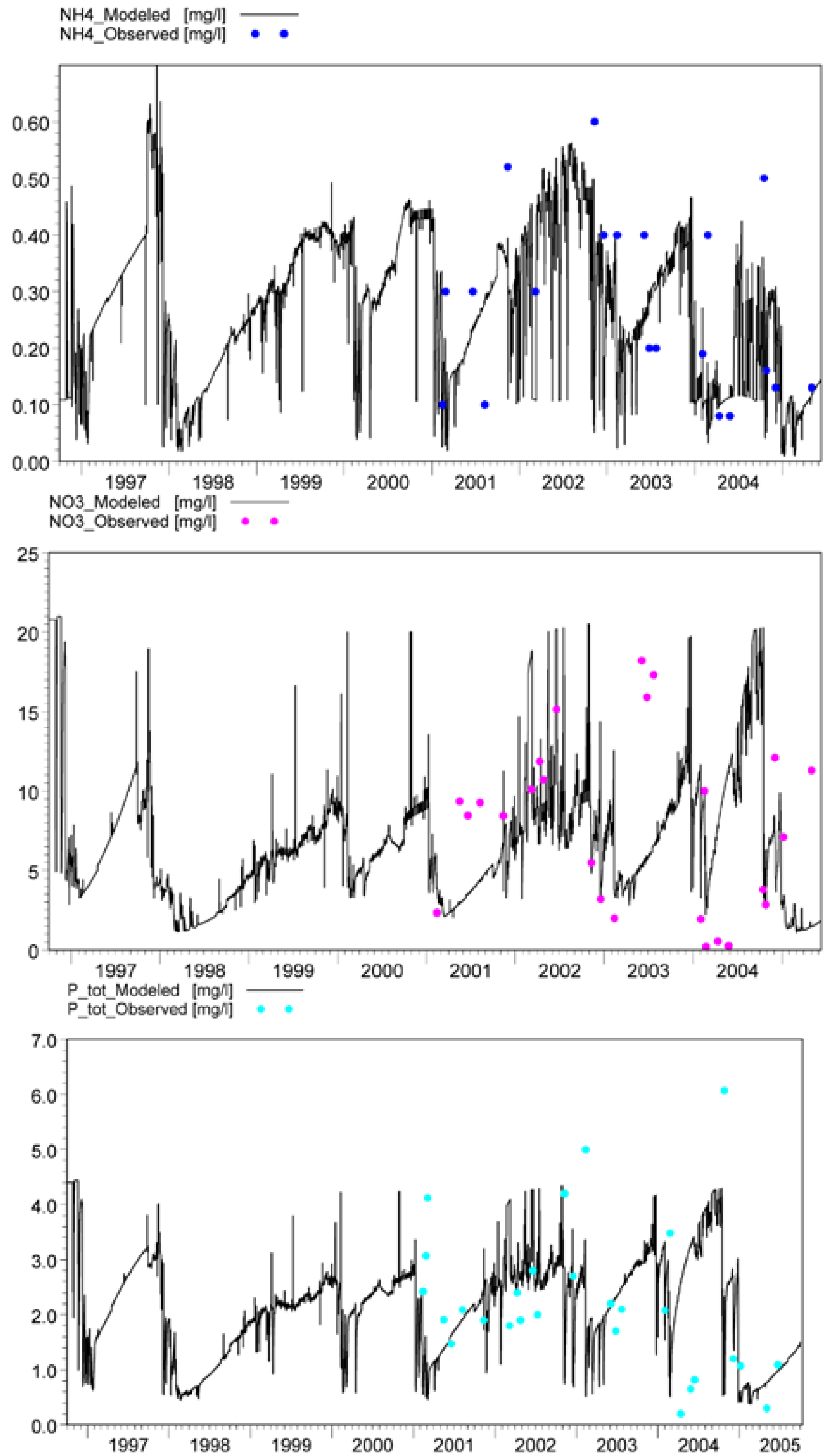


Figure B-2 Time Series comparison of modeled and observed NH4, NO3 and total P at the ME-CC mass emission site (N253)