Appendix D

Wet and Dry Weather Models

Used in the Chollas Creek Metals Total Maximum Daily Load

California Regional Water Quality Control Board, San Diego Region

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1. Watershed Modeling and General Considerations

Models are developed as tools to perform experiments on watersheds that would otherwise be impractical or impossible due to cost, personnel, or time constraints (Nix, 1994). A significant advantage of watershed modeling is the ability to process and effectively present copious amounts of spatial and time-series data. Additionally, models can prove beneficial in data-limited environments; they can estimate values for unavailable or incomplete data sets by utilizing available preexisting data in the model calibration process. These functionalities allow users to determine the impacts of different parameters on the natural processes occurring in a watershed.

Watershed-scale models range from simple to complex. Simple models are used to rapidly identify critical areas in the environment and are often utilized when data limitations and financial constraints prohibit the use of more complex models. Simple models describe a limited number of hydrologic and water quality processes and are used to estimate pollutant loadings, thus acting as a screening tool. More complex models depend on deterministic algorithms that closely simulate the physical processes in the watershed. Additionally, such models are data intensive and require substantial model calibration to accurately depict the natural system.

In selecting an appropriate approach to support the Total Maximum Daily Load (TMDL) for Chollas Creek, technical and regulatory criteria were considered. Technical criteria include the physical system in question, including the constituents of interest and watershed or stream characteristics and processes (physical domain, source contributions, critical conditions, and constituents). Consideration of each topic was critical in selecting the most appropriate modeling system to address the types of sources associated with the listed waters.

Representation of the physical domain is perhaps the most important consideration in model selection. The physical domain is the focus of the modeling effort—typically, either the receiving water itself or a combination of the contributing watershed and the receiving water. Selection of the appropriate modeling domain depends on the constituents and the conditions under which the stream exhibits impairment. For streams affected additionally or solely by nonpoint sources or primarily rainfall-driven flow and pollutant contributions, a dynamic approach is recommended. Dynamic watershed models consider time-variable nonpoint source contributions from a watershed surface or subsurface. Some models consider monthly or seasonal variability, while others enable assessment of conditions immediately before, during, and after individual rainfall events. Dynamic models require a substantial amount of information regarding input parameters and data for calibration purposes.

1.1. Source Contributions of Metal Loads

The primary sources contributions of metal loads to Chollas Creek had to be considered in the model selection process. Accurately representing contributions from nonpoint sources and regulated point sources is critical in properly representing the system and ultimately evaluating potential load reduction scenarios.

Water quality monitoring data were not sufficient to fully characterize all sources of metals in the Chollas Creek watershed. However, analyses of the available data indicate that the main sources are associated with surface runoff. As a result, the models selected to develop copper, lead, and zinc TMDLs for the Chollas Creek watershed need to address the major source categories during dry and wet weather conditions.

1.2. Critical Conditions

The critical condition is the set of natural conditions, including flow rates and critical points that identifies when and where a water body exhibits the most vulnerability. In the Chollas Creek Metals TMDL project, separate critical flow conditions were identified for dry and wet weather conditions. This allowed for a better characterization of the critical condition than only addressing a single critical flow condition. Additionally for the Chollas Creek Metals TMDL project, a critical point was selected at the mouth of the Chollas Creek watershed. A critical point is a location in an impaired water body that is selected based on high pollutant loads predicted at that location. Not only does the Clean Water Act (CWA) require that critical conditions be taken into account [40 CFR 130.7(c)], but both the identification of dry and wet weather critical flow conditions and the Chollas Creek watershed's critical point are useful in conservatively assessing impairments to Water Quality Objectives (WQOs) and in directing implementation of load reduction strategies. However, although this critical point for water quality assessment is utilized for TMDL analysis, compliance to WQOs must be assessed and maintained for all segments in the Chollas Creek watershed to ensure that beneficial uses are protected.

1.3. Constituents

Another important consideration in model selection and application is the constituent(s) to be assessed. Choice of state variables is a critical part of model implementation. The more state variables included, the more difficult the model will be to apply and calibrate. However, if key state variables are omitted from the simulation, the model might not simulate all necessary aspects of the system and might produce unrealistic results. A delicate balance must be met between minimal constituent simulation and maximum applicability.

The focuses of the Chollas Creek Metals TMDL project is assessing the copper, lead, and zinc loads that cause impairment to the beneficial uses of the Chollas Creek watershed. These metal loads can be estimated by combining the flow rates and concentration. Factors affecting the concentration of metals include hardness, pH, and available sediment. Metal concentrations in the water column are also influenced by in-stream losses and settling. In-stream metal dynamics can be extremely complex, and accurate estimation of concentrations relies on a host of interrelated environmental factors. The available data provided few insights into which other factors might be most influential on metal behavior for the model.

1.4. Regulatory Criteria

A properly designed and applied model provides the source analysis component of the Chollas Creek Metals TMDL project. The Regional Water Quality Control Board, San Diego Region's (Regional Board) Basin Plan establishes, for all waters in the San Diego region, the beneficial uses to be protected, the WQOs that those uses, and an implementation plan that achieves those objectives (Regional Board, 1994). For the watershed source analysis and the implementation plan, it is also important that the modeling platform enable examination of gross land use loading as well as in-stream concentration.

1.5. Application of San Diego Regional Hydrologic Model for both Dry and Wet Weather Models

The San Diego regional hydrologic model described in this appendix was originally designed to simulate dry weather bacteria concentrations in the San Diego region, as described in *Bacteria TMDLs for Beaches and Inland Surface Waters of the San Diego Region – DRAFT* (Tetra Tech, Inc., 2004). Because the flow model was based on data from the San Diego region and has robustly calibrated and validated measured parameters for the San Diego region, it is appropriate to use for the Chollas Creek Metals TMDL project. This single set of parameters was calibrated and validated over a diverse geographic (includes mountainous and coastal regions as well as highly urbanized and open areas) and temporal scale (includes extreme dry and wet weather periods), and can therefore be applied to many of the ungaged streams within the San Diego region, including Chollas Creek.

Without this regional set of parameter values, a watershed model would be unfeasible for the source analysis support needed for the Chollas Creek Metals TMDL project. By applying the regionally calibrated hydrology parameter values to the updated watershed delineations and land use reclassifications for the Chollas Creek watershed, flow was simulated for the watershed. Current analyses utilize the calibrated flow parameters from the San Diego regional hydrologic model, while considering additional local information. This appendix describes model set-up, calibration, and validation of the San Diego regional hydrologic model, emphasizes why this regional model is applicable to the Chollas Creek watershed, and notes the modifications that were made to adapt the model for the Chollas Creek watershed.

1.6. Model Calibration and Validation

After any model is configured, model calibration and validation must be performed to ensure the natural environment is represented as accurately as possible. For watershed modeling, this is generally a two-phase process, with hydrology (flow rate) calibration and validation completed before repeating the process for water quality (pollutant concentration). Upon completion of the calibration and validation at selected locations, a calibrated dataset containing parameter values for each modeled land use and pollutant was developed.

2. Estimated Existing Loads for Dry and Wet Weather Conditions

2.1. Explanation of Dry and Wet Weather Conditions

A distinction is made between dry and wet weather conditions because the sources and amounts of metals vary between the two scenarios and implementation measures will be specific to these conditions. Existing copper, lead, and zinc loads were estimated for both dry and wet weather conditions to provide year-round representation of the Chollas Creek watershed.

Utilizing separate approaches for dry and wet weather conditions ensured that the Chollas Creek Metals TMDL project addressed the variable flow patterns in the Chollas Creek watershed with an appropriate methodology. A flow-based cutoff to separate dry and wet weather conditions, as opposed to a dry and wet weather season approach, was applied to accurately capture rainfall events and sustained dry periods throughout the year. The dry weather flow approach uses a steady-state model to estimate existing loads during dry periods that are not addressed through the wet weather flow rate approach.

Before existing loads for dry and wet weather conditions could be estimated, the two conditions need finite definitions. Dry weather conditions are based on dry weather days that were selected based on the criterion that less than 0.2 inch of rainfall was observed on each of the previous three days[1]. A wet weather condition was characterized as any flow greater than the dry weather condition criteria as predicted by the dry weather model based on the definition above.

2.2. Dry and Wet Weather Critical Flow Conditions

The dry weather critical flow condition was based on predictions of steady-state flows, which were derived through modeling analysis of average dry weather flows observed in the San Diego region. The dry weather critical condition was based on the prediction of steady-state flows. As described in section 3, regionally calibrated model parameters were developed through a modeling analysis of average dry weather flows observed in Aliso Creek (2001), Rose Creek (2001-2002), and Tecolote Creek (2001-2002). These parameters were applied to the Chollas Creek watershed to determine the watershed-specific critical dry weather flow condition.

To ensure protection of the Chollas Creek watershed during wet weather conditions, a critical flow condition was selected based on identification of the 93rd percentile of annual rainfall observed over the past 14 years (1990 through 2003) at multiple rainfall gages in the San Diego region. Essentially the critical flow condition was based on the wettest year of the past 14 years. This resulted in selection of 1993 as the critical wet year for assessment of wet weather conditions. This critical flow condition was consistent with studies performed by the Southern California Coastal Research Project (SCCWRP), where a 90th percentile year was selected based on rainfall data for the Los Angeles Airport from 1947 to 2000, also resulting in selection of 1993 as the critical wet year (Regional Water Quality Control Board, Los Angeles Region (LARWQCB), 2002).

2.3. Estimated Existing Annual Loads from Dry and Wet Weather Models

According to the CWA [40 CFR 130.2 (i) and 40 CFR 130.7 © (1)] a TMDL document must analyze all sources, and the magnitude and location of the sources. In order to comply with

[1] This definition comes from the California Department of Environmental Health's general advisory that is issued to alert the public of ocean and bay water contamination by urban runoff. It is also supported by CFR section 122.21 and section 122.26.

the CWA, both the dry and wet weather models were used to estimate existing annual loads of copper, lead, and zinc. In addition the mass loadings estimated from the model outputs also offer support for the implementation plan. Relative amounts of mass loadings for dry and wet weather conditions can identify where more serious problems occur and on which subwatersheds or land uses efforts should be concentrated. For example, for all three metals, freeways and commercial/institutional land uses have the highest relative loading contributions. Responsible parties may want to concentrate efforts on controlling metal sources in these areas.

The simulated flow rate was combined with average in-stream dry weather concentrations for dissolved copper, lead, and zinc in order to estimate basin-wide existing loads for each metal (Table 1). The estimated loads for the dry weather critical flow conditions were the same as the average estimated loads for the dry weather typical condition because the dry weather metal concentration could not be simulated due to limited observed data for calibration. The estimated existing loads for the wet weather critical flow rate condition and the average estimated existing loads (1990-2003) for the wet typical weather condition are provided in Table 2 and Table 3 for each metal. All estimated existing loads are calculated at the mouth of the Chollas Creek watershed, which is the critical point.

Table 1. Estimated existing loads (grams per year) for the dry weather critical flow condition and average estimated existing loads for the dry weather typical condition at the critical point

Copper (dissolved)	Lead (dissolved)	Zinc (dissolved)
692	168	986

Table 2. Estimated existing loads (grams per year) for the wet weather critical flow rate condition at the mouth of the Chollas Creek watershed

Copper (dissolved)	Lead (dissolved)	Zinc (dissolved)
984,549	705,142	5,993,255

Table 3. Average estimated existing loads (grams per year) for the average wet weather condition for 1990 through 2003 at the critical point.

Copper (dissolved)	Lead (dissolved)	Zinc (dissolved)
232,137	194,007	1,326,407

2.4. Model Assumptions/Limitations

While highly beneficial tools for analyzing surface runoff pollution problems, all mathematical models are based on assumptions or inferences made about the processes and systems being simulated, which must be considered (Charbeneau & Barrett, 1998; Loague, Corwin, & Ellsworth, 1998; Nix, 1994; Tim & Jolly, 1994). These limitations include the steep learning curve for model use, the accuracy of the mathematical equations, and inadequacies and assumptions of the input data (Charbeneau & Barrett, 1998; Nix, 1994; Tim & Jolly, 1994). Model users must keep in mind that a model is a tool; and while it can extract information, it cannot overcome data inadequacies or assumptions. The specific assumptions made with the modeling approach used for in the Chollas Creek Metals TMDL project include but are not limited to the following:

2.4.1. General Model Assumptions

- The critical point was assumed to be at the mouth of the Chollas Creek watershed.
- Water quality monitoring data were not sufficient to fully characterize all sources of metals in the Chollas Creek watershed.
- The limited data available provide few insights into which other factors might be most influential on metal behavior for the model

2.4.2. Wet Weather Model Assumptions

The following assumptions are relevant to the Loading Simulation Program written in C++ (LSPC) model developed to simulate wet-weather sources of metals in Chollas Creek.

- *Source Representation* - All sources can be represented through build-up/wash-off of metals from specific land use types.
- *Flow* - Because modeled and observed flow ranges are similar, a simulation program hydrology model flow rate results were considered representative of flow in the Chollas Creek watershed. Differences can be explained by localized events, and until additional flow data become available, further calibration is not possible, nor warranted.
- *Water Quality Data* - Observed water quality data, unlike stream flow data, are usually not continuous; thus making time-series comparisons difficult and reducing the accuracy of the water quality model calibration.
- *General LSPC/HSPF Model Assumptions* - Many model assumptions are inherent in the algorithms used by the LSPC watershed model and are reported extensively in Bicknell et al. (1996).
- *Land Use* - The San Diego Association of Governments (SANDAG) land use GIS dataset is assumed representative of the current land use areas. For areas where significant changes in land use have occurred since the creation of these datasets, model predictions may not be representative of observed conditions.
- *Stream Representation* - Each delineated subwatershed was represented with a single stream assumed to be a completely mixed, one-dimensional segment with a trapezoidal cross-section.
- *Hydrologic Modeling Parameters* - Hydrologic modeling parameters were developed during previous modeling studies in Southern California (e.g., LA River, San Jacinto River) and refined through calibration to stream flow data collected in the San Diego region. Through the calibration and validation process (reported in the Bacteria TMDLs for the San Diego Region), a set of modeling parameters were obtained specific to land use and hydrologic soil groups. These parameters are assumed to be

representative of the hydrology of the Chollas Creek watershed, which is presently ungaged and therefore unverified.

- *Water Quality Modeling Parameters* - Dynamic models require a substantial amount of information regarding input parameters and data for calibration purposes. All sources of metals from watersheds are represented in the LSPC model as build-up/wash-off from specific land use types. Limited data are currently available in the San Diego region to allow development of unique modeling parameters for simulation of build-up/wash-off, so initial parameters values were obtained from land use-specific storm water data in the Los Angeles region. These build-up/wash-off modeling parameters were refined during the calibration and validation process in which observed data from Chollas Creek were compared with the model predicted values.
- *Lumped Parameter Model Characteristic* - LSPC is a lumped-parameter model and is assumed to be sufficient for modeling transport of flows and metal loads from watersheds in the region. For lumped parameter models, transport of flows and metal loads to the streams within a given model subwatershed cannot consider relative distances of land use activities and topography that may enhance or impede time of travel over the land surface.
- *First-order Losses* - Each stream is modeled assuming first-order loss of metals.
- *Wet-weather Critical Condition* – The critical wet-weather condition was selected based on identification of the 93rd percentile of annual rainfalls observed over the past 12 years (1990 through 2002) at multiple rainfall gages in the San Diego region. This resulted in selection of 1993 as the critical wet year for assessment of wet weather loading conditions. This condition was consistent with studies performed by SCCWRP, where a 90th percentile year was selected based on rainfall data for the Los Angeles Airport (LAX) from 1947 to 2000, also resulting in selection of 1993 as the critical year (LARWQCB, 2002).

2.4.3. Dry Weather Model Assumptions

The following assumptions are relevant to the watershed modeling system developed for simulation of steady-state dry-weather flows and sources of metals.

- *Limited Dry Weather Data* - Because there were only seven in-stream dry weather metal concentration data points in the Chollas Creek watershed, copper, lead, and zinc concentrations could not be simulated. Therefore, land use specific loadings and more detailed analyses could not be calculated.
- *Stream Representation* - This predictive model represents the stream network as a series of plug-flow reactors, with each reactor having a constant, steady state flow and pollutant load.
- *Flow Condition* - These constant flows were assumed representative of the average flow caused by various urban land use practices (e.g., runoff from lawn irrigation or sidewalk washing).
- *Channel Geometry* - Channel geometry during low-flow, dry-weather conditions is assumed to be represented appropriately using equations derived from flows and physical data collected at 53 U.S. Geological Survey (USGS) stream gages in Southern California.

- *Steady-state Model Configuration* - Although dry-weather flows vary over time for any given stream, for prediction of average conditions in the stream, flows were assumed to be steady state.
- *Plug Flow Model Configuration* - Plug flow reaction kinetics were assumed sufficient in modeling dry-weather, steady state stream routing.
- *Sources for Characterization of Dry-weather Conditions* - Data used for characterization of dry-weather flows were assumed representative of conditions throughout the region.
- *Methods for Characterization of Dry-weather Conditions* - The equations derived through multivariable regression analyses were assumed sufficient to represent the dry-weather flows as a function of land use and watershed size. This assumption was verified through model calibration and validation reported.
- *Stream Infiltration* - Losses of volume through stream infiltration were modeled assuming infiltration rates were constant for each of the four hydrologic soil groups (A, B, C, and D[2]). Infiltration rates were based on literature vales and refined through model calibration and validation. The resulting infiltration rates were 1.368 inches per hour (in/hr) (Soil Group A), 0.698 in/hr (Soil Group B), 0.209 in/hr (Soil Group C), and 0.084 in/hr (Soil Group D). These infiltration rates are within the range of values found in literature (Wanielisata et al., 1997). These infiltration rates are assumed representative for all streams studied in the region within each hydrologic soil group.
- *Dry-weather Critical Condition* - The critical dry period was based on predictions of steady-state flows based on results of analysis of average dry-weather flows observed in Aliso Creek, Rose Creek, and Tecolote Creek. Dry-weather days were selected based on the criterion that less than 0.2 inch of rainfall was observed on each of the previous 3 days.

3. Dry Weather Model

During dry weather conditions, many streams exhibit a sustained base flow even if no rainfall has occurred for a significant period to provide storm water runoff or groundwater flows. These sustained flows are generally understood to result from various urban land use practices (e.g. lawn irrigation runoff, car washing, and sidewalk washing) and are referred to as urban runoff. As these urban runoffs travel across land areas (e.g. lawns and other urban surfaces), accumulated metal loads are carried from these areas to receiving waterbodies.

[2] Group A Soils have low runoff potential and high infiltration rates even when wet. They consist chiefly of sand and gravel and are well drained to excessively-drained. Group B Soils have moderate infiltration rates when wet and consist chiefly of soils that are moderately-deep to deep, moderately- to well-drained, and moderately course textures. Group C Soils have low infiltration rates when wet and consist chiefly of soils having a layer that impedes downward movement of water with moderately-fine to fine texture. Group D Soils have high runoff potential, very low infiltration rates and consist chiefly of clay soils. These soils also include urban areas (USDA, 1986).

The dry weather model was used to estimate the flow rates of urban runoff in the Chollas Creek watershed. The average metal concentrations were used to estimate the existing metal concentrations that end up in Chollas Creek from urban runoff transportation of metal loads. Figure 1 is a visual representation of how the model outputs were used. Because there were only seven in-stream dry weather metal concentration data points in the Chollas Creek watershed, copper, lead, and zinc concentrations could not be simulated. The simulated flow values from a San Diego regional hydrologic model were instead combined with average in-stream dry weather metal concentrations for dissolved copper, lead, and zinc to calculate estimated basin-wide loads for each metal (Table 1).

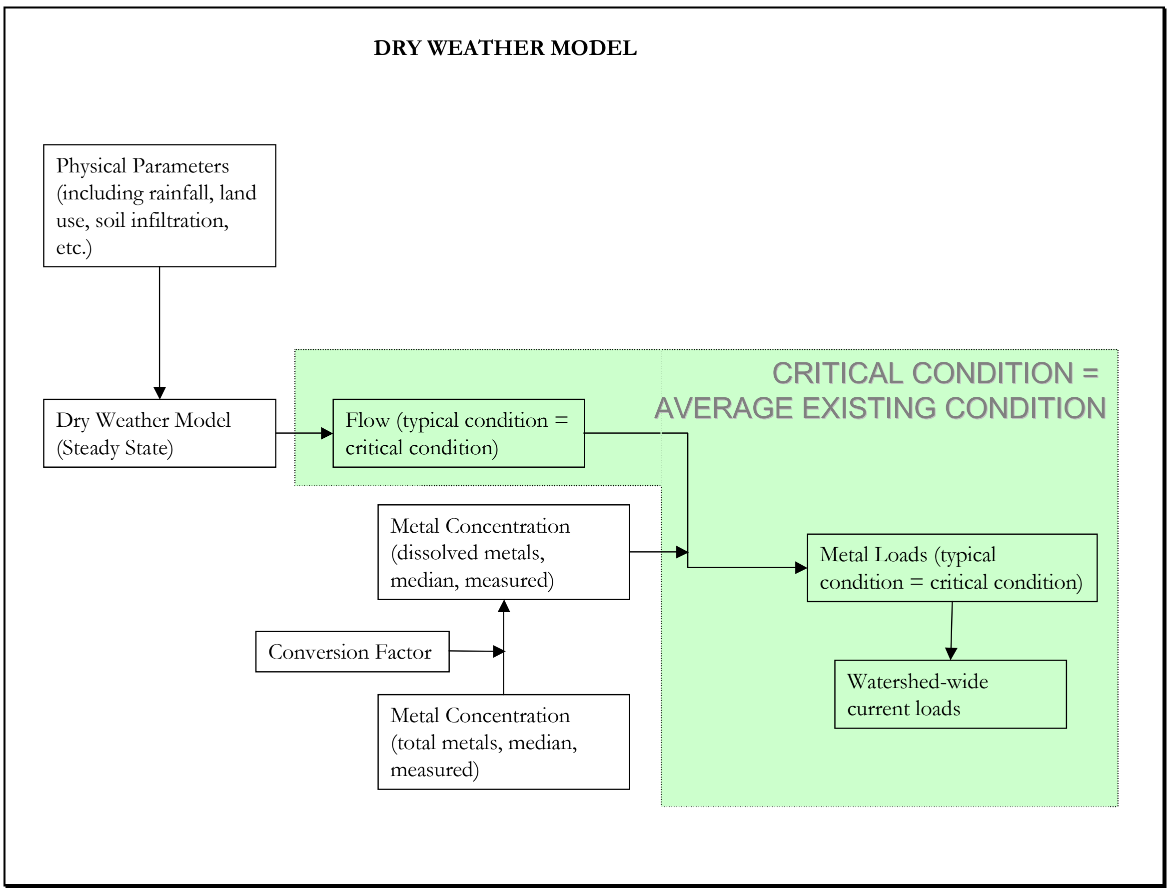


Figure 1. Dry weather model outputs.

3.1 Dry Weather Modeling Details

To estimate sources from dry weather urban runoff, a steady-state spreadsheet was developed for the San Diego region to model dry weather flow in the watershed. However, because limited in-stream dry weather metal concentration data were available for model calibration and validation, copper, lead, and zinc concentrations could not be simulated and average values from available data were used. The calibrated, low flow, steady-state model was used to estimate flows during dry weather conditions. These constant flows were assumed representative of the average flow caused by various urban land use practices (e.g., runoff from lawn irrigation or sidewalk washing).

