THE GREEN VISIONS PLAN

for 21st century southern california

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19. Hydrology and Water Quality Modeling of the Santa Monica Bay Watershed

Jingfen Sheng
John P. Wilson

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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.

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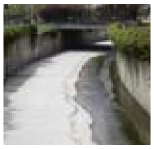

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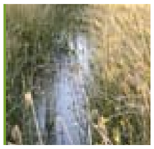
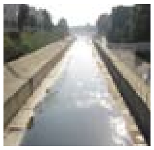




Executive Summary

The “Green Visions Plan for Twenty-first Century Southern California” project’s watershed health assessment seeks to support and inform region-wide planning efforts that promote habitat conservation, water quality protection, and the creation of new recreational opportunities. In this report, hydrologic models of the Green Vision Plan watersheds were developed for use as a tool for watershed planning, resource assessment, and ultimately, water quality management purposes. The modeling package selected for this application is the Danish Hydrology Institute’s (DHI) MIKE BASIN. MIKE BASIN is a watershed model of hydrology and water quality, which includes modeling of both land surface and subsurface hydrologic and water quality processes. It 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—09/2005). Both quantitative and qualitative comparisons were developed to support the model performance evaluation effort.

The calibration and validation results, based on the graphic comparison and error analyses described herein, demonstrate a fair to good representation of the observed flow data. Statistical comparisons and model performance evaluation were performed at three stream locations throughout the watershed, for annual runoff, daily and monthly streamflow, water balance components, and annul water quality. These comparisons demonstrate conclusively that the model is a good representation of the water balance and hydrology of the Topanga Canyon and Malibu Creek subwatersheds. The model has demonstrated consistently fair to good simulations of total water volume and high winter and spring flow conditions, but poor modeling of summer low flows for the minimally developed subwatersheds draining into Santa Monica Bay.

The water quality simulations did not match the mean concentrations and temporal variations in concentrations of NH4, NO3 and Total P. Graphically, some sampled concentrations were captured while others were missed in the pollutographs and it does not always predict the temporal variability of the pollutograph. The model results demonstrated the spatial distribution of the nutrient concentration and loading throughout the watershed. The highest NH4 loadings occur in the urbanized Ballona Creek and Dominguez Channel subwatersheds. The upper Malibu Creek, mainly the Hidden Valley area where many agricultural activities occur, and several catchments in Ballona Creek and Dominguez Channel contribute large NH4 and NO3 loadings. The Tapia WRF is a significant source of all three nutrient constituents to the Santa Monica Bay waters.

1 Introduction

The hydrology and water quality simulation presented in this report is a part of the Green Visions Plan for 21st Century Southern California project. The primary focus of the Santa Monica Bay Watershed water quality modeling is to determine the pollutant concentration and loads entering the stream network and to what degree surface waters are subject to water quality impairments. Accurate simulation of hydrology and water quality in the study area is difficult due to the complexity of the hydrologic processes in the semi-arid environment and the severity of human modifications to the natural systems. Increased urbanization has been shown to result in increased runoff and pollutant loading to receiving waters (USEPA 1995, USEPA Region 9 2004, Schueler and Holland 2000, Davis et al. 2001, Sheng and Wilson 2008). The watershed asset assessment for the GVP study area shows that the greater area of impervious surfaces associated with urban landscapes resulted in increased magnitude and frequency of surface runoff in the Ballona Creek and other urban watersheds (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 various sources of impairment scattered throughout the watershed (e.g. metals, bacteria, nutrients, trash, and toxicity) (CRWQCB-LAR, 2001a, 2004a, b, 2005, 2006; McPherson et al. 2002; Stein and Tiefenthaler 2004, Tetra Tech 2002). Models of various kinds (e.g. simple conceptual and spreadsheet models, TMDL mass balance models, EPA's HSPF model) have been deployed to determine allowable loadings for the various sources and for removing these impairments in the watershed. Different from all these studies, this report focused on the simulation of hydrology and nutrient loads and concentrations for the entire Santa Monica Bay watershed and demonstration of the spatial and temporal variation in nutrient loading within the watershed.

A basin scale model, MIKE BASIN was developed by the Danish Hydrology Institute (DHI; Portland, Oregon) and was used to represent the hydrologic and water quality conditions in the Santa Monica Bay 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 resources. The MIKE BASIN Water Quality (WQ) module adds the capacity to conduct water quality simulations. MIKE BASIN is structured as a network model in which the rivers and their major tributaries are represented by a network comprising branches and nodes. The branches represent individual stream sections while the nodes represent confluences and locations where certain activities may occur. MIKE BASIN is an extension to ESRI's ArcView GIS (Environmental Systems Research Institute, Redlands, California), such that existing GIS information can be included in the water resource simulations. The network of rivers and nodes is also edited in ArcView. The MIKE BASIN water allocation modeling structure is illustrated in Figure 1.

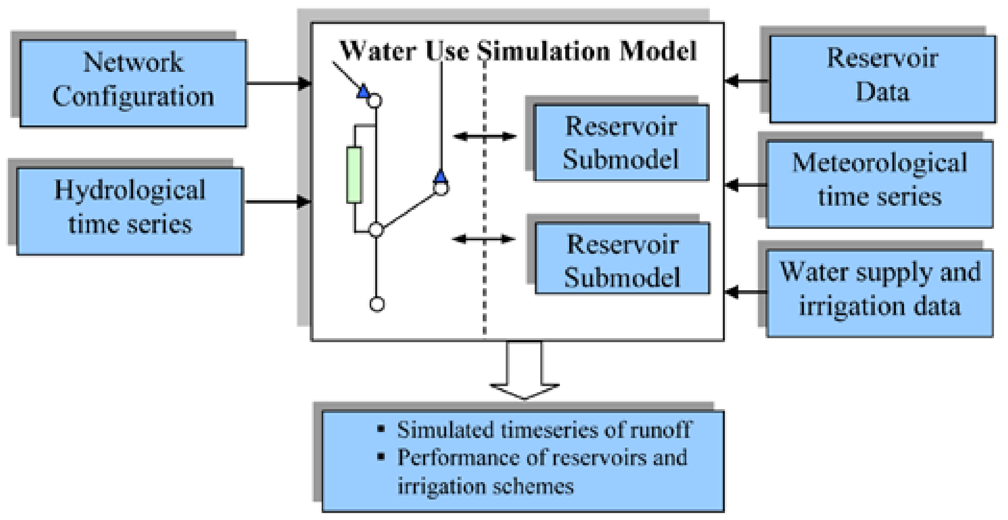


Figure 1 MIKE BASIN's water allocation modeling structure (DHI 2007)

MIKE BASIN operates on the basis of a digitized river network. Figure 2 shows the schematic layout of this network. All information regarding the configuration of the river branch network, location of water users, channels for intakes and outlets to and from water users, and reservoirs are defined by on-screen editing. Basic input to the model

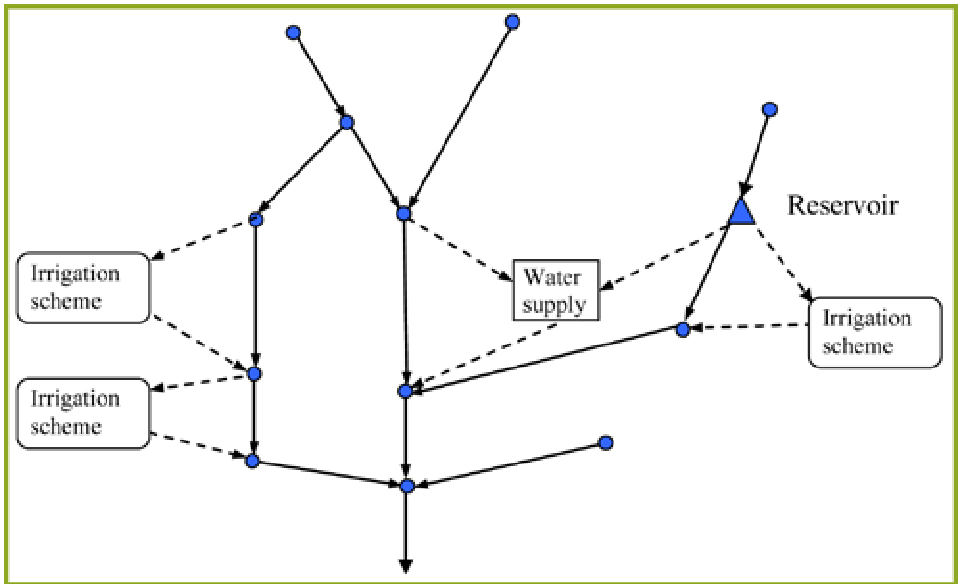


Figure 2 Schematic layout of MIKE BASIN's network modelling approach (DHI 2007)

consists of time series data of various types. A time series of catchment rainfall is all that is required to generate 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 describing hydraulic conditions in river reaches and channels, hydropower characteristics, groundwater characteristics, etc. may be used as well.

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

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

The SMB watershed has a wide variety of land cover and land use characteristics. Subwatersheds to the north are comprised of national recreation areas and other protected open space. Subwatersheds to the south encompass portions of Santa Monica and other coastal cities, and are almost entirely urbanized. Only three subwatersheds (Ballona Creek, Malibu Creek and Topanga Canyon) representing 64% of the total SMB watershed area are currently monitored. The water quality problems associated with wet weather in SMB appear to be amplified due to the dry climate. Not only are portions of SMB extremely urbanized, but rainstorms are infrequent, enabling pollutants to build-up for long time periods between storm events (Ackerman and Schiff 2001). The wet season in southern California extends from October to April. The majority of precipitation occurs in January and February. An average of 12 storm events per year is received in the study area (Stenstrom and Strecker 1993).

2 Data Needs for Watershed Hydrologic Modeling

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

2.1 Precipitation

Meteorological data are a critical component of the hydrology model. MIKE BASIN requires appropriate representation of precipitation and potential evapotranspiration (ET). Daily precipitation data are sufficient to represent hydrologic and water quality in the model at the watershed scale. Within the SMB watershed, the Los Angeles County Department of Public Works (LADPW), Ventura County Watershed Protection Department (VCWPD) and National Weather Service (NWS) maintain networks of precipitation stations, most of which have been continuously operating for 30 years or longer. Stations with daily records at least spanning from October 1996 to September 2005 were selected for the model (Table 1). Their locations within the SMB watershed are shown in Figure 3.

Some of the calibration stations have missing data in the time series. The missing periods were filled using nearby stations with values weighted based on the ratio of the annual averages over their common period record. The precipitation data were applied to the subwatersheds based on a Thiessen polygon approach using the selected gauges. A Thiessen

Table 1 Precipitation data records selected for the model

Station ID	Station Name	Latitude	Longitude	Elevation (ft)	Sources
42214	Culver City	34.000	-118.417	17	NCDC
45114	LA Municipal ARPT	33.933	-118.383	30	NCDC
49152	UCLA	34.067	-118.450	131	NCDC
716	LA Ducommun St Precip	34.053	-118.237	306	LADPW
121C	Lake Sherwood-County Fire S	34.141	-118.875	960	VCWPD
169	Thousand Oaks-Weather Station	34.179	-118.851	805	VCWPD
188A	Newbury Park-County Fire St	34.186	-118.929	640	VCWPD
228C	Beverly Hills City Hall	34.100	-118.394	250	LADPW
5B	Calabasas	34.157	-118.637	924	LADPW
1264	Calabasas Landfill	34.140	-118.710	800	LADPW
447C	Carbon Canyon	34.038	-118.649	50	LADPW
292D	Encino Reservoir	34.149	-118.516	1075	LADPW
20B	Girard Reservoir	34.152	-118.610	986	LADPW
482	Los Angeles – USC	34.021	-118.288	208	LADPW
1217	Los Angeles Country Club	34.069	-118.421	380	LADPW
794	Lower Franklin Reservoir	34.095	-118.411	585	LADPW
1070	Manhattan Beach	33.883	-118.389	182	LADPW
1266	Mission Canyon Landfill	34.144	-118.479	1150	LADPW
1129B	Nicholas Canyon	34.048	-118.916	340	LADPW
13C	North Hollywood - Lakeside	34.146	-118.354	550	LADPW
43D	Palos Verdes Estates	33.799	-118.391	216	LADPW
1011B	Palos Verdes Fire Station	33.757	-118.353	1272	LADPW
1252	Palos Verdes Landfill	33.761	-118.334	400	LADPW
1251	Palos Verdes-Whites Point	33.714	-118.317	100	LADPW
1253	Point Water Pollution Control	33.803	-118.283	40	LADPW
1216	Rancho Palos Verdes	33.753	-118.392	780	LADPW
42C	Redondo Beach City Hall	33.845	-118.389	70	LADPW
1006	San Pedro - City Reservoir	33.744	-118.296	150	LADPW
634C	Santa Monica	34.012	-118.491	94	LADPW
1194	Santa Ynez Reservoir	34.073	-118.566	735	LADPW
336	Silver Lake Reservoir	34.102	-118.265	445	LADPW
237C	Stone Canyon Reservoir	34.106	-118.454	865	LADPW
1158	Torrance Municipal Airport	33.800	-118.336	102	LADPW
11D	Upper Franklin Canyon Reservoir	34.119	-118.410	867	LADPW
680B	Westwood (UCLA)	34.069	-118.442	430	LADPW
1223	Woodland Hills - Sherman	34.168	-118.649	1035	LADPW
306H	Zuma Beach	34.021	-118.828	15	LADPW

