Appendix F

Wet Weather and Dry Weather Model Configuration, Calibration, and Validation

Appendix F
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F Introduction

Bacteria loading to bay and harbor beaches are generally associated with three main sources, which are described below:

(1) ***Upstream watershed area.*** Bacteria accumulate on the land surface at different rates. These rates vary considerably and are dependent on the activities associated with a land use.

(2) ***Near-shore area.*** Bacteria may also accumulate on the land surface immediately surrounding a receiving waterbody. These near-shore areas can support bird populations, whose feces contain large quantities of bacteria that build up on the land surface.

(3) ***Direct sources.*** Sources within the shoreline waters may contribute bacteria. These sources may include bird populations that deposit feces directly into the water, terrestrial and aquatic wildlife, and other sources within the waters.

During precipitation events and through dry weather transport mechanisms, bacteria loads from the watershed and near-shore areas are delivered to receiving waterbodies through stream networks and stormwater collection systems. Often, watershed-based bacteria sources are associated with land use-specific accumulation rates. There is often a correlation between sources of bacteria and specific land use types. Specific land use types may have higher relative accumulation rates of bacteria, or may be more likely to deliver bacteria to water bodies through stormwater collection systems. Near-shore contributions and direct deposition typically can be linked to the bird population and their dropping rates.

In order to assess the linkage between bacteria sources and impaired waters, a modeling system may be utilized to simulate the build-up and wash-off of bacteria and the hydrologic, hydraulic and hydrodynamic processes that affect delivery to and response of the receiving waters. Understanding and modeling of these processes provides the necessary decision support for TMDL development and allocation of loads to sources.

TMDL calculations were based on comprehensive wet and dry weather modeling systems, which linked watershed hydrology, receiving water hydrodynamics, and their pollutant loading characteristics. The Loading Simulation Program C++ (LSPC) (USEPA, 2003a) was applied to simulate watershed hydrology and pollutant loading during wet weather conditions. LSPC is a recoded C++ version of the USEPA's Hydrological Simulation Program–FORTRAN (HSPF) that relies on fundamental (and USEPA-approved) algorithms. A steady-state spreadsheet model was developed to simulate these processes during dry weather conditions. The Environmental Fluid Dynamic Code (EFDC) (USEPA, 2003b) was used to simulate the complex flow and pollutant transport patterns in the bays during both wet and dry weather.

The watershed component of this TMDL (wet weather and dry weather) is a direct application of the regionally calibrated models from the *Total Maximum Daily Loads for Indicator Bacteria Project I – Beaches and Creeks in the San Diego Region* (hereafter referred to as Bacteria TMDL Project I) (San Diego Water Board, 2007). The EFDC hydrodynamic model incorporates flow and loading from the watershed and subsequently determines their impact on the impaired shorelines as the pollutants are transported through the bays. This document describes the modeling methodologies employed during the development of bacteria TMDLs for the impaired shorelines of San Diego Bay (SDB) and Dana Point Harbor (DPH) (see Appendix J for maps of the areas modeled). Specifically, Section F.1 describes the LSPC wet weather watershed model, Section F.2 describes the dry weather steady-state model of the watershed, and Section F.3 provides details on the wet and dry weather EFDC model. Section F.4 discusses the application and utility of the three individual models as well as their collective role in calculation of the current TMDL and potential future functionality.

F.1 Wet Weather Watershed Model – LSPC

In the present study, an LSPC model was configured for the watersheds contributing to impaired shorelines of SDB and DPH (see Appendix J for watershed maps) and was then used to simulate the flow and loading from a watershed, or a series of hydraulically connected subwatersheds, if applicable. Configuration of the model involved subdividing the watersheds into modeling units, followed by continuous simulation of flow and water quality for these units using meteorological, land use, soils, stream, and bacteria representation data. Development and application of the watershed model to address the project objectives involved a number of important steps:

1. Watershed Segmentation
2. Configuration of Key Wet Weather Watershed Model Components
3. Wet Weather Watershed Model Calibration and Validation

F.1.1 Watershed Segmentation

Watershed segmentation refers to the subdivision of the bay watersheds into smaller, discrete subwatersheds for modeling and analysis. This process determines the land surface area that contributes flows and pollutants to each of the downstream receiving waterbodies. This subdivision was primarily based on topographic variability and storm water conveyance system networks.

A 30-meter Digital Elevation Model (DEM) was the primary source of topography data; however, this resolution was not fine enough to segment the watersheds that have relatively flat contributing areas. The 30-meter DEM was used to delineate the Baby Beach watershed. Storm water conveyance system data were used for the remaining watersheds. The Port of San Diego provided the coastal storm water conveyance system data that were used for delineating the Shelter Island Shoreline Park (SANGIS, 2004). The subwatersheds draining to the impaired shorelines of SDB and DPH identified by the watershed segmentation are presented in Appendix J.

F.1.2 Configuration of Key Wet Weather Watershed Model Components

Configuration of the watershed model involved consideration of five major components:

- Meteorological data;
- Land use representation;
- Hydrologic representation;
- Pollutant representation; and,
- Waterbody representation.

These components provided the basis for the LSPC model's ability to estimate flow and pollutant loadings. Detailed discussions about the development of each component for the LSPC model are provided in the following subsections.

F.1.2.1 Meteorology

Meteorological data are a critical component of the watershed model. Meteorological data essentially drive the watershed model. Rainfall and other parameters are key inputs to LSPC's hydrologic algorithms. The LSPC model requires an 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 (or finer resolution) data were considered in the precipitation data selection process. Rainfall-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 have been accessed from a number of sources in an effort to develop the most representative dataset for the bay and harbor watersheds. Hourly rainfall data were obtained from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) and the Automatic Local Evaluation in Real Time (ALERT) Flood Warning System managed by the County of San Diego. The above data were reviewed based on geographic location, period of record, and missing data to determine the most appropriate meteorological stations. In addition, hourly evapotranspiration data were obtained from the California Irrigation Management Information System (CIMIS). Based on the review of the available data, the meteorological data were utilized from three area weather stations for the period of January 1990 to May 2004 (Figure F-1) were selected.

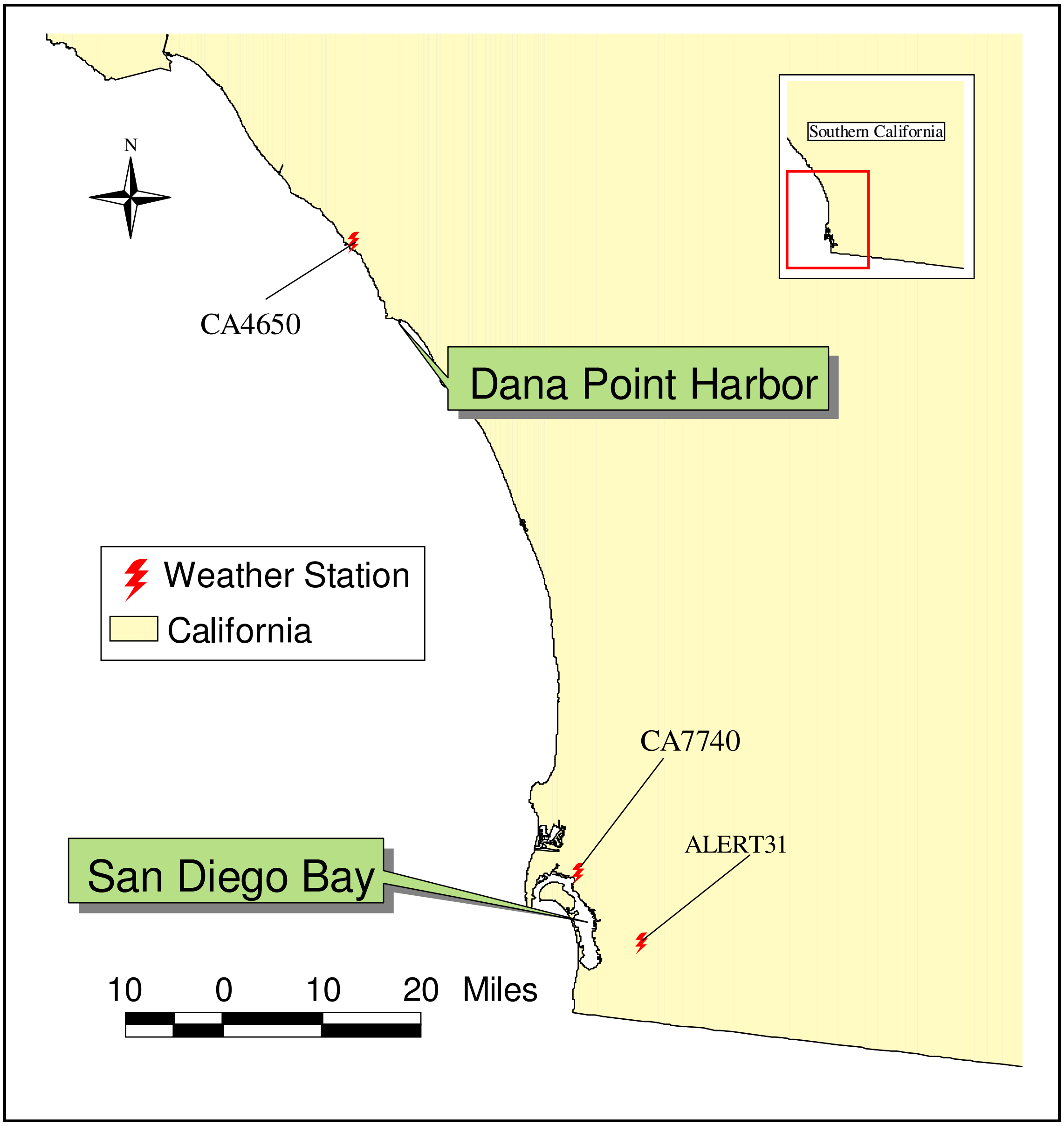

Figure F-1. Weather Stations Utilized for Wet Weather Modeling

F.1.2.2 Land Use Representation

The LSPC watershed model requires a basis for distributing hydrologic and pollutant loading parameters. Hydrologic variability within a watershed is influenced by land surface and subsurface characteristics. Variability in pollutant loading is highly correlated to land use practices. Land use representation provides the basis for distributing soils and pollutant loading characteristics throughout the watershed.

