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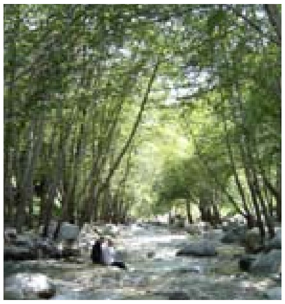
THE GREEN VISIONS PLAN

for 21st century southern california



20. Hydrology and Water Quality Modeling of the San Gabriel River Watershed

Jingfen Sheng
John P. Wilson

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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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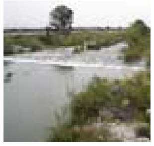

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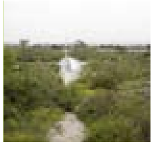


Executive Summary

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 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 is intended 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 and validation for selected stations over a nine-year period (10/1996 – 9/2005). Both quantitative and qualitative comparisons were developed to support the model performance evaluation effort.

The calibration and validation were performed at 12 stream locations throughout the watershed, for annual runoff, daily and monthly stream flow, water balance components, and annul water quality. Validation results at all sites above Whittier Narrows Dam regarding the total flow volume predictions ranged from fair to very good (Figures A-8, A-9, and A-10), but the predictions below the Whittier Narrows fell far below the range of fair to good. Hence, poor model performance was recorded at both the F262C-R San Gabriel River above Florence Avenue and the 11088000/ F42B-R San Gabriel River at Spring Street near Los Alamitos, CA gauging stations (Figures A-11 and A-12). Among these validations, the 10th percentile high flows are normally underestimated and the 50th percentile low flows are overestimated up to 5,000%. Such overestimation is largely due to the fact that in the upper portions of the watershed, water flows underground during the dry season with surface flows in the headwaters percolating rapidly into alluvial aquifers in the San Gabriel Valley.

The water quality simulations were not as satisfactory as the flow simulations in reproducing the observed sample concentrations. Many predictions of constituent concentrations fell outside the range of criteria used for the water quality assessment. Graphically, some sample concentrations were captured while others were missed in the pollutographs and it did not always predict the temporal variability of the pollutograph. The water quality module had difficulties in producing extremely high or low concentration values in the pollutographs at the selected monitoring sites (Figures B-1 and B-2), which suggests that the daily time stamp used for the model runs may have smoothed out the in-stream water quality pulse or dilution that likely occurs over very short time periods.

1 Introduction

The hydrology and water quality simulations presented in this report are a part of the Green Visions Plan for 21st Century Southern California project. The primary focus of the San Gabriel 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. 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 loadings 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 numerous urban subwatersheds of the San Gabriel River watershed (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 San Gabriel River and its tributaries caused by metals and trash. Simple conceptual spreadsheet models, TMDL mass balance models and EPA's HSPF model have been developed and/or implemented to determine allowable loadings for the various sources and removing these impairments in the watershed (CRWQCB-LAR 2000, 2006). Different from all these studies, this report focused on the simulation of hydrology and nutrient loads and concentrations in a spatial and temporal framework that could assist users to identify reaches and catchments of concern and to visualize the spatio-temporal variations of preselected constituents across the entire 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 San Gabriel 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 other 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.

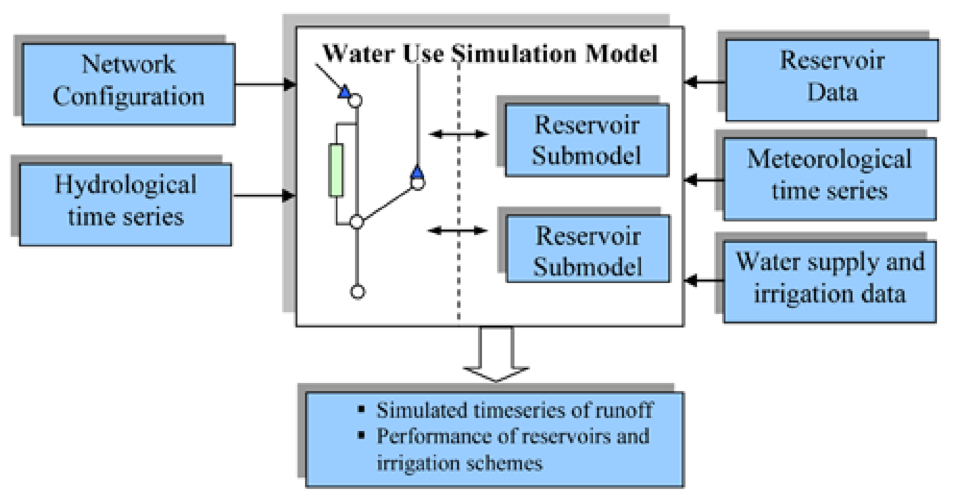


Figure 1 MIKE BASIN's water allocation modeling structure (DHI 2007)

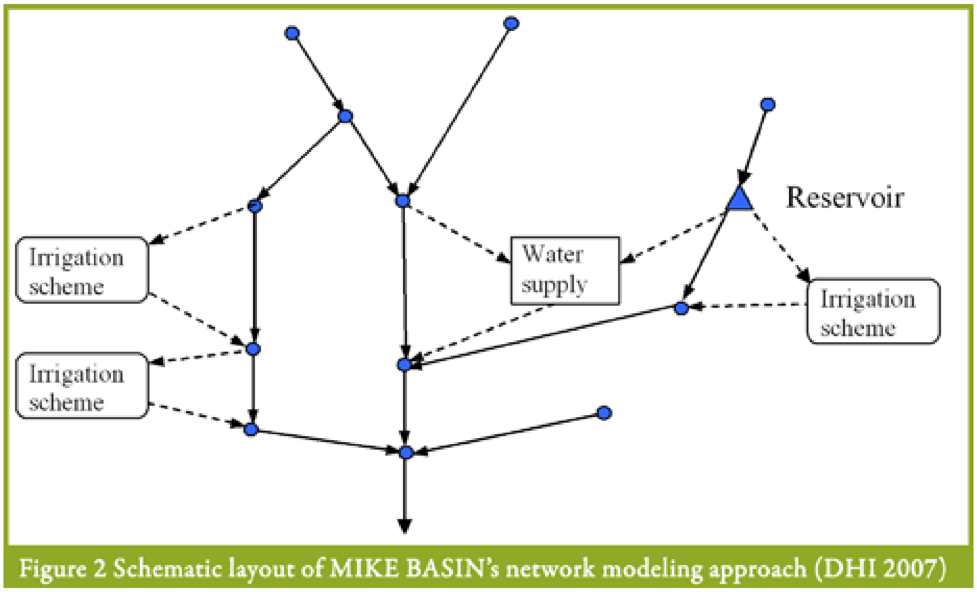


Figure 2 Schematic layout of MIKE BASIN's network modeling approach (DHI 2007)

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 set of global 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 San Gabriel River 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 hydrologic, 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; Section 5 describes the model results; and Section 6 discusses model performance and offers recommendations regarding the surface water impairments and sources.

The San Gabriel River watershed is the largest watershed in the San Gabriel Mountains drainage system of southern California, encompassing a total land area of 690.7 mi2. Land uses within the uppermost portion of the watershed are dominated by forest, recreation and natural open space, and they remain in a relatively natural state and are ecologically intact. From the foothills of the San Gabriel Mountains to the outlet to the Pacific Ocean, the drainage system is surrounded by dense urban development. Within the San Gabriel River valley, the majority of land has been converted to residential and commercial uses. Overall, land uses within the watershed consist of 47.0% urban, 0.8% agriculture, 51.2% open space and forest, and 1.0% water (SCAG 2001).

Table 1 Precipitation data records selected for the model

Station ID	Station Name	Elevation (ft)	Source	Latitude	Longitude
43452	Glendore West	280	NCDC	34.150	-117.85
45085	Long Beach Daugherty Fld	9	NCDC	33.817	-118.15
46006	Mount Wilson FC 338B	1747	NCDC	34.233	-118.07
47749	San Dimas Fire Warden FC95	291	NCDC	34.100	-117.80
47776	San Gabriel Canyon PH	227	NCDC	34.150	-117.90
334B	Cogswell Dam Precip	2300	LA_ALERT	34.243	-117.96
1088B	La Habra Hgts Precip	445	LA_ALERT	33.948	-117.96
134C	Pudd Div Precip	1130	LA_ALERT	34.129	-117.78
627	San Gab Pow House Precip	744	LA_ALERT	34.156	-117.91
425B	San Gabriel Dam Precip	1481	LA_ALERT	34.206	-117.86
356C	Spadra Precip	690	LA_ALERT	34.042	-117.81
223C	Big Dalton Dam	1587	LA_OBSER	34.168	-117.81
497	Claremont - Slaughter	1350	LA_OBSER	34.126	-117.73
93C	Claremont Police Station	1170	LA_OBSER	34.096	-117.72
387B	Covina City Yard	508	LA_OBSER	34.084	-117.90
269D	Diamond Bar Fire Station	870	LA_OBSER	33.997	-117.82
174B	Glendora	930	LA_OBSER	34.129	-117.82
287B	Glendora - City Hall	785	LA_OBSER	34.136	-117.86
196C	La Verne - Fire Station	1050	LA_OBSER	34.102	-117.77
1254	Long Beach Reclamation Plan	20	LA_OBSER	33.803	-118.09
1255	Los Coyotes Reclamation Plan	70	LA_OBSER	33.885	-118.11
225	Montana Ranch – Lakewood	47	LA_OBSER	33.843	-118.12
390B	Morris Dam	1210	LA_OBSER	34.181	-117.88
255F	Mt. San Antonio College – S	720	LA_OBSER	34.045	-117.84
1095	Orange County Reservoir	660	LA_OBSER	33.935	-117.88
1271	Pomona Waste Reclamation Pl	786	LA_OBSER	34.055	-117.79
96C	Puddingstone Dam	1030	LA_OBSER	34.092	-117.81
1258	Puente Hills Landfill	300	LA_OBSER	34.026	-118.03
95	San Dimas – Fire Warden	955	LA_OBSER	34.107	-117.81
89B	San Dimas Dam	1350	LA_OBSER	34.153	-117.77
1257	San Jose Creek Reclamation	275	LA_OBSER	34.032	-118.02
1260	Spadra Landfill	700	LA_OBSER	34.043	-117.83
406C	West Azusa	505	LA_OBSER	34.115	-117.92
1274	Whittier – Valna Drive	255	LA_OBSER	33.961	-118.02
106F	Whittier City Hall	300	LA_OBSER	33.983	-118.05
40192	Anaheim	102	NCDC	33.867	-117.850
107D	Downey – Fire Department	110	LA_OBSER	33.930	-118.146
172B	Duarte	548	LA_OBSER	34.141	-117.967
108D	El Monte Fire Department	275	LA_OBSER	34.075	-118.042
1041B	Santa Fe Dam	427	LA_OBSER	34.118	-117.973

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 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 watershed scale. Within the San Gabriel River watershed, the Los Angeles County Department of Public Works (LADPW) and National Weather Service (NWS) maintain networks of precipitation stations, most of which have been continuously operating for 30 years or longer. Stations with daily records spanning from at least 10/1996 to 9/2006 were selected for the model (Table 1). Their locations relative to the watershed are shown in Figure 3 along with other stream runoff, evapotranspiration and water quality monitoring stations.

Table 2 Evaporation stations in/near the San Gabriel River Watershed

Source	Evaporation ID/Name	Latitude	Longitude	Elevation	Annual average (in)
LADPW	63 C Santa Anita Dam	34.184	-118.020	35.56	4.02
LADPW	89 B San Dimas Dam	34.153	-117.771	34.29	4.24
LADPW	96 C Puddingstone Dam	34.092	-117.807	26.16	4.74
LADPW	223 B Big Dalton Dam	34.168	-117.810	40.31	4.07
LADPW	334 B Cogswell Dam	34.244	-117.960	58.42	4.37
LADPW	390 B Morris Dam	34.181	-117.879	30.73	6.68
LADPW	425 B San Gabriel Dam	34.205	-117.861	37.62	5.66
CIMIS	78 Pomona	34.058	-117.812	18.54	3.82
CIMIS	82Claremont	34.130	-117.696	41.15	4.26
CIMIS	159 Monrovia	34.145	-117.985	15.11	5.76
CIMIS	174 Long Beach	33.797	-118.094	0.43	3.80

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

For model input, daily ET values are preferred. Unfortunately, only monthly data are currently available

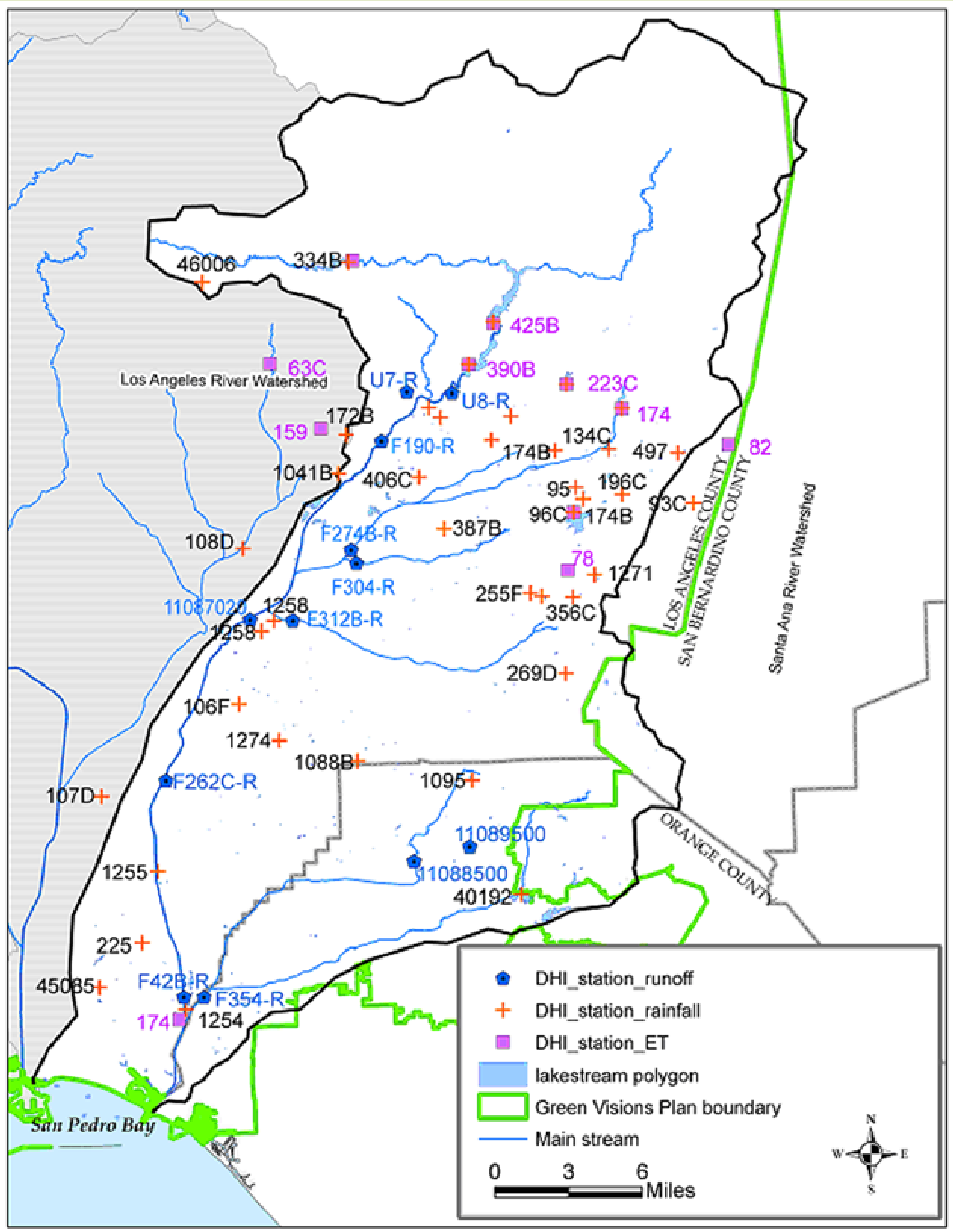


Figure 3 Precipitation, stream flow and evapotranspiration gauge locations in/near the San Gabriel River watershed

for the LADPW stations. Daily data are available at 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 to a given latitude in that month. Cloud cover was not considered when distributing monthly evaporation to daily values due to lack of cloud cover data. The climatic map of the region shows an estimated pan coefficient of 0.70-075, 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 1. Daily records from 10/1/1996-09/30/2005 were obtained for these 12 stream gauges on the main stem and its tributaries. Four gauges were selected for the primary calibration and validation with the daily data, which were USGS 11084500/LADPW U-R Fish Creek above the mouth of the canyon, LADPW F304-R Walnut Creek above Puente Avenue, USGS 11088500 Brea Creek below Brea Creek Dam near Fullerton CA, and USGS 11089500 Fullerton Creek below Fullerton Dam near Brea CA. The other eight gauges listed in Table 3 were used as consistency checks and for further validation of the model performance.

2.4 Point Source Discharges

During model configuration, six 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 of flow from October 1996 to September 2005. Daily discharge data were not available for the simulation period and average design flow rates were used for each site to overcome this limitation.

The other major sources of flows to the 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 to the system. More than 100 active stormwater dischargers were identified in the watershed along the main stem the San Gabriel River and major tributaries of Coyote Creek, San Jose Creek and Walnut Creek, but unfortunately there were no data available for these sources to assist with model configuration.

Table 3 Stream flow stations in the San Gabriel River watershed

STATION_ID	Station name	Drainage (mi^2)	Flow records		Elevation (ft)
			From	To	
11088500	Brea Creek below Brea Dam near Fullerton	22	1942	Present	
11089500	Fullerton Creek below Fullerton Dam near Brea	5	1941	Present	
11084500/U7-R	Fish Creek near Duarte CA	6	1916	Present	906
F304-R	Walnut Creek above Puente Avenue	58	1952	2005	340
F312B-R	San Jose Channel below Seventh Avenue	83.4	1955	2005	215
F354-R	Coyote Creek below Spring Street	185	1963	2005	
F274B-R	Dalton Wash at Merced Avenue	36	1949	2005	348
U8-R	San Gabriel River below Morris Dam	214	1894	2005	868
F190-R	San Gabriel River at Foothill Boulevard	230	1932	2005	
11087020	San Gabriel River above Whittier Narrows Dam	442	1955	Present	
F262C-R	San Gabriel River above Florence Avenue				
11088000/ F42B-R	San Gabriel River at Spring Street near Los Alamitos CA	472	1928	Present	

2.5 Water Regulation Data

The upper watershed contains a series of reservoirs with flood control dams (Cogswell, San Gabriel and Morris Dams). Spillway crests, minimum and water conservation pool, flood control levels, and height-discharge look-up tables were incorporated into the MIKE BASIN configuration.

In addition to the flood control facilities, water storage facilities play an equally important role in conserving the storm and other waters. The conserved water stored in 17 spreading facilities adjacent to river channels and in soft-bottom channels percolate into underlying groundwater basins for later pumping. There are no monitoring data to describe inflows and outflows to these facilities. To estimate the amount of water that is diverted off the channel and infiltrated with these facilities, the total monthly volume of water that is conserved, imported and reclaimed as reported by the LADPW was used. For each individual facility, the amount of water diverted from the storm water equals the difference in storage between the total water spread and the imported and reclaimed water.

The Santa Fe Dam is an element of the Los Angeles County Drainage Area (LACDA) flood control system. The primary purpose of Santa Fe Dam is to provide flood protection to downstream communities along the San Gabriel River between the Santa Fe and Whittier Narrows Dams, and, in conjunction with the Whittier Narrows Dam, provide flood protection along the Rio Hondo Channel, Los Angeles River, and San Gabriel River. Santa Fe Dam contains sixteen hydraulically operated gates set to pass low flows and build a debris pool during high inflows. Discharge rates within the debris pool allow the LACDPW to divert the flow to its spreading facilities, thereby enhancing water conservation. Once the reservoir level reaches an elevation 456 feet, flood control releases are initiated and the flood pool is drained as rapidly as possible. As soon as the flood pool is drained, releases are reduced so that LACDPW can resume water conservation operations (USACE, LAD 2008).

The Santa Fe Reservoir Spreading Grounds behind the dam receive imported water releases from the Upper San Gabriel Valley Municipal Water District's USG-3 outlet and from the San Gabriel Valley Municipal Water District's outlet to Beatty Channel. The San Gabriel River channel between Santa Fe Dam and the Whittier Narrows Basin is soft-bottomed with riprap sides. LACDPW has constructed a rubber dam in the San Gabriel River channel just downstream of the Walnut Creek confluence which can impound up to 400 AF (USACE LA District 1998).