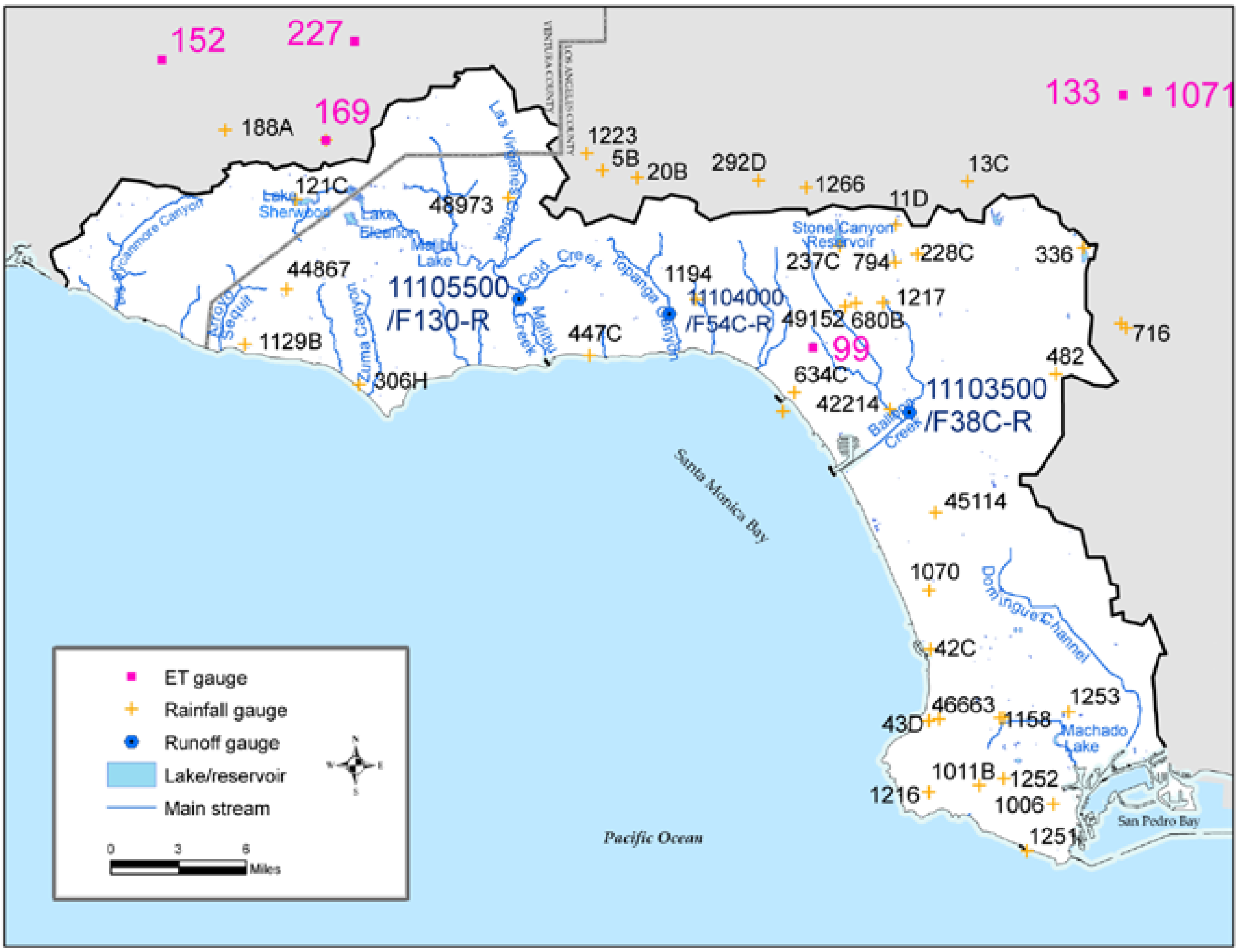


Figure 3 Precipitation, flow and evapotranspiration gauge locations in/near the Santa Monica Bay watershed

polygon approach is a standard hydrologic technique to define the watershed area that will receive the rainfall recorded at the gauge; it constructs polygons around each gauge using perpendicular bisecting lines drawn at the midpoint of connecting lines between each gauge.

2.2 Potential Evapotranspiration

Pan evaporation data were used to derive the estimates of potential evapotranspiration required by MIKE BASIN. There are two sites within or nearby the watershed that can provide daily/monthly ET data. One is provided by the California Irrigation Management Information System (CIMIS), and the other is located in Ventura County and operated by the VCWPD. The sites are listed in Table 2 below.

For model input, daily ET values are preferred. Daily data are available at CIMIS stations but only for limited (i.e. recent) periods. Therefore, monthly data ET were used for calibration and validation in this study. The monthly data were then disaggregated to daily values using the disaggregation function in the Time Series Analysis module of the model, which distributed each monthly value at the given latitude in that month. Cloud cover was not considered when distributing monthly evaporation to daily val-

Table 2 Evaporation stations in/near the Santa Monica Bay watershed

Source	Evaporation ID/Name	Latitude	Longitude	Elevation (ft)	Annual average (in)
CIMIS	99 Santa Monica	-118.476	34.041	8.64	3.64
VCWPD	169 Thousand Oaks-West	-118.851	34.179	805	5.01

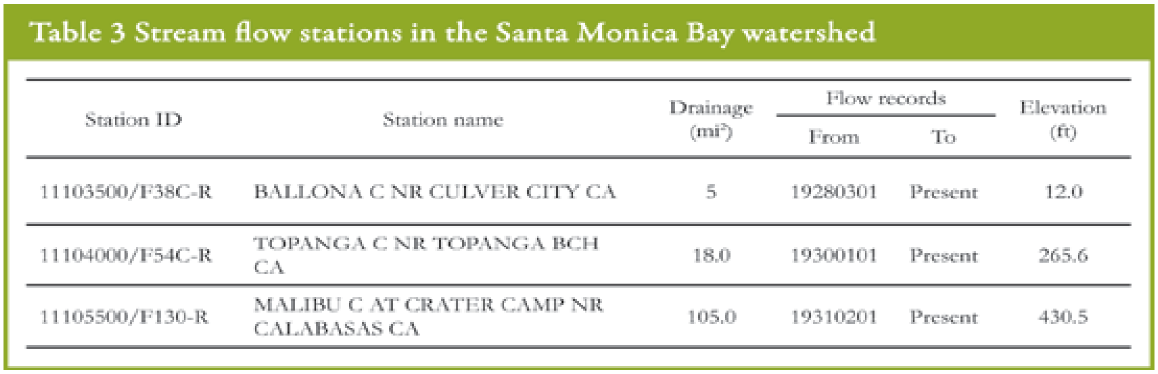


Table 3 Stream flow stations in the Santa Monica Bay watershed

Station ID	Station name	Drainage (mi^2)	Flow records		Elevation (ft)
			From	To	
11103500/F38C-R	BALLONA C NR CULVER CITY CA	5	19280301	Present	12.0
11104000/F54C-R	TOPANGA C NR TOPANGA BCH CA	18.0	19300101	Present	265.6
11105500/F130-R	MALIBU C AT CRATER CAMP NR CALABASAS CA	105.0	19310201	Present	430.5

ues due to lack of cloud cover data. The climatic map of the region shows an estimated pan coefficient of 0.70-0.75, and the value of 0.74 recommended by Aqua Terra Consultants (2004) was used to estimate potential evapotranspiration in the model runs.

2.3 Streamflow

To calibrate the model, simulated daily streamflow data were compared with observed daily flows. Daily flow records from 10/1/1996 to 09/30/2005 were obtained for three stream gauges located on the Malibu, Topanga Canyon and Ballona Creek tributaries (Figure 1). The gauge USGS 11104000 was selected for the primary calibration and the other two used for further validation of the model performance (Table 3).

2.4 Point Source Discharges

The Tapia Water Reclamation Facility (Tapia WRF) wastewater treatment plant was configured in the model due to its large associated loading. This facility contributes significant flow in the winter months to Malibu Creek or Las Virgenes Creek through discharge points 001 and 002 (Table 4). No discharge is currently routed to the percolation ponds. Currently, discharge to Malibu Creek is not allowed during the summer season when the sand berm forms and closes off the entrance to Malibu Lagoon from the ocean (CRWQCB-LAR 2002). The mean summer effluent discharge rates from April to September ranged from <0.1 to 0.6 mgd. In comparison, the mean discharge rates during the winter months (October to February) were approximately 8 to 10 mgd (LVMWD 1996). Daily discharge data were not available for the simulation period at the two discharge points. Average design flow rates were used in the model simulation from October 1996 to September 2005. Table 4 characterizes the median concentrations for NH4, NO3, and total P from the Tapia WRF point source (Tetra Tech 2002).

2.5 Water Regulation Data

A number of lakes, reservoirs and dams are situated within the watershed including Westlake Lake, Lake Sherwood, Lake Eleanor, and Lake Lindero in the headwater areas; Malibu Lake along the middle part of Malibu Creek; the Upper Stone Canyon and Lower Stone Canyon Reservoir complex that provides water to communities in the Santa Monica Mountains and West Los Angeles; Lake Hollywood,

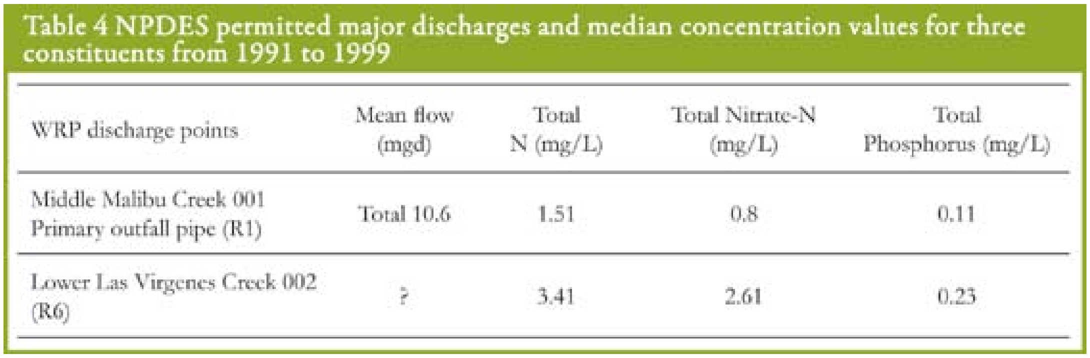


Table 4 NPDES permitted major discharges and median concentration values for three constituents from 1991 to 1999

WRP discharge points	Mean flow (mgd)	Total N (mg/L)	Total Nitrate-N (mg/L)	Total Phosphorus (mg/L)
Middle Malibu Creek 001 Primary outfall pipe (R1)	Total 10.6	1.51	0.8	0.11
Lower Las Virgenes Creek 002 (R6)	?	3.41	2.61	0.23

a man-made reservoir to store and provide treated water to the distribution system via pipelines; Upper and Lower Franklin Canyon Reservoir; and Machado Lake, also known as Harbor Park Lake which is an urban lake that serves as the flood retention basin for urban drains. Detailed data such as spillway crest, minimum pool, water conservation pool, flood control levels, and height-discharge lookup tables that are preferred by the model configuration were not available. Assumed simple reservoir nodes that may not reflect the real operations were added to the model and this lack of knowledge of the dam operating schedules may have limited our ability to estimate low flows in the watershed.

2.6 Water Quality Data

The variability of non-point source contributions is represented through dynamic representation of hydrology and land use practices. Selected water quality constituent loading fluxes (e.g. nitrogen, phosphorus) associated with different land uses were obtained from SCCWRP and LADPW. Land use data were obtained from SCAG (2001). Event mean fluxes by land use were estimated by averaging a large number of water quality samples taken on certain types of land use classes (Table 5). 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 complex runoff behavior.

Most of the agricultural activity that occurs in the Malibu Creek watershed consists of pastures and grazing in the Hidden Valley area. Smaller agricultural areas are found in parts of the Stokes Creek, Lower Las Virgenes Creek, and Triunfo Creek subwatersheds. Orchards or vineyards occur in small areas within the Triunfo Creek, Hidden Valley, Lower Malibu Creek, and Malibu Lagoon subwatersheds. Agricultural lands introduce nutrients to waterways through both surface runoff and erosion during storms and through shallow groundwater flows. The nutrient sources include fertilizers applied during cultivation; organic litter from the plants, grasses, or trees; erosion of the surface soils; waste accumulation from grazing animals; and soluble nutrients released during the decomposition and mineralization of plant litter and animal waste. Manure produced by horses, cattle, sheep, goats, birds, and other wildlife in the watershed are sources of both nutrients and bacteria. These loads can be introduced directly to the receiving waters in the case of waterfowl or cattle wading in streams, or they may occur as nonpoint sources during storm runoff. Horses are the most prevalent domestic animals in the Malibu Creek watershed.

Domestic septic systems are a significant source of nutrients, even when they are well sited and functioning properly, because they introduce nutrients to shallow groundwater that may eventually enter surface waters. Nitrogen is particularly mobile in groundwater, while phosphorus has a tendency to be adsorbed by the soils. Except for the city of Malibu, most of the medium to high-density residential developments in the watershed are on sewer systems. However, septic systems are still used in lower density rural residential areas and in the city of Malibu. The total number of systems in the watershed was estimated at 2,420 in 2001 (Tetra Tech 2002). Several hundred thousands of gallons per day are estimated to be discharged from private residences in the Malibu area (CRWQCB-LAR 2001b). While it is presumed that most of these systems are providing adequate treatment of bacteria and nutrients, Warshall and Williams (1992) estimated that approximately 30 single family residences with onsite systems were "short circuited" and therefore contributing elevated levels of bacteria and nutrients to the Malibu Creek outlet nearly 20 years ago. Unfortunately, the extent of the locations, designs, depth to groundwater and current performance of these systems could not be quantified from existing data.

In the MIKE BASIN Load Calculator, the impact of septic systems on surface water quality can be configured as a function of population and treatment efficiencies of the systems. The treatment efficiencies vary between 0 and 1, with 0 representing no retention and 1 representing complete retention. Treatment efficiency values for various zones were obtained for three constituents during the calibration process (Table 6) and the zone boundaries were designated in accordance with the upstream subwatersheds

Table 5 Event mean flux values for selected constituents

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

Table 6 Calibrated treatment efficiency values for different zones

Zone	NH4	NO3	TP
Ballona Creek	0.985	0.99	0.995
Dominguez Channel	0.985	0.99	0.995
Malibu Creek and others	1	0.4	0.7

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 square grid cells measuring approximately 300 m on a side 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 subwatershed is the sum of the loadings from all sources and then specified as properties of the catchment in the model. The estimated concentrations were compared with the sample data for the graphic error analysis. Figure 4 shows the water quality monitoring sites including mass emission and land use sites in the watershed.

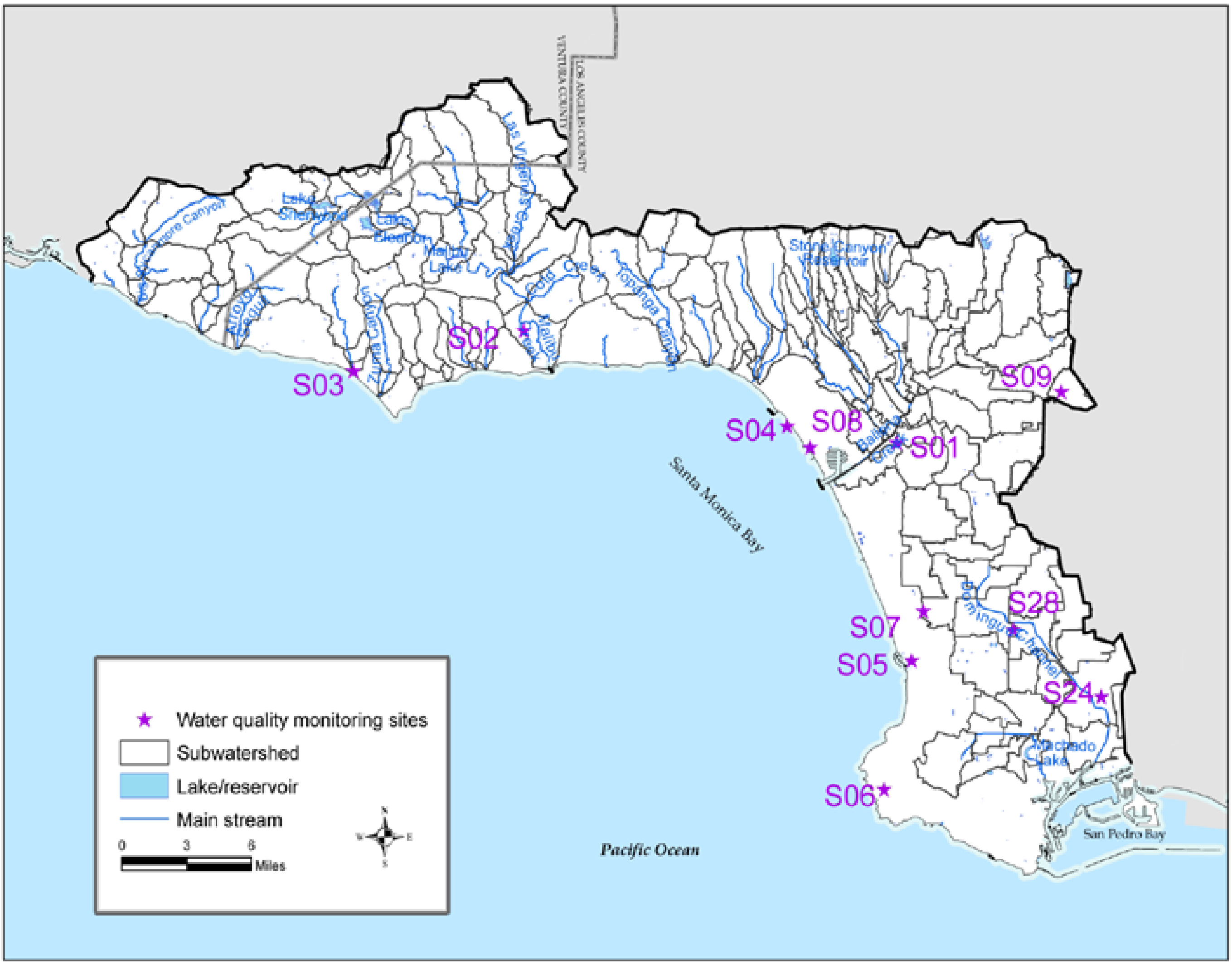


Figure 4 Watershed and stream segmentation

Samples at land use sites were taken in specific years and no reoccurring sample data are available at these sites. Table 7 lists three mass emission sites that have sample data suitable for model calibration and/or validation. Our goal is to investigate long-term average loadings to the receiving waters; therefore, mean flux and other static pollutant sources are adequate to represent the spatial variations in constituent loadings across the watershed. However, we would need to be able to characterize inter-storm and intra-site variability to estimate loads on shorter time scales.

