A Two-Phased Approach for Simulation of Nutrients and Pathogens in the Los Angeles River Watershed

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Abstract

The Los Angeles River watershed covers 824 square miles, of which, approximately 364 square miles are covered by forest or open space land including the area near the headwaters, which originate in the Santa Monica, Santa Susana, and San Gabriel Mountains. The remaining area is highly urbanized including the San Fernando Valley and portions of the City of Los Angeles. Major flood events at the turn of the century initiated flood control projects in the watershed that led to dramatic alterations of the natural hydrology of the river. Presently, most of the Los Angeles River, and its major tributaries, are concrete lined with numerous dams, spreading grounds, and other hydraulic control structures.

The development of the Los Angeles River nutrient and pathogen Total Maximum Daily Loads (TMDL) required that the full range of pollutants, sources, and flow conditions, typical of heavily urbanized areas, be addressed for a single water body. Although the climatic issues are specific to the southern west coast region, the processes and types of issues encountered can be viewed as typical for urban TMDLs across the country. The development of modeling tools for use in simulation of the water quality conditions, and ultimately for use in determination of allowable loadings, needed to address many issues typical of urban areas.

Due to the range of pollutants and flow conditions present in the LA River, the model simulations were conducted in two phases. Phase I, addressed nutrients and pathogens for the low flow (or dry-weather) conditions, which occur during the summer months (May through September). This phase included detailed analysis of source flows and loadings into the system, as well as simulation of the along channel nutrient transformation processes and uptake by periphyton growing along the concrete channel. Phase II addressed pathogens for the high flow (or wet weather) conditions, which occur during the winter months (October through April). This required simulation of the watershed hydrology and pollutant loadings due to build up and wash-off from the urban areas surrounding the river. The wet-weather analyses focused primarily on pathogens in the system, and utilized pollutographs measured under various land use conditions in the development of the hydrologic and water quality models.

Introduction

The LA River watershed is one of the largest in the region covering 824 square miles. It is also one of the most diverse in terms of land use patterns. Approximately 364 square miles of the watershed are covered by forest and open space; most of the lands are concentrated at the headwaters located in the Santa Monica, Santa Susana, and San Gabriel Mountains. The remainder of the watershed is highly developed. Figure 1 shows the LA River watershed in relation to neighboring counties and the State of California.