The Whittier Narrows divert flows to the Rio Hondo Channel if the inflow to the reservoir exceeds the groundwater recharge capacity of the spreading grounds along the Rio Hondo or the bed of the lower San Gabriel River. The Rio Hondo and San Gabriel sides of the reservoir each have their own water conservation pools. If the capacity of the water conservation pool on the Rio Hondo Channel side is exceeded, flows are released into the Rio Hondo Channel at a rate which does not exceed the downstream channel capacity of either the Rio Hondo Channel or the Los Angeles River. If the capacity of the water conservation pool on either side of the reservoir is exceeded a release of approximately 5,000 cfs can be made into the San Gabriel River. If the pool in the reservoir exceeds flood control storage, the gates on the San Gabriel River outlet begin to open automatically and emergency releases are made into the river (USACE, Los Angeles District, no date).

Further downstream, along the Rio Hondo Channel and San Gabriel River, are several spreading grounds used for groundwater recharge. The stretch of the river below the Whittier Narrows area overlies the Central (Groundwater) Basin which contains a number of both shallow and deeper aquifers. The San Gabriel River and Rio Hondo Channel are unlined in this area, allowing for groundwater recharge from the San Gabriel Coastal Basin and Rio Hondo Spreading Grounds, respectively (Woodward-Clyde Consultants 1994).

2.6 Water Quality Data

The Load Calculator Module in the MIKE BASIN model was used to determine pollution loads in subwatersheds. It calculated average mass fluxes of pollutants for individual sunwatersheds (e.g. kg/catchment/year) and these estimates were then passed to the MIKE BASIN water quality model 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 cases. Five wastewater reclamation plants (WRPs) that discharge directly to the surface waters were incorporated into the model as time variable point sources of pollutants. Median constituent concentrations for each point source were obtained from the Sanitation Districts of Los Angeles County and are summarized in Table 4.

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 SCCWRP and LADPW. 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 certain types of 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 loadings to the receiving waters; therefore, mean flux and other static pollutant sources are adequate to represent the spatial variations in constituent loadings across the watershed. However, understanding inter-storm and intra-site variability might be crucial for estimating loads on shorter time scales.

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. There are numerous septic systems used for the disposal of wastewater in the foothills of the San Gabriel Mountains. Nitrogen is quite mobile in groundwater, while phosphorus has a tendency to be absorbed by the soil. However, the fate of the contributions to groundwater from these types of disposal systems is not very well understood and even less is known about the contributions from these sources to surface waters. The impact of the sewer system on surface water quality can be configured as a function of the population and treatment

Table 4 NPDES permitted major discharges and median concentrations of three constituents in the San Gabriel River model

WRP	Mean flow (cfs)	Ammonia-N (mg/L)	Nitrate-N (mg/L)	Phosphorus (mg/L)
Pomona	4.6	9.9	2.5	4.5
Whittier Narrows	4.1	1.0	6.2	2.1
San Jose Creek #1	29.9	8.8	4.5	6.0
San Jose Creek #2_west	32.8	No data	No data	No data
San Jose Creek #3_east	42.3	1.5	4.6	7.0
Los Coyotes	48.8	8.2	3.0	1.0
Long Beach	23.7	8.7	3.6	4.5

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-N	49.9	94.1	74.5	1.8	56.5
Nitrate-N	271	275.1	287.1	50.8	219.2
Phosphate	20.9	103	83.1	14.1	76.1

efficiencies of the system in the MIKE BASIN Load Calculator. The treatment efficiencies can be specified as time variable varying 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 constituents during the calibration process (Table 6). The zone boundaries were designated in accordance with the upstream subwatersheds for each of the water quality calibration sites.

Table 6 Calibrated treatment efficiency values for different zones

Zone	NH4	NO3	TP
Coyote Creek	0.99	0.99	0.99
Others	1	0.96	1

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 loading in each catchment is the sum of the loadings from all sources and then specified as one properties of the catchment in the model. The estimated concentrations were compared with the sample data for the graphic error analysis. Table 7 lists sites that have water quality monitored by the LADPW, and Figure 4 shows the locations of these monitoring sites. Samples at land use sites were taken in specific years and no reoccurring sample data are available at these sites. The S14 San Gabriel River at SGR Parkway mass emission station is located about 0.8 miles downstream from the Whittier Narrows Dam, and the S13 Coyote Creek at Spring Street mass emission station is located 1.5 miles above the confluence of Coyote Creek and the San Gabriel River. NH4, NO3, TP and other constituents were analyzed periodically for selected storm events and dry weather conditions.

Table 7 Water quality monitoring sites within the San Gabriel River watershed

Station ID	Station Name	Site Type	Data
S13	Coyote Creek @ Spring Street	Mass Emission	1998-2007
S14	San Gabriel River @ SGR Parkway	Mass Emission	1998-2007
S22	Private Drain 314	Commercial	2006-2007
TS13	Big Dalton Wash & Walnut Creek @ Francisquito Avenue	Tributary	2006-2007
TS14	Puente Creek @ Don Julian Road	Tributary	2006-2007
TS15	Upper San Jose Creek @ Don Julian Road	Tributary	2006-2007
TS16	Maplewood Channel @ Alondra Boulevard	Tributary	2006-2007
TS17	North Fork Coyote Creek @ Artesia Boulevard	Tributary	2006-2007
TS18	Project 21 @ Wardlow Road	Tributary	2006-2007

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 San Gabriel 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 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 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 216 subwatersheds in the final MIKE BASIN model runs (Figure 4).

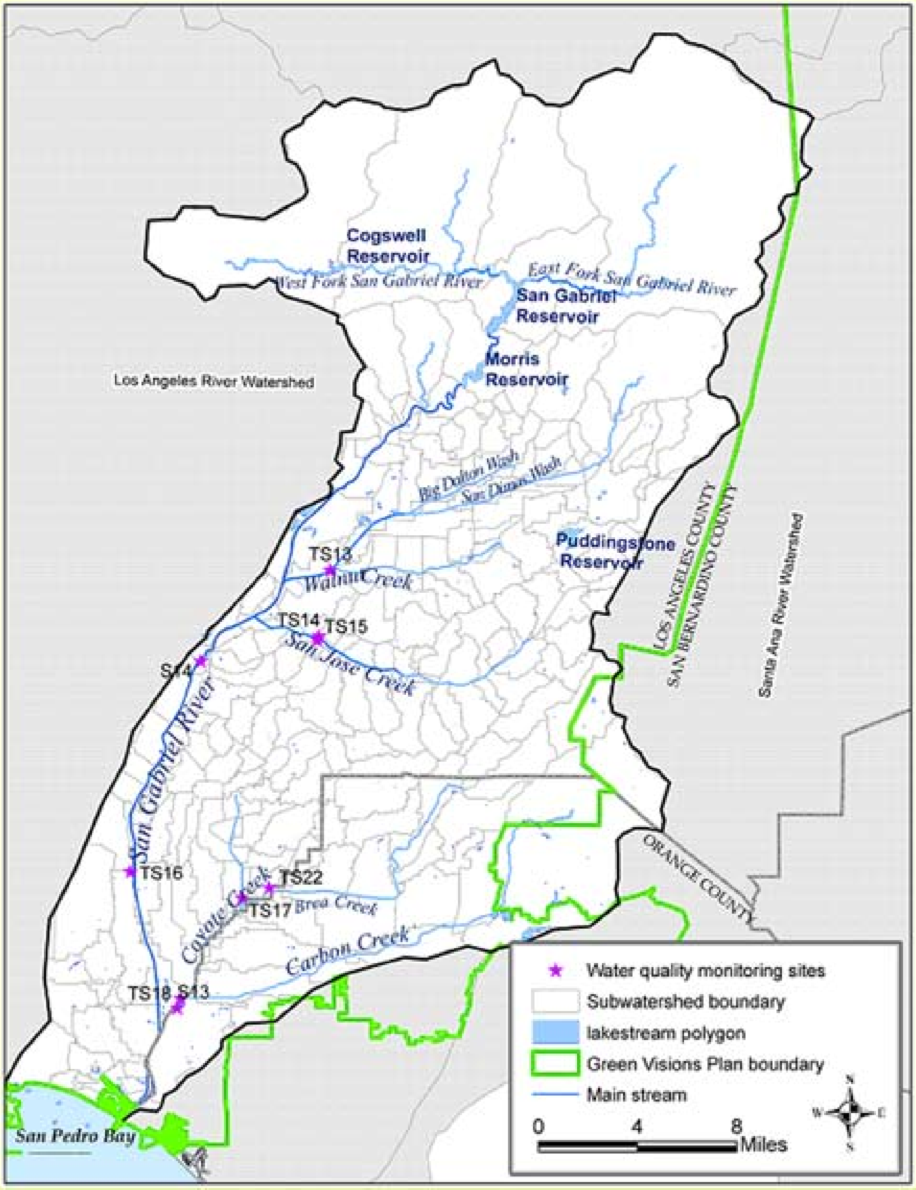


Figure 4 Watershed and stream segmentation

4. Model Calibration and Validation

4.1 NAM Rainfall-Runoff 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 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.

The NAM model requires precipitation and evapotranspiration 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 sub-catchment level that we delineated. As a result, no modifications were made to the precipitation observations, and each subwatershed was assigned precipitation and evapotranspiration time series using the Thiessen polygin method.

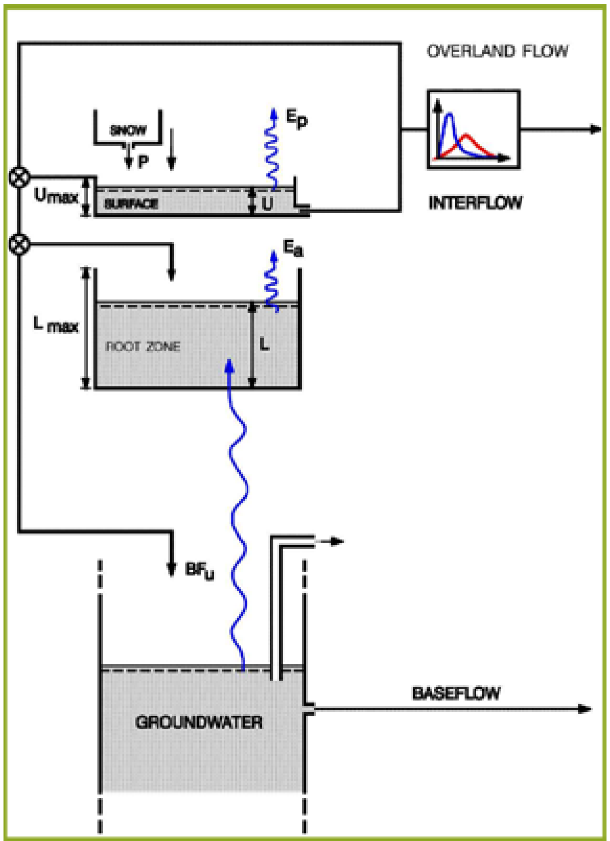


Figure 5 NAM model schematic

Table 8 Main NAM parameters

Symbol	Definition	Usual Value	Implications
Umax	Maximum surface storage content	10-25 mm	Evaporation; small peaks
Lmax	Maximum root zone storage content	50-250 mm	Evaporation; water balance
CQof	Overland flow coefficient	0.01-0.99	Divides excess rainfall into runoff and infiltration
TOF	Root zone threshold value for overland flow	0.0-0.7	Delays overland flow at the beginning of wet season
TG	Root zone threshold value for recharge	0.0-0.7	Delays groundwater recharge at the beginning of wet season
CKBF	Time constant for routing baseflow	500-5,000 hours	Determines shape of baseflow hydrograph
CK1,2	Time constant for routing overland flow	3-48 hours	Determines shape of peaks

Multiple reservoir-dam systems were accommodated in MIKE BASIN by simulating the performance of specified operating policies using associated operating rule curves generated from the dam and reservoir operation data provided by LACPW. 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 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

The San Gabriel River Watershed has undergone many alterations over the years in the form of storm water retention basins, spreading ponds, reservoirs, flow augmentation and urban irrigation. Some of these controls are incorporated into the model through basic configurations. However, such representation is limited due to both limitations of the model structure and data availability. No consistent monitoring has been performed on individual spreading in terms of the groundwater intake, discharge rate to surface streams, and the temporal characteristics of these interventions. Therefore, to model such a complex system, a series of subwatersheds representing minimally altered (i.e. natural forest covered) to mixed levels of alteration and finally to highly controlled subwatersheds were selected for calibration. Specifically, if the model accurately reproduces the hydrology of these similar subwatersheds with the corresponding calibration parameters, the flow variability observed in the other subwatersheds may be attributed to varying levels of alteration.

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 10/1/1996 to 9/30/2005 was selected for the hydrology/water quality simulations. The calibration was performed on the three selected subwatersheds for this time period and the calibrated datasets containing parameter values for rainfall runoff simulation were extrapolated to all ungauged catchments exhibiting similar physical, meteorological, and land use characteristics. Subsequently, model validation runs were performed to test the calibrated parameters at nine 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 in-stream 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, 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 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 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 (R^2) values that may be appropriate for judging how well the model is performing based on the daily and monthly simulation results. 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 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

4.2.1 Hydrology Calibration Results

Figure A-1 shows the calibration results for the USGS 11088500 Brea Creek 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 runoff volume of the stream versus time for both observation and simulation data. Regression analyses were performed for daily values. The graphs at the bottom of Figure A-1 show that the model performs well in reproducing daily flows given the model achieved a coefficient of determination (R^2) of 0.85.

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

Table A-1 presents the error analysis performed on the predicted volumes. The volume comparisons indicate that the model performs reasonably well during high flows and winter periods but fair to poorly during the low flow and summer periods. The model very slightly under-predicts the high flows and over-predicts the low flows during the summer. Both the time-variable plots and the volume comparisons indicate that the model is very good at reproducing the observed data for this minimally controlled headwater station.

Model results for the USGS 11089500 at Fullerton Creek gauging station were similar to the aforementioned station located on Brea Creek. Figure A-2 and Table A-2 show the time-variable plots and volume error analyses, respectively, for the Fullerton Creek gauging station. The graphic comparisons show that the model did reasonably well in reproducing the observed flow pattern at this location. Specifically, an analysis of the error indicates that the model predicts total volume and the volumes under high flow regimes very well while over-estimating low flows.

Calibration was also performed for another minimally regulated subwatershed at the USGS 11084500/U7-R Fish Creek gauging station (Figure A-3 and Table A-3). Total stream volume and volumes during high flow seasons were satisfactorily predicted given an R^2 of 0.84. Most of the discrepancies in the predictions occurred during high flows. The graphic comparison also shows that several small magnitude storms from 10/1998 to 5/1999 and from 10/2001 to 5/2002 were not captured by the

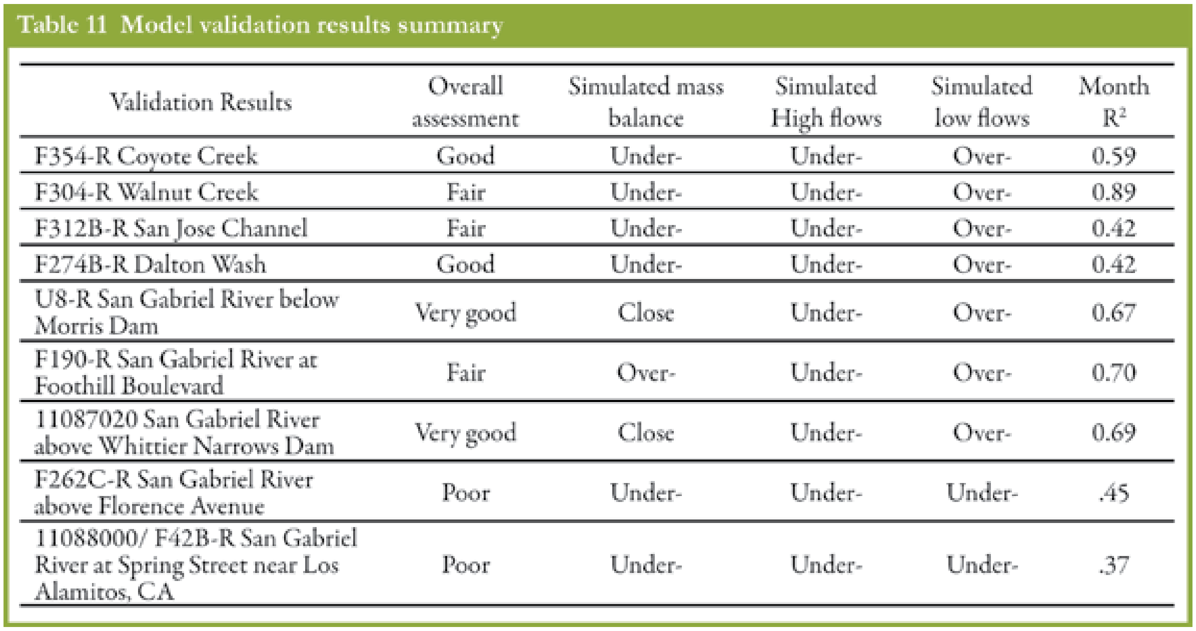


Table 11 Model validation results summary

Validation Results	Overall assessment	Simulated mass balance	Simulated High flows	Simulated low flows	Month R^2
F354-R Coyote Creek	Good	Under-	Under-	Over-	0.59
F304-R Walnut Creek	Fair	Under-	Under-	Over-	0.89
F312B-R San Jose Channel	Fair	Under-	Under-	Over-	0.42
F274B-R Dalton Wash	Good	Under-	Under-	Over-	0.42
U8-R San Gabriel River below Morris Dam	Very good	Close	Under-	Over-	0.67
F190-R San Gabriel River at Foothill Boulevard	Fair	Over-	Under-	Over-	0.70
11087020 San Gabriel River above Whittier Narrows Dam	Very good	Close	Under-	Over-	0.69
F262C-R San Gabriel River above Florence Avenue	Poor	Under-	Under-	Under-	.45
11088000/ F42B-R San Gabriel River at Spring Street near Los Alamitos, CA	Poor	Under-	Under-	Under-	.37

model (as was the case for the two previous subwatersheds as well).

4.2.2 Hydrology Validation Results

After calibrating the hydrology, the model was implemented using calibrated hydrologic parameters at nine more locations along the main stem and tributaries for the period 10/1996 to 09/2005. Validation results were assessed through time-variable plots and regression analyses for the stations LADPW F274B-R, U8-R, F190-R, USGS 11087020, F262C-R, and USGS 11088000/ F42B-R shown in Figures A-4 through A-11. Table 11 summarizes the model validation results.

The validation results for the F354-R Coyote Creek gauging station show the model was good in reproducing observed flows based on the recommended criteria. The high flows are under-predicted and low flows are over-predicted, which are persistent trends across the calibration and validation analyses performed for the San Gabriel River watershed. This (and other) station(s) receive urban runoff which likely causes the discrepancies in predicting dry weather flows.

The stream gauge station F312B-R, located on San Jose Channel below Seventh Avenue, is partially regulated by the Thompson Creek Dam and Pomona wastewater treatment plant. The validation results for this location are shown in Figure A-5. The model shows an unsatisfactory performance in predicting flow conditions: the total flow volume and high flows are under-predicted, indicating that the discharges from urban runoff and the wastewater treatment plant heavily control flow rates in the channel at this station. Many storm events were not reproduced in Figure A-5.

The Dalton Wash subwatershed gauged at F274B-R is a complex hydraulic and hydrologic system that is compounded by a series of scattered spreading grounds, operational dams (Big Dalton, San Dimas and Puddingston Division), non-operational debris basins, and urban storm runoff outfalls from residential areas. The validation results show over-predictions in all low flow conditions but fair results for the winter and spring high flow seasons given the recommended criteria.

The total flow volume validation results at all sites above Whittier Narrows Dam range from fair to very good (Figures A-6 to A-9), but the predictions below the Whittier Narrows showed poor performances at the F262C-R San Gabriel R above Florence Avenue and 11088000/ F42B-R San Gabriel River at Spring Street near Los Alamitos, CA gauging stations (Figures A-10 and A-11). Among these validations, the 10th percentile high flows are normally under-estimated and the 50th percentile low flows are over-estimated by as much as 5,000%. Such over-estimation is largely due to the fact that in the upper portions of the watershed, river flow is underground during the dry season with surface flows in the headwaters percolating rapidly into alluvial aquifers in the San Gabriel Valley (Los Angeles County Flood Control District 1975).