Two sources of land use data were used in this modeling effort. The primary source of data was the San Diego Association of Governments (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) to address the Dana Point Harbor watersheds in Orange County.

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 thirteen categories for modeling. Selection of these land use categories was based on the availability of monitoring data and literature values that could be used to characterize individual land use contributions and critical bacteria-contributing practices associated with different land uses. For example, multiple urban categories were represented independently (e.g., high density residential, low density residential, and commercial/institutional), whereas forest and other natural categories were grouped. Table F-1 presents the land use distribution in each of the watersheds.

Table F-1. Land Use Areas (Acres) of Each Impaired Shoreline Watershed

Watershed / **Land Use**	Dana Point Harbor	San Diego Bay
	Baby Beach	Shelter Island Shoreline Park
Low Density Residential (1100)	193.8	0.0
High Density Residential (1200)	165.6	0.0
Commercial/ Institutional (1400)	82.5	0.0
Industrial/ Transportation (1500)	3.6	0.0
Military (1600)	0.0	0.0
Parks/ Recreation (1700)	17.1	100
Open Recreation (1800)	29.7	0.0
Agriculture (2000)	0.0	0.0
Dairy/ Intensive Livestock (2400)	0.0	0.0
Horse Ranches (2700)	0.0	0.0
Open Space (4000)	30.3	0.0
Water (5000)	0.0	0.0
Transitional (7000)	0.0	0.0
Total	**522.6**	**10.2**

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 (USDA, 1986) as summarized in Table F-2. The other eight land use categories are assumed to be 100% pervious.

Table F-2. Percent Impervious for Urban Land Uses (based on TR-55)

Land Use	Pervious Percentage	Impervious Percentage
Industrial/Transportation	18%	72%
Low Density Residential	85%	15%
High Density Residential	35%	65%
Commercial/Institutional	15%	85%
Parks/Recreation	88%	12%

F.1.2.3 Hydrology Representation

Hydrologic representation refers to the modules, or algorithms, in the LSPC model used to simulate hydrologic processes (e.g., surface runoff, evapotranspiration, and infiltration). The hydrology in the model was represented with the LSPC PWATER (water budget simulation for pervious land segments) and IWATER (water budget simulation for impervious land segments) hydrology modules, which are identical to those in HSPF model. These hydrology modules were used to simulate the hydrology for all pervious and impervious land units (Bicknell et al., 1996) in the LSPC model.

Designation of key hydrologic parameters in the PWATER and IWATER hydrology modules of LSPC were required. These parameters are associated with infiltration rates, groundwater flow, and overland flow. Robust hydrology calibration and validation were performed previously for gaged watersheds in the San Diego Region Bacteria TMDL Project I (San Diego Water Board, 2007). The parameter values derived from this previous modeling effort were input to the PWATER and IWATER hydrology modules to parameterize the watersheds in this project. None of the SDB or DPH shoreline watersheds have historic recorded streamflow. Therefore, no further hydrology calibration or validation was performed.

F.1.2.4 Pollutant Representation

Pollutant representation refers to the modules, or algorithms, in the LSPC model used to simulate pollutant loading processes (primarily accumulation and wash-off). Pollutant loading processes for total coliform (TC), fecal coliform (FC), and *Enterococcus* (ENT) 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) water quality modules, which are identical to those in the HSPF model. These modules simulate the accumulation of pollutants during dry weather conditions and the wash-off of pollutants during wet weather conditions (rainy periods or storm events) for pervious and impervious land units in the LSPC model.

Land-use-specific accumulation rates and buildup limits were initially obtained from a study performed by the Southern California Coastal Water Research Project (SCCWRP) to support bacteria TMDL development for Santa Monica Bay (Los Angeles Water Board, 2002). These initial values from the SCCWRP study served as baseline conditions for water quality calibration; the appropriateness of these values to the San Diego Region was validated through comparison with local water quality data (San Diego Water Board, 2007). Because these buildup limits and accumulation rates have already been validated for the San Diego Region Bacteria TMDL Project I (San Diego Water Board, 2007), they were considered suitable for use in this smaller-scale modeling effort and thus were incorporated into the PQUAL and IQUAL water quality modules.

F.1.2.5 Waterbody Representation

Waterbody representation refers to modules, or algorithms, in the LSPC model used to simulate flow and pollutant transport through streams and rivers. 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 is generally used to determine the representative stream reach for each subwatershed. The resolution of the NHD network was not fine enough to capture the streams in the bay and harbor subwatersheds. Instead, a representative reach for each subwatershed was approximated in a geographic information system (GIS) using the DEM and storm water conveyance system network data. Once the representative reach was identified, slopes were calculated based on DEM data and stream lengths measured from the new 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.

F.1.3 Wet Weather Watershed Model Calibration and Validation

After the LSPC watershed model was configured, model calibration and validation was performed. Model validation for hydrology and water quality occurs after model calibration. The entire model calibration and validation process is generally a two-phase process, with hydrology calibration and validation completed before repeating the calibration and validation process for water quality. Model calibration refers to the adjustment or fine-tuning of modeling parameters until the model is able to reproduce previous observations from a particular location and time period. Subsequently, model validation is performed to test the calibrated parameters to see if the model can reproduce previous observations at different locations or for different time periods, without further adjustment.

No flow and water quality data were available to further validate the previously calibrated and validated parameters (San Diego Water Board, 2007). The general calibration and validation process is described below and details are provided regarding this current modeling effort, where applicable. To ensure that the model results are as current as possible and to provide for a range of hydrologic conditions, the meteorological data used during the previous study were extended so that the current simulations span from January 1991 through May 2004.

F.1.3.1 Hydrology Calibration and Validation

Hydrology is the first model component of the watershed model to be calibrated because estimation of bacteria loading relies heavily on streamflow prediction. The hydrology calibration involves a comparison of model results to in-stream flow observations at selected locations and time periods. After running the model and comparing results, key hydrologic parameters are adjusted and additional model simulations are performed. This iterative process can be repeated until the simulated model results closely represent the stream system and reproduce previously observed streamflow patterns and magnitudes.

Model validation is then performed to test the calibrated parameters to see if the model can reproduce previous observations at different locations or for different time periods, without further adjustment. These validation results essentially confirm the appropriateness and applicability of the hydrologic parameters derived during the calibration process.

Regionally-calibrated, land use-specific hydrology parameter values were developed while modeling the entire San Diego Region for Bacteria TMDL Project I (San Diego Water Board, 2007). These values were used to parameterize the SDB and DPH shoreline watersheds. 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 wet and dry conditions), and can be applied to the ungaged streams within the San Diego Region. Without this regional set of parameter values, a watershed model would be unfeasible for TMDL linkage analysis and the calculation of loading capacities along ungaged streams. A detailed description of this robust calibration, which included thirteen USGS gages throughout the San Diego Region, is described in the Bacteria TMDL Project I (San Diego Water Board, 2007). This report also documents the methods employed to develop, evaluate, and interpret model results.

Key considerations in the hydrology calibration and validation include the overall water balance, the high-flow/low-flow distribution, stormflows, and seasonal variation. Two methods for evaluation of calibration and validation performance are often used: graphical comparison and the relative error method. Graphical comparisons are 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, baseflow recession, time distributions, and other pertinent factors often overlooked by statistical comparisons. The model's accuracy is primarily assessed through interpretation of the time-variable plots. The relative error method is used to support the goodness of fit evaluation through a quantitative comparison.

F.1.3.2 Water Quality Calibration and Validation

After a model is calibrated and validated for hydrology, water quality model simulations are performed. As described above, previously calibrated, land use specific accumulation and maximum build up rates for TC, FC, and ENT (Los Angeles Water Board, 2002) were used for the water quality model simulations. Since these values have been successfully applied to recent bacteria models in southern California, they were considered to be sufficiently calibrated. These values were validated for the San Diego Region in Bacteria TMDL Project I by comparing the model results with available monitoring data (San Diego Water Board, 2007).

F.2 Dry Weather Watershed Model

The variable nature of bacteria sources from the SDB and DPH shoreline watersheds during dry weather required an approach that relied on detailed analyses of flow and water quality monitoring data to identify and characterize sources. This TMDL utilized empirical equations previously calibrated and validated in the San Diego Region for Bacteria TMDL Project I (San Diego Water Board, 2007) to represent water quantity and water quality associated with dry weather runoff from various land uses.