3.1.1 Dry Weather Model Use of the Chollas Creek Watershed Representation
The initial step in this watershed-based analysis was to clearly define the watershed boundary. Therefore, before the model could be configured, an appropriate scale for analysis was determined. Model subwatersheds were delineated based on CALWTR 2.2, a standard nested watershed delineation scheme, watersheds, stream networks, locations of flow and water quality monitoring stations, consistency of hydrologic factors, and land use uniformity. The subwatersheds, soil types, and stream lengths used in the dry weather model were identical to those described in the wet weather model. Figure 2 provides a schematic of the stream network for the Chollas Creek watershed, which includes model segment connectivity, used for the Chollas Creek Metals TMDL project. Section 4.2 also provides a more detailed discussion of the watershed representation used for the wet weather model.

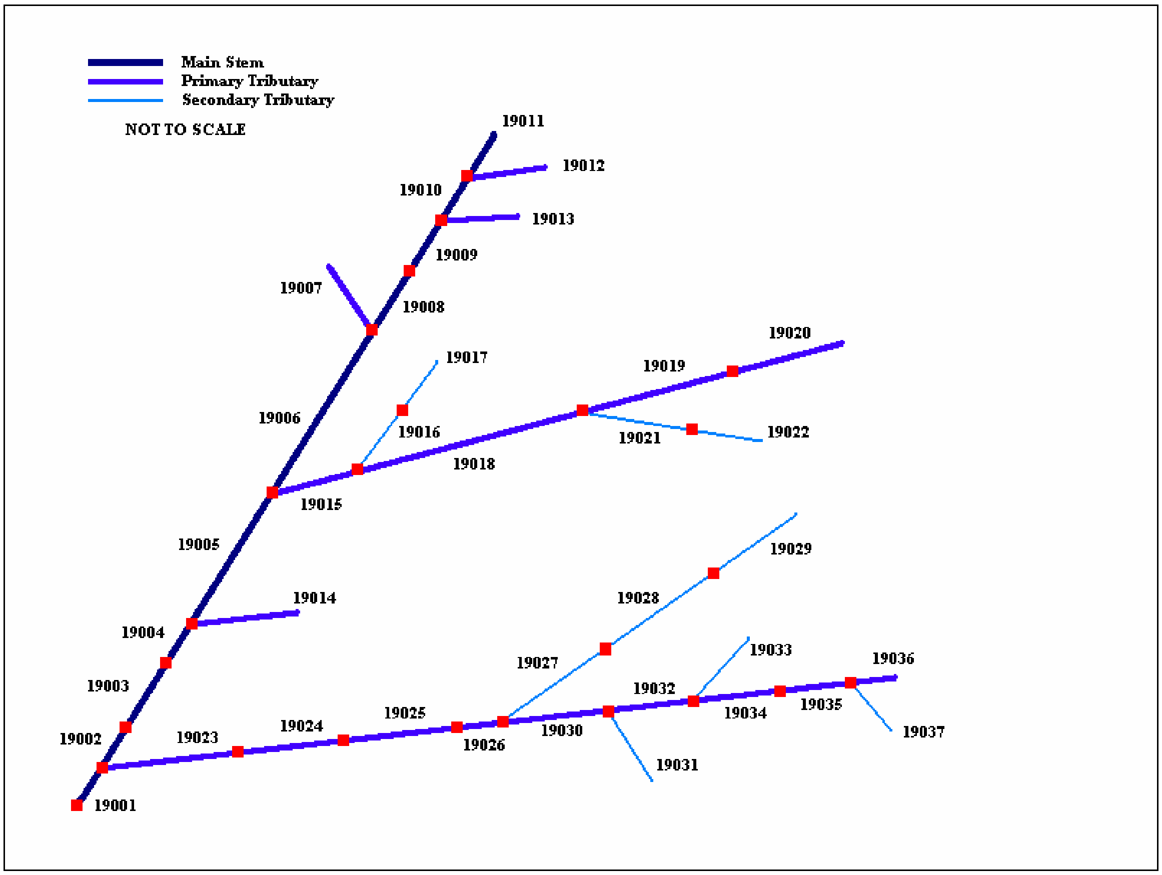


Figure 2. Schematic of model segments (indicated by subwatershed identification numbers) for Chollas Creek and its tributaries. Each segment is identified with a model number.[3]

[3] See Figure 11 for the segments as they appear on a map of the Chollas Creek watershed.

3.1.2. Channel Geometry

Precise channel geometry data were not available for the modeled stream segments; therefore, stream dimensions were estimated from analysis of observed data from other areas. Analyses were performed on flow data and associated stream dimension data from 53 USGS gages throughout Southern California. For this analysis, all flow less than 15 cubic feet per second (ft^3/s) was assumed to represent dry weather flow conditions. Using these dry weather flow data, the relationship between flow and cross-sectional area was estimated ($R^2 = 0.51$). The following regression equation describes the relationship between flow and cross-sectional area:

$$A = e^{0.2253 \times Q}$$

where:

A = cross-sectional area, feet squared (ft^2)
Q = flow, cubic feet per second (ft^3/s)

In addition, data from the USGS gages were used to determine the width of each segment based on a regression between cross-sectional area and width. The relationship with the greatest correlation ($R^2 = 0.75$) was based on the natural logarithms of each parameter. The following regression equation describes the relationship between cross-sectional area and width:

$$LN(W) = (0.6296 \times LN(A)) + 1.3003 \quad \text{or} \quad W = e^{((0.6296 \times LN(A)) + 1.3003)}$$

where:

W = width of model segment (ft)
A = cross-sectional area (ft^2)

3.1.3. Steady-State Mass Balance Overview

To represent the linkage between dry weather source contributions and in-stream response, a steady-state mass balance model was developed to simulate transport of pollutants in the impaired stream segment. This predictive model represents the stream network as a series of plug-flow reactors, with each reactor having a constant, steady state flow and pollutant load. A plug-flow reactor can be thought of as an elongated rectangular basin with a constant level in which advection (unidirectional transport) dominates (Figure 3).

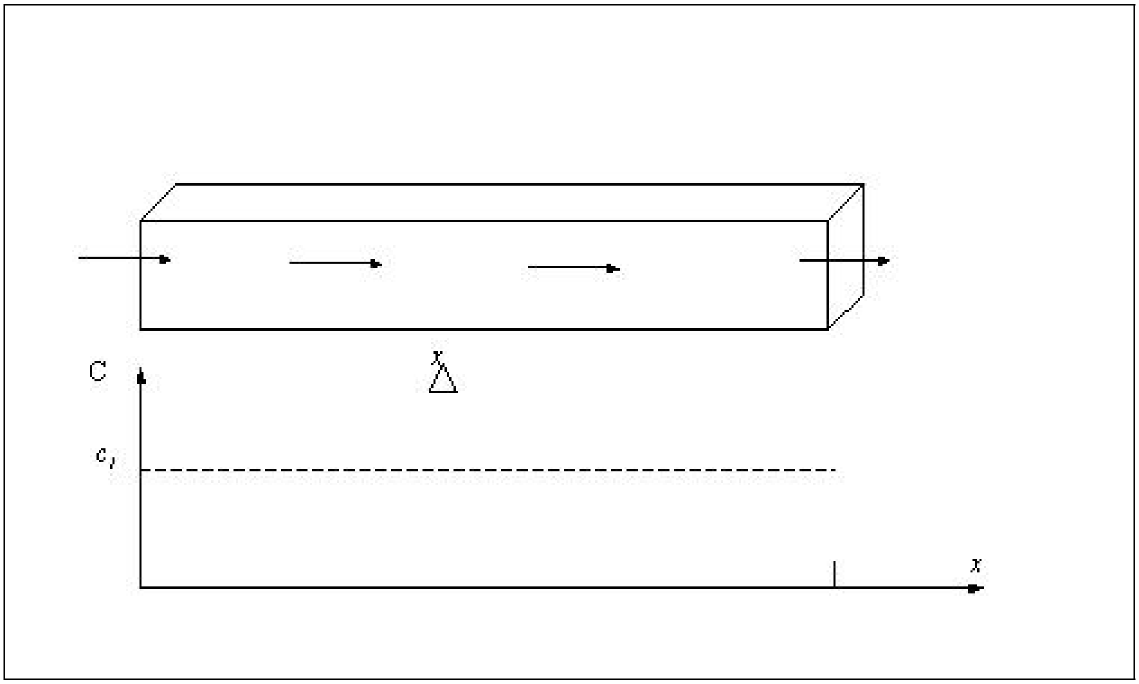


Figure 3. Theoretical plug-flow reactor. See following equations for definition of variables.

This modeling approach relies on basic segment characteristics, which include flow, width, and cross-sectional area. Model segments are assumed to be well-mixed laterally and vertically at a steady-state condition (constant flow input). Variations in the longitudinal dimension determine changes in flow and pollutant concentrations. A "plug" of a conservative substance introduced at one end of the reactor will remain intact as it passes through the reactor. The initial concentration of a pollutant from multiple sources can be represented based on empirically derived inflows as a single input at the injection point. Each reactor defines the mass balance for the pollutant and flow. At points further downstream, the concentration can be estimated based on first-order loss and mass balance.

3.1.4. Dry Weather Model Equations

There are two core equations used in the dry model, one to represent the mass balance and one to represent the loss of concentration downstream.

A mass-balance of the watershed load and, if applicable, of the load from the upstream tributary were performed to determine the change in concentration. This is represented by the following equation:

$$C_0 = \frac{Q_r C_r + Q_t C_t}{Q_r + Q_t}$$

where:

Q = flow (ft^3/s)
C = concentration

In the previous equation, Q_r and C_r refer to the flow and concentration from the receiving watershed and Q_t and C_t refer to the flow and concentration from the upstream tributary. The concentration estimated from this equation was then used as the initial concentration (C_0) in the loss equation for the receiving segment.

To describe instream losses, a first order rate equation was derived. An initial concentration (C_0) for inflow was set as an upstream boundary condition. The final water column concentration (C) in a segment can be estimated using the loss equation given below:

$$\frac{dc}{dt} = -kc \quad \text{or} \quad C = C_0 e^{-kt} = C_0 e^{-\left(k\frac{x}{u}\right)}$$

where:

C_0 = initial concentration
C = final concentration
k = loss rate (1/day)
χ = segment length (miles)
u = stream velocity (miles per day)

3.2. Dry Weather Model Use of a San Diego Regional Hydrologic model

The San Diego regional hydrologic model used estimates of subwatershed inflows obtained through analysis of available data. Data collected as part of detailed monitoring efforts of Aliso Creek (performed by the Orange County Pubic Facilities and Resources Department and the Orange County Public Health Laboratory) and of Rose Creek and Tecolote Creek (performed by the City of San Diego) were analyzed to estimate dry weather flow data. Information from these studies was assumed sufficient for use in characterizing dry weather flow conditions for the entire study area.

For each of the detailed studies, flow data were collected throughout the year at stations within the watersheds (27 stations for Aliso Creek, 3 stations for Rose Creek, and 2 stations for Tecolote Creek). The watersheds were delineated to each sampling location. Analyses were performed to determine whether there is a correlation between the respective land use types and average dry weather flow data collected at the mouth of each subwatershed.

The results of the analyses showed good correlation between flow and commercial/institutional, open space, and industrial/transportation land uses (R^2 = 0.78). The following equation was derived from the analysis:

$$Q = (A_{1400} \times 0.00168) + (A_{4000} \times 0.000256) - (A_{1500} \times 0.00141)$$

where:

Q = flow (ft^3/s)
A_{1400} = area of commercial/institutional (acres)
A_{4000} = area of open space, including military operations (acres)
A_{1500} = area of industrial/transportation (acres)

The empirical equation presented above that represented water quantity associated with dry weather urban runoff from various land uses can be used to predict flow. Figure 4 shows the flow predicted by the above equation compared to observed data for Aliso Creek, Rose Creek, and Tecolote Creek.

Overall, the statistical relationship established between each land use area and flow showed good correlation with the observed flow data. To improve model fit, model calibration and validation were conducted.

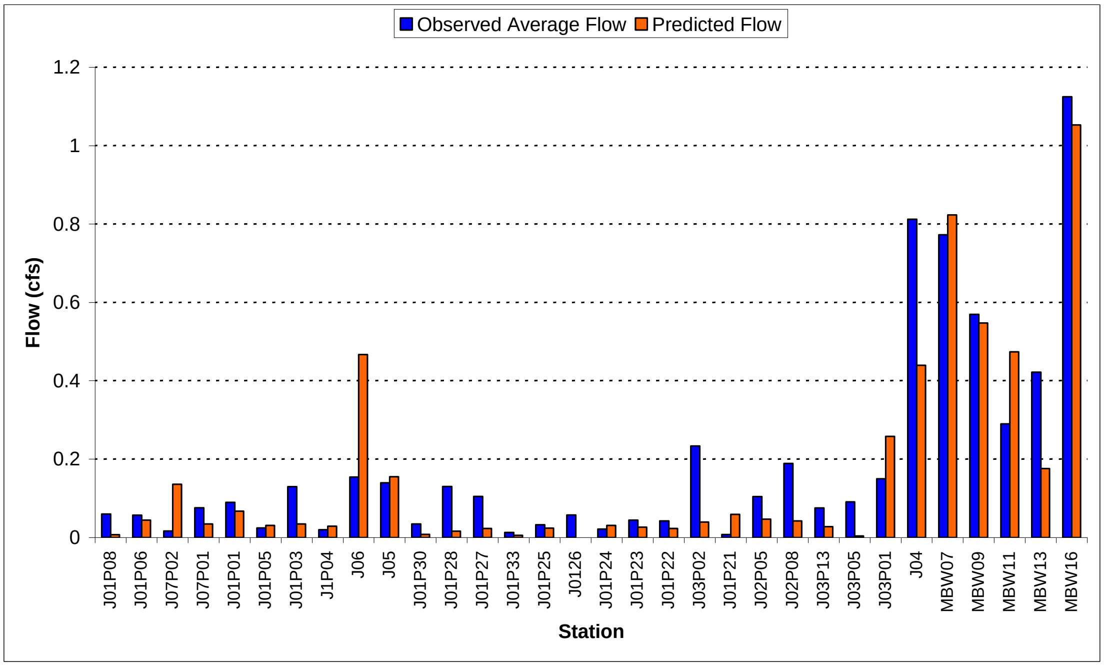


Figure 4. Predicted and observed flows in Aliso Creek, Rose Creek, and Tecolote Creek indicated by station numbers (Tetra Tech, Inc., 2004).

3.2.1. Calibration and Validation of the San Diego Regional Hydrologic model

Model calibration was performed using data from Aliso Creek and Rose Creek. Calibration involved the adjustment of infiltration rates to reflect observed in-stream flow conditions. Following model calibration, a separate validation process was undertaken to verify the predictive capability of the model in other watersheds. Table 4 lists the sampling locations used in calibration and validation, along with their corresponding watershed identification number from the San Diego regional hydrologic model. Figure 5 shows the sampling locations and their proximity to the Chollas Creek watershed. The model results presented in the next sections, especially the model calibration and validation, directly apply to the Chollas Creek watershed modeling effort because the Chollas Creek watershed is within the San Diego region.

Table 4. Sampling location for calibration and validation. (Tetra Tech, Inc., 2004)

Calibration – Flow	**Validation – Flow**

Watershed	Sampling Location	Watershed	Sampling Location	Watershed	Sampling Location	Watershed	Sampling Location
208	J01P22	214	J01P01	1602	MBW17	1701	MBW06
209	J01P23	215	J01TBN8	1603	MBW15	1702	MBW07
210	J01P28	219	J04	1605	MBW11	1703	MBW10
211	J01P27	220	J03P13	1606	MBW13	1704	MBW08
212	J06	221	J03P01	1607	MBW24	1705	MBW09
213	J01P05	1601	MBW20			403	USGS 11047300

Watersheds beginning with a "2" are located in Aliso Creek, with a "4" are in San Juan Creek, with a "16" are in Rose Creek and with a "17" are in Tecolote Creek.

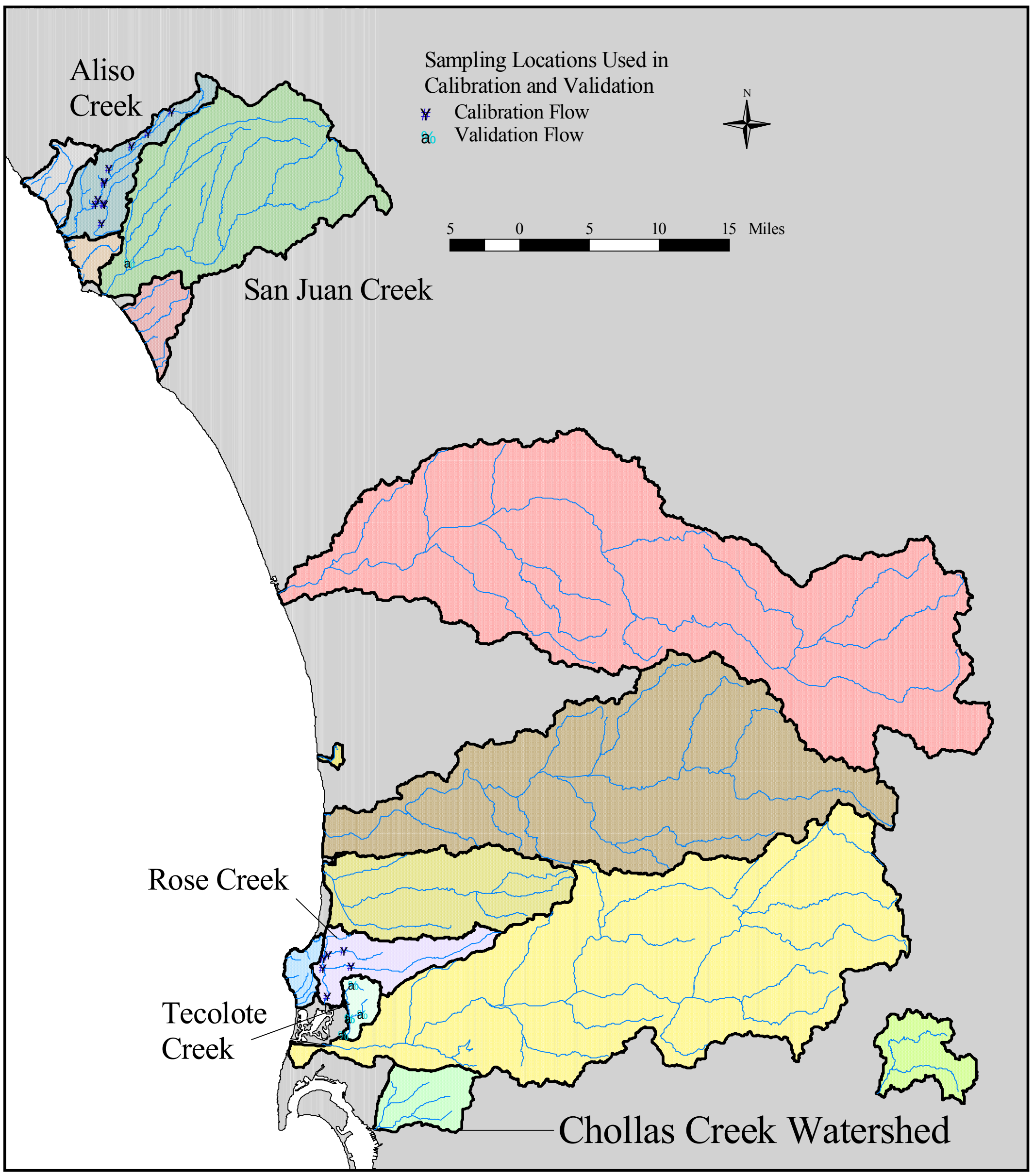


Figure 5. Sampling locations used for San Diego regional hydrologic model calibration and validation. (Tetra Tech, Inc., 2004)

3.2.2. San Diego Regional Hydrologic Model Calibration and Validation Results
Infiltration rates vary by soil type and model configuration included identifying a soil type for each subwatershed. Stream infiltration was calibrated by adjusting the infiltration rate. This rate was adjusted for each soil type within ranges identified from literature values (USEPA, 2000a). The goal of calibration was to minimize the difference between average observed flow and modeled flow at each calibration station location (Table 4). The model closely predicted observed flows and the calibration results are graphically presented in Figure 6.

The calibrated infiltration rates were 1.368 in/hr for Soil Group A, 0.698 in/hr for Soil Group B, 0.209 in/hr for Soil Group C, and 0.084 in/hr for Soil Group D. The infiltration rates for Soil Groups B, C, and D fall within the range of values described in the literature. The calibrated rate for Soil Group A is below the range identified in Wanielisata et al. (1997); however, Soil Group A is not present in the Chollas Creek watershed, which is dominated by Soil Groups C and D.

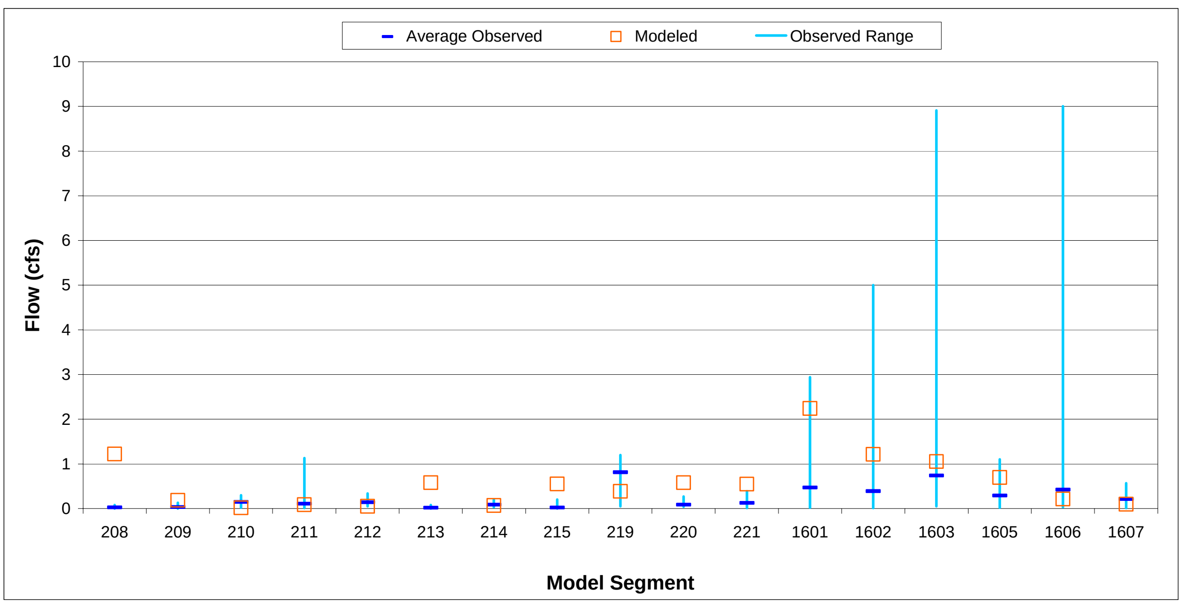


Figure 6. Calibration results of modeled versus observed flow. Model segment numbers are from the San Diego regional hydrologic model. (Tetra Tech, Inc., 2004)

Subsequent to model calibration, the model was validated using six stations in the San Juan Creek and Tecolote Creek Watersheds. (Table 4) The model-predicted flows were within the observed ranges of dry weather flows (Figure 7), demonstrating very good overall model fit.

