NOVEMBER 2009

THE GREEN VISIONS PLAN

for 21st century southern california

22. Hydrology and Water Quality Modeling of the Los Angeles River Watershed

Jingfen Sheng
John Wilson

Acknowledgements: Financial support for this work was provided by the San Gabriel and Lower Los Angeles Rivers and Mountains Conservancy, as part of the "Green Visions Plan for 21st Century Southern California" Project. The authors thank Jennifer Wolch for her comments and edits on this report. The authors would also like to thank Eric Stein, Drew Ackerman, Ken Hoffman, Wing Tam, and Betty Dong for their timely advice and encouragement.

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

Preferred Citation: Sheng, J., and Wilson, J.P., 2009. The Green Visions Plan for 21st Century Southern California. 22. Hydrology and Water Quality Modeling of the Los Angeles River Watershed. University of Southern California GIS Research Laboratory, Los Angeles, California.

This report was printed on recycled paper.

GIS research laboratory
Department of Geography
College of Letters, Arts, and Sciences
University of Southern California
Los Angeles, CA 90089-0255
www.usc.edu/dept/geography/gislab

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.

www.greenvisionsplan.net

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Executive Summary

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

Land use, topography, hydrology, population, rainfall and meteorological data were used to develop the model segmentation and input, and detailed streamflow data were selected to conduct model calibration and validation 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 14 stream locations throughout the watershed, for annual runoff, daily and monthly stream flow, water balance components, and annul water quality. The results, based on the graphic comparison and error analyses described herein, demonstrated a fair to good representation of the observed flow data. As shown in Figures A-5 through A-11, the model simulated the total water volumes fairly well for the 10 validation sites. Very good validation results were achieved for simulating the 90th percentile high flows while the 10th percentile low flows were poorly simulated with over-predictions at all sites.

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 acceptable values that was 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 reproducing extremely high or low concentration values in the pollutographs that were recorded with instantaneous samples (Figures B-1 through 5), which suggests the inadequate sensitivity of the water quality module to the pollutant sources using the current time stamp. The daily time stamp used for the MIKE BASIN model runs might 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 simulation presented in this report is a part of the Green Visions Plan for 21st century Southern California project. The primary focus of this Los Angeles River Watershed water quality modeling is to determine the pollutant concentration and loads entering the stream network and to what degree surface waters are subject to water quality impairments. Accurate simulation of hydrology and water quality in this study area is difficult due to the complexity of the hydrologic processes operating in the semi-arid environment and the severity of human modifications to the natural systems. Increased urbanization has been shown to result in increased runoff and pollutant loading to receiving waters in many studies (USEPA 1995, Schueler and Holland 2000, Davis et al. 2001). 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 storm runoff peaks in the urbanized subwatersheds such as those found in Alhambra, Compton, and Arcadia Wash (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 the Los Angeles River and its tributaries caused by metals, nutrients, trash and bacteria. Models of various kinds (e.g. simple conceptual and spreadsheet models, TMDL mass balance models and EPA's HSPF model) were developed and implemented in the water quality analysis for determining allowable loadings for the various sources and removing these impairments in the watershed (CREST 2007; CRWQCB-LAR 2003, 2004, 2007a). Different from all these studies, this report focused on the simulation of hydrology and nutrient loads and concentrations for the Los Angeles River watershed and demonstration of the spatial and temporal framework variation in nutrient loadings across the entire watershed.

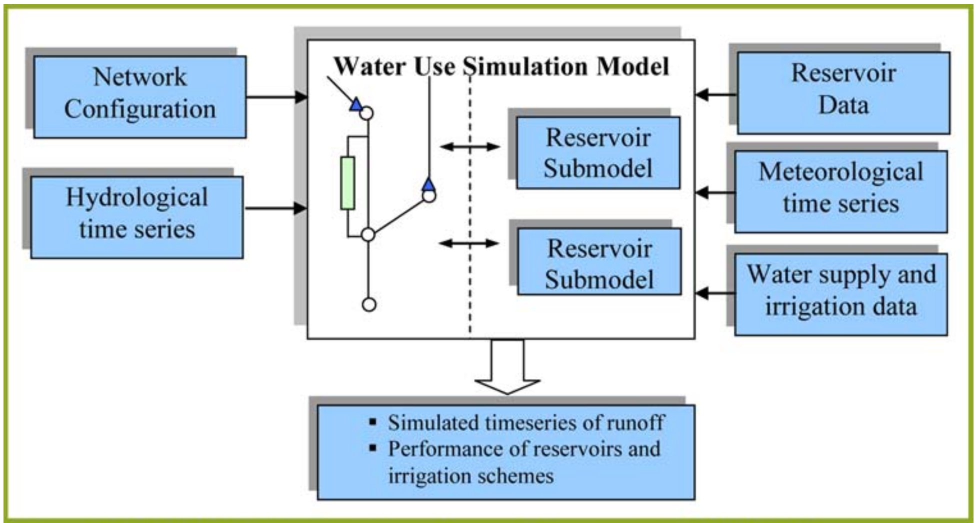


Figure 1 MIKE BASIN's water allocation modeling structure (DHI 2007)

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

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

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

Often, several users may want to receive water from the same resource. Within the MIKE BASIN network model concept, such a situation is represented by several users connected to a single supply node. A very important feature in MIKE BASIN is a set of rules and local algorithms that guide the allocation of surface waters. Rules affect at least the node they are attached to, and possibly a second node, the extraction point of the former. Multiple rules can be associated with a single water user. However, the implementation of rules does not account for delays in flow routing, water quality pulse or dilution and groundwater processes. The overall modeling concept in MIKE BASIN is to find stationary solutions for each time step. Accordingly, time series input and output are presumed to contain flux-averaged values for some period between two time stamps, not pulses at a time stamp (DHI 2007).

This report documents the hydrology and water quality simulation results produced with MIKE BASIN for the Los Angeles 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 hydrological, meteorological, and other data needed for the simulation; Sections 3 and 4 document the watershed segmentation based on multiple criteria, and the calibration / validation procedures used for selected subwatersheds within the Los Angeles River watershed; Section 5 describes the model results; and Section 6 discusses model performance and offers some recommendations regarding the surface water impairments and contributing sources.

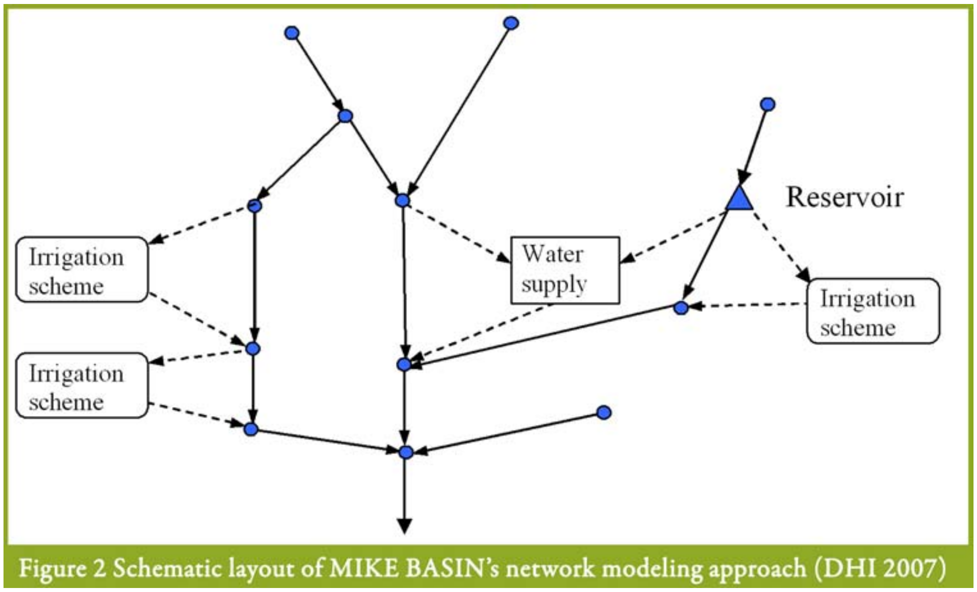


Figure 2 Schematic layout of MIKE BASIN's network modeling approach (DHI 2007)

The Los Angeles River watershed covers a land area of 773.5 mi^2, bordered by the San Gabriel River Watershed to the east, and forms a "double watershed" hydrological system with the San Gabriel River watershed through the Whittier Narrows Dam on the Rio Hondo Channel. Approximately 44% of the watershed area is classified as forest or open space. These areas are primarily within the headwaters of the Los Angeles River in the Santa Monica, Santa Susana and San Gabriel Mountains, including the Angeles National Forest. Major tributaries to the river include Burbank Western Channel, Pacoima Wash, Tujunga Wash, Verdugo Wash, Arroyo Seco, and Rio Hondo Channel at the south of the Glendale Narrows. The natural hydrology of the Los Angeles River watershed has been altered by channelization and the construction of dams, flood control systems and spreading facilities. The Los Angeles River and many of its tributaries are lined with concrete for most or all of their lengths. Soft-bottomed segments of the Los Angeles River occur in several places where groundwater upwelling prevented armoring of the river bottom.

2 Data Needs for Watershed Hydrologic Modeling

Precipitation, potential evaportranspiration, 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. 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 (DHI 2007).

2.1 Precipitation

MIKE BASIN requires appropriate representation of precipitation and potential evapotranspiration (ET). Daily precipitation data are sufficient to represent hydrology and water quality conditions at the regional scale. Within the Los Angeles River watershed, the Los Angeles County Department of Public Works (LADPW) and the National Weather Service (NWS) maintain a network of precipitation stations. Stations with daily records spanning the period from 10/1996 to 9/2005 were selected for the model (Table 1). Their locations relative to the watershed are shown in Figure 3.

Some of the calibration stations have some missing data in the time series. The missing periods were filled using nearby stations with values weighted to the ratio of the annual averages over their common period record. The precipitation data were assigned to the catchments based on a Thiessen polygon approach. 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. If more than one gauge fell in the same catchment, the gauge with better data was selected to represent the precipitation time series for that catchment.

2.2 Potential Evapotranspiration

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

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

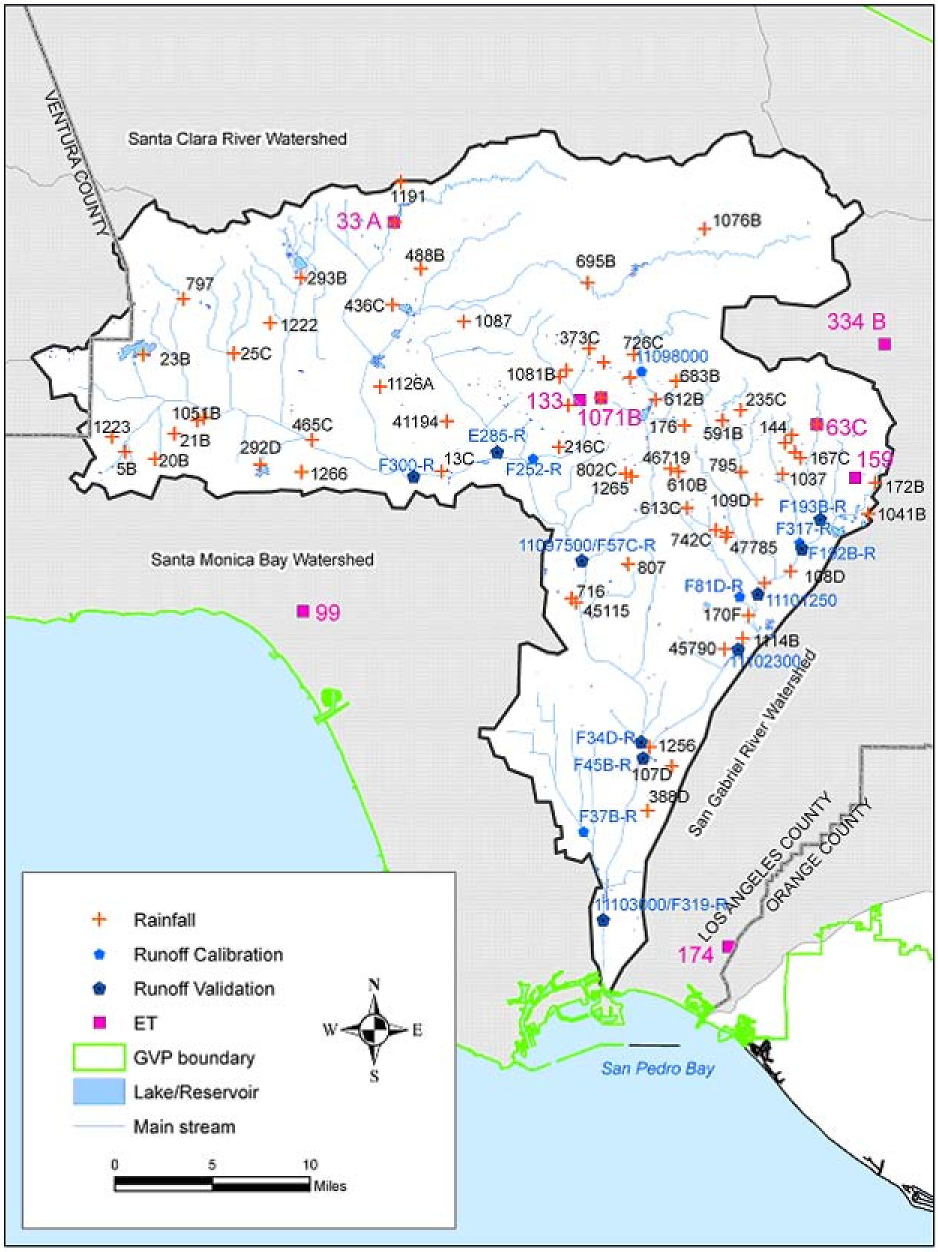


Figure 3 Precipitation, stream flow and evapotranspiration gauge locations in or near the Los Angeles River watershed

Table 1 Precipitation data records selected for the model

Station ID	Station Name	Elevation (ft)	Source	Latitude	Longitude
144	Sierra Madre Dam	1100	LA_OBSER	34.176	-118.042
169	Sierra Madre Pumping Plant	700	LA_OBSER	34.163	-118.039
176	Altadena - Rubio Canyon	1125	LA_OBSER	34.182	-118.138
716	LA Ducommun St Precip	306	LA_ALERT	34.053	-118.237
795	Pasadena – Jourdan	705	LA_OBSER	34.148	-118.087
797	De Soto Reservoir	1127	LA_OBSER	34.271	-118.587
807	Ascot Reservoir	620	LA_OBSER	34.079	-118.187
1037	Arcadia – Arboretum	565	LA_OBSER	34.147	-118.050
1087	Green - Verdugo Pumping Plant	1340	LA_OBSER	34.257	-118.336
1191	Bear Divide	2700	LA_OBSER	34.360	-118.394
1222	Northridge – Garland	911	LA_OBSER	34.254	-118.509
1223	Woodland Hills – Sherman	1035	LA_OBSER	34.168	-118.649
1256	South Gate Transfer Station	100	LA_OBSER	33.944	-118.166
1259	Whittier Narrows Reclamation	225	LA_OBSER	34.066	-118.065
1261	La Canada Reclamation Plant	1800	LA_OBSER	34.217	-118.187
1265	Scholl Canyon Landfill	1000	LA_OBSER	34.144	-118.185
1266	Mission Canyon Landfill	1150	LA_OBSER	34.144	-118.479
41194	BURBANK VALLEY PUMP PLANT	200	NCDC	34.183	-118.350
41484	CANOGA PARK PIERCE COLLEGE	241	NCDC	34.183	-118.567
44628	LA CRESCENTA FC 251	477	NCDC	34.217	-118.250
45115	LOS ANGELES WBO	70	NCDC	34.050	-118.233
45790	MONTEBELLO	73	NCDC	34.017	-118.100
46719	PASADENA	263	NCDC	34.150	-118.150
47785	SAN GABRIEL FIRE DEPT	137	NCDC	34.100	-118.100
1041B	Santa Fe Dam	427	LA_OBSER	34.118	-117.973
1051B	Canoga Park - Pierce College	800	LA_OBSER	34.181	-118.573
1071B	Descanso Gardens	1325	LA_OBSER	34.202	-118.213
1076B	Monte Cristo Ranger Station	3360	LA_OBSER	34.328	-118.122
107D	Downey - Fire Department	110	LA_OBSER	33.930	-118.146
1081B	Glendale – Gregg	1350	LA_OBSER	34.196	-118.242
108D	El Monte Fire Department	275	LA_OBSER	34.075	-118.042
109D	West Arcadia	547	LA_OBSER	34.128	-118.073
1114B	Whittier Narrows Dam	239	LA_OBSER	34.025	-118.084
1126A	Los Angeles-East Valley	780	LA_OBSER	34.208	-118.410
13C	North Hollywood – Lakeside	550	LA_OBSER	34.146	-118.354
167C	Arcadia Pumping Plant No. 1	611	LA_OBSER	34.159	-118.034
170F	Potrero Heights	285	LA_OBSER	34.042	-118.079
172B	Duarte	548	LA_OBSER	34.141	-117.967
175B	La Canada Irrigation District	2020	LA_OBSER	34.228	-118.211
20B	Girard Reservoir	986	LA_OBSER	34.152	-118.610
216C	Glendale-Jackson	550	LA_OBSER	34.165	-118.250
21B	Woodland Hills	875	LA_OBSER	34.171	-118.593
227D	San Gabriel - Bruington – O	472	LA_OBSER	34.105	-118.109
235C	Henniger Flats	2550	LA_OBSER	34.194	-118.088
23B	Chatsworth Reservoir	900	LA_OBSER	34.229	-118.622
251C	La Crescenta	1440	LA_OBSER	34.222	-118.244
25C	Northridge – LAWP	810	LA_OBSER	34.231	-118.541

Table 1 Precipitation data records selected for the model, continued

292D	Encino Reservoir	1075	LA_OBSER	34.149	-118.516
293B	Los Angeles Reservoir	1150	LA_OBSER	34.288	-118.482
294B	Sierra Madre - Mira Monte Precip	985	LA_OBSER	34.170	-118.048
33A	Pacoima Dam Precip	1950	LA_ALERT	34.330	-118.399
373C	Briggs Terrace	2200	LA_OBSER	34.238	-118.224
388D	Paramount - County Fire Department	80	LA_OBSER	33.897	-118.167
436C	Hansen Dam	1110	LA_OBSER	34.269	-118.400
465C	Sepulveda Dam	683	LA_OBSER	34.168	-118.470
488B	Kagel Canyon Patrol Station	1450	LA_OBSER	34.296	-118.375
591B	Santa Anita Reservoir	1205	LA_OBSER	34.186	-118.104
5B	Calabasas	924	LA_OBSER	34.157	-118.637
610B	Pasadena - City Hall	864	LA_OBSER	34.148	-118.143
612B	Pasadena - Chlorine Plant	1160	LA_OBSER	34.201	-118.164
613C	Pasadena Fire Station	779	LA_OBSER	34.121	-118.135
63C	Santa Anita Dam Precip	1400	LA_ALERT	34.184	-118.020
683B	Sunset Ridge	2110	LA_OBSER	34.215	-118.146
695B	Tujunga Canyon - Vogel Flat	1850	LA_OBSER	34.287	-118.226
726C	Angeles Crest Guard Station	2300	LA_OBSER	34.234	-118.184
742C	San Gabriel Fire Department	445	LA_OBSER	34.103	-118.099
802C	Eagle Rock Reservoir Precip	1085	LA_ALERT	34.146	-118.190

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, which distributed each monthly value at the given latitude in that month. Cloud cover was not considered when distributing monthly evaporation to daily values due to 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 Stream Flow Data

To calibrate the model, simulated flow results were iteratively compared with observed streamflows to obtain the best hydrologic parameter sets for the MIKE BASIN model runs. Daily flow records from 10/1996 to 09/30/2006 were obtained for 14 stream gauges on the main stem and its tributaries. Four gauges – the USGS 11098000 Arroyo Seco near Pasadena CA, the LADPW F252 Verdugo Wash at Estelle Avenue, the USGS 11101380/F81D-R Alhambra Wash near Klingerman Street, and the LADPW F37B-R Compton Creek near

Table 2 Evaporation stations located in or near the Los Angeles River watershed

ID	Name	Elevation (ft)	Source	Latitude	Longitude	Annual average (in)
334 B	Cogswell Dam	58.42	LADPW	34.244	-117.960	4.37
33 A	Pacoima Dam	38.10	LADPW	34.330	-118.400	7.27
63 C	Santa Anita Dam	35.56	LADPW	34.184	-118.020	4.02
1071 B	Descanso Gardens	33.66	LADPW	34.202	-118.213	3.92
99	Santa Monica	8.64	LADPW	34.041	-118.476	3.64
133	Glendale	28.22	CIMIS	34.200	-118.232	3.31
159	Monrovia	15.11	CIMIS	34.145	-117.985	5.76
174	Long Beach	0.43	CIMIS	33.797	-118.094	3.80

Greenleaf Drive gauging stations – were selected for the calibration with daily data. The other 10 gauges located along the main stem and major tributaries listed in Table 3 were used as consistency checks and for further validation of the model performance. Several USGS stream gauges have been discontinued or converted to partial-record stations operated jointly with the LADPW. For calibration and validation purposes, the records from those gauges were combined into one continuous time series, if appropriate based on double-mass curve analyses to assess the continuity of the record. The records were combined at the paired gauges where no systematic difference is found between their data measurements. The paired gauges included the USGS 11101380 and F81D-R, USGS 11097500 and F57C-R, USGS 11098500 and F34D-R, and the USGS 1110300 and F319-R gauging stations.

2.4 Point Source Discharges

Pollutants from dense clusters of residential, industrial and other urban activities have impaired water quality in various parts of watershed. A large number of permitted point sources added to this complex mixture of pollutant sources associated with urban and stormwater runoff. A majority of the 144 NPDES discharges go directly to the Los Angeles River. Burbank Western Channel receives three discharges, Compton Creek receives seven, and Rio Hondo receives sixteen such discharges (CRWQCB-LAR 2007b). Of the 1,336 dischargers enrolled under the general industrial storm water permit program in the watershed, the largest numbers occur in the cities of Los Angeles (with many of these located within the community of Sun Valley), Vernon, South Gate, Long Beach, Compton, and Commerce. There are a total of 456 construction sites enrolled under the construction storm water permit program with the larger sites located in the upper watershed, including parts of the San Fernando Valley (CRWQCB-LAR 2007b).

During model configuration, three major National Pollutant Discharge Elimination System (NPDES) dischargers were incorporated into the MIKE BASIN model as point sources of flow and nutrients due to their large associated loadings (Table 4). During dry weather, most of the flow in the Los Angeles River is comprised of wastewater effluent from these treatment plants. Each point source was included in the model as a time variable source of flow from 10/1996 to 09/2005.