Characterization of dry-weather flow and indicator bacteria concentrations was based on analyses of data collected during studies of four watersheds in the San Diego Region. Two of these watersheds, Aliso Creek and San Juan Creek, are located in Orange County and are representative of conditions in the northern part of the Region. The remaining two watersheds, Rose Creek and Tecolote Creek, are located in San Diego County and discharge to Mission Bay. Three of these watersheds, Aliso Creek, San Juan Creek, and Tecolote Creek, are associated with water quality impairments due to bacteria and are therefore representative of conditions that may contribute to similar impairments in neighboring watersheds. Land uses for all four watersheds are consistent with other impaired watersheds in this study, with varying amounts of urban/residential land uses and open space in different subwatersheds.

The modeling approach was originally designed to simulate dry weather bacteria concentrations in the San Diego Region, as described in Bacteria TMDL Project I (San Diego Water Board, 2007). Robust model calibration and validation of flow and bacteria were performed for this initial model application. The SDB and DPH shoreline watersheds model utilizes calibrated parameters from the Bacteria TMDL Project I. The remainder of this section describes model set-up, calibration, and validation of the Bacteria TMDL Project I dry weather model, while noting modifications that were made to specify the model for the SDB and DPH shoreline watersheds.

F.2.1 Dry Weather Watershed Model Configuration

This predictive model for Bacteria TMDL Project I represented the streams as a series of plug-flow reactors, with each reactor having a constant source of flow. A plug-flow reactor can be thought of as an elongated rectangular basin with a constant level in which advection (unidirectional transport) dominates (Figure F-2).

Although not used in the SDB and DPH watersheds due to their small size, the plug-flow reactor models were essential in testing of modeling assumptions in Bacteria TMDL Project I, and comparison to instream monitoring data. As a result, a general description of development of the plug flow reactor models is discussed to provide a basis for assessing the successful application of the approach for flow and bacteria density estimation in Bacteria TMDL Project I, and hence the acceptability of the simplified application of the approach for SDB and DPH.

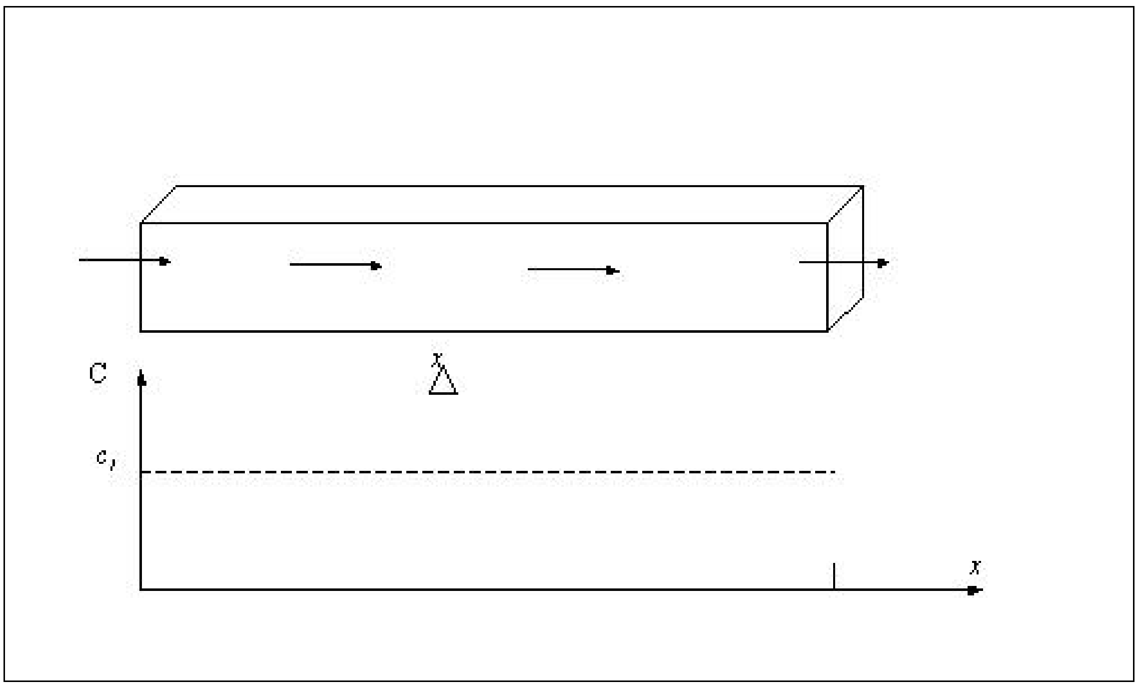

Figure F-2. Theoretical Plug-Flow Reactor

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 can be entered and multiple source contributions can be lumped and represented as a single input based on empirically derived inflows for 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.

F.2.1.1 Physical Representation

Before the model could be configured, an appropriate scale for analysis was determined. Model subwatersheds were delineated based primarily on topographic variability and storm water conveyance system networks. The subwatersheds, soil types, and stream lengths used in the dry weather model were identical to those described in the wet weather model (see Sections F.1.1 and F.1.2.2 for subwatershed descriptions and Appendix J for watershed maps).

F.2.1.2 Conceptual Representation

Using an upstream boundary condition of initial concentration (C_0) for inflow, the final water column concentration (C) in a segment can be calculated with the loss equation given below:

$$\frac{dc}{dt} = -kc \qquad \text{or} \qquad C_{out} = C_{in}e^{-kt} = C_{in}e^{-\left(k\frac{x}{u}\right)} \qquad (1)$$

where:

C_{in} = initial concentration (MPN/100ml)
C_{out} = final concentration (MPN/100ml)
k = loss rate (1/d)
χ = segment length (mi)
u = stream velocity (mi/d)

At each confluence, a mass balance of the watershed load and, if applicable, the load from the upstream tributary are performed to determine the change in concentration. This is represented by the following equation:

$$C_0 = \frac{Q_r C_r + Q_t C_t}{Q_r + Q_t} \qquad (2)$$

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 calculated from this equation is then used as the initial concentration (C_0) in the loss equation for the receiving segment.

For calculation of outflows from the reach, the following equation is used. Infiltration rates for the model were determined through model calibration and comparison to literature ranges (see Section F.2.2), and are dependent on stream length and width.

$$Q = Q_t + Q_r - I \qquad (3)$$

where:

I = infiltration (ft^3/s)

Precise channel geometry data were not available for the modeled stream segments; therefore, stream dimensions were estimated from analysis of observed data. For Bacteria TMDL Project I, analyses were performed on flow data and associated stream dimension data from 53 USGS gages throughout southern California. For this analysis, it was assumed that all flow less than 15 cubic feet per second (ft^3/s) represented dry weather flow conditions. Using these dry weather 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:

$$A = e^{0.2253 \times Q} \qquad (4)$$

where:

A = cross-sectional area (ft^2)
Q = flow (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:

$$ln(W) = (0.6296 \times ln(A)) + 1.3003 \quad \text{or} \quad W = e^{((0.6296 \times LN(A)) + 1.3003)} \qquad (5)$$

where:

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

F.2.2 Estimation of Dry Weather Runoff

Dry weather runoff flow data were not available for any of the SDB or DPH shoreline watersheds. To overcome this data limitation, flow parameters from the regionally calibrated dry weather watershed model for Bacteria TMDL Project I TMDLs was utilized. The remainder of this section describes the methodology used to predict flow for the Bacteria TMDL Project I model (San Diego Water Board, 2007).

An analysis was performed using dry weather data from the Aliso Creek (27 stations), Rose Creek (3 stations) and Tecolote Creek (2 stations) watersheds to determine whether there is a correlation between the respective land use types and the average of dry weather flow measurements collected at the mouth of each subwatershed.
Table F-3 lists the stations and number of flow measurements used in this analysis.

Table F-3. Number of Flow Measurements at Each Station Used in Analyses

Watershed	Station	No. of Flow of Measurements
Aliso Creek	J01P08	35
	J01P06	21
	J07P02	40
	J07P01	38
	J01P01	40
	J01P05	39
	J01P03	40
	J01P04	40
	J06	15
	J05	39
	J01P30	39
	J01P28	39
	J01P27	40
	J01P33	40
	J01P25	40
	J01P26	40
	J01P24	35
	J01P23	40
	J01P22	39
	J03P02	39
	J01P21	32
	J02P05	39
	J02P08	40
	J03P13	38
	J03P05	40
	J03P01	39
	J04	6
Rose Creek	MBW11	7
	MBW13	80
	MBW16	76
Tecolote Creek	MBW7	23
	MBW9	77

Selection of stations used in the analyses considered the number of flow measurements, the size of the watershed, as well as strategic locations of multiple watersheds representative of varied land uses. A linear relationship was established based on land use areas, with coefficients established through a *step-wise* multivariable regression analyses. For this regression, variables (land use areas) were added to the regression in a step-wise approach, and *p*-values were evaluated for each parameter. A *p*-value of less than 0.05 for each variable was used to determine their statistical significance. Some variables added at an early state of the regression analysis became statistically insignificant as additional variables were subsequently added to the model, which verified the necessity for a robust *step-wise* regression analyses over other more simplified methods. The resulting equation showed a good correlation between the flow and the commercial/institutional, open space and industrial/transportation land uses

(R^2 = 0.78). The following is the resulting equation from the analysis (p-values for each variable are listed below):

$$Q = (A_{COM} \times 0.00168) + (A_{OPS} \times 0.000256) - (A_{IND} \times 0.00141) \quad (6)$$

where:

Q = flow (ft^3/s)
A_{COM} = area of commercial/institutional (acres) (p-value = 6E-13)
A_{OPS} = area of open space, including military operations (acres) (p-value= 0.029)
A_{IND} = area of industrial/transportation (acres) (p-value = 0.002)

The empirical equation presented above that represents water quantity associated with dry weather runoff from various land uses can be used to predict flows. Figure F-3 shows the flow predicted by the above equation compared to observed data for Aliso Creek, Rose Creek, and Tecolote Creek.