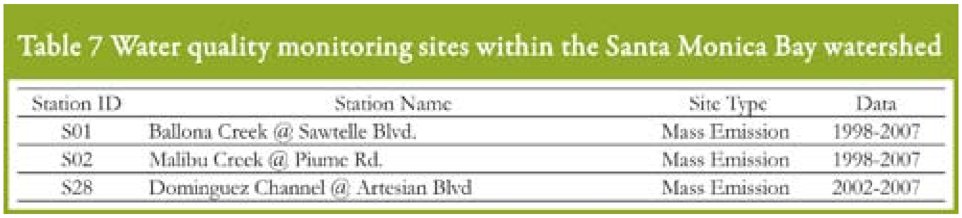


Table 7 Water quality monitoring sites within the Santa Monica Bay watershed

Station ID	Station Name	Site Type	Data
S01	Ballona Creek @ Sawtelle Blvd.	Mass Emission	1998-2007
S02	Malibu Creek @ Piume Rd.	Mass Emission	1998-2007
S28	Dominguez Channel @ Artesian Blvd	Mass Emission	2002-2007

3 Subwatershed Delineation and Characterization

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

For the SMB watershed, this segmentation was primarily based on the stream networks, topographic variability, and secondarily on the location of flow and water quality monitoring stations, consistency of hydrologic and land use factors, and the existing catchment boundary layer. The stream network was generated from the 1:24K NHD data set with minor revisions from various sources of aerial imagery, storm drainage data and topographic maps (Sheng et al. 2007). Catchment boundaries were delineated for each individual river segment using the improved 1:24K NHD dataset and the Nature Conservancy Tool (FitzHugh 2005; Sheng et al. 2007). The highly segmented catchment units were accordingly lumped into larger subwatersheds based on the flow direction, stream network, drain network, land use map, and stream/water quality gauges. The entire watershed was aggregated into 145 subwatersheds in the final MIKE BASIN model runs (Figure 4). Many tiny coastal catchments where tributaries run very short distances to the ocean were not included in the modeling, which focuses on the Malibu Creek, Ballona Creek, Topanga Canyon, and Dominguez Channel subwatersheds.

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 the ground water storages (Figure 5). The NAM model was prepared with nine parameters representing four default storages. These five parameters were specified for each representative subwatershed (Table 8). Parameter values were derived from the rainfall-runoff calibration implemented in several representative subwatersheds (see Figures A-1 through A-4 for additional details). Initial values of overland flow, interflow, baseflow, and groundwater storage were also specified for each of the MIKE BASIN subwatersheds that required rainfall-runoff modeling.

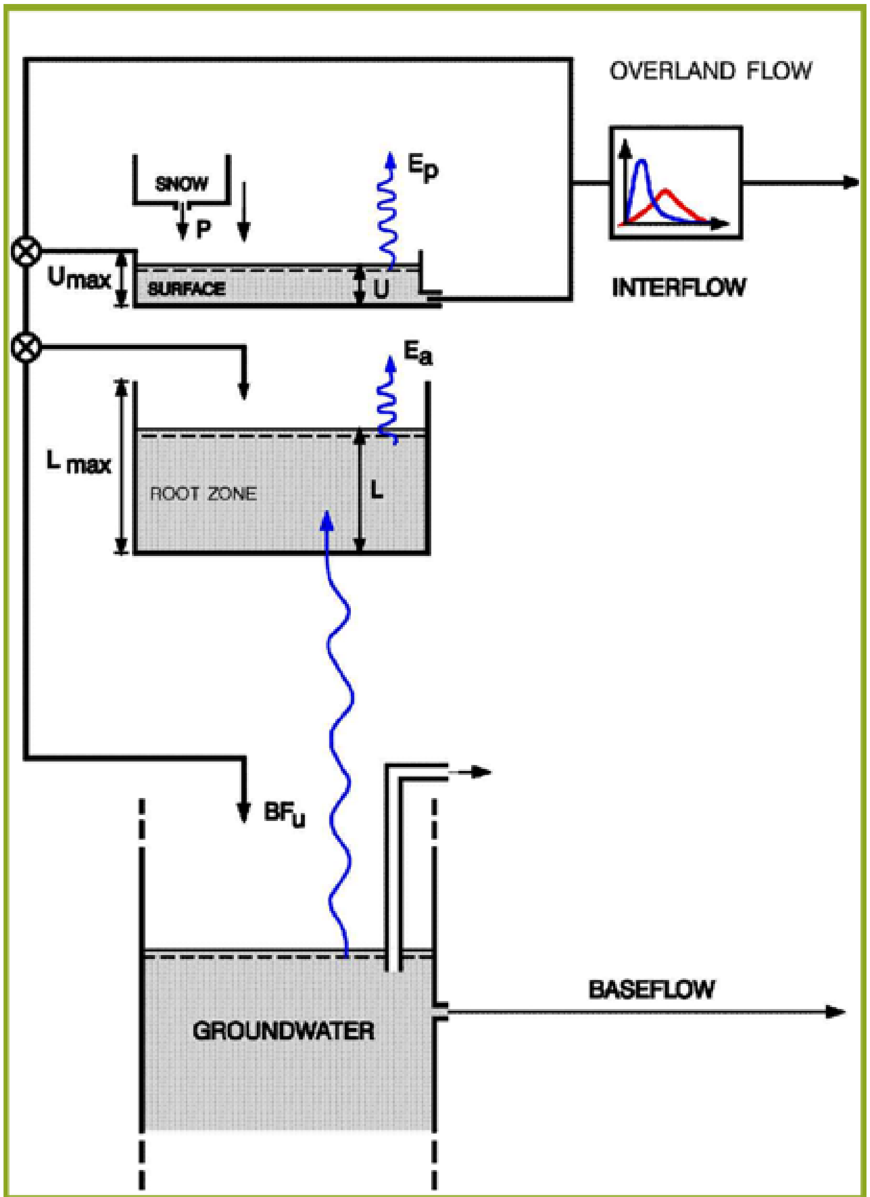


Figure 5 NAM model schematic

The NAM model requires precipitation and evapotranspiration input data. The Thiessen polygon method was used to determine precipitation time series for each subwatershed by assigning precipitation from a meteorological station to a computed polygon representing that station's data. The influence of storm pattern and elevation on the precipitation was evaluated by comparing the annual average precipitation derived from the ANUSPLIN

Table 8 Main NAM parameters

Symbol	Definition	Usual Value	Implications
Umax	Maximum surface storage content	10-25 mm	Evaporation; small peaks
Lmax	Maximum root zone storage content	50-250 mm	Evaporation; water balance
CQof	Overland flow coefficient	0.01-0.99	Divides excess rainfall in runoff and infiltration
TOF	Root zone 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

(Hutchinson 1995) simulated precipitation surface with the annual observations. The comparisons implied that current precipitation observations are spatially adequate in representing precipitation distribution for the sub-catchment level that we delineated. As a result, no modifications were made to the precipitation observations and each subwatershed was assigned precipitation and evapotranspiration time series using the Thiessen polygon method.

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 tasks for the water quality simulations. Upon completion of the calibration and validation at selected locations, a calibrated dataset containing parameter values for rainfall runoff simulation for each selected subwatershed was developed. Calibration is the adjustment or fine-tuning of rainfall-runoff modeling parameters to reproduce observations. The calibration was performed on the Topanga Canyon subwatershed from 10/1/1996 to 9/30/2005 and the values were extrapolated for all ungauged subwatersheds exhibiting similar physical, meteorological, and land use characteristics. Subsequently, model validation was performed to test the calibrated parameters at two more locations for the simulation period from 10/1/1996 to 9/30/2005, without further adjustment.

Hydrology is the first model component calibrated because estimation of pollutant loadings relies heavily on flow prediction. The hydrology calibration involves a comparison of model results to in-stream flow observations at selected locations. After comparing the results, key hydrologic parameters were adjusted and additional model simulations were performed. This iterative process was repeated until the simulation results represented the hydrological behaviour 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 modelling the rainfall–runoff process at the catchment scale, the total catchment runoff often constitutes the only available information for evaluating this objective. Thus, the amount of information provides certain limitations on how to evaluate the calibration objective.

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

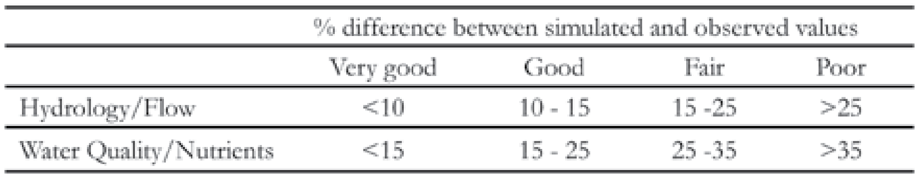
It is very important to note that, in general, trade-offs exist between the different objectives. For instance, one may find a set of parameters that provide a very good simulation of peak flows but a poor simulation of low flows, and vice versa.

The model's performance was evaluated through time-variable plots and regression analyses for each station on both a daily and a seasonal basis. Some general guidance used by EPA's HSPF model users over the past decade was adopted to help assess the MIKE BASIN model accuracy (e.g. Donigian 2000) (Table 9). Table 10 also presents the range of coefficient of determination (R^2) values that may be appropriate for judging how well the model is performing based on the daily and monthly simulations.

4.2.1 Hydrology Calibration Results

Figure A-1 shows the calibration results for the USGS11104000/F54C-R Topanga Canyon gauging station near Topanga Beach. The table in Figure A-1 summarizes the calibrated parameters. A nine-year time series plot of modeled and observed daily flows is presented here along with a mass curve showing cumulative runoff volume of the stream versus time for both observation and simulation data. Regression analyses were performed for daily values. The graphs

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

Table 10 R^2 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

at the bottom Figure A-1 show that the model performs well in reproducing daily flows given a coefficient of determination (R^2) of 0.81.

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

4.2.2 Hydrology Validation Results

After calibrating hydrology, the model was implemented using calibrated hydrologic parameters at two more locations along Malibu and Ballona Creeks for the period 10/1/1996 to 9/30/2005. Calibrated parameters obtained from the Topanga Canyon subwatershed were applied to all natural forested or minimally developed catchments. No calibration data are available for the urban catchment; therefore, parameters calibrated for the Alhambra urban subwatershed in the Los Angeles River watershed were adopted and applied to all urban subwatersheds such as those draining into Ballona Creek and the Dominguez Channel. Validation results were assessed through time-variable plots and regression analyses for the USGS 11105500/ F130-R MAILBU CREEK AT CRATER CAMP NR CALABASAS CA and USGS 11103500/F38C-R BALLONA CREEK NR CULVER CITY CA gauging stations in Figures A-2 and A-3.

The USGS 11105500/ F130-R gauge located in Malibu Creek near the city of Calabasas captures runoff from 272 km^2, or roughly 52% of the subwatershed. The watershed is approximately 86% undeveloped and largely pervious. The model provided fair simulations of the total water volume and water volumes in spring and winter, but it also over-predicted the flows in all seasons (Figure A-2). All seven annually occurring winter storm events were reflected on the prediction curve. Unlike the simulation in Ballona Creek, some augmented winter storm events that result from the extensive impervious land surfaces were not captured by the model. This shortcoming reoccurred in all five of the watersheds in the GVP study area. It shows the difficulties encountered using MIKE BASIN to model flows and water balances in heavily urbanized watersheds. The USGS 11103500/F38C-R gauges the flow from 230 km^2 (i.e. roughly 44% of the area) of the Ballona Creek subwatershed. Unlike Malibu Creek, the Ballona Creek subwatershed is approximately 88% developed and largely impervious, and therefore is a distinctly different watershed. The model provided reasonably fair to good simulations of total water volume and high winter and spring flow conditions, but poor simulations of summer low flows (Figure A-3). The model did not produce all storm peaks as it did for the Malibu Creek and Topanga Canyon subwatersheds with minimum levels of development.

4.3 Water Quality Calibration and Validation

MIKE BASIN can simulate the quality in surface and ground waters resulting from point and non-point sources. The water quality module then simulates the reactive steady-state transport of these substances. First-order rate laws are assumed for all default substances predefined in the model, including NH4, NO3, DO, BOD, TP, and E-coli. This steady-state approach is consistent with MIKE BASIN's solution to the water allocation problem. Thus, advection cannot be modeled properly with MIKE BASIN, such that pulses of solute entering the stream do not travel downstream as simulation time advances. Specific routing approaches can be defined (e.g. linear, Muskingum, wave translation) in individual reaches, such that the residence time and the effects of mixing between reach storage and inflows can be properly specified in the model.

After the model was calibrated and validated for hydrology, water quality simulations were performed from 10/1/1996 through 9/30/2005. The water quality load calculator was calibrated by comparing model output with pollutographs for NH4, NO3, and TP observed at two mass emission 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 simulated pollutographs and the observations.

To assess the predictive capability of the model, the final output was graphically compared to observed data. Figures B-1 and B-2 present the time-series plots of model results and observed data at two monitoring sites. The LADPW monitors mass emission stations S01 at Ballona Creek and S02 at Malibu Creek. NH4, NO3, TP and other constituents were analyzed periodically for certain selected wet storm events and dry weather conditions. 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 analysis.