Below Whittier Narrows, partial flows in the main channel are diverted to the Rio Hondo Channel during high flow periods via the Whittier Narrows diversion channel. From Whittier Narrows Dam to Florence Avenue, the lower San Gabriel River also allows spreading by percolation through its unlined bottom. Five inflatable rubber dams were also installed in the 1980s to increase spreading capacity along this portion of the river, replacing sand levees that washed out when high flows occurred (LADPW 2008). The model did not and could not account for this part of the regulation, water spreading, and diversion regimes due to limitations linked to both model conceptualization and data availability. The 11088000/F42B-R San Gabriel River at Spring Street near Los Alamitos, CA gauging station is the most downstream gauge on the main stem. Similar to upstream main stem stations, the model under-predicted flows on this part of the river due to unaccounted urban storm flows and augmented in-stream infiltration practices during low flow periods. The Los Angeles County Flood Control District (1975) indicates that river flows below the Whittier Narrows consist mostly of treatment plant effluent (at least 90%), urban and nonpoint-source runoff, and industrial flows during most of the year. All of the upstream controls and diversions and point discharges contribute to the error statistics falling outside the recommended criteria.

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 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 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 1998 through 2005. The water quality load calculator was calibrated by comparing model output with pollutographs for NH3-N, NO3-N, and TP observed at two locations in the San Gabriel 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 the three aforementioned constituents resulted from this 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 time-series plots of model results and observed data at the S13 and S14 mass emission sites. NH4, NO3, TP and other constituents were 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, it was reported that the total discharge to several nodes of the stream network were zeros for a couple of simulations, which led to the extremely high concentrations of the three constituents. Therefore, the results for such time periods (see the period from 10/1996 to 12/1996 for examples) were ignored in both the output pollutographs and subsequent analyses.

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

Sites		NH4 [mg/l]	NO3 [mg/l]	TP [mg/l]
S14	Modeled	0.49	3.59	0.28
	Observed	0.48	2.87	0.36
	Error (%)	2.1	25.1	-22.2
S13	Modeled	0.95	1.74	0.36
	Observed	0.69	1.33	0.30
	Error (%)	37.7	30.8	20.0

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. At the selected monitoring sites, the water quality model had difficulty in producing extremely high or low concentration values in the pollutographs that were yielded from the instantaneous samples taken in the field (Figures B-1 and B-2), which suggests likely the inadequate sensitivity of the water quality module to the pollutant sources using the current time stamp. The daily time stamp might have smoothed out the in-stream water quality pulse or dilution that likely occurs over very short time periods.

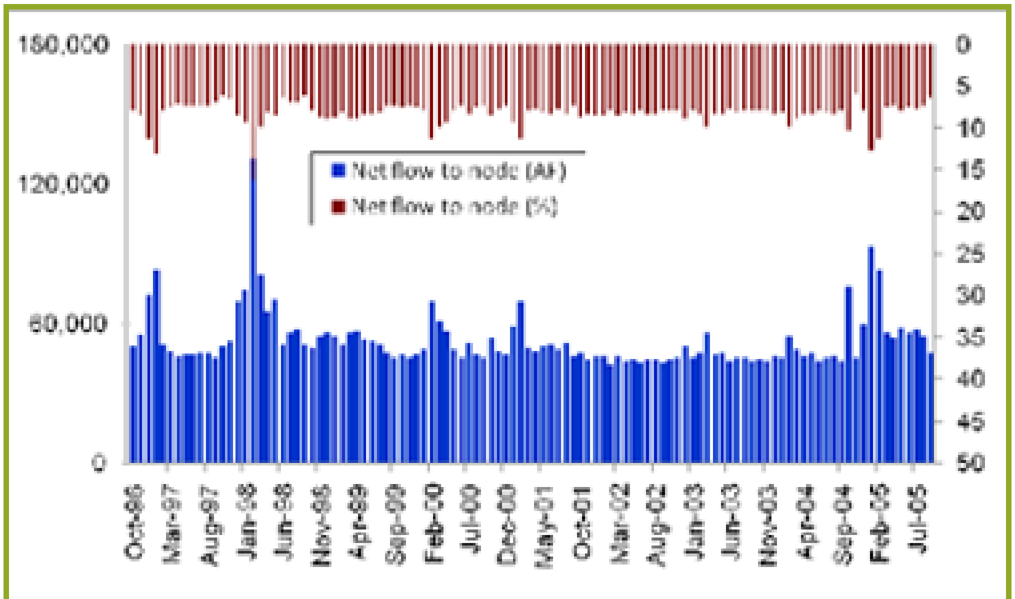


Figure 6 Flow volumes in acre feet (AF) and as a percentage of annual flows for the San Gabriel River at Westminster Avenue

The mean values of the modeled and observed time series are summarized in Table 12. Errors of various degrees occurred with different constituents. It seems that larger errors occurred at the S13 compared to the S14 mass emission site. Overall, the pollutograph predictions and resulting mean concentrations fell outside the range of recommended criteria that are used for the hydrology assessment. Simulations of water quality barely met the fair performance standard if the fair performance threshold was relaxed to 40%.

5 Results

The variations of flow and water quality in the San Gabriel River watershed are characterized based on the model simulation results. Figure 6 depicts a time-series plot of modeled monthly flows in acre-feet and as a percentage of the corresponding annual flow for the San Gabriel River at Westminster Avenue just below the confluence of the San Gabriel River and Coyote Creek. The monthly average in-stream flow in the San Gabriel River at the outlet was estimated about 53,000 AF during the simulation period, which is about 30% lower than observations (based on the model calibration/validation results).

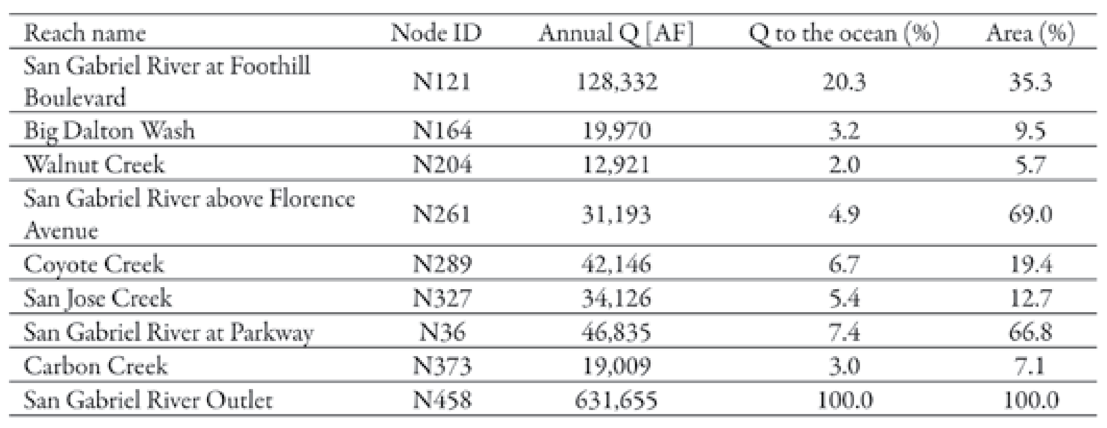
The monthly flows do not vary as much as the flows in the other watersheds in the GVP study area, for which the monthly flows vary by several orders of magnitude. The predicted highest flow of 130,000 AF occurred in February 1998 and the lowest value of 42,000 AF occurred in February 2002. These totals amounted to 16 and 6% of the annual total, respectively. From 1996 to 2005, the wet-weather flows (from November to the following April) accounted for 54% of the annual discharge from the San Gabriel River.

The discharge generally increases as we move down the channel system and the contributions from the various tributaries usually vary in space and time as well (see Figure 7 for examples). The average inflows from several major tributaries to the main channel are summarized in Table 13. Substantial tributary inflows occur at the San Gabriel River above Foothill Boulevard (N121) gauging station. The upper SGR provides 20.3% of the total inflow to the ocean on average (Table 13), but flow from the upper part of the watershed often does not get past Santa Fe Dam. The spreading grounds recharge water to the San Gabriel Groundwater Basin underlying the San Gabriel Valley (CRWQCB-LAR 2006). The reach between the San Gabriel River at Foothill Boulevard (N121) and San Gabriel River above Florence Avenue (N261) gauging stations provides very little inflow to the main channel. Waters entering the main stem from San Jose and Walnut Creek may be diverted through the Whittier Narrows area to the Los Angeles River. Those waters remaining in the San Gabriel River will often recharge at the downstream spreading grounds. The Montebello Forebay is a recharge facility located immediately downstream of Whittier Narrows Dam and allows infiltration into the Central Basin groundwater aquifer. Groundwater is recharged either by percolation through the unlined bottom of the river or by the diversion of water to the San Gabriel Coastal Basin Spreading Grounds by way of rubber dams. Water that is not captured in these spreading facilities flows to the ocean. The flow at the outlet (N458) largely depends on the inflow below the San Gabriel River above Florence Avenue (N261) reach including the inflows from Coyote Creek and urban storm discharges along the main channel.

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 San Gabriel River at Westminster Avenue at the bottom of the watershed. Figure 8 depicts a time-series plot of modeled monthly loads and as a fraction of the corresponding annual loads.

Monthly average in-stream loads of 22,000, 33,000 and 6,000 kg of NH4, NO3 and TP, respectively were estimated at the San Gabriel River outlet during the simulation period. The monthly loads varied by several orders of magnitude. Temporal variations in nutrient loads are relatively similar between the three nutrients, and less month-to-month variability is observed with the nutrients than the flow patterns. The largest variations occur in the winter storm season (e.g. December to February) and the total loads associated with winter storms generally contribute much higher percentages to the ocean than those from the other seasons. The in-stream NO3 loads in February 1998 reached approximately 130,000 kg

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



Reach name	Node ID	Annual Q [AF]	Q to the ocean (%)	Area (%)
San Gabriel River at Foothill Boulevard	N121	128,332	20.3	35.3
Big Dalton Wash	N164	19,970	3.2	9.5
Walnut Creek	N204	12,921	2.0	5.7
San Gabriel River above Florence Avenue	N261	31,193	4.9	69.0
Coyote Creek	N289	42,146	6.7	19.4
San Jose Creek	N327	34,126	5.4	12.7
San Gabriel River at Parkway	N36	46,835	7.4	66.8
Carbon Creek	N373	19,009	3.0	7.1
San Gabriel River Outlet	N458	631,655	100.0	100.0

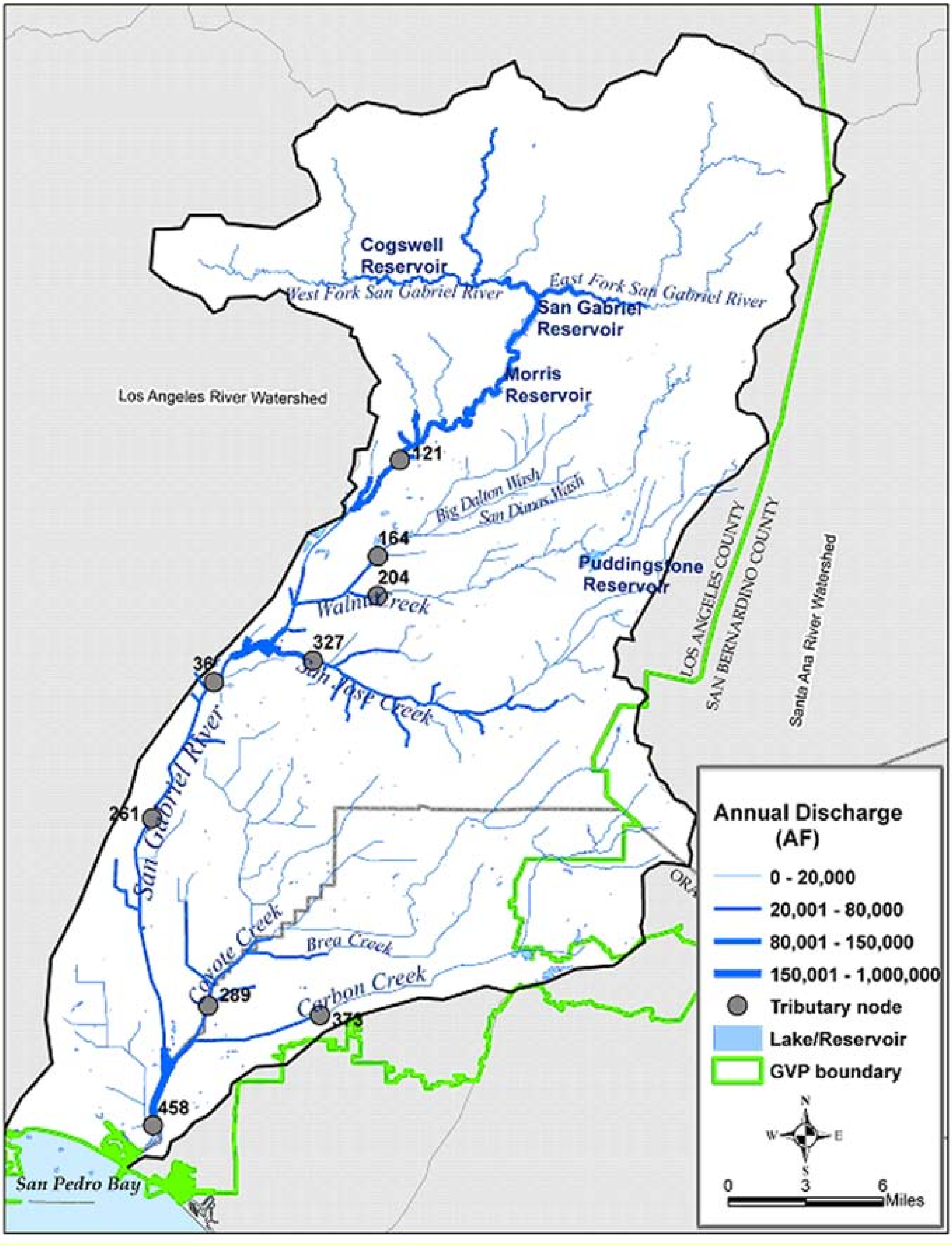


Figure 7 Cumulative flow discharges along the stream network

compared to only 17,000 kg during many of the dry season months.

The nutrient loads vary along the stream network but generally increase from upstream to downstream locations. The average annual loads from several selected major tributaries to the watershed totals are summarized in Table 14. Figure 9 summarizes the spatial distribution of the nutrient loadings along the stream network. The tributary contributions vary depending on the land uses in their subwatersheds. Substantial tributary NH4 and NO3 loads occur at the San Jose Creek confluence, where 20.1% and 26.7% of the total NH4 and NO3 loads, respectively are provided to the ocean total on average (Table 14). Along the main stem, a significantly large portion of the NH4 and NO3 loads are added to the main stem between the San Gabriel River above Florence Avenue (N261) and the San Gabriel River Outlet (N67) gauging stations into which the Los Coyotes and Long Beach WRPs discharge. The Walnut, Coyote, San Jose and Carbon Creek subwatersheds provide larger proportions of the total loads than their land areas would suggest because these subwatersheds include large urbanized areas.

Figure 10 demonstrates the spatial distribution of nutrient flux (i.e. sources) in each catchment. The highest nutrient fluxes in NH4, NO3 and TP are observed in the catchments where wastewater treatment plants are located (e.g. Pomona, San Jose and Los Coyotes WRPs). The highest annual fluxes for NH4, NO3 and TP of 47,599, 303,067 and 150,833 kg/sq km, respectively were estimated in the catchment containing the San Jose WRP. Relatively high NH4 fluxes are also found in urbanized subwatersheds such as Coyote Creek, Carbon Creek and the lower San Gabriel River. The catchments associated with high NO3 fluxes are scattered along the major tributaries such as Walnut Creek, Big Dalton Wash, the middle portion of the San Gabriel River, and Coyote Creek. The TP flux distribution map shows a similar pattern to that of NH4, with large concentrations occurring in the Coyote and Brea Creek subwatersheds.

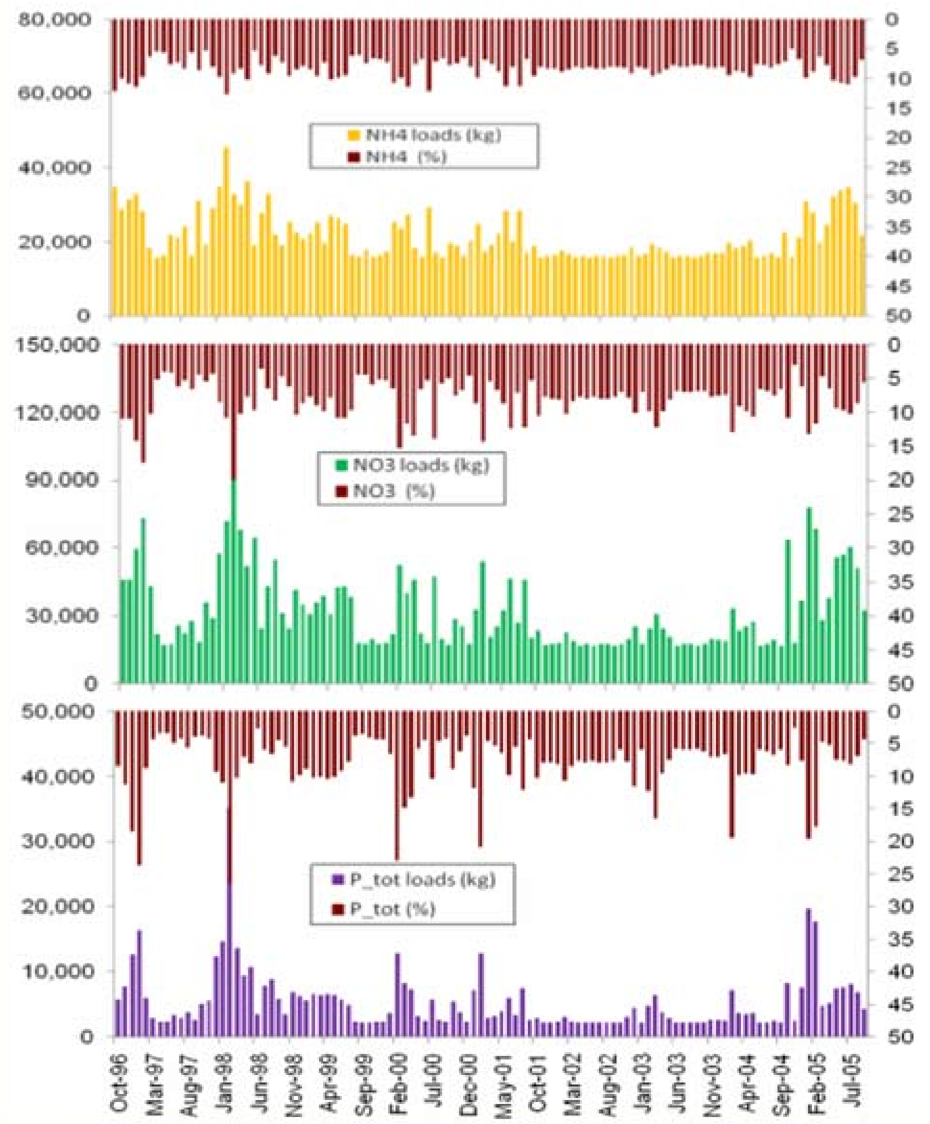


Figure 8 Monthly nutrients loads in kilograms and percentages for the San Gabriel River at Westminster Avenue