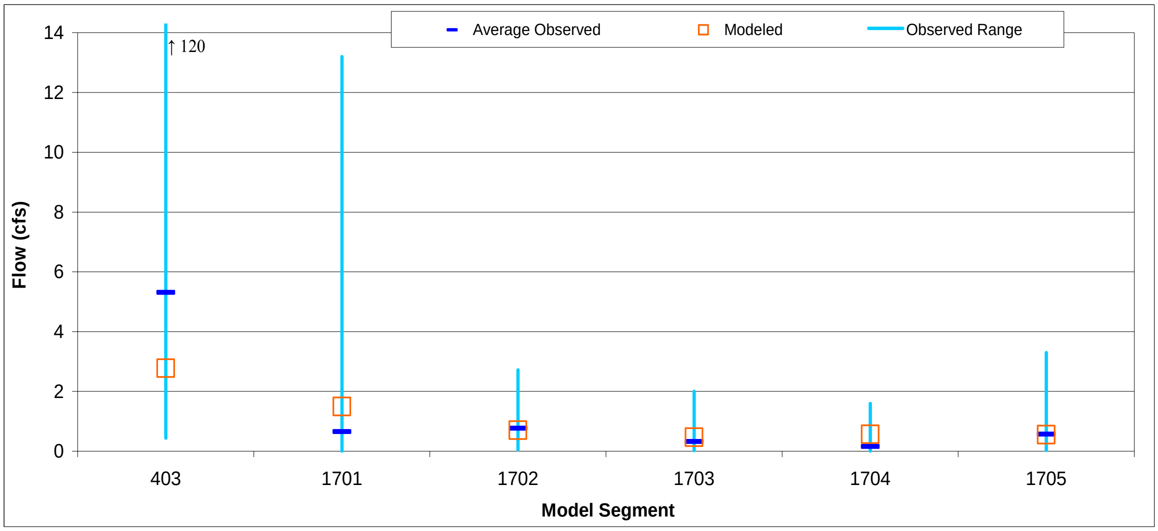


Figure 7. Validation results of modeled versus observed flow. Model segment numbers are from the San Diego regional hydrologic model. (Tetra Tech, Inc., 2004)

3.3. Summary of the Dry Weather Model Results

The steady-state model is calibrated for flow; however, data were not adequate to model dry weather metal loads from specific sources. At a future time, additional water quality data could be readily incorporated into the model and then be used to estimate pollutant concentrations in Chollas Creek or to support load allocations for another TMDL project. At that time, the pollutant concentrations in each segment could be estimated using metals concentration data, an in-stream loss rate, stream infiltration, basic channel geometry, and flow rate data.

3.3.1. San Diego Regional Hydrologic Model Application

Per the equation in section 3.1.4, for each model segment in the Chollas Creek watershed mass balances were performed on the following: inflows from upstream segments, input from local surface runoff, stream infiltration and evaporation, and outflow. The resulting overall dry weather model flow rate for Chollas Creek was 2.28 cubic feet per second (cfs). There is currently only one observed flow value available for comparison with the San Diego regional hydrologic model flow results: a flow measurement of 1.0 cfs was recorded at the in-stream dry weather flow data sampling location DW298. The corresponding model output for this location was 1.33 cfs indicating that the model is consistent with the magnitude of the measured dry weather flow rate datum.

3.3.2. Use of Average In-Stream Metals Concentration

As mentioned before, the model is currently configured to simulate steady-state pollutant concentrations through a mechanism similar to that for flow. Specifically, concentrations can be estimated in each reactor, or segment, using water quality data, a loss rate, basic channel geometry, and flow. Loss rates, which can be attributed to settling and other environmental conditions, were modeled as first-order. Model calibration and validation can be performed by adjusting the rate of in-stream loss so that the predicted concentrations more closely match the observed data.

The amount of available dry weather metal concentration data currently prohibits the full utilization of the water quality, or concentration, component of this model, which has only been calibrated for bacteria to date. If sufficient data become available to establish a relationship between land use and metal concentrations during dry weather conditions, this feature of the model could be used to simulate source loadings and transport of pollutants in the Chollas Creek watershed and to help support other TMDL projects. Therefore, only the average observed concentrations were used to calculate the dry weather portion of the total estimates (Table 1).

4. Wet Weather Model

Wet weather source contributions of metal loads are generally associated with the wash-off of metal loads that have accumulated on the land surface. During rainfall events, these metal loads are delivered to the water body through creeks and storm water collection systems. Often, source contributions of metal, such as copper, lead, and zinc, loads can be linked to specific land use types that have higher relative accumulation rates, or are more likely to deliver metals to water bodies due to delivery through storm water collection systems. To assess the link between sources of metals and the impaired waters, a modeling system may be utilized that simulates the build-up and wash-off of metals and the hydrologic and hydraulic processes that affect delivery.

In order to model these processes for the Chollas Creek watershed, the watershed itself had to be delineated and categorized as subwatersheds with certain land uses. The land uses incorporated into the watershed model are described and illustrated in Appendix E, along with a table that identifies the subwatershed area associated with each land use. Next, observed rainfall data collected from the San Diego County storm water programs and other special studies were used to calibrate land use and soil-specific parameters in the watershed. Hydrology and water quality simulations were then performed for 1990 through 2003 to obtain modeled flow rates and concentrations, respectively. Transport processes of metal loads from the source to the impaired waterbodies were also simulated in the model with a first-order in-stream loss rate based on literature values. The model execution provided two outputs: estimated water quality concentration and estimated flows. These two outputs, in turn, can be used to estimate existing land use specific and subwatershed specific mass loads.

These estimated daily loads, which are based on model-predicted flows and metal concentrations, allowed for assessment of existing loading to the Chollas Creek watershed. To estimate the existing loads, first the maximum hourly total metal concentration was determined for each wet weather day predicted during the critical wet year. These maximum concentrations were then calculated as maximum daily values and then converted to the dissolved metal fraction by applying the appropriate acute conversion factor provided in the California Toxic Rule (CTR). Next, these dissolved metal values were multiplied by their respective average daily flow to estimate the existing dissolved metal load (Figure 8).

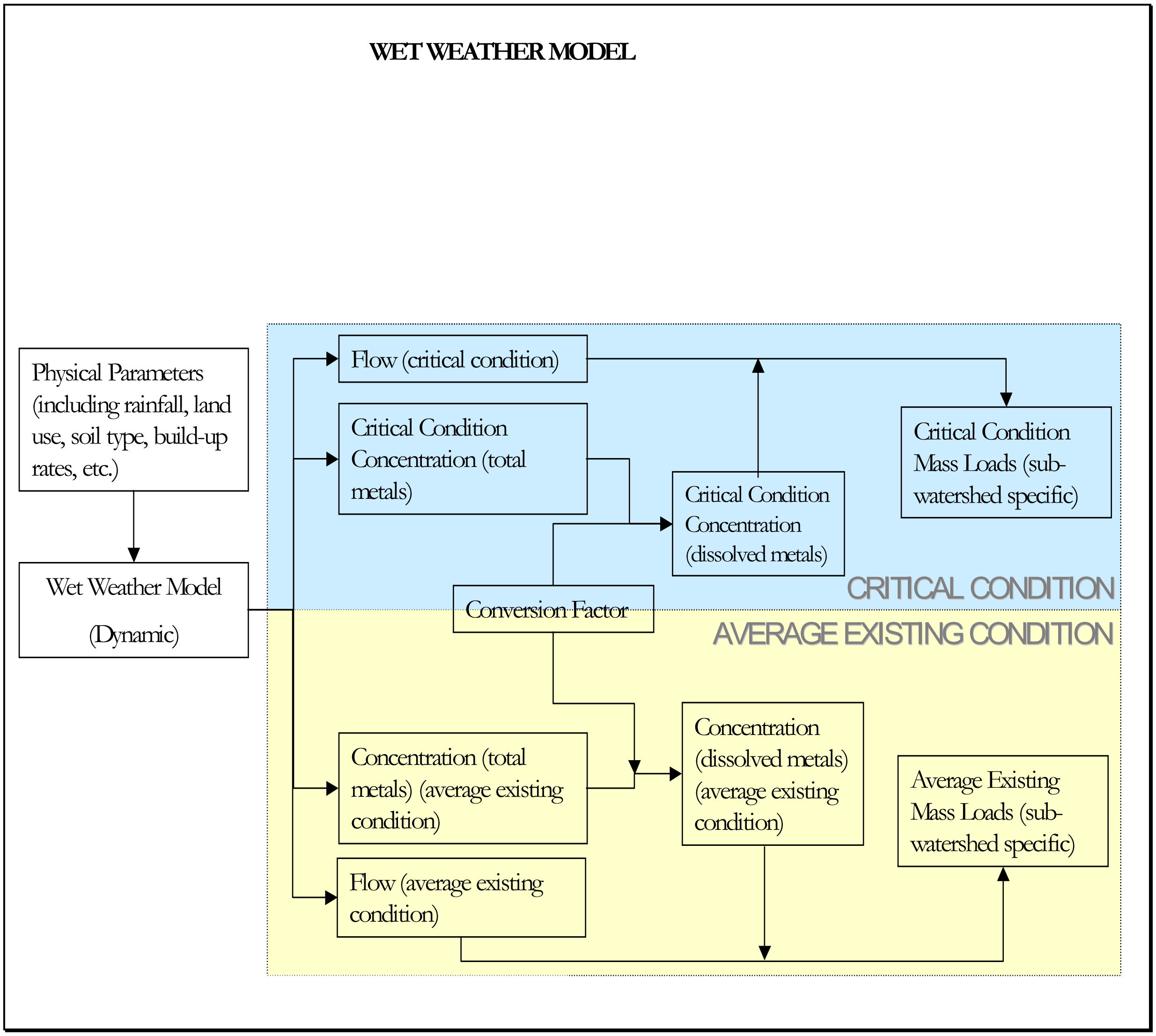


Figure 8. Wet weather model outputs.

4.1. Wet Weather Model Programs

Due to the complex nature of analyzing storm water contributions by drainage area associated with the Chollas Creek watershed, the source analysis for the Chollas Creek Metals TMDL project is based partly on a complex watershed model for wet weather conditions. This type of watershed analysis approach is a strategy for comprehensively addressing land management and water quality and quantity issues over an entire watershed. This approach is applicable to watersheds throughout the world because local information is taken into consideration. Such information includes the local geography and meteorological conditions.

The watershed model chosen to support the source analysis, which will in turn be used in the implementation plan, was the USEPA LSPC, a re-coded version of USEPA's Hydrological Simulation Program -FORTRAN (HSPF), which simulated the hydrologic processes and the metal loading to receiving waterbodies in the Chollas Creek watershed. A description of the model programs and the basic process of modeling used to support the Chollas Creek Metals TMDL project follows

4.1.1. HSPF Program

HSPF, an adaptation of the Stanford Watershed Model, was primarily developed to evaluate the effect of land use changes on water, sediment, and pollutant movement (Donigian, Imhoff, Bicknell, & Kittle, 1984). This model uses geographic and continuous meteorological data to compute stream flow and can then simulate both point and nonpoint source pollution through a wide range of complex mathematical equations. These equations represent surface and subsurface hydrologic conditions, including interflow and evapotranspiration, as well as water quality processes (Bicknell, Imhoff, Kittle, Jobes, & Donigian, 2001). Coefficients for these conditions and processes are manipulated during model calibration. HSPF is over 30 years old and has been extensively applied, despite its substantial learning curve (Whittemore, 1998). There have been hundreds of applications of HSPF all over the world, ranging from the 62,000 square mile Chesapeake Bay tributary area to a few-acre plot near Watkinsville, Georgia (USGS, 2002).

4.1.2. LSPC Program

LSPC is a program for dynamically modeling watersheds and is essentially a re-coded version of HSPF, which has further been integrated with a geographic information system (GIS), comprehensive data storage and management capabilities, and a data analysis/post-processing system into a convenient PC-based windows interface that dictates no software requirements. LSPC has been applied and calibrated in many Southern California waterbodies including the Los Angeles, San Gabriel, and San Jacinto Rivers and 20 watersheds in the San Diego region.

4.1.3. General Simulation Process

Understanding and modeling hydrologic and hydraulic processes provides the necessary decision support for TMDL development and implementation. A basic function of the model can be described in several steps:

(1) **LSPC Execution**. This process involved launching LSPC, inputting necessary data, and performing initial model simulations.
(2) **Comparison of Results**. Upon successful execution of LSPC, model results were compared with observed data and analyzed for accuracy and applicability.
(3) **Parameter Adjustments for Model Calibration**. The analyses performed in step 2 determine which parameters, if any, should be altered in this step to more accurately predict the observed data.
(4) **Simulation Runs for Model Calibration**. This step involved performing additional model runs with the adjusted parameter values.
(5) **Model Validation**. This step involved testing the calibrated parameters using independent date ranges and gage locations.

Steps 2, 3, and 4 described above are an iterative process and were performed in order, but eventually terminated with an analysis of the model results. These intermediate steps were conducted until the model results achieved satisfactory agreement with the natural system. See Figures 9 and 10 for a visual representation.

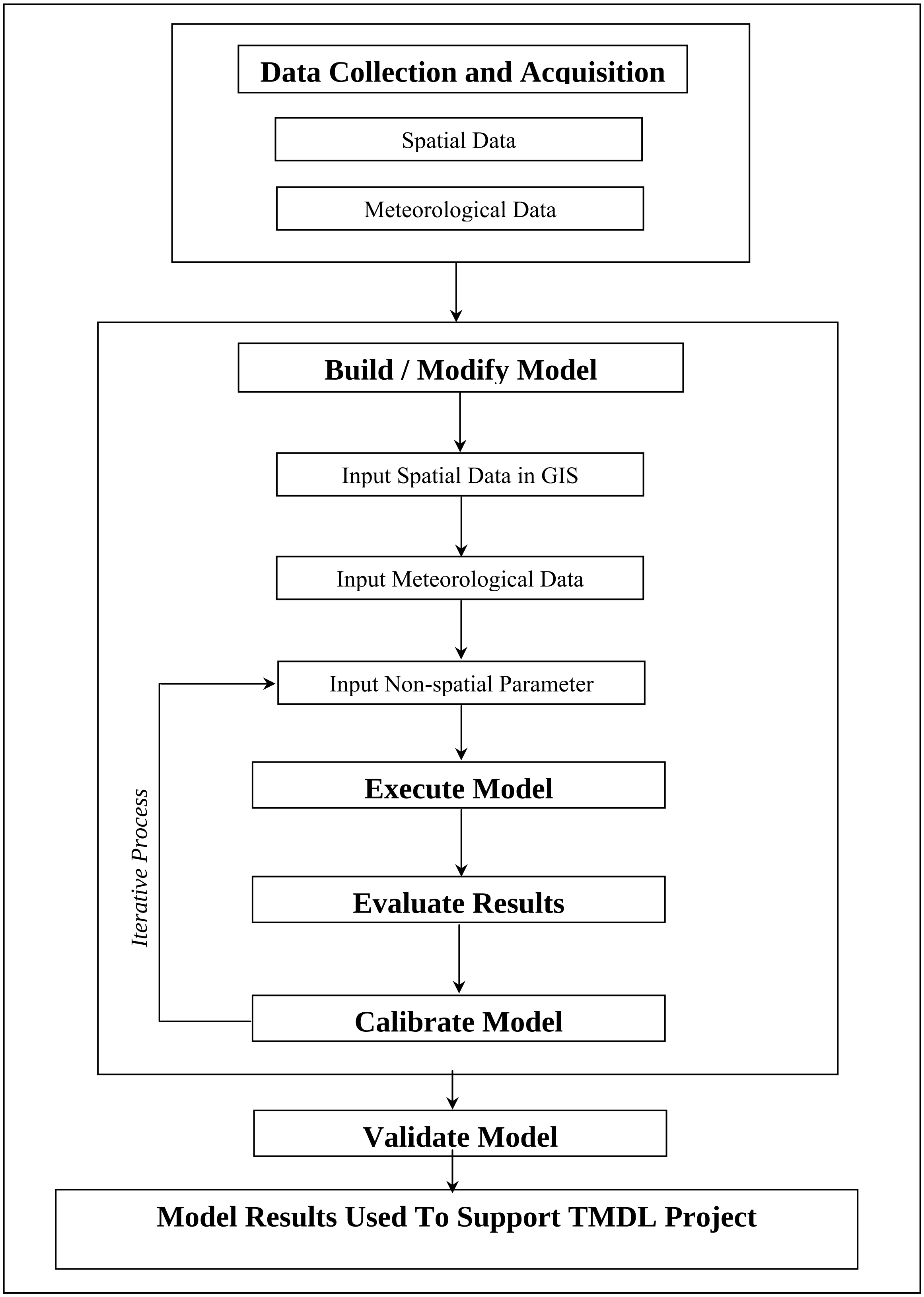


Figure 9. Overview of the methodology used.

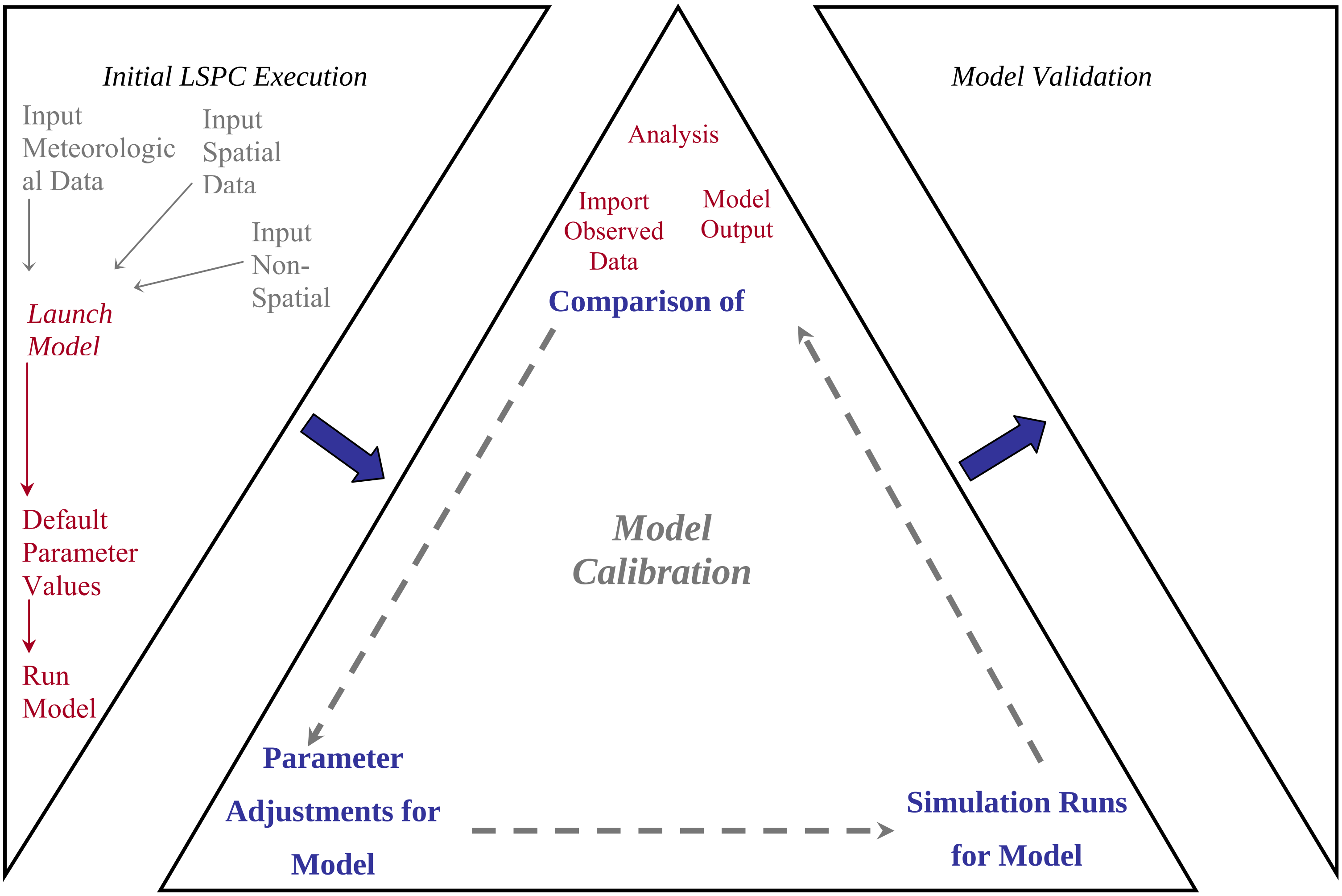


Figure 10. Hydrologic Simulation Program – Fortran (HSPF) modeling process

4.2. Wet Weather Model Details

Configuration of the watershed model involved consideration of four major components: water body representation, land use representation, meteorological data, hydrologic, and pollutant representation. These components provided the basis for the model's ability to estimate flow and pollutant loadings. Water body representation refers to LSPC modules or algorithms used to simulate flow and pollutant transport through streams and rivers. The land use representation provides the basis for distributing soils and pollutant loading characteristics throughout the basin. In addition to these components, meteorological data, hydrological representation and pollutants representation is very important. Meteorological data essentially drive the watershed model. Rainfall and other parameters are key inputs to LSPC's hydrologic algorithms. Hydrologic and pollutant representation refers to the LSPC modules or algorithms used to simulate hydrologic processes (e.g., surface runoff, evapotranspiration, and infiltration) and pollutant loading processes (primarily accumulation and wash-off). This section describes more of the specific details that were used in modeling the Chollas Creek watershed.

4.2.1. Wet Weather Model Water Body Representation

Each delineated subwatershed was represented with a single stream assumed to be completely mixed, one-dimensional segments with a trapezoidal cross-section. The National Hydrography Dataset (NHD) stream reach network for USGS hydrologic units 18070301 through 18070305 were used to determine the representative stream reach for each subwatershed. The Chollas Creek watershed is in the 18070304 USGS hydrologic unit.

Once the representative reach was identified, slopes were estimated based on digital elevation models (DEM) data and stream lengths measured from the original NHD stream coverage. In addition to stream slope and length, mean depths and channel widths are required to route flow and pollutants through the hydrologically connected subwatersheds. Mean stream depth and channel width were estimated using regression curves that relate upstream drainage area to stream dimensions. An estimated Manning's roughness coefficient of 0.2 was also applied to each representative stream reach.

4.2.2. Wet Weather Model Watershed Segmentation

As mentioned in section 3.1.1, the initial step in any watershed-based analysis is to clearly define the watershed boundary. A watershed is defined as a drainage basin, or an area of land in which all waters drain to a single river system (Heathcote, 1998). Watershed segmentation refers to the subdivision of watersheds into smaller, discrete subwatersheds for modeling and analysis. This subdivision was primarily based on the stream networks and topographic variability, and secondarily on the locations of flow and water quality monitoring stations, consistency of hydrologic factors, land use consistency, and existing watershed boundaries (based on CALWTR 2.2 watershed boundaries).

For this current model application, the Chollas Creek watershed was divided into thirty-seven separate sub-basins (Figure 11). These subwatersheds were based on the stream network and topographic data and were further delineated to each station where wet weather metal concentration data was collected. Delineation to the water quality stations allows for direct comparison between model output and observed water quality data in order to evaluate what subwatersheds were sources of metal loads to The Chollas Creek watershed.