The water quality simulations are not satisfactory in terms of reproducing the mean concentrations and temporal variations in the three constituent concentrations. Graphically, some sampled concentrations were captured while others were missed in the pollutographs and they do not always predict the temporal variability of the pollutograph. The mean values of the modeled and observed time series are summarized in Table 11. The model resulted in over-estimated mean concentrations of NH4, NO3, and TP by various degrees. Many extremely low and high concentration values of NH4 and NO3 were not simulated by the model 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 pulse or dilution that likely occurs over very short time periods.

The simulation for TP was better with much smaller errors. The variation of NH4 and NO3 is much larger than TP, which may reflect much more complicated (dynamic) processes on the land surface and also in the water bodies themselves. The errors resulting from the simulations for the Malibu Creek site were larger than those produced for the Ballona Creek site, although Figure B-2 shows a better fit with the sample observations in the Malibu Creek subwatershed.

The variations of flow and water quality in the Malibu and

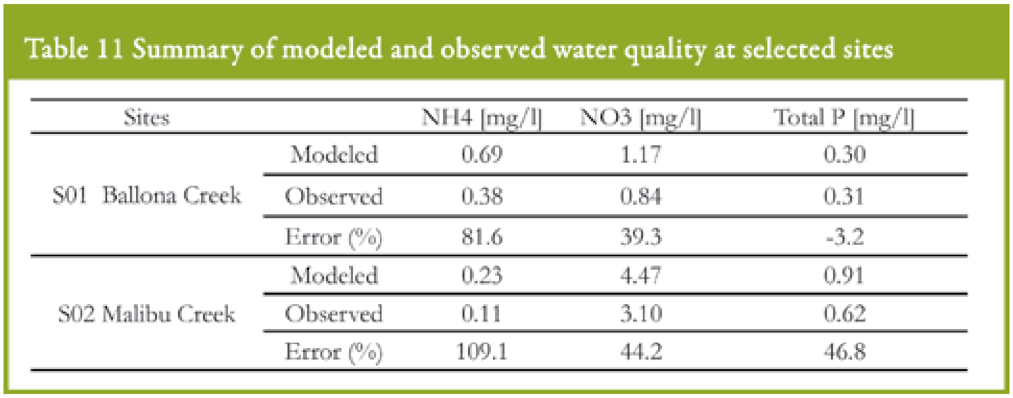


Table 11 Summary of modeled and observed water quality at selected sites

Sites		NH4 [mg/l]	NO3 [mg/l]	Total P [mg/l]
S01 Ballona Creek	Modeled	0.69	1.17	0.30
	Observed	0.38	0.84	0.31
	Error (%)	81.6	39.3	-3.2
S02 Malibu Creek	Modeled	0.23	4.47	0.91
	Observed	0.11	3.10	0.62
	Error (%)	109.1	44.2	46.8

Ballona Creek subwatersheds are indicative of conditions in the SMB watershed. Figure 6 depicts time-series plots of modeled monthly flows in acre feet and as a percentage of the corresponding annual flows at the outlets of the Malibu (left) and Ballona (right) Creek subwatersheds.

Average monthly in-stream flow in Malibu Creek was about 5,000 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 65,000 AF compared to the lowest volume of 1,000 AF predicted for many dry months (Figure 6). The contributions of monthly discharges to the annual total varied from 50 to 2%. The winter flows contribute the majority of the annual flow to the ocean. The flows are significantly lower and less variable during the dry summer period. From 1996 to 2005, dry-weather flows accounted for 20.7% of the annual discharge from the Malibu Creek watershed. A similar pattern was observed in Ballona Creek as well. The dry-weather flows accounted for 26.7% of the annual discharge from Ballona Creek.

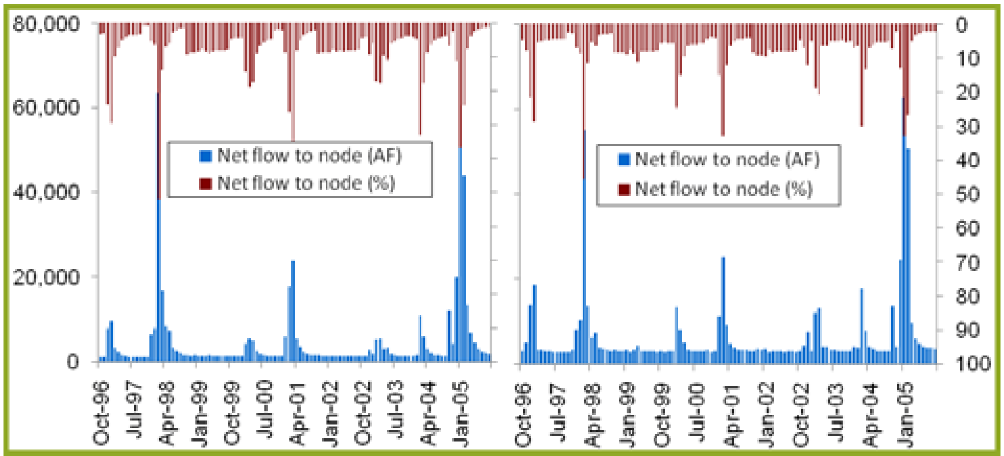


Figure 6 Flow volumes in acre feet and as a percentage of annual flows for Malibu and Ballona Creeks

The contributions of the inland tributaries and discharges of the various streams to SMB vary substantially (Figure 7). Ballona Creek is the largest subwatershed that provides about half of the annual flow to SMB among the four largest streams (Ballona Creek, Dominguez Channel, Topanga Canyon Creek, and Malibu Creek) draining to the ocean (Table 12). Ballona Creek is entirely lined in concrete and starts from a complex underground network of storm drains. All of its tributaries are concrete lined channels that lead to covered culverts upstream, which expedite the conveyance of storm flows and result in larger surface runoff production ratios than occurs in natural watersheds. Malibu Creek is the second largest stream that contributes 37.8% of the annual flow to the ocean (Table 12). Historically, there is little flow in the summer months, and much of the natural flow that does occur in summer in the upper tributaries comes from springs and seepage areas. During rainstorms the runoff from the watershed may increase flows in the creeks dramatically. Substantial tributary flows are provided by Potrero Canyon Creek (N224; Figure 7) which contributes 37% of the total inflow to the ocean from Malibu Creek. These upstream areas are largely undeveloped. There is some limited agricultural land use. Most of the residential and commercial/ industrial land use is in the area around Westlake Village. Nearly all the runoff from this

Table 12 Annual discharges from major streams and tributaries and percentages of flows reaching the ocean

Reach name	Node ID	Annual Q [AF]	Ocean Q (%)	Area (%)
Upper Ballona Creek	N156	48,132	29.8	13.6
Sepulveda Channel	N213	13,278	8.2	9.4
Ballona Creek	N214	78,115	48.4	40.7
Potrero Canyon Creek	N224	22,599	14.0	12.0
Medea Creek	N225	10,328	6.4	7.9
Dominguez Channel	N245	12,770	7.9	22.0
Las Virgenes Creek	N49	9,914	6.1	7.7
Topanga Canyon	N81	9,508	5.9	6.3
Malibu Creek	N82	60,977	37.8	31.0

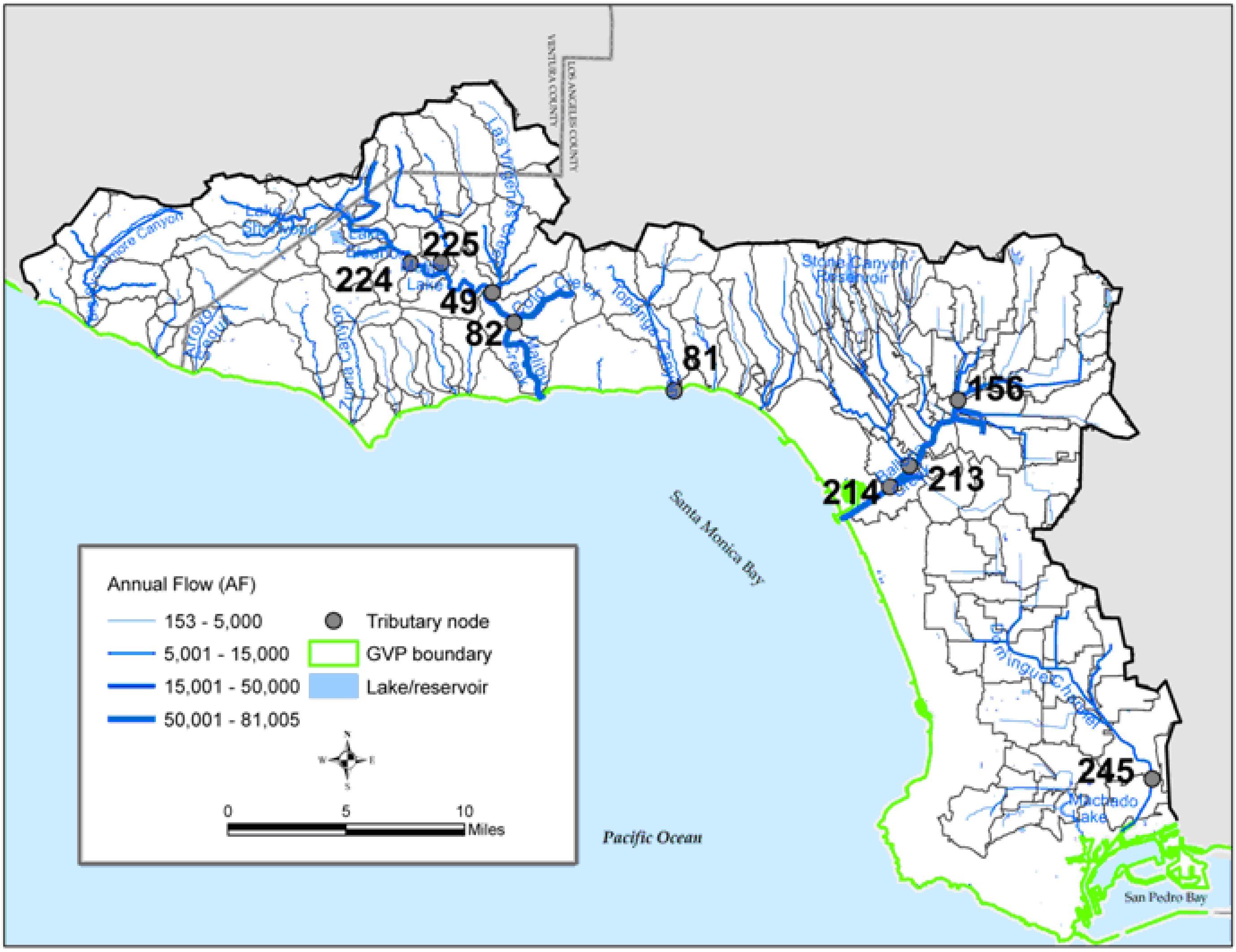


Figure 7 Cumulative flow discharges along the stream network

large watershed area is funneled to Malibu Lake.

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 at the outlet of the Ballona Creek subwatershed as time-series plots of modeled monthly loads and as a percentage of the corresponding annual loads. Monthly average loads at the Ballona Creek outlet were about 5,000, 10,000, and 3,000 kg for NH4, NO3 and TP, respectively during the simulation period. Temporal variations in nutrient loads are relatively similar for these three nutrients. Less month-to-month variability is observed with the nutrients than the flow patterns. The large variation occurs in the storm seasons (e.g. December, January and February) while significantly lower and less variable monthly loads were predicted during the non-storm season. Larger percentages of the winter loadings make it to the ocean compared to the other three seasons as well. From 1996 to 2005, wet-weather NH4 loads (November through the following March) accounted for 50% of the annual loads of NH4 and 60-70% of the annual loadings of NO3 and TP from Ballona Creek.

The nutrient loads vary along the stream network. The average annual loads from several major tributaries are summarized in Table 13. The Ballona Creek (N214) and Dominguez Channel (245)subwatersheds are two of the biggest nutrient sources in SMB, discharging 64 and 30% of the NH4 loads, respectively. The percentage contributions of NO3 and TP loads from these two watersheds are slightly lower than for NH4. Malibu Creek

Figure 8 Monthly nutrients loads in kilograms and percentages for Ballona Creek at Sawtelle Blvd (N121)

(82) is the second largest subwatershed in terms of area and accounts for a substantial fraction of the NO3 and TP loads to SMB. Within the Malibu Creek subwatershed, the Triunfo (N224) and Medea Creek (225) tributaries provide large nutrient loads to Malibu Creek because of higher levels of residential and commercial activity in and around several small lakes (e.g. Lindero Creek and Westlake, Lake Sherwood). Ranches also contribute to the high loads in these areas given their presence in Hidden Valley (the upper portion of Triunfo Creek), Lower Triunfo Creek and Lower Medea Creek. Figure 9 summarizes the spatial distribution of nutrient loadings along the stream network.

Figure 10 shows the spatial distribution of nutrient sources in each catchment. High NH4 and NO3 fluxes occur in the Ballona Creek and Dominguez Channel subwatersheds where most urban development occurs and in the headwaters of the Triunfo Creek watershed where many agricultural activities occur. The Tapia WRF is a significant source of all three nutrients. The highest estimated annual fluxes for NH4, NO3 and TP were 1,043, 3,058, and 628 kg/km2, respectively. The highest NH4 flux occurs in the catchment where the Tapia WRF is located, and the highest NO3 and TP fluxes are associated with an unnamed coastal creek, 3.5 miles south of the Topanga Canyon Creek outlet. The NO3 and TP flux distributions are similar, with high fluxes associated with residential land uses.

Parts of the stream network including Malibu Creek, Medea Creek, Las Virgenes, and Lindero Creek were included on the Clean Water Act Section 303(d) list of impaired waters for at least one nitrogen-related pollutant (USEPA Region 9 2006). To address the listings the Basin Plan has identified water quality objectives and adopted standards for different streams (CWQCB-LAR 1994a, b). During the summer (April 15-November 15), the total N (nitrate-nitrite) and total P targets are 1.0 and 0.1 mg/l respectively for all water bodies. In the winter months (November 16-April 14), the total N target is 8 mg/l (nitrate-nitrite) for all water bodies. No total P target was specified for the winter months. The U.S. Environmental Protection Agency lists and reports stresses that these target values are proposed only for waters in the Malibu Creek watershed. The simulated results were used for estimating the total loads and assessing the degree of water quality impairment for surface waters in a time and location specific way based on the Basin Plan that has been adopted by the California Regional Water Quality Control Board. Figures B-1and B-2 show that the nutrient concentrations fell below the target during the simulation time period at both the S01 Ballona Creek and S02 Malibu Creek mass emission sites. Figure 11 summarizes the daily NO3 loads calculated using the simulated daily water flow volume and NO3 concentration for the S01 Ballona Creek (N121) gauging station.