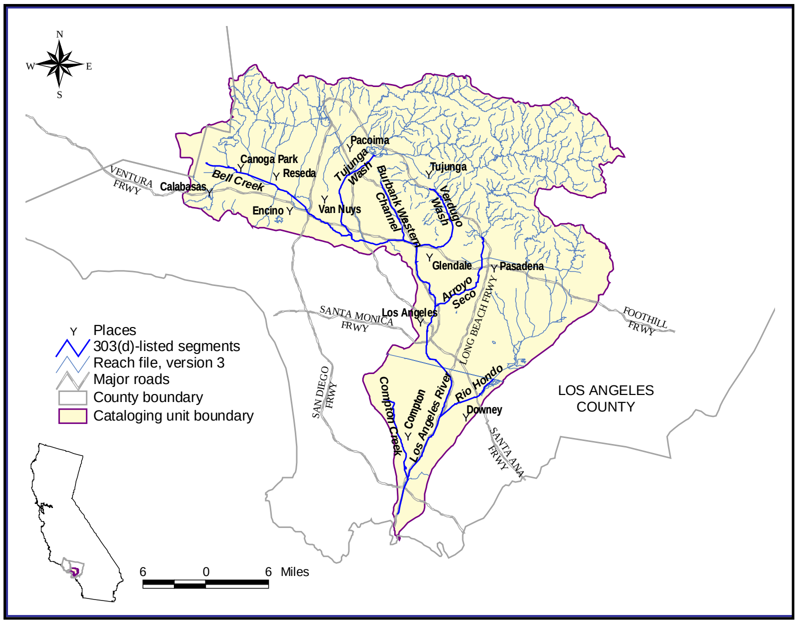

Figure 1: Location Map for LA River Watershed

The 55-mile LA River flows from the Santa Monica Mountains at the western end of the San Fernando Valley to the Pacific Ocean. The headwaters of the Los Angeles River are located in the Santa Monica Mountains. Below the Santa Monica Mountains, the Los Angeles River flows east through the southern portion of the San Fernando Valley a heavily developed residential and commercial area. The LA River turns in an area known as the Glendale Narrows and flows south for approximately 25 miles through industrial and commercial areas and is bordered by railyards, freeways, and major commercial and government buildings. The river discharges to the Pacific Ocean at Queensway Bay, a portion of San Pedro Bay in Long Beach. In order to control flooding at the beginning of the century, major alterations to the river were constructed; these included dams, levees, concrete lining, and other control structures. By the 1950s most of the river was lined with concrete.

The majority of the LA River is considered impaired due to the non-attainment of beneficial uses caused by a variety of pollutants. The 1998 303(d) list identified the following pollutants as sources of impairment: pH, ammonia, metals, coliform, trash, scum, algae, oil, chlorpyrifos, as well as pesticides, and volatile organics. Some of these pollutants are of concern throughout the length of the river while others are of concern only in certain reaches. The beneficial uses threatened or impaired by degraded water quality in the LA River are aquatic life, wildlife habitat, contact and non-contact recreation, groundwater recharge, and municipal water supply. Figure 2 presents a plan view of the LA River showing the listed segments.

The lower part of the river flows through a heavily urbanized area and most of the non-point sources of pollution are due to runoff during storm events and direct discharge from storm drains due to local water use practices. Non-point sources include: improper use, disposal, or storage of hazardous chemicals; lawn and garden activities; turf management (e.g., golf courses); on-site disposal systems; pets and wildlife; and contributions from homeless encampments.

Presently there are six major permitted point source discharges, and 29 minor permitted discharges. Review of the NPDES permits for the major and minor discharges identified that if all permitted facilities were at their design flow conditions, the six majors would account for approximately 60-80 percent of the point source flow to the LA River. As many of the minors are storm water related, their contribution during dry periods will be negligible. Additionally, examination of the design flows for the Glendale, Tillman, and Burbank Water Reclamation Plants, in relation to the other three majors, shows that these three facilities account for nearly 85-100 percent of the major design discharge.

The Los Angeles River has two distinct climatologic periods that drive the flow conditions. The typical dry-weather period from May through September is characterized by little rainfall and steady flows within the River. The flows range from less then 1 cubic meter per second (CMS) at the headwaters up to 6 CMS at the confluence with San Pedro Bay. During this time the dominant flow contribution comes from the three major point source discharges (60-90 percent of the flows). The typical wet period runs from October through April. This period is marked by occasional storms, typically 10-12 per year. Due to the highly modified nature of the Los Angeles River system the flows during storm events are flashy with flow rates reaching up to 1300 CMS during a short 3 to 4 hour period.