Table 3 Stream flow stations in the Los Angeles River watershed

Station ID	Station Name	Drainage Area (mi^2)	Elevation (ft)	Latitude	Longitude
USGS11098000	Arroyo Seco near Pasadena	16.0	1398	34.222	-118.178
LADPW F252-R	Verdugo Wash at Estelle Avenue	26.8		34.156	-118.273
11101380/F81D-R	Alhambra Wash near Klingerman Street	15.2		34.056	-118.086
LADPW F37B-R	Compton Creek near Greenleaf Drive	22.6		33.881	-118.224
LADPW E285-R	Burbank-Western Storm Drain	25.0		34.161	-118.305
LADPW F193B-R	Santa Anita Wash at Longden Avenue	18.8		34.114	-118.016
LADPW F192B-R	Rio Hondo below Lower Azusa Avenue	40.9		34.092	-118.032
USGS11101250	Rio Hondo above Whittier Narrows Dam	91.2		34.058	-118.072
USGS11102300	Rio Hondo below Whittier Narrows Dam	124.0		34.017	-118.088
LADPW F45B-R	Rio Hondo above Stuart and Gray Road	140.0		33.936	-118.175
LADPW F300-R	Los Angeles River at Tujunga Avenue	401.0		34.142	-118.379
USGS11097500/F57C-R	Los Angeles River above Arroyo Seco	475.9	293	34.081	-118.227
USGS11098500/F34D-R	Los Angeles River below Firestone Blvd	596.0		33.948	-118.173
USGS11103000/F319-R	Los Angeles River below Wardlow	815.0	12	33.817	-118.205

Photo 1 Glendale Los Angeles River Water Reclamation Plant Effluent Outfall (CRWQCB- LAR 2007a)

Photo 2 Storm drain enters Los Angeles at Lankershim Boulevard (Circa 1991) (CRWQCB- LAR 2007a)

Complete daily discharge data were not available for the simulation period. To overcome the gap in the time series, average design flow rates were used for each site for the missing time period. The D.C. Tillman Wastewater Reclamation Plant (WRP) operated by the City of Los Angeles, discharges directly to the Los Angeles River just below the Sepulveda Dam and also via two lakes in the Sepulveda Basin. It discharges approximately 53 million gallons per day (mgd) to the Los Angeles River. The Los Angeles-Glendale WRP, operated by the City of Los Angeles, discharges approximately 14.2 mgd directly into the Los Angeles River in the Glendale Narrows (Photo 1). The Los Angeles-Glendale Burbank discharges approximately 5.4 mgd directly into the Burbank Western Channel (LARWQCB 1998).

The other uncounted major sources of flows to river system are scattered urban runoff at stormwater outlets (Photo 2), which are a particularly significant portion of flow during the dry-weather season. Urban practices such as lawn irrigation and car wash contribute to urban runoff. Urban runoff originating from curbside catch basins enters into underground tunnels and runs into flood control channels in the Los Angeles River watershed. The storm drain system receives no treatment or filtering and is completely separate from the sanitary sewer system (CRWQCB-LAR 2007a). There are approximately 100,000 catch basins that collect stormwater and urban runoff from streets in Los Angeles County and the total length of the storm drain system exceeds 1,500 miles based on information from large municipalities. Approximately 100 million gallons of water flows through the Los Angeles storm drain system on an average dry day. When it rains, the runoff flowing through the storm systems can increase to 10 billion gallons (CRWQCB-LAR 2007a). Unfortunately the length of the system, the locations of all storm drain and the water volumes from inlets are not known exactly and therefore were not considered in this modeling effort.

2.5 Water Regulation Data

Dam regulation data were obtained from the LADPW for the Pacoima, Big Tujunga, Devils Gate, Eaton Wash, and Santa Anita Wash dams. Spillway crest, minimum pool, 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

Table 4 NPDES permitted major discharges and average constituent concentrations used in the Los Angeles River model

WRP	flow (mgd)	Ammonia-N (mg/l)	Nitrate-N (mg/l)	Phosphate (mg/l)
D.C.Tillman	53	12	0.5	1.7
Burbank	5.4	12	0.5	1.7
Glendale	14.2	12	0.5	1.7

the storm and other waters. These water spreading facilities are located in areas where the underlying soils are permeable and hydraulically connected with the underlying aquifers. The conserved water stored in 18 spreading facilities adjacent to river channels and in soft-bottom channels percolate into underlying groundwater basins for later pumping. There was no monitoring data found for inflows and outflows to the facilities. To estimate the amount of water that is diverted off the channel and spread out in the facilities, the total monthly volumes of water that are conserved, imported and reclaimed (as reported by the LADPW) were used. For each individual facility, the amount of spread water diverted from the storm water equals the difference in storage between the total spread water and the imported and reclaimed water.

For the Rio Hondo Coastal Basin and Peck Road Spread Grounds, storm water was sometimes diverted from the San Gabriel River and delivered to these two spreading grounds via the Santa Fe Dam and Whittier Narrows diversion channels, respectively. During dry weather, virtually all of the water in the Rio Hondo goes to groundwater recharge, so little or no flow reaches the spreading grounds. During storm events, the flow in the Rio Hondo Channel is not used for spreading, reaches the Los Angeles River (CRWQB-LAR 2007a). Flow records for the tributaries above the spreading grounds were used instead to estimate the diversion rates at the site. Specifically, the diversion amount is roughly assumed to be the change in the discharge between total upstream inflows and downstream outflows.

2.6 Water Quality Data

The Load Calculator Module in MIKE BASIN was used to determine pollution loads in catchments. It calculated average mass fluxes of pollutants for individual subcatchments (in kg/catchment/year) and uses these results to estimate pollution loadings in the entire watershed. The Load Calculator considers all of the point and non-point source contributions. The D.C. Tillman, Burbank and Glendale wastewater reclamation plants that discharge directly to the surface waters were incorporated into the model as time variable point sources of pollutants – see Table 4 for the average nutrient concentrations in effluents from these three wastewater reclamation plants (Ackerman et al. 2003). The variability of the non-point source contributions is represented through dynamic representation of hydrology and land practices. Selected water quality constituent loading fluxes (e.g. nitrogen, phosphorus) associated with different land uses were obtained from research conducted by SCCWRP and LADPW. Land use data were obtained from SCAG (2001). The event mean fluxes by land use class were estimated by averaging a large number of water quality samples taken on these land use classes (see Table 5 for additional details).

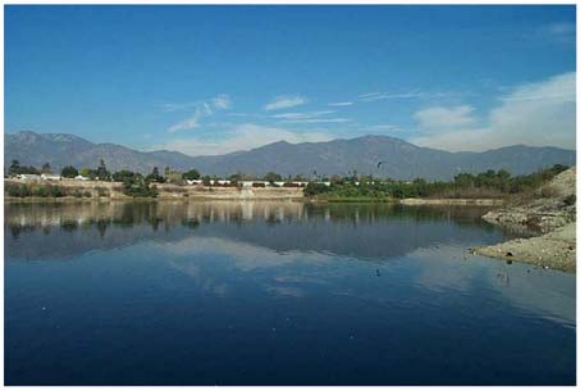


Photo 3: Recharge basin at Peck Road Water Conservation Park (RMC 2004)

Photo 4: Recharge basin at Rio Hondo Spreading Ground

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

Flux (kg/km^2/yr)	Ammonia-N	Nitrate-N	Phosphate
Agriculture	49.9	271.0	20.9
Commercial	94.1	275.1	103.0
Industrial	74.5	287.1	83.1
Open Space	1.8	50.8	14.1
Residential	56.5	219.2	76.1

The constituent flux from a given land use will vary from site to site and storm to storm. This variability is magnified when the area of interest is expanded from single land use areas to watersheds because of the complexity of runoff behavior. Our goal is to investigate long-term average loading to the receiving waters; therefore, we assumed that the mean fluxes and other static parameters were adequate to represent the spatial variations in constituent loadings across the watershed. Some knowledge and understanding of the inter-storm and intra-site variability would be crucial to estimate pollutant 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 (on-site wastewater treatment systems) are used in areas where direct connection to sewer lines is not possible and have been used as a form of wastewater disposal for many decades. There are several thousand septic systems used for the disposal of wastewater throughout the Los Angeles River watershed; they are generally located in the San Fernando Valley, the foothills of the San Gabriel Mountains, the Hollywood Hills, Calabasas, and the Santa Monica Mountains (CRWQCB-LAR 2007a). Nitrogen is quite mobile in groundwater, while phosphorus has a tendency to be absorbed by the soils. However, the contributions from the sewer system to groundwater are not very well understood and even less is known about the contributions from the groundwater discharge to surface waters.

The impact of sewer system on surface water quality is configured as a function of the population and treatment efficiencies of the system in the MIKE BASIN Load Calculator. The treatment efficiencies can be specified as values between 0 and 1, with 0 representing no retention and 1 representing complete retention. Treatment efficiency values for various zones were therefore obtained for the three nutrients of interest during the calibration processes (Table 6). The zone boundaries were designated in accordance with the upstream subwatersheds for each of the water quality calibration sites.

The population in each subwatershed was estimated using the 2001 LandScanTM Global Population Database (Bhaduri et al. 2002; see http://www.ornl.gov/landscan/ for additional details). The grid-based LandScan population density was generated by 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 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. The locations of these monitoring sites are shown in Figure 4. Samples at land use sites were taken in specific years and no

Table 6 Calibrated treatment efficiency values for different zones

Zone	NH4	NO3	TP
Verdugo above LADPW F252-R	0.99	0.98	0.98
RioHondo above LADPW F45B-R	0.99	0.96	0.99
Arroyo Seco above Griffith Avenue	0.99	0.99	0.99
Aliso Creek above Saticoy Street	0.999	0.995	0.99
Others	1	0.985	1

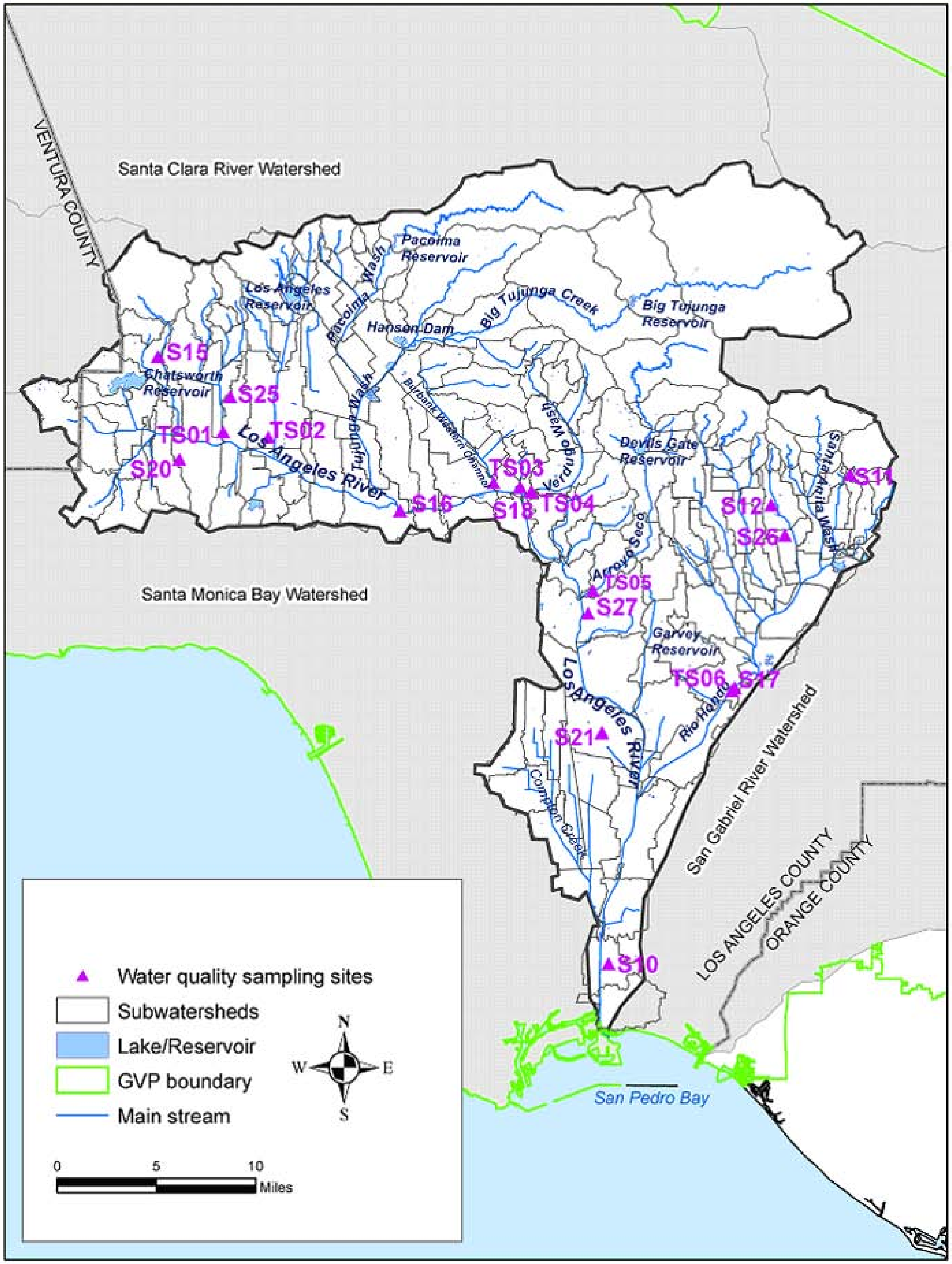


Figure 4 Watershed and stream segmentation

Table 7 Water quality monitoring sites within the Los Angeles River watershed

Station ID	Station Name	Site Type	Data
S10	**LA River at Wardlow Rd**	**Mass Emission**	**1988-2007**
S11	Sawpit Creek	Open Space	1998-2001
S12	Project 1402	Low Density Residential	N/A
S15	Browns Creek	Open Space	N/A
S16	LA River at Tujunga	Mass Emission	N/A
S17	Rio Hondo Channel	Mass Emission	N/A
S18	Project 620	High Density Single Family Residential	1998-2001
S20	Project 3857	High Density Residential	N/A
S21	Project 1	Industrial	N/A
S25	Project 474 at Nordoff	Educational	1998-2001
S26	Project 404	Multiple Family Residential	1998-2001
S27	Project 156	Mixed Residential	1998-2001
TS01	**Aliso Creek at Saticoy St**	**Tributary**	**2002-2004**
TS02	Bull Creek at Saticoy Blvd	Tributary	2002-2004
TS03	Burbank Western System	Tributary	2002-2004
TS04	**Verdugo Wash**	**Tributary**	**2002-2004**
TS05	**Arroyo Seco at Griffin Av**	**Tributary**	**2002-2004**
TS06	**Rio Hondo Ch at Beverly**	**Tributary**	**2002-2004**

repeat sample data are available at these sites. The S10 Los Angeles River at Wardlow Road mass emission site and the TS01, TS04, TS05 and TS06 sites listed in Table 7 that monitor receiving waters were selected for model calibration/validation.

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'. 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. The 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.

The segmentation process was primarily based on the stream networks, topography, locations of flow and water quality monitoring sites, land use consistency, and the existing catchment boundary layers. 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 2007). Catchment boundaries were delineated for each individual river segment using the improved 1:24K NHD dataset and the Nature Conservancy Tool (McHugh 2001, Sheng 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 Los Angeles River watershed was aggregated from 1,783 catchment units into 171 subwatersheds in the MIKE BASIN model (Figure 4).

4. Model Calibration and Validation

4.1 MIKE BASIN Rainfall-runoff NAM Model Configuration

In MIKE BASIN, the NAM Rainfall-Runoff model is used to link rainfall and runoff. The NAM model is a deterministic, lumped, conceptual rainfall-runoff model accounting for the water content in up to four different storages representing the surface zone, root zone and ground water storage (Figure 5). The NAM model was prepared with nine parameters representing the four default storages and seven of these nine 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 conditions regarding initial values of overland flow, interflow, baseflow, groundwater and snow storage were also specified for each of the MIKE BASIN subwatersheds in which the rainfall-runoff relationship was modeled.

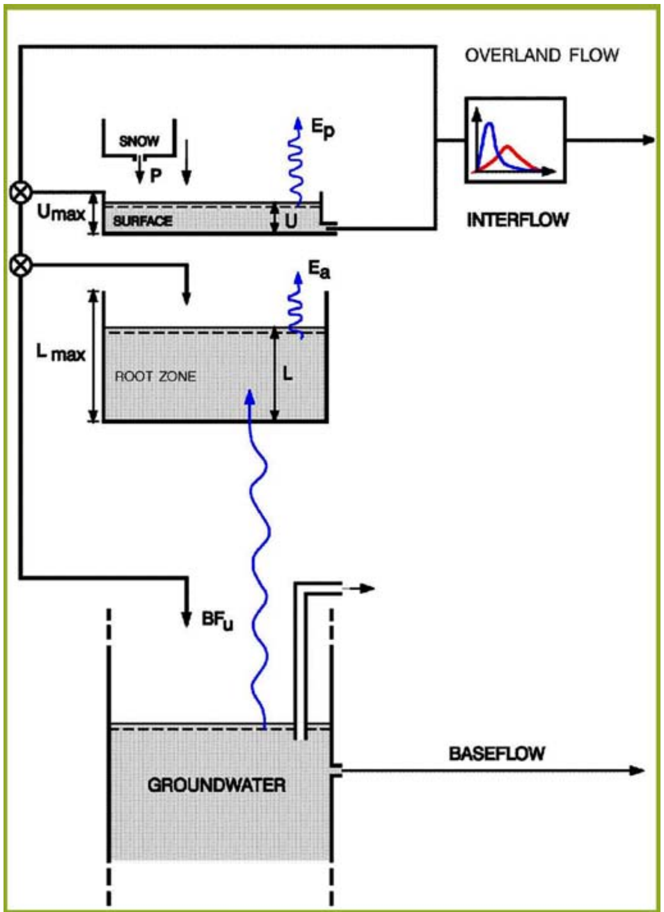


Figure 5 NAM model schematic

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

The Pacoima, Big Tujunga, Devils Gate, Eaton Wash, and Santa Anita reservoir-dam systems were also incorporated in MIKE BASIN. The performance of specified operating policies was simulated using operating rule curves generated from the operation data provided by the LADPW. These define the desired storage volumes, water levels and releases at any time as a function of existing water level, time of year, demand for water and anticipated inflows.

4.2 Hydrology Calibration and Validation

After the model was configured, model calibration and validation were carried out. This is generally a two-phase process, with hydrology calibration and validation completed before conducting the same process for water quality simulation. Calibration is the adjustment or fine-tuning of rainfall-runoff modeling parameters to

Table 8 Main NAM parameters

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

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 as the hydrology/water quality simulation period. The calibration was performed on the four selected subwatersheds and calibrated datasets containing parameter values for rainfall runoff simulation were extrapolated for all ungauged catchments exhibiting similar physical, meteorological, and land use characteristics. Subsequently, more validation runs were performed to test the calibrated parameters at ten more locations for the same time period, without further adjustment.

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

The calibration scheme used by the MIKE 11 autocalibration module includes 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 (R2) values that may be appropriate for

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

judging how well the model is performing based on the daily and monthly simulations. To supplement the model accuracy assessment, relative errors of model-simulated water volumes with various hydrologic and time-variable considerations were determined to assess the model performance for each calibration and validation analysis.

4.2.1 Hydrology Calibration Results

Figure A-1 shows the calibration results for the USGS 11098000 Arroyo Seco near Pasadena CA gauging station. The table in Figure A-1 summarizes the calibrated parameters. A time series plot of modeled and observed daily flows for the time period from 10/1996 to 09/2005 is reproduced in Figure A-1 and shows that the model is not sensitive to the small storm events generated by small precipitation measurements. The large storms were picked up by the model but the small storm peaks were not generated on the plot. These outcomes were repeated in most of the calibration plots. A mass curve showing the cumulative stream runoff plotted against time for both observation and simulation data is reproduced in Figure A-1 as well. Regression analyses were performed using both daily and monthly values and the graphs at the bottom of Figure A-1 show that the model performed better in reproducing average monthly values than daily values given that the coefficient of determination (R2) associated with monthly values (R2=0.93) was much higher than the corresponding value for (R2= 0.77) daily values.

Table A-1 presents the error analysis performed on the predicted seasonal flow volumes. The volume comparisons indicate that the model performed satisfactorily when predicting high flows and total, fall, winter and spring flow volumes, but fairly poorly during the low flow periods (e.g. summers). Both the time-variable plots and volume comparisons indicate that the model reproduced the observation data for this minimally controlled headwater station. Similarly good results were simulated for LADPW F252 Verdugo Wash at Estelle Avenue (Figure A-2 and Table A-2) given that the observed flow patterns for all seasons were closely reproduced.

Some additional calibrations were performed for two heavily urbanized subwatersheds that are gauged at Alhambra Wash and Compton Creek. Overall, the calibration analysis yielded lower coefficient of determination values (see Figures A-3 and A-4 for additional details) compared to the results produced in the natural headwater subwatersheds. Relative errors were larger for all simulated flow conditions and fell out range of the good performance (see Tables A-3 and A-4 for additional details). The natural flow regimes in these two calibration subwatersheds were substantially modified given the noticeable increases in peak discharge, reductions in flood duration, increases in dry-weather base flows and sharply peaked hydrographs in which flows increase quite rapidly after the beginning of rain events and decline rapidly after rainfall ceases. These rainfall-runoff relationships – which frequently characterize urban watersheds – were not well represented in the model. The calibration procedures identified the parameters that ensure the “best fit” between observation and simulation data. It might not reflect the rainfall-runoff processes occurring on the impermeable surfaces that dominate

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 11 Model validation results summary

Validation sites	Overall assessment	Simulated High flows	Simulated low flows	Monthly R^2
E285 Burbank-Western Storm Drain	Very good	Very good	Poor	0.93
F193B-R Santa Anita Wash at Longden Avenue	Very good	Very good	Poor	0.64
F192B-R Rio Hondo below Lower Azusa Avenue	Very good	Very good	Very poor	0.08
11101250 Rio Hondo above Whittier Narrows Dam	Very good	Fair	Poor	0.70
11102300 Rio Hondo below Whittier Narrows Dam	Very good	Very good	Poor	0.97
F45B-R Rio Hondo above Stuart and Gray Road	Fair	Very good	Poor	0.97
F300-R Los Angeles River at Tujunga Avenue	Fair	Poor	Poor	0.95
F57C-R Los Angeles River above Arroyo Seco	Very good	Poor	Fair	0.93
F34D-R Los Angeles River below Firestone Boulevard	Very good	Fair	Fair	0.98
F319-R Los Angeles River below Wardlow Road	Very good	Good	Poor	0.97

many urban areas. Among two urban calibrations, the total water volumes and 90th percentile high flows were consistently under-estimated by more than 20%. No consistency was achieved for other seasonal flow conditions – the model was over- or under- tuned to fit the observation data at various times and showed little consistency in representing flow patterns but for the aforementioned high flows.

4.2.2 Hydrology Validation Results

After calibrating hydrology, the model was implemented using calibrated rainfall-runoff parameters at ten more other locations along the main stem and tributaries for the period 10/1/1996 to 9/30/2005. Calibrated parameters obtained from the ArroyoSeco and Verdugo subwatersheds were accordingly applied to forested or minimally developed catchments and the Alhambra Wash and Compton Creek parameter sets were applied to the remainder of the catchments. Validation results were assessed through time-variable plots and regression analyses as shown in Figures A-5 through A-14. Table 10 summarizes the overall results from the validation processes.