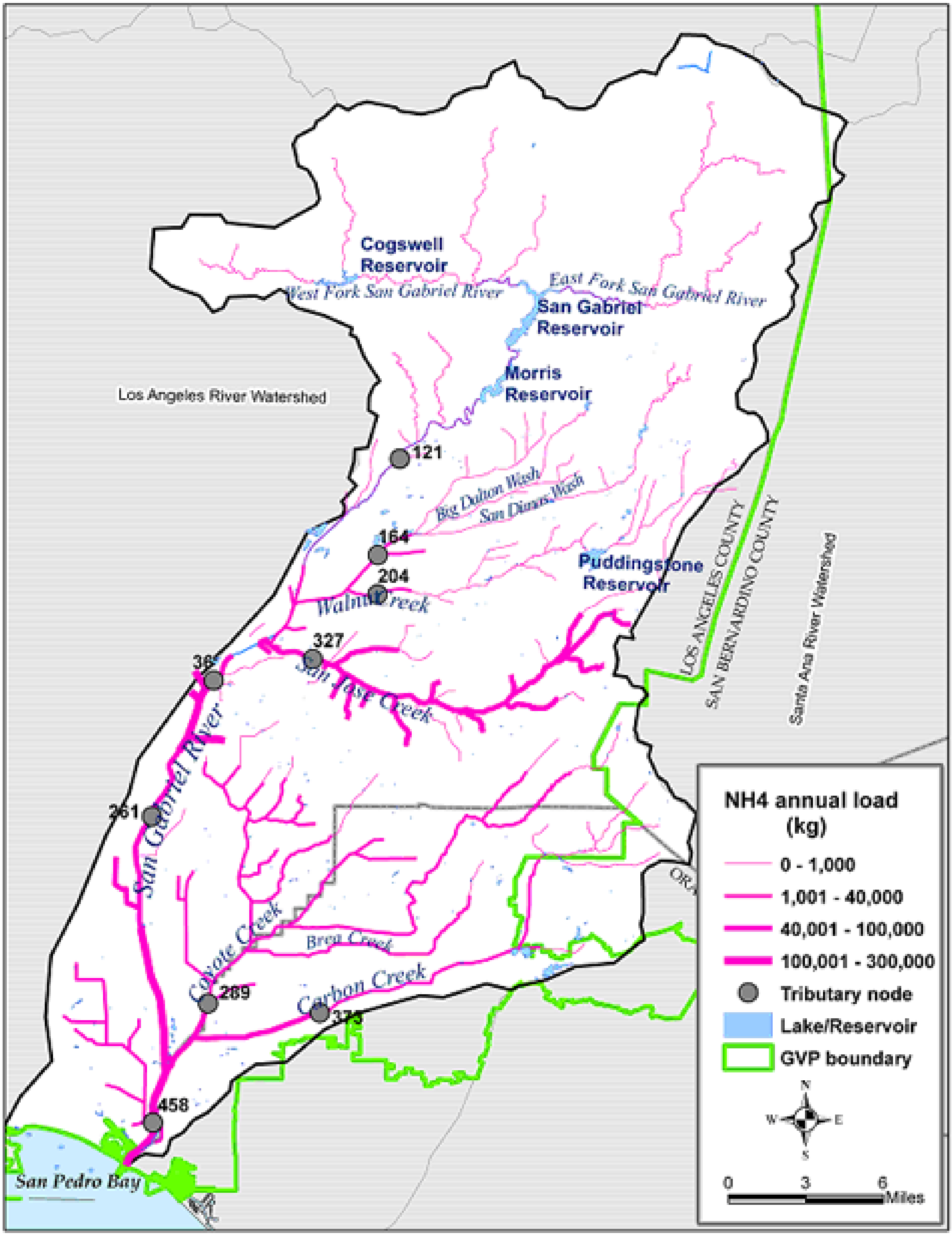


Figure 9a NH4 loads along the stream network

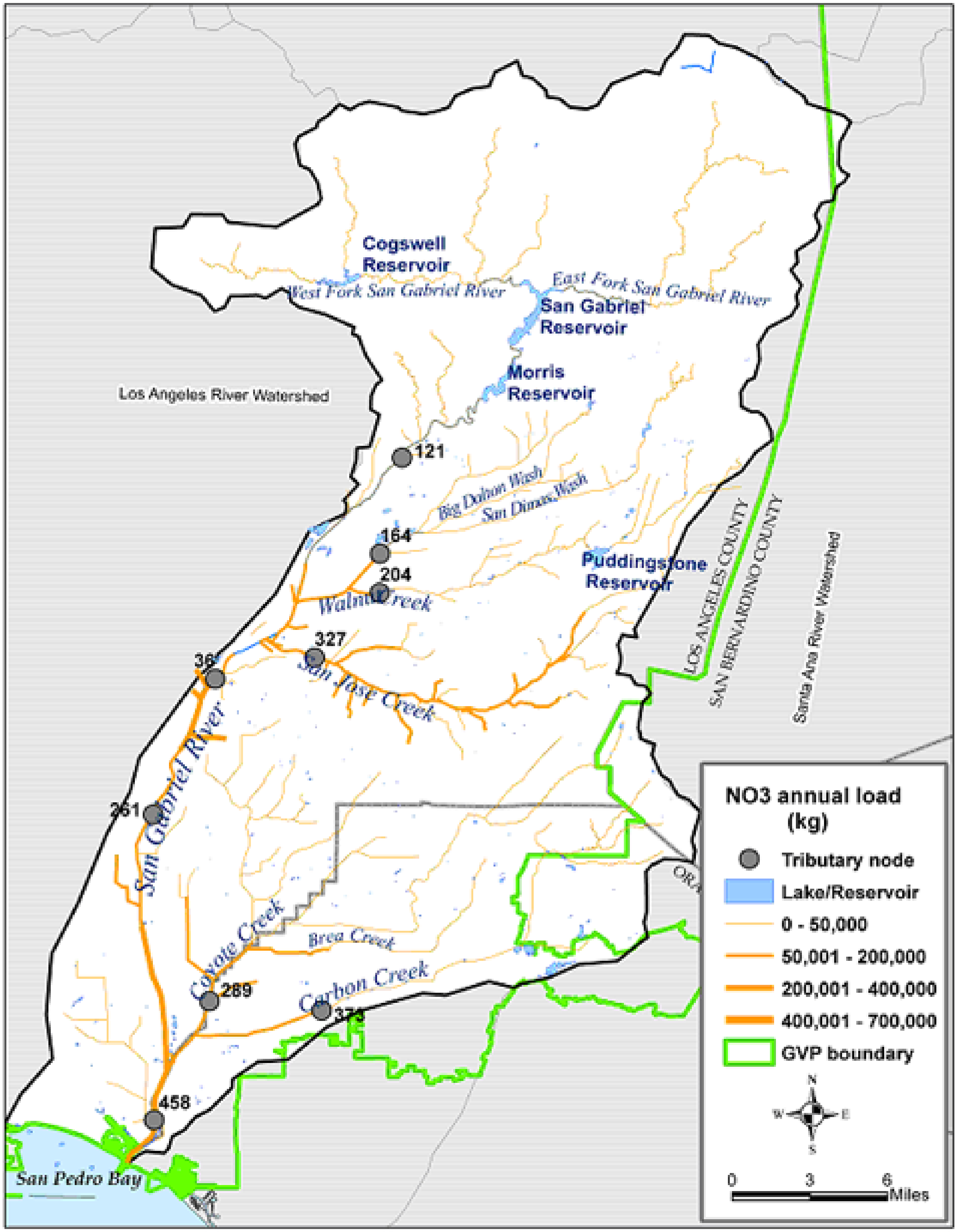


Figure 9b NO3 loads along the stream network

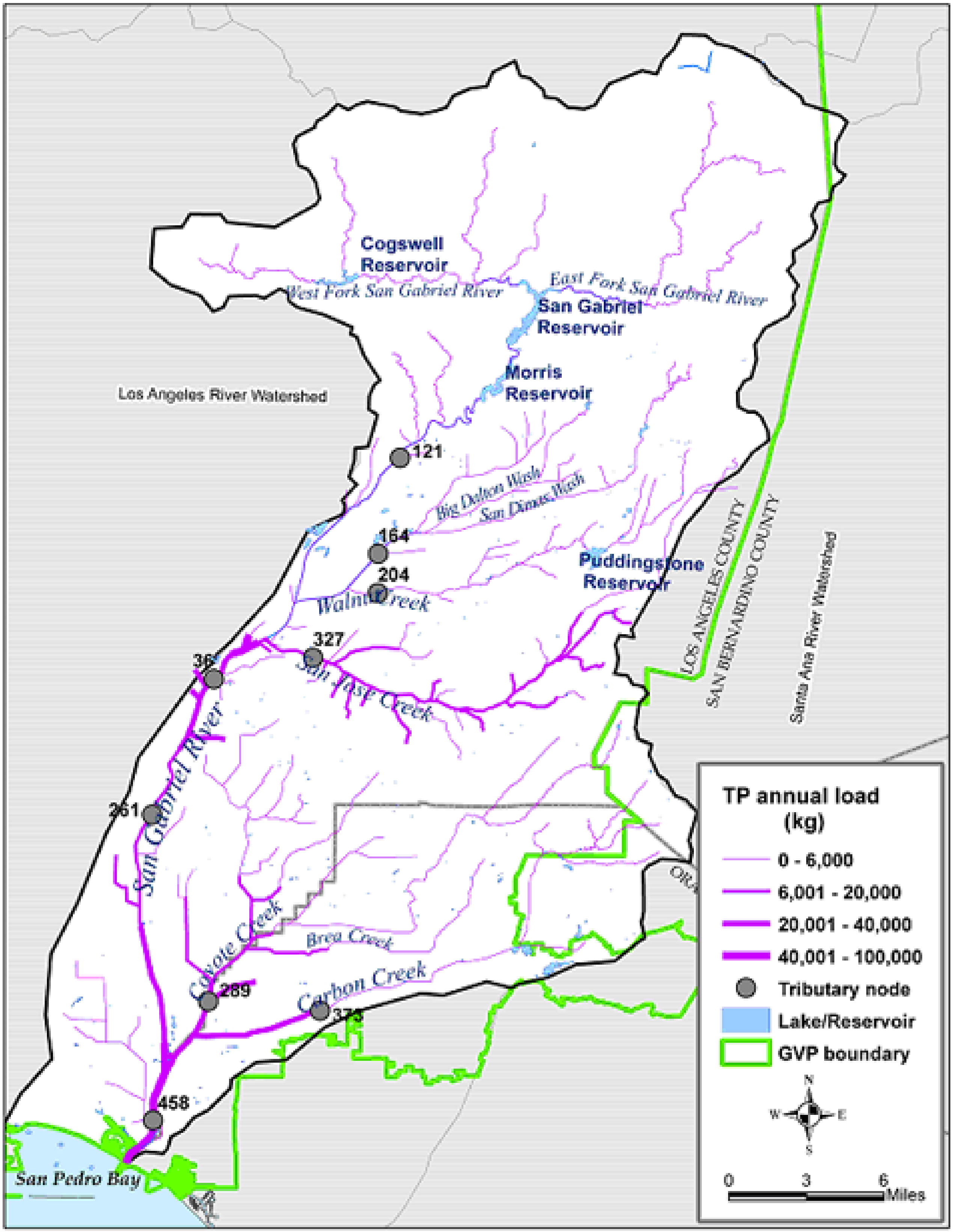


Figure 9c TP loads along the stream network

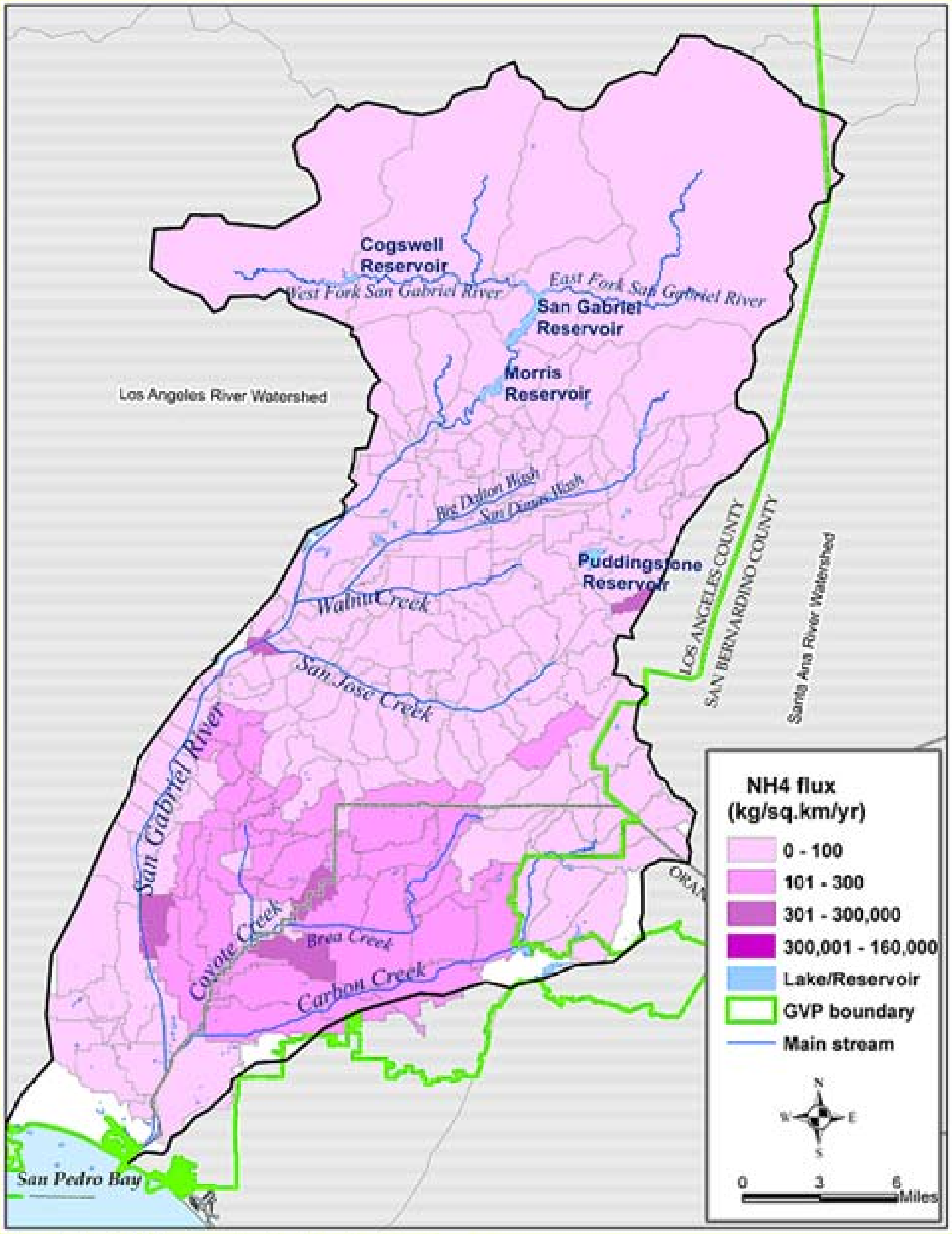


Figure 10a NH4 flux associated with each subcatchment

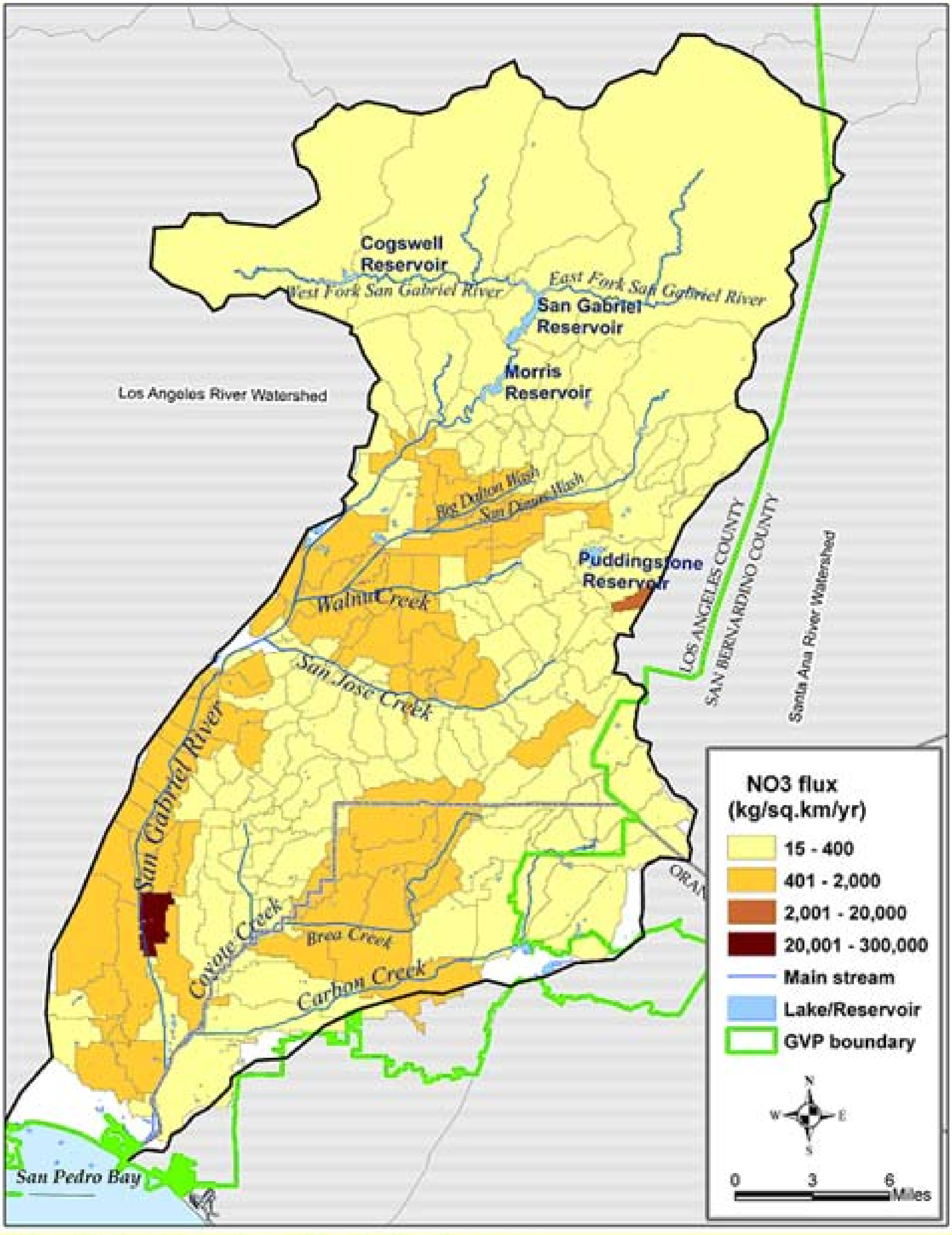


Figure 10b NO3 flux associated with each subcatchment

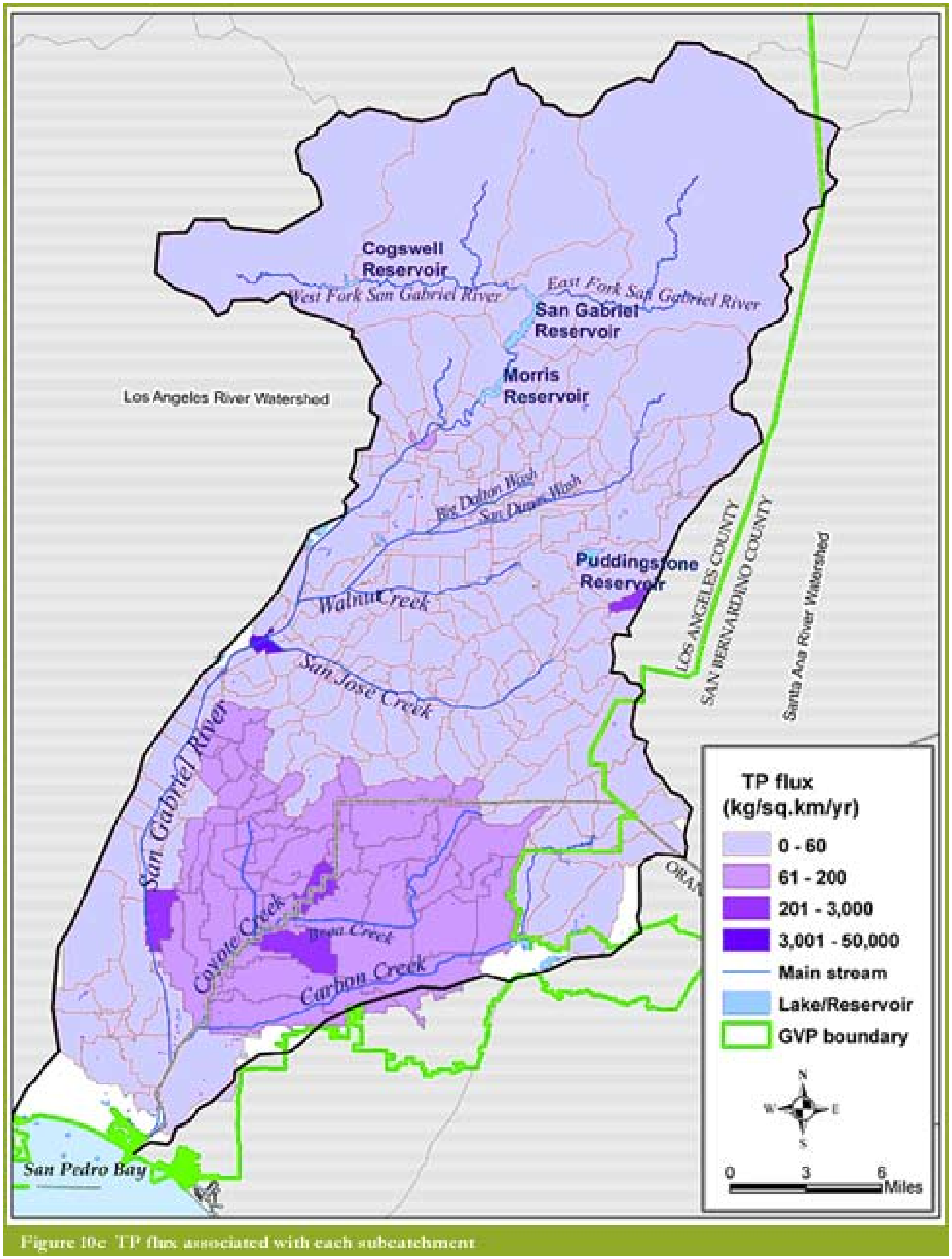


Figure 10c TP flux associated with each subcatchment

Table 14 Annual nutrient loads from main channel reaches and 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 (%)
San Gabriel River at Foothill Boulevard	N121	347	**0.1**	13,728	**3.6**	404	**0.6**	35.3
Big Dalton Wash	N164	1,086	**0.4**	30,908	**8.0**	593	**0.9**	9.5
Walnut Creek	N204	1,048	**0.4**	30,347	**7.8**	352	**0.5**	5.7
San Gabriel River above Florence Avenue	N261	46,924	**18.4**	117,780	**30.5**	15,977	**24.7**	69.0
Coyote Creek	N289	30,121	**11.8**	81,547	**21.1**	21,332	**32.9**	19.4
San Jose Creek	N327	51,302	**20.1**	103,237	**26.7**	10,452	**16.1**	12.7
San Gabriel River at Parkway	N36	77,225	**30.2**	178,383	**46.1**	23219	**35.9**	66.8
Carbon Creek	N373	7,342	**2.9**	20,753	**5.4**	5,678	**8.8**	7.1
San Gabriel River Outlet	N458	255,320	**100.0**	386,672	**100.0**	64,761	**100.0**	100.0

The simulated results were used to estimate the total loads and assess the degree of water impairments for surface waters in a time- and location-specific way based on the Basin Plan that was adopted by the California Water Quality Control Board. The Basin Plan set the objective for nitrite as nitrogen at 1 mg/l, nitrate as nitrogen at 8 mg/l and combined nitrate and nitrite (as nitrogen) at 8 mg/l for the main stem of the San Gabriel River, and 10 mg/l for other tributaries and groundwater (CRWQCB-LAR 1994). The nitrate and nitrite targets for TMDLs are specified as 30-day average concentrations in this Basin Plan. Based on these numeric targets, water quality at various locations can be evaluated using the nutrient concentration output results demonstrated in Figures B-1 and B-2. These outputs show that the NH4 and NO3 concentrations were below the target of 10 mg/l during the simulation time period at the S14 mass emission site; however, the simulated NO3-N concentration at the S13 Coyote Creek mass emission site very likely exceeded the target concentration of 10 mg/l during certain time periods (Figure B-2). Figure 11 shows the daily NO3 load calculation using the simulated daily water flow volume and NO3 concentration for the S14 San Gabriel River at Parkway mass emission site.