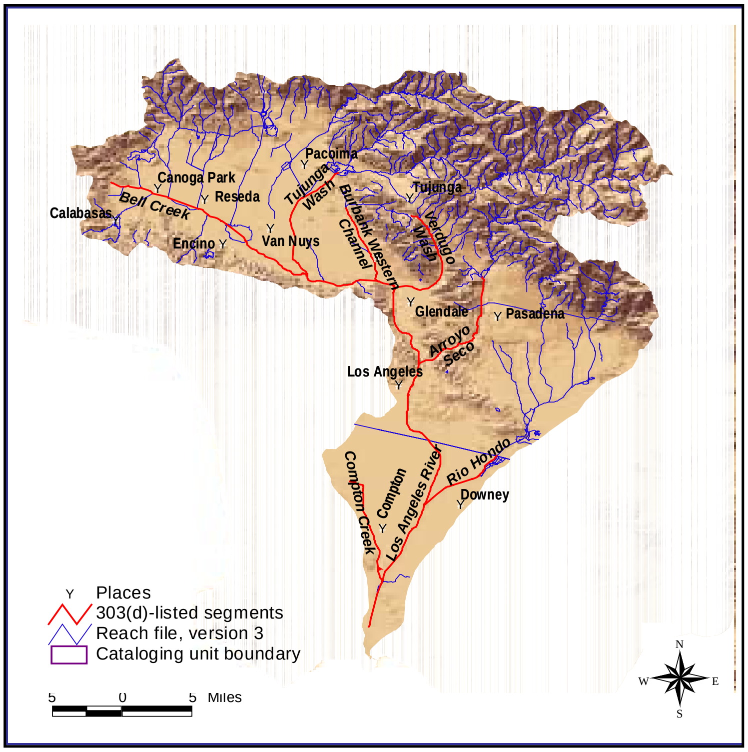

Figure 2: Listed Reaches in the LA River Watershed

Model Development

In order to address the varied conditions and listed pollutants within the Los Angeles River watershed, a system of models was developed that provided simulation of the overland flow, in-stream hydrodynamics, and in-stream water quality. The system design was such that all flow and water quality conditions experienced within the Los Angeles River watershed could be simulated using one set of tools. For the purposes of this report, Phase I consisted of simulation of the in-stream processes during typical dry-weather conditions and was focused upon nutrients, algal biomass, and pathogens. Phase II consisted of simulation of the watershed loading and in-stream transport of pollutants during typical wet-weather conditions and was focused primarily on pathogens.

The modeling system developed consisted of the Hydrologic Simulation Program FORTRAN (HSPF) watershed model for simulation of overland hydrology and pollutant loadings, the Environmental Fluid Dynamics Code (EFDC) for simulation of the one-dimensional hydrodynamics and pollutant transport along the main stem and the listed tributaries (Hamrick, 1996), and the Water Quality Analysis and Simulation Program (WASP) for simulation of the in-stream water quality kinetics and periphyton uptake (Ambrose et al, 1988, DiToro et al, 1983). The following provides a summary of the development and application of the models during wet and dry periods and issues faced in evaluation of urban loadings.

Dry Weather Approach

The EFDC and WASP models were utilized to simulate the in-stream hydrodynamics and water quality for Phase I. Figure 2 presented the extent of the listed segments; this corresponds to the physical boundaries of the EFDC and WASP models. The data used in the development of the model parameters came from intensive surveys and special studies conducted by the Southern California Coastal Water Research Project (SCCWRP) during dry weather in 2000 and 2001 (SCCWRP, 2001). The data included in-stream concentrations and flows at multiple locations, dye studies, periphyton densities and growth rates, and nitrification rates.

Accurate simulation of the in-stream transport processes and associated time of travel was critical for simulation of the nutrient uptake processes and pathogen decay. This in turn required that the physical characteristics of the system be well defined. Figures 3 and 4 show photos of two sections of the LA River with the associated EFDC cross-section. The photos identify a key aspect, the low flow channel. This channel directs the water under low-flow conditions without allowing spreading and therefore reduction of the velocities. Additionally, much of the algal growth occurs in areas where the flow during dry weather is outside of the low-flow channel. Under these conditions, the cross-sectional average velocities are reduced and periphytic algae are allowed to attach and grow. Therefore, for the low-flow, or dry-weather conditions, the model must accurately reflect the geometry, elevation, and slope of the channel.