For the ten validated stations, the total stream water volumes fell well within the recommended criteria. Very good validation results were achieved at eight of the ten sites. The 90th percentile high flows were pretty closely or slightly under-predicted while the 10th percentile low flows were generally over-estimated. Low flows were actually closely simulated at the sites on the main stem of the Los Angeles River. The overall validation results suggest satisfactory model performance and that the model adequately represents the overall water balance of the system with the exception of the low flows (i.e. baseflow conditions).

Validation results for Rio Hondo Channel below Lower Azusa Avenue were impacted to a large extent by dam regulations (e.g. the Monrovia, Sawpit, and Little Santa Anita Creek, and the Santa Fe Dam reservoir complexes). The flow diverted from Santa Fe Dam was routed via Sawpit Wash to the Peck Road Spreading Basin and Rio Hondo Spreading Ground. However, this portion of the flow into the Rio Hondo system was not configured as a time variable flow condition in the model since it only interferes with a very short portion of the surface flow and ends in the spreading grounds without substantially changing the downstream water balance. The simplification of the temporal variations in the inflows and outflows to the Rio Hondo Channel system may have adversely affected model performance at daily and even monthly scales.

4.3 Water Quality Calibration and Validation

MIKE BASIN can simulate water quality in surface and ground water, 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 can not 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 specific reaches, such that the residence time and the effects of mixing between reach storage and inflows can be properly specified in the model.

After the model was calibrated and validated for hydrology, water quality simulations were performed from 10/1996 through 9/2005. The water quality load calculator was calibrated by comparing model output with pollutographs for NH3-N, NO3-N, and TP observed at five water quality monitoring sites. After comparing the results, key parameters in configuring the load calculator such as pollutant treatment coefficients and runoff coefficients were adjusted accordingly. This iterative process was repeated until the "best fit" was estimated between the simulated pollutographs and observations.

To assess the predictive capability of the model, the final output was graphically compared to observed data. Figures B-1 through B-5 present time-series plots of model predictions and observed data at the S10, TS01, TS04, TS05, and TS06 monitoring sites. The S10 site monitors the water quality of the Los Angeles River before it enters the ocean and the other four sites are located along the main tributaries where they merge with the main channel. 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, we found that the total discharge to several nodes of the stream network was close to zero for a couple of simulations, which led to the extremely high concentrations of the three constituents. Therefore, the results from this time period (10/1996-12/1996) were ignored in the output pollutographs and all subsequent analyses.

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

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

Selected sites		NH4 [mg/l]	NO3 [mg/l]	P_tot [mg/l]
TS01 Aliso Creek at Saticoy Street	Modeled	0.21	1.01	0.54
	Observed	1.20	0.78	0.63
	Error (%)	-82.5	**28.5**	**-13.3**
TS04 Verdugo Wash	Modeled	0.36	1.04	0.42
	Observed	0.16	0.83	0.38
	Error (%)	125.0	**25.1**	**11.1**
TS05 Arroyo Seco at Griffin Avenue	Modeled	0.84	1.33	0.54
	Observed	0.47	0.64	0.46
	Error (%)	78.7	106.9	**16.6**
TS06 Rio Hondo Channel at Beverly	Modeled	0.29	1.27	0.19
	Observed	0.47	1.96	0.45
	Error (%)	**-38.3**	**-35.5**	-58.2
S10 Los Angeles River at Wardlow Road	Modeled	1.23	1.01	0.59
	Observed	0.68	1.10	0.51
	Error (%)	80.9	**-8.7**	**16.7**

concentrations were captured while others were missed in the pollutographs and it did not always predict the temporal variability of the pollutograph. At the selected monitoring sites, the water quality model had difficulties in producing extremely high and low concentrations in the pollutographs (see Figures B-1 through B-5 for additional details), which likely suggests 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 pulses or dilution that likely occurs over very short time periods.

At the TS01 site, a very high NH4 concentration value of 12.1 mg/l was reported on 2/25/2003, which was about 60 times the average concentration reported at this site. This sample was not included in the error analysis and certainly it was not predicted by the model either. Similarly, a very high TP concentration of 8.24 mg/l, which was 20 times the average concentration, was reported on 10/28/2004 at the S10 site. Such sample data were not included in the relevant analyses.

The mean values of the modeled and observed time series minus the aforementioned outliers are summarized in Table 11. The simulation results for NO3 and TP were slightly better than those for NH4 in terms of error percentages and could be considered to represent "fair" performance based on the preset water quality criteria.

5 Results

The variations of flow and water quality in the Los Angeles 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 flows at the outlet (i.e. the Los Angeles River below Wardlow Road gauging station).

Average monthly in-stream flow in Los Angeles River at the outlet was about 30,000 AF during the simulation period. The monthly flows are highly variable with discharge varying by several orders of magnitude. The flow discharge in January 2005 reached approximately 350,000 AF compared to only 8,000 AF in July 2002. The flows are significantly lower and less variable during the dry seasons. The predominant contribution to dry-weather intream flow comes from the point source discharges plus urban runoff and groundwater baseflow. The percentage of the annual discharge varies from 2 to 45% from month to month, and the winter flows contribute the majority of the annual flow to the ocean.

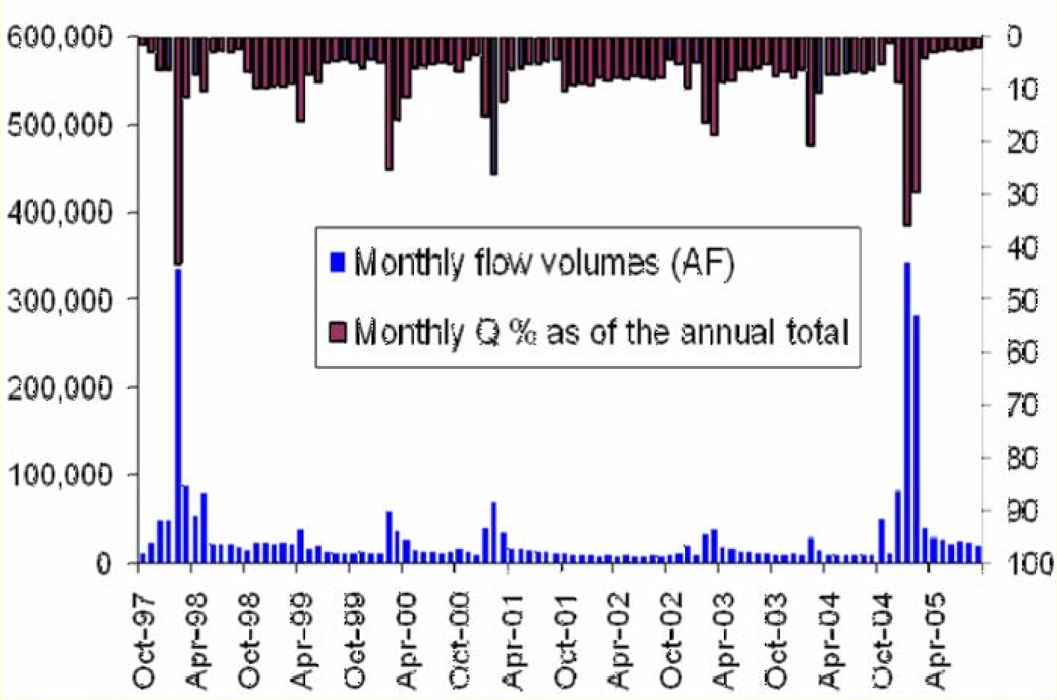


Figure 6 Flow volumes in acre feet (AF) and as a percentage of annual flows for the Los Angeles River below Wardlow Road

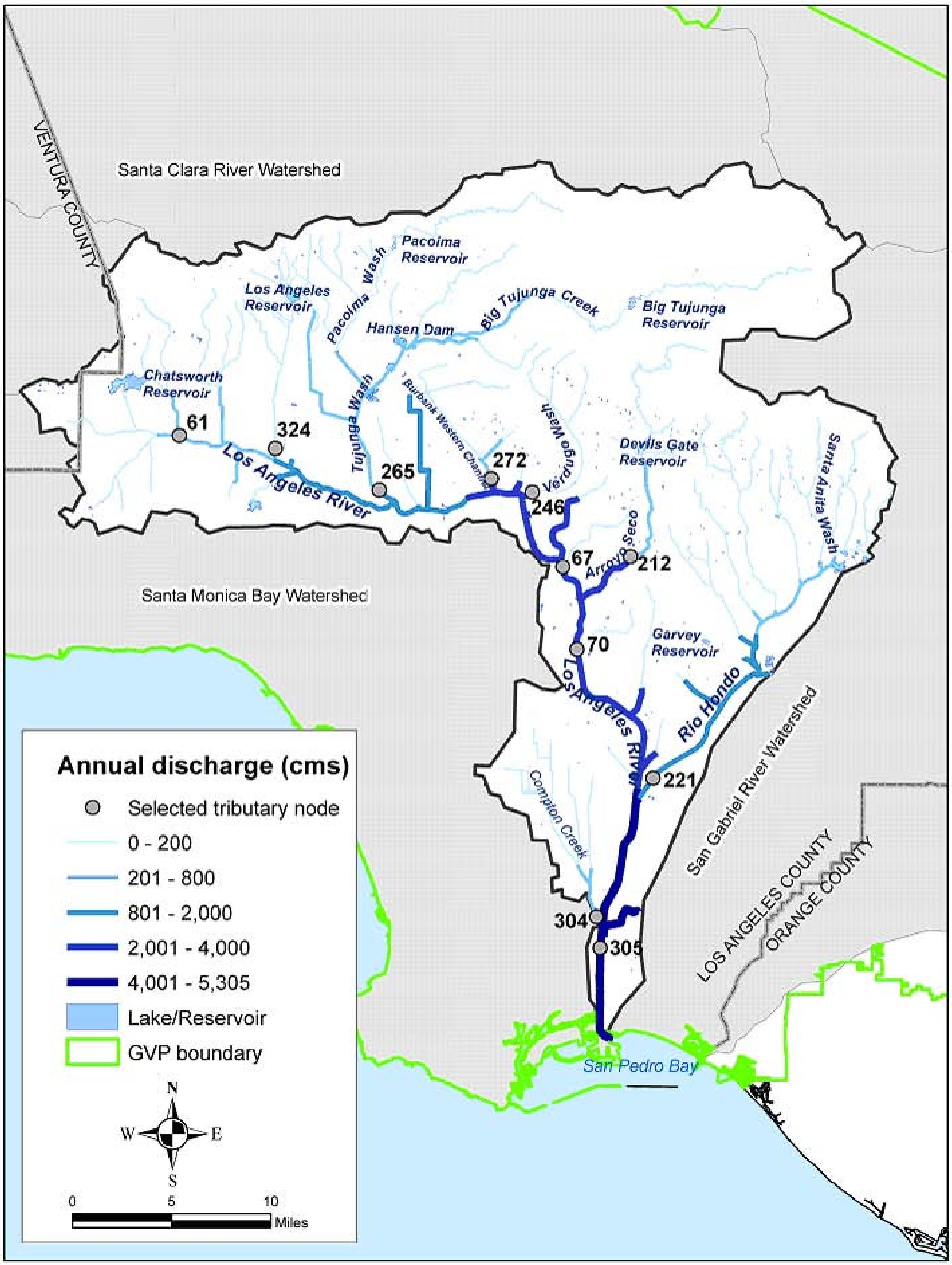


Figure 7 Cumulative flow discharges along the stream network

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

Reach name	Node ID	Annual Q [AF]	Q to the ocean (%)	Area (%)
Arroyo Seco	N212	17,624	4.8	5.1
Rio Hondo Channel	N221	77,747	21.3	16.5
Verdugo Wash	N246	11,248	3.1	3.1
Tujunga Wash	N265	18,718	5.1	28.0
Burbank Wester	N272	15,742	4.3	2.8
Compton Creek	N304	21,254	5.8	5.1
Los Angeles River below Wardlow Road (outlet node)	N305	365,547	100.0	100.0
Bull Creek	N324	9,206	2.5	3.6
Upper Los Angeles River	N61	15,266	4.2	8.3
Los Angeles River at Feliz Boulevard	N67	197,212	53.9	62.5
Los Angeles River below Arroyo Seco	N70	228,458	62.5	70.4

Flow generally increases moving downstream. Tributary inflow volumes vary in space as well (Figure 7). The average inflows from several major tributaries to the watershed total flow are summarized in Table 13. The Rio Hondo Channel contributes 21.3% of the total inflow to the ocean on average, but the contributions from this source are much lower (sometimes zero) during the dry season because most of the water in the channel is used for groundwater recharge. The Tujunga Wash subwatershed makes up about 28% of the watershed area but it contributes only 5.1 % of the total flow to the ocean largely due to the upstream dam flow regulations. The flow contribution of the remainder of the subwatersheds to the total flow is more or less in proportion to their watershed areas.

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 Los Angeles River below Wardlow Road at the bottom of the watershed. Figure 8 depicts a time-series plot of modeled monthly loads and the percentages of the corresponding annual loads.

Average monthly in-stream loads in the Los Angeles River at the outlet were about 36,000, 32,000, and 18,000 kg for NH4, NO3 and TP, respectively, during the simulation period. Temporal variations in nutrient loads are relatively similar between three nutrients and less month-to-month variability is observed with the nutrients than the flow patterns. The largest variation occurs in the storm seasons (e.g. December through February) while significantly lower and less variable monthly loads are experienced during the non-storm season. The total loads contributed with winter storms are much larger than those from the three other seasons: the 110,000 kg of NH4 predicted in February 1998, for example, is nearly four times greater than the 30,000 kg predicted in July 2002. The February 1998 and July 2002 loads contributed 20 and 8% of the annual load, respectively.

The nutrient loads vary along the stream network. The average annual loads from several selected major tributaries to the watershed total loads are summarized in Table 14. Figure 9 summarizes the spatial distribution of nutrient loads along the stream network. The tributary loads are a function of the land uses in the subwatersheds. Large portions of the NH4 and TP loads occurs above the Los Angeles River at Feliz Boulevard (N67) and below the upper Los Angeles

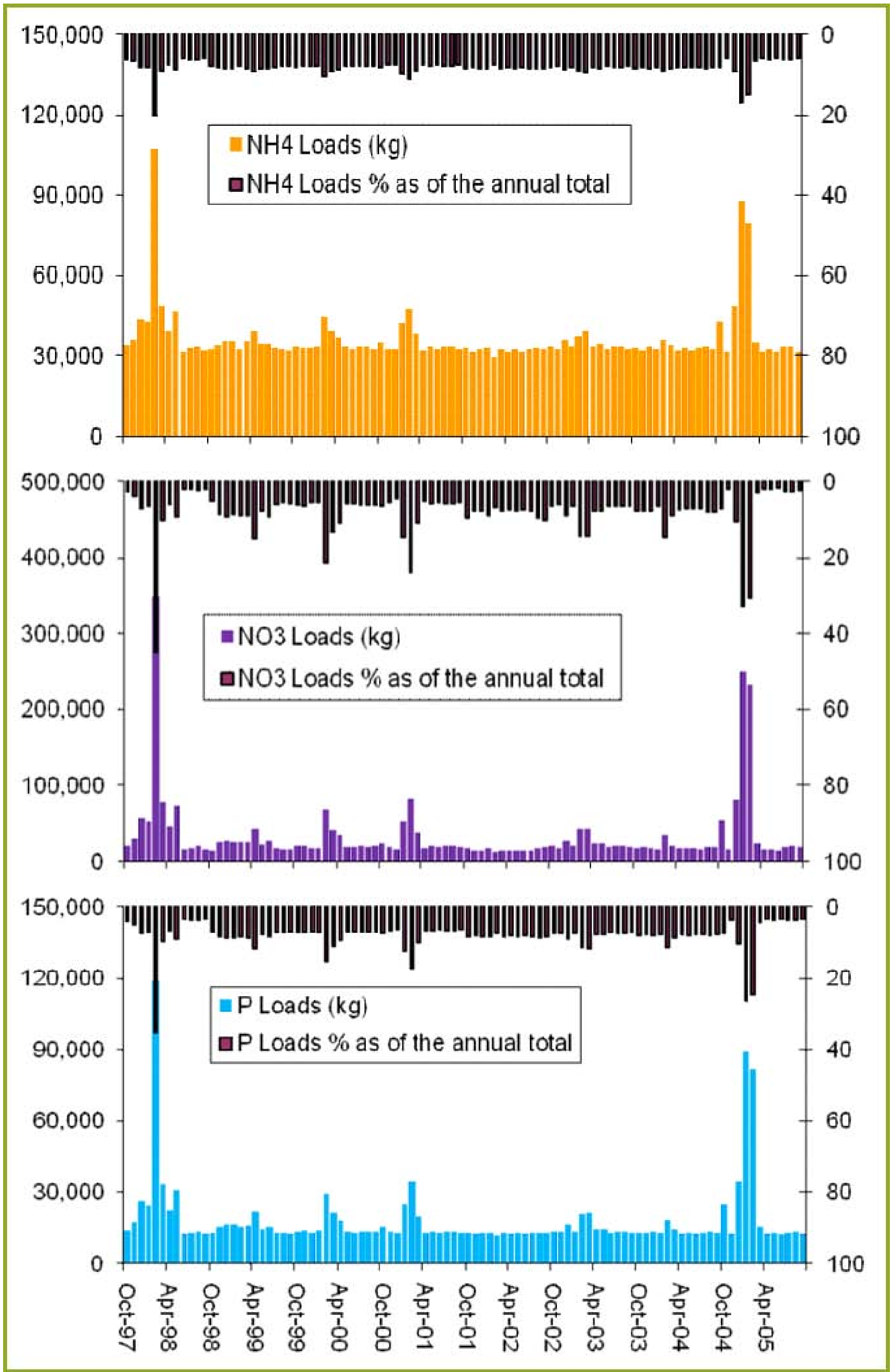


Figure 8 Monthly nutrients loads in kg and percentages for the Los Angeles River below Wardlow Road

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

Reach Name	Node ID	NH4(kg)	**NH4 % to the ocean**	NO3 (kg)	**NO3 % to the ocean**	TP (kg)	**TP % to the ocean**	Area (%)
Arroyo Seco	N212	3,716	**0.8**	12,159	**3.1**	4,134	**2.0**	5
Rio Hondo Channel	N221	14,950	**3.4**	69,115	**17.5**	13,679	**6.3**	17
Verdugo Wash	N246	3,265	**0.7**	10,644	**2.7**	4,053	**1.9**	3
Tujunga Wash	N265	4,850	**1.1**	25,797	**6.5**	10,060	**4.6**	28
Burbank Wester	N272	29,684	**6.8**	13,310	**3.4**	12,502	**5.8**	3
Compton Creek	N304	5,458	**1.2**	43,649	**11.0**	6,775	**3.1**	5
Los Angeles River below Wardlow Road	N305	437,362	**100**	395,448	**100**	216,404	**100**	100
Bull Creek	N324	2,782	**0.6**	11,767	**3**	4,883	**2.3**	4
Upper LAR	N61	4,316	**1.0**	19,486	**4.9**	7,797	**3.6**	8
Los Angeles River at Feliz Boulevard	N67	399,599	**91.4**	194,687	**49.2**	177,454	**82.0**	63
Los Angeles River below Arroyo Seco	N70	407,463	**93.2**	222,719	**56.3**	185,318	**85.6**	70

River (N61) gauging stations due to the presence of the D.C. Tillman and Burbank wastewater reclamation plants. The Rio Hondo Channel contributes 17.5% of the total NO3 loads to the ocean on average (Table 14). With the exception of the Burbank and Compton subwatersheds, the contributions of specific subwatersheds to the total loads than would be the case if the loads were proportional to the areas covered by each subwatershed.

Figure 10 demonstrates the spatial distribution of the nutrient flux (i.e. sources) in each subcatchment. The spatial patterns in nutrient flux are relatively similar between the three nutrients. The highest nutrient fluxes of NH4, NO3 and TP were observed in the subcatchment in which the D.C. Tillman wastewater treatment plant is located – these fluxes were 23,286, 3,320, 7,724 kg/sq.km for NH4, NO3 and TP, respectively. Relatively high NH4 fluxes were reported for urban subwatersheds such as the Burbank and Verdugo Washes, the lower Arroyo Seco, and the middle portion of the Rio Hondo Channel.

The earlier studies have pointed out that a large portion of the Los Angeles River is listed as impaired on the 2006 303(d) list for ammonia, nutrients, algae, and/or pH (CRWQCB-LAR 2003). The simulated results were used to estimate the total loads and assess the degree of water impairment 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 1mg/l, nitrate as nitrogen at 8mg/l and combined nitrate and nitrite (as nitrogen) at 8mg/l for the main stem of the Los Angeles River and the Rio Hondo Channel, and 10 mg/l for other tributaries and groundwater aquifers (CRWQCB-LAR 1994). The nitrate and nitrite targets for TMDLs in the Basin Plan are specified as 30-day average concentrations. Given these numeric targets, the water quality at various locations can be evaluated using the nutrient concentration output results summarized in Figures B-1 through B-5. Figures B-1, B-2, B-3 and B-5 show that the NH4 and NO3 concentrations fell below the target of 10mg/L during the simulation time period at the TS01, TS04, TS05, and S10 mass emission sites. In contrast, the simulated NO3-N concentration at the TS06 Rio Hondo site exceeded the target concentration during certain time periods (Figure B-4). Figure 11 illustrates the daily NO3 loads calculation using the simulated daily water flow volume and NO3 concentration for the S10 Los Angeles River at Wardlow Road site.