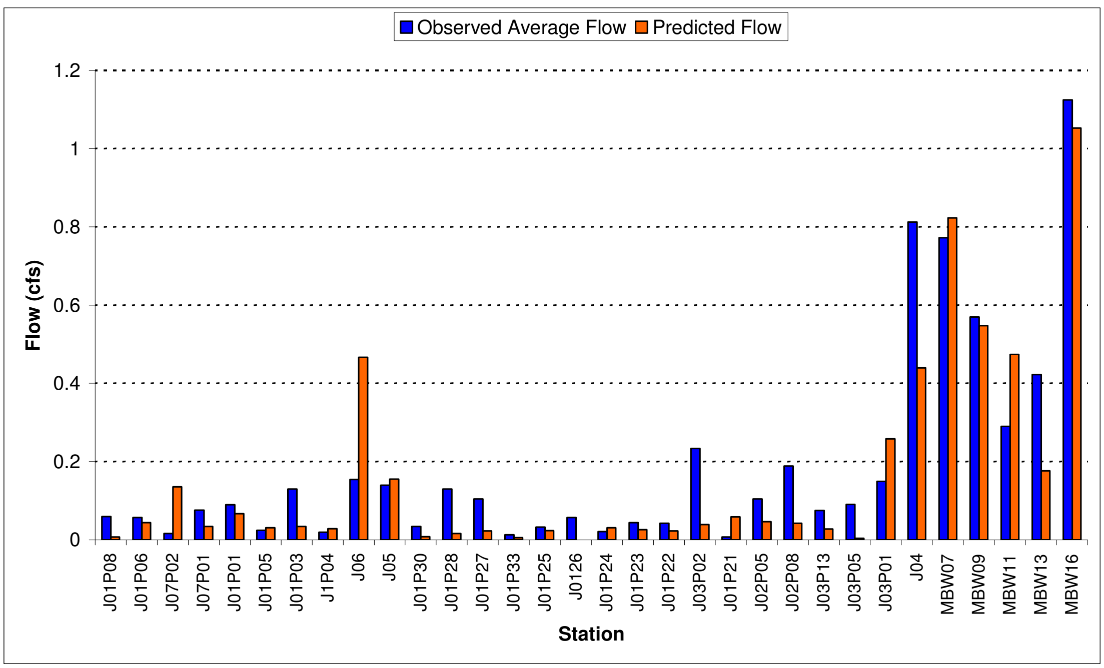

Figure F-3. Predicted and Observed Flows in Aliso Creek, Rose Creek, and Tecolote Creek

Overall, the statistical relationship established between each land use area and flow showed good correlation with the observed flow data. To improve model fit in Bacteria TMDL Project I, model calibration and validation were conducted based on the plug-flow reactor assumptions (see Section F.2.4). The equation presented above was used to estimate inflows from the SDB and DPH shoreline watersheds as part of this current TMDL project.

F.2.3 Estimation of Bacteria Densities

Like dry weather runoff flow data, no bacteria water quality data were available for the SDB and DPH shoreline watersheds. To overcome this data limitation, water quality parameters from the regionally-calibrated dry weather model for Bacteria TMDL Project I were utilized. The remainder of this section describes the methodology used to predict bacteria densities for the Bacteria TMDL Project I dry weather watershed model (San Diego Water Board, 2007).

An analysis was performed using data from subwatersheds tributary to Aliso Creek (27 stations), Tecolote Creek (5 stations), Rose Creek (4 stations) and San Juan Creek (9 stations) to determine the correlation between dry weather FC concentrations, land use distribution and the overall size of the subwatersheds. For comparison, geometric means were calculated for each station using all dry weather data collected. Large data sets were preferred to reduce random error and normalize observations at each site. For example, if a station has 40 dry weather samples, the geometric mean of bacteria concentrations can be used for that station with confidence that they are representative of the range of conditions that normally occur. Likewise, if a station has only two samples, there is less confidence. It was critical that the data were normalized as well as possible before regression analysis so that variability did not propagate error. However, no criteria were developed for selection of stations based on the number of samples for representative geometric mean calculations. Rather, station selection included qualitative evaluation for consideration in the analyses. Specific stations of Rose Creek, Tecolote Creek, and San Juan Creek were selected for analyses even though few samples were available at these locations for geometric mean calculations. These stations were selected based on multiple reasons, including the relatively low indicator bacteria concentrations observed, strategic locations of watersheds to provide an expanded spatial coverage for analyses, size of the watershed, or representation of key land uses.

Table F-4. Number of Water Quality Samples at Each Station Used in Analyses

Watershed	Station	Number of Samples FC	TC	ENT
Aliso Creek	J01P08	40	40	40
	J01P06	39	39	39
	J07P02	40	40	40
	J07P01	40	40	40
	J01P01	40	40	40
	J01P05	40	40	40
	J01P03	40	40	40
	J01P04	40	40	40
	J06	40	40	40
	J05	40	40	40
	J01P30	40	40	40
	J01P28	40	40	40
	J01P27	40	40	40
	J01P33	40	40	40
	J01P25	40	40	40
	J01P26	40	40	40
	J01P24	40	40	40
	J01P23	40	40	40
	J01P22	40	40	40
	J03P02	40	40	40
	J01P21	33	33	33
	J02P05	40	40	40
	J02P08	40	40	40
	J03P13	40	40	40
	J03P05	40	40	40
	J03P01	40	40	40
	J04	40	40	40
Rose Creek	MBW13	55	80	60
	MBW15	22	78	26
	MBW16	18	76	21
	MBW24	3	7	3
Tecolote Creek	MBW6	5	70	8
	MBW7	6	23	11
	MBW8	5	27	15
	MBW9	20	77	25
	MBW10	40	88	54
San Juan Creek	SJ13	11	11	11
	SJ14	10	10	10
	SJ15	11	11	11
	SJ16	11	11	11
	SJ19	3	3	3
	SJ20	11	11	11
	SJ21	11	11	11
	SJ29	2	2	2
	SJ32	11	11	11

As part of the TMDL development for Bacteria TMDL Project I, a regression analysis was performed to determine whether there is correlation between the representative geometric mean of FC data at each station, the percent of each land use category in the subwatershed, and the total watershed area. Coefficients in the equation were established through a *step-wise* multivariable regression analyses. For this regression, variables (percent of land uses) were added to the regression in a step-wise approach, and *p*-values were evaluated for each parameter. Percentages of land uses were used instead of land use areas since concentrations are not expected to increase with the size of the watershed, but rather due to the density of specific land uses. To include a function for reduction of bacteria concentration due to watershed size and increased potential for bacteria die-off (prior to entering the stream), an additional variable was added for watershed area. A *p*-value of less than 0.05 for each variable was used to determine their statistical significance (although this criterion was relaxed for open recreation which slightly exceeded at 0.067). As with the flow analysis, some variables added at an early state of the regression analysis became statistically insignificant as additional variables were subsequently added to the model, verifying the need for a robust *step-wise* regression analyses over other more simplified methods.

Results showed a good correlation between the natural log of FC concentrations and low-density residential, high-density residential, industrial/transportation, open space, transitional, commercial/institutional, and recreation land uses, as well as subwatershed size (R^2=0.74). The following regression equation describes the correlation between land use, fecal coliform concentration, and watershed area. Figure F-4 illustrates the observed geometric means and predicted concentrations at each sampling station.

$$ln(FC) = 8.48 \times (\%LU_{LDR}) + 9.81 \times (\%LU_{HDR}) + 8.30 \times (\%LU_{IND}) + 8.46 \times (\%LU_{OPS}) + 10.76 \times (\%LU_{TRN}) + 6.60 \times (\%LU_{COM}) + 17.92 \times (\%LU_{PRK}) + 12.85 \times (\%LU_{OPR}) - 0.000245 \times A \quad (7)$$

where: FC = fecal coliform concentration (MPN/100 ml)
$\%LU_{LDR}$ = percent of low density residential (p-value = 8E-16)
$\%LU_{HDR}$ = percent of high density residential (p-value = 7E-15)
$\%LU_{IND}$ = percent of industrial/transportation (p-value = 0.005)
$\%LU_{OPS}$ = percent of open space, including military operations (p-value = 7E-24)
$\%LU_{TRN}$ = percent of transitional space (p-value = 1E-19)
$\%LU_{COM}$ = percent of commercial/institutional (p-value = 4E-9)
$\%LU_{PRK}$ = percent of park/recreation (p-value = 0.009)
$\%LU_{OPR}$ = percent of open recreation (p-value = 0.067)
A = total area of watershed (acres) (p-value = 1E-7)