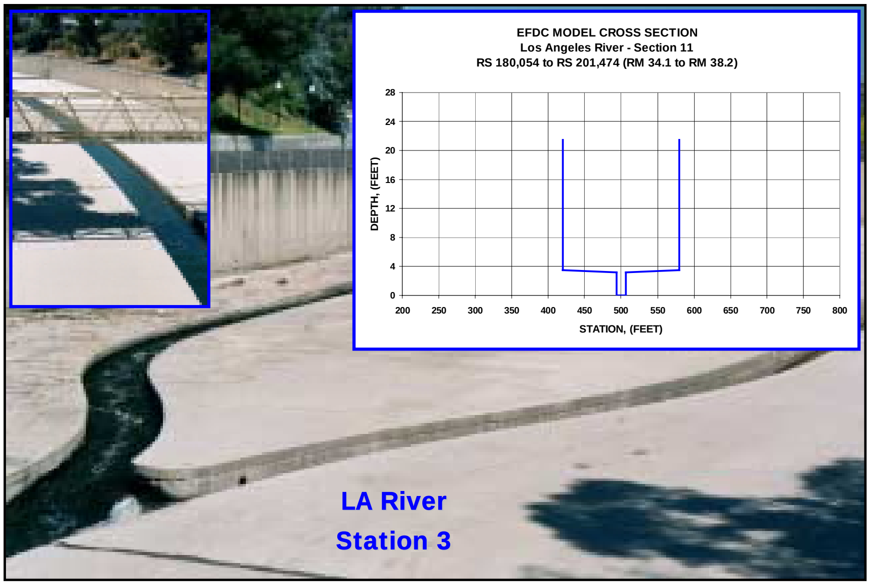

Figure 3: Photo and Cross-Section at LA River Station 3

Figure 3 presents photos of a cross-section of the river along the main channel with the flow restricted to the low flow channel. The dimensions and elevations from the cross-sections, obtained from design drawings for the flood control project, were utilized in the development of the EFDC 1-D model. This aspect of the simulations was unique to the urban conditions and allowed the removal of one uncertainty that often exists in model development, the accurate representation of the physical characteristics of the domain.

As stated earlier, there are six major permitted point source discharges to the LA River and its tributaries, and 29 minor permitted discharges. During the dry period, flows within the system are dominated by the point sources with 60-90 percent of the flow accounted for. Of the major and minor discharges, three wastewater reclamation plants make up nearly 90 percent of the flow. These are the Glendale, Tillman and Burbank Waste Water Reclamation Plants (WWRP). The remaining flows are made up of storm drain inflows, headwater flows into the tributaries from areas outside of the listed segments, and groundwater inflow. Figure 5 presents the distribution of the flows measured during a sampling event in September of 2000, the Burbank facility is lumped into the tributary inflow as it flows into the Burbank Channel and not directly to the Los Angeles River. Nuisance flows are dry-weather storm drain inputs. As the figure shows, approximately 14 percent of the flows were not quantified during this sampling event and represent unmeasured storm drain inflows or groundwater.

Figure 4: Photo and Cross-Section at LA River Station 6

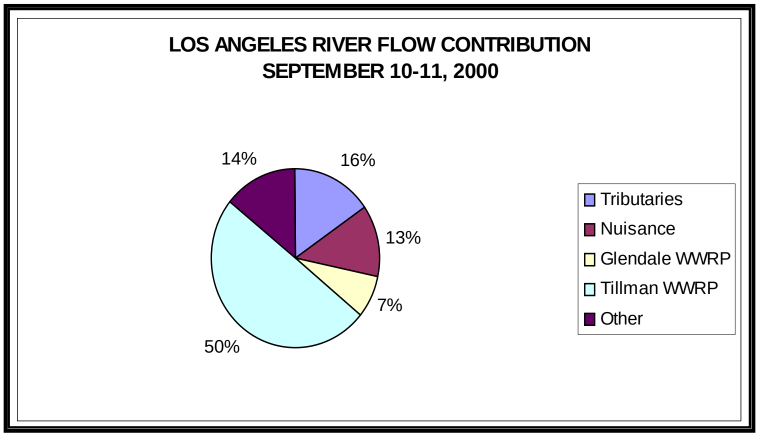

Figure 5: Breakdown of Flows to the LA River

Calibration of the time of travel and transport in EFDC under low-flow conditions was verified against a series of dye studies conducted along the main stem of the river. The transport velocity in the system is the cross-sectional average; this is what the model needs to accurately simulate. In some reaches of the system the flows are not restricted to the low-flow channel and spread out over the cross-section, this is shown in Figure 4. When this situation occurs, the distribution of flow across the channel varies significantly with faster flows in the area of the low flow channel, and friction dominated slower flows in the spreading areas. Utilizing the dye study results, the representative cross-sectional average velocity over a stretch of river was calculated by tracking the centroid of the dye mass. The top graph in Figure 6 presents the simulated cross-sectional average velocity over the length of the river. The wide variations occur due to various inputs and physical conditions including, inflows from the WWRP facilities, movement through varying cross-sections, as well as flow entirely in the low flow channel (areas of higher velocity) and flow outside (areas of reduced velocity). The bottom graph focuses in on a reach of river where a dye study was conducted with the simulated and measured cross-sectional average velocities presented. Other comparisons from dye study results showed similar levels of agreement, lending confidence in the models simulation of the cross-sectional average transport through the system.