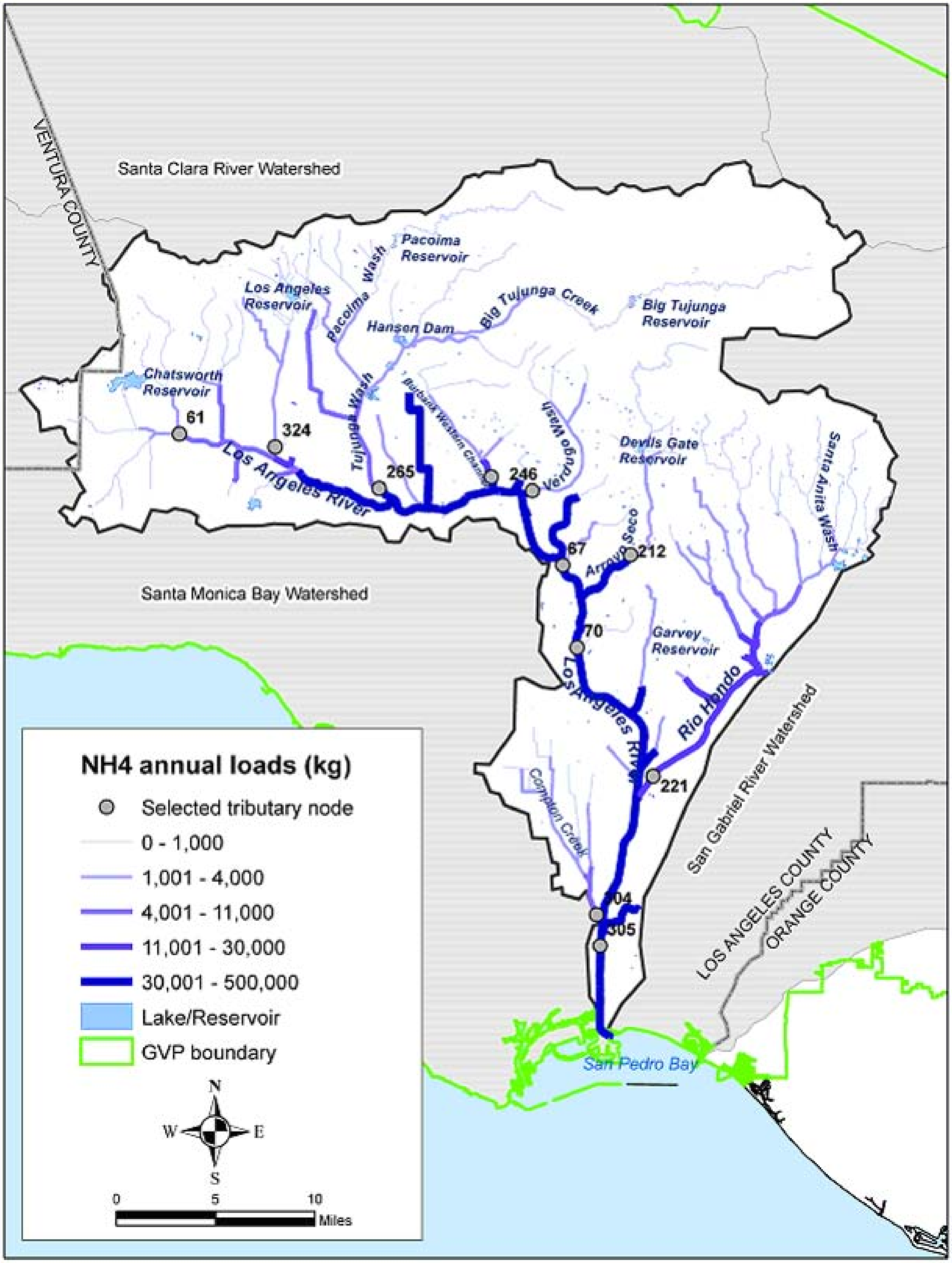


Figure 9a NH4 loads along the stream network

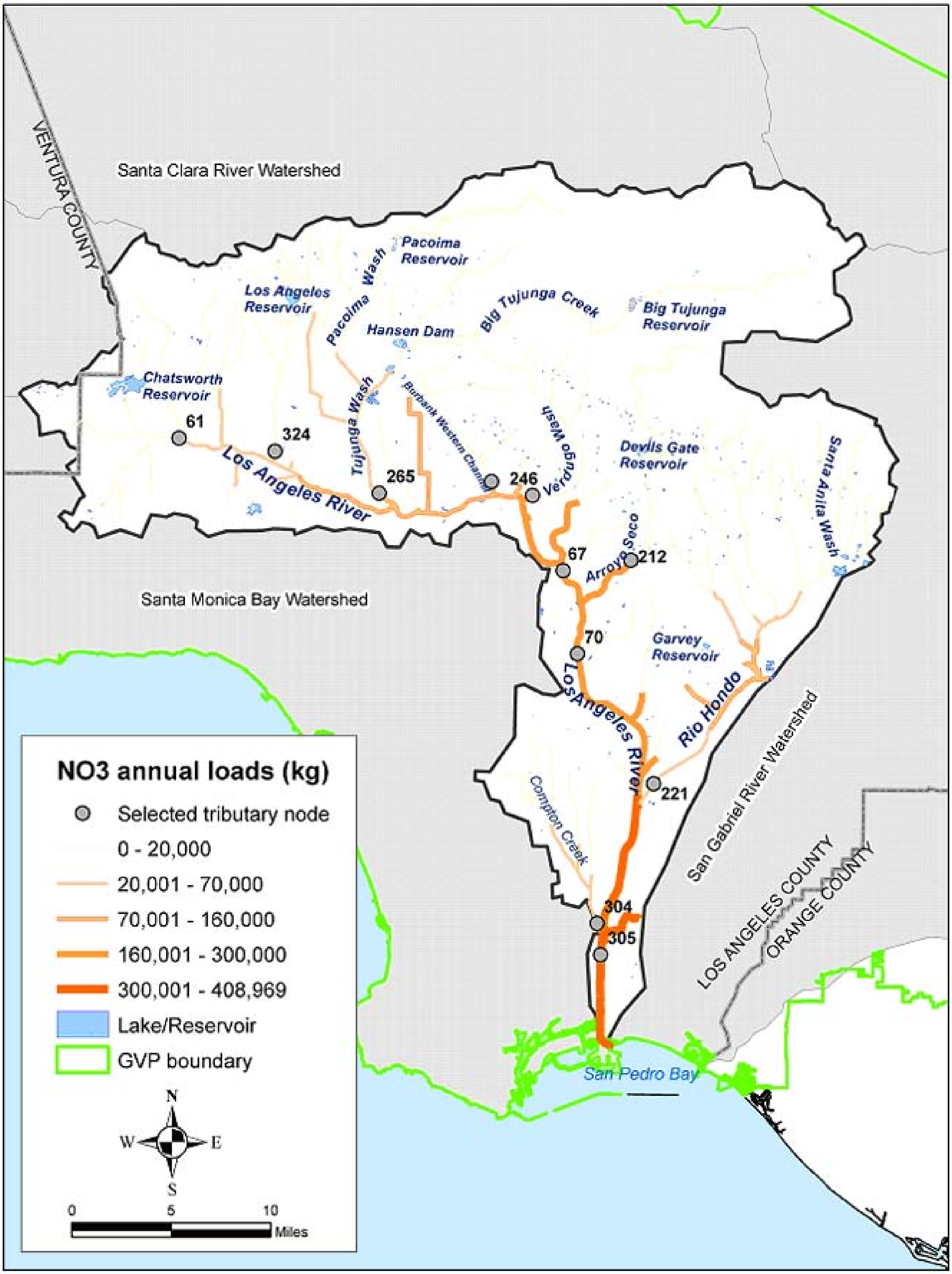


Figure 9b NO3 loads along the stream network

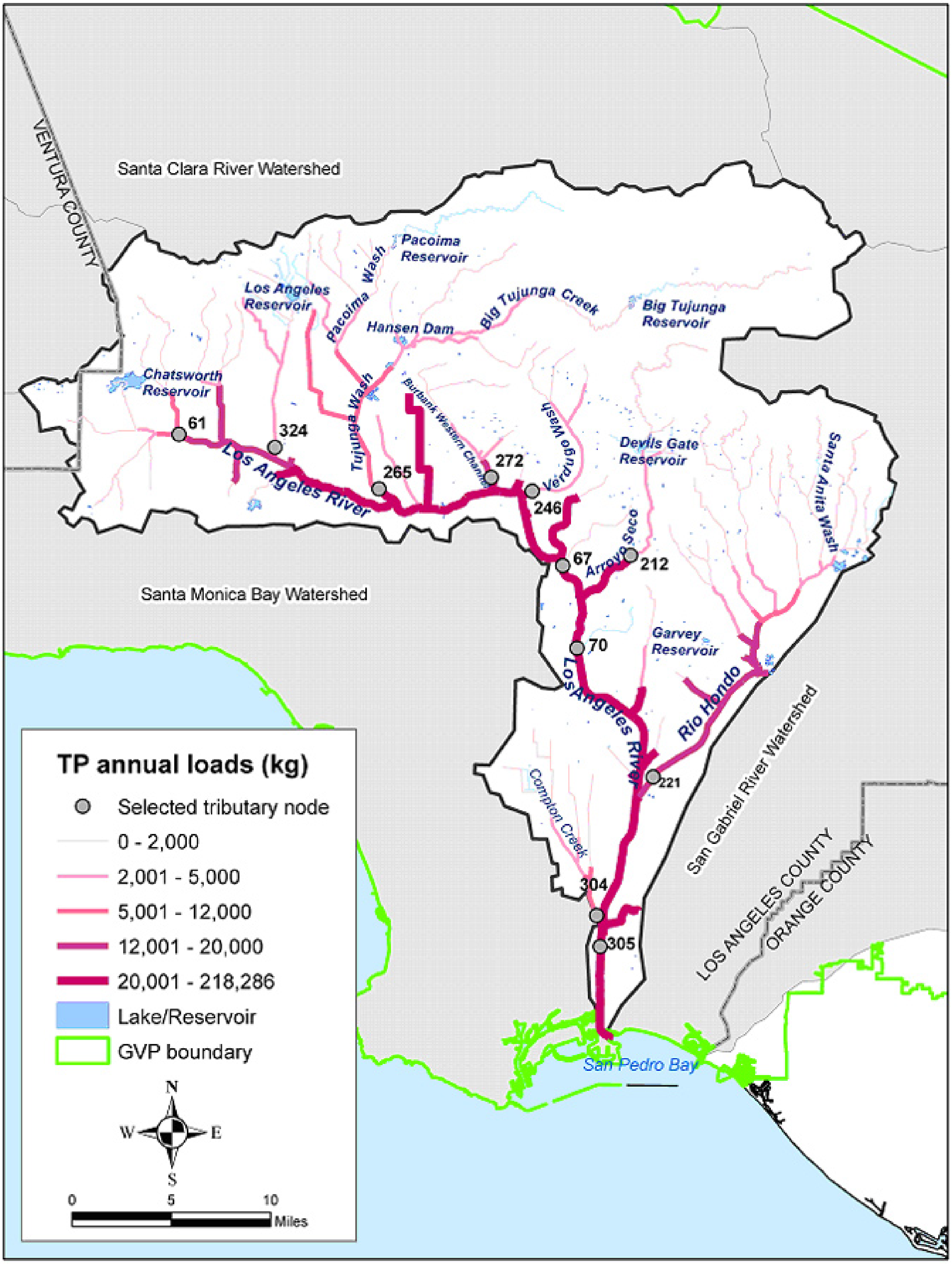


Figure 9c TP loads along the stream network

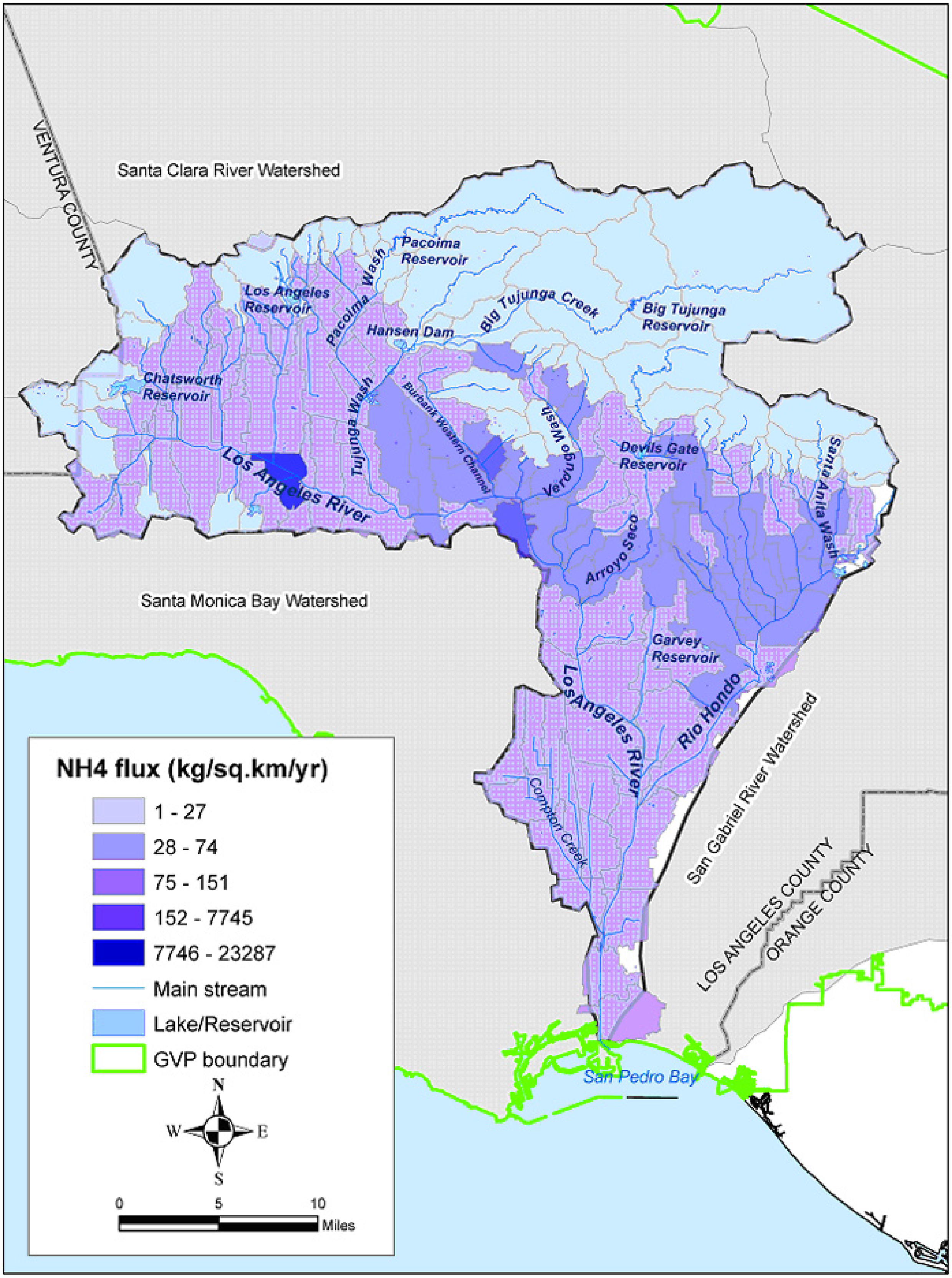


Figure 10a NH4 flux associated with each subcatchment

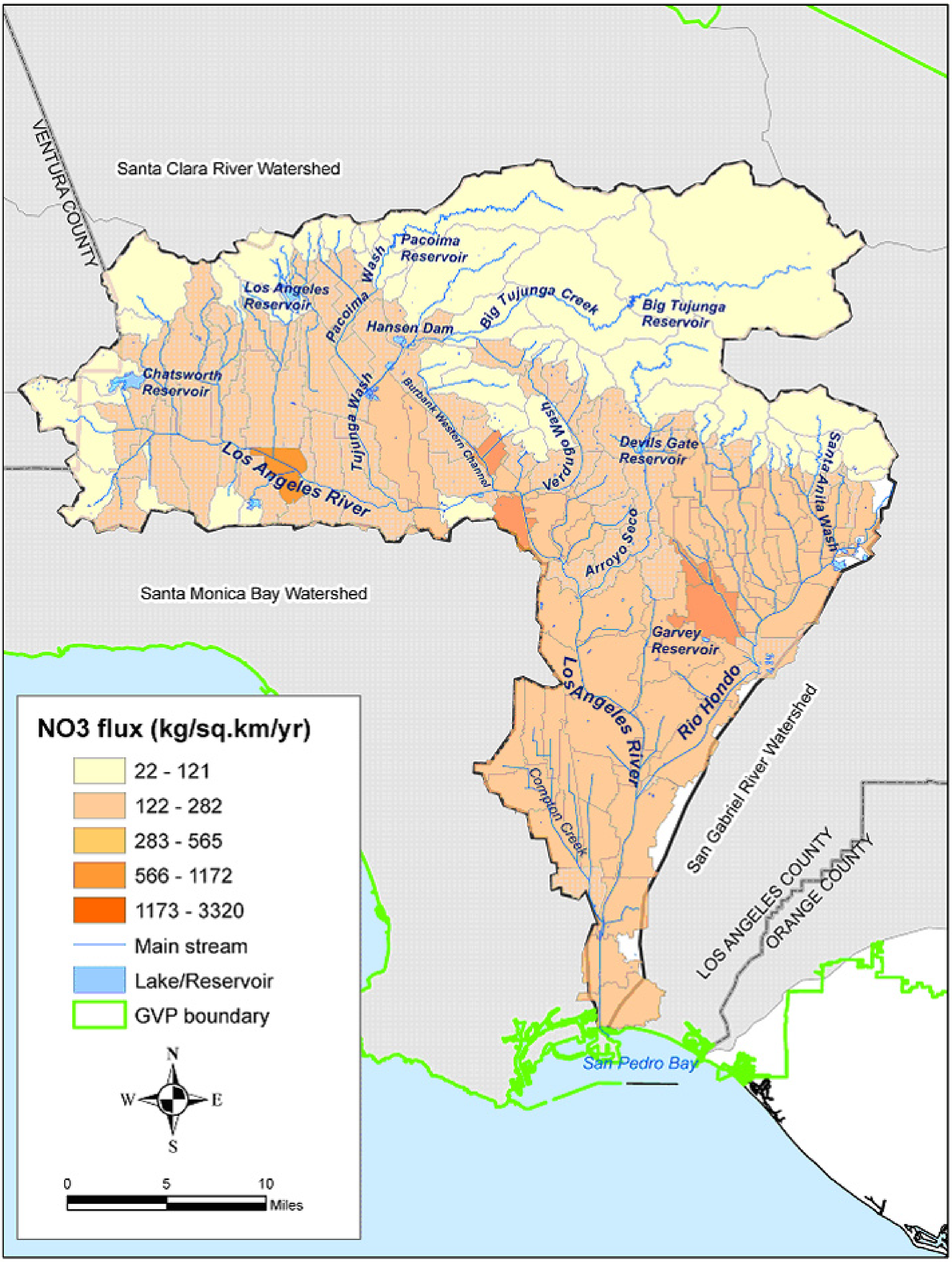


Figure 10b NO3 flux associated with each subcatchment

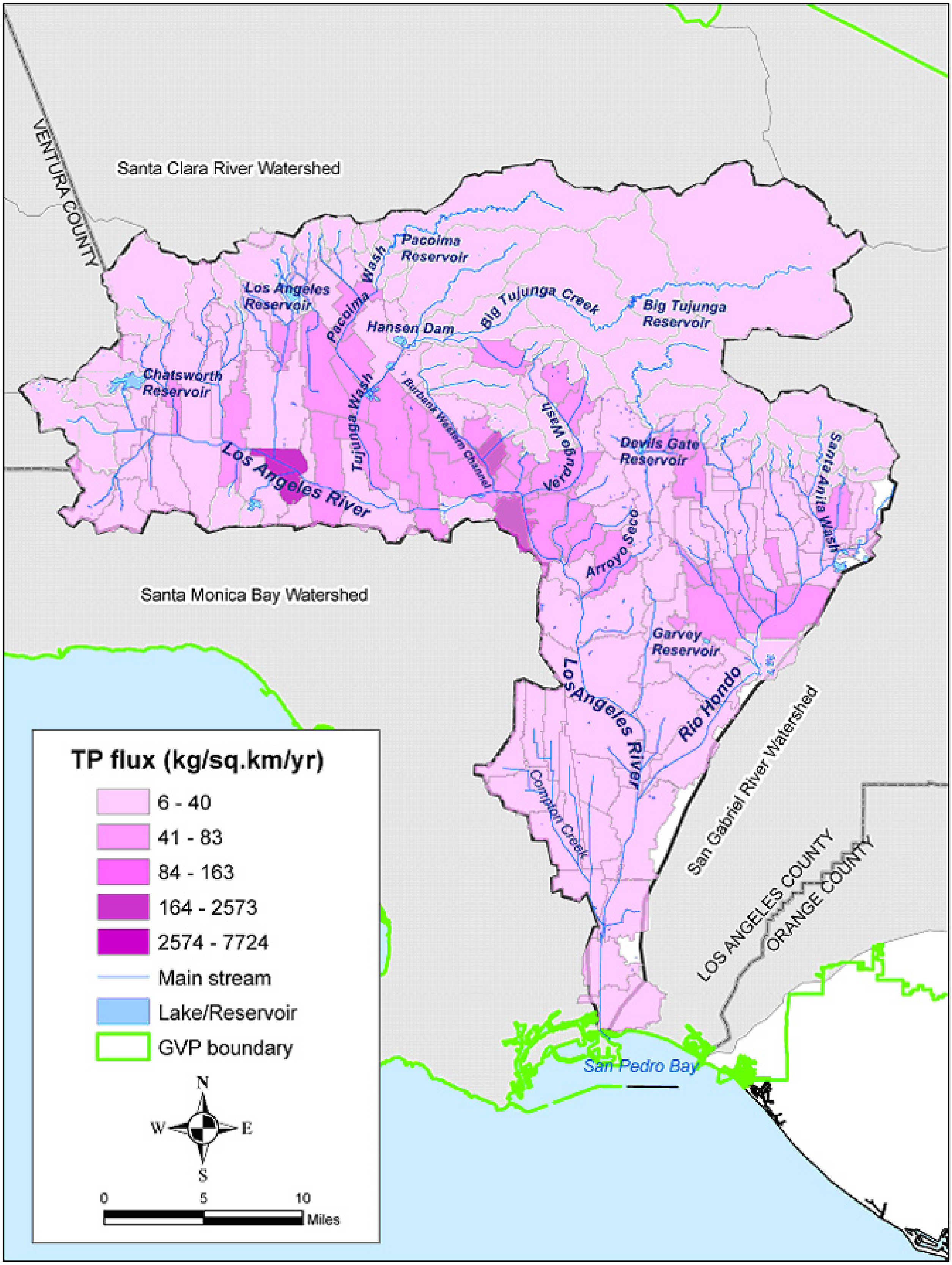


Figure 10c TP flux associated with each subcatchment

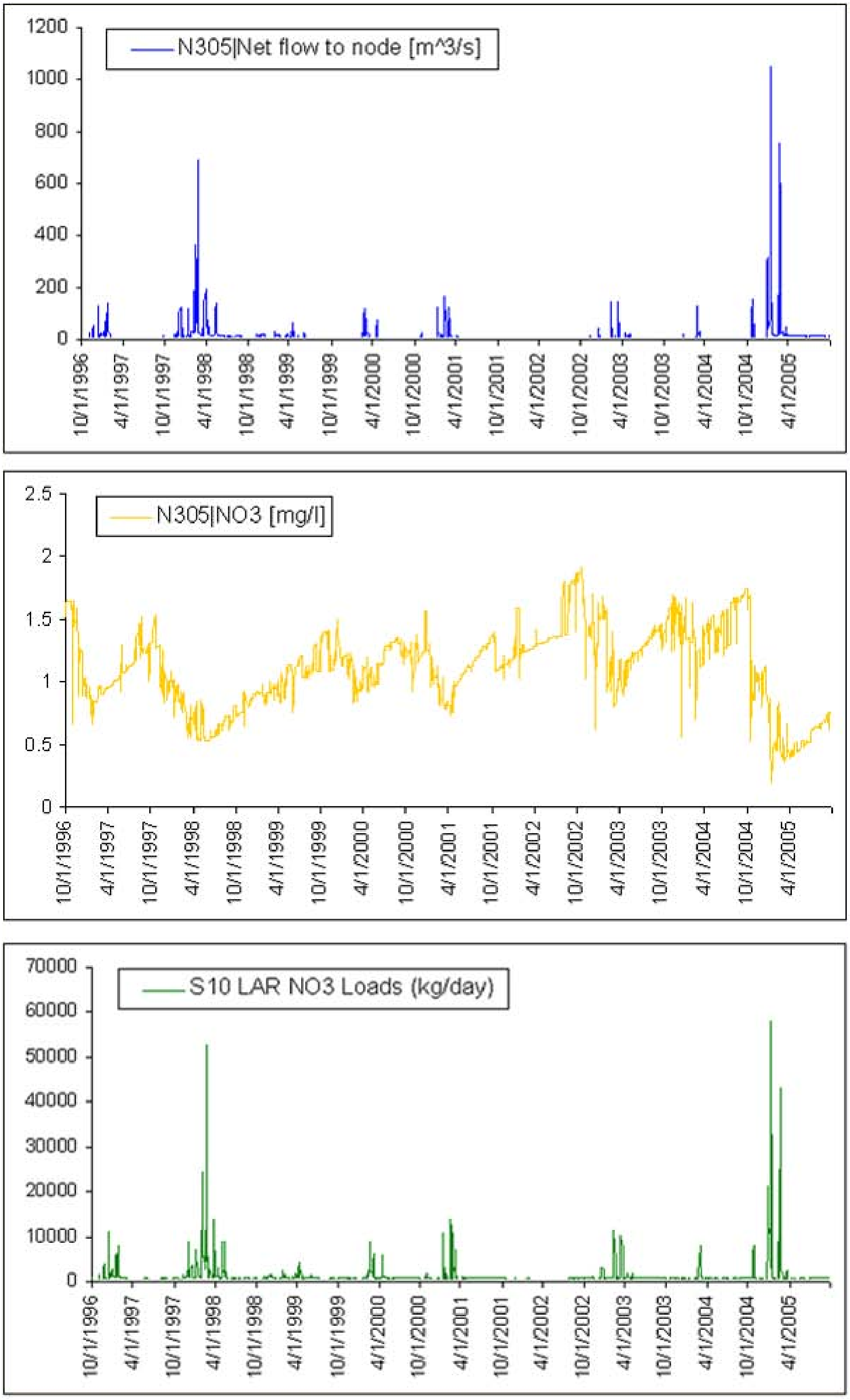


Figure 11 NO3 load calculation using the simulated flow volume and NO3 concentration for the S10 Los Angeles River at Wardlow Road (N305) mass emission site

6 Discussion and Conclusions

MIKE BASIN combines the power of ArcGIS with comprehensive hydrologic modeling and was implemented in the Los Angeles River watershed to address water resource and water quality issues. For hydrologic simulations, MIKE BASIN builds on a network model in which branches represent individual stream 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 Los Angeles River watershed based on water availability and utilization using hydrological data from 10/1996 through 09/2005.