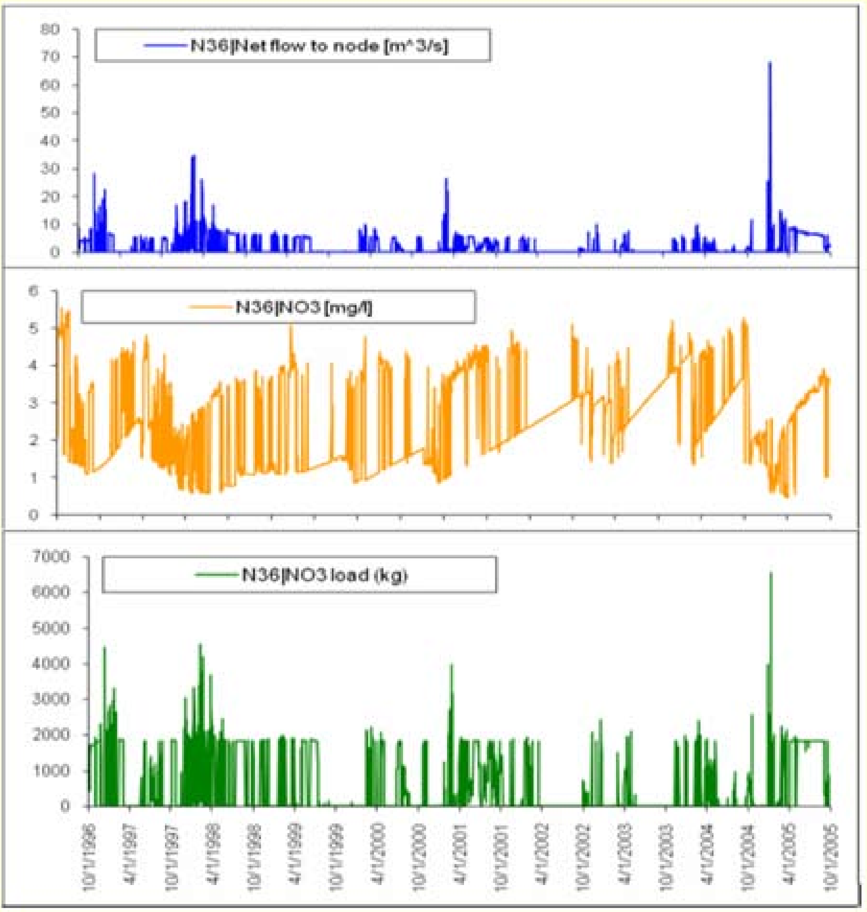


Figure 11 NO3 load calculation using the simulated flow volume and NO3 concentration for the S14 San Gabriel River at Parkway (N36) mass emission

6 Discussion and Conclusions

MIKE BASIN combines the power of ArcGIS with comprehensive hydrologic modeling and was implemented in the San Gabriel River watershed to address water allocation, conjunctive use, 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 entire 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, delivery priorities for users, linkages to upstream nodes, water quality rate parameters, temperature, non-point loadings, a weir constant for re-aeration, the transport time and water depth or Q-h relationship, and the concentrations of selected effluent(s). Key outputs included mass balances, detailed flow descriptions throughout the water system, water diversions, and descriptions of various water quality constituents.

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. The monthly average in-stream flow in the San Gabriel River at the outlet was estimated at 53,000 AF during the simulation period, which is about 30% lower than the observations used for the model evaluation. The highest predicted monthly flow of 130,000 AF occurred in February 1998 and the lowest predicted monthly flow of 42,000 AF in February 2002. The percent of monthly flow to the annual total ranged from 6% to 16% accordingly.

Substantial tributary inflows occur above the San Gabriel River at Foothill Boulevard (N121) gauging station. The MIKE BASIN results predict that the upper San Gabriel River provides 20.3% of the total outflow to the ocean on average. However, flow from the upper part of the watershed often does not get past the Santa Fe Dam and the spreading grounds recharge water to the San Gabriel Groundwater Basin underlying the San Gabriel Valley. The reach between the San Gabriel River at Foothill Boulevard (N121) and San Gabriel River above Florence Avenue (N261) gauging stations provides very little inflow to the main channel. Waters entering the main stem from San Jose and Walnut Creek may be diverted through the Whittier Narrows area to the Los Angeles River. Those waters remaining in the San Gabriel River will often recharge at the downstream spreading grounds. The flow at the San Gabriel River outlet (N458) gauging station largely depends on the inflow below the San Gabriel River above Florence Avenue (N261) gauging station reach including the inflows from Coyote Creek and urban storm discharges along the main stem.

Monthly average in-stream loads in the San Gabriel River at the outlet were about 22,000, 33,000, and 6,000 kg for NH4, NO3 and TP, respectively, during the simulation period. The monthly loads are highly variable with loads varying by several orders of magnitude. The largest variation occurs in the storm season (e.g. December through February) with significantly lower and less variable monthly loads during the dry season months. The total loads associated with winter storms generally contribute much higher fractions of their loads to the ocean compared with flows in the other seasons.

The tributary nutrient loads vary depending on the land uses present in each subwatershed. Substantial tributary NH4 and NO3 loads are added at the San Jose Creek confluence, where 20.1% and 26.7% of the total NH4 and NO3 loads, respectively are provided to the ocean total on average. Along the main stem, substantial NH4 and NO3 loads are added in the reach between the San Gabriel River above Florence Avenue (N261) and San Gabriel River outlet (N67) gauging stations into which the Los Coyotes and Long Beach WRPs discharge. The subwatersheds of Walnut, Coyote, San Jose, and Carbon Creeks provide larger loadings in relative terms than their land areas would suggest as well.

The highest nutrient fluxes for NH4, NO3 and TP were observed in the catchments where wastewater treatment plants are located (e.g. the Pomona, San Jose and Los Coyotes WRPs). The highest annual fluxes of 47,599, 303,067 and 150,833 kg/sq. km for NH4, NO3 and TP, respectively were estimated in the catchment where the San Jose WRP is located for example. Relatively high NH4 fluxes were also estimated for urban subwatersheds such as Coyote Creek, Carbon Creek and the lower San Gabriel River. The catchments associated with high NO3 flux were scattered across the watershed along the major tributaries and included Walnut Creek, Big Dalton Wash, the middle San Gabriel River reach, and Coyote Creek. The TP flux distribution map shows the similar pattern as the NH4 flux distribution, where large loadings are located in the Coyote and Brea Creek subwatersheds.

Overall, the modeled results should provide users with simple, intuitive yet in-depth insight for 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-4 through A-11, the model simulates the hydrology in a reasonable manner. The magnitude of the results is similar to the observed flows with various degrees of error associated with different locations in the watershed. Calibration results in three small catchments fell within the recommended criteria and showed satisfactory performance. The model total flow volume simulations for all sites above the Whittier Narrows Dam ranged from fair to very good, but the predictions below the Whittier Narrows Dam fell far short of this range as illustrated by the poor performance noted at the F262C-R San Gabriel River above Florence Avenue and 11088000/F42B-R San Gabriel River at Spring Street near Los Alamitos, CA gauging stations. Among all these simulations, the 10th percentile high flows are normally under-estimated and the 50th percentile low flows are over-estimated by as much as 5,000%. The latter result is largely due to the fact that river flow occurs underground during the dry season because surface flows in the headwaters percolate rapidly into alluvial aquifers as the streams cross the San Gabriel Valley (Los Angeles County Flood Control District 1975).

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 surfaces and in streams for these pollutants. The mean concentration (EMC) by land use is an approximate method for estimating the average water quality conditions. Temporal variations in the stream concentrations were substantial but not represented in the input parameters, which might have negatively impacted the estimates of nutrients loadings. It is very likely that large storm drains discharge during some storms and not others and these kinds of non-linear effects were not captured in the MIKE BASIN model parameterization.

Two other issues of broad concern warrant a brief mention as well. First, a large portion of the nutrient loads in the San Gabriel River watershed derives from sources beyond the control of dischargers, especially atmospheric deposition. Direct air deposition to water bodies was treated as a non-point source from the Los Angeles National Forest. Air deposition that enters the stream network via 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. 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, and are provided by point source discharges, urban runoff, and groundwater baseflow. Simulation of these two different flow regimes using different approaches is preferred when there is adequate input data and the desire to assess TMDL compliance. However, wet- and dry-weather nutrient simulations are not differentiated in the MIKE BASIN package, which may limit applications of the modeling results for estimating TMDL compliance and/or the assessment of BMP designs, which require not only estimates of annual loads but also loadings at much finer temporal scales.

This report has focused on assessing the sources and average loads of nutrients to the surface waters 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. The simulated water quality time series at each of the node points of the stream network do, however, offer some understanding of the spatio-temporal variability of the nutrient loadings and concentrations at the basin scale. The results do identify those parts of the watershed and the times of the year on which further research should focus if we are to improve our management of the water supply and quality issues affecting the San Gabriel River and its numerous tributaries.

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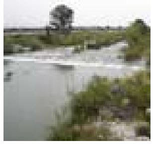
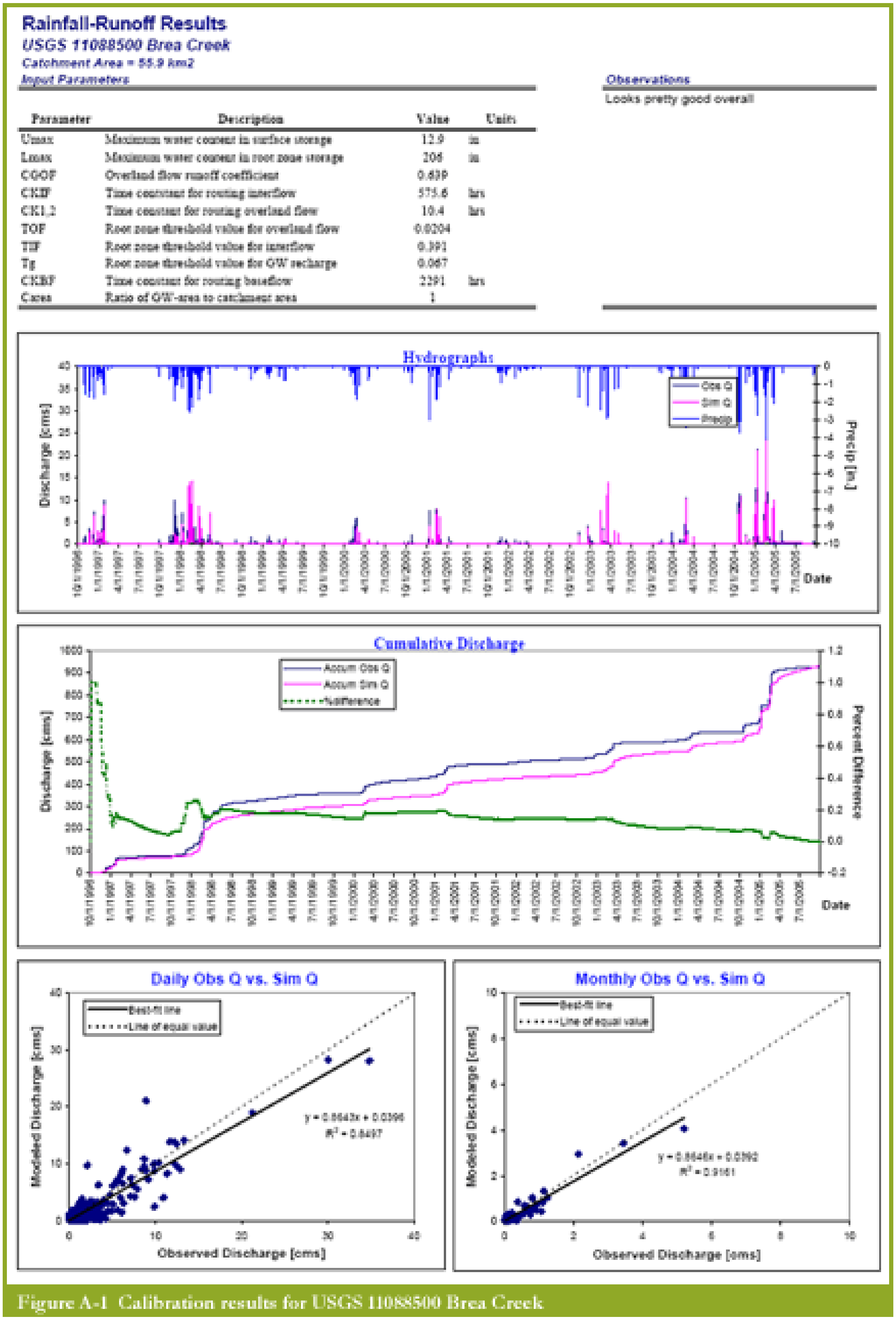
Appendix A

Hydrology Calibration and Validation Graphs and Tables





Rainfall-Runoff Results

USGS 11088500 Brea Creek

Catchment Area = 55.9 km2

Input Parameters

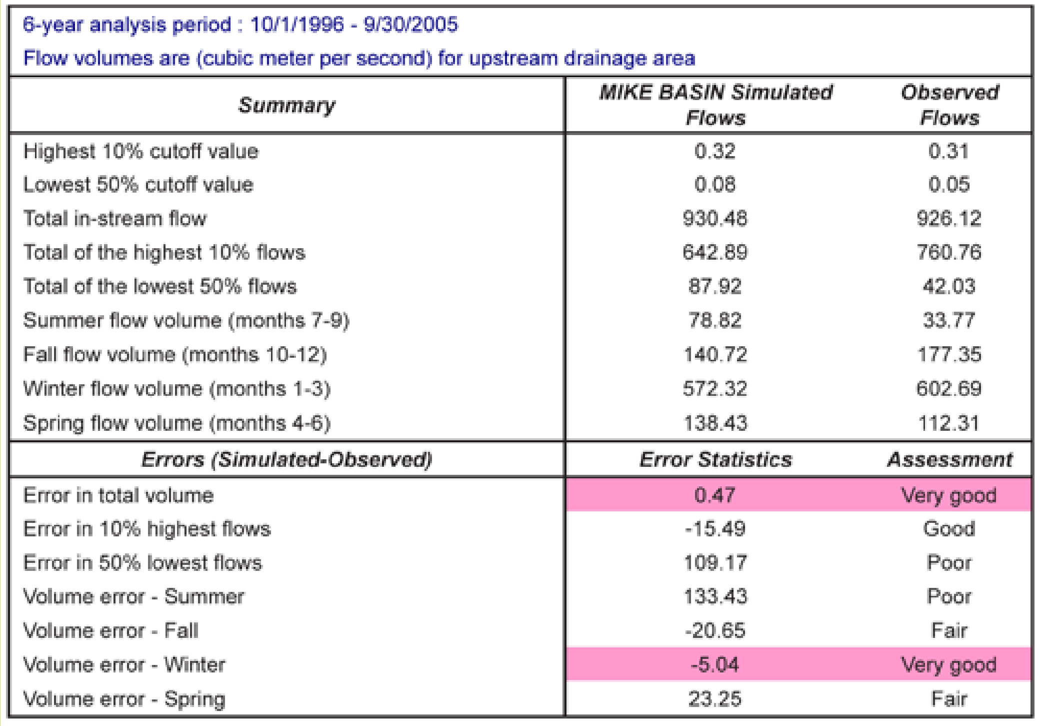
Parameter	Description	Value	Units
Umax	Maximum water content in surface storage	12.9	in
Lmax	Maximum water content in root zone storage	206	in
CQOF	Overland flow runoff coefficient	0.639	
CKIF	Time constant for routing interflow	575.6	hrs
CK1,2	Time constant for routing overland flow	10.4	hrs
TOF	Root zone threshold value for overland flow	0.0204	
TIF	Root zone threshold value for interflow	0.391	
Tg	Root zone threshold value for GW recharge	0.067	
CKBF	Time constant for routing baseflow	2291	hrs
Carea	Ratio of GW-area to catchment area	1	

Observations

Looks pretty good overall

Figure A-1 Calibration results for USGS 11088500 Brea Creek

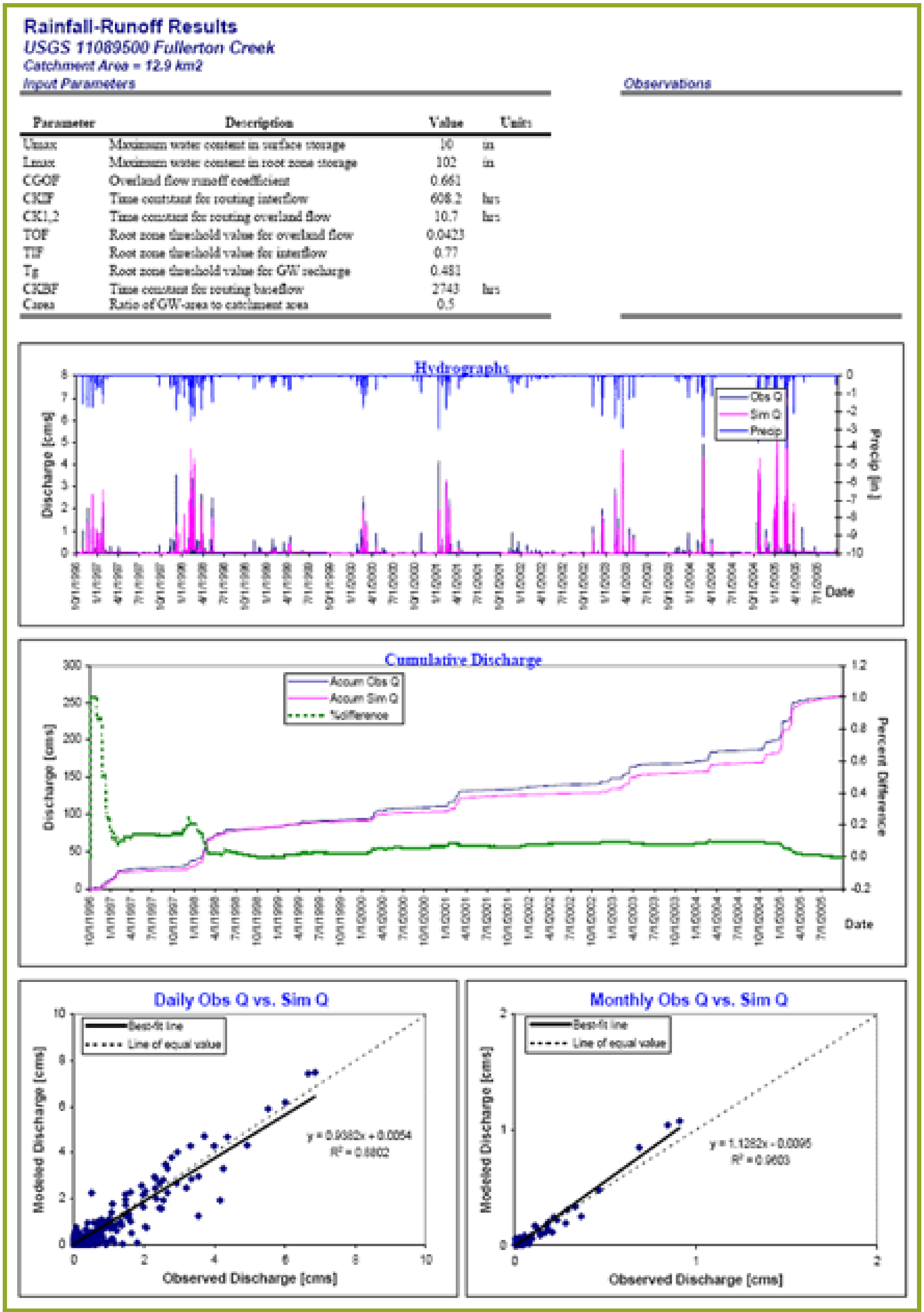
Table A-1 Calibration Error Analysis for USGS 11088500 Brea Creek