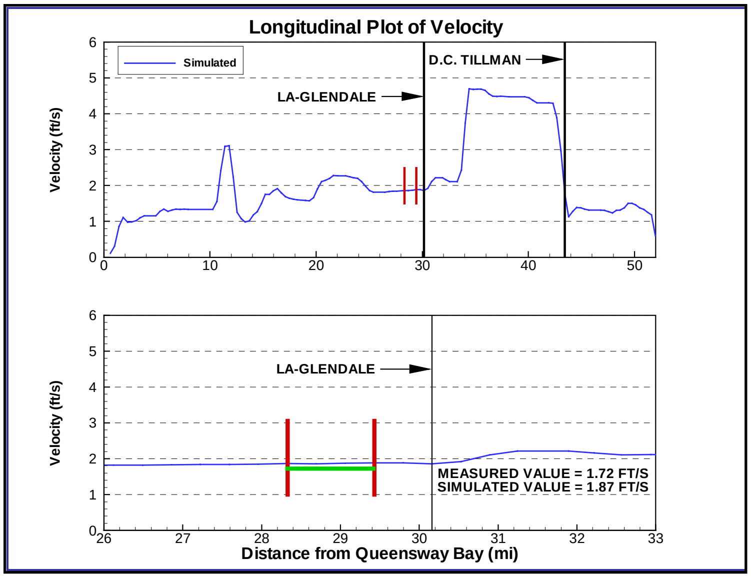

Figure 6: Longitudinal Velocities in LA River

A critical aspect of the nutrient TMDL was the growth of attached algal communities along the main stem; a nuisance condition that was undesirable. The development of a nutrient (and associated algal response) model within the LA River required an evaluation of the relationship between the sources and the impact on the receiving water, as well as accurate simulation of the times of transport and associated residence time. Due to the many factors that dynamically influence in-stream nutrient concentrations, this relationship was developed using a hydrodynamic and water quality model linkage. The linkage of these models permitted representation of major processes associated with nutrient cycling and algal uptake. Additionally, for evaluation of the pathogens the model allowed accurate transportation and simulation of pathogen decay.

Within the original EUTRO5 framework of the WASP model, the state variable that represented phytoplankton was modeled using chlorophyll-a as the input. Consequentially, the subroutine for phytoplankton considered both movement within the water column (vertical) as well as movement between segments (horizontal). For the Los Angeles River simulations, it was desired to model periphyton communities that had no movement either vertically or horizontally (i.e., attached algae). The WASP subroutine for phytoplankton was therefore modified to model attached algae. The subroutine followed the framework used by Warwick et al. (1997).

EUTRO5 was augmented to represent periphyton using the existing framework for phytoplankton growth kinetics. Mathematical relationships based on the impacts of temperature, available light, available nutrients, stream velocity, and density-dependant interactions were incorporated into the algae growth kinetics framework within EUTRO. The major differences between modeling techniques for attached and free-floating algae are: (1) periphyton are expressed in terms of aerial densities rather than volumetric concentrations; (2) periphyton growth can be limited by the availability of bottom substrate; (3) the availability of nutrients to the periphyton matrix is influenced by current velocity; and (4) periphyton are not subject to transport. The application used in the LA River simulations did not consider the effects of grazing on the growth of algae, the densities then become a function of the growth rate balanced by the death rate and respiration.