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

The spatio-temporal variations of flow and water quality in the Los Angeles River watershed were characterized based on the model simulation results. The monthly flows are highly variable with discharge varying by several orders of magnitude. The winter flows contribute the majority of the annual flow to the ocean. The flows are significantly lower and less variable during the dry seasons. The predominant contribution to dry-weather in-stream flow comes from the point source discharges plus urban runoff and groundwater baseflow. Tributary inflow volumes vary in space (Figure 7), but the Rio Hondo Channel contributes 21.3% of the total inflow to the ocean on average (Table 13).

Monthly average in-stream loads in Los Angeles River at the outlet were about 36,000, 32,000, and 18,000 kg for NH4, NO3 and TP, respectively, during the simulation period. Temporal variations in nutrient loads are relatively similar and less month-to-month variability is observed with the nutrients than the flow patterns. The largest variation occurs in the storm seasons (e.g. December through February) while significantly lower and less variable monthly loads occur during the dry season. Tributary incoming loads vary depending on the land uses in the subwatersheds. Substantial NH4 and TP loads occur above the Los Angeles River at Feliz Boulevard (N67) and below the upper Los Angeles River (N61) gauging stations because these stations mark the locations of the D.C. Tillman and Burbank wastewater reclamation plants. The Rio Hondo Channel also contributes large NO3 loads to the main channel. The nutrient flux maps in Figure 10 show the spatial distribution of nutrients associated with different subcatchments. The highest nutrient fluxes for NH4, NO3 and TP are observed in the catchments where the wastewater treatment plants are located and to a lesser extent, subwatersheds with large urban populations (i.e. land uses).

Overall, the modeled results should provide users with simple, intuitive and yet in-depth insights 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-6 through A-15, the model simulates the total water volumes fairly well. Very good validation results were achieved for simulating the 90th percentile high flows while the 10th percentile low flows were poorly simulated with over-predictions at all sites.

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 it did not always predict the temporal variability evident in the pollutographs. The water quality model had difficulties in reproducing the extremely high and low concentration values in the pollutographs that were yielded from the field samples (Figures B-1 through B-5), which points to the inadequate sensitivity of the water quality module to the pollutant sources using the current time stamp. The daily time stamp used for the model runs might have smoothed out the in-stream water quality pulse or dilution that likely occurs over very short time periods or the errors that have been introduced when the nutrient samples were captured and/or lab analysis performed.

Two other issues of broad concern warrant a brief mention as well. First, a certain portion of the nutrient loads in the watershed derives from sources beyond the control of dischargers, especially atmospheric deposition. Direct air deposition to water bodies was treated as a nonpoint source from the Santa Monica and San Gabriel Mountains. 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, which 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 (Larry Walker Associates 2005). However, wet- and dry- weather nutrient simulations are not differentiated in the MIKE BASIN package, which may limit applications of the modeling results for estimating TMDL compliance and/or assessment of BMP designs, which require not only estimates of average loads, but also loads at a much finer temporal scale.

This report has focused on assessing the sources and baseline loads of nutrients to the surface water and the relative impairment of surface water quality in the watershed. The wet weather runoff volume contributes the majority of the total discharge and the overall accuracy of the model is determined by the predictability of the wet weather volume. It is still great challenge to obtain time series flow and water quality data for the thousands of industrial and urban runoff dischargers that are scattered across the entire region. Lastly, the simulated water quality time series at each of the node points of the stream network offers some understanding of the spatio-temporal variability of the nutrient loads and concentrations at the basin scale while being inadequate for site-specific projects. Actual design specifications should be used with further validation and site-specific data for applications such as BMP project designs.

The results do, however, identify those parts of the watershed and times of the year that further research should focus on if we are to improve our managements of the water supply and quality issues affecting the tributaries and subwatersheds that drain into the Los Angeles River.

References

Ackerman, D, Schiff, K.C., Trim, H., and Mullin, M., 2003. Characterization of water quality in the Los Angeles River. Bulletin (Southern California Academy of Sciences)

Aqua Terra Consultants. 2004. Hydrologic Modeling of the Calleguas Creek Watershed with the U.S.EPA Hydrologic Simulation Program – FORTRAN (HSPF). Submitted to Larry Walker Associates and Ventura County Watershed Protection District and Calleguas Creek Watershed Management Plan, August 27, 2004.

Bhaduri, B., Bright, E., Coleman, P., and Dobson, J., 2002. LandScan: Locating people is what matters. GeoInformatics 5, 34-37.

Bright, E.A., 2002. LandScan Global Population 1998 Database. Oak Ridge National Laboratory. URL: http://www.ornl.gov/sci/gist/projects/LandScan/landscan_doc.htm#Summary

California Regional Water Quality Control Board Los Angeles Region (CRWQCB – LAR). 1994. Water Quality Control Plan: Los Angeles Region Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties. June 1994.

CRWQCB – LAR. 2003. Los Angeles River Nitrogen Compounds and Related Effects TMDL. Adopted on July 10, 2003.

CRWQCB – LAR. 2004. Total Maximum Daily Load for Metals - Los Angeles River and Tributaries

CRWQCB – LAR. 2007a. Substitute Environmental Document for the Los Angeles River Watershed Trash TMDL.

CRWQCB – LAR. 2007b. Watershed Management Initiative Chapter: 2.1 Los Angeles River Watershed http://www.swrcb.ca.gov/rwqcb4/water_issues/programs/regional_program/wmi/ws_losangeles.shtml

Cleaner Rivers through Effective Stakeholder-led TMDLs (CREST). 2007. Sampling and Analysis Plan for the Los Angeles River Bacteria Source Identification Study - A monitoring project overseen by the Cleaner Rivers through Effective Stakeholder-led TMDLs (CREST) collaborative Process. August 2007. http://www.crestmdl.org/studies/FINAL_SAP_CREST_BSI_Study_08290.pdf

Davis, A.P., Shokouhian, M., and Shubei, N., 2001. Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. Chemosphere 44: 997-1009.

DHI, 2007. MIKE BASIN manual.

Donigian, Jr., A.S., 2000. HSPF Training Workshop Handbook and CD. Lecture #19. Calibration and Verification Issues, Slide #L19-22. EPA Headquarters, Washington Information Center, 10-14 January, 2000. Presented and prepared for U.S. EPA, Office of Water, Office of Science and Technology, Washington, D.C.

Los Angeles Regional Water Quality Control Board (LARWQCB). 1998. Los Angeles River Watershed Water Quality Characterization.

Madsen, H., 2000. Automatic calibration of a conceptual rainfall–runoff model using multiple objectives. Journal of Hydrology 235 (3) 276-288

Schueler, T.R. and Holland, H.K., 2000. The Practice of Watershed Protection. Center for Watershed Protection. Ellicott City, MD.

Sheng, J., Wilson, J. P., Chen, N., Devinny, J.S., and Sayre, J.M., 2007. Evaluating the Quality of the National Hydrography Dataset for Watershed Assessments in Metropolitan Areas, GIScience and Remote Sensing 44, 283-304.

Sheng, J., and Wilson, J. P., 2008. The Green Visions Plan for 21st Century Southern California. 16. Watershed Assets Assessment, University of Southern California GIS Research Laboratory and Center for Sustainable Cities, Los Angeles, California.

Southern California Associated Governments. 2001. http://www.scag.ca.gov/

The Rivers and Mountains Conservancy (RMC), 2004. Rio Hondo watershed management plan http://www.rmc.ca.gov/plans/water.html

United States Environmental Protection Agency (USEPA). 1995. National Water Quality Inventory: 1994 Report to Congress. EPA/841/R-95/005.United States Environmental Protection Agency, Washington, DC.

Appendix A
Hydrology Calibration and Validation Graphs and Tables

Rainfall-Runoff Results

USGS 11098000 Arroyo Seco near Pasadena CA

Catchment Area = 41.4 km2

Input Parameters

Parameter	Description	Value	Units
Umax	Maximum water content in surface storage	19.4	in
Lmax	Maximum water content in root zone storage	28.6	in
CGOF	Overland flow runoff coefficient	0.911	
CKIF	Time contstant for routing interflow	733.1	hrs
CK1,2	Time constant for routing overland flow	22.6	hrs
TOF	Root zone threshold value for overland flow	0.922	
TIF	Root zone threshold value for interflow	0.534	
Tg	Root zone threshold value for GW recharge	0.586	
CKBF	Time constant for routing baseflow	1607	hrs
Carea	Ratio of GW-area to catchment area	1	

Observations

Forest

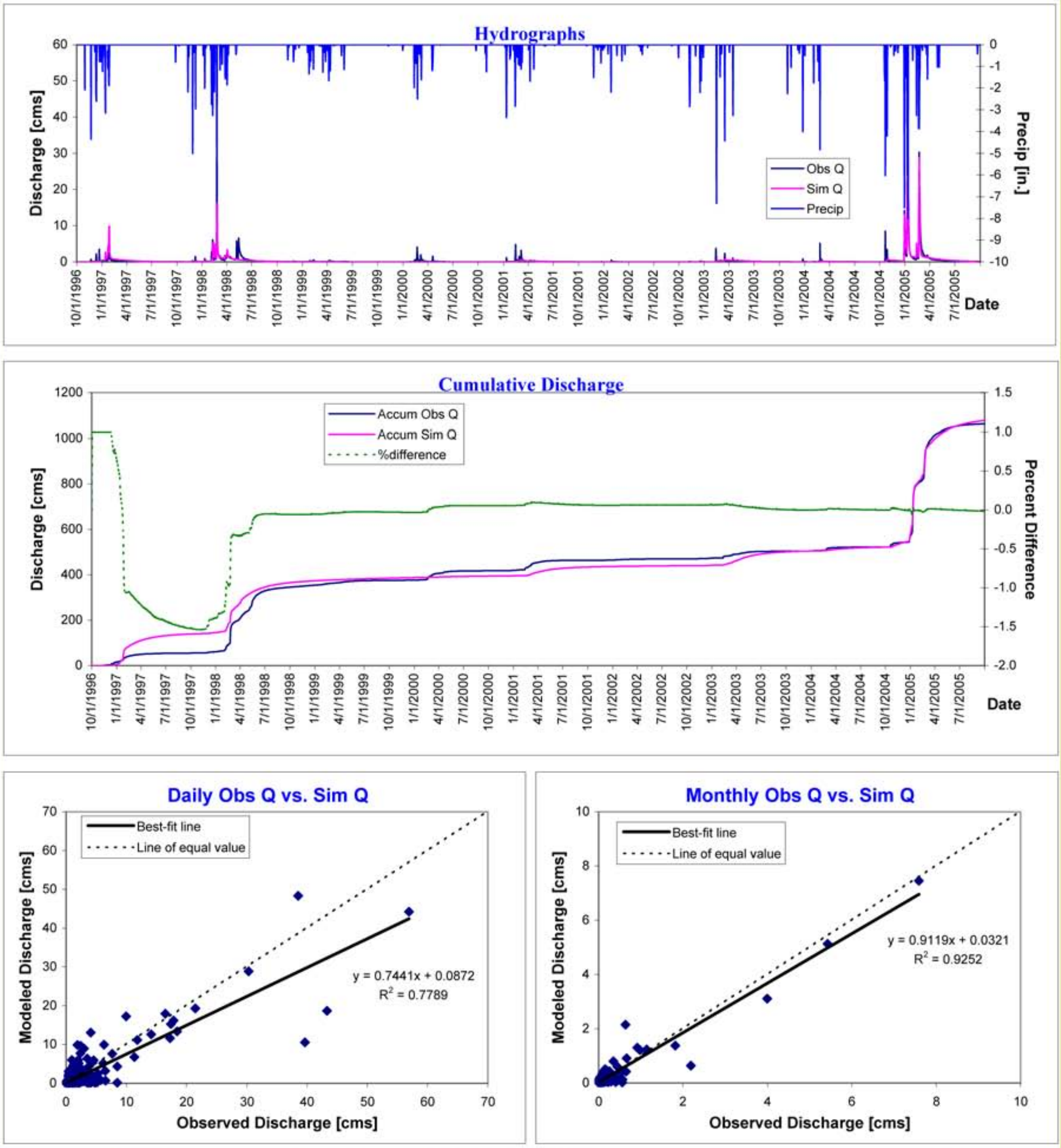


Figure A-1 Calibration results for the USGS 11098000 Arroyo Seco near Pasadena CA gauging station

Table A-1 Calibration error analysis for the USGS 11098000 Arroyo Seco near Pasadena CA gauging station

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

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

Summary	***MIKE BASIN Simulated Flows***	***Observed Flows***
Highest 10% cutoff value	0.56	0.54
Lowest 50% cutoff value	0.05	0.04
Total in-stream flow	1077.40	1062.77
Total of the highest 10% flows	771.59	846.42
Total of the lowest 50% flows	37.92	22.63
Summer flow volume (months 7-9)	70.59	28.71
Fall flow volume (months 10-12)	90.47	87.69
Winter flow volume (months 1-3)	705.63	736.68
Spring flow volume (months 4-6)	210.57	209.63
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	1.38	Very good
Error in 10% highest flows	-8.84	Very good
Error in 50% lowest flows	67.54	Poor
Volume error – Summer	145.87	Poor
Volume error – Fall	3.17	Very good
Volume error – Winter	-4.21	Very good
Volume error – Spring	0.45	Very good

Rainfall-Runoff Results

LADPW F252 Verdugo Wash At Estelle Avenue

Catchment Area = 69.4 km2

Input Parameters

Parameter	Description	Value	Units
Umax	Maximum water content in surface storage	10.6	in
Lmax	Maximum water content in root zone storage	132	in
CGOF	Overland flow runoff coefficient	0.325	
CKIF	Time contstant for routing interflow	624.9	hrs
CK1,2	Time constant for routing overland flow	10.7	hrs
TOF	Root zone threshold value for overland flow	0.0634	
TIF	Root zone threshold value for interflow	0.487	
Tg	Root zone threshold value for GW recharge	0.268	
CKBF	Time constant for routing baseflow	2707	hrs
Carea	Ratio of GW-area to catchment area	1	

Observations

mix land use hilly area

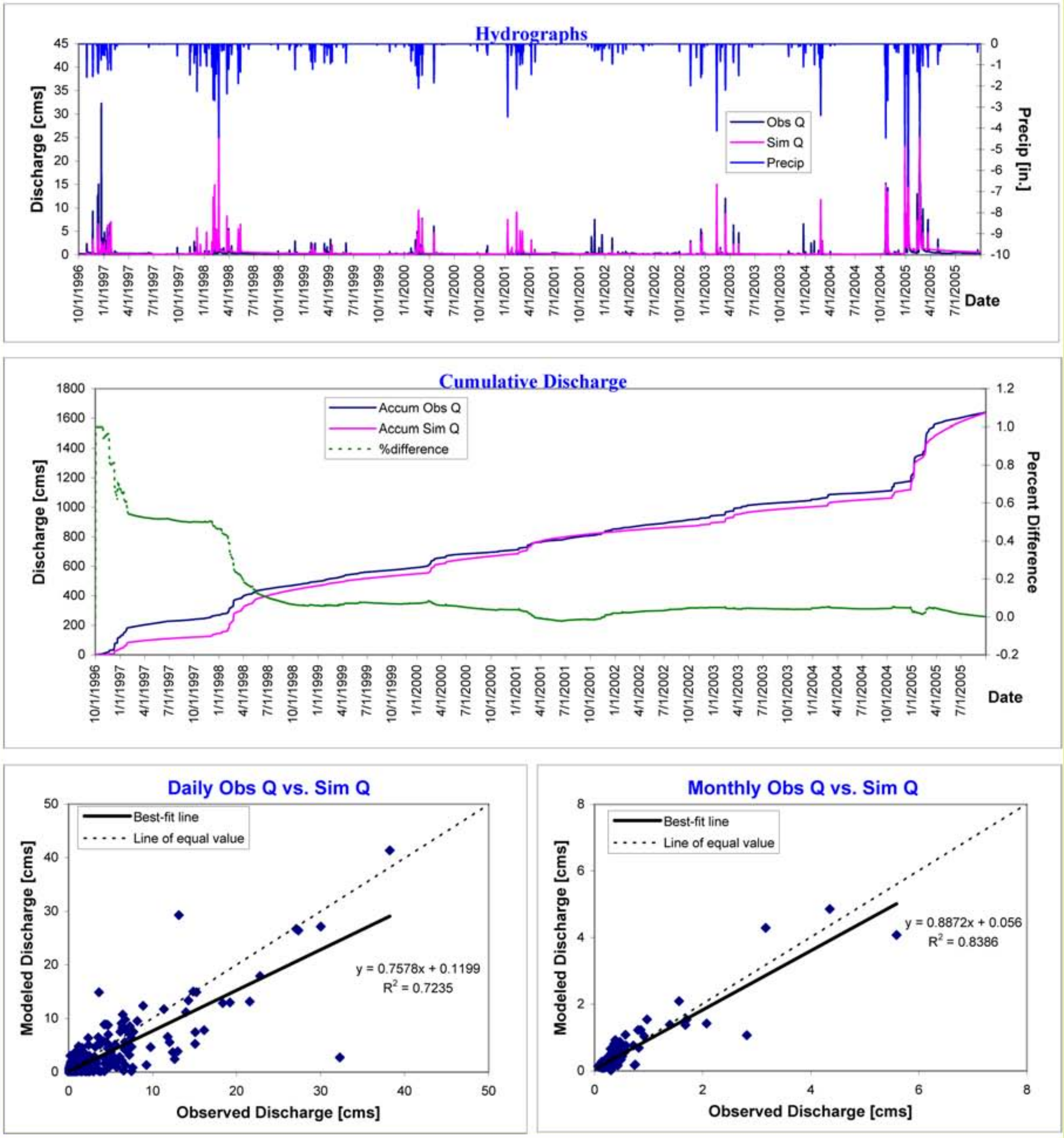


Figure A-2 Calibration results for the LADPW F252 Verdugo Wash at Estelle Avenue gauging station

Table A-2 Calibration error analysis for the LADPW F252 Verdugo Wash at Estelle Avenue gauging station

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

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

Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	0.83	0.48
Lowest 50% cutoff value	0.19	0.20
Total in-stream flow	1636.53	1639.77
Total of the highest 10% flows	953.41	1047.64
Total of the lowest 50% flows	219.44	227.49
Summer flow volume (months 7-9)	198.22	169.58
Fall flow volume (months 10-12)	291.85	407.88
Winter flow volume (months 1-3)	832.68	817.47
Spring flow volume (months 4-6)	313.21	244.49
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	-0.20	Very good
Error in 10% highest flows	-8.99	Very good
Error in 50% lowest flows	-3.54	Very good
Volume error - Summer	16.89	Fair
Volume error - Fall	-28.45	Fair
Volume error - Winter	1.86	Very good
Volume error - Spring	28.11	Fair

Rainfall-Runoff Results

USGS 11101380/F81D-R Alhambra Wash Near Klingerman Street

Catchment Area = 39.4 km2

Input Parameters

Parameter	Description	Value	Units
Umax	Maximum water content in surface storage	12.1	in
Lmax	Maximum water content in root zone storage	102	in
CGOF	Overland flow runoff coefficient	0.54	
CKIF	Time contstant for routing interflow	296.4	hrs
CK1,2	Time constant for routing overland flow	11.3	hrs
TOF	Root zone threshold value for overland flow	0.0154	
TIF	Root zone threshold value for interflow	0.228	
Tg	Root zone threshold value for GW recharge	0.113	
CKBF	Time constant for routing baseflow	1275	hrs
Carea	Ratio of GW-area to catchment area	0.5	