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	0.32	0.31
Lowest 50% cutoff value	0.08	0.05
Total in-stream flow	930.48	926.12
Total of the highest 10% flows	642.89	760.76
Total of the lowest 50% flows	87.92	42.03
Summer flow volume (months 7-9)	78.82	33.77
Fall flow volume (months 10-12)	140.72	177.35
Winter flow volume (months 1-3)	572.32	602.69
Spring flow volume (months 4-6)	138.43	112.31
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	0.47	Very good
Error in 10% highest flows	-15.49	Good
Error in 50% lowest flows	109.17	Poor
Volume error - Summer	133.43	Poor
Volume error - Fall	-20.65	Fair
Volume error - Winter	-5.04	Very good
Volume error - Spring	23.25	Fair



Rainfall-Runoff Results

USGS 11089500 Fullerton Creek

Catchment Area = 12.9 km2

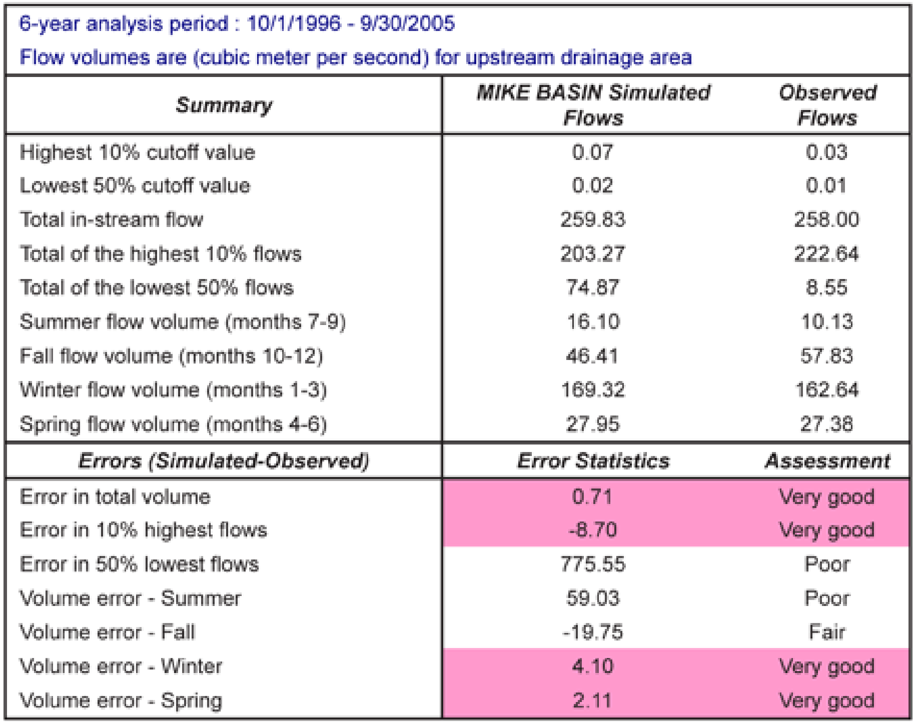
Input Parameters

Parameter	Description	Value	Units
Umax	Maximum water content in surface storage	10	in
Lmax	Maximum water content in root zone storage	102	in
CQOF	Overland flow runoff coefficient	0.661	
CKIF	Time constant for routing interflow	608.2	hrs
CK1,2	Time constant for routing overland flow	10.7	hrs
TOF	Root zone threshold value for overland flow	0.0423	
TIF	Root zone threshold value for interflow	0.77	
Tg	Root zone threshold value for GW recharge	0.481	
CKBF	Time constant for routing baseflow	2743	hrs
Carea	Ratio of GW-area to catchment area	0.5	

Observations

Figure A-2 Calibration results for USGS 11089500 Fullerton Creek

Table A-2 Calibration Error Analysis for USGS 11089500 Fullerton Creek



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	0.07	0.03
Lowest 50% cutoff value	0.02	0.01
Total in-stream flow	259.83	258.00
Total of the highest 10% flows	203.27	222.64
Total of the lowest 50% flows	74.87	8.55
Summer flow volume (months 7-9)	16.10	10.13
Fall flow volume (months 10-12)	46.41	57.83
Winter flow volume (months 1-3)	169.32	162.64
Spring flow volume (months 4-6)	27.95	27.38
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	0.71	Very good
Error in 10% highest flows	-8.70	Very good
Error in 50% lowest flows	775.55	Poor
Volume error - Summer	59.03	Poor
Volume error - Fall	-19.75	Fair
Volume error - Winter	4.10	Very good
Volume error - Spring	2.11	Very good

Rainfall-Runoff Results

USGS 11084500/U7-R Fish Creek

Catchment Area = 16.2 km2

Input Parameters

Observations

Parameter	Description	Value	Units
Umax	Maximum water content in surface storage	12.1	in
Lmax	Maximum water content in root zone storage	103	in
CQOF	Overland flow runoff coefficient	0.948	
CKIF	Time constant for routing interflow	659.1	hrs
CK1,2	Time constant for routing overland flow	12	hrs
TOF	Root zone threshold value for overland flow	0.982	
TIF	Root zone threshold value for interflow	0.38	
Tg	Root zone threshold value for GW recharge	0.724	
CKBF	Time constant for routing baseflow	1901	hrs
Carea	Ratio of GW-area to catchment area	1	

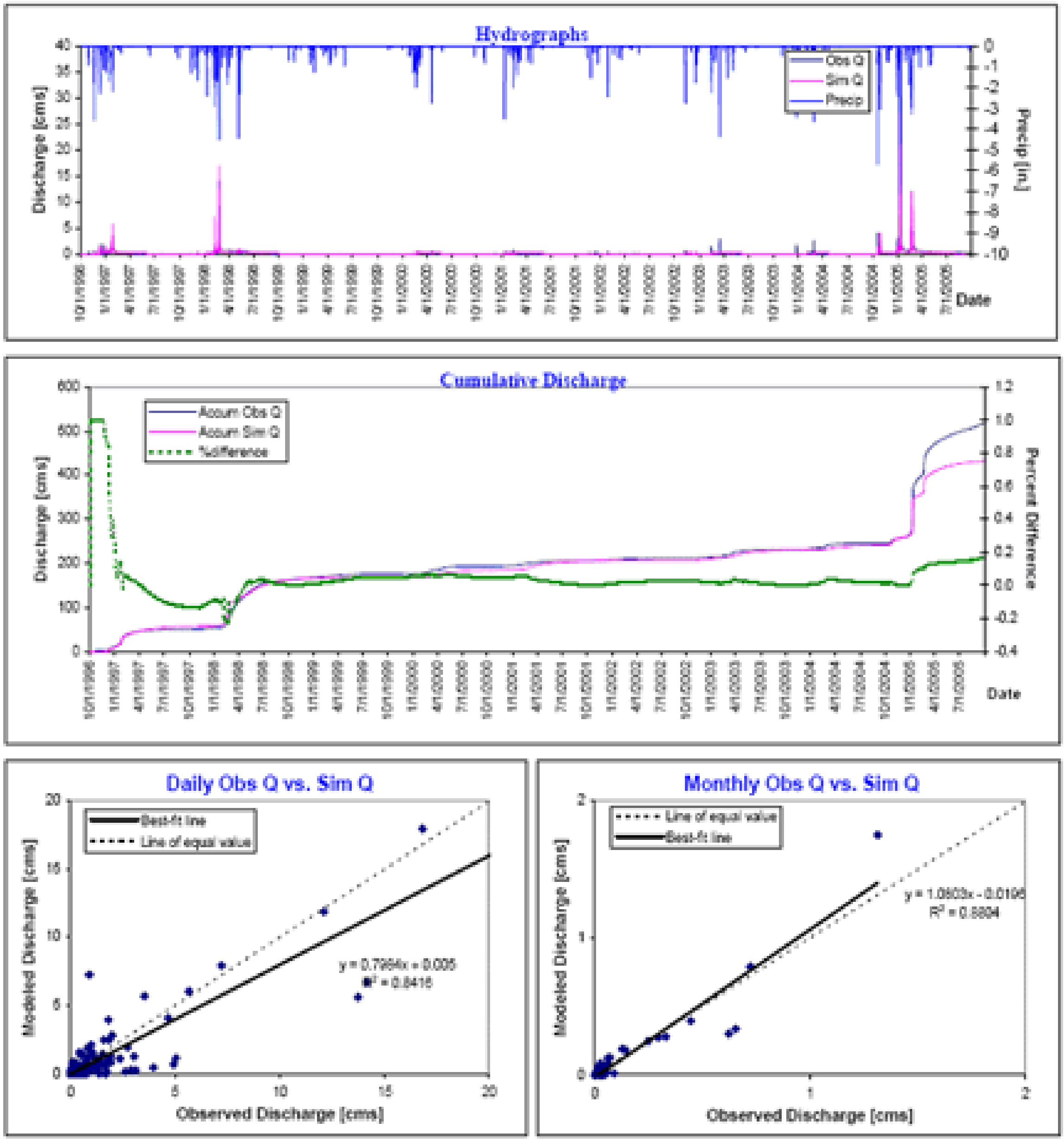
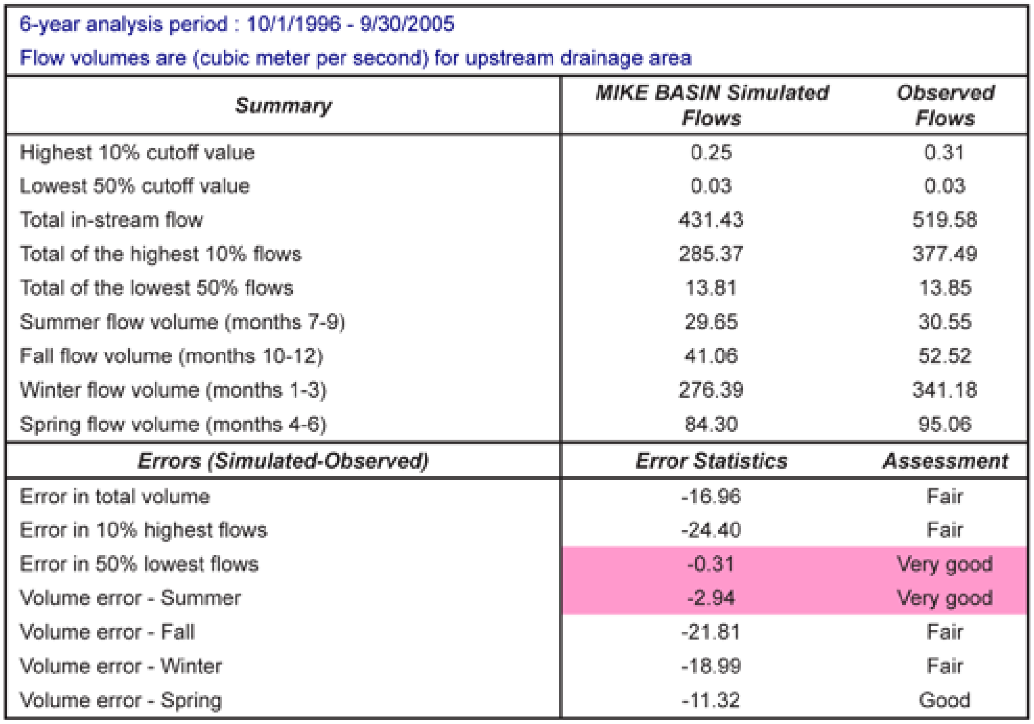


Figure A-3 Calibration results for USGS 11084500/U7-R Fish Creek

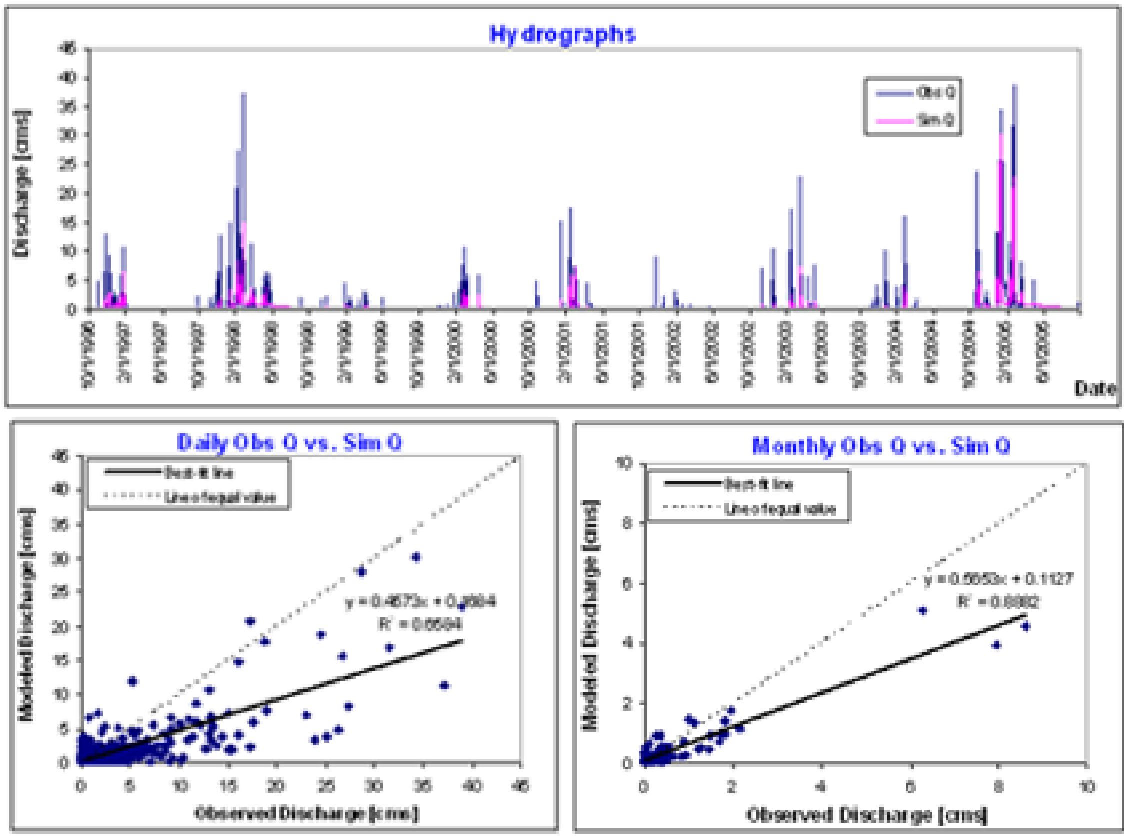
Table A-3 Calibration Error Analysis for USGS 11084500/U7-R Fish Creek

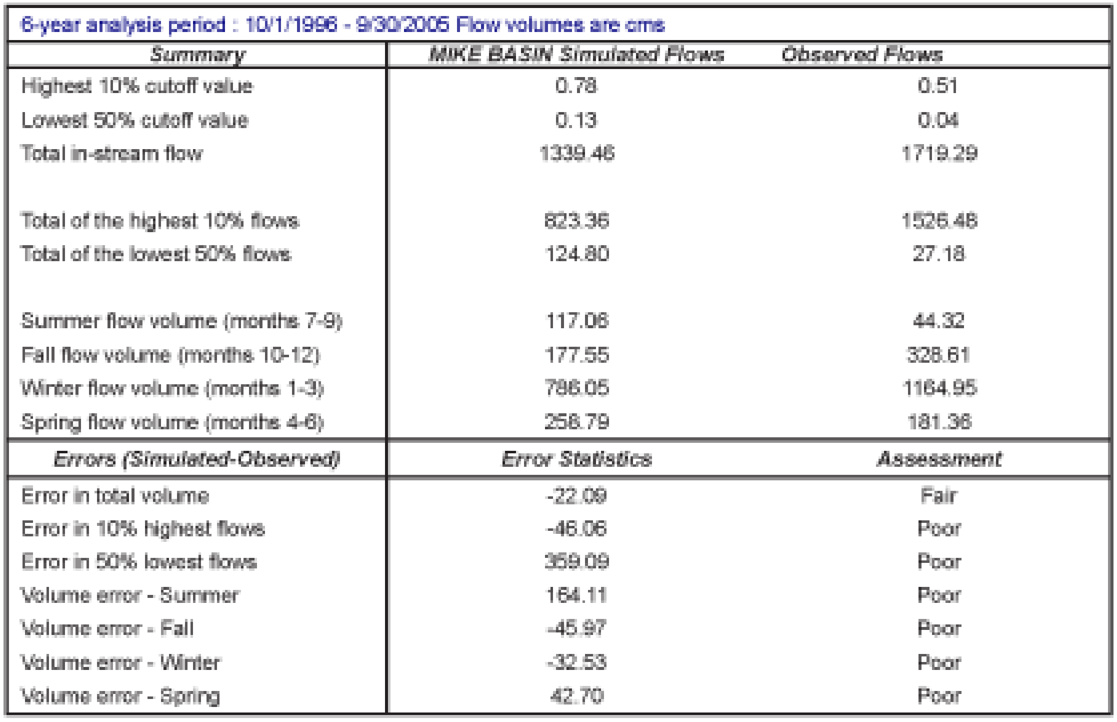


6-year analysis period : 10/1/1996 - 9/30/2005

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

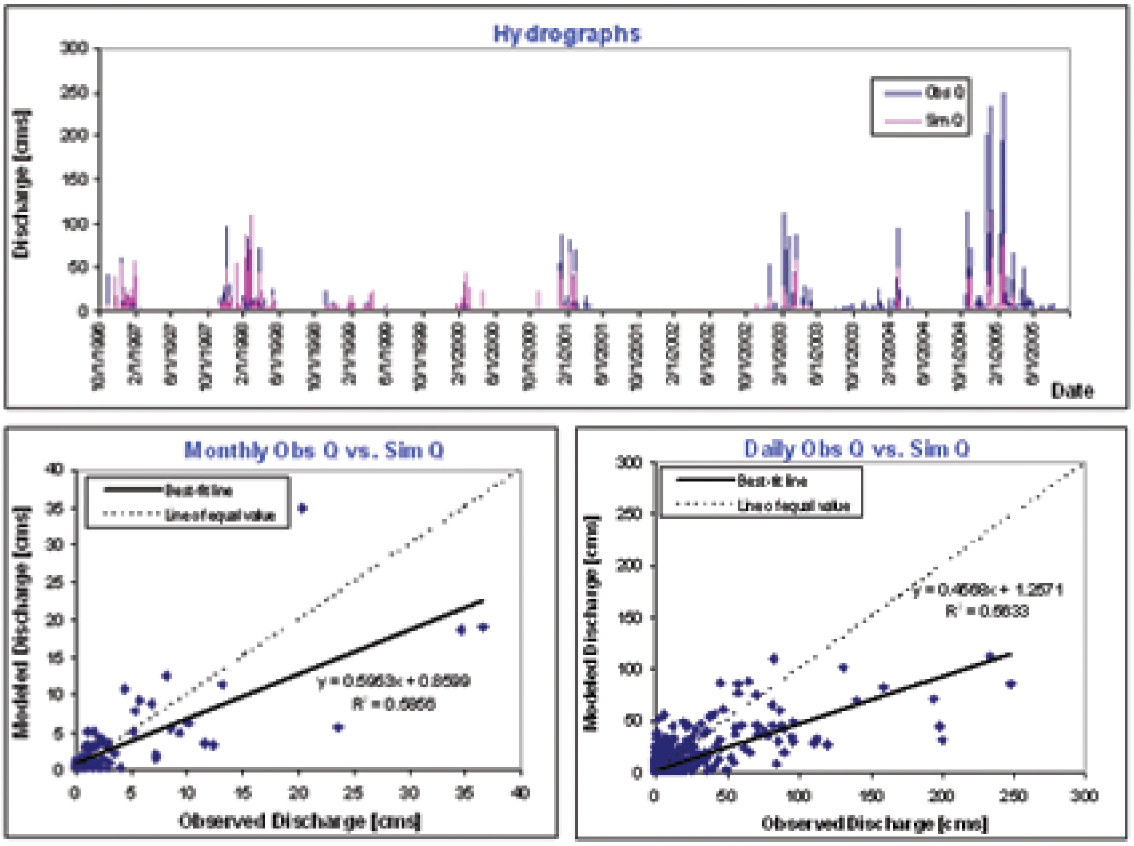
Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	0.25	0.31
Lowest 50% cutoff value	0.03	0.03
Total in-stream flow	431.43	519.58
Total of the highest 10% flows	285.37	377.49
Total of the lowest 50% flows	13.81	13.85
Summer flow volume (months 7-9)	29.65	30.55
Fall flow volume (months 10-12)	41.06	52.52
Winter flow volume (months 1-3)	276.39	341.18
Spring flow volume (months 4-6)	84.30	95.06
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	-16.96	Fair
Error in 10% highest flows	-24.40	Fair
Error in 50% lowest flows	-0.31	Very good
Volume error - Summer	-2.94	Very good
Volume error - Fall	-21.81	Fair
Volume error - Winter	-18.99	Fair
Volume error - Spring	-11.32	Good