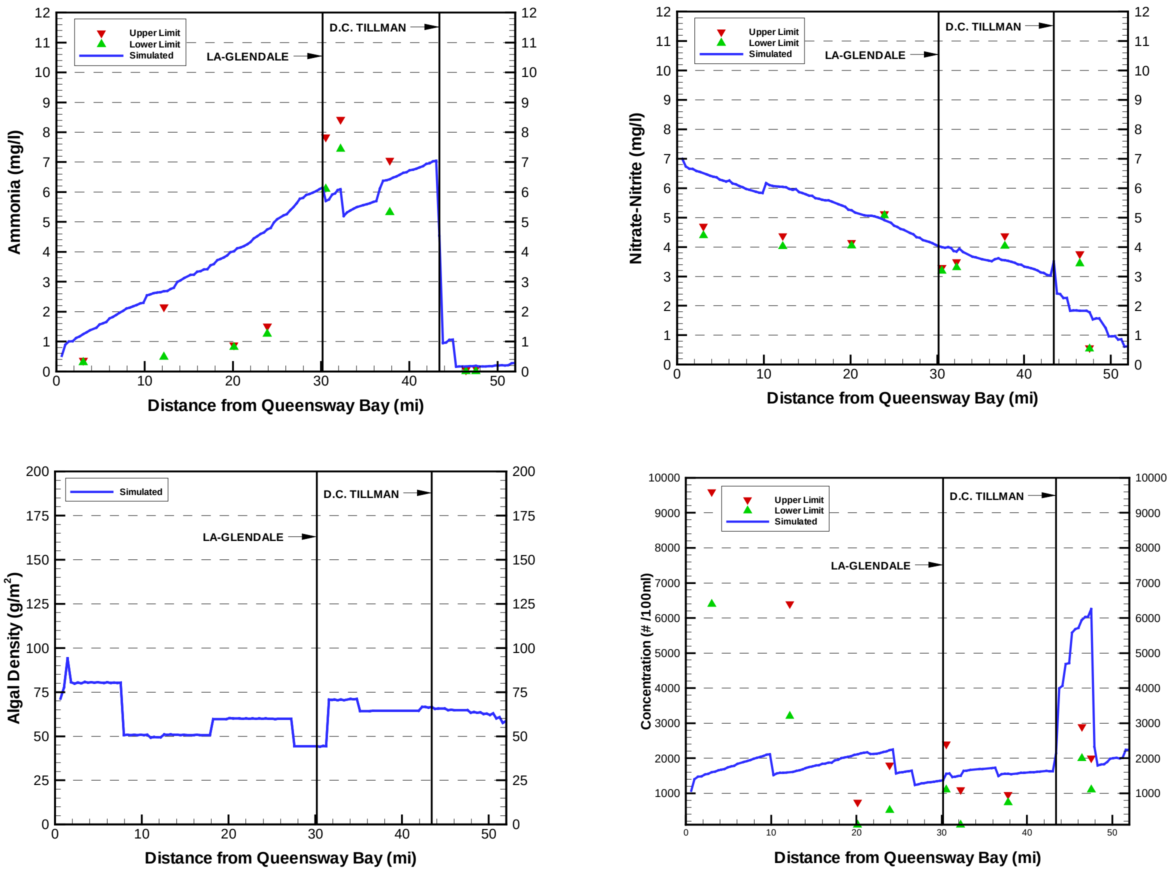

Figure 7: Longitudinal Comparison of Simulated and Measured Nutrients, Algea, and Coliforms

Water quality model calibrations were performed by evaluation of the longitudinal distribution of nutrients, algae and pathogens under the somewhat steady state conditions which occur during dry weather. Figure 7 presents the longitudinal distributions of the key parameters simulated plotted against the measured data for period of the intensive surveys in the summer of 2001. The results show the longitudinal distributions for Ammonia, Nitrate/Nitrite, Attached Algae (periphyton), and Pathogens. The results show the input associated with the Tillman facility and the significant levels of ammonia discharged to the system. These levels represent a problem relative to nutrient enrichment as well as ammonia toxicity. Following the Tillman discharge the results show nitrification moving down the system with a rise in Nitrate/Nitrite past the discharge from the Glendale Plant. While the simulations show continued nitrification in the system moving downstream, the additional uptake in nitrogen indicates that perhaps the algal growth conditions and degree of uptake are under represented.