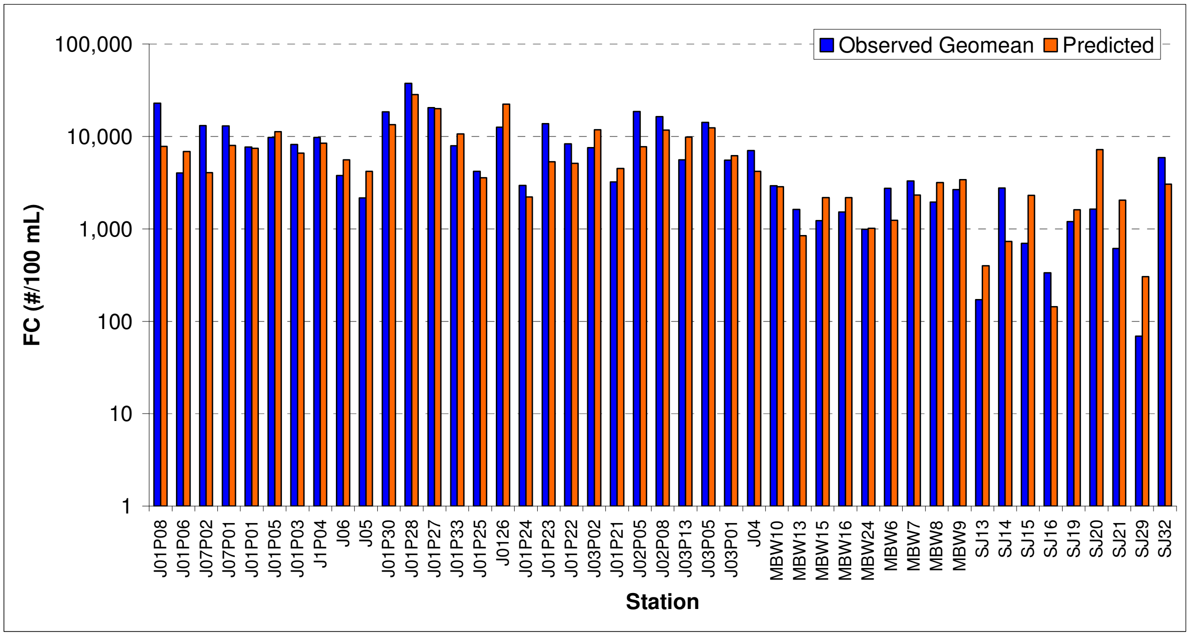

Figure F-4. Predicted Versus Observed Fecal Coliform Concentrations

The methodology for estimating FC concentrations was not as successful for prediction of TC and ENT. For Bacteria TMDL Project I, similar regression analyses were performed to determine whether there were relationships between TC and ENT and land use and subwatershed size, but no acceptable correlations were found. As a result, a separate approach was used for estimating TC and ENT concentrations in dry weather runoff for each watershed.

Analyses of geometric means of FC data collected at each station were performed on similar geometric means of TC and ENT data collected at the same stations. The analyses resulted in a single, normalized value of FC, TC, and ENT at each station. Regression analyses were performed to determine whether there is a correlation between FC and levels of TC and ENT. Results showed a good correlation in predicting TC and ENT as a function of FC (R^2=0.67 and R^2=0.77, respectively). The following equations describe the relationship observed between FC and TC/ENT (units of FC and TC/ENT are consistent):

$$TC = 5.0324 \times FC \quad \text{and} \quad ENT = 0.8466 \times FC \qquad (8)$$

Figures F-5 and F-6 illustrate the observed geometric means and predicted concentrations for TC and ENT, respectively. The TMDL equations for TC, FC, and ENT from Bacteria TMDL Project I were applied to the SDB and DPH shoreline watersheds to estimate bacteria densities impacting the impaired shoreline segments.

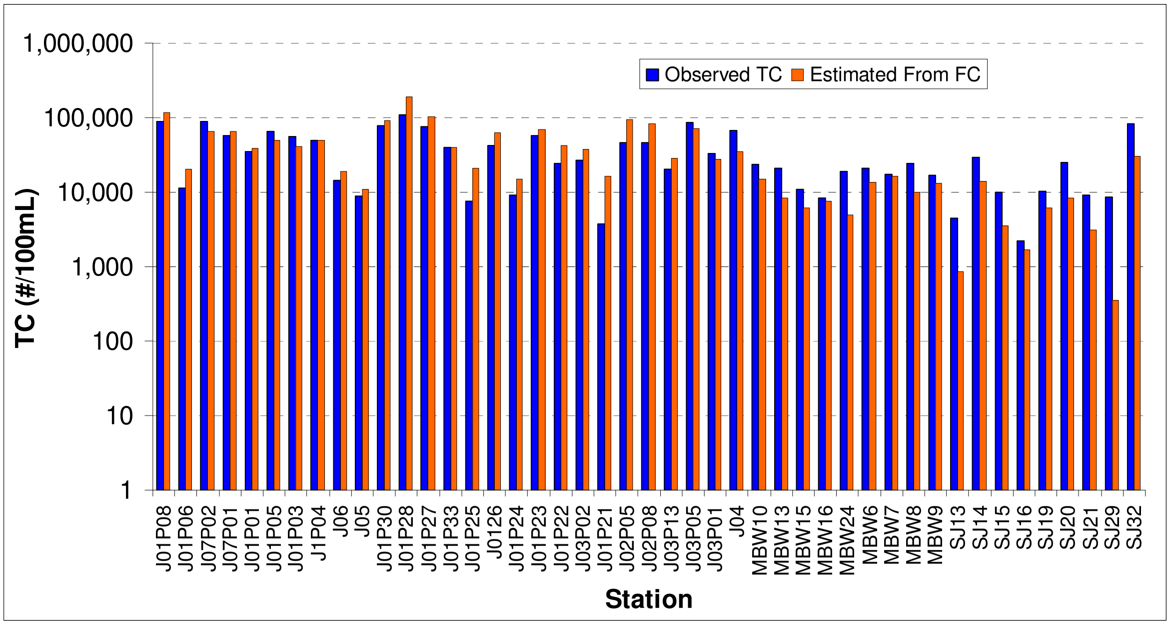

Figure F-5. Predicted Versus Observed Total Coliform Concentrations

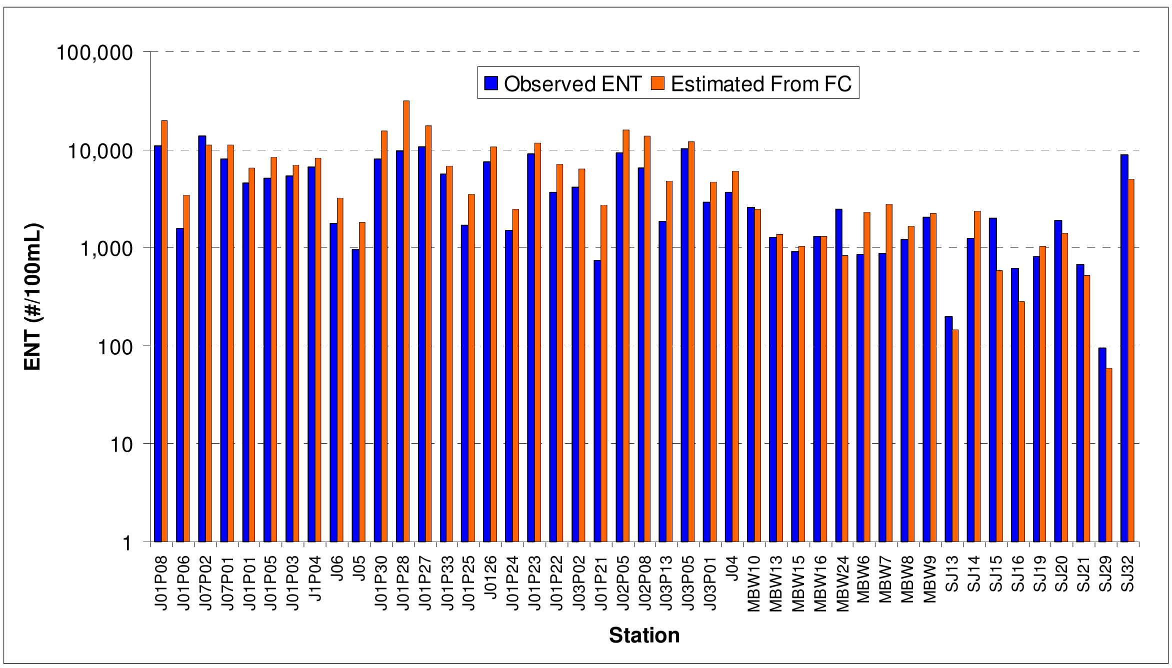

Figure F-6. Predicted Versus Observed Enterococci Concentrations

F.2.4 Dry Weather Watershed Model Calibration and Validation

During the development of TMDLs for Bacteria TMDL Project I, calibration of the plug-flow reactor model 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.

Model assumptions for stream reach infiltration and bacterial die-off rates were derived through calibration based on data collected within reaches of Aliso Creek (11 stations) and Rose Creek (6 stations). Some of these stations were also used for development of regression equations for prediction of flow and FC concentrations from watersheds, however, effects of infiltration or bacteria die-off that may be implicitly incorporated in the regression equations (e.g., negative correlation of bacteria concentration to watershed size suggests effects of bacteria die-off in equation 7) were not considered duplicated in the reach assumptions. Model configuration of multiple subwatersheds and reaches differed from single representative watersheds used in regression analyses, and required incorporation of assumptions for reach infiltration and bacterial die-off to account for losses occurring during transport. Each model subwatershed used the regression equations to estimate flow and bacterial concentration that were routed through a network of stream reaches that ultimately met locations corresponding to monitoring stations used for calibration. However, watersheds used for regression analyses represented a single watershed for the same area, with no stream routing. Hence, the infiltration and die-off rates developed for the reaches were not consistent with errors associated with regression equations applied to the entire watershed without reach routing and losses considered. To further prove the independence of the calibration procedure from the regression analyses, data from five additional instream monitoring stations that were not used for regression analyses were also used for calibration. Model validation included nine additional stations not included in the regression analyses.