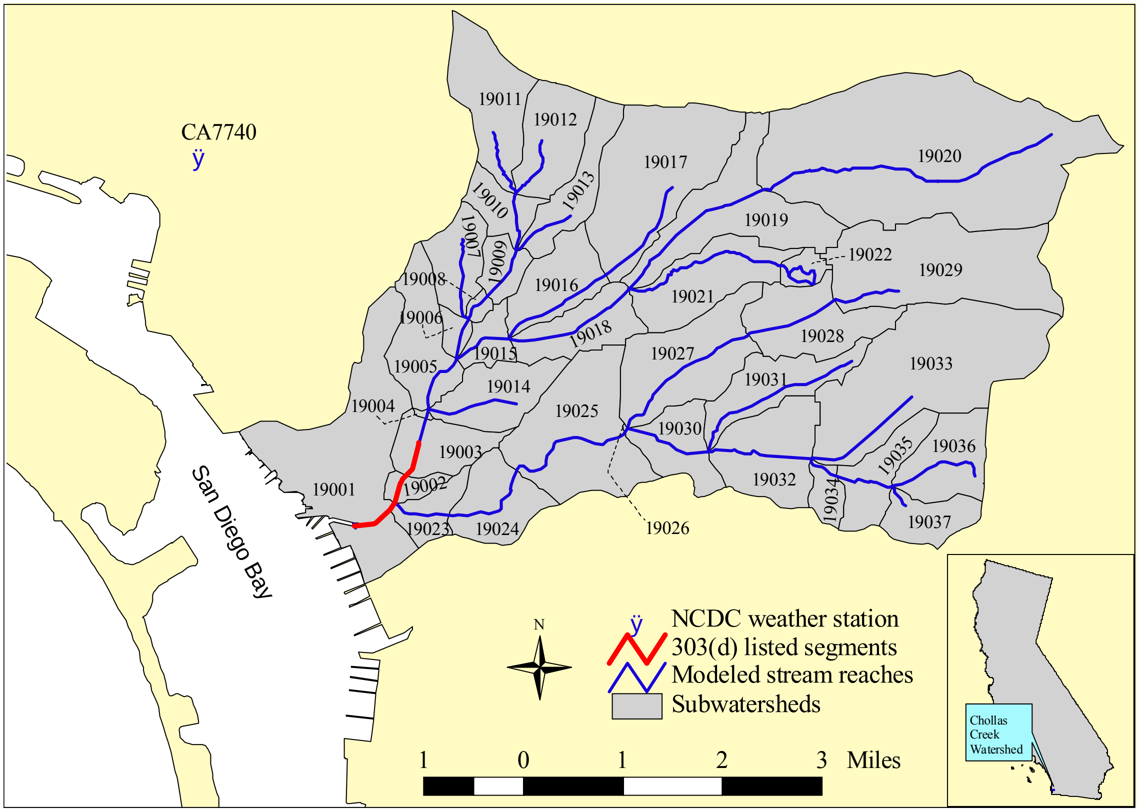


Figure 11. The Chollas Creek watershed. The numbers refer to the segment identifications used in the models.

The Chollas Creek watershed boundary was based primarily on the Cal Water GIS coverage. The only exception is the western-northwestern border. This border was refined from the Cal Water boundary based on the shape file provided by the Regional Board. This border was further refined using the topography lines on the USGS quadrangle maps. See Figure 12 for an illustration of the final watershed boundary, the Regional Board boundary, and the Cal Water boundary. The three boundaries overlap around the entire watershed except for the western-northwestern edge.

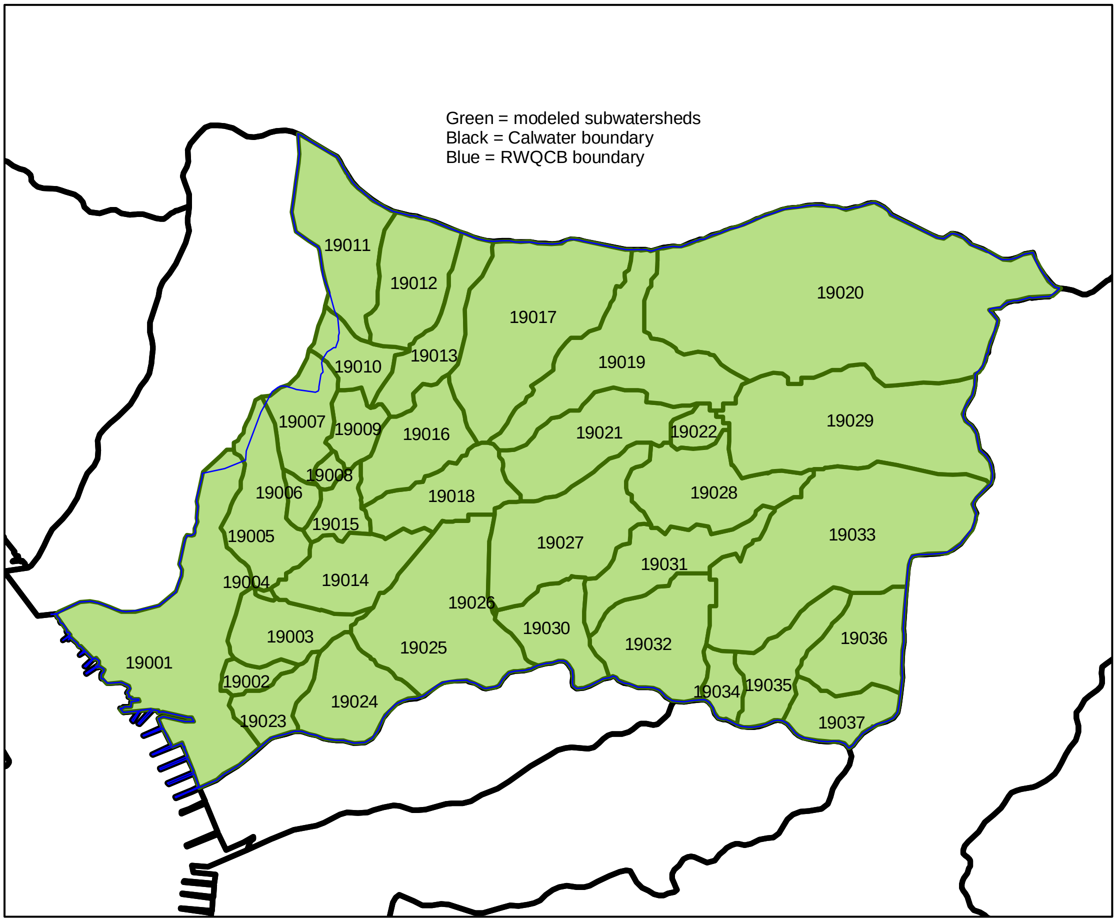


Figure 12. Three boundaries comprising the watershed boundary for Chollas Creek with model segment identification numbers.

4.2.3. Wet Weather Model Land Use Representation

The watershed model requires a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability throughout the basin, which is influenced by land surface and subsurface characteristics. Representing variability in pollutant loading, which is highly correlated to land practices, also is necessary. The basis for this distribution was provided by land use coverage of the entire modeled area.

Three sources of land use data were used in the San Diego regional hydrologic model modeling effort. The primary source of data was the SANDAG 2000 land use dataset that covers San Diego County. This dataset was supplemented with land use data from the Southern California Association of Governments (SCAG) for Orange County and portions of Riverside County. A small area in Riverside County was not covered by either land use dataset. To obtain complete coverage, the 1993 USGS Multi-Resolution Land Characteristic data were used to fill this remaining data gap.

Although the multiple categories in the land use coverage provide much detail regarding spatial representation of land practices in the watershed, such resolution is unnecessary for watershed modeling if many of the categories share hydrologic or pollutant loading characteristics. Therefore, many land use categories were grouped into similar classifications, resulting in a subset of 13 categories for the San Diego region (Tetra Tech, 2004).

For the current modeling effort, land use reclassification was also performed. SANDAG was the only source necessary for land use data in the Chollas Creek watershed. The original SANDAG land uses were grouped into categories that share hydrologic and metal loading characteristics. For example, many urban categories were represented independently (e.g., high density residential, low density residential, industrial, and commercial/ institutional) because they have different levels of impervious cover and their associated metal-contributing practices (and thus, accumulation rates) vary. During the reclassification process, land uses were kept hydrologically consistent with the land use classifications for the San Diego regional hydrologic model so that the regionally calibrated land use-specific hydrology parameters could be applied to the current modeling effort. Appendix E provides descriptions of the land uses used and the areas associated with each land use grouping for the Chollas Creek Metals TMDL project.

LSPC algorithms require that land use categories be divided into separate pervious and impervious land units for modeling. This division was made for the appropriate land uses (primarily urban) to represent impervious and pervious areas separately. The division was based on typical impervious percentages associated with different land use types from the Soil Conservation Service's TR-55 Manual (Soil Conservation Service, 1986).

In addition, soil data were obtained from the U.S. Department of Agriculture (USDA) Natural Resources Conservation Services State Soil Geographic (STATSGO) database. Topographic data, or DEM, were obtained from USEPA's Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) system (USEPA, 1998).

4.2.4. Wet Weather Model Meteorology

Meteorological data are a critical component of the watershed model. LSPC requires appropriate representation of precipitation and potential evapotranspiration. In general, hourly precipitation (or finer resolution) data are recommended for nonpoint source modeling. Therefore, only weather stations with hourly-recorded data were considered in the precipitation data selection process. Storm water runoff processes for each subwatershed were driven by precipitation data from the most representative station. These data provide necessary input to LSPC algorithms for hydrologic and water quality representation.

Meteorological data were accessed from a number of sources in an effort to develop the most representative dataset for the San Diego region. Hourly rainfall data were obtained from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA), the Automatic Local Evaluation in Real Time (ALERT) Flood Warning System managed by the County of San Diego, and the California Irrigation Management Information System (CIMIS). The above data were reviewed based on geographic location, period of record, and missing data to determine the most appropriate meteorological stations. Ultimately, meteorological data were utilized from 16 area weather stations for January 1990 to September 2002 (Figure 13) for the San Diego regional hydrologic model. The spatial variability captured by these weather stations greatly enhanced the hydrology calibration and validation and development of the regionally calibrated parameters, which were utilized for the Chollas Creek Metals TMDL project.

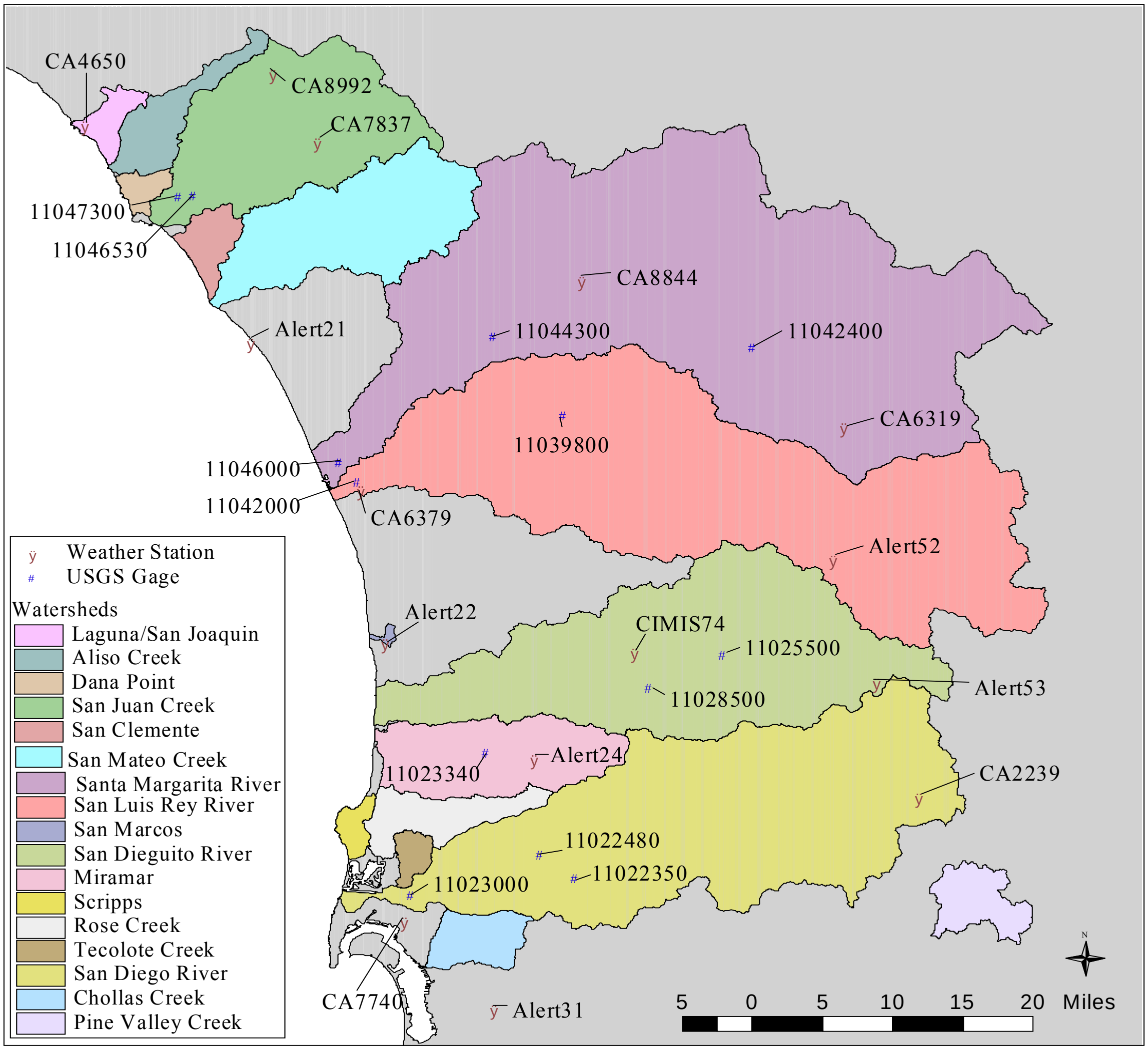


Figure 13. Weather stations and flow gages utilized for the San Diego regional hydrological model.[4]

Long-term hourly wind speed, cloud cover, temperature, and dew point data are available for a number of weather stations in the San Diego region. Data from San Diego Airport, Lindbergh Field, (#CA7740 on Figure 13) were obtained from NCDC for characterization of meteorology of the modeled watersheds. Using these data, the METCMP (Computation of Meterological Time Series) utility, available from USGS, was employed to estimate hourly potential evapotranspiration.

Lindbergh Field is the most representative weather station for the Chollas Creek watershed with hourly data. In order to utilize the most current data possible for the Chollas Creek Metals TMDL project, the period of record for Lindbergh Field meteorological data was extended through 2003.

[4] Table 5 gives more information on data collected at each station.

4.2.5. Wet Weather Model Hydrology Representation

Generally, LSPC hydrologic simulations combine the observed meteorological data and the physical characteristics of the watershed. Surface runoff in a watershed was simulated in four components: surface runoff from impervious surfaces, surface runoff from pervious surfaces, interflow from pervious areas, and groundwater flow (Donigian et al., 1984). Parameter values within LSPC represented different characteristics of these components.

Here, the LSPC PWATER (water simulation for pervious land segments) and IWATER (water simulation for impervious land segments) modules, which are identical to those in HSPF, were used to represent hydrology for all pervious and impervious land units (Bicknell et al., 1996). Designation of key hydrologic parameters in the PWATER and IWATER modules of LSPC were required. As discussed previously, in order to satisfy this requirement, the regionally calibrated hydrologic parameter values from the San Diego regional hydrologic model were used. Model calibration and validation of the San Diego regional hydrologic model is discussed the next section, thus describing the applicability of these parameter values to the Chollas Creek watershed.

In some watersheds, in addition to the streams which route flow and transport pollutants through the watersheds, there are several reservoirs that are large enough to impound a significant portion of flow during wet weather periods. There is one small reservoir in the Chollas Creek watershed; however, it drains an extremely small land area and is not hydrologically connected to the main stream network in the watershed. Therefore, the Chollas Reservoir was not simulated as an impoundment in the LSPC model.

4.2.6. Wet Weather Model Metals Water Quality Representation

For the San Diego regional hydrologic modeling efforts, six major inland dischargers were incorporated into the LSPC model as point sources of flow and bacteria concentration. Each point source was located in the Santa Margarita River watershed – five at Camp Pendleton and one along Murrieta Creek (Santa Rosa Water Reclamation Facility). Although the Santa Margarita River watershed had no waterbodies impaired from bacteria loads, it was simulated in the wet weather model due to the availability of flow rates and bacteria concentration monitoring data, which were used for hydrologic and water quality calibration and validation. There are no inland dischargers impacting flow in the Chollas Creek watershed. However, discussion of the facilities in the Santa Margarita River Watershed is important because they were incorporated into the flow model calibration and validation for the San Diego regional hydrologic model, which was utilized during this current LPSC application.

Loading processes for copper, lead, and zinc loads were represented for each land unit using the LSPC PQUAL (simulation of quality constituents for pervious land segments) and IQUAL (simulation of quality constituents for impervious land segments) modules, which are identical to those in HSPF. These modules simulate the accumulation of pollutants during dry periods and the wash-off of pollutants during storm events. Starting values for parameters relating to land use-specific accumulation rates and buildup limits, were derived from 1997 through 1999 storm water program data from the County of Los Angeles (LACDPW, 1998, 1999). These starting values served as baseline conditions for water quality calibration. Although atmospheric deposition may be an issue in the watersheds, it was not explicitly simulated in the watershed model. It was, however, represented implicitly in the model through use of the land use- and pollutant-specific accumulation rates.

4.3. Wet Weather Model Calibration and Validation

As described above, model calibration is an iterative process, because it involves the adjustment or fine-tuning of modeling parameters to reproduce observations. After modifying individual parameters, a new simulation was performed for different LSPC modules, at multiple locations throughout the San Diego region, and for the same time periods. The resultant simulated and observed stream flows were then compared. This process was repeated until the best agreement between the modeled and observed flows was achieved. This method provides the most accurate prediction possible for the hydrologic functions by ensuring that heterogeneities were represented.

Subsequently, model validation was performed to test the calibrated parameters at different locations or for different time periods, without further adjustment. Model validation consisted of re-running the model for a different date range using the same parameter values as the calibrated model. The results of this simulation were then compared to applicable observed data. This process performs a similar function to that of a control test subject, in which the model validation results indicate if selected parameter values are representative of the hydrologic functions of the watershed over time. If model validation indicates that the model results are not representative of the watershed over a certain time period, model calibration may be repeated or the model user may evaluate the watershed-specific functions responsible for the differences.

4.3.1. General Hydrologic Calibration and Validation for Wet Weather Conditions

Hydrology is the first model component calibrated because estimation of pollutant 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 simulated results closely represented the system and reproduced observed flow patterns and magnitudes. The last step is to validate the hydrologic model output with observed flow data.

The first step in hydrologic calibration is to establish an annual water balance between modeled and actual flow rates. The following water balance can estimate surface runoff: precipitation minus actual evapotranspiration, deep percolation, and change in soil moisture. Parameters in the PWATER and IWATER sub-modules had the greatest impact on these hydrologic functions. Specifically, LZSN, INFILT, LZETP, and DEEPFR were the key parameters that govern the water balance. (Figure 14)

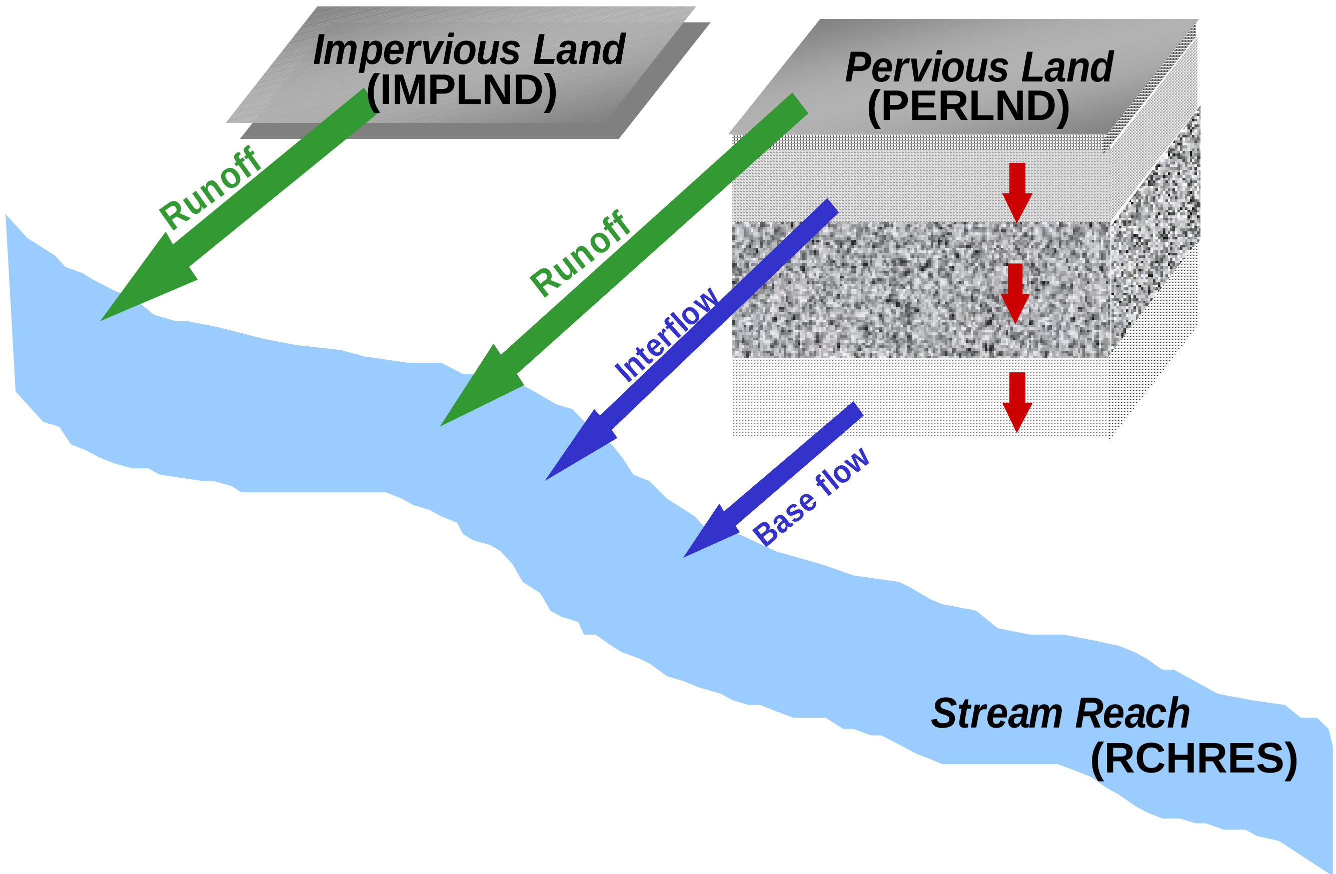


Figure 14. Physical representation of the three LSPC modules (USEPA, 1998).

The LZSN parameter is the lower zone nominal soil moisture storage. It is related to the precipitation patterns and soil characteristics in the subwatershed. Specifically, increasing LZSN will increase actual evapotranspiration, thus decreasing annual surface runoff (USEPA, 2000). The index to mean soil infiltration rate is represented by INFILT. This parameter controls the overall distribution of the available moisture from precipitation that has been intercepted into the ground. This parameter is usually utilized to represent seasonal surface runoff distributions. Increasing the value of INFILT will ultimately decrease surface runoff since it increases the transfer of water to the lower zone and groundwater. The LZETP parameter is a coefficient that represents the lower zone evapotranspiration and as values of LZETP increase, evapotranspiration increases thereby decreasing annual surface runoff. The last key parameter to effect annual water balance is DEEPFR, or the fraction of infiltrating water lost to inactive groundwater. Decreasing DEEPFR results in higher base flow and an increase in annual water balance (Donigian et al., 1984).