Wet Weather Approach

The HSPF model was utilized to simulate the pathogen loadings under wet-weather or storm conditions and the loads were then routed through EFDC with first order decay to simulate the in-stream transport and decay moving through the system. Given the flashy nature of the system and the very short travel times during storm events, decay processes provide little alteration to the in-stream concentrations of pathogens during the wet weather events.

The development of the HSPF model involved delineation of the LA River Watershed into sub-watersheds to provide loading to the system. Within the less developed areas, standard delineation practices were utilized based upon the digital elevation model available for the area. In the urban areas standard delineation techniques are not sufficient due to the storm water infrastructure that provides drainage to the river. Delineation in these areas therefore was accomplished using GIS coverage of the storm water distribution system and “sewersheds” were established that encompass areas drained to the same location within the River.

Intensive storm event surveys conducted by SCCWRP provided the baseline data for calibration of the watershed model (SCCWRP, 2002). SCCWRP collected time series measurements during storm event conditions at various locations throughout the Los Angeles River watershed and neighboring watersheds. These stations were isolated to various single land use elements and provided site specific data on the build-up and wash-off of pathogens during flow events. Figure 8 presents the locations of the land-use stations within and adjacent to the LA River Watershed. Utilizing the land-use data, the parameters within the HSPF model were adjusted to provide the best fit under the isolated simulations of the land-use stations. The model parameters were then utilized within the overall watershed simulation model to project flows and concentrations at mass

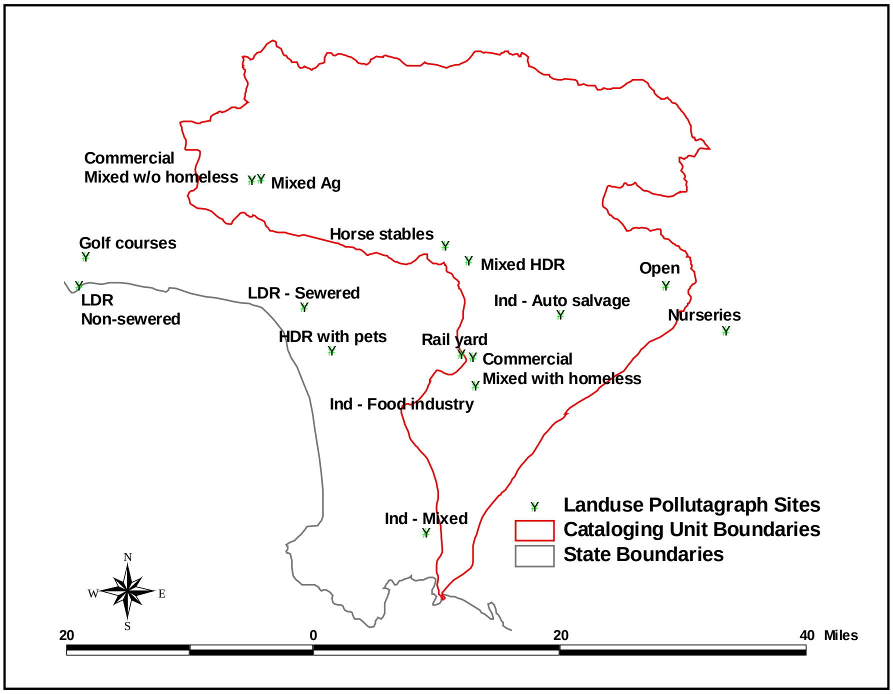

Figure 8: Land Use Specific Stormwater Sampling Stations

emission sites. Additional intensive surveys by SCCWRP provided storm event time series (pollutographs) at the primary stations along the Los Angeles River. Figure 9 presents the simulated and measured E Coli and Total Coliform at the Wardlow Station at the base of the Los Angeles River for a single storm event. The results show that utilizing the land use specific parameterization of the model under predicts E Coli concentration by approximately 30 percent, while Total Coliform are only slightly under predicted.