6-year analysis period : 10/1/1996 - 9/30/2005 Flow volumes are cms

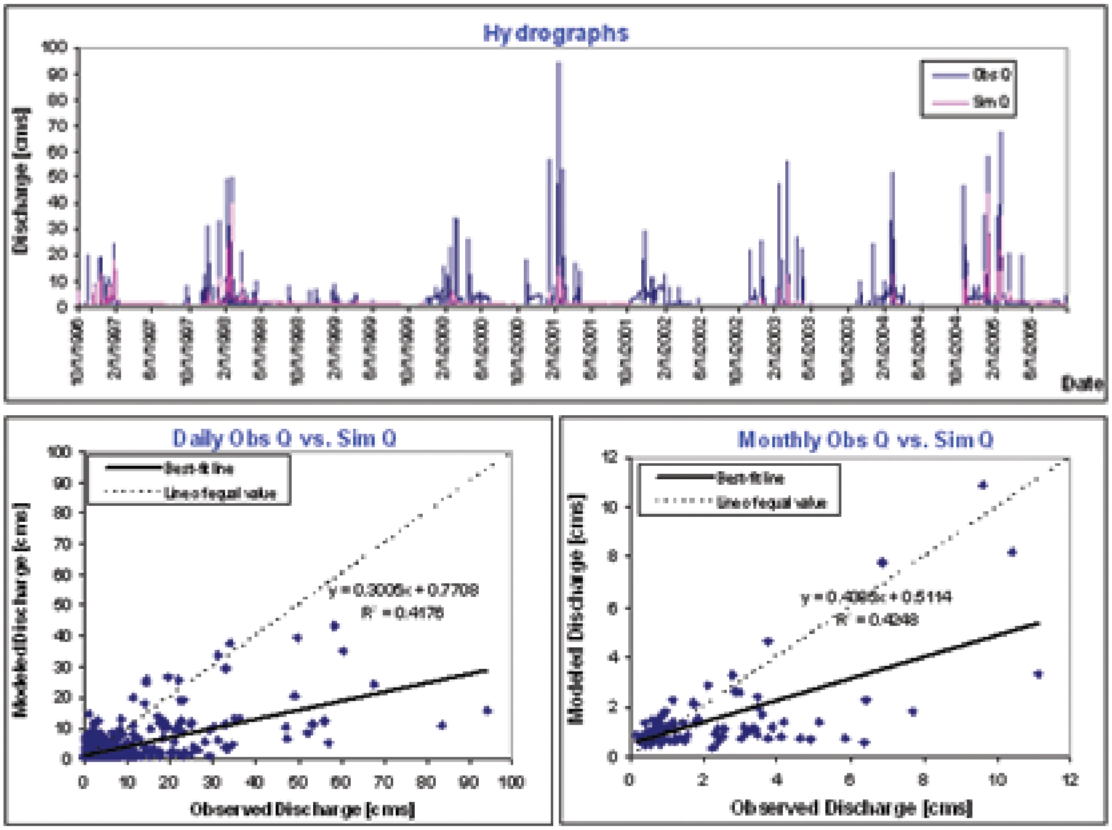
Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	0.78	0.51
Lowest 50% cutoff value	0.13	0.04
Total in-stream flow	1339.46	1719.29
Total of the highest 10% flows	823.36	1526.48
Total of the lowest 50% flows	124.80	27.18
Summer flow volume (months 7-9)	117.06	44.32
Fall flow volume (months 10-12)	177.55	328.61
Winter flow volume (months 1-3)	786.05	1164.95
Spring flow volume (months 4-6)	258.79	181.36
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	-22.09	Fair
Error in 10% highest flows	-46.06	Poor
Error in 50% lowest flows	359.09	Poor
Volume error - Summer	164.11	Poor
Volume error - Fall	-45.97	Poor
Volume error - Winter	-32.53	Poor
Volume error - Spring	42.70	Poor

Figure A-4 Validation results for LADPW F304-R Walnut Creek



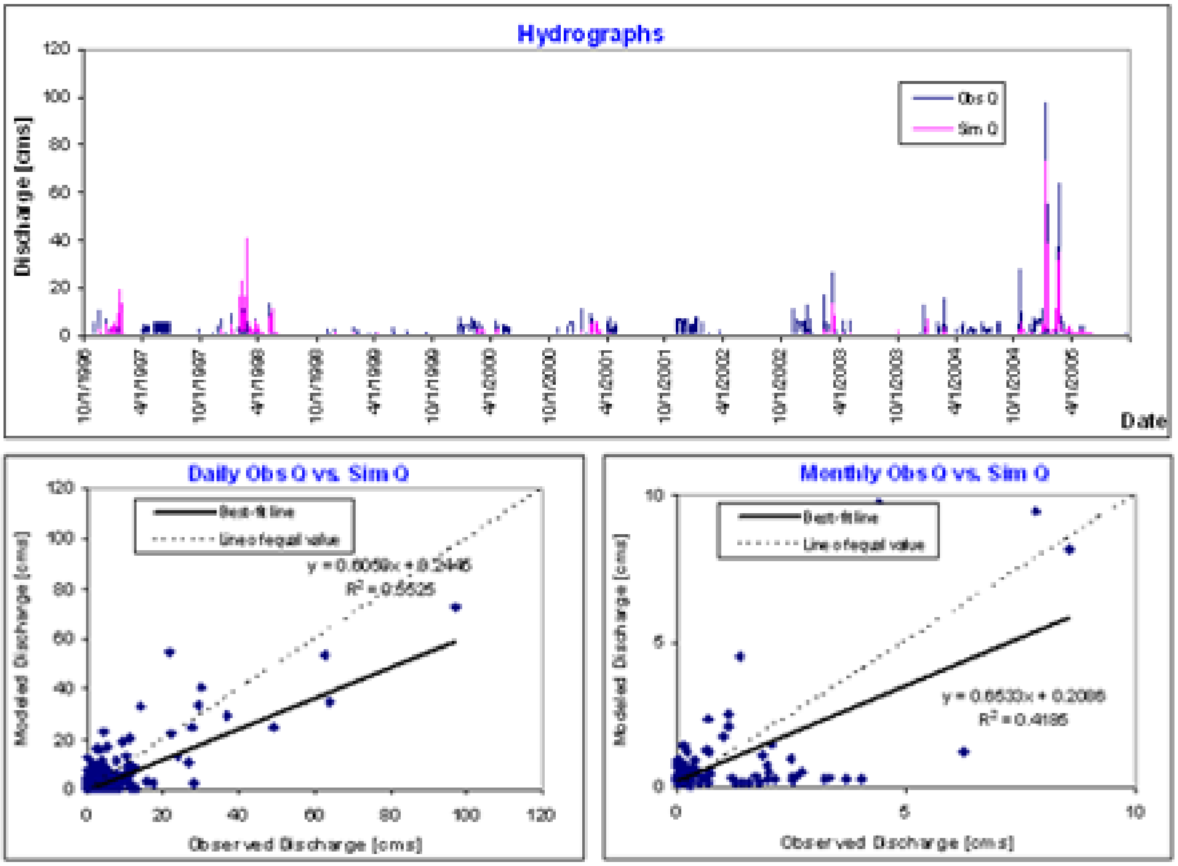
6-year analysis period : 10/1/1996 - 9/30/2005 Flow volumes are cms		
Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	3.89	4.14
Lowest 50% cutoff value	0.80	0.62
Total in-stream flow	8570.66	9741.26
Total of the highest 10% flows	5796.17	7463.96
Total of the lowest 50% flows	714.19	413.97
Summer flow volume (months 7-9)	595.61	602.25
Fall flow volume (months 10-12)	1797.32	2227.73
Winter flow volume (months 1-3)	5016.34	5671.96
Spring flow volume (months 4-6)	1161.38	1238.41
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	-12.02	Good
Error in 10% highest flows	-22.34	Fair
Error in 50% lowest flows	72.52	Poor
Volume error - Summer	-1.10	Very good
Volume error - Fall	-19.32	Fair
Volume error - Winter	-11.56	Good
Volume error - Spring	-6.22	Very good

Figure A-5 Validation results for LADPW F354-R Coyote Creek



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	1.97	4.25
Lowest 50% cutoff value	0.85	0.62
Total in-stream flow	4413.32	6258.52
Total of the highest 10% flows	1753.80	3590.04
Total of the lowest 50% flows	1128.89	665.98
Summer flow volume (months 7-9)	728.15	413.85
Fall flow volume (months 10-12)	844.97	1812.94
Winter flow volume (months 1-3)	1929.11	3066.14
Spring flow volume (months 4-6)	911.09	965.17
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	-29.48	Fair
Error in 10% highest flows	-51.15	Poor
Error in 50% lowest flows	69.51	Poor
Volume error - Summer	75.94	Poor
Volume error - Fall	-53.39	Poor
Volume error - Winter	-37.08	Poor
Volume error - Spring	-5.60	Very good

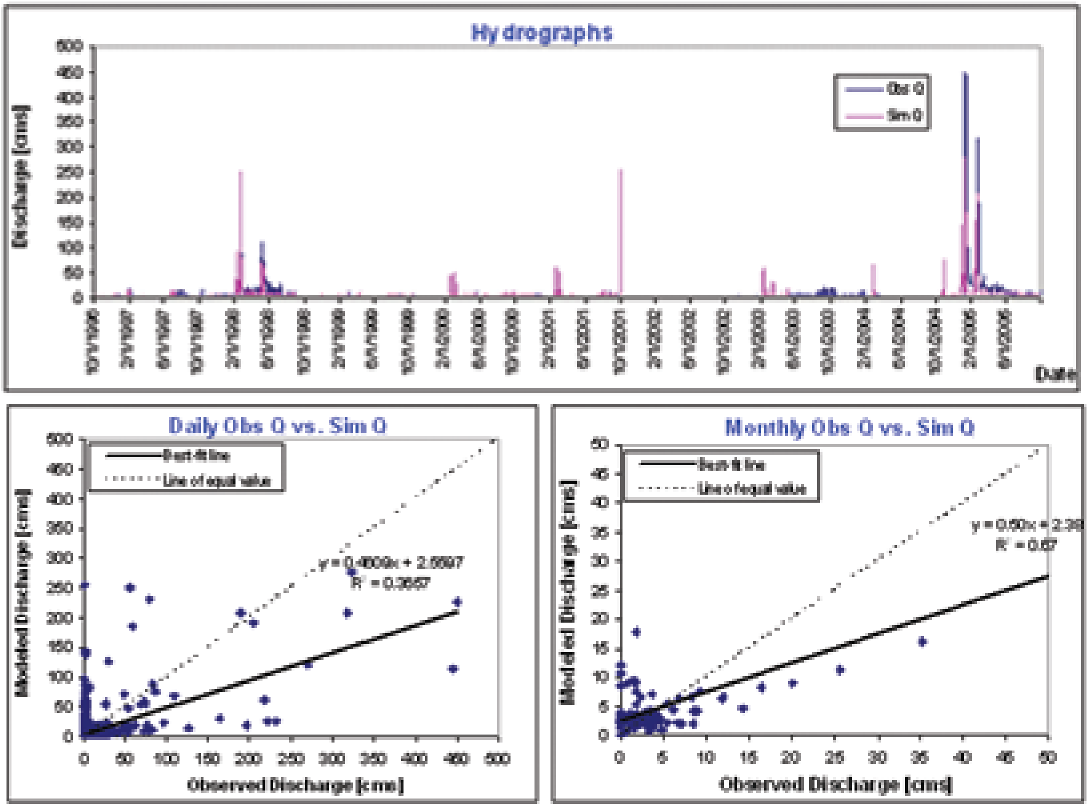
Figure A-6 Validation results for LADPW F312B-R San Jose Channel

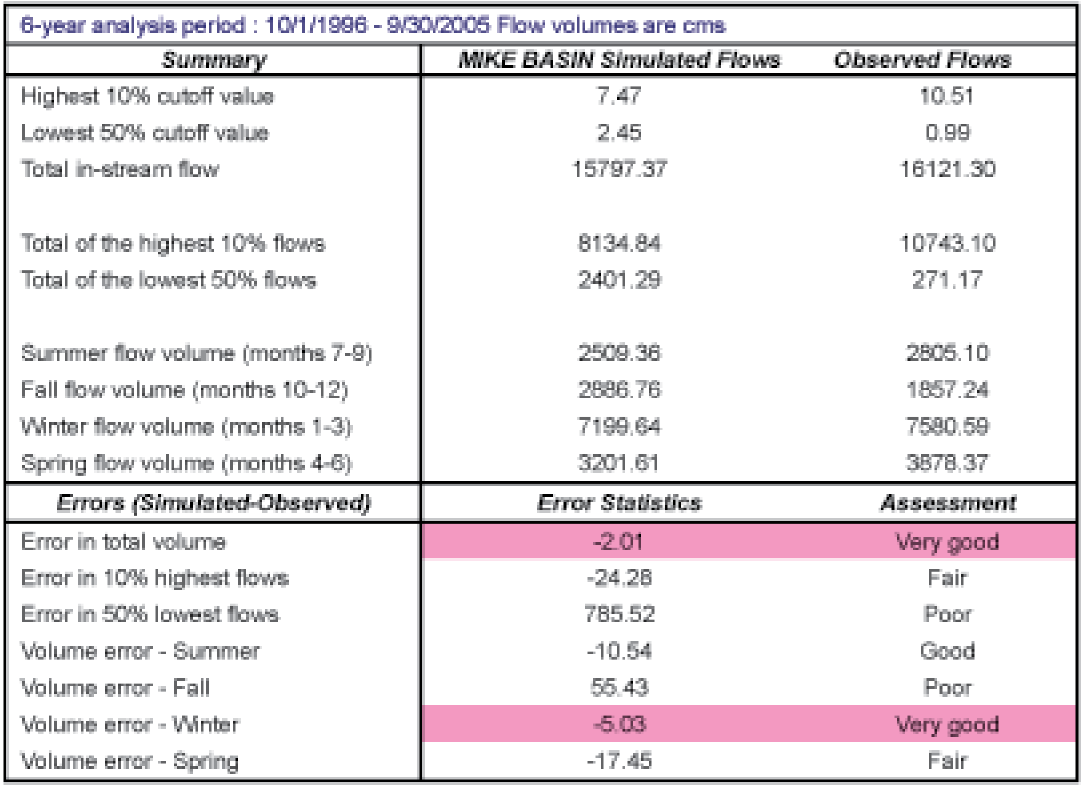


6-year analysis period : 10/1/1996 - 9/30/2005 Flow volumes are cms

Summary	MIKE BASIN Simulated Flows	Observed Flows
Highest 10% cutoff value	1.23	2.87
Lowest 50% cutoff value	0.32	0.04
Total in-stream flow	2555.64	2892.03
Total of the highest 10% flows	1474.66	2285.45
Total of the lowest 50% flows	350.12	24.90
Summer flow volume (months 7-9)	273.11	106.63
Fall flow volume (months 10-12)	350.19	917.68
Winter flow volume (months 1-3)	1474.33	1259.67
Spring flow volume (months 4-6)	458.02	608.05
Errors (Simulated-Observed)	**Error Statistics**	**Assessment**
Error in total volume	-11.63	Good
Error in 10% highest flows	-35.48	Poor
Error in 50% lowest flows	1306.22	Poor
Volume error - Summer	156.13	Poor
Volume error - Fall	-61.84	Poor
Volume error - Winter	17.04	Fair
Volume error - Spring	-24.67	Fair

Figure A-7 Validation results for LADPW F274B-R Dalton Wash

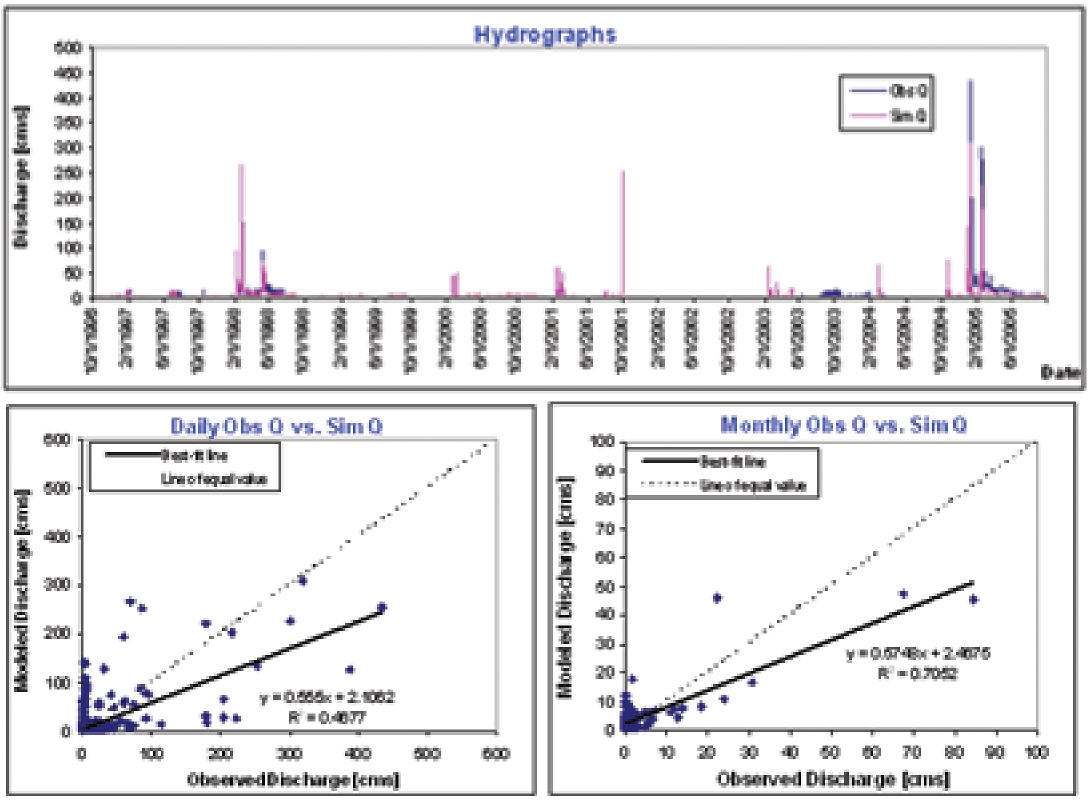




6-year analysis period : 10/1/1996 - 9/30/2005 Flow volumes are cms

Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	7.47	10.51
Lowest 50% cutoff value	2.45	0.99
Total in-stream flow	15797.37	16121.30
Total of the highest 10% flows	8134.84	10743.10
Total of the lowest 50% flows	2401.29	271.17
Summer flow volume (months 7-9)	2509.36	2805.10
Fall flow volume (months 10-12)	2886.76	1857.24
Winter flow volume (months 1-3)	7199.64	7580.59
Spring flow volume (months 4-6)	3201.61	3878.37
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	-2.01	Very good
Error in 10% highest flows	-24.28	Fair
Error in 50% lowest flows	785.52	Poor
Volume error - Summer	-10.54	Good
Volume error - Fall	55.43	Poor
Volume error - Winter	-5.03	Very good
Volume error - Spring	-17.45	Fair