Subsequent to establishing an annual water balance, hydrographs for selected storm events can be adjusted to better agree with observed values. There are a variety of parameters that can be altered to effectively calibrate such hydrographs. However, continuous flow data over individual storms are necessary to create the desired hydrographs. These data were not available for The Chollas Creek watershed; therefore, stream flow calibration was limited to the annual water balance.

In addition to hydrologic calibration of the surface water, performed by adjusting parameters in the PWATER and IWATER sub-modules, hydraulic calibration was conducted using the RCHRES sub-module. The overall flows simulated in the RCHRES sub-module are a result of the overland hydrology from pervious and impervious lands and the stream characteristics contained in the hydrologic function tables (Donigian et al., 1984).

The rest of this discussion is divided into two sections: one on regional hydrological simulations and one on the application of these regional hydrology simulations to the Chollas Creek watershed. The hydrology simulations conducted for the San Diego region resulted in a regionally calibrated set of parameter values. These parameters were applied to the Chollas Creek watershed in order to make flow predictions.

4.3.2. Wet Weather Model Use of the San Diego Region Hydrologic Model

Gaging stations representing diverse hydrologic regions of the San Diego region were used for calibration, including eleven USGS flow gage stations (Table 5 and Figure 13). These gaging stations were selected because they either had a robust historical record or they were in a strategic location (i.e. along a listed water quality limited segment, downstream of a reservoir, or along an otherwise unmonitored reach).

Table 5. USGS Stations Used For Hydrology Calibration and Validation

Station Number	Station Name	Historical Record	Selected Calibration Period	Selected Validation Period	Watershed and Model Subwatershed

11022480	San Diego River at Mast Road near Santee, CA	5/1/1912 - 9/30/2002	1/1/1991 - 12/31/1996	1/1/1997 - 12/31/2001	San Diego River (1805)
11023000	San Diego River at Fashion Valley at San Diego, CA	1/18/1982 - 9/30/2002	1/1/1991 - 12/31/1996	1/1/1997 - 12/31/2001	San Diego River (1801)
11023340	Los Penasquitos Creek near Poway, CA	10/1/1964 - 9/30/2002	1/1/1991 - 12/31/1996	1/1/1997 - 12/31/2001	Miramar (1406)
11025500	Santa Ysabel Creek near Ramona, CA	2/1/1912 - 9/30/2002	1/1/1991 - 12/31/1996	1/1/1997 - 12/31/2001	San Dieguito (1316)
11028500	Santa Maria Creek near Ramona, CA	12/1/1912 - 9/30/2002	1/1/1991 - 12/31/1996	1/1/1997 - 12/31/2001	San Dieguito (1324)
11042000	San Luis Rey River at Oceanside, CA	10/1/1912 - 11/10/1997; 4/29/1998 - 9/30/2002	9/1/1993 - 8/31/1997	5/1/1998 - 4/30/0202	San Luis Rey (702)
11042400	Temecula Creek near Aguanga, CA	8/1/1957 - 9/30/2002	1/1/1991 - 12/31/1996	1/1/1997 - 12/31/2001	Santa Margarita (658)
11044300	Santa Margarita River at FPUD Sump near Fallbrook, CA	10/1/1989 - 9/30/2002	1/1/1991 - 12/31/1996	1/1/1997 - 12/31/2001	Santa Margarita (615)
11046000	Santa Margarita River at Ysidora, CA	3/1/1923 - 2/25/1999; 10/1/2001 - 9/30/2002	1/1/1991 - 12/31/1995	1/1/1996 - 12/31/1998	Santa Margarita (602)
11046530	San Juan Creek at La Novia Street Bridge near San Juan Capistrano, CA	10/1/1985 - 9/30/2002	1/1/1991 - 12/31/1996	1/1/1997 - 12/31/2001	San Juan (411)
11047300	Arroyo Trabuco near San Juan Capistrano, CA	10/1/1970 - 9/30/1989; 10/1/1995 - 9/30/2002	10/1/1995 - 4/30/1999	5/1/1999 - 4/30/2002	San Juan (403)
11022350	Forester Creek near El Cajon, CA	10/1/1993 - 9/30/2002	none (insufficient period of record)	1/1/1991 - 9/30/1993	San Diego River (1843)
11039800	San Luis Rey River at Couser Canyon Bridge near Pala, CA	10/1/1986 - 1/4/1993	none (insufficient period of record)	1/1/1991 - 12/31/1992	San Luis Rey (711)

January 1991 through September 2002 was selected as the time period for the regional simulation.[5] The calibration years were selected based on annual precipitation variability and the availability of observation data to represent a continuum of hydrologic conditions: low, mean, and high flow. Calibration for these conditions was necessary to ensure that the model would accurately predict a range of conditions over a longer period of time.

Key considerations in the hydrology calibration included the overall water balance, the high-flow/low-flow distribution, storm-flows, and seasonal variation. At least two criteria for

[5] The range was expanded for the Chollas Creek metals TMDL (January 1991 through December 2003) because newer meteorological data was available at the time of simulation.

goodness of fit were used for calibration: graphical comparison and the relative error method. Graphical comparisons were extremely useful for judging the results of model calibration; time-variable plots of observed versus modeled flow provided insight into the model's representation of storm hydrographs, base flow recession, time distributions, and other pertinent factors often overlooked by statistical comparisons. The model's accuracy was primarily assessed through interpretation of the time-variable plots. The relative error method was used to support the goodness of fit evaluation through a quantitative comparison.

After calibrating hydrology at the eleven locations, a validation of these hydrologic parameters was made through a comparison of model output to different time periods at the same gages as well as two additional gages (Table 1). The validation essentially confirmed the applicability of the regional hydrologic parameters derived during the calibration process. Validation results were assessed similar to calibration: via graphical comparison and the relative error method.

Hydrology calibration and validation results, including time series plots and relative error tables, are presented for each gage in Appendix E of the draft TMDL report for bacteria impairment in the San Diego region (Tetra Tech, Inc., 2004). The calibration results, which are presented first, include graphs to represent overall model fit, seasonal trends, and two time series plots. A table that quantifies the model results and observed gage data follows these graphs. This table also provides relative errors between the modeled and observed values in the storm volumes and highest flows. The presentation of model validation results follows the calibration tables and graphs for each gage. Two additional gages that had a relatively less historical record were used as additional validation. Validation was assessed through a time series plot and a relative error table identical to the calibration table.

To ensure that the watershed delineation and land use reclassification processes performed for the Chollas Creek watershed did not significantly alter the predicted hydrology, the current model output was compared with the regional model output specifically for the Chollas Creek watershed. Although the Chollas Creek watershed does not have a stream gage collecting daily flow data, data were available for a series of storms (or for a period of time during a storm season) between 2001 and 2003.

4.3.3. Metal Concentration Calibration and Validation for the Chollas Creek Watershed
Once the stream flow was calibrated and validated, other hydrologically-dependent functions, including metal concentration, were simulated in order to calibrate the remaining model parameters. Regionally calibrated land use-specific accumulation and maximum build up rates for metals are not available in Southern California;[6] therefore, a more traditional water quality calibration and validation process was performed. In addition, observed water quality data, unlike stream flow data, are usually not continuous; thus making time-series comparisons difficult and reducing the accuracy of the water quality model calibration.

The available wet weather metal concentration data (Appendix A) was separated into calibration and validation groups based on sampling stations. Station SD(8)-1 was used for calibration, because it had the most data (approximately 35 metal concentrations). Because

[6] Ideally these rates would be available and could be used with water quality simulations to further validate their accuracy

the rest of the water quality monitoring stations had only three to five metal concentration data points, the remaining data were separated into two groups with similar spatial representation of land uses and of watersheds (Figure 15).

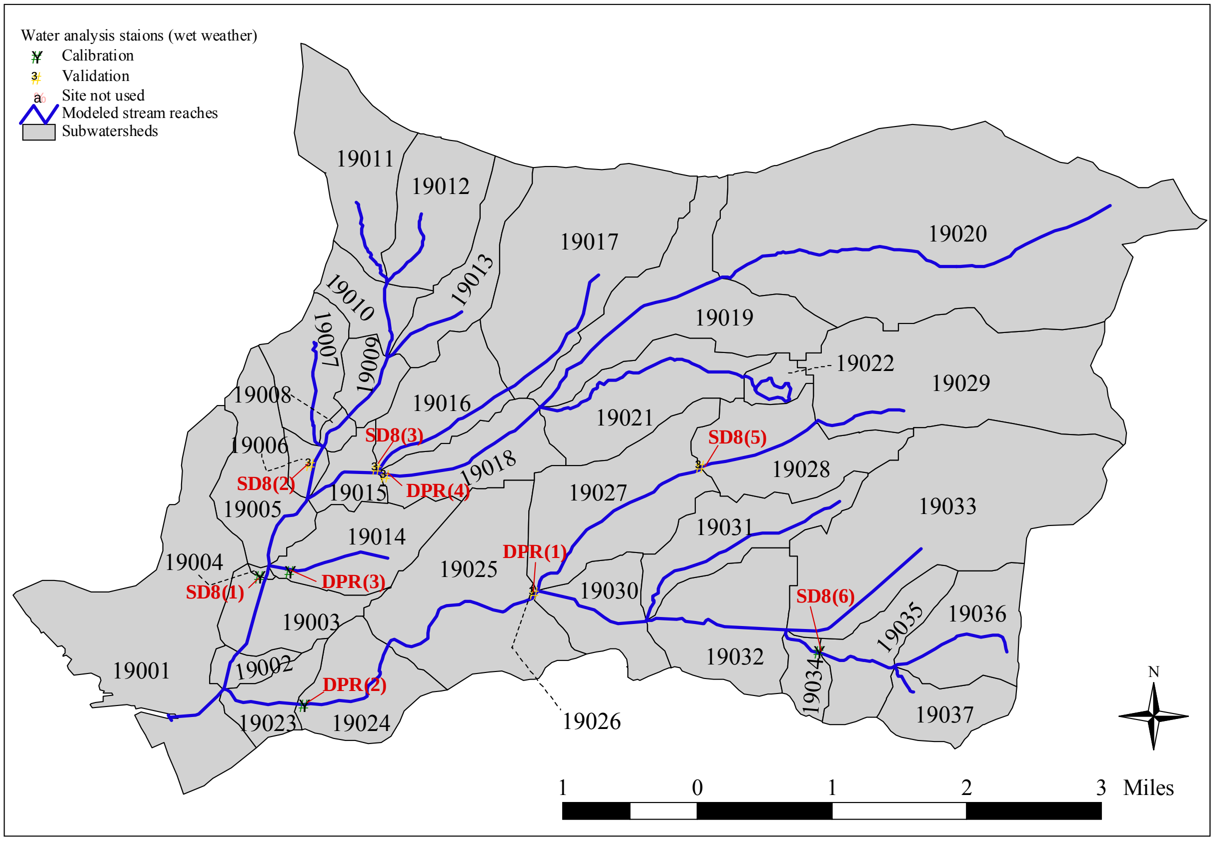


Figure 15. Map of monitoring locations used for model calibration and validation of the wet weather model.

After the appropriate calibration and validation groups were defined, the starting values for parameters relating to land use-specific accumulation rates (ACQOP) and buildup limits (SQOLIM) were defined. Their values were input for each stream reach and land use in the surrounding subwatershed. The ACQOP parameter is the daily pollutant accumulation rate. Based on this value, the concentration of a constituent accumulates until it reaches the maximum storage level, represented by SQOLIM. Additionally, the WSQOP[7] parameter is the rate of surface runoff that will remove 90 percent of the stored constituent per hour. This parameter, along with the modeled surface runoff, controls the overall pollutant loading to the stream (Bicknell, Imhoff, Kittle, Donigian, & Johanson, 1996). The initial accumulation rates used for this model were derived from land use specific metals data collected for the County of Los Angeles storm water program (LACDPW, 1998, 1999). Initial maximum build up rates were obtained from literature values (Butcher, 2003). These starting values served as initial conditions for water quality calibration.

[7] WQSOP is the rate of surface runoff that results in 90 percent wash off of fecal coliform bacteria in one hour (in/hr).

Once model setup was complete, baseline simulations were performed. After entering the accumulation rate and wash-off data for each stream reach and its associated land uses, simulations were performed during time periods that overlapped the hydrology simulations. The modeled results were then compared with observed concentration data for copper, lead, and zinc. To assess model fit with available data, the time series model output was statistically and graphically compared to the observed data. Similar to the hydrology calibration process, the key parameter values (ACQOP and SQOLIM) were adjusted based on these differences and the simulations were performed again.

Once the water quality model calibration was complete, model validation was performed. This process is identical to the model validation procedures described above for hydrology validation. Namely, the model was run again using the calibrated parameter values for different monitoring locations. The results of this simulation were then compared to applicable observed metal concentration data to determine the predictive value of the model. Depending on the results of the water quality validation, the model can be considered complete, or model calibration may be repeated. (Figure 9)

4.4. Summary of Wet Weather Model Calibration and Validation

The observed flow hydrographs were on a sub-hourly time scale; however, the simulations were performed at an hourly timescale. For a comparison of the modeled and observed results, the data were summarized into average daily values and general statistical comparisons were made between the two sets of values (Appendix F). Because of the differences in time scale, the comparison is not entirely accurate.

4.4.1. Wet Weather Model Flow Rate Results

Overall, during calibration, the model predicted increased flow rates during dates when storm events had occurred. This is because the wet weather condition and surface runoff flow rate are dependent on rainfall. Occasional storms were over-predicted or under-predicted depending on the spatiality of the meteorologic and gage stations compared to the location of storms that did not cover the entire Chollas Creek watershed. The validation results also showed a good fit between modeled flow rates and observed flow rates, thus confirming the applicability of the calibrated hydrologic parameters to the San Diego region.

Minor differences were observed (the current model predicted flows approximately 8 percent higher than those from the San Diego regional hydrologic model) which resulted from the changes to the stream network and subwatershed boundaries in the current application. Specifically for the Chollas Creek Metals TMDL project, the total stream lengths increased while the total watershed area was nearly the same. This resulted in less opportunity for infiltration, because as water passed over the land surface it had to travel a shorter distance to reach a stream than it did in the simulation initially ran for the San Diego region hydrologic model (i.e. overland flow was reduced). This small difference between the hydrology results was considered acceptable, especially when compared to the significant benefit of using the more detailed stream network for the Chollas Creek Metals TMDL project.

Figure 16 compares the predicted flow with these average daily observed flows. Model predictions generally fell within the range of observed data; however, some peaks were observed that were not predicted by the model. These differences are likely due to localized storms that impacted the Chollas Creek watershed, but were not detected at the modeled weather station, Lindbergh Field. In addition, the shortest time step simulated was one hour, while the observed data were on a five or fifteen minute time step. The model output and observed data were both summarized to obtain average daily flow for comparative purposes. Therefore, the storm hydrographs, including maximum storm peaks, are not represented in Figure 16. Because modeled and observed flow ranges are similar, the LSPC hydrology model flow rate results were considered representative of flow in the Chollas Creek watershed. Differences can be explained by localized events, and until additional flow data become available, further calibration is not possible, nor warranted.

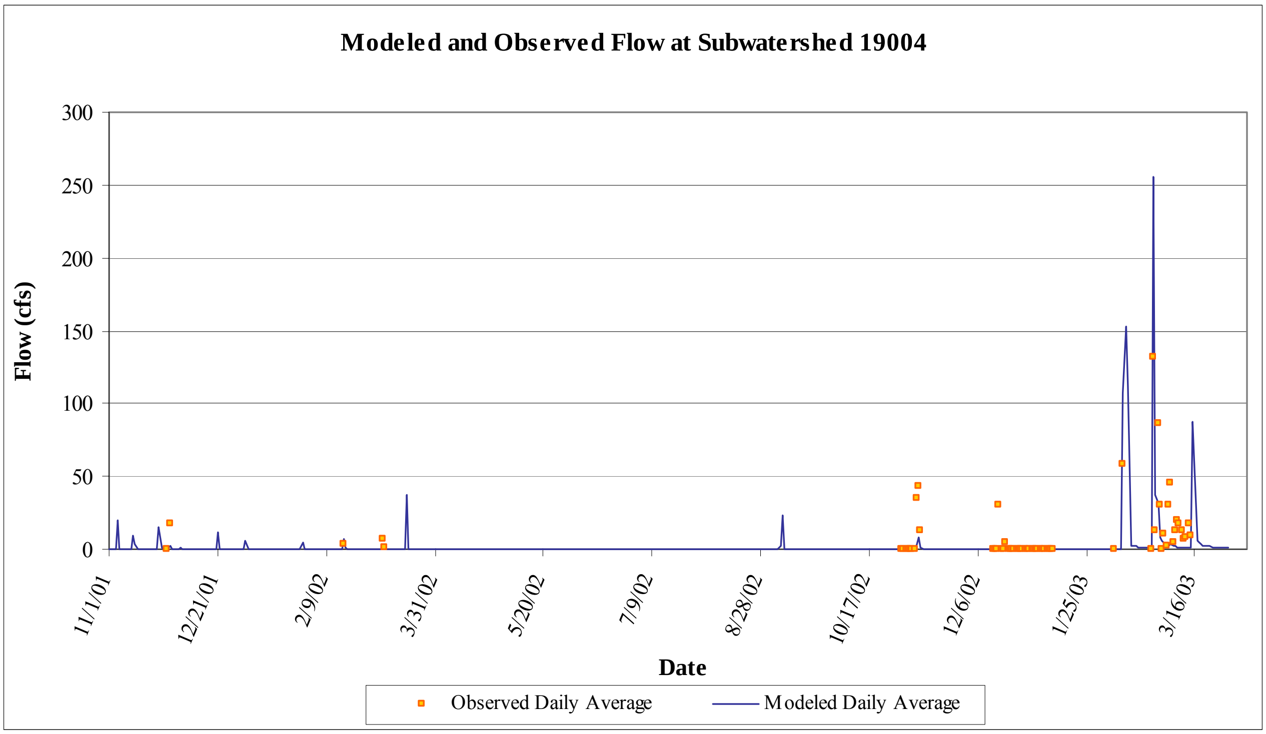
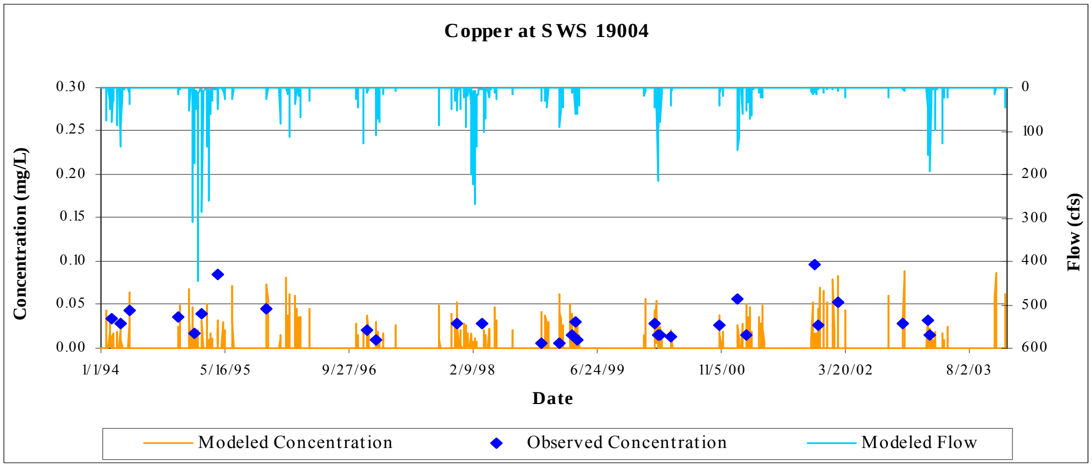
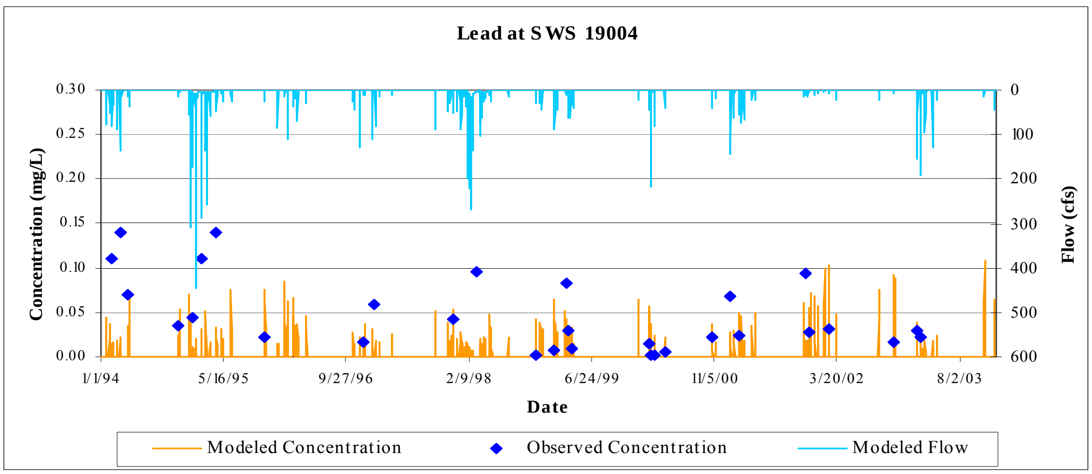


Figure 16. Modeled and observed flow at the Chollas Creek watershed Mass Loading Station

4.4.2. Wet Weather Model Metal Concentration Results
Figures 17, 19, 21, and 23 present time series graphs of modeled and observed data for the calibrated subwatersheds. Figures 18, 20, 22, and 24 are box plot graphs showing the minimum, mean, and maximum modeled values for the dates with corresponding observed data. These plots indicate that the model predicts copper, lead, and zinc concentrations well within the range of observed data and following similar patterns and magnitudes. This is especially evident in subwatersheds where there are data across a wide temporal range (Figures 17 and 18).

Using the same parameter values, model simulations were performed for validation of the calibrated parameters. Figures 25 through 34 present time series graphs and box plots for the validation subwatersheds. These results confirm the previous conclusion that the model closely predicts the observed data for copper, lead, and zinc concentrations.