Observations

urban, very simiar to the Arcadia Wash subwatershed

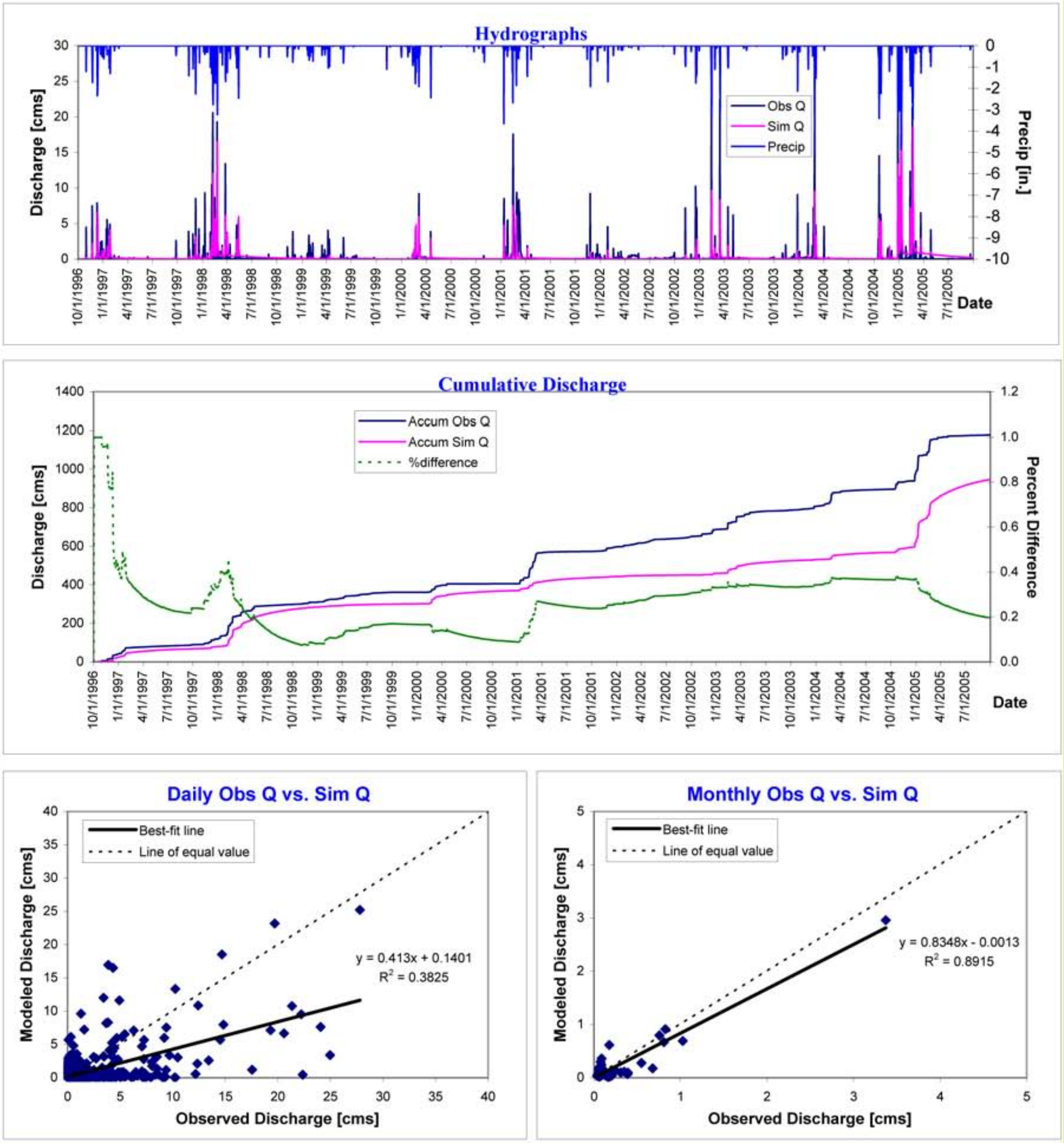


Figure A-3 Calibration results for the USGS 11101380/F81D-R Alhambra Wash near Klingerman Street gauging station

Table A-3 Calibration error analysis for the USGS 11101380/F81D-R Alhambra Wash near Klingerman Street gauging station

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

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

Summary	***MIKE BASIN Simulated Flows***	***Observed Flows***
Highest 10% cutoff value	0.49	0.31
Lowest 50% cutoff value	0.08	0.05
Total in-stream flow	947.42	1178.98
Total of the highest 10% flows	630.46	1006.49
Total of the lowest 50% flows	60.89	37.44
Summer flow volume (months 7-9)	88.82	52.27
Fall flow volume (months 10-12)	128.43	248.98
Winter flow volume (months 1-3)	546.98	737.76
Spring flow volume (months 4-6)	182.95	139.93
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	-19.64	Fair
Error in 10% highest flows	-37.36	Poor
Error in 50% lowest flows	62.61	Poor
Volume error - Summer	69.91	Poor
Volume error - Fall	-48.42	Poor
Volume error - Winter	-25.86	Fair
Volume error - Spring	30.74	Fair

Rainfall-Runoff Results

LADPW F37B-R Compton Creek near Greenleaf Drive

Catchment Area = 58.5 km2

Input Parameters

Parameter	Description	Value	Units
Umax	Maximum water content in surface storage	10.4	in
Lmax	Maximum water content in root zone storage	105	in
CGOF	Overland flow runoff coefficient	0.823	
CKIF	Time contstant for routing interflow	263.4	hrs
CK1,2	Time constant for routing overland flow	11.8	hrs
TOF	Root zone threshold value for overland flow	0.0241	
TIF	Root zone threshold value for interflow	0.231	
Tg	Root zone threshold value for GW recharge	0.0594	
CKBF	Time constant for routing baseflow	2466	hrs
Carea	Ratio of GW-area to catchment area	0.5	

Observations

urban

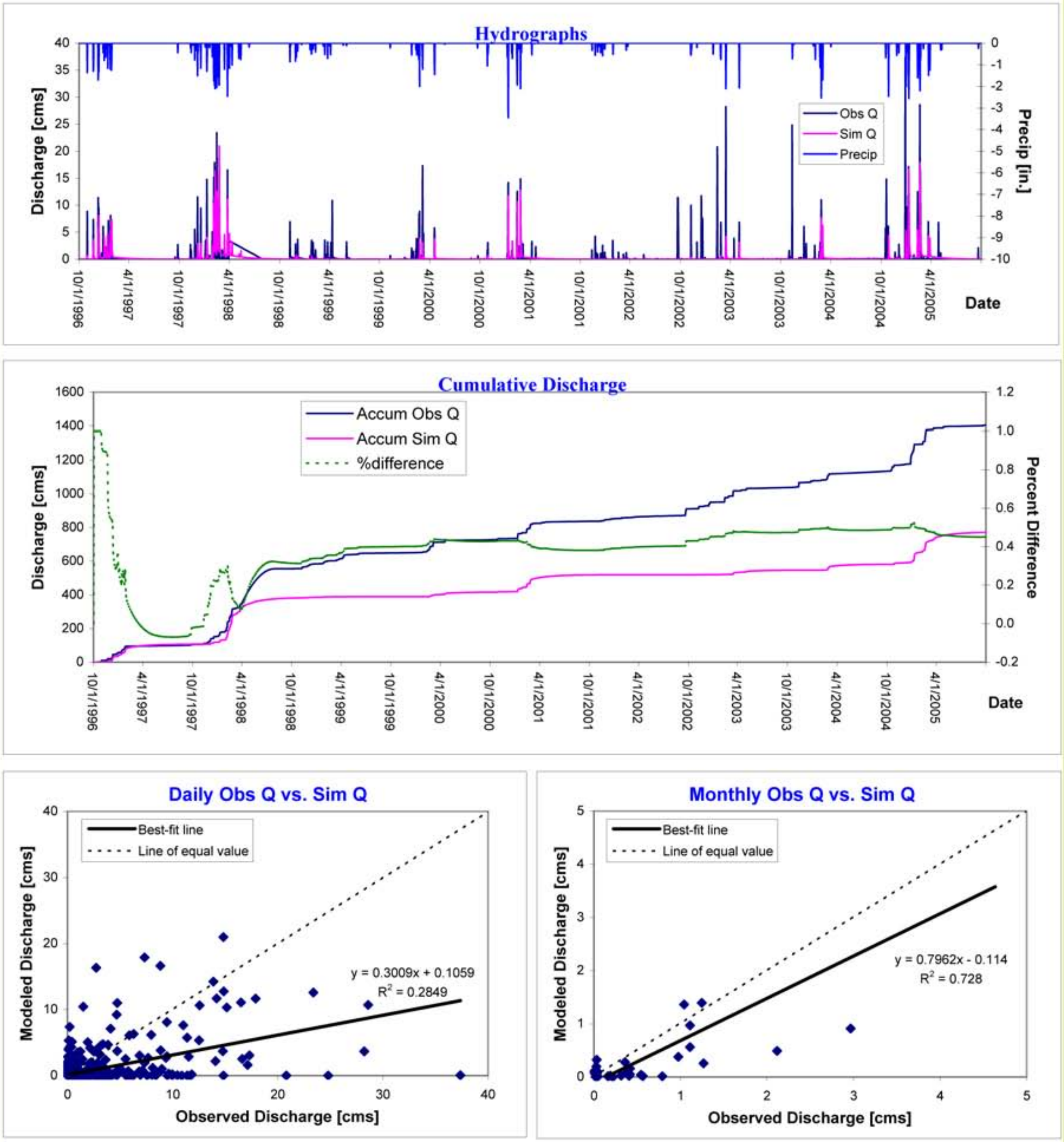


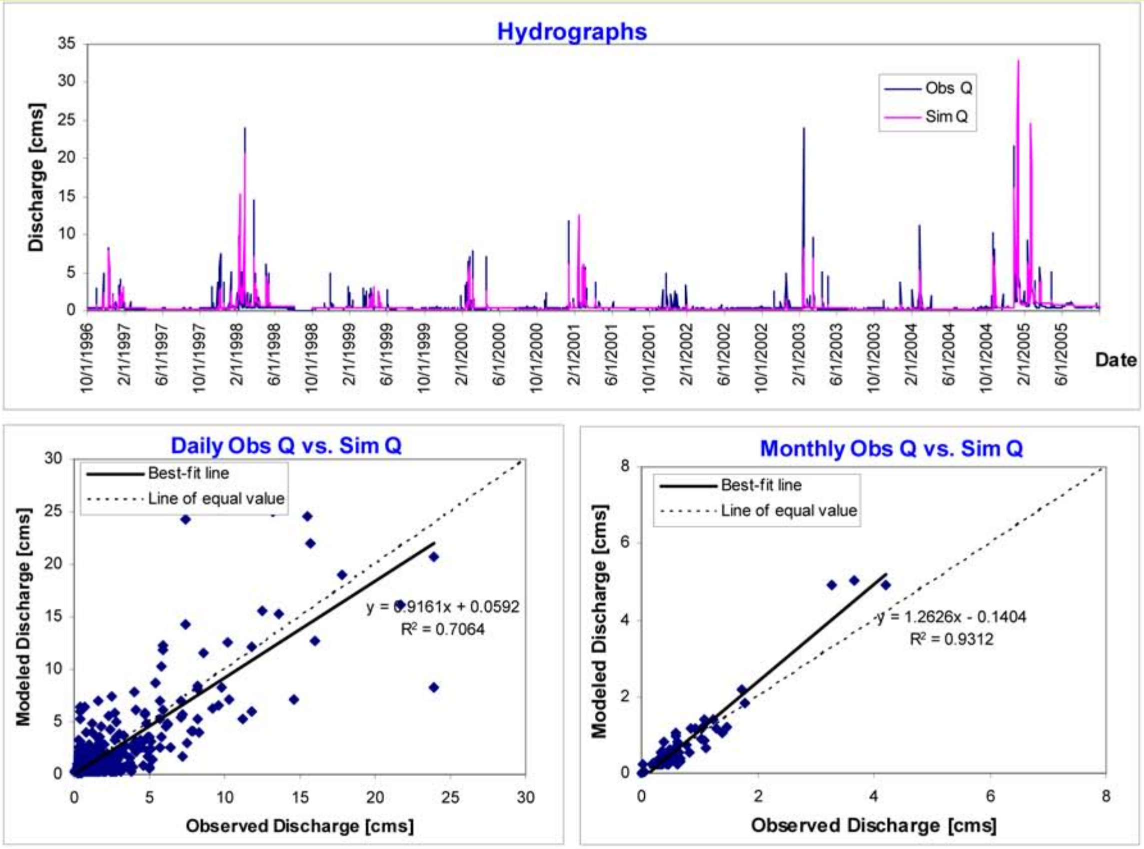
Figure A-4 Calibration results for the LADPW F37B-R Compton Creek near Greenleaf Drive gauging station

Table A-4 Calibration error analysis for the LADPW F37B-R Compton Creek near Greenleaf Drive gauging station

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

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

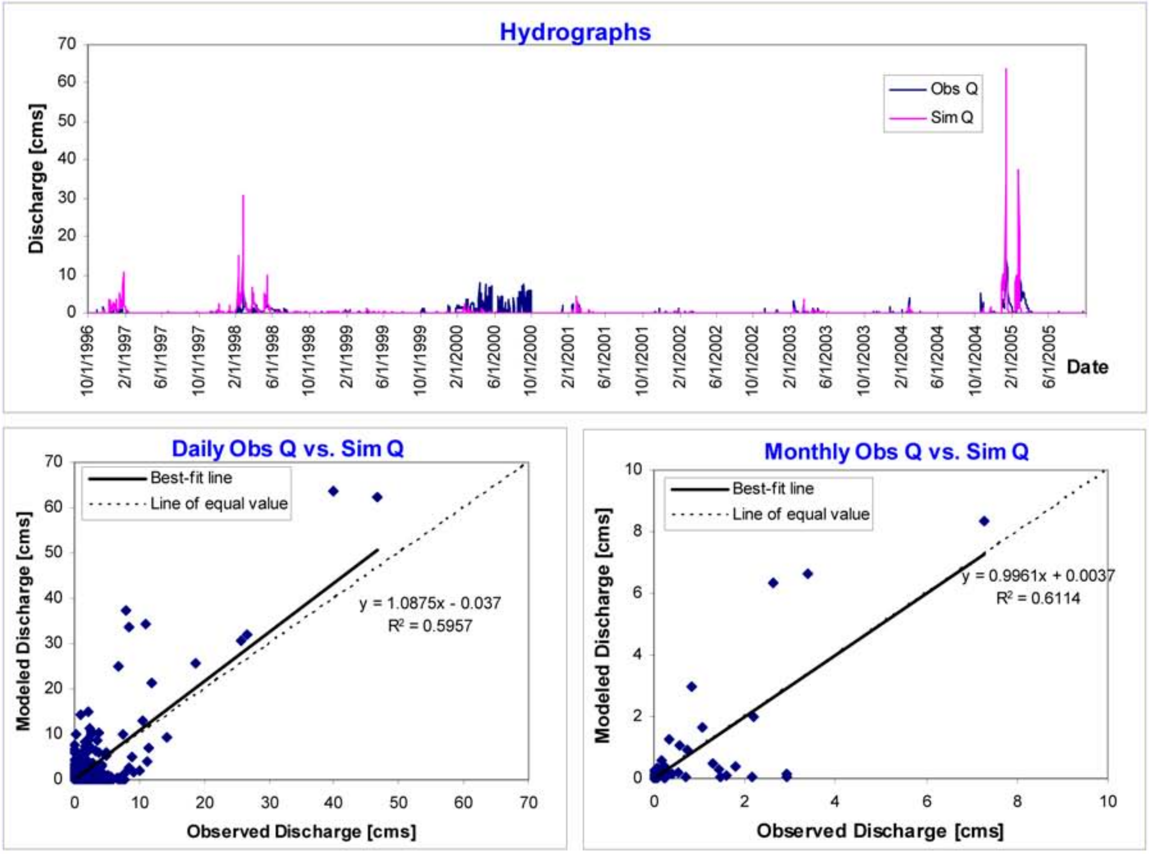
Summary	***MIKE BASIN Simulated Flows***	***Observed Flows***
Highest 10% cutoff value	0.37	0.46
Lowest 50% cutoff value	0.03	0.03
Total in-stream flow	770.56	1403.51
Total of the highest 10% flows	604.25	1352.52
Total of the lowest 50% flows	13.81	27.39
Summer flow volume (months 7-9)	26.26	86.04
Fall flow volume (months 10-12)	78.67	335.32
Winter flow volume (months 1-3)	541.00	696.15
Spring flow volume (months 4-6)	124.59	285.93
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	-45.10	Poor
Error in 10% highest flows	-55.32	Poor
Error in 50% lowest flows	-49.57	Poor
Volume error - Summer	-69.48	Poor
Volume error - Fall	-76.54	Poor
Volume error - Winter	-22.29	Poor
Volume error - Spring	-56.42	Poor



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

Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	0.82	0.59
Lowest 50% cutoff value	0.30	0.31
Total in-stream flow	1929.39	1892.46
Total of the highest 10% flows	958.17	965.66
Total of the lowest 50% flows	407.46	291.17
Summer flow volume (months 7-9)	249.34	252.75
Fall flow volume (months 10-12)	355.74	447.37
Winter flow volume (months 1-3)	927.54	848.17
Spring flow volume (months 4-6)	396.76	343.79
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	1.95	Very good
Error in 10% highest flows	-0.78	Very good
Error in 50% lowest flows	39.94	Poor
Volume error – Summer	-1.35	Very good
Volume error – Fall	-20.48	Fair
Volume error – Winter	9.36	Very good
Volume error – Spring	15.41	Good

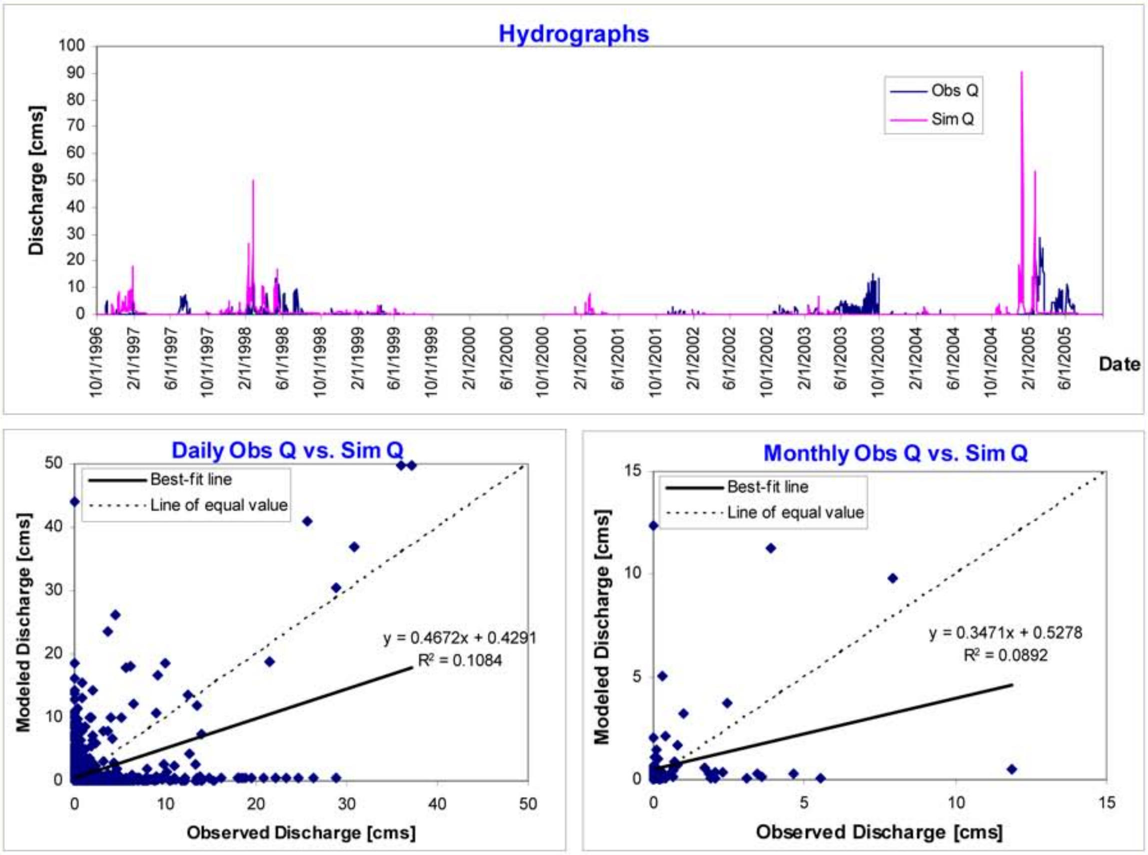
Figure A-5 Validation results for the LADPW E285 Burbank-Western Storm Drain gauging station



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	0.41	0.91
Lowest 50% cutoff value	0.04	0.02
Total in-stream flow	1226.62	1236.55
Total of the highest 10% flows	1042.39	1066.72
Total of the lowest 50% flows	37.26	14.07
Summer flow volume (months 7-9)	35.98	195.51
Fall flow volume (months 10-12)	131.89	75.71
Winter flow volume (months 1-3)	898.53	704.61
Spring flow volume (months 4-6)	160.22	260.71
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	-0.80	Very good
Error in 10% highest flows	-2.28	Very good
Error in 50% lowest flows	164.86	Poor
Volume error – Summer	-81.60	Poor
Volume error – Fall	74.22	Poor
Volume error – Winter	27.52	Fair
Volume error – Spring	-38.54	Poor

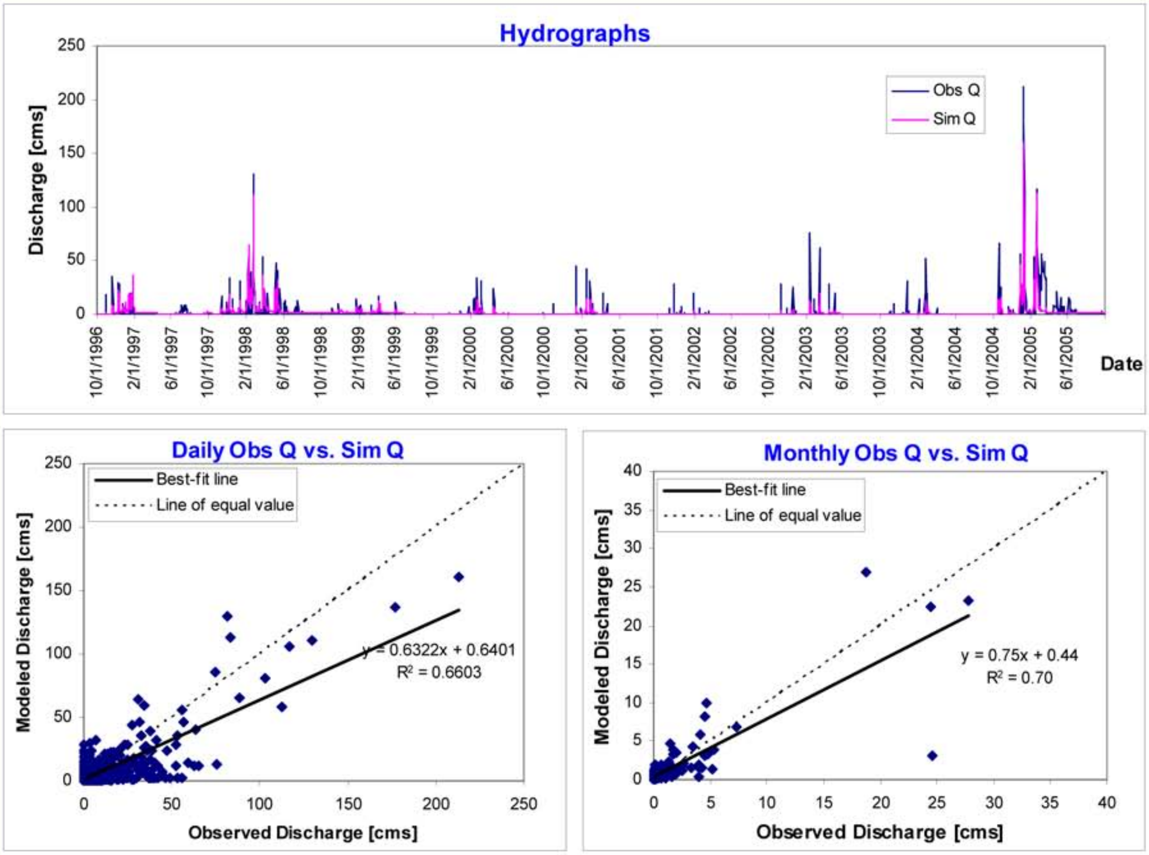
Figure A-6 Validation results for the LADPW F193B-R Santa Anita Wash at Longden Avenue gauging station