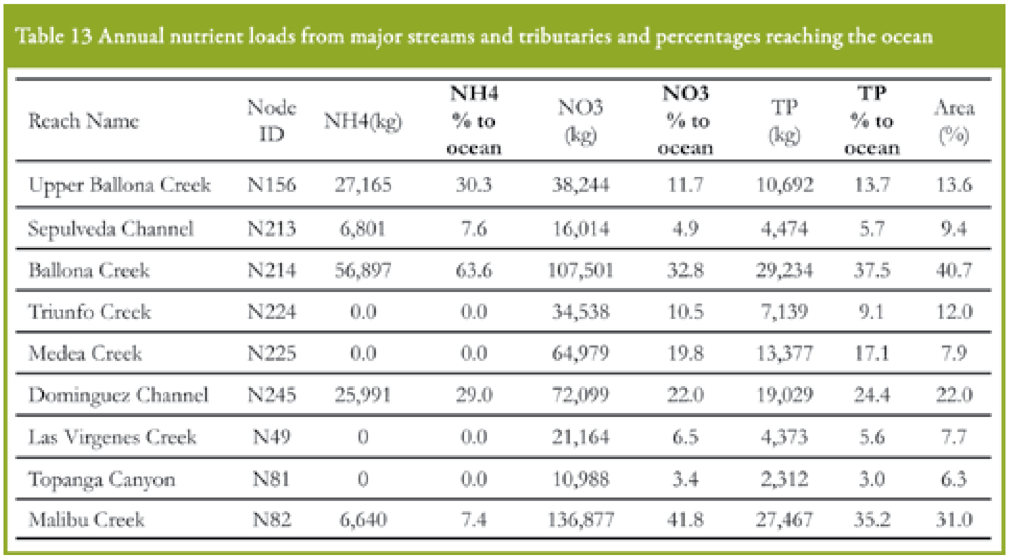


Table 13 Annual nutrient loads from major streams and tributaries and percentages reaching the ocean

Reach Name	Node ID	NH4(kg)	**NH4 % to ocean**	NO3 (kg)	**NO3 % to ocean**	TP (kg)	**TP % to ocean**	Area (%)
Upper Ballona Creek	N156	27,165	30.3	38,244	11.7	10,692	13.7	13.6
Sepulveda Channel	N213	6,801	7.6	16,014	4.9	4,474	5.7	9.4
Ballona Creek	N214	56,897	63.6	107,501	32.8	29,234	37.5	40.7
Triunfo Creek	N224	0.0	0.0	34,538	10.5	7,139	9.1	12.0
Medea Creek	N225	0.0	0.0	64,979	19.8	13,377	17.1	7.9
Dominguez Channel	N245	25,991	29.0	72,099	22.0	19,029	24.4	22.0
Las Virgenes Creek	N49	0	0.0	21,164	6.5	4,373	5.6	7.7
Topanga Canyon	N81	0	0.0	10,988	3.4	2,312	3.0	6.3
Malibu Creek	N82	6,640	7.4	136,877	41.8	27,467	35.2	31.0