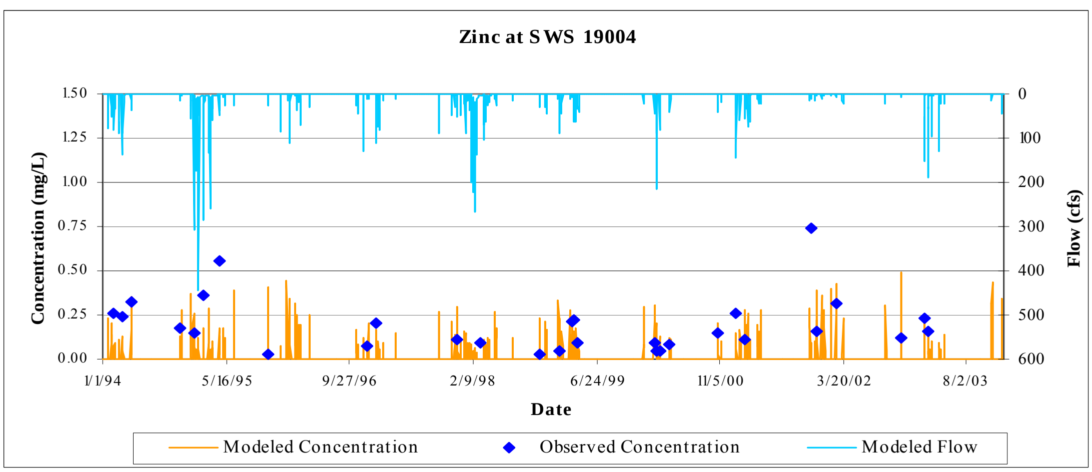


Figure 17. Time-series comparison of modeled and observed wet weather metals concentrations at sampling location SD8(1) (model calibration)

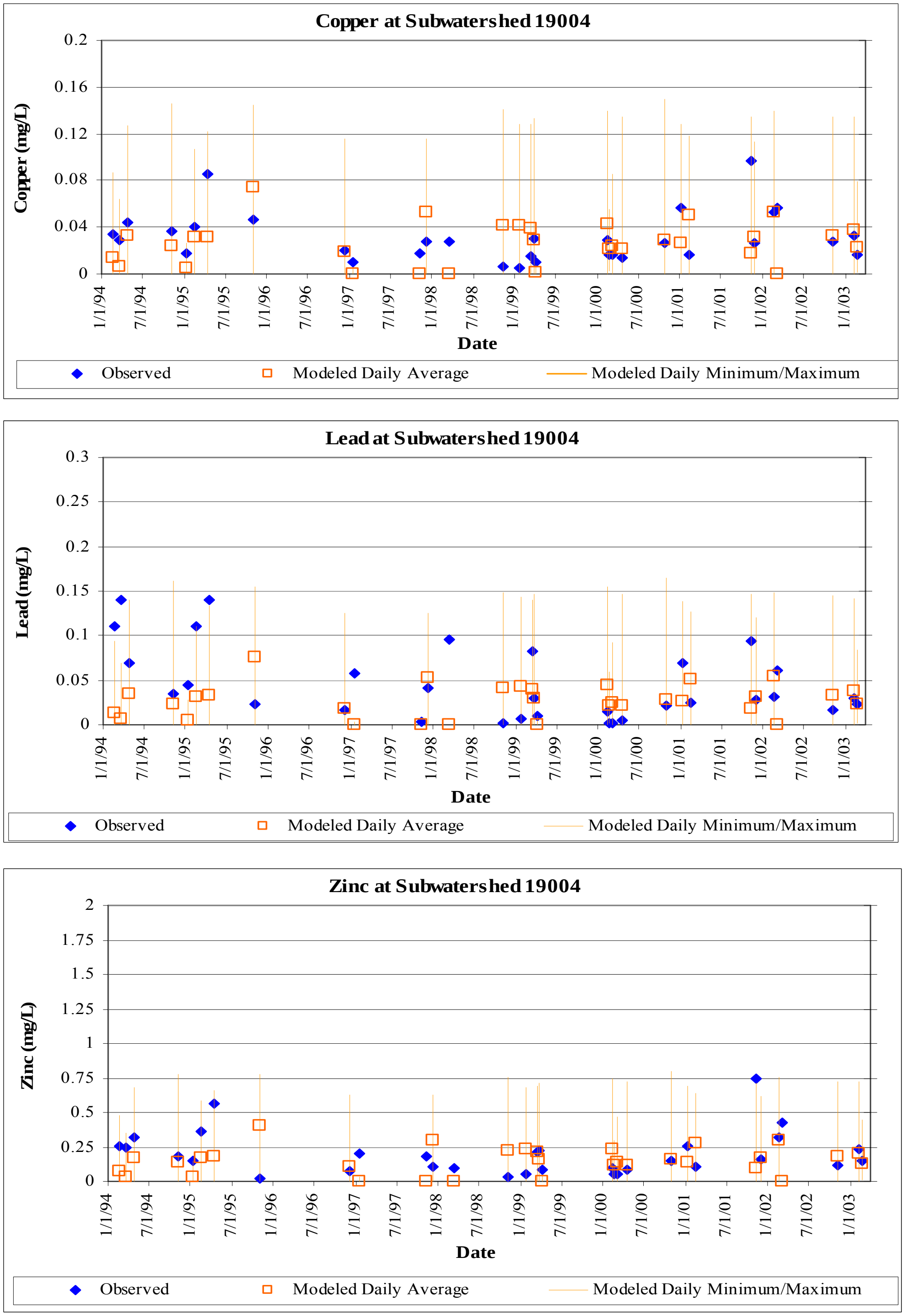


Figure 18. LSPC model results and corresponding observed metals data at sampling location SD8(1) (model calibration)

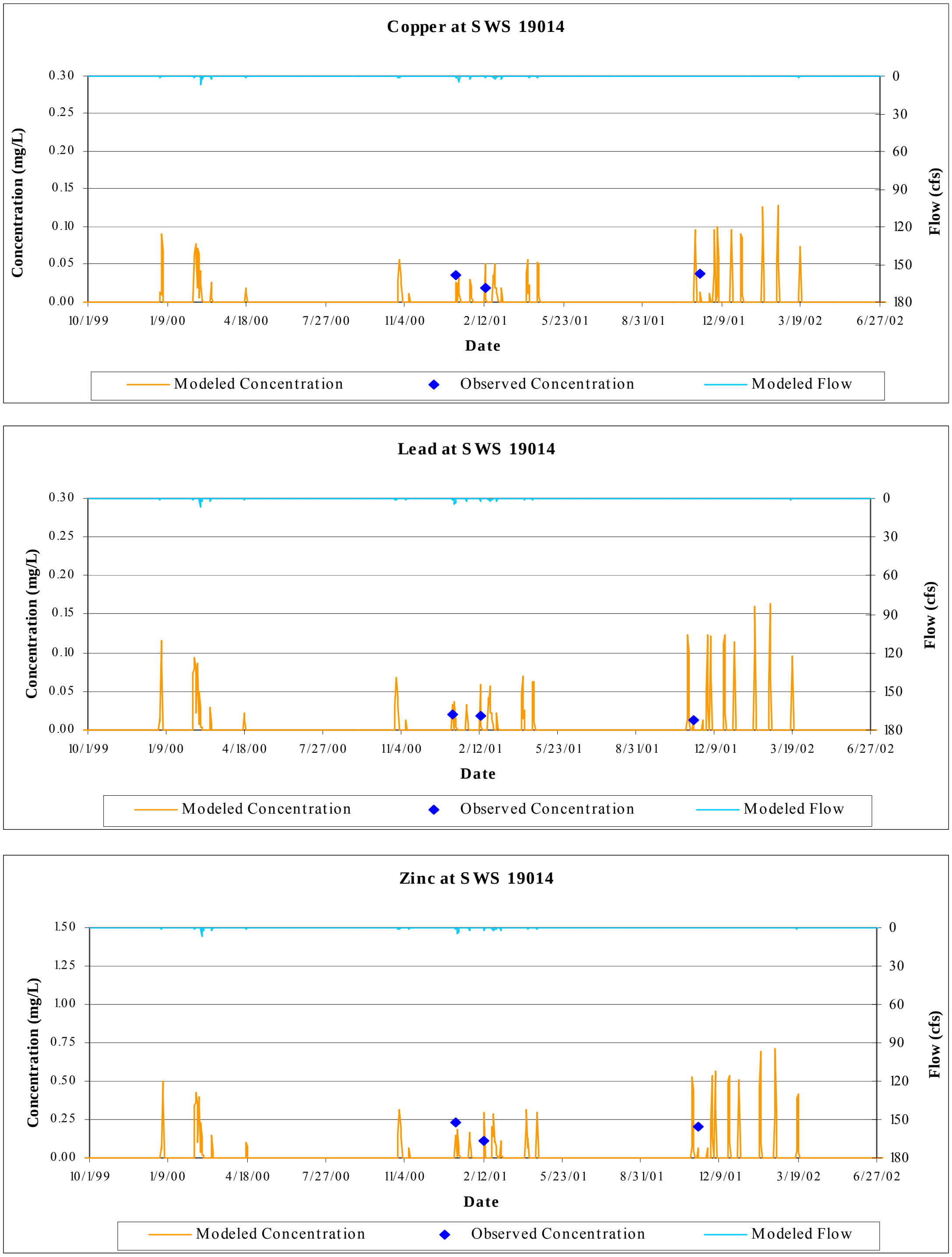


Figure 19. Time-series comparison of modeled and observed wet weather metals concentrations at sampling location DPR(3) (model calibration).

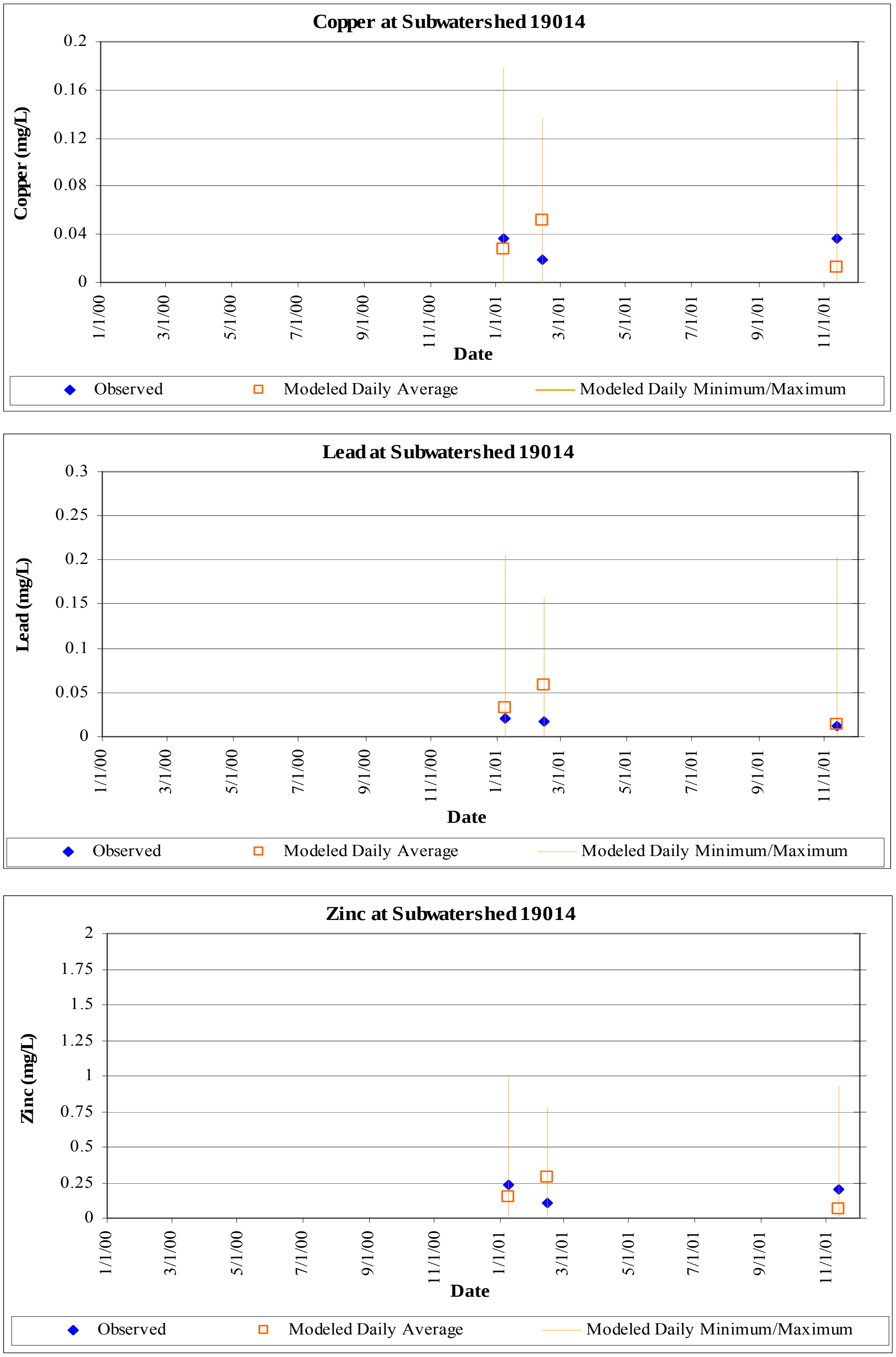


Figure 20. LSPC model results and corresponding observed metals data at sampling location DPR(3) (model calibration)

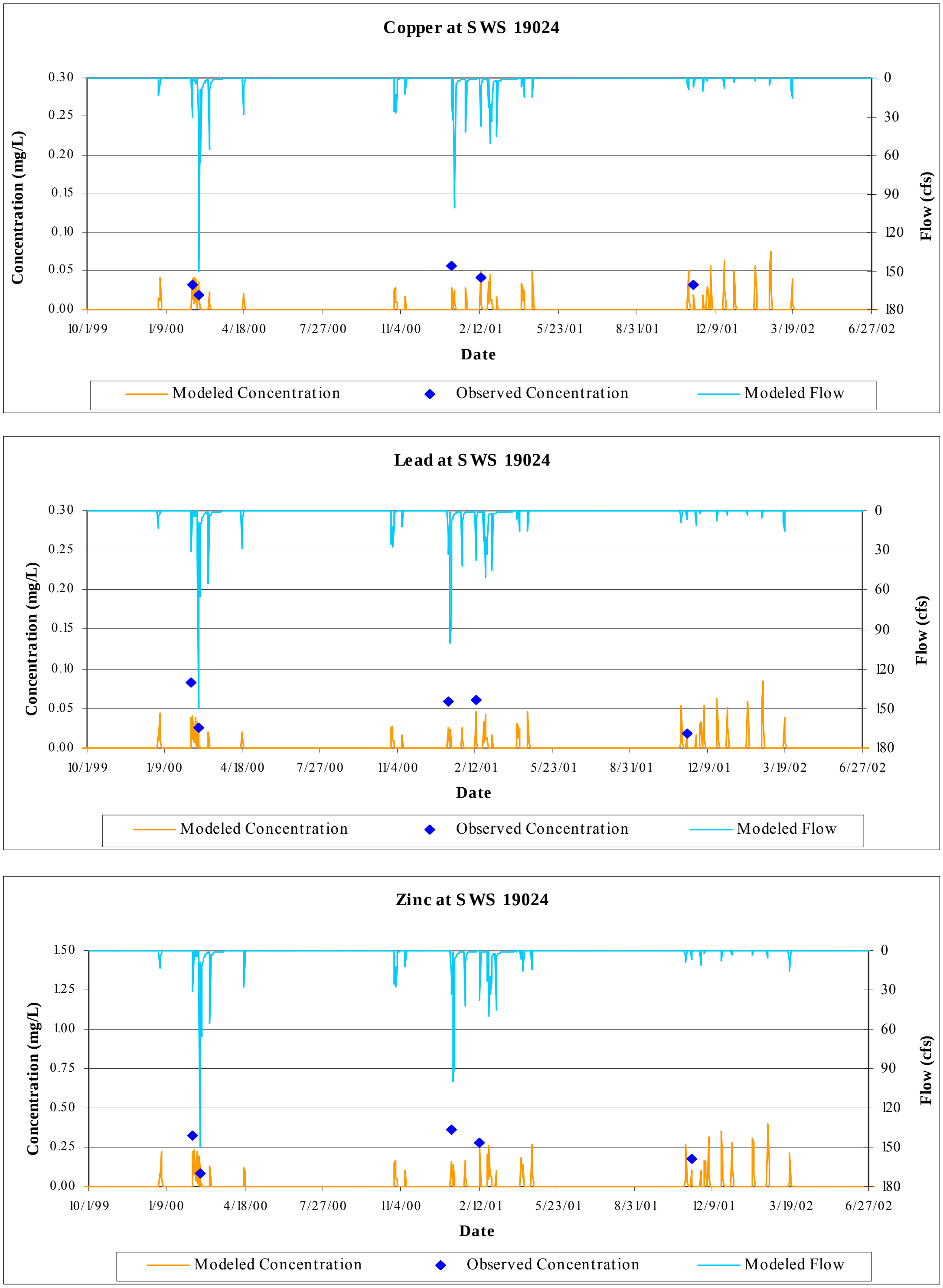


Figure 21. Time-series comparison of modeled and observed wet weather metals concentrations at sampling location DPR(2) (model calibration)

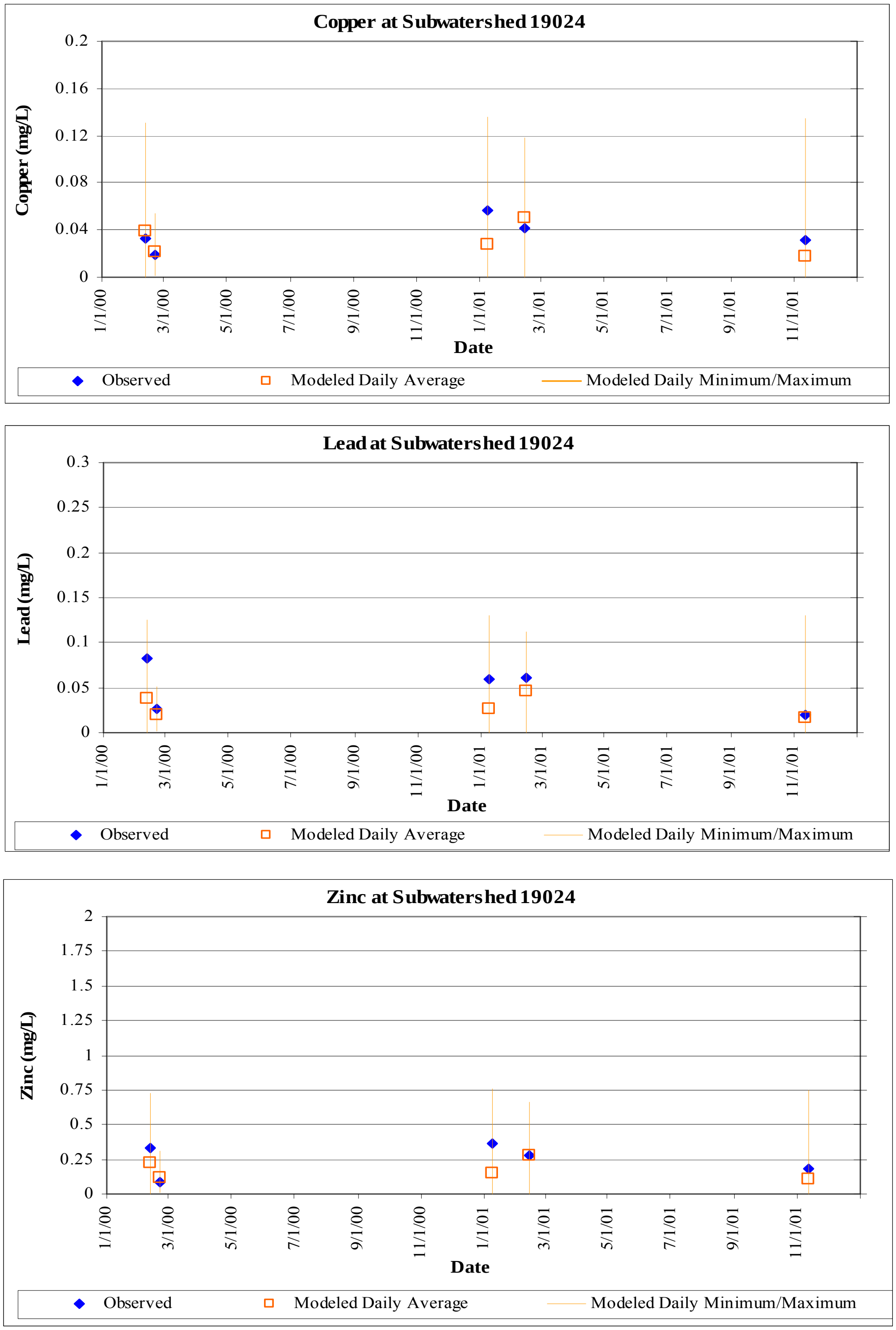
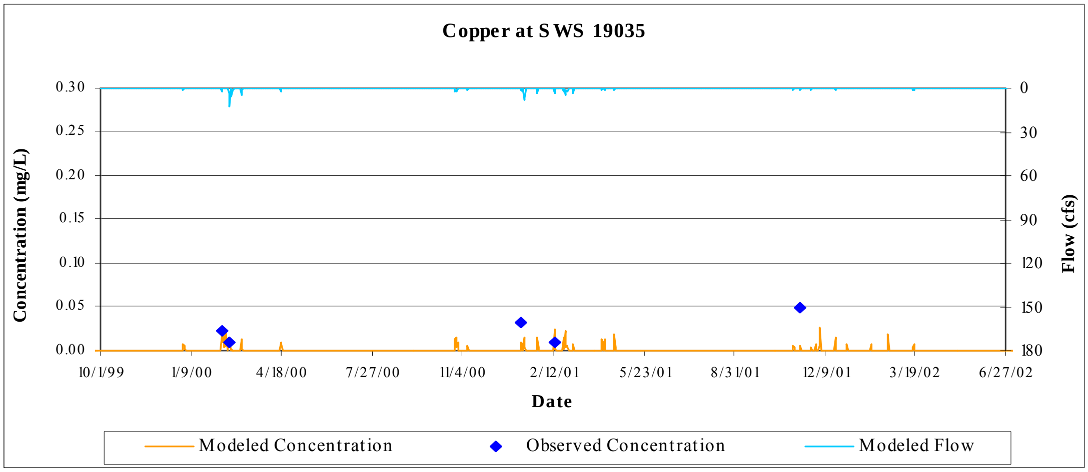
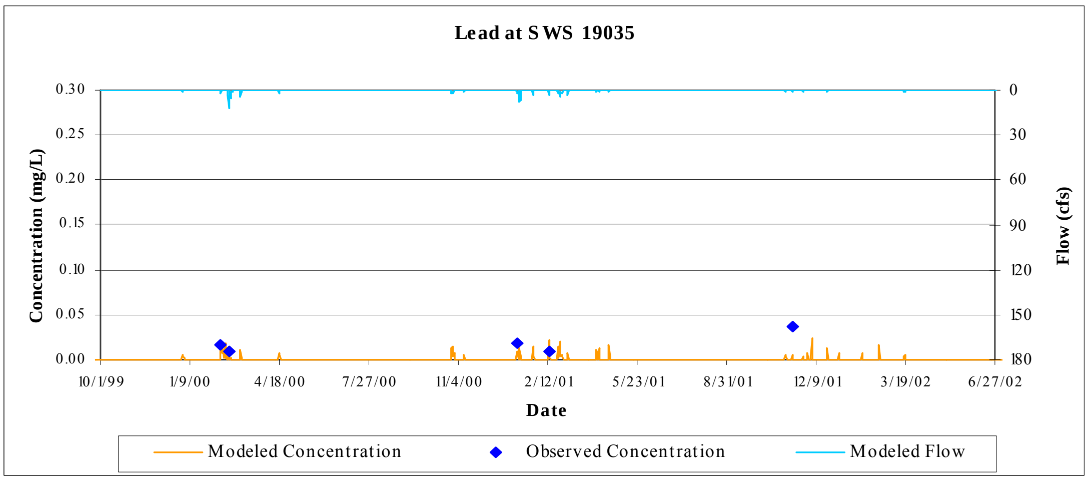


Figure 22. LSPC model results and corresponding observed metals data at sampling location DPR(2) (model calibration)