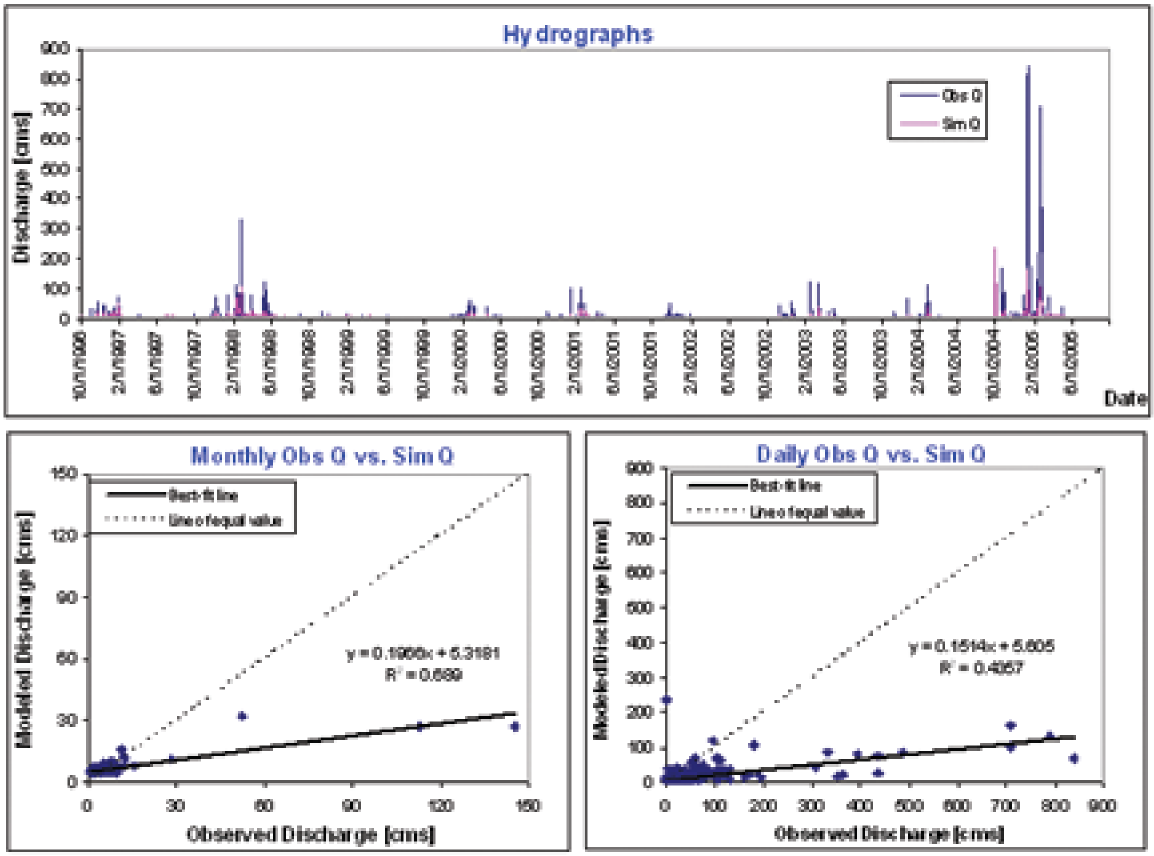
Figure A-8 Validation results for LADPW U8-R San Gabriel River below Morris Dam



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	7.00	13.14
Lowest 50% cutoff value	2.18	0.28
Total in-stream flow	14933.64	12107.87
Total of the highest 10% flows	8327.58	8778.79
Total of the lowest 50% flows	1774.92	30.74
Summer flow volume (months 7-9)	2087.35	1298.39
Fall flow volume (months 10-12)	2629.19	835.51
Winter flow volume (months 1-3)	7319.79	6914.00
Spring flow volume (months 4-6)	2897.31	3059.97
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	23.34	Fair
Error in 10% highest flows	-5.14	Very good
Error in 50% lowest flows	5674.36	Poor
Volume error - Summer	60.76	Poor
Volume error - Fall	214.68	Poor
Volume error - Winter	5.87	Very good
Volume error - Spring	-5.32	Very good

Figure A-9 Validation results for LADPW F190-R San Gabriel River at Foothill Blvd

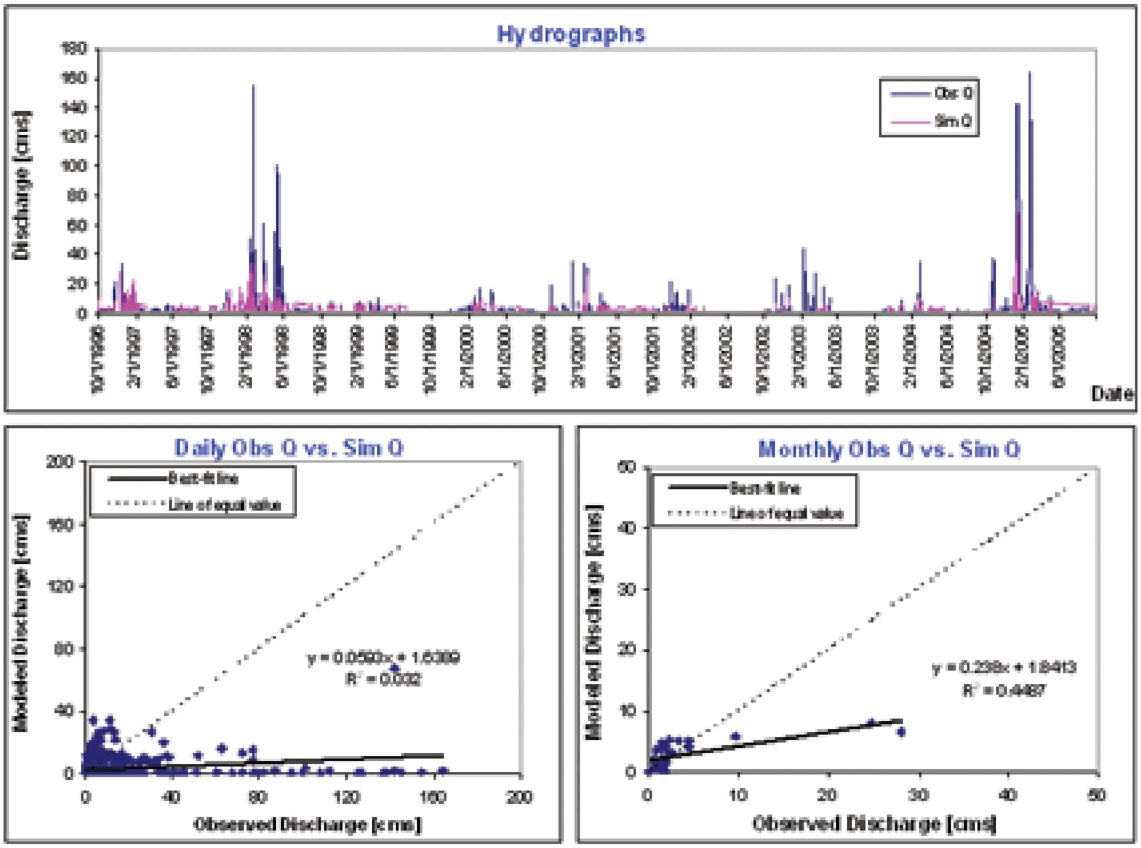


6-year analysis period : 10/1/1996 - 9/30/2005 Flow volumes are cms

Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	8.29	8.35
Lowest 50% cutoff value	5.16	1.95
Total in-stream flow	21724.77	21841.64
Total of the highest 10% flows	1831.14	15151.75
Total of the lowest 50% flows	7687.59	1886.98
Summer flow volume (months 7-9)	4278.71	1220.29
Fall flow volume (months 10-12)	4813.49	4045.23
Winter flow volume (months 1-3)	7775.97	13482.59
Spring flow volume (months 4-6)	4856.61	3092.91

Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	-0.54	Very good
Error in 10% highest flows	-87.91	Poor
Error in 50% lowest flows	307.40	Poor
Volume error - Summer	250.63	Poor
Volume error - Fall	18.99	Fair
Volume error - Winter	-42.33	Poor
Volume error - Spring	57.02	Poor

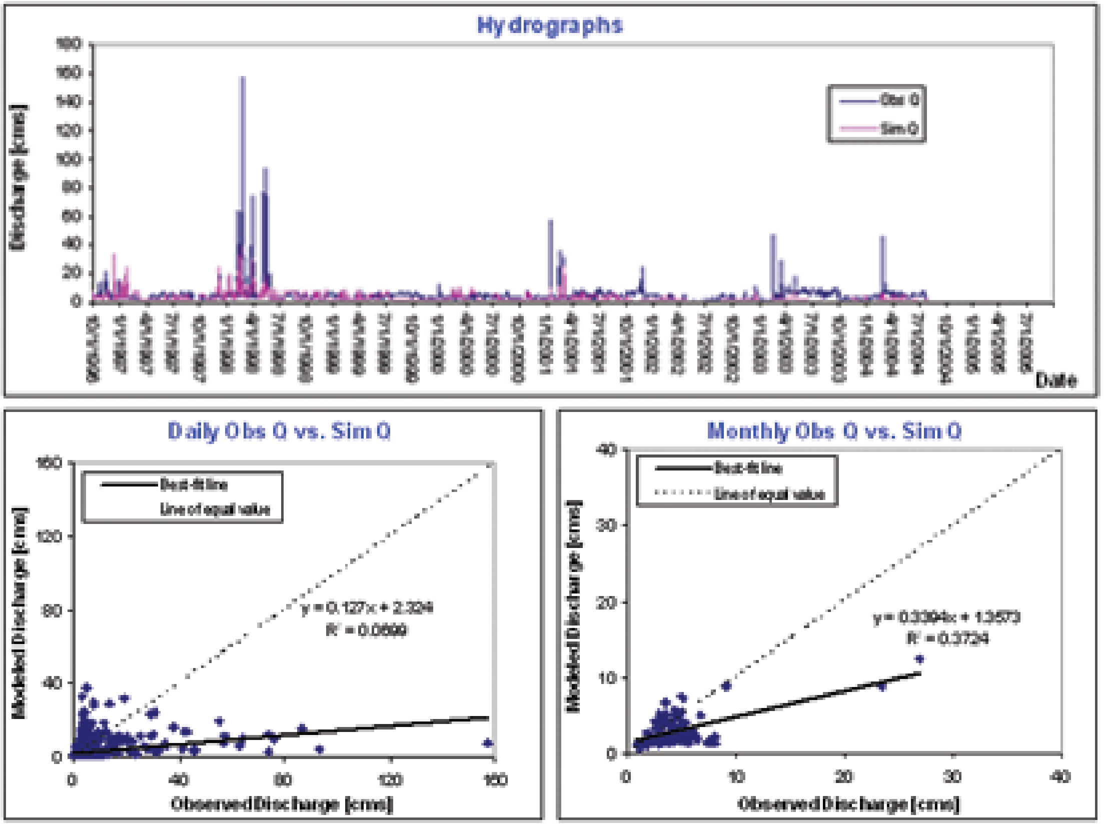
Figure A-10 Validation results for LADPW F45B-R Rio Hondo above Stuart and Gray Road



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	6.28	4.79
Lowest 50% cutoff value	0.04	0.93
Total in-stream flow	5890.97	9310.89
Total of the highest 10% flows	2962.82	6139.89
Total of the lowest 50% flows	26.45	389.50
Summer flow volume (months 7-9)	1314.00	690.41
Fall flow volume (months 10-12)	940.56	1657.71
Winter flow volume (months 1-3)	1759.76	4975.74
Spring flow volume (months 4-6)	1876.65	1987.03
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	-36.73	Poor
Error in 10% highest flows	-51.74	Poor
Error in 50% lowest flows	-93.21	Poor
Volume error - Summer	90.32	Poor
Volume error - Fall	-43.26	Poor
Volume error - Winter	-64.63	Poor
Volume error - Spring	-5.55	Very good

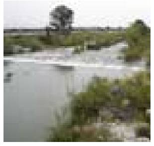
Figure A-11 Validation results for F263C San Gabriel River Below San Gabriel River Parkway



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	6.19	6.94
Lowest 50% cutoff value	1.82	3.54
Total in-stream flow	8234.61	12855.54
Total of the highest 10% flows	2704.23	3870.83
Total of the lowest 50% flows	2141.00	3527.41
Summer flow volume (months 7-9)	1605.70	2950.76
Fall flow volume (months 10-12)	1852.69	2648.23
Winter flow volume (months 1-3)	2649.81	3544.36
Spring flow volume (months 4-6)	2126.41	3712.20
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	-35.95	Poor
Error in 10% highest flows	-30.14	Poor
Error in 50% lowest flows	-39.30	Poor
Volume error - Summer	-45.58	Poor
Volume error - Fall	-30.04	Poor
Volume error - Winter	-25.24	Fair
Volume error - Spring	-42.72	Poor

Figure A-12 Validation results for USGS 11088000/ F42B-R San Gabriel River at Spring Street near Los Alamitos CA

Appendix B
Water Quality Calibration and Validation Graphs and Tables



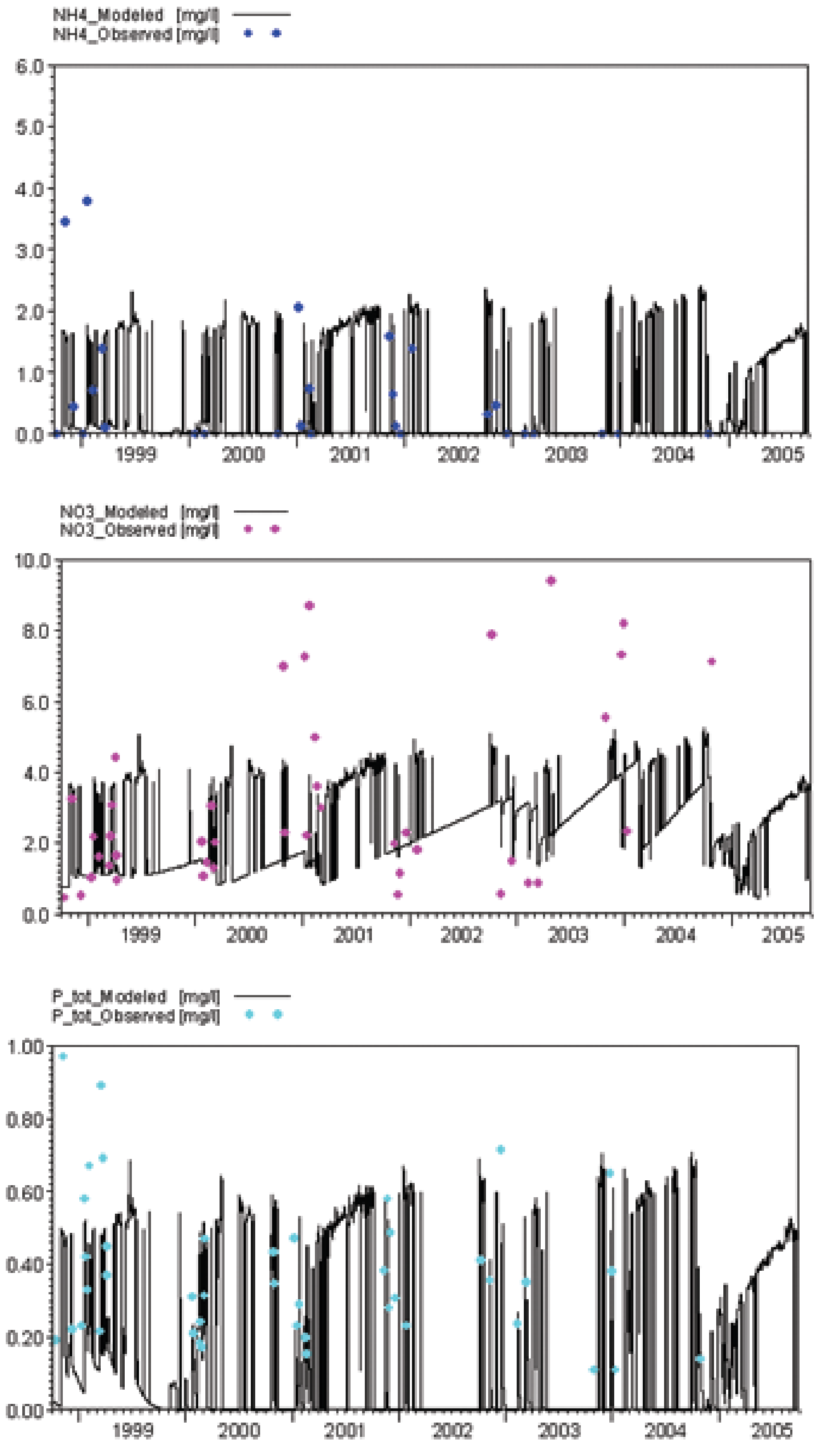


Figure B-1 Time series comparison of modeled and observed NH4, NO3 and P_tot at the S14 San Gabriel River at SGR Pkwy Mass Emission site

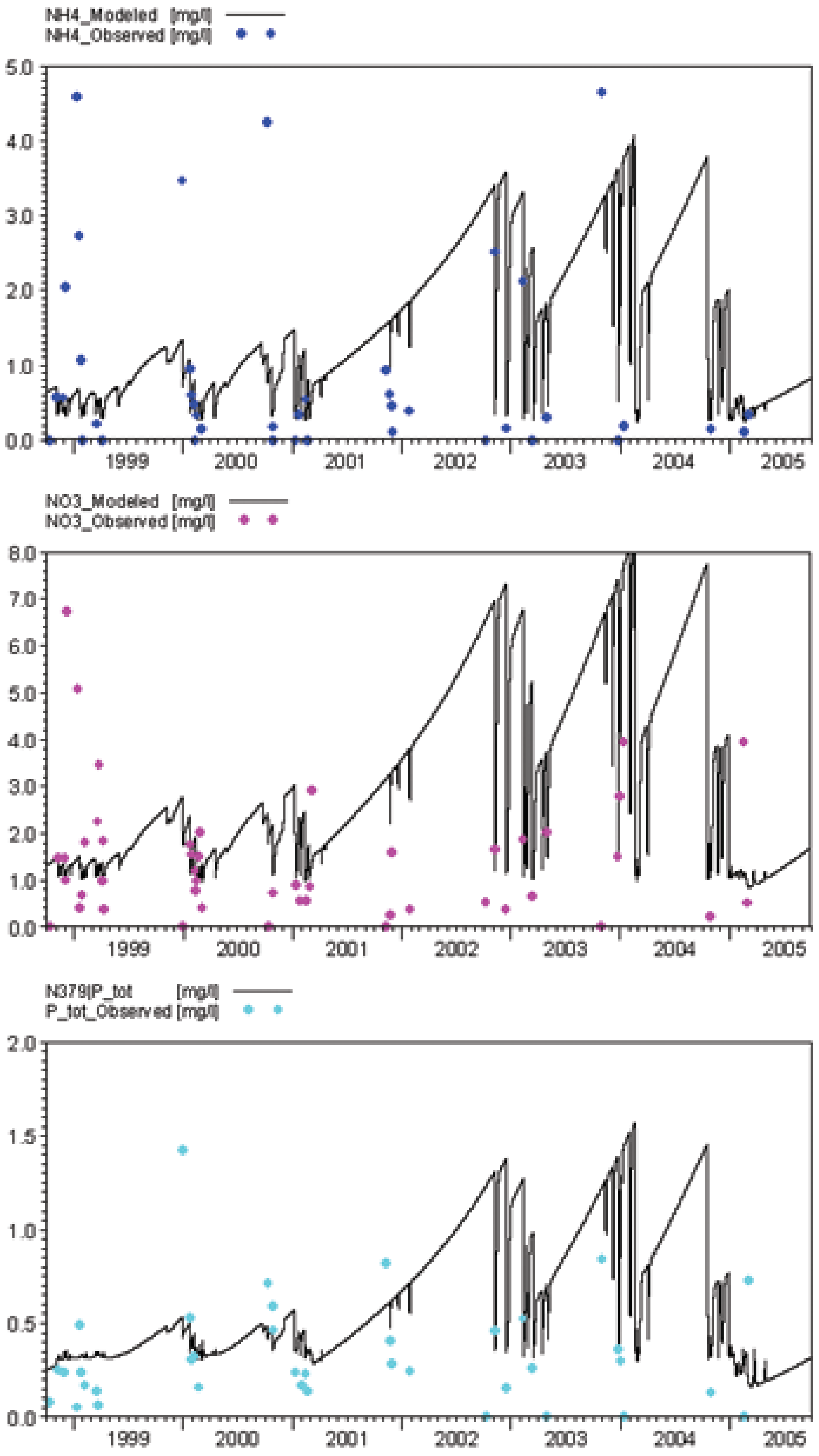


Figure B-2 Time series comparison of modeled and observed NH4, NO3 and P_tot at the S13 Coyote Creek Mass Emission site