The calibration was completed by adjusting infiltration rates to reflect observed in-stream flow conditions and adjusting bacteria die-off rates to reflect observed in-stream bacteria concentrations. Following model calibration to in-stream flow and bacteria concentrations, a separate validation process was undertaken to verify the predictive capability of the model in other watersheds. Table F-5 lists the sampling locations used in calibration and validation, along with their corresponding watersheds.

Table F-5. Calibration and Validation Sampling Locations

Calibration – Flow and Bacteria		Validation – Flow		Validation – Bacteria	
Watershed	**Sampling Location**	**Watershed**	**Sampling Location**	**Watershed**	**Sampling Location**
208	J01P22	403	USGS11047300	402	SJ04
209	J01P23	1701	MBW06	403	SJ05
210	J01P28	1702	MBW07	405	SJ18
211	J01P27	1703	MBW10	406	SJ24
212	J06	1704	MBW08	408	SJ1
213	J01P05	1705	MBW09	409	SJ29 & SJ17
214	J01P01			411	SJ06
215	J01TBN8			413	SJ08 & SJ07
219	J04			414	SJ30 & SJ09
220	J03P13			416	SJ15
221	J03P01			1701	MBW06
1601	MBW20			1702	MBW07
1602	MBW17			1703	MBW10
1603	MBW15			1704	MBW08
1605	MBW11			1705	MBW09
1606	MBW13				
1607	MBW24				

F.2.4.1 Dry Weather Watershed Hydrology Model Calibration and Validation

Infiltration rates vary by soil type and, as described in Section F.2.1, the dry weather watershed 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. The goal of calibration was to minimize the difference between average observed flow and modeled flow at each calibration station location. The model closely predicted observed flows and the calibration results are graphically presented in Figure F-7.

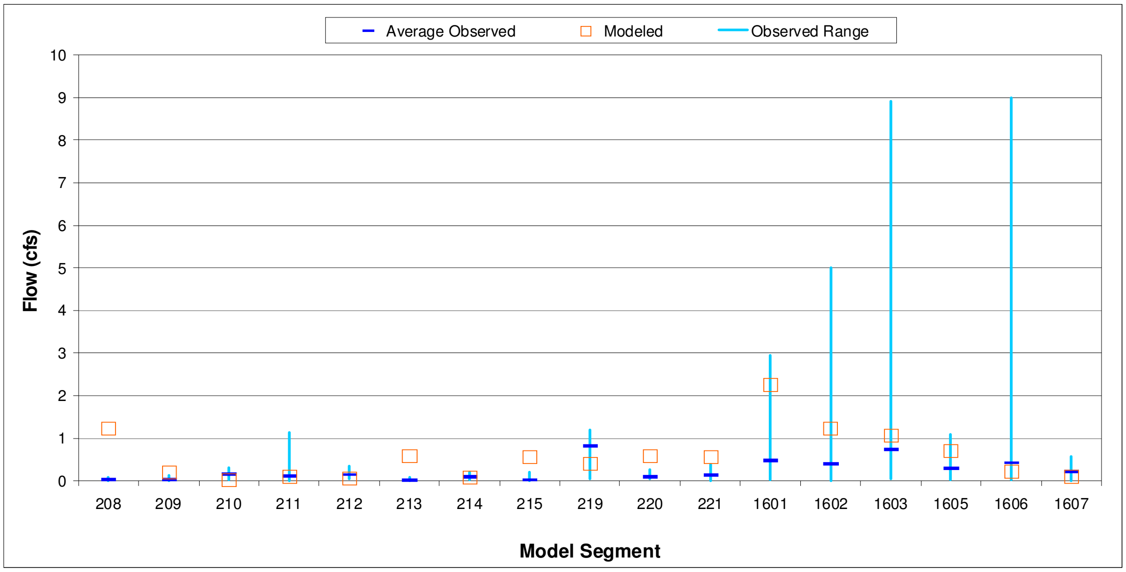

Figure F-7. Calibration Results of Modeled Versus Observed Flow

The calibrated infiltration rates were 1.368 inches per hour (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 (Wanielisata et al., 1997). 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 modeled watersheds, which is dominated by Soil Group C.

Subsequent to the model calibration, the model was validated using six stations in the San Juan Creek and Tecolote Creek watersheds. The model-predicted flows were within the observed ranges of dry weather flows (Figure F-8), demonstrating very good overall model fit.

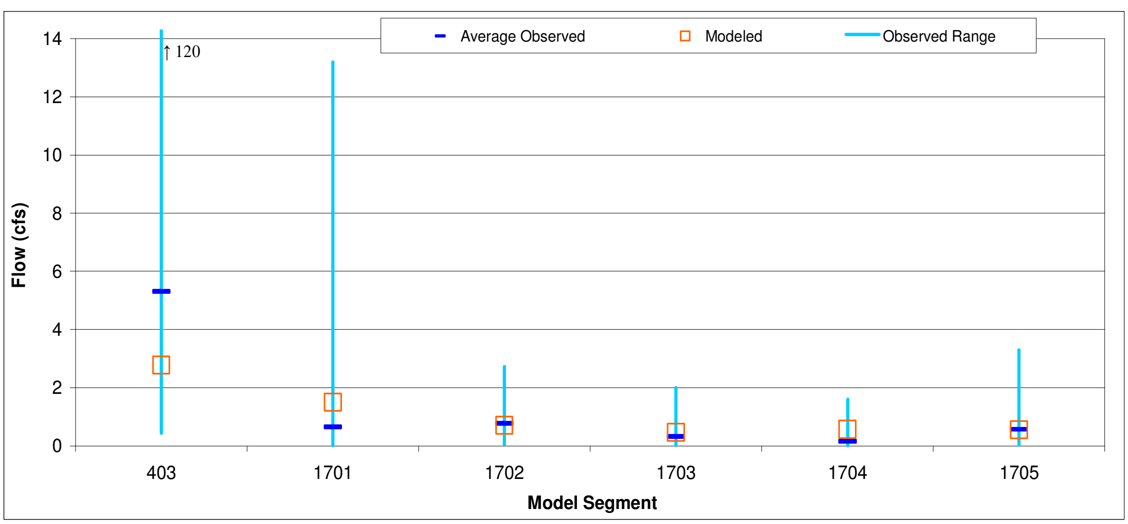

Figure F-8. Validation Results of Modeled Versus Observed Flow

F.2.4.2 Dry Weather Watershed Bacteria Model Calibration and Validation

The modeled first-order die-off rate reflects the net effect on bacteria of various environmental conditions, such as solar radiation, temperature, dissolved oxygen, nutrients, regrowth, deposition, resuspension, and toxins in the water. The die-off rates for TC, FC, and ENT were used as calibration parameters to minimize the difference between observed in-stream bacteria levels and dry weather watershed model predictions. Calibration results for TC, FC, and ENT are presented in Figures F-9 through F-11. Die-off rates were determined TC (0.209 1/d), FC (0.137 1/d), and ENT (0.145 1/d). These values are within the range of die-off rates used in various modeling studies as reported by USEPA (1985). Sixteen stations were used in calibrating die-off rates for Bacteria TMDL Project I.

Model validation to in-stream water quality was conducted using 15 stations on Tecolote Creek and San Juan Creek. The results of the water quality dry weather watershed model validation for Bacteria TMDL Project I are presented in Figures F-12 though F-14.

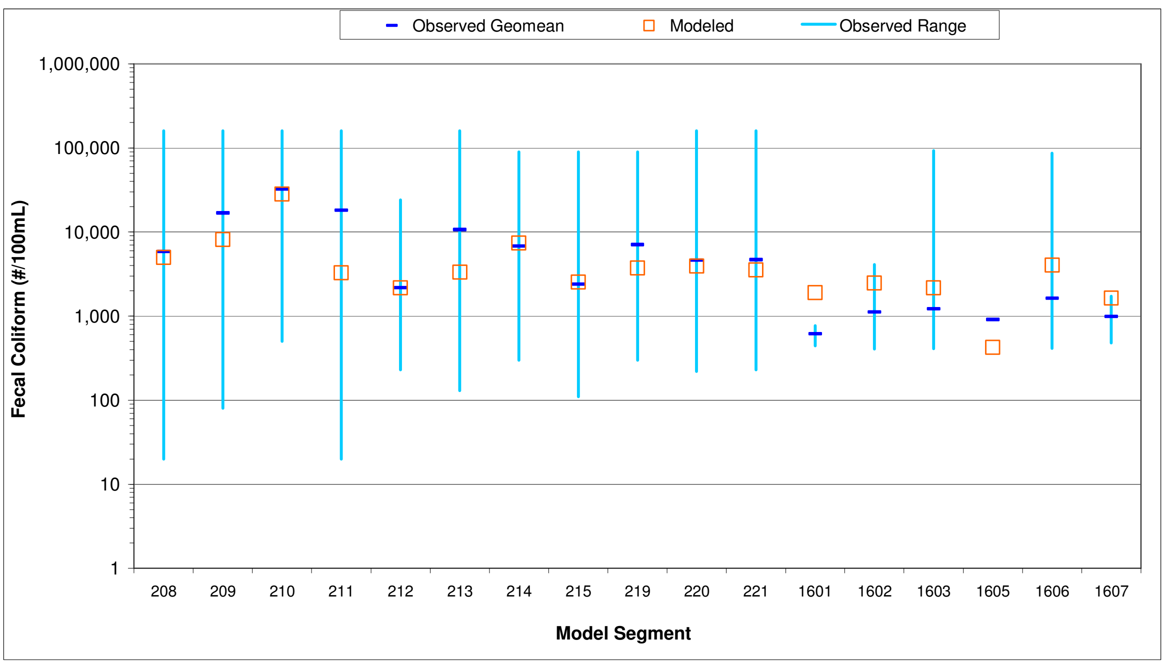

Figure F-9. Calibration Modeled Versus Observed In-Stream Fecal Coliform Concentrations