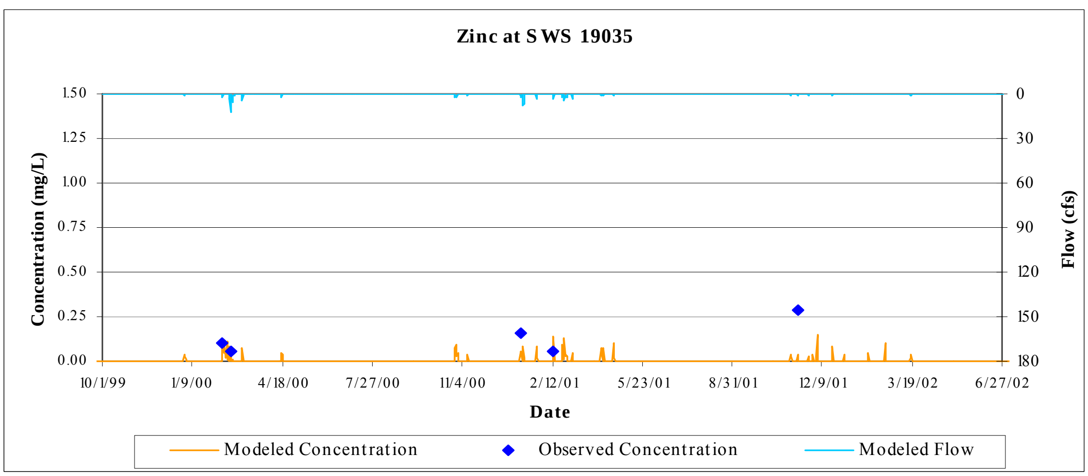


Figure 23. Time-series comparison of modeled and observed wet weather metals concentrations at sampling location SD8(6) (model calibration)

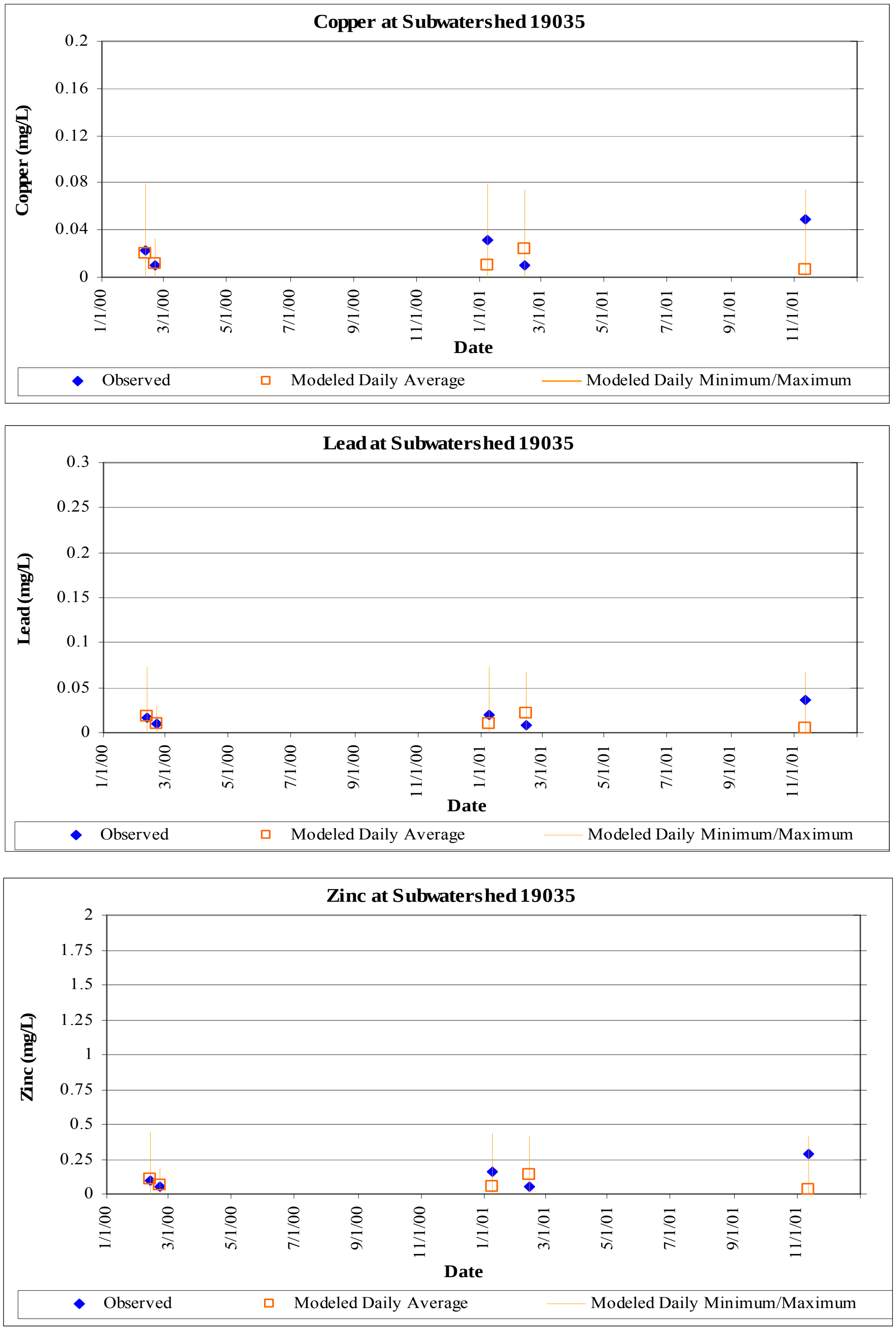


Figure 24. LSPC model results and corresponding observed metals data at sampling location SD8(6) (model calibration)

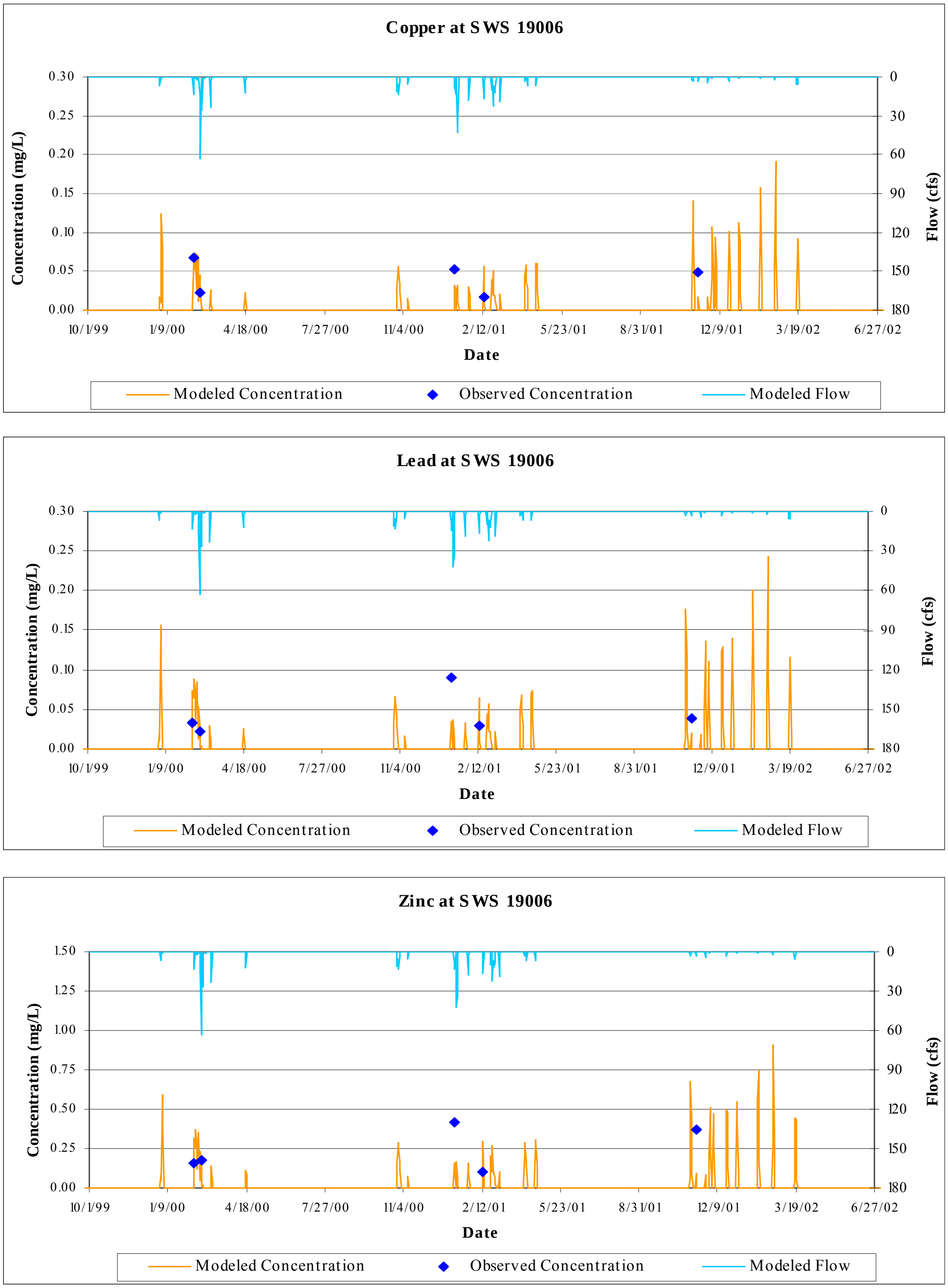
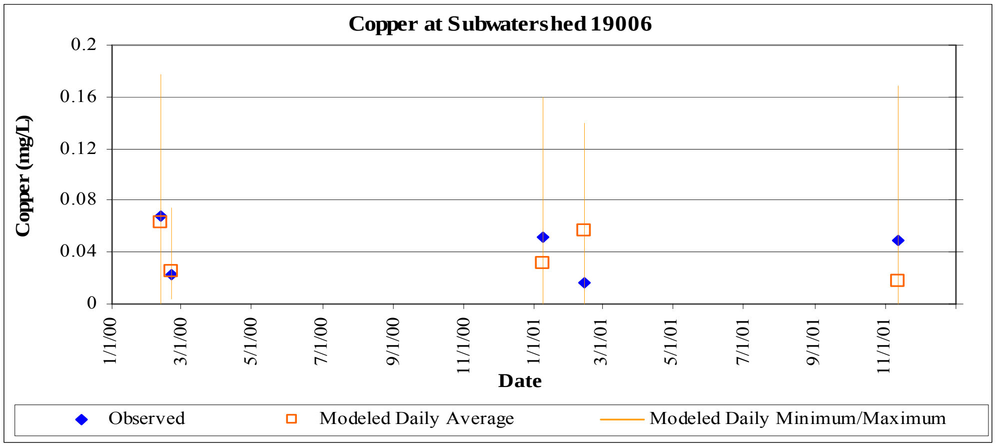
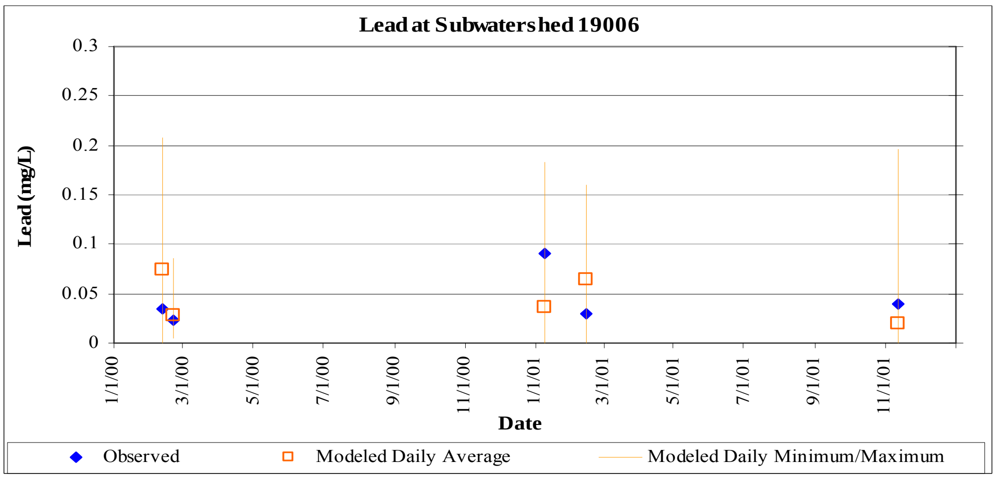


Figure 25. Time-series comparison of modeled and observed wet weather metals concentrations at sampling location SD8(2) (model validation)





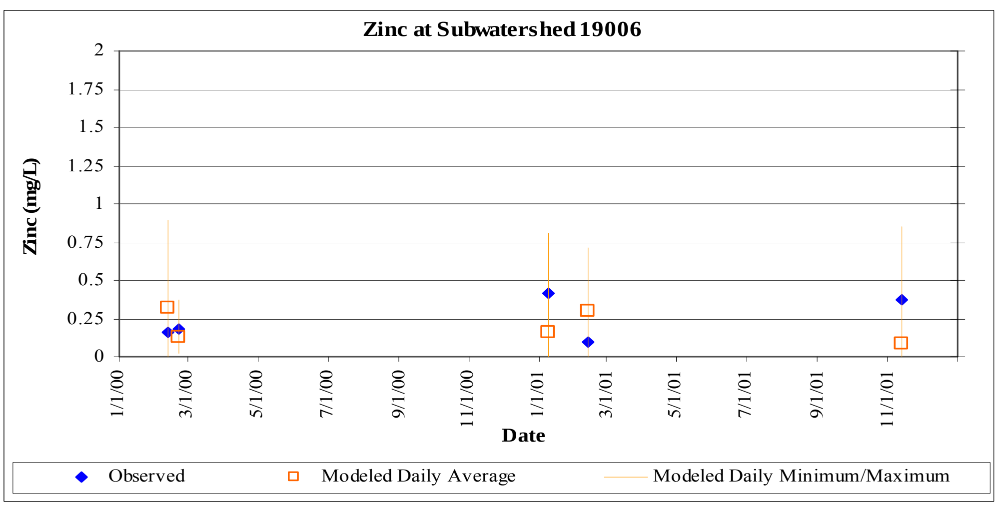


Figure 26. LSPC model results and corresponding observed metals data at sampling location SD8(2) (model validation)

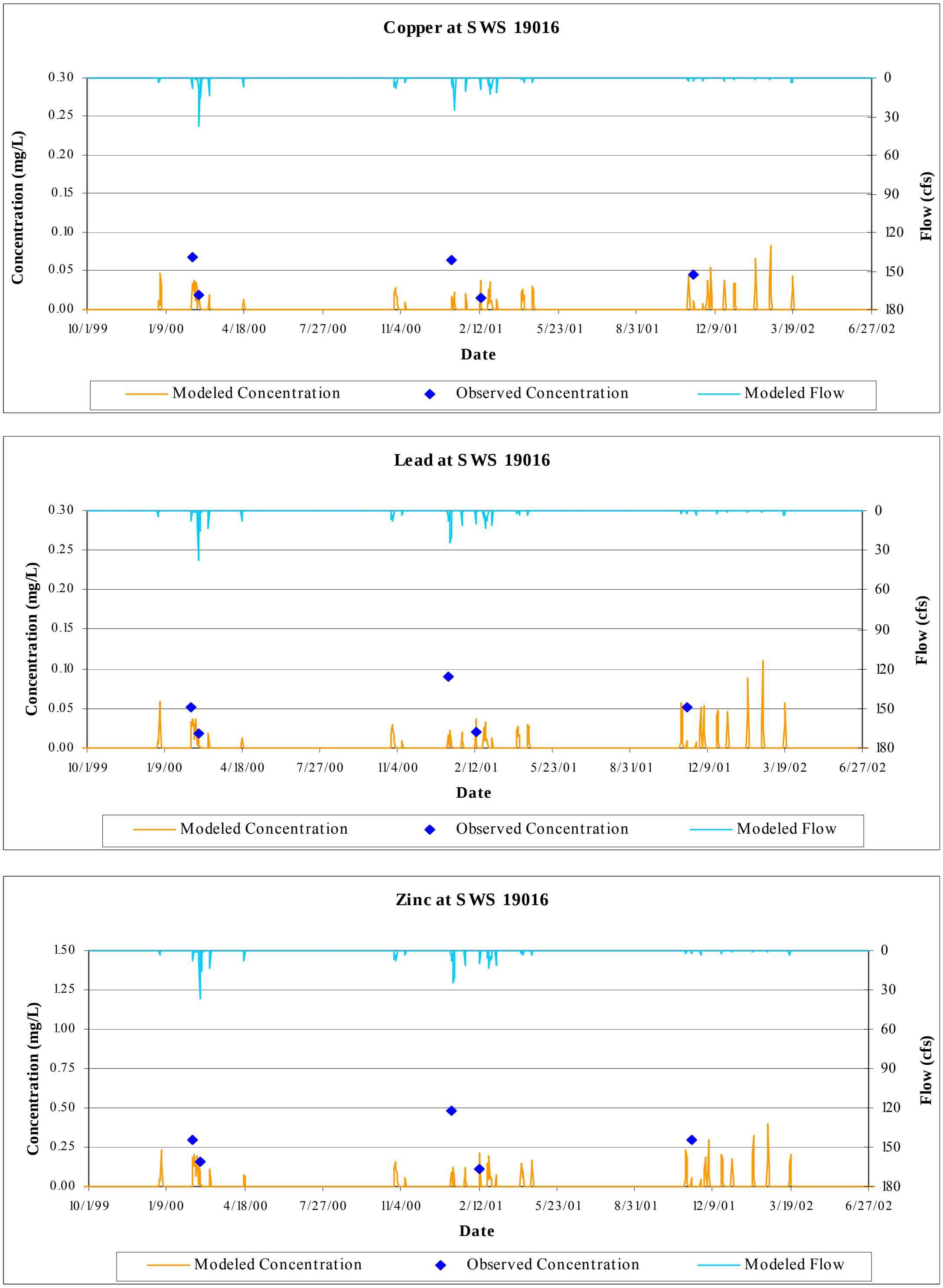
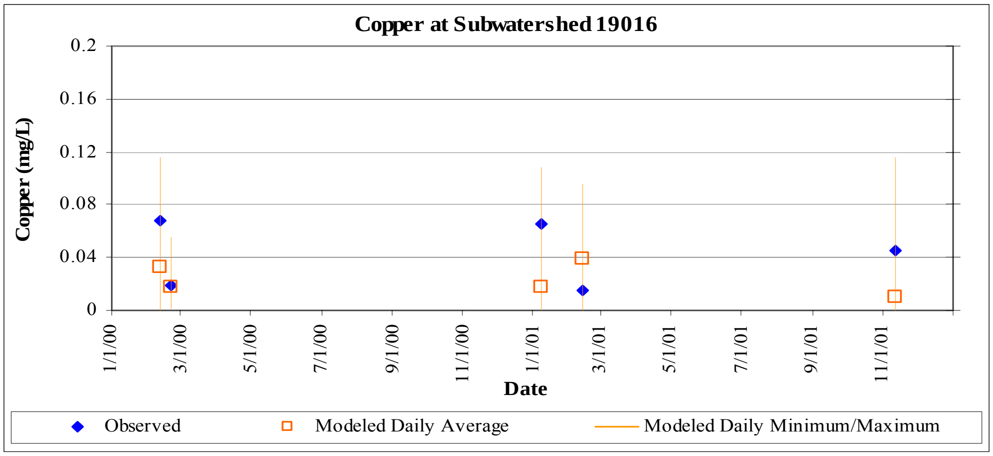
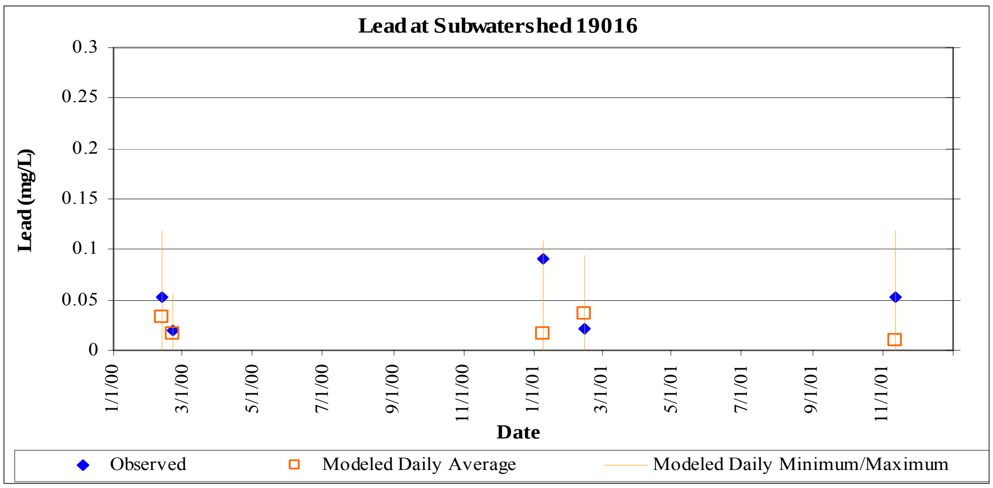


Figure 27. Time-series comparison of modeled and observed wet weather metals concentrations at sampling location SD8(3) (model validation)





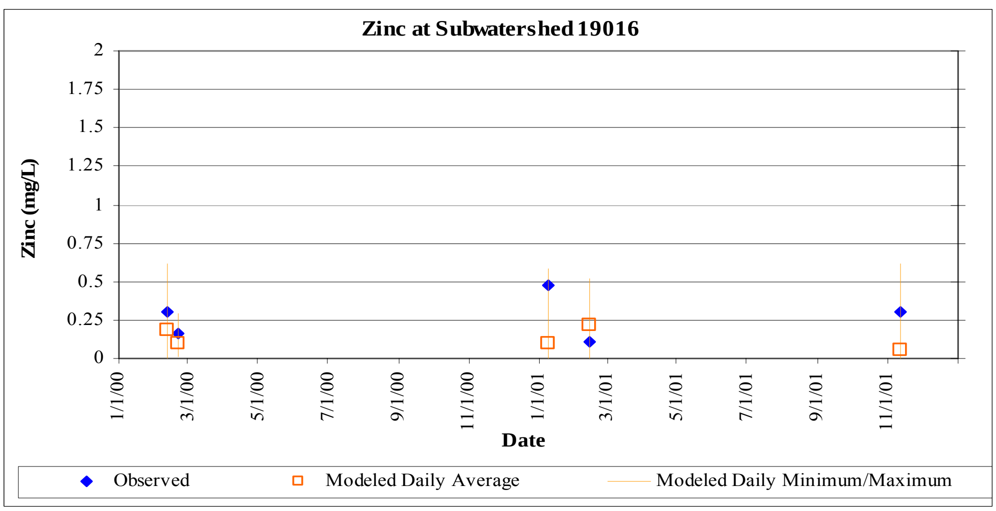
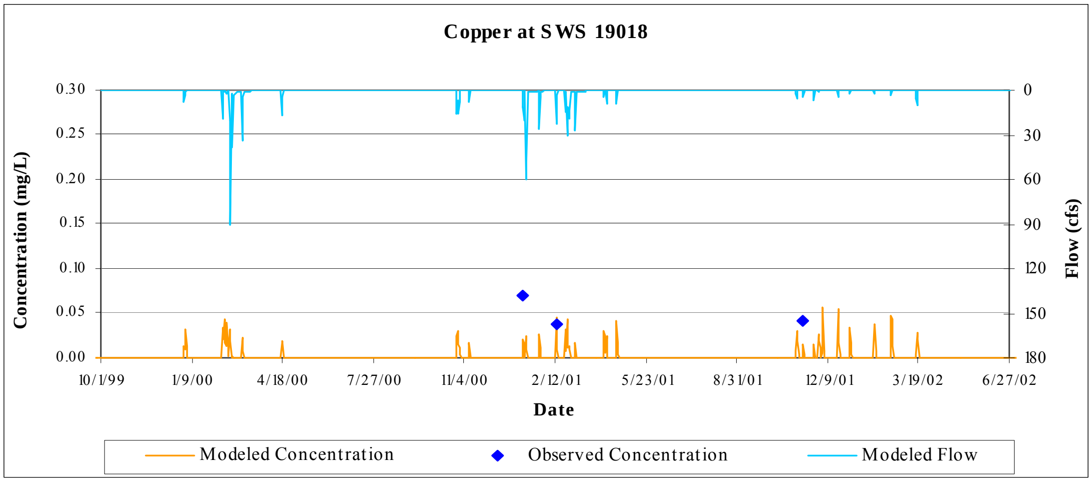
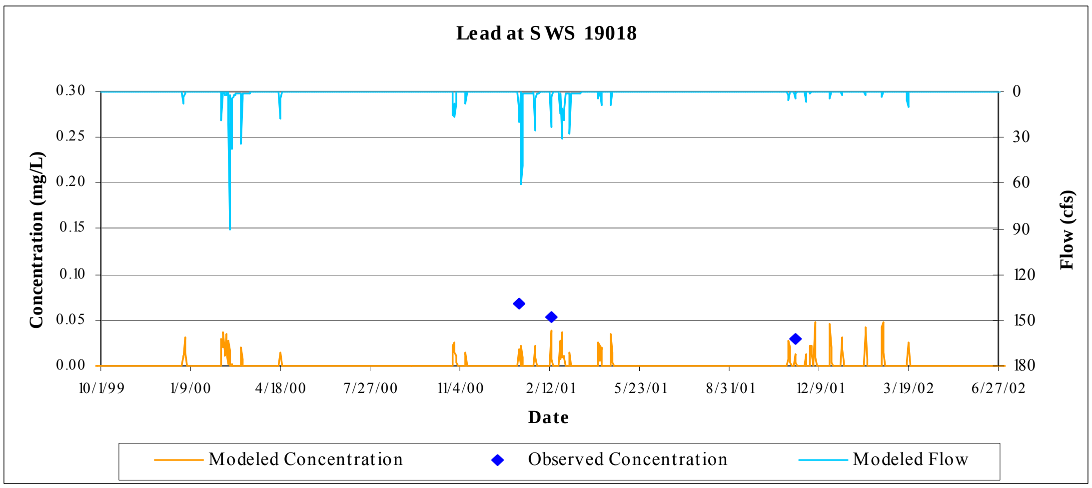