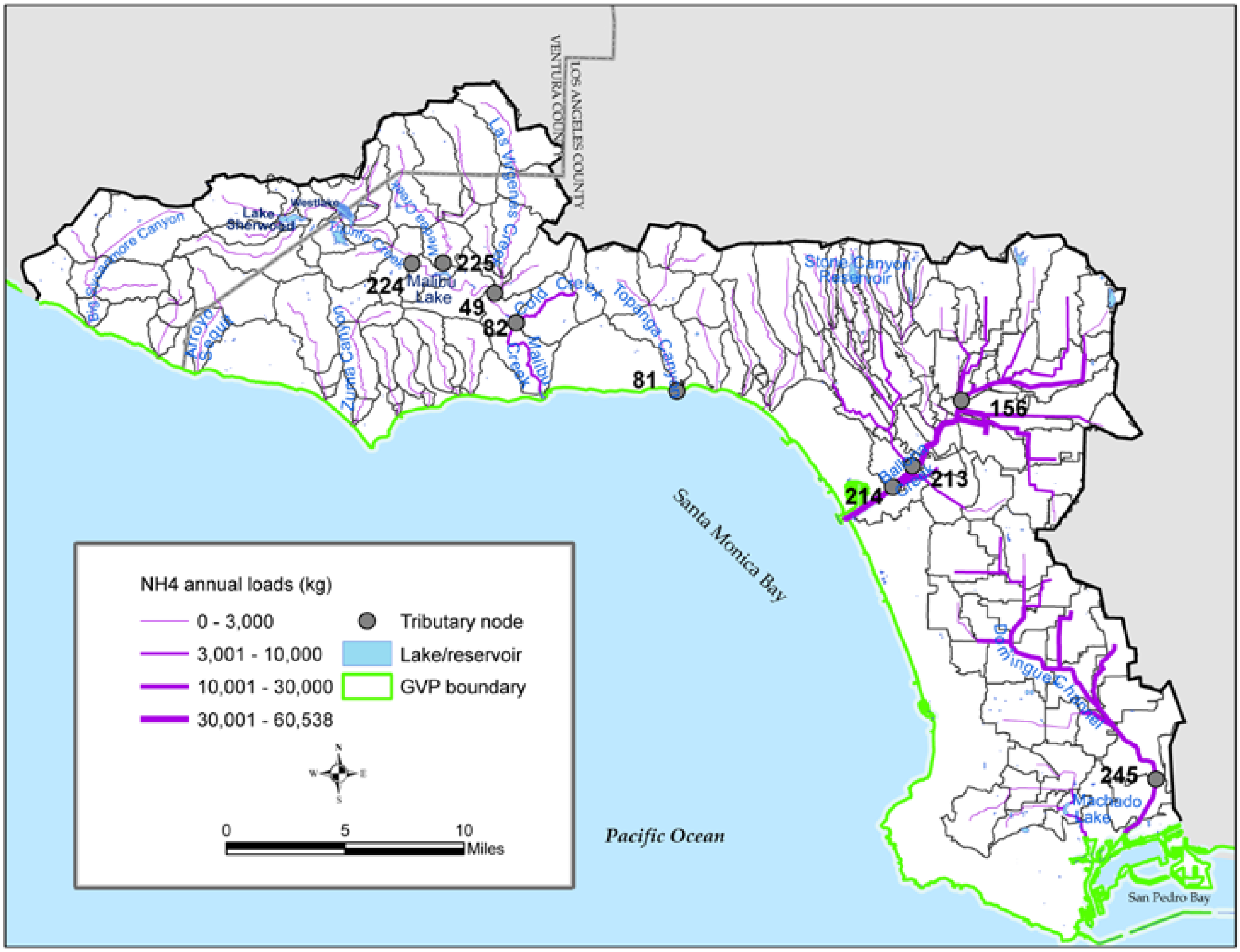


Figure 9a NO4 nutrient loads along the stream network

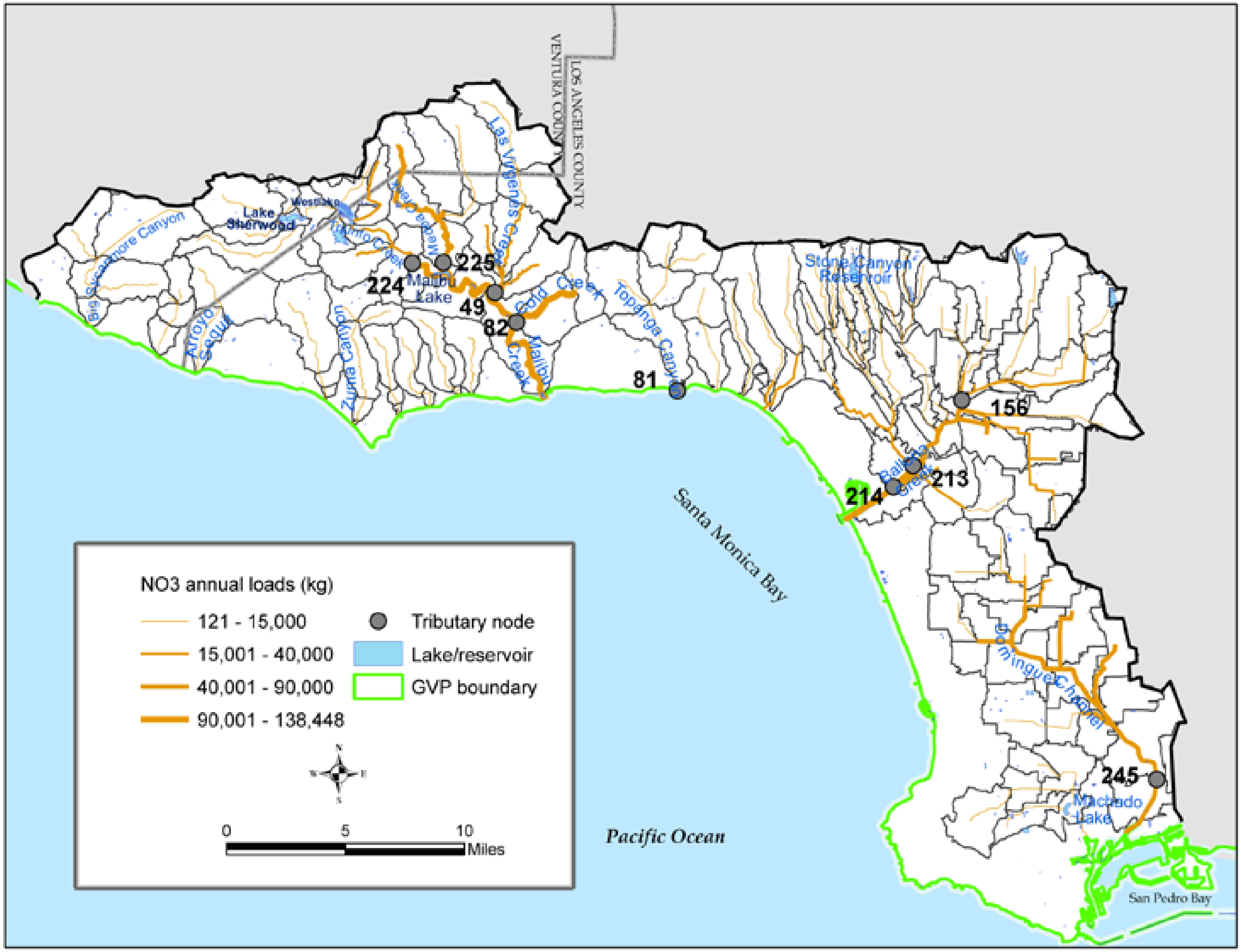


Figure 9b NO3 nutrient loads along the stream network

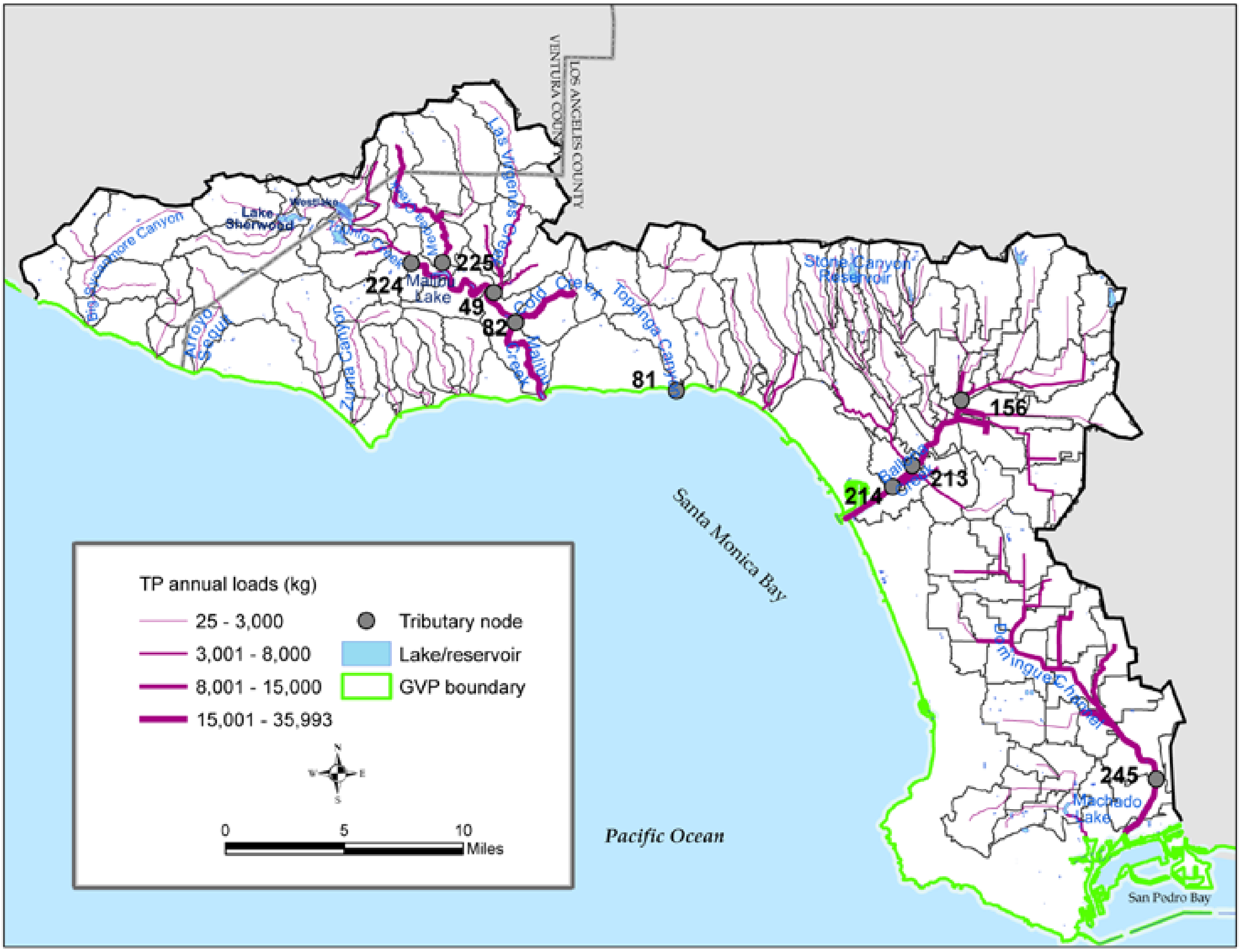


Figure 9c TP nutrient loads along the stream network

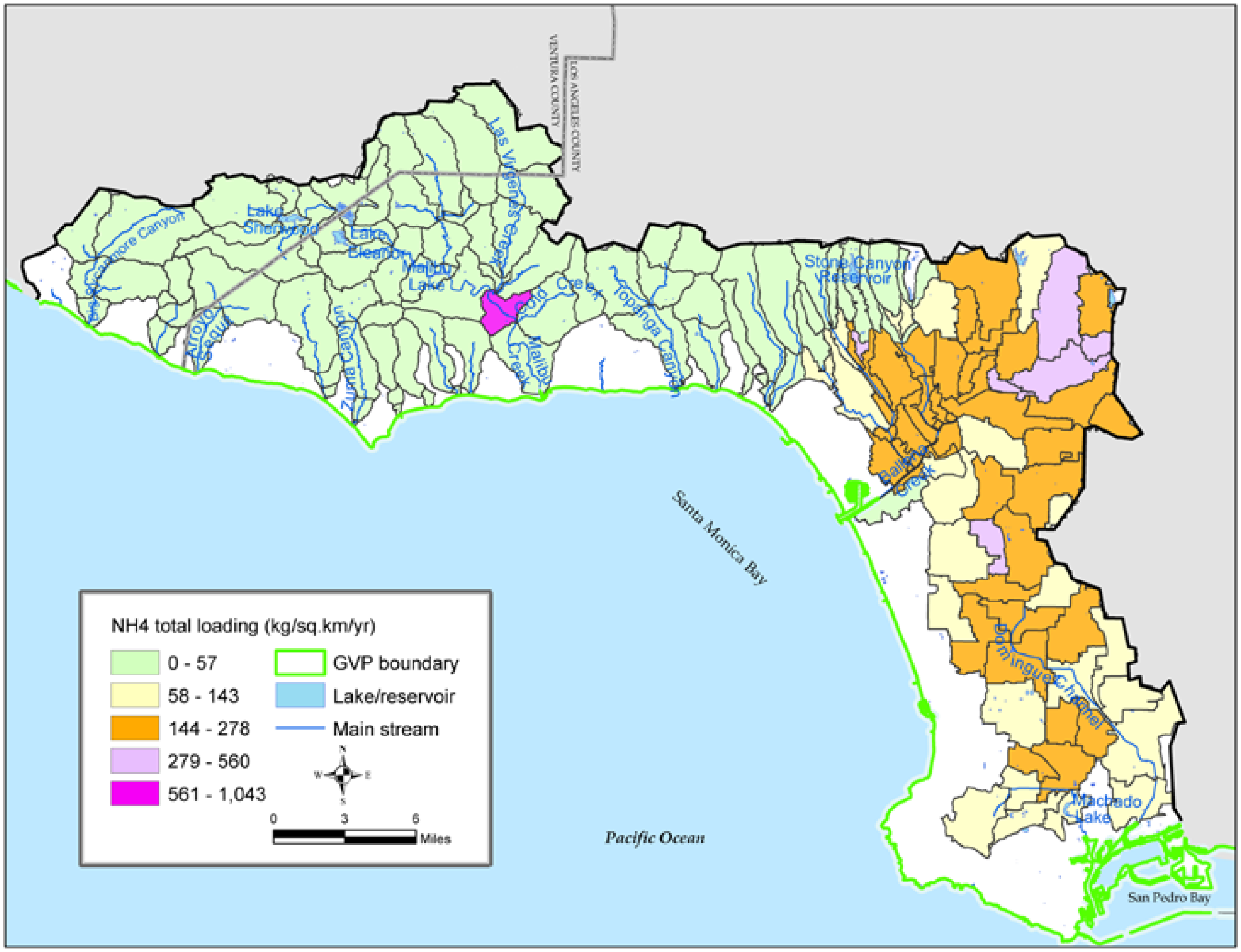


Fig 10a NH4 nutrient fluxes associated with each subcatchment

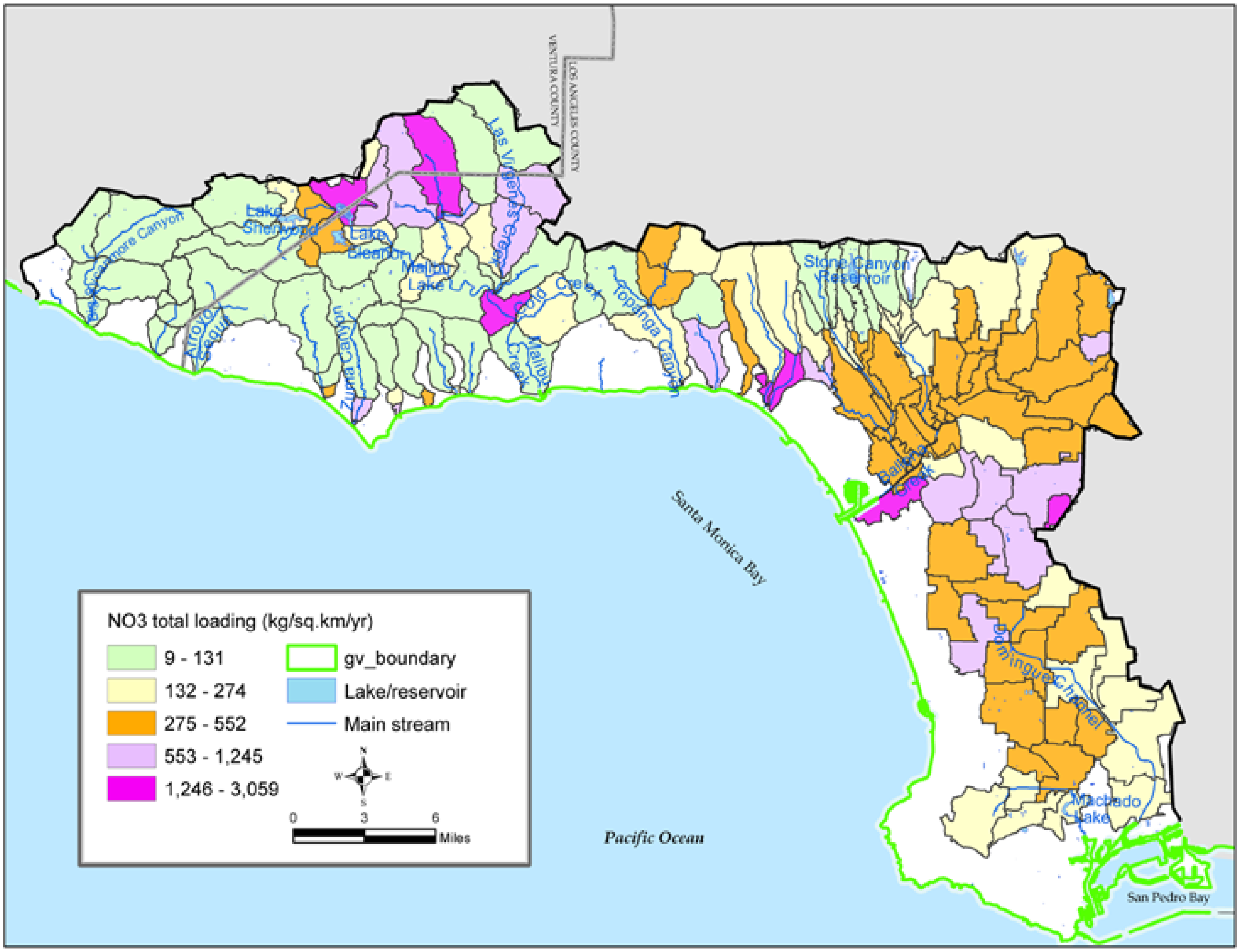


Figure 10b NO3 nutrient fluxes associated with each subcatchment

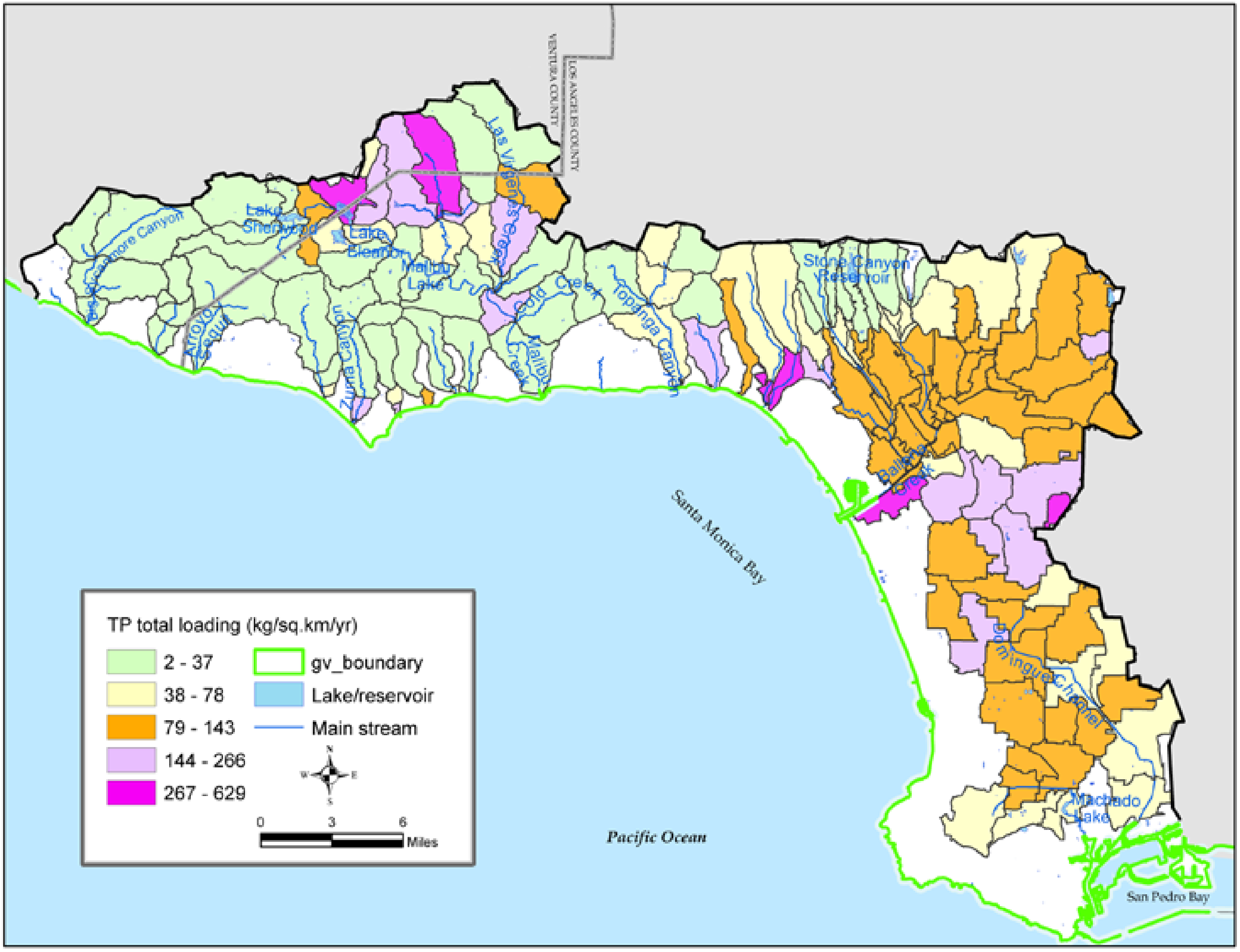


Figure 10c TP nutrient luxes associated with each subcatchment

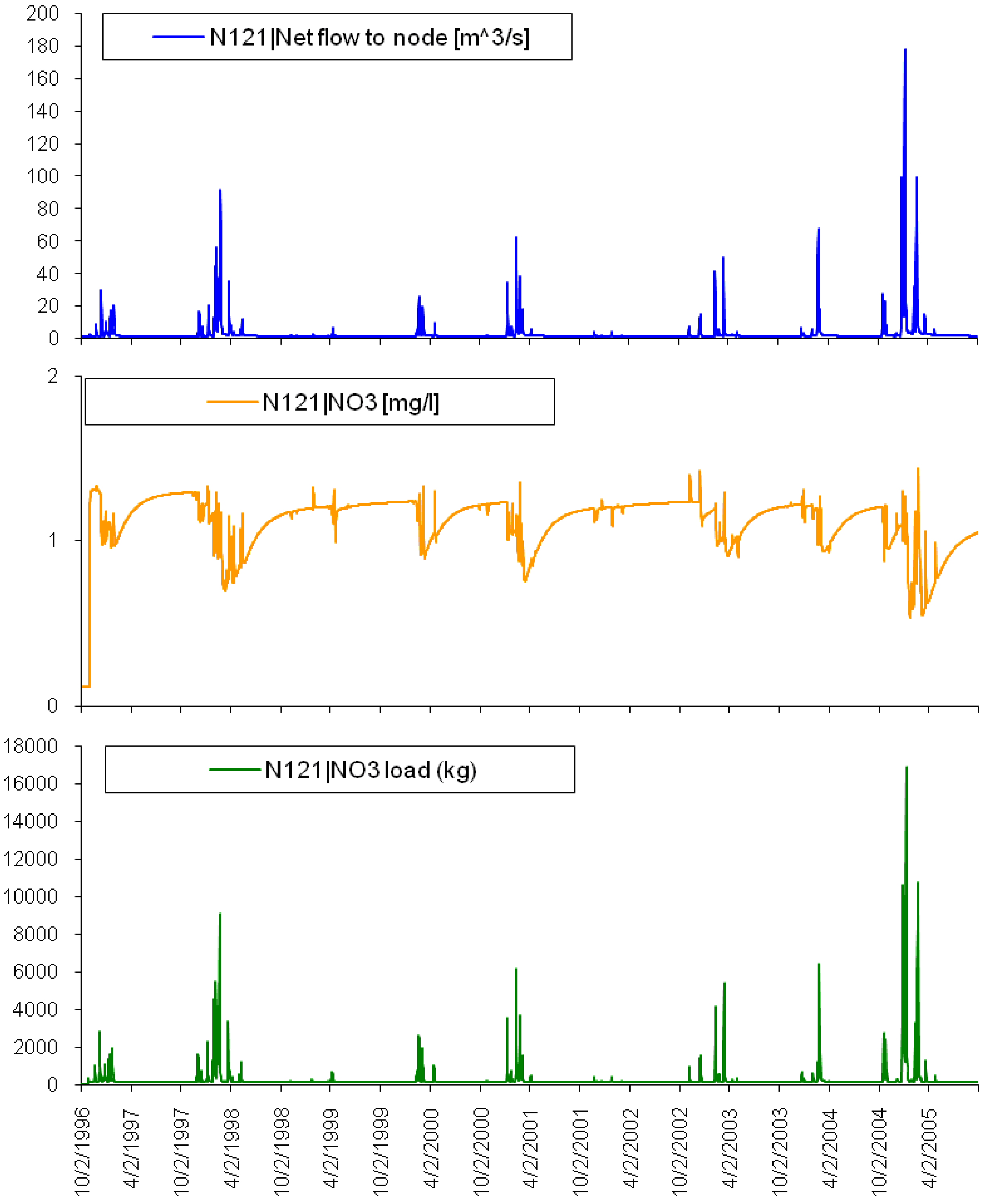


Figure 11 NO3 load estimated using the simulated flow volume and NO3 concentration for the S01 Ballona Creek (N121) mass emission site

6 Discussion and Conclusions

MIKE BASIN combines the power of ArcGIS with comprehensive hydrologic modeling and was implemented in the Santa Monica Bay watershed to address water resource and water quality issues. For hydrologic simulations, MIKE BASIN builds a network model in which branches represent individual stream sections and the nodes represent confluences, diversions, reservoirs, and 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 be modeled. Daily simulations were generated for the SMB subwatersheds based on water availability and utilization data from 1996 through 2005.

Key inputs to the model included the digitized river system layout, withdrawal and reservoir locations, a time series of water demand, the ground water 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, and water quality rate parameters, temperature, non-point loads, a weir constant for re-aeration, transport time and water depth or Q-h relationship, and effluent 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 Malibu Creek Bay 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 season. The predominant contribution to dry-weather instream flow comes from point source discharges such as urban runoff and groundwater baseflow. From 1996 to 2005, the dry-weather flows accounted for 26.7% of the annual volume of discharge from the Ballona Creek watershed for example.