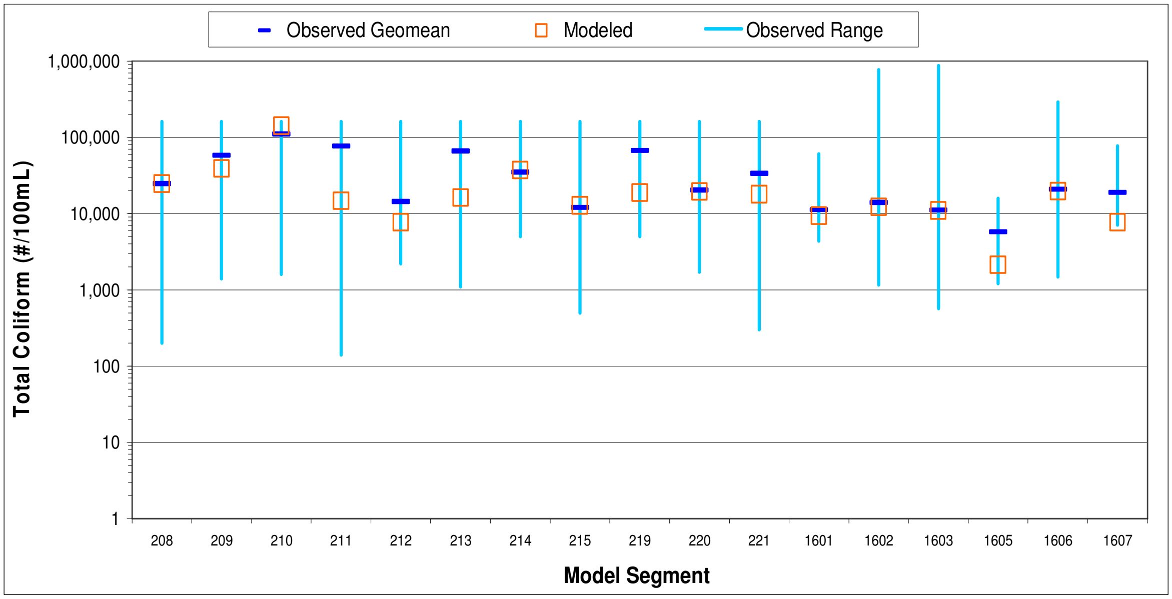

Figure F-10. Calibration Modeled Versus Observed In-Stream Total Coliform Concentrations

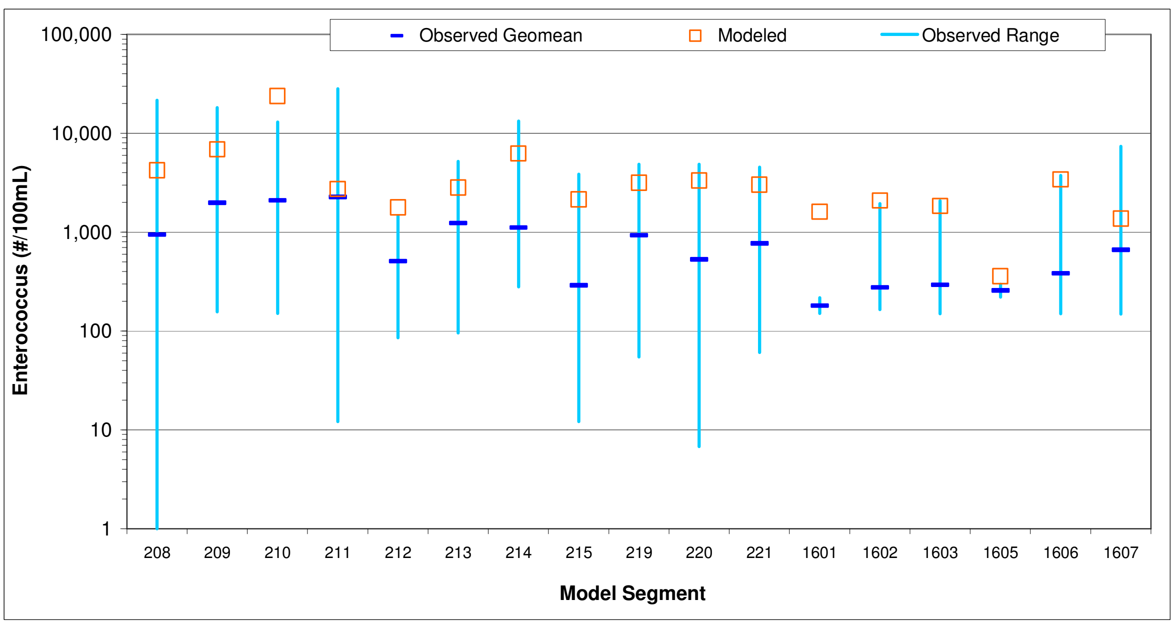

Figure F-11. Calibration Modeled Versus Observed In-Stream Enterococci Concentrations

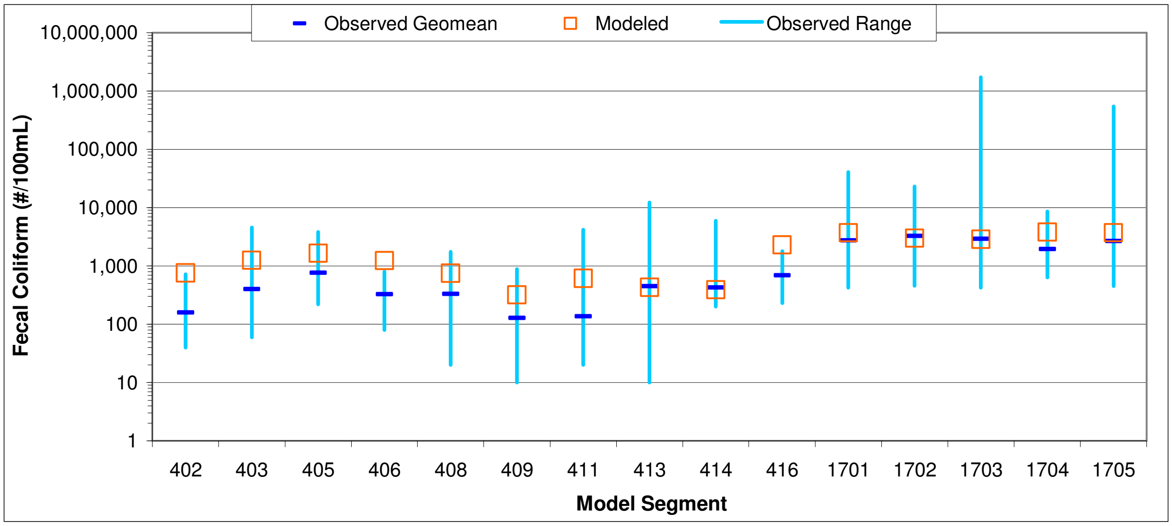

Figure F-12. Validation Modeled Versus Observed In-Stream Fecal Coliform Concentrations

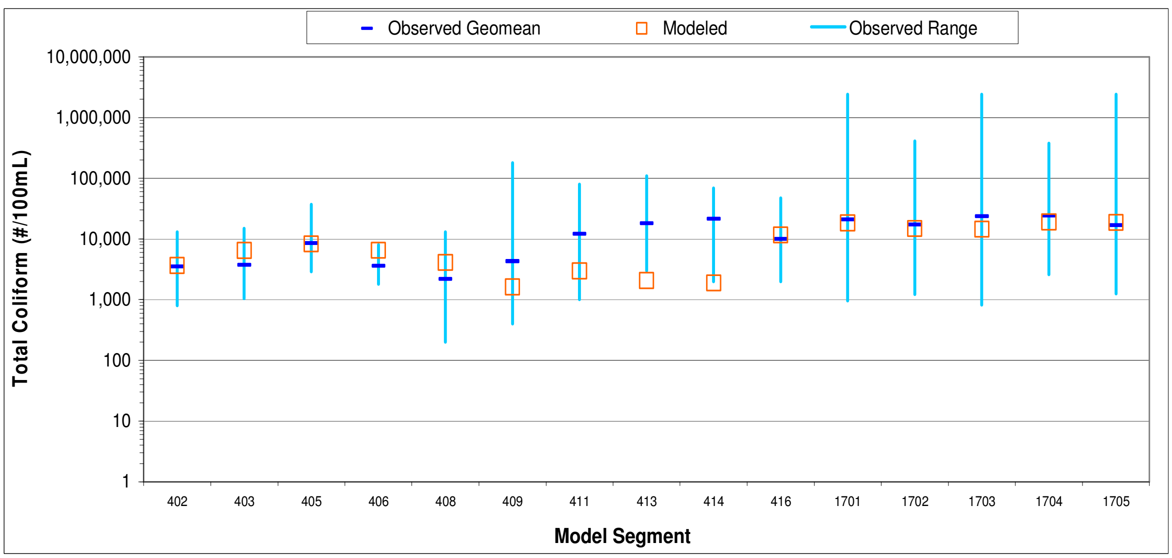

Figure F-13. Validation Modeled Versus Observed In-Stream Total Coliform Concentrations