Figure 28. LSPC model results and corresponding observed metals data at sampling location SD8(3) (model validation)





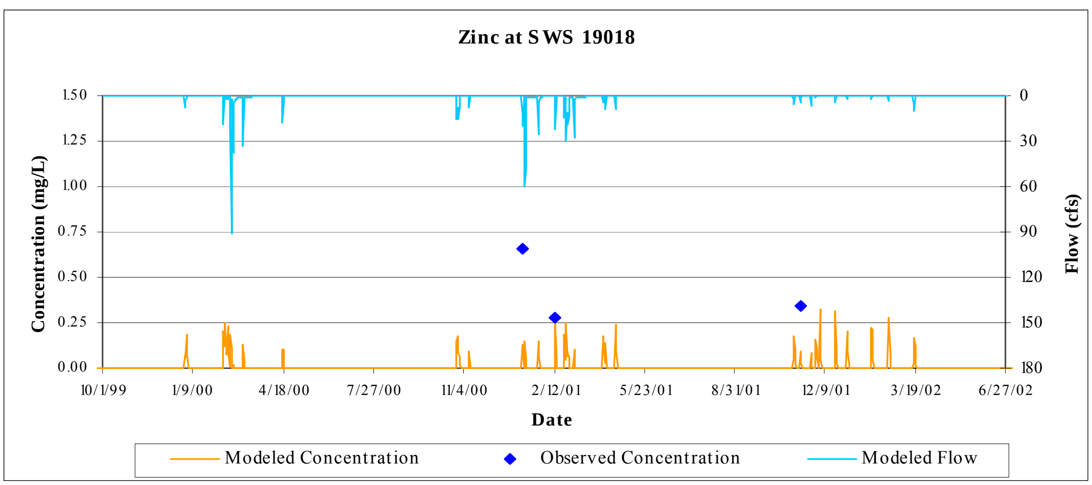


Figure 29. Time-series comparison of modeled and observed wet weather metals concentrations at sampling location DPR(4) (model validation)

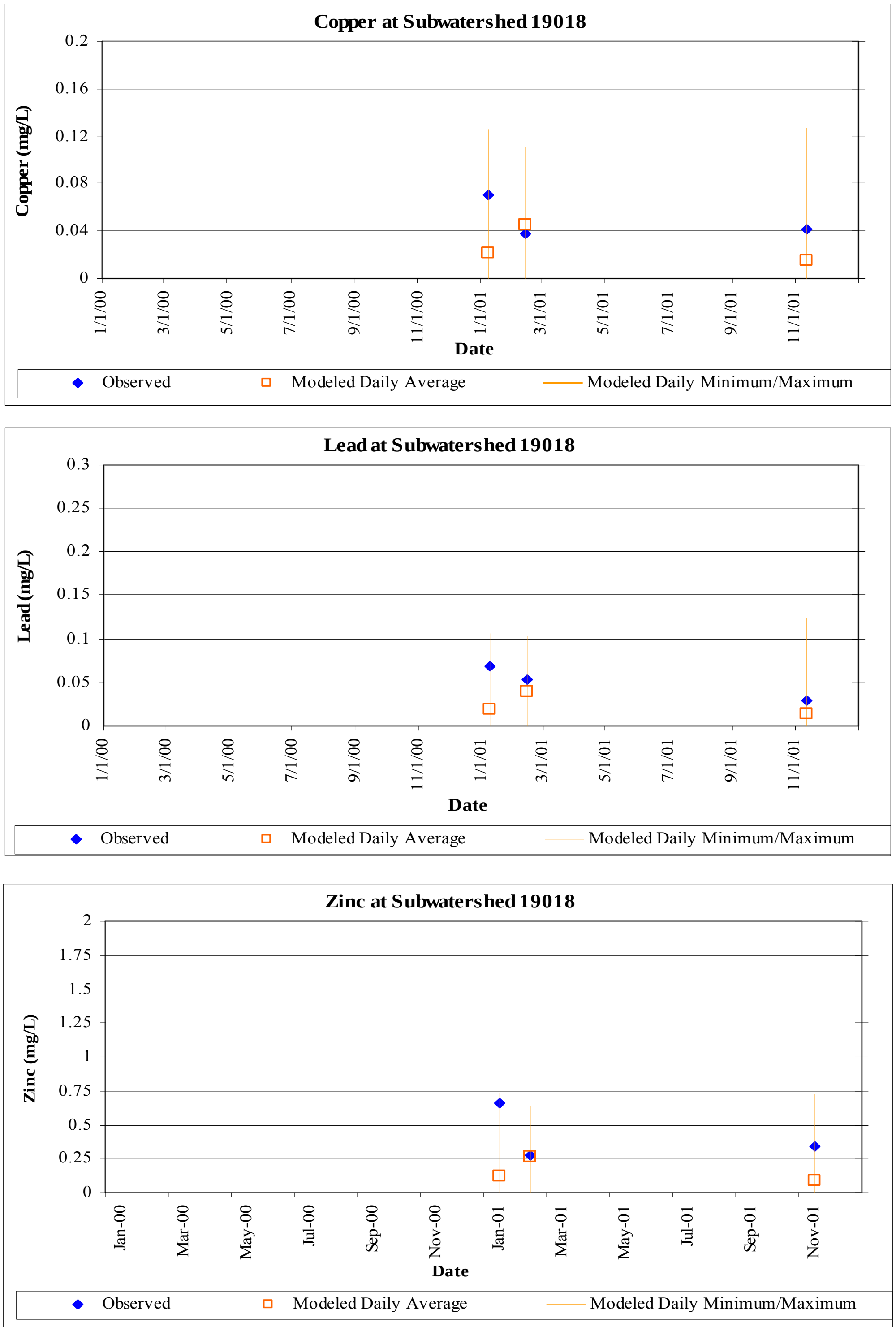


Figure 30. LSPC model results and corresponding observed metals data at sampling location DPR(4) (model validation)

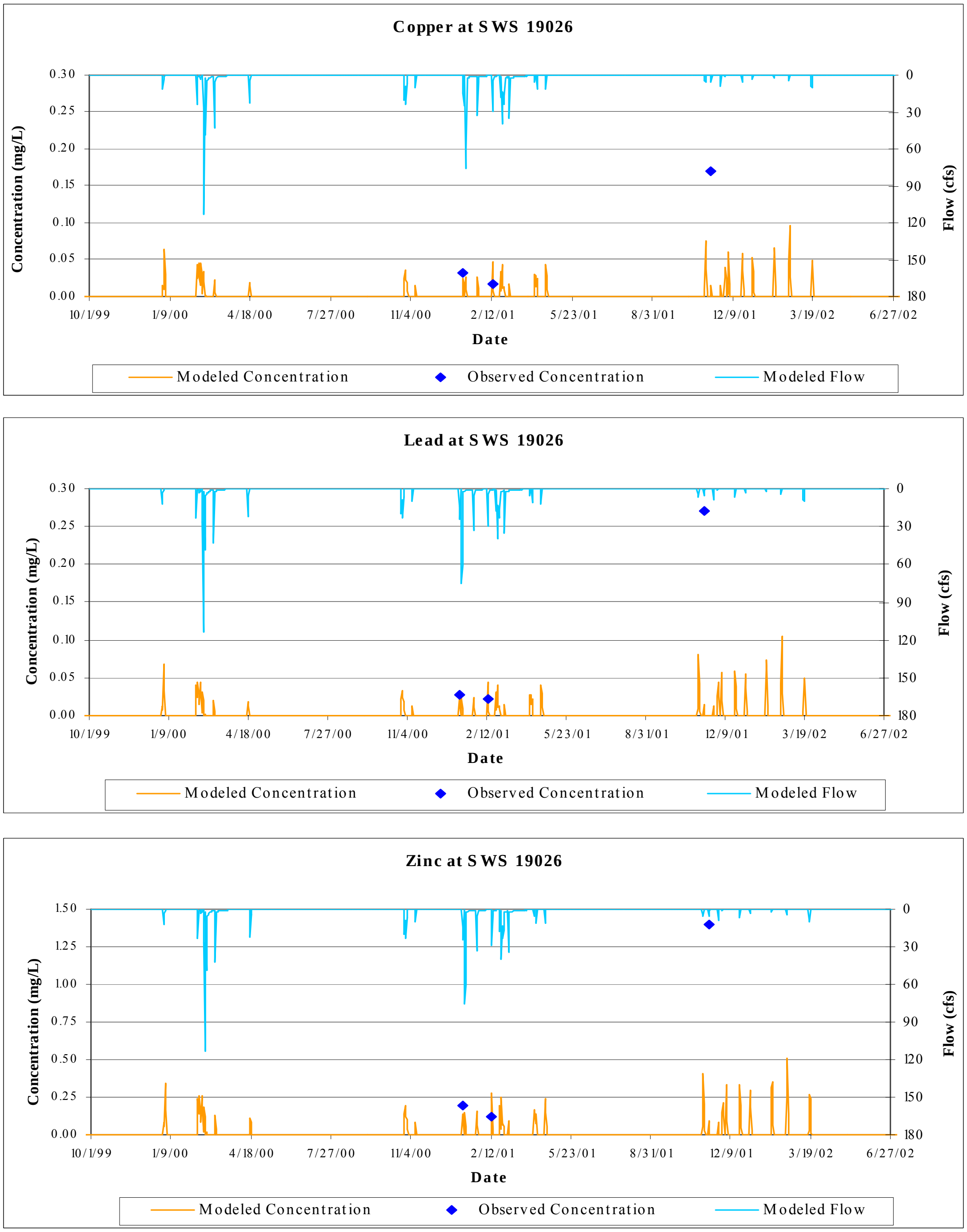


Figure 31. Time-series comparison of modeled and observed wet weather metals concentrations at sampling location DPR(1) (model validation)

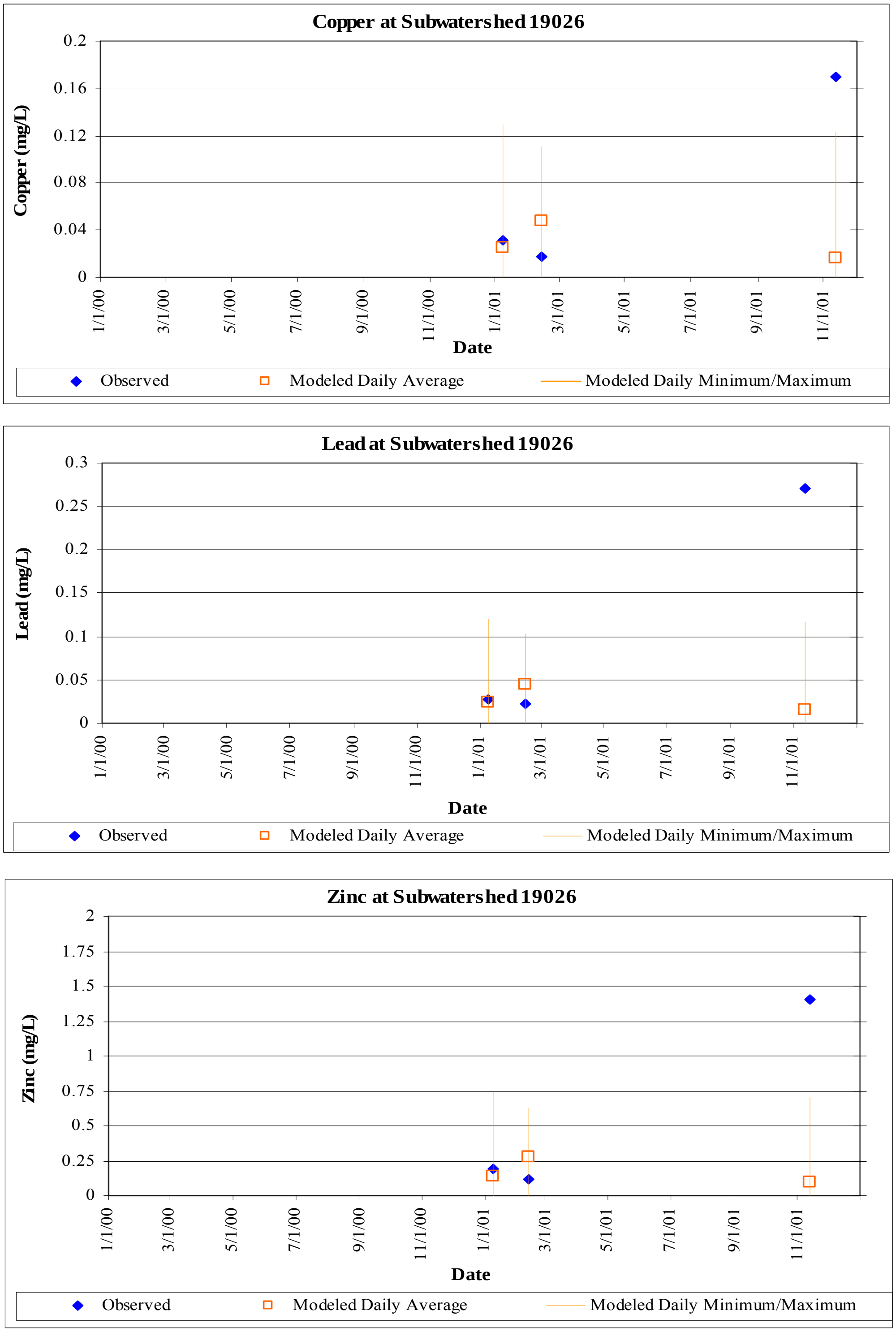


Figure 32. LSPC model results and corresponding observed metals data at sampling location DPR(1) (model validation)

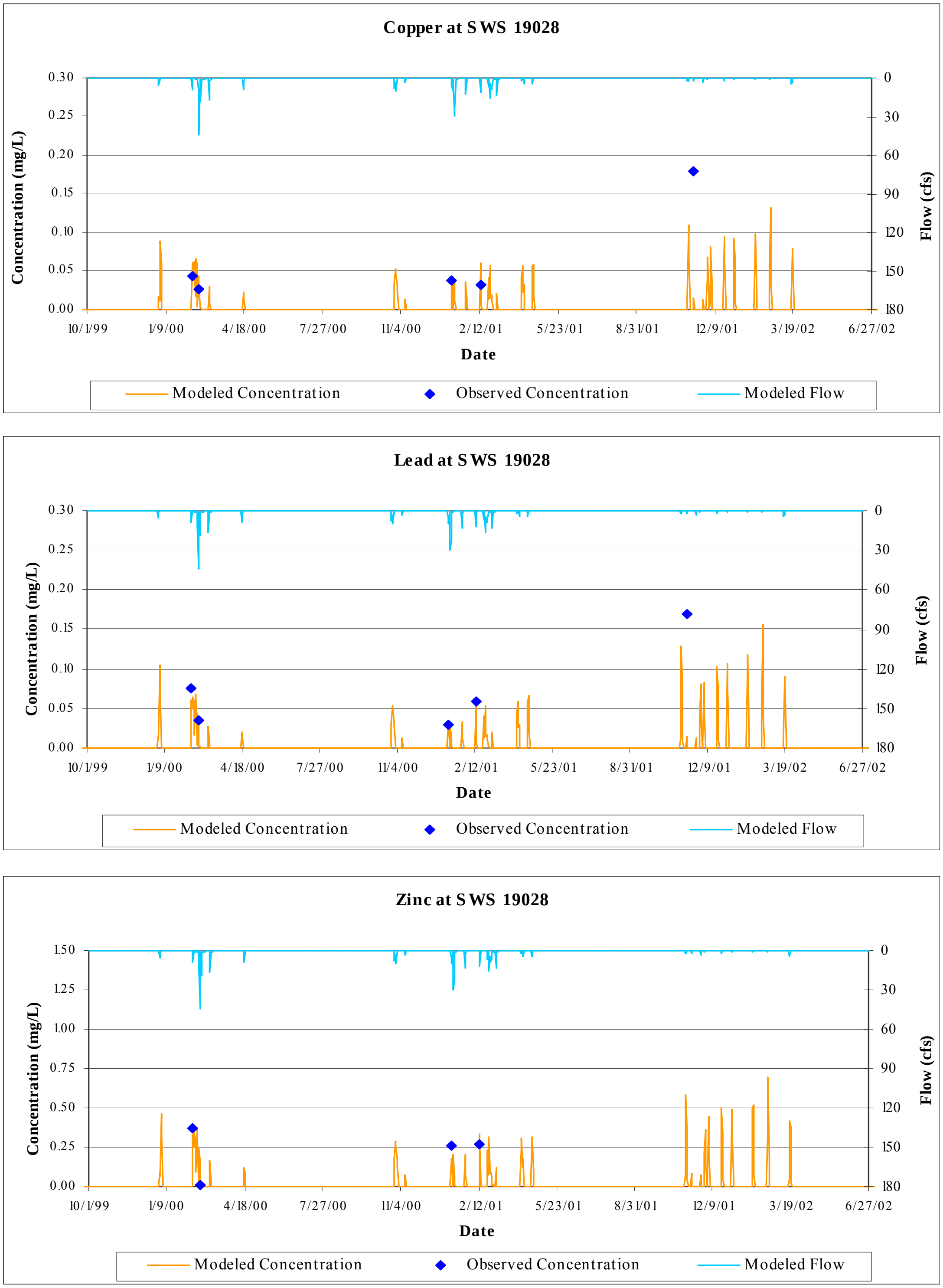


Figure 33. Time-series comparison of modeled and observed wet weather metals concentrations at sampling location SD8(5) (model validation)

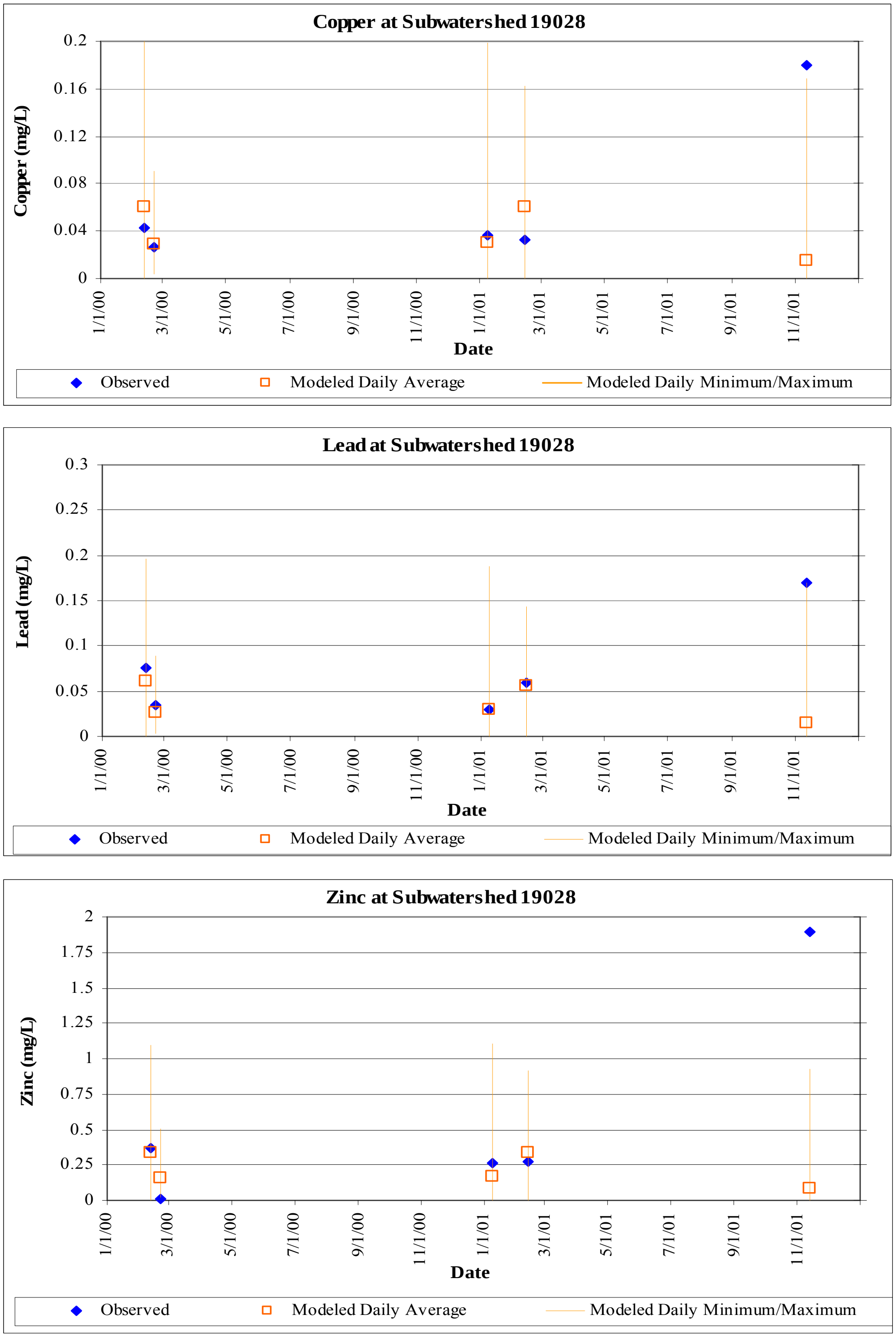


Figure 34. LSPC model results and corresponding observed metals data at sampling location SD8(5) (model validation)

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