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	1.76	0.98
Lowest 50% cutoff value	0.00	0.13
Total in-stream flow	2048.32	2206.01
Total of the highest 10% flows	1827.85	1715.77
Total of the lowest 50% flows	0.04	85.15
Summer flow volume (months 7-9)	503.49	97.82
Fall flow volume (months 10-12)	112.30	303.59
Winter flow volume (months 1-3)	814.18	1476.42
Spring flow volume (months 4-6)	618.35	328.19
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	-7.15	Very good
Error in 10% highest flows	6.53	Very good
Error in 50% lowest flows	-99.95	Poor
Volume error – Summer	414.73	Poor
Volume error – Fall	-63.01	Poor
Volume error – Winter	-44.85	Poor
Volume error – Spring	88.41	Poor

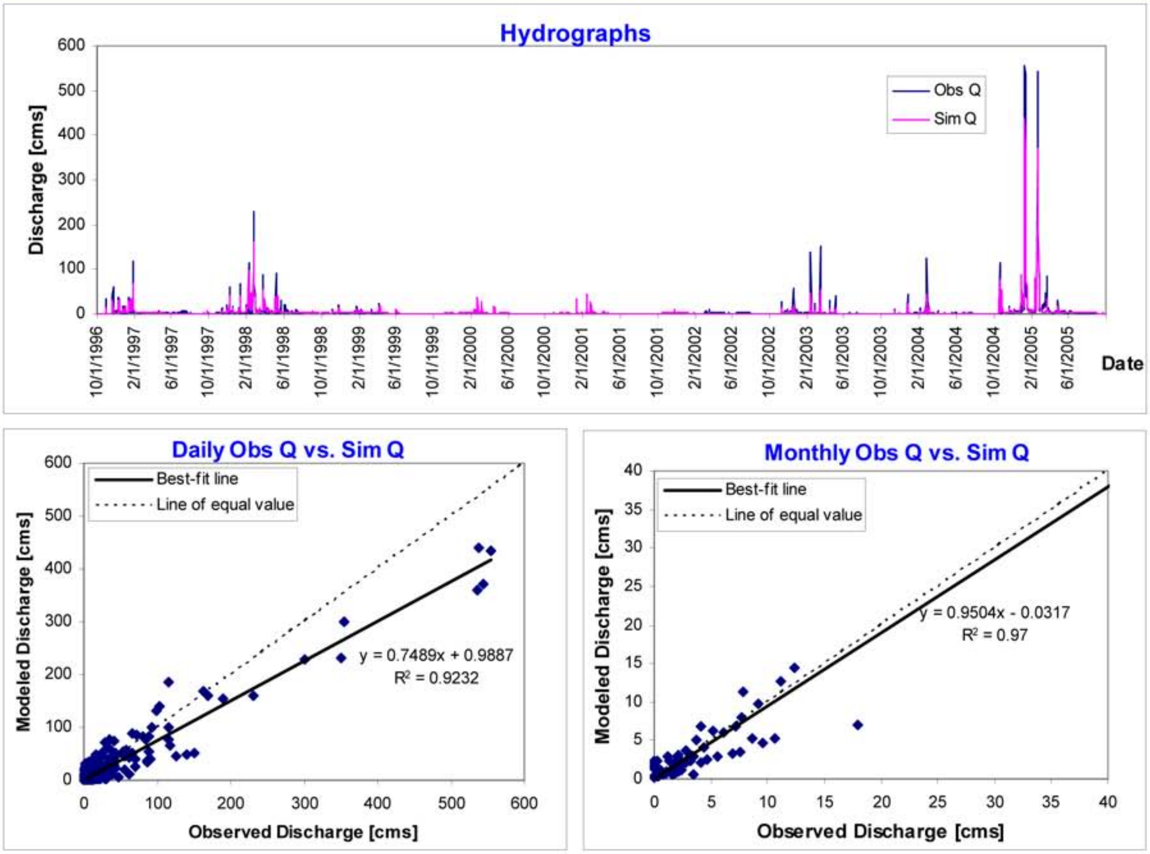
Figure A-7 Validation results for the LADPW F192B-R Rio Hondo Channel below Lower Azusa Avenue gauging station



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	2.75	2.15
Lowest 50% cutoff value	0.40	0.04
Total in-stream flow	5970.78	6108.00
Total of the highest 10% flows	4107.06	5761.01
Total of the lowest 50% flows	334.80	42.67
Summer flow volume (months 7-9)	382.87	236.15
Fall flow volume (months 10-12)	953.20	824.66
Winter flow volume (months 1-3)	3661.98	4093.20
Spring flow volume (months 4-6)	972.73	953.99
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	-2.25	Very good
Error in 10% highest flows	-28.71	Fair
Error in 50% lowest flows	684.70	Poor
Volume error – Summer	62.13	Poor
Volume error – Fall	15.59	Fair
Volume error – Winter	-10.53	Very good
Volume error – Spring	1.96	Very good

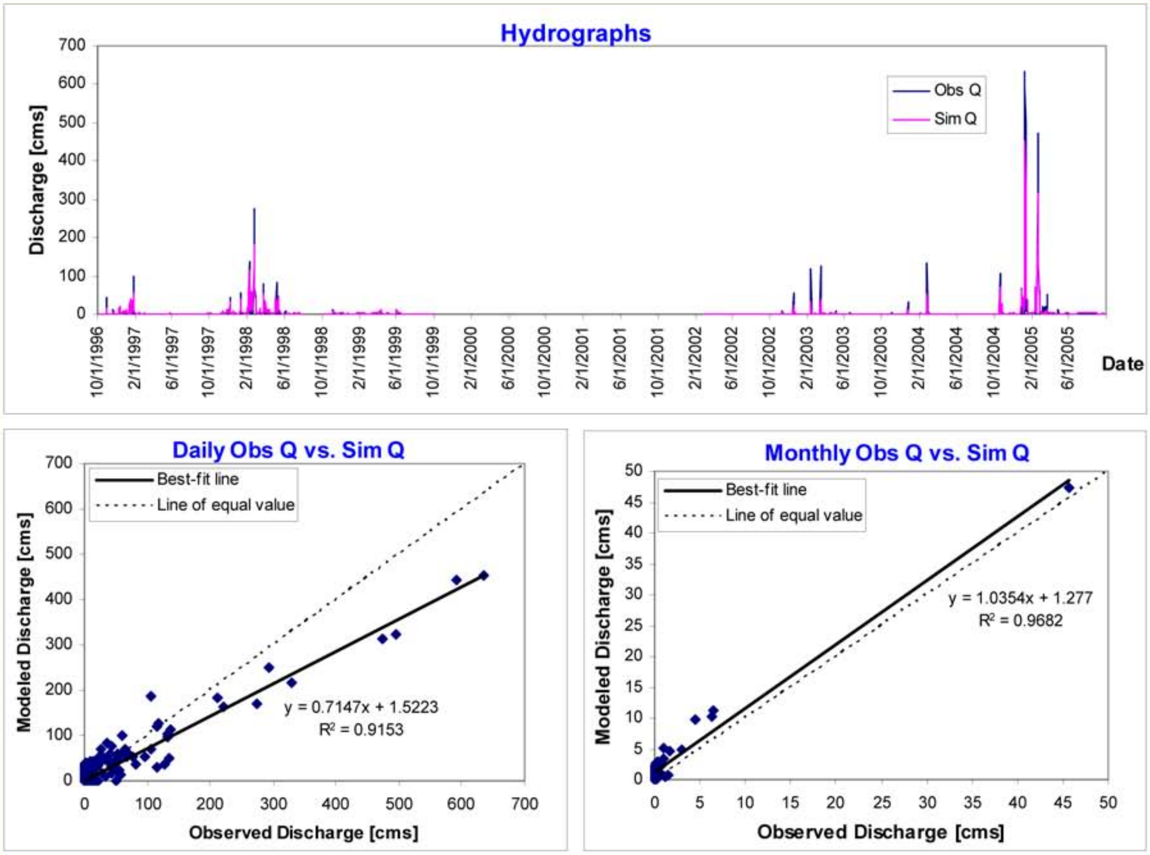
Figure A-8 Validation results for the USGS 11101250 Rio Hondo above Whittier Narrows Dam gauging station



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

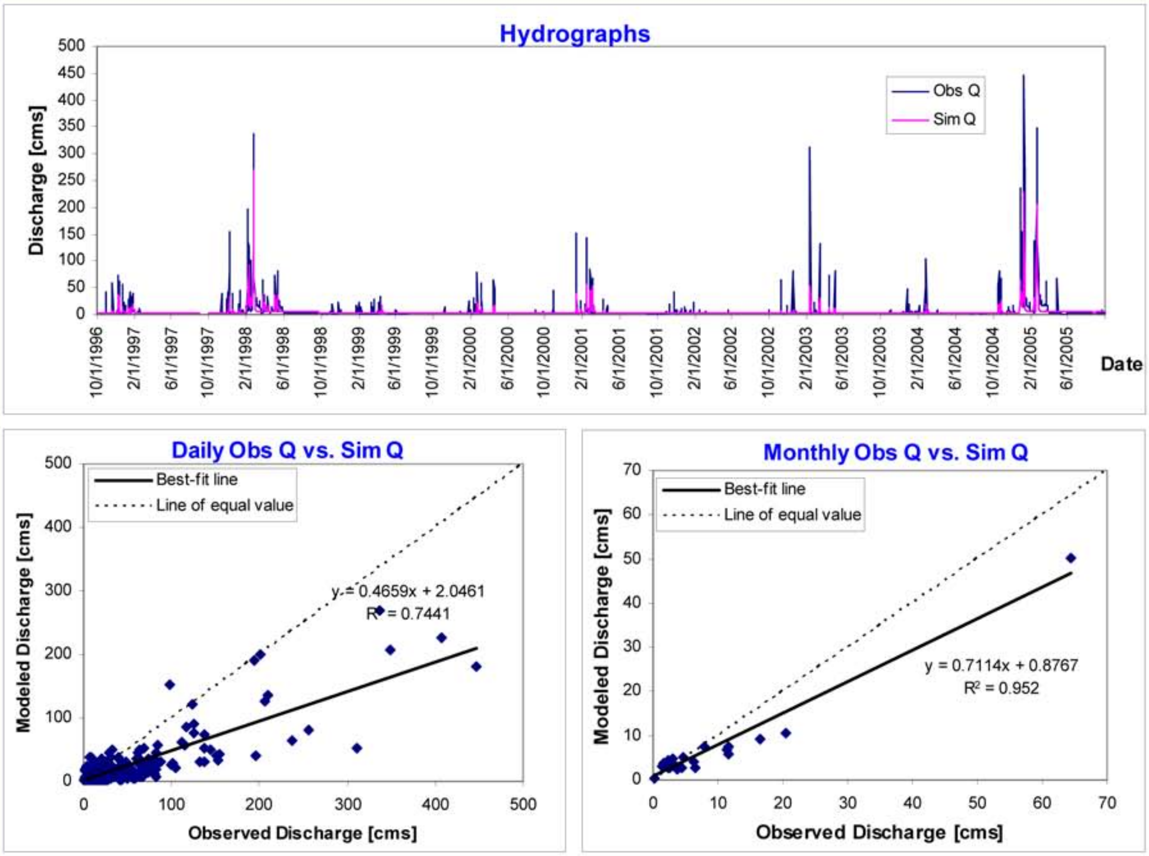
Summary	***MIKE BASIN Simulated Flows***	***Observed Flows***
Highest 10% cutoff value	6.26	4.96
Lowest 50% cutoff value	1.33	1.34
Total in-stream flow	12531.80	13303.49
Total of the highest 10% flows	9371.97	9066.86
Total of the lowest 50% flows	451.72	1073.69
Summer flow volume (months 7-9)	439.13	795.31
Fall flow volume (months 10-12)	2022.92	2237.69
Winter flow volume (months 1-3)	8358.36	8454.27
Spring flow volume (months 4-6)	1711.39	1816.22
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	-5.80	Very good
Error in 10% highest flows	3.37	Very good
Error in 50% lowest flows	-57.93	Poor
Volume error – Summer	-44.79	Poor
Volume error – Fall	-9.60	Very good
Volume error – Winter	-1.13	Very good
Volume error – Spring	-5.77	Very good

Figure A-9 Validation results for the USGS 11102300 Rio Hondo below Whittier Narrows Dam gauging station



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	3.88	0.99
Lowest 50% cutoff value	0.55	0.01
Total in-stream flow	8756.24	7302.67
Total of the highest 10% flows	7132.97	7159.80
Total of the lowest 50% flows	177.84	3.60
Summer flow volume (months 7-9)	425.85	78.46
Fall flow volume (months 10-12)	1095.15	592.59
Winter flow volume (months 1-3)	6287.31	6272.36
Spring flow volume (months 4-6)	947.92	359.25
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	19.90	Fair
Error in 10% highest flows	-0.37	Very good
Error in 50% lowest flows	4839.33	Poor
Volume error – Summer	442.78	Poor
Volume error – Fall	84.81	Poor
Volume error – Winter	0.24	Very good
Volume error – Spring	163.86	Poor

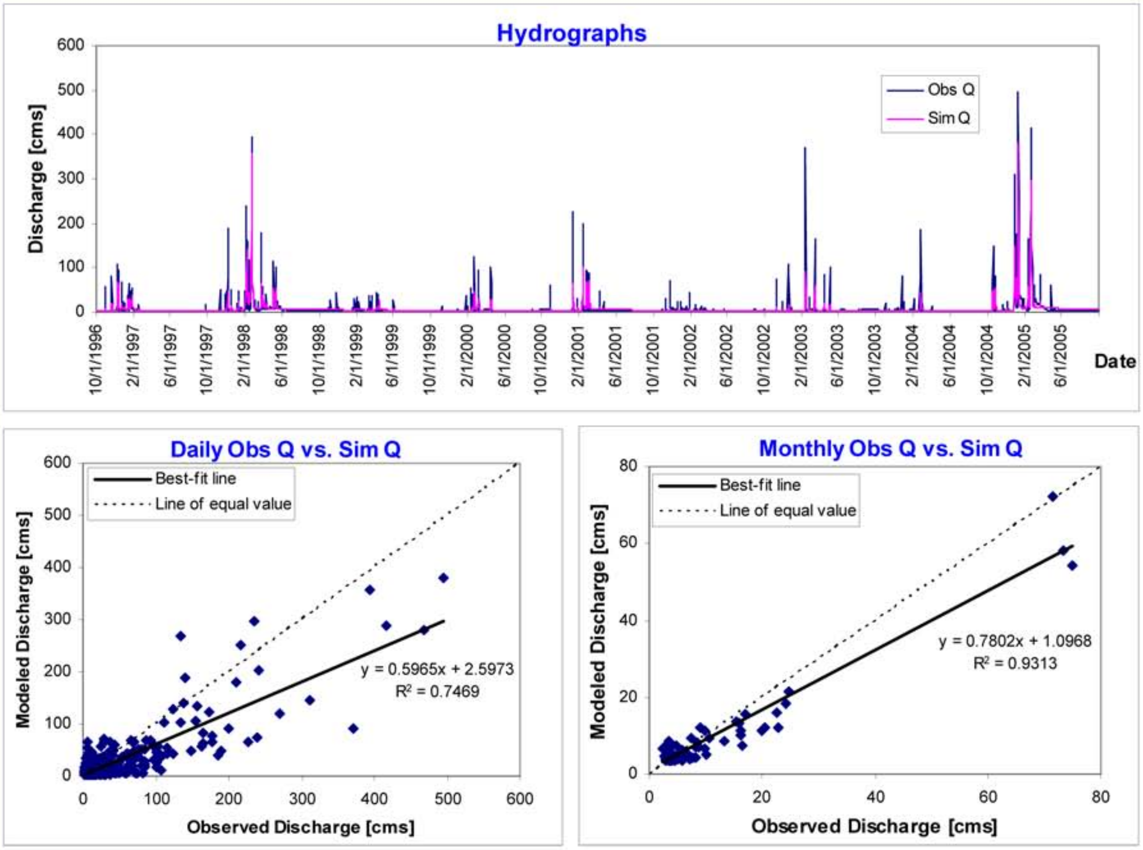
Figure A-10 Validation results for the LADPW F45B-R Rio Hondo above Stuart and Gray Road gauging station



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

Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	5.37	7.23
Lowest 50% cutoff value	3.09	2.41
Total in-stream flow	15995.70	20025.31
Total of the highest 10% flows	6535.58	13043.22
Total of the lowest 50% flows	4522.28	3242.34
Summer flow volume (months 7-9)	2667.96	1778.61
Fall flow volume (months 10-12)	2997.22	4011.02
Winter flow volume (months 1-3)	7055.15	11106.18
Spring flow volume (months 4-6)	3275.38	3129.49
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	-20.12	Fair
Error in 10% highest flows	-49.89	Poor
Error in 50% lowest flows	39.48	Poor
Volume error - Summer	50.00	Poor
Volume error – Fall	-25.28	Fair
Volume error – Winter	-36.48	Poor
Volume error – Spring	4.66	Very good

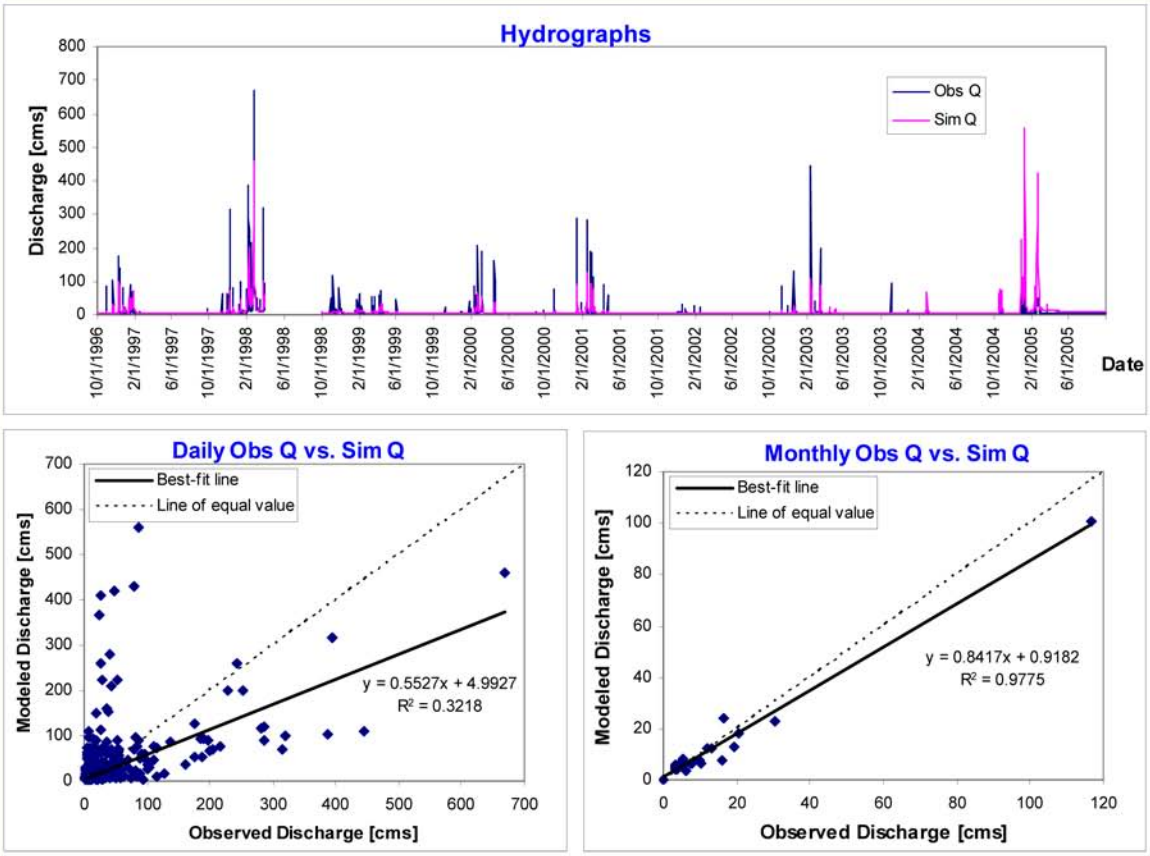
Figure A-11 Validation results for the LADPW F300-R Los Angeles River at Tujunga Avenue gauging station



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

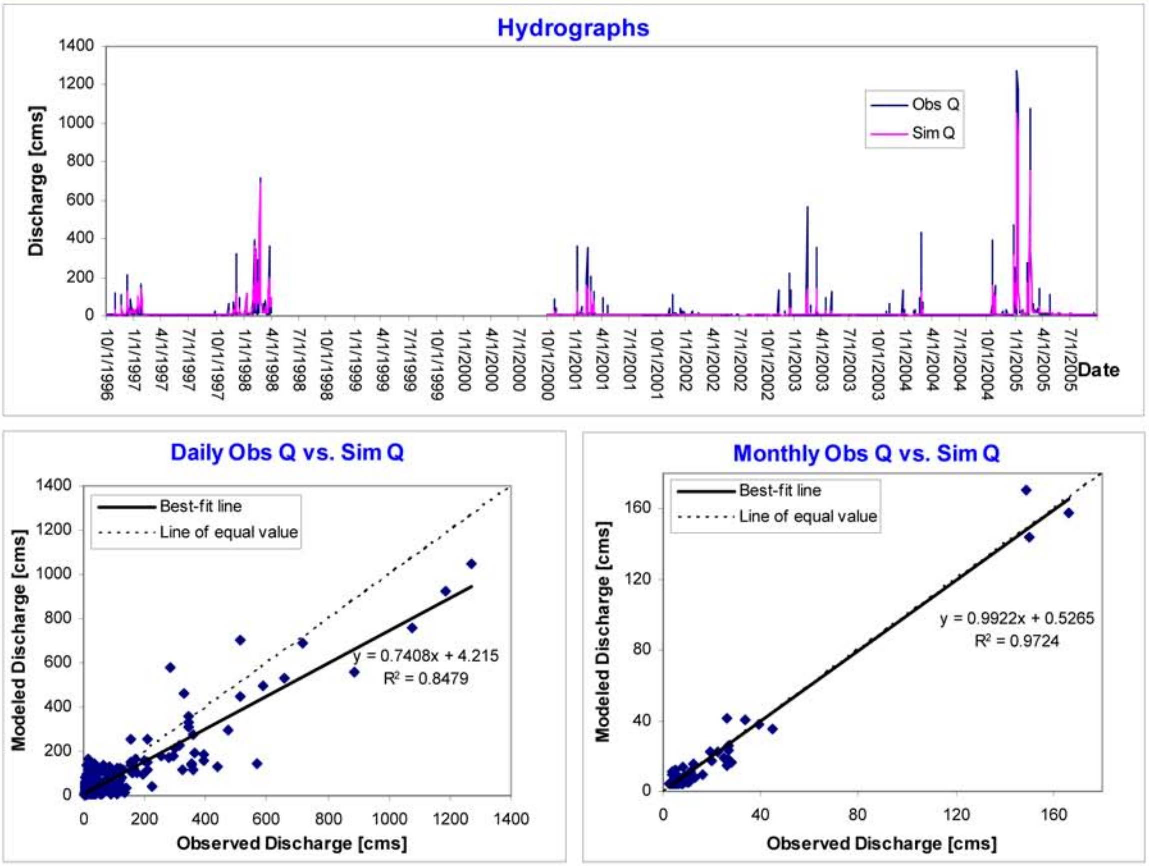
Summary	***MIKE BASIN Simulated Flows***	***Observed Flows***
Highest 10% cutoff value	8.83	7.83
Lowest 50% cutoff value	4.44	3.54
Total in-stream flow	24616.14	26961.43
Total of the highest 10% flows	10675.09	16139.47
Total of the lowest 50% flows	6455.46	5046.85
Summer flow volume (months 7-9)	3929.74	2919.27
Fall flow volume (months 10-12)	4653.03	5743.59
Winter flow volume (months 1-3)	11117.35	13832.47
Spring flow volume (months 4-6)	4916.02	4466.10
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	-8.70	Very good
Error in 10% highest flows	-33.86	Poor
Error in 50% lowest flows	27.91	Fair
Volume error – Summer	34.61	Poor
Volume error – Fall	-18.99	Fair
Volume error – Winter	-19.63	Fair
Volume error – Spring	10.07	Very good