Monthly average in-stream loads in Ballona Creek at the outlet were about 5,000, 10,000, and 3,000 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 compared to the flow patterns. The largest variation occurs in the stormy winter months while significantly lower and less variable monthly loads occur during the dry summer season. The total loads associated with winter storms accounted for 60-70% of the annual loadings of NO3 and TP and 50% of the annual loading of NH4 from Ballona Creek.

The Ballona Creek (N214) and Dominguez Channel (N245) subwatersheds are the two largest nutrient sources to Santa Monica Bay, discharging about 64% and 30% of the total NH4 loads, respectively. The percentage of the NO3 and TP loads contributed by these two subwatersheds is slightly lower. Malibu Creek (N82) is the second largest subwatershed in area and accounts for a substantial fraction of the NO3 and TP loads to the Bay as well. Within the Malibu Creek subwatershed, the Triunfo Creek (N224) and Medea Creek (225) are two tributaries that yield high nutrient loads due to the presence of residential and agricultural land uses concentrated in a few areas including Hidden Valley (i.e. the upper part of the Triunfo Creek subwateshed), Lower Triunfo Creek and Lower Medea Creek.

Overall, the model results should provide users with simple and intuitive 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-2 and A-3, the model simulates the hydrology for undeveloped subwatersheds reasonably well but did not perform nearly so well for the urbanized Ballona Creek subwatershed.

In addition, the simulation of the water quality components of NH4, NO3, and TP were less satisfactory due to errors in the hydrologic simulations and our limited understanding of the generation, transportation and degradation dynamics on the land surface and in streams for these pollutants. Temporal variations in the in-stream concentrations are significant but not represented in the input parameters, which might have negatively impacted the estimates of nutrient loadings. It is very likely that large storm drains discharge only in certain time periods and not during other periods (i.e. in the Ballona Creek watershed for example), but it was not possible to incorporate this temporal variability in the model parameterization.

Two other issues of broad concern warrant a brief mention as well. The first is that a large fraction of the nutrient loads in the Santa Monica Bay watershed derives from sources beyond the control of dischargers, especially atmospheric deposition. Direct air deposition to water bodies was treated as a nonpoint source, whereas air deposition that enters the stream network via the land surface was included in the event mean flux values for each land use category. Secondly, flow conditions during the wet- and dry-weather periods are significantly different. Flows during the wet-weather periods are generated by storm runoff. Stormwater runoff in the sewered urban areas of the watershed is carried to the river through a system of storm drains. During the dry-weather periods the flows are extremely low and less variable, and 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 a desire to assess TMDL compliance. However, wet- and dry- weather nutrient simulations are not differentiated in MIKE BASIN, which may limit applications of the modeling results for estimating TMDL compliance and/or the evaluation of the impacts of specific BMP projects, which require not only estimates of annual loads, but also loads at a much finer temporal scale.

This report has focused on assessing the sources and average loads of nutrients to the surface waters and the relative impairment of surface water quality in the watershed. It is a great challenge to obtain time series flow and water quality data for hundreds and thousands of industrial and urban runoff dischargers that are scattered across the entire region. The simulated water quality time series at each of the node points of the stream network offer some understanding of the spatio-temporal variability of the nutrient loads and concentrations at the basin scale. The MIKE BASIN model results help to identify those parts of the watershed and the times during the year that will determine the success of future efforts to manage water supply and water quality issues affecting Santa Monica Bay.

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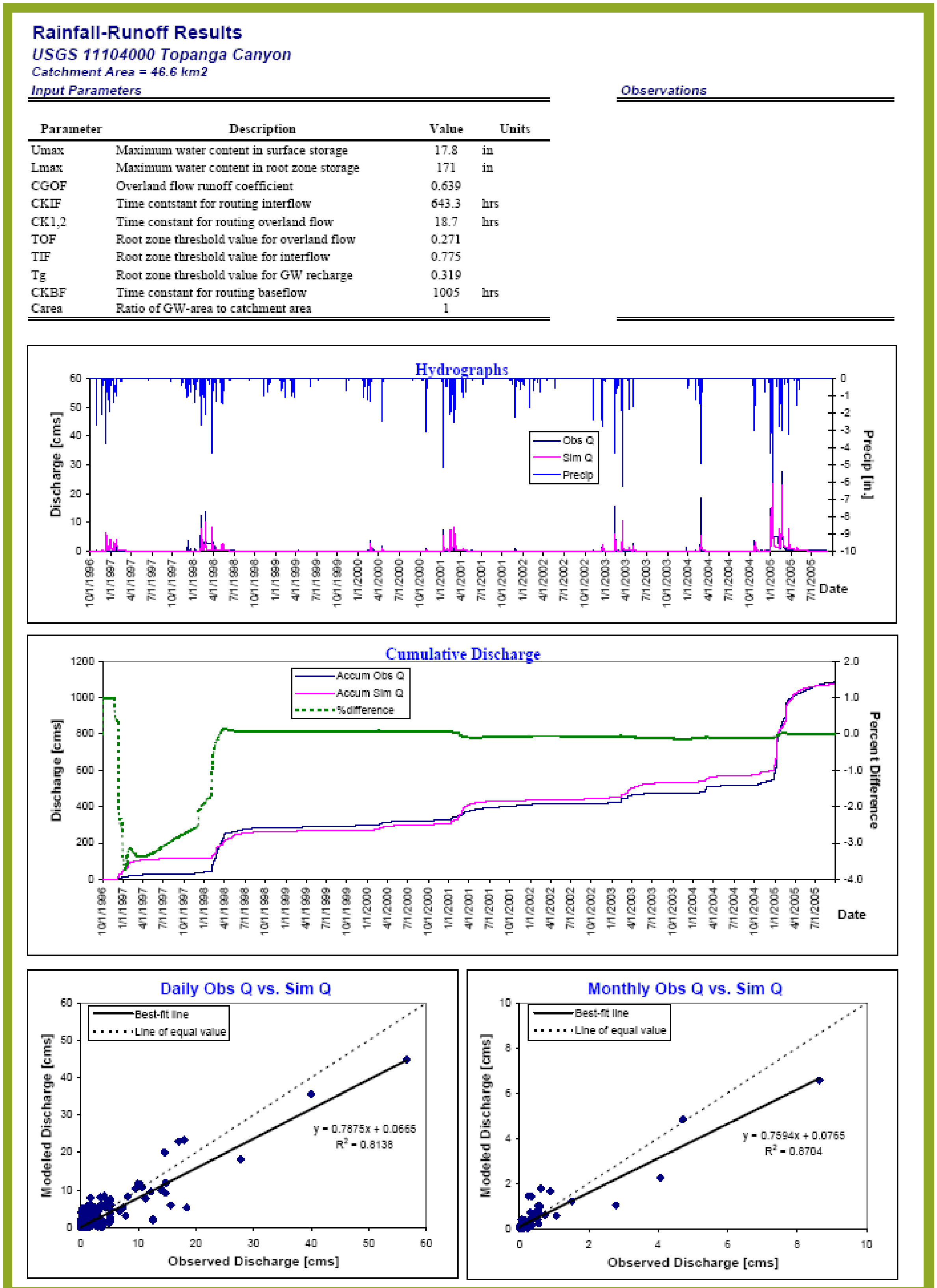
Appendix A

Hydrology Calibration and Validation Graphs and Tables



Rainfall-Runoff Results

USGS 11104000 Topanga Canyon

Catchment Area = 46.6 km2

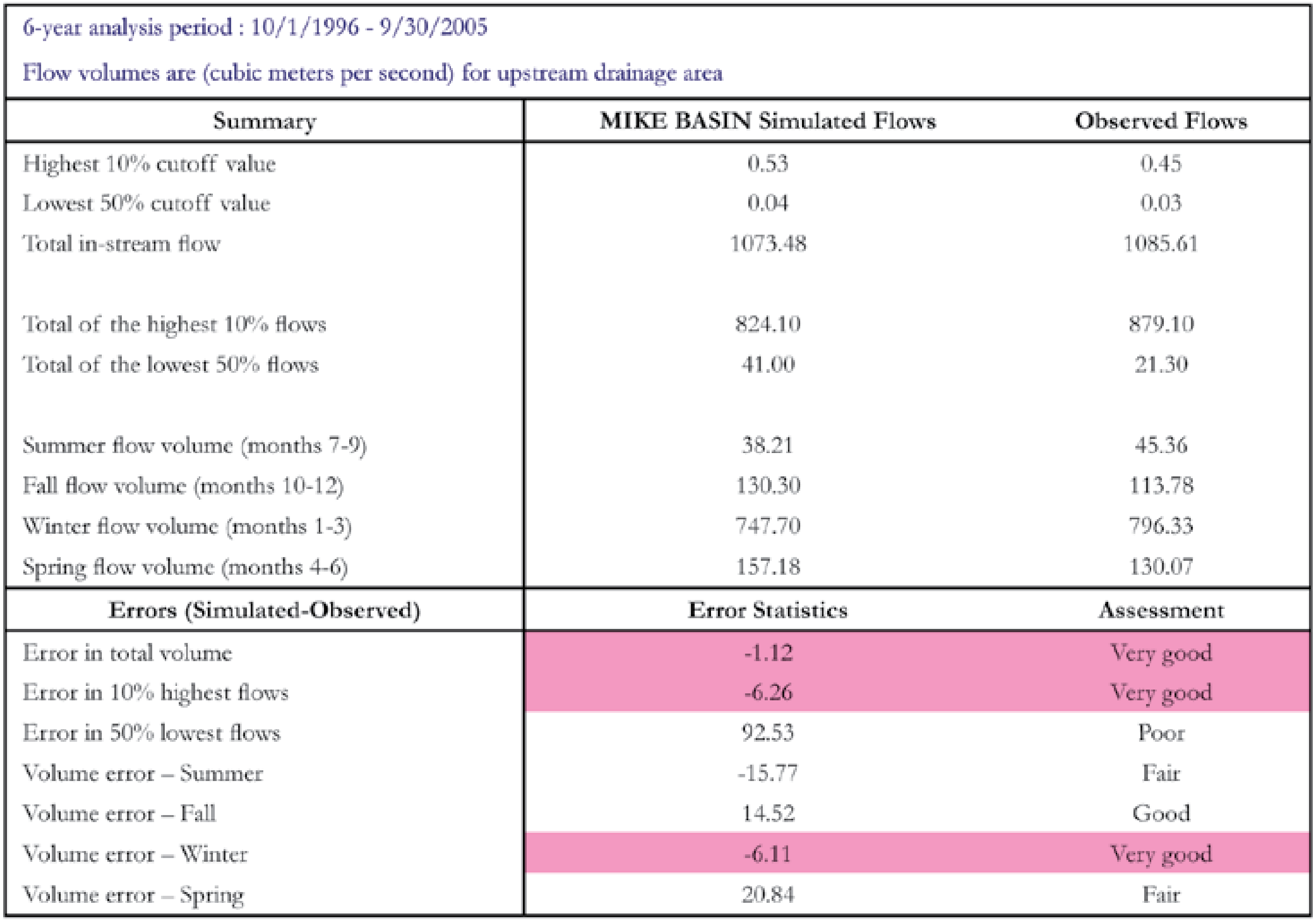
Input Parameters

Observations

Parameter	Description	Value	Units
Umax	Maximum water content in surface storage	17.8	in
Lmax	Maximum water content in root zone storage	171	in
CGOF	Overland flow runoff coefficient	0.639	
CKIF	Time contstant for routing interflow	643.3	hrs
CK1,2	Time constant for routing overland flow	18.7	hrs
TOF	Root zone threshold value for overland flow	0.271	
TIF	Root zone threshold value for interflow	0.775	
Tg	Root zone threshold value for GW recharge	0.319	
CKBF	Time constant for routing baseflow	1005	hrs
Carea	Ratio of GW-area to catchment area	1	

Figure A-1 Calibration results for USGS 11104000/F54C-R TOPANGA CREEK NR TOPANGA BCH CA gauging station

Table A-1 Calibration error analysis for USGS 11104000/F54C-R TOPANGA CREEK NR TOPANGA BCH CA gauging station

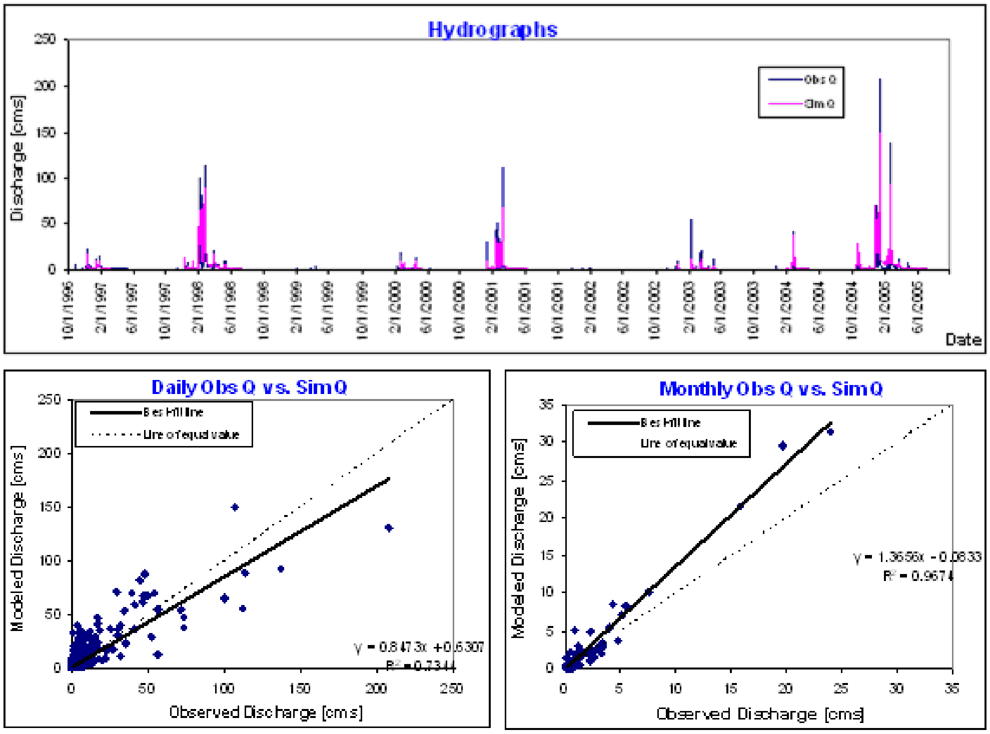


6-year analysis period : 10/1/1996 - 9/30/2005

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

Summary	MIKE BASIN Simulated Flows	Observed Flows
Highest 10% cutoff value	0.53	0.45
Lowest 50% cutoff value	0.04	0.03
Total in-stream flow	1073.48	1085.61
Total of the highest 10% flows	824.10	879.10
Total of the lowest 50% flows	41.00	21.30
Summer flow volume (months 7-9)	38.21	45.36
Fall flow volume (months 10-12)	130.30	113.78
Winter flow volume (months 1-3)	747.70	796.33
Spring flow volume (months 4-6)	157.18	130.07