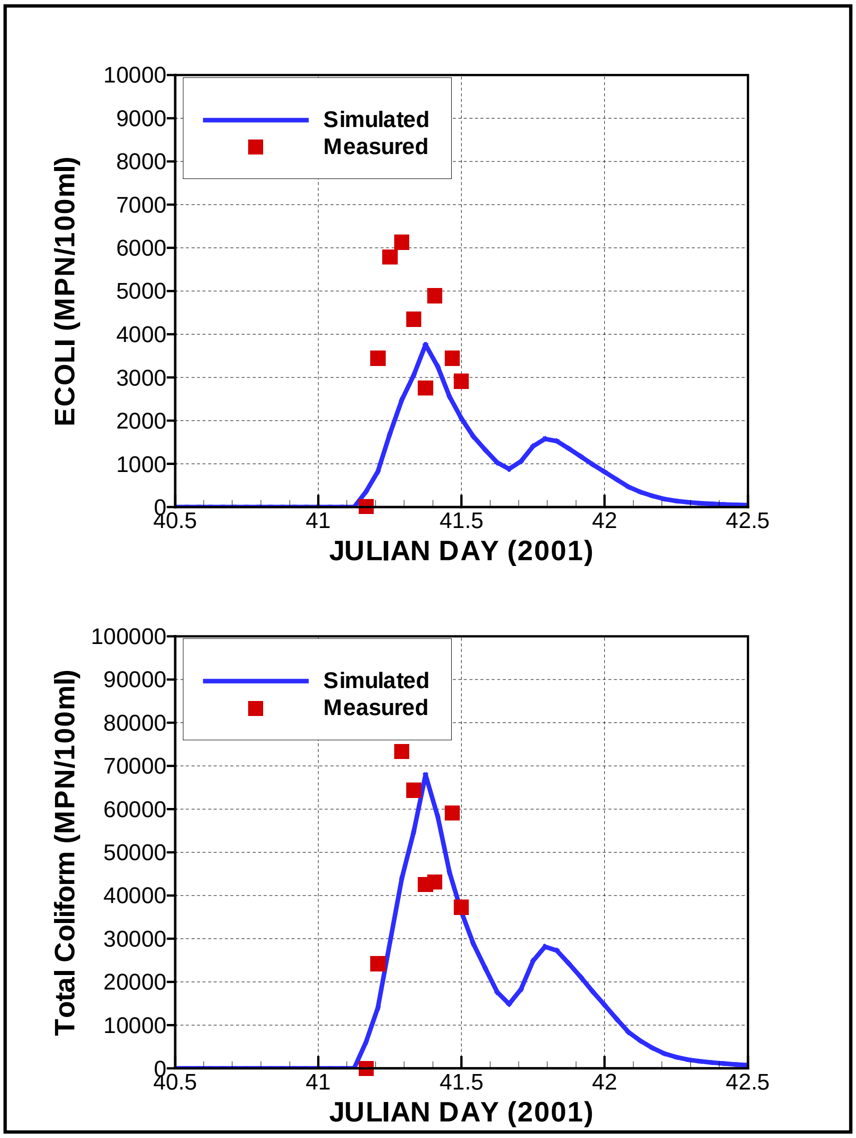

Figure 9: Simulated versus Measured Pathogens at Wardlow

Summary and Conclusions

A system of models was developed for the simulation of nutrient and pathogen dynamics within the Los Angeles River and it's watershed in a two-phase approach. Phase I addressed nutrients and pathogens under low-flow, dry-weather conditions. Phase II addressed pathogen loadings under high-flow, wet-weather conditions. This system of models utilized HSPF for simulation of the watershed pathogen loads, EFDC for simulation of the in-stream transport processes in the listed segments, and WASP for simulation of the in-stream water quality kinetics in the listed segments. The development of the modeling system addressed numerous issues associated with urban conditions including; the delineation of "sewersheds" to provide accurate drainage pathways; storm-drain inflows under dry-weather conditions; short-duration high-intensity storm event hydrographs; the influence and growth of nuisance periphyton on concrete structures; development of urban land-use specific model parameterization; and the impacts of point source discharges. The models simulate the key processes well and provide a useful set of tools for TMDL development, reduction scenario evaluation, and TMDL implementation.

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