Figure A-12 Validation results for the LADPW F57C-R Los Angeles River above Arroyo Seco gauging station



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	11.48	6.76
Lowest 50% cutoff value	4.83	3.71
Total in-stream flow	29247.63	24876.63
Total of the highest 10% flows	14630.74	14176.77
Total of the lowest 50% flows	6475.42	5382.15
Summer flow volume (months 7-9)	3625.29	2775.99
Fall flow volume (months 10-12)	5798.59	5879.71
Winter flow volume (months 1-3)	15332.60	12660.01
Spring flow volume (months 4-6)	4491.16	3560.93
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	17.57	Fair
Error in 10% highest flows	3.20	Very good
Error in 50% lowest flows	20.31	Fair
Volume error - Summer	30.59	Fair
Volume error - Fall	-1.38	Very good
Volume error - Winter	21.11	Fair
Volume error - Spring	26.12	Fair

Figure A-13 Validation results for the LADPW F34D-R Los Angeles River below Firestone Boulevard gauging station



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	11.48	6.76
Lowest 50% cutoff value	4.83	3.71
Total in-stream flow	29247.63	24876.63
Total of the highest 10% flows	14630.74	14176.77
Total of the lowest 50% flows	6475.42	5382.15
Summer flow volume (months 7-9)	3625.29	2775.99
Fall flow volume (months 10-12)	5798.59	5879.71
Winter flow volume (months 1-3)	15332.60	12660.01
Spring flow volume (months 4-6)	4491.16	3560.93
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	17.57	Fair
Error in 10% highest flows	3.20	Very good
Error in 50% lowest flows	20.31	Fair
Volume error - Summer	30.59	Fair
Volume error - Fall	-1.38	Very good
Volume error - Winter	21.11	Fair
Volume error - Spring	26.12	Fair

Figure A-14 Validation results for the LADPW F319-R Los Angeles River below Wardlow Road gauging station

Appendix B
Water Quality Calibration and Validation Graphs and Tables

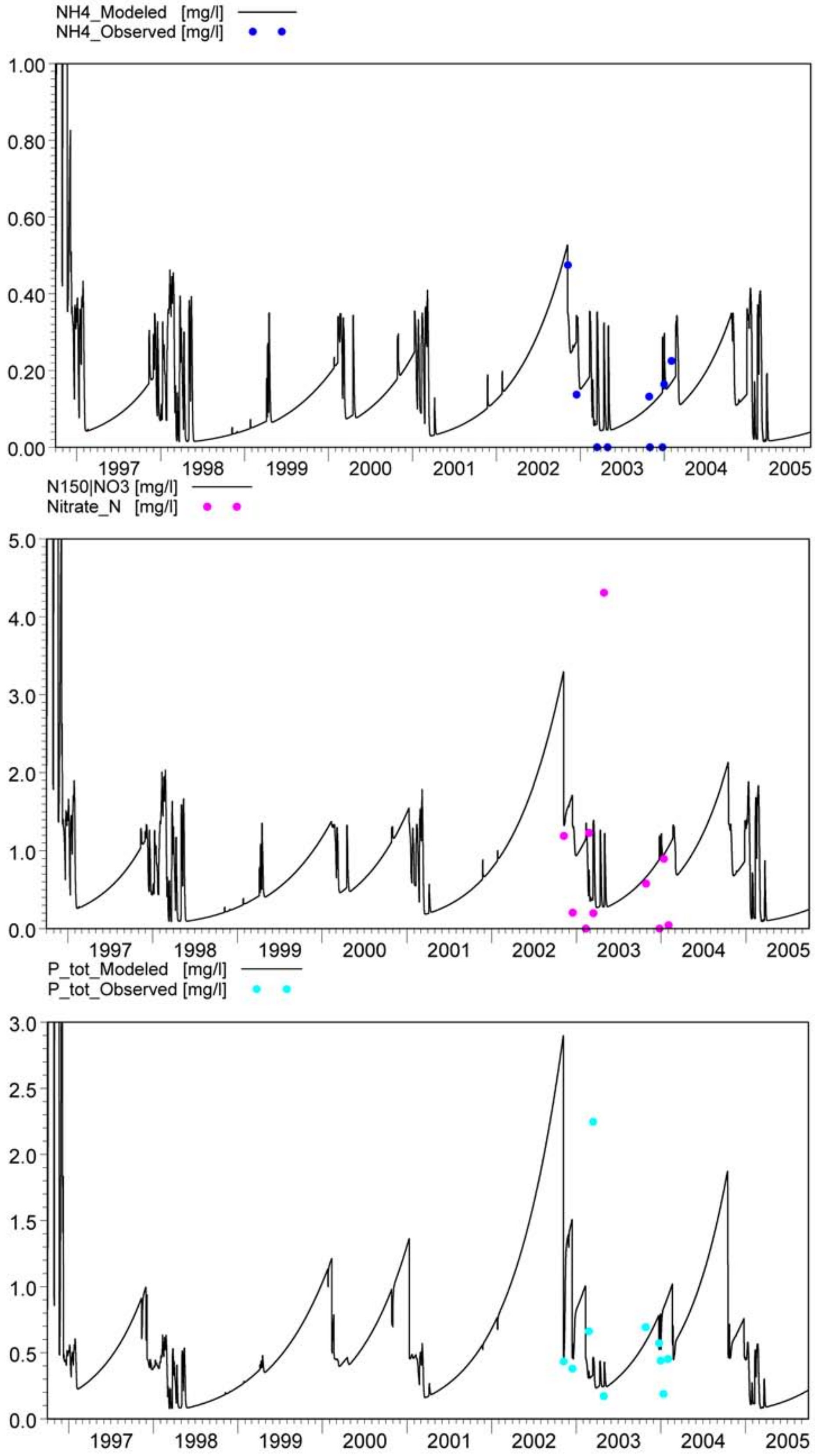


Figure B-1 Time series comparison of modeled and observed NH4, NO3, and TP at the TS01 Aliso Creek at Saticoy Street mass emission site

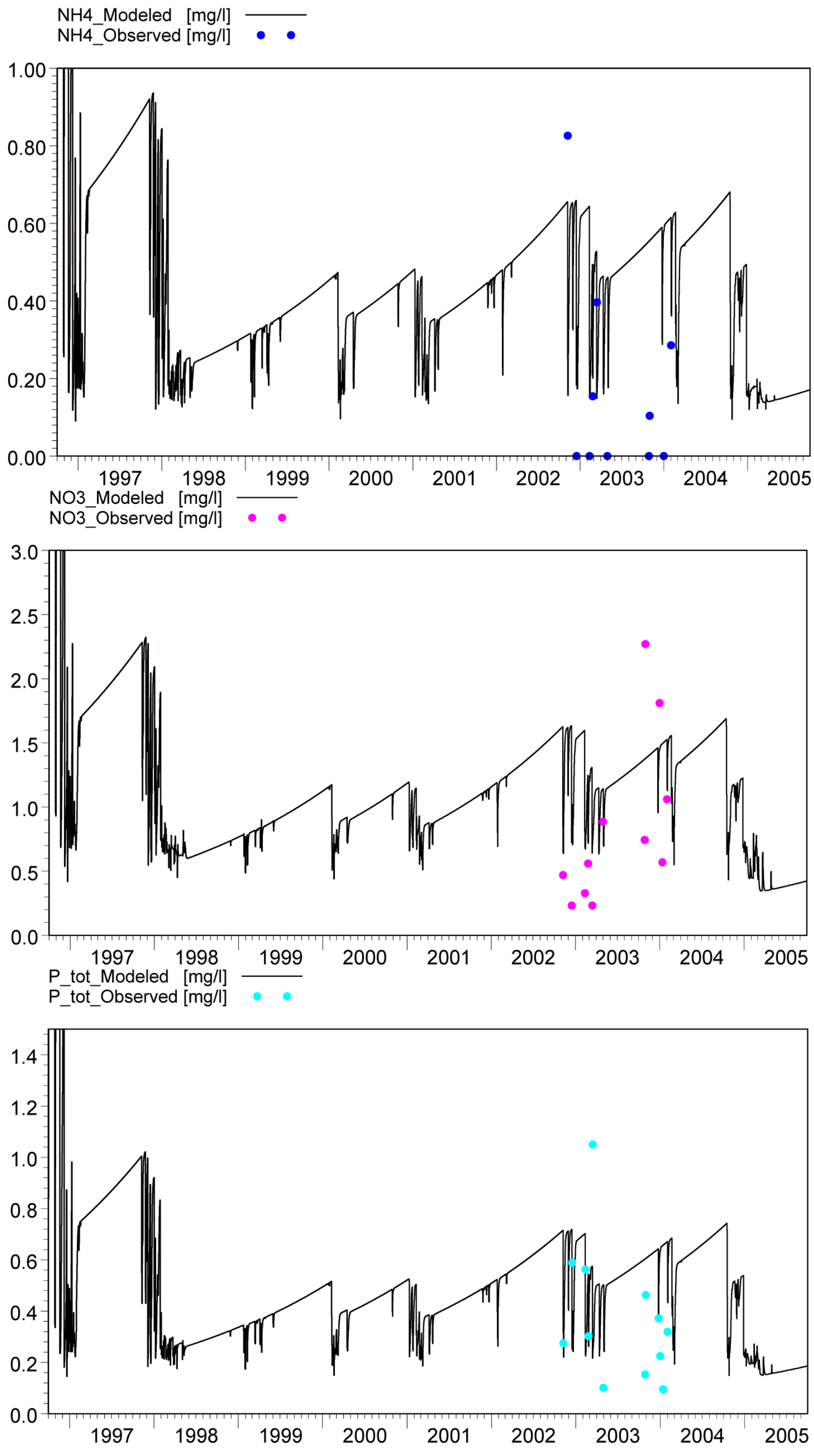


Figure B-2 Time series comparison of modeled and observed NH4, NO3 and P_tot at the TS04 Verdugo Wash site

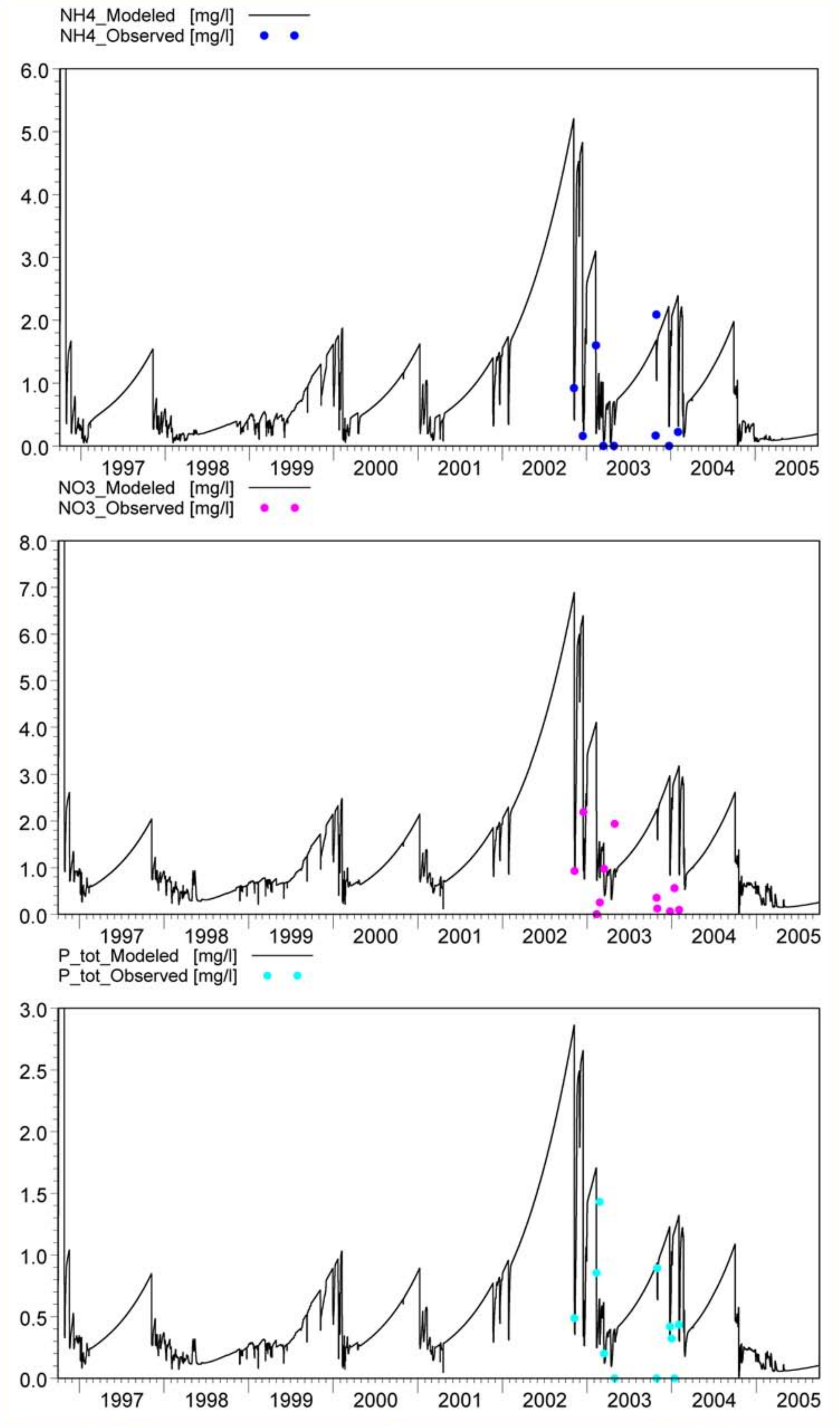


Figure B-3 Time series comparison of modeled and observed NH4, NO3, and TP at the TS05 Arroyo Seco at Griffin Avenue mass emission site

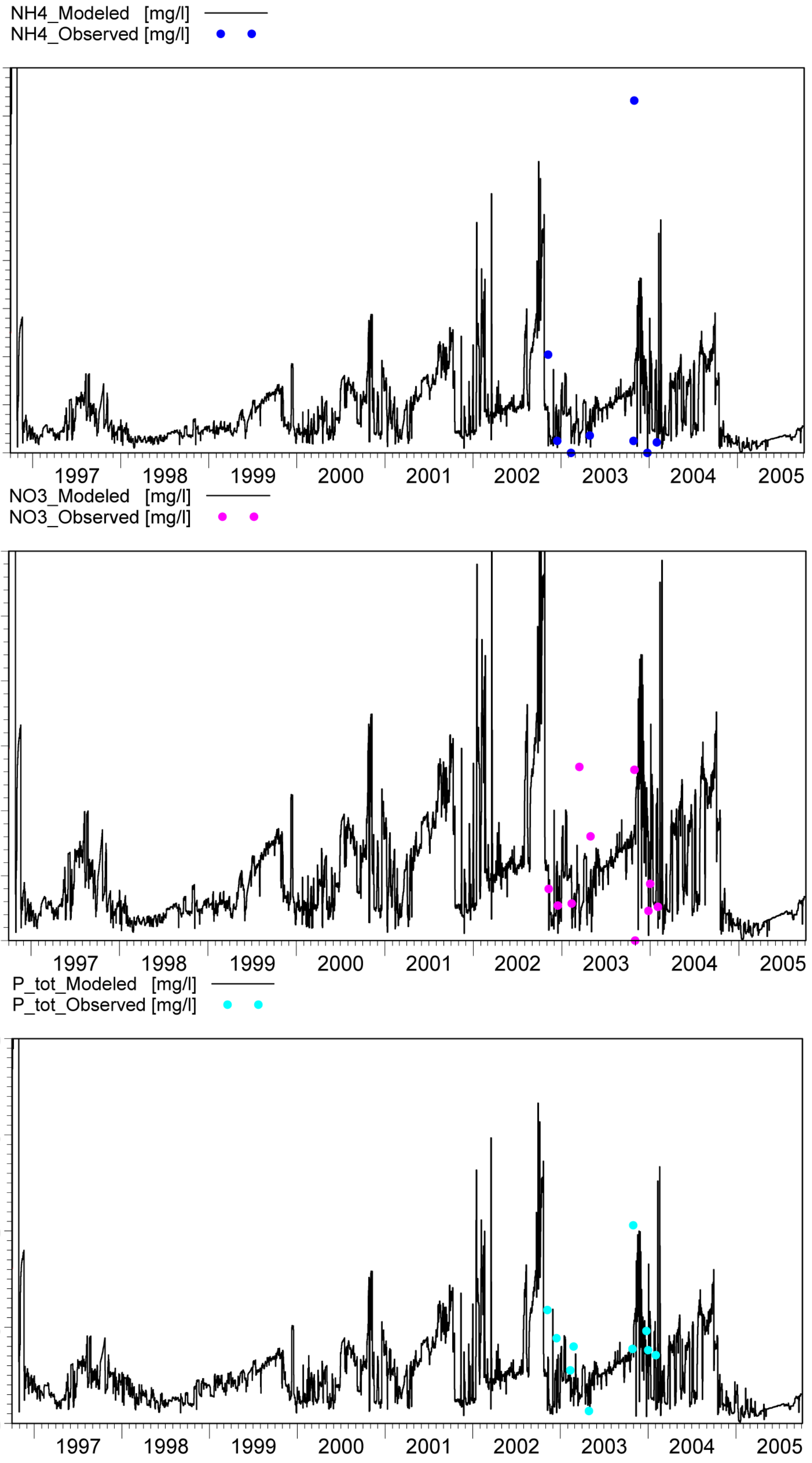


Figure B-4 Time series comparison of modeled and observed NH4, NO3, and TP at the TS06 Rio Hondo Channel at Beverly mass emission site

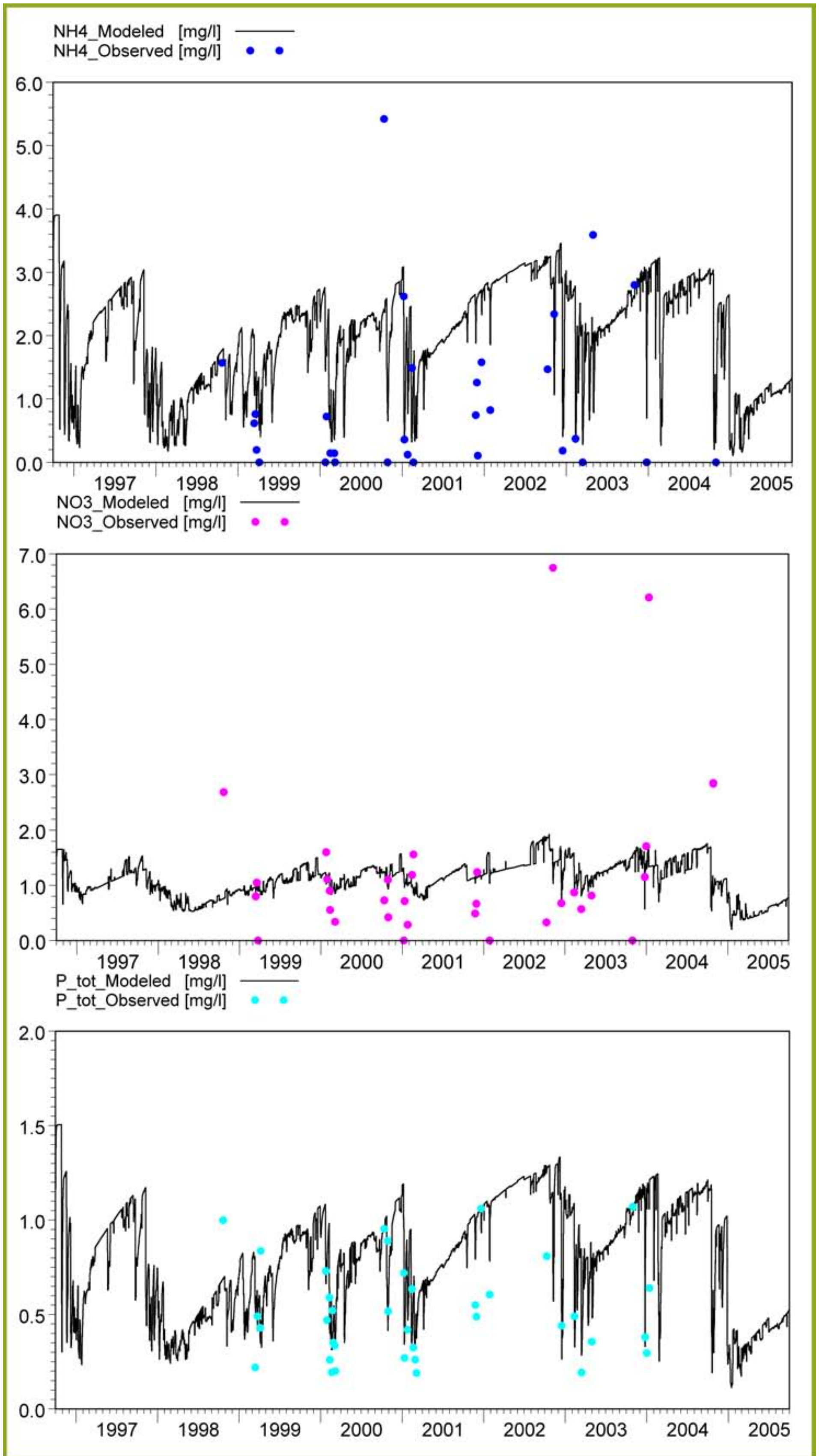


Figure B-5 Time Series comparison of modeled and observed NH4, NO3 and TP at the S10 Los Angeles River at Wardlow Road mass emission site