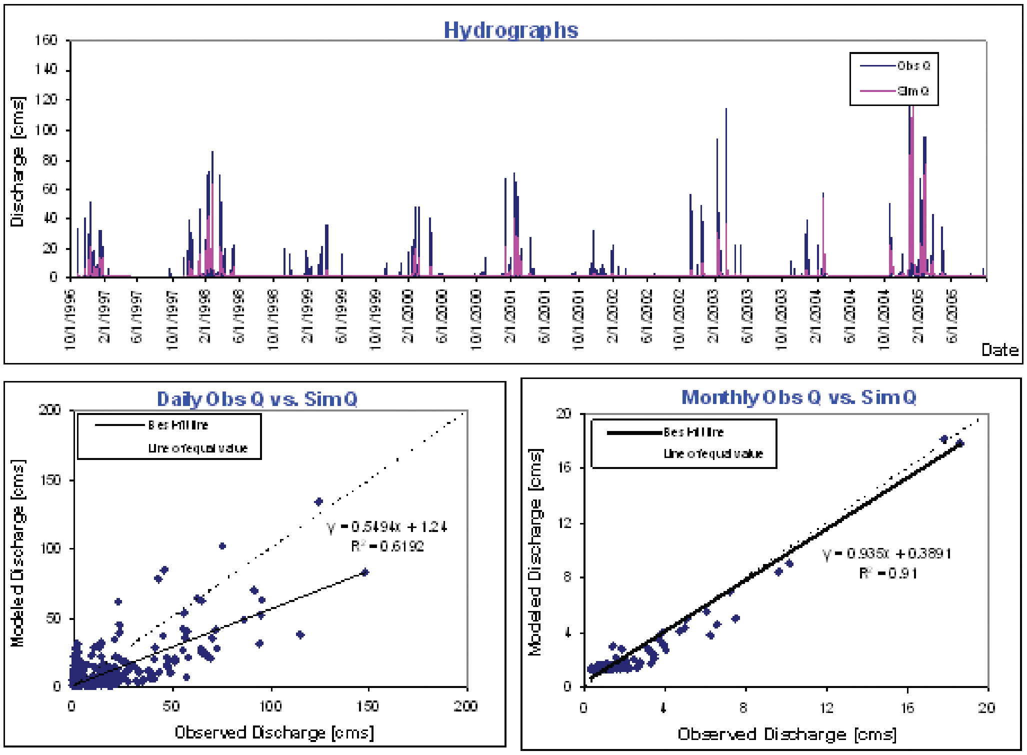
Errors (Simulated-Observed)	Error Statistics	Assessment
Error in total volume	-1.12	Very good
Error in 10% highest flows	-6.26	Very good
Error in 50% lowest flows	92.53	Poor
Volume error – Summer	-15.77	Fair
Volume error – Fall	14.52	Good
Volume error – Winter	-6.11	Very good
Volume error – Spring	20.84	Fair

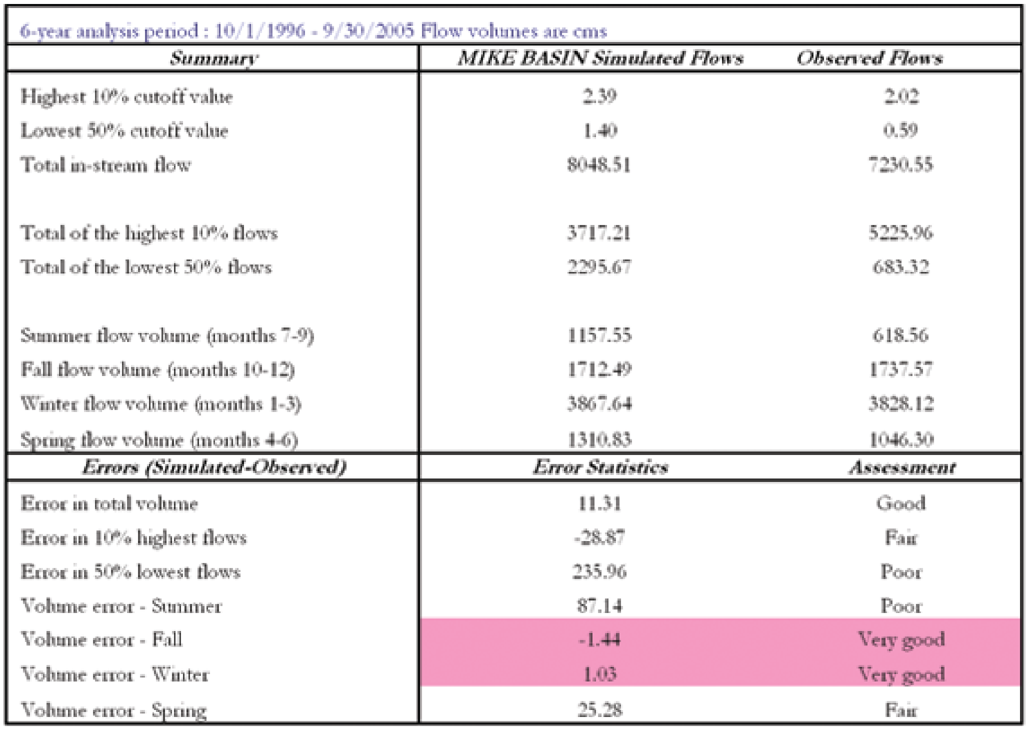


6-year analysis period : 10/1/1996 - 9/30/2005 Flow volumes are cms

Summary	*MIKE BASIN Simulated Flows*	*Observed Flows*
Highest 10% cutoff value	3.11	2.12
Lowest 50% cutoff value	0.23	0.27
Total in-stream flow	5886.26	4500.54
Total of the highest 10% flows	4491.71	3400.34
Total of the lowest 50% flows	237.73	229.69
Summer flow volume (months 7-9)	206.53	103.62
Fall flow volume (months 10-12)	750.53	496.96
Winter flow volume (months 1-3)	4164.98	3253.82
Spring flow volume (months 4-6)	764.22	646.14
Errors (Simulated-Observed)	***Error Statistics***	***Assessment***
Error in total volume	30.79	Fair
Error in 10% highest flows	32.10	Poor
Error in 50% lowest flows	3.50	Very good
Volume error - Summer	99.31	Poor
Volume error – Fall	51.02	Poor
Volume error – Winter	28.00	Fair
Volume error – Spring	18.27	Fair

Figure A-2 Validation results for USGS 11105500/F130-R MALIBU CREEK AT CRATER CAMP NR CALABASAS CA 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	2.39	2.02
Lowest 50% cutoff value	1.40	0.59
Total in-stream flow	8048.51	7230.55
Total of the highest 10% flows	3717.21	5225.96
Total of the lowest 50% flows	2295.67	683.32
Summer flow volume (months 7-9)	1157.55	618.56
Fall flow volume (months 10-12)	1712.49	1737.57
Winter flow volume (months 1-3)	3867.64	3828.12
Spring flow volume (months 4-6)	1310.83	1046.30
Errors (Simulated-Observed)	*Error Statistics*	*Assessment*
Error in total volume	11.31	Good
Error in 10% highest flows	-28.87	Fair
Error in 50% lowest flows	235.96	Poor
Volume error - Summer	87.14	Poor
Volume error - Fall	-1.44	Very good
Volume error - Winter	1.03	Very good
Volume error - Spring	25.28	Fair

Figure A-3 Validation results for USGS 11103500/F38C-R BALLONA CREEK NR CULVER CITY CA gauging station

Appendix B
Water Quality Calibration and Validation Graphs and Tables

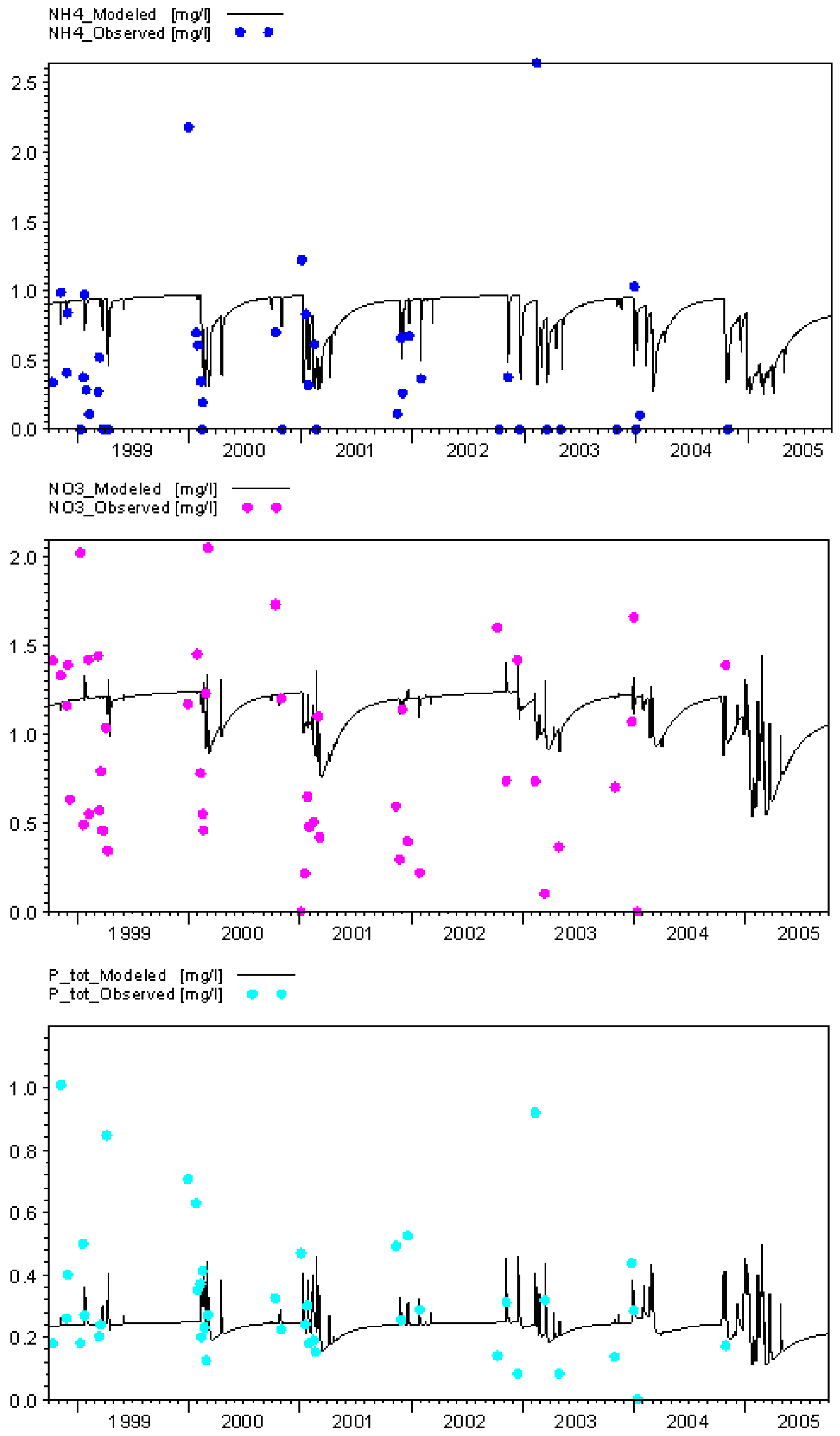


Figure B-1 Time series comparison of modeled and observed NH4, NO3 and P_tot concentrations at the S01 Ballona Creek Mass Emission site

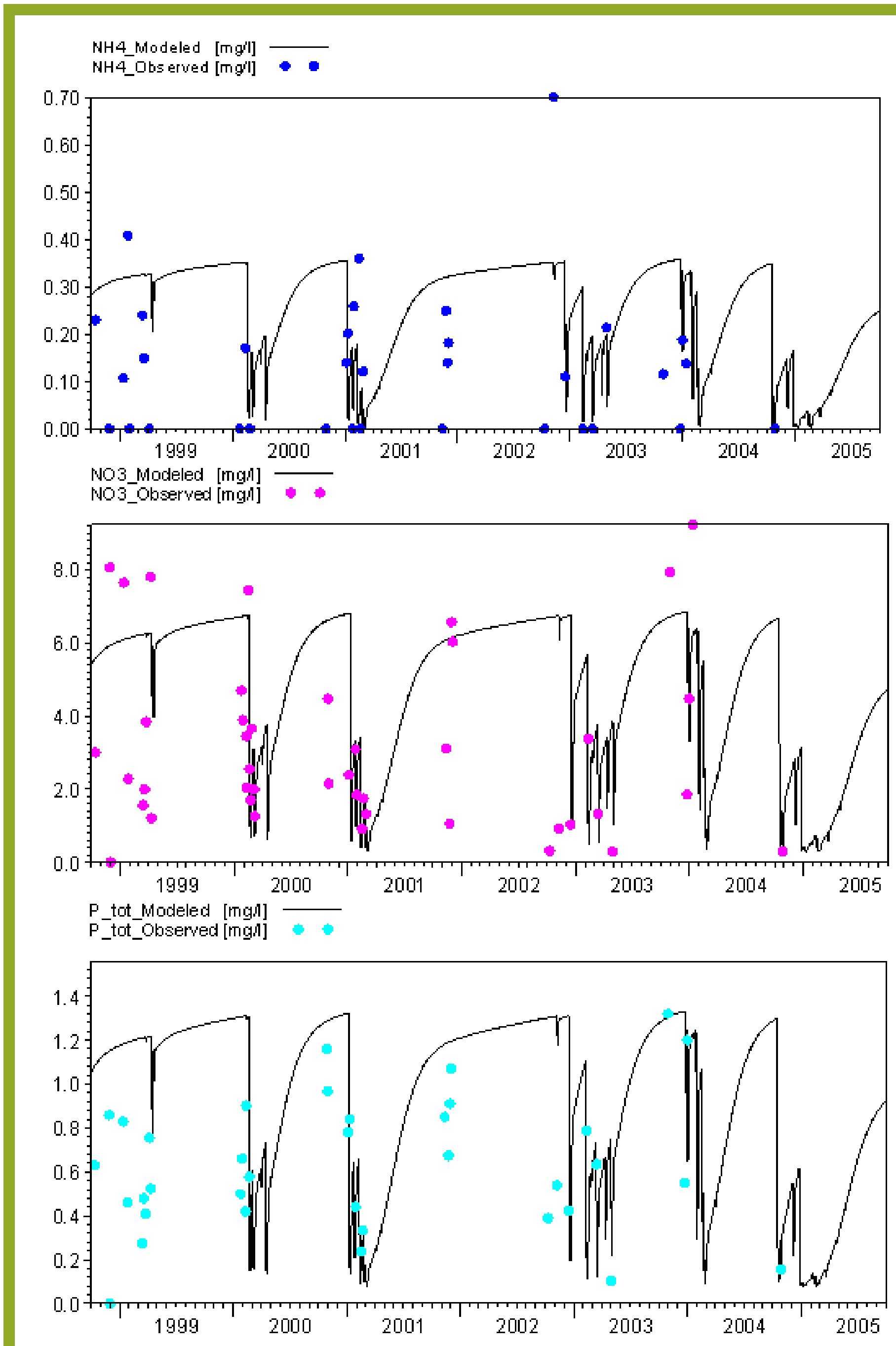


Figure B-2 Time series comparison of modeled and observed NH4, NO3 and P_tot concentrations at the S02 Malibu Creek Mass Emission site