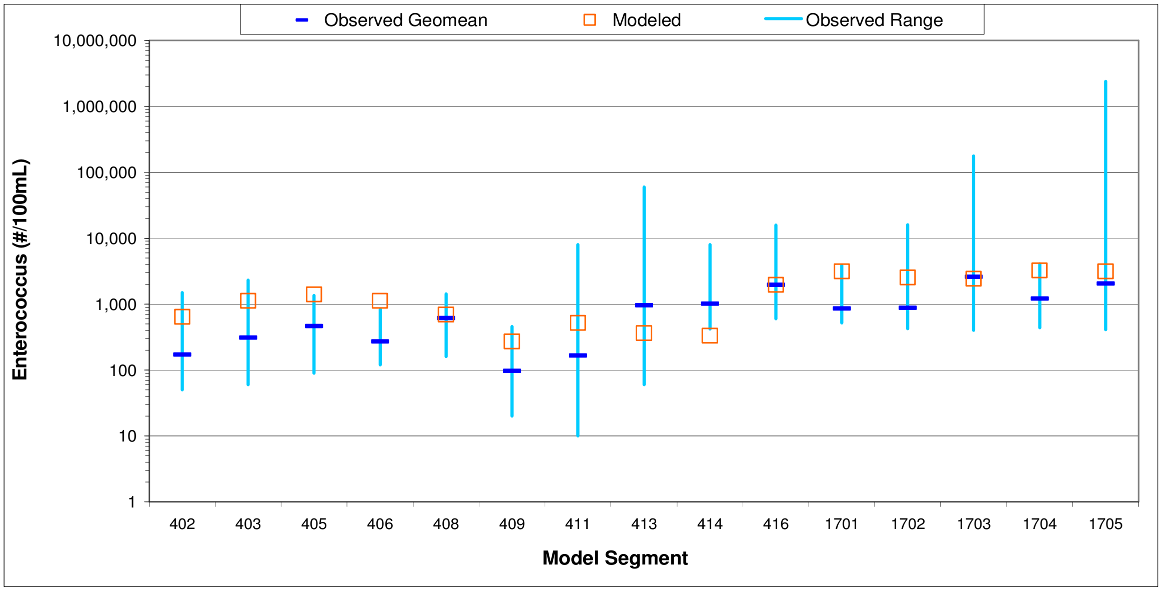

Figure F-14. Validation Modeled Versus Observed In-Stream Enterococci Concentrations

F.2.4.3 Dry Weather Watershed Model Application to San Diego Bay and Dana Point Harbor Watersheds

As described previously, regionally-calibrated parameters and equations were applied to the SDB and DPH shoreline watersheds. However, each of the watersheds draining to the shoreline areas consisted of a single watershed without multiple subwatersheds included for routing purposes (see Appendix J). Only single watersheds were considered necessary for modeling due to the small size of the drainage areas. As a result, only equations 6, 7, and 8 were used in estimating dry weather flows and bacterial densities from these watersheds. The plug-flow reactor models were not required for routing of associated bacterial loads from these areas, as they discharge directly to the shorelines.

Further validation could not be conducted for flow or bacteria due to lack of dry weather monitoring data in the watersheds of interest. The application of the dry weather watershed model and its role in calculation of the SDB and DPH shoreline TMDLs is discussed in Section F.4.

F.3 Wet and Dry Weather Receiving Water Model– EFDC

A hydrodynamic and bacteria transport model was developed to simulate the water budget and the fate and transport of bacteria to the receiving waters of the impaired shoreline segments in SDB and DPH. The computational framework of the receiving water models are based on the EFDC model, a comprehensive three-dimensional model capable of simulating hydrodynamics, salinity, temperature, suspended sediment, water quality, and the fate of toxic metals. The EFDC model is a widely accepted model (particularly by USEPA) and is capable of simulating 21 water quality parameters, including dissolved oxygen, suspended algae, various components of carbon, nitrogen, phosphorous, and bacteria.

San Diego Bay

The shoreline segment located at Shelter Island Shoreline Park within SDB was included in this receiving water analysis for indicator bacteria. Bacteria usually show strong local source-concentration response patterns (i.e., the concentration of bacteria in a specific location is usually directly caused by sources discharged nearby). Therefore, very high spatial resolution is necessary to accurately represent the source-concentration link.

Although the entire San Diego Bay can be simulated with a sufficiently fine grid to achieve the necessary resolution for each of the shoreline segment areas, a model configured with that level of detail could incur prohibitive computational time. To overcome this limitation, a two-stage approach was adopted, which achieves sufficient resolution for the shoreline segment areas with reasonable computational times. The first stage involved developing a coarse grid, vertically-integrated, two-dimensional hydrodynamic model to simulate water circulation and water elevation fluctuation throughout the bay. The objective of this coarse grid model was to provide open boundary conditions for the fine grid model of the impaired shoreline segment area. The second stage involved developing a separate fine grid model for the impaired shoreline segment of Shelter Island Shoreline Park (see Appendix J for maps). The high-resolution grid was better able to capture the intricate shoreline features of the impaired shoreline segment and near-field variability, which is critical for representing the bacteria source-concentration relationship.

The EFDC model application of Shelter Island Shoreline Park simulated both hydrodynamics and TC, FC, and ENT bacteria densities. The Shelter Island Shoreline Park fine grid model was used to identify potential sources causing the bacteria fluctuations in the observed data.

Dana Point Harbor

The shoreline segment located at Baby Beach within DPH shoreline was included in this receiving water analysis for indicator bacteria. The entire harbor was simulated with a sufficiently fine grid to achieve the necessary resolution at Baby Beach (see Appendix J for a map). The model of the entire harbor was configured to simulate hydrodynamics associated with tidal flushing and TC, FC, and ENT bacteria densities.

Model Configuration

Configuration of the EFDC models for SDB and DPH (sections F.3.1 and F.3.2 and section F.3.3, respectively) involved identifying and processing bathymetric data, developing model grids, defining boundary and initial conditions, and creating a linkage with the wet weather (LSPC) and dry weather (steady-state) watershed models using lateral inputs. Boundary conditions are fixed conditions applied to the modeling system to drive the hydrodynamic simulation. Three types of boundary conditions were applied to the models: open ocean, lateral flux, and meteorological.

Open ocean boundary conditions consist of time-variable tidal water levels, temperature, and salinity. The lateral flux boundary conditions include the wet weather and dry weather inflow of water from the watershed. The wet weather watershed flows were configured based on the results of the calibrated LSPC watershed model (section F.1). Constant dry weather watershed flows were estimated from the steady-state dry weather watershed model (section F.2), developed and calibrated for Bacteria TMDL Project I. The spatial representation of these inflow boundary conditions was determined by mapping the geographical coordinates of the watershed outlets on the individual model grids. The meteorological boundary condition is represented by time-variable weather conditions including solar radiation, wind speed and direction, air temperature, atmospheric pressure, relative humidity, and cloud cover.

For water quality simulations, bacteria loads associated with the watershed flows were also input as a lateral boundary condition. Time-variable wet weather and constant dry weather concentrations were used to develop the bacteria loading time-series for each watershed inflow location. In addition to the watershed loading, a lumped source of bacteria loading was incorporated into the models. This lumped source characterized all other unquantifiable sources, including the aerial contribution from waterfowl, accumulated waterfowl feces on beaches, and/or other unidentified sources within the receiving waters.

In hydrodynamic modeling, initial conditions provide a starting point for the model to progress through time. Initial temperature, salinity, flow velocity, and water depth values were specified for the entire domain of each model. These data, especially for temperature and salinity, were limited within the bays. Therefore, in the absence of data, reasonable assumptions or extrapolations of data were made.

January 1, 2001 through December 31, 2002 was selected as the model simulation time period. This period corresponds to the two years in which the most comprehensive data were available for model configuration and comparison. It should be noted that for simulation over a long time period, such as over a year or multiple years (as was the case for this simulation), the overall model performance is not sensitive to the initial conditions for velocity and temperature. The remainder of this section provides additional details regarding the configuration and application of the EFDC models of SDB (sections F.3.1 and F.3.2) and DPH (section F.3.3).

F.3.1 Coarse Grid Receiving Water Model for the San Diego Bay

F.3.1.1 Grid Generation

The model domain for SDB includes the entire bay up to the mouth, which encompasses an area of approximately 50 square kilometers. The model is comprised of 138 computation cells (Figure F-15). The maximum and minimum cell widths (I direction) are 354 meters and 1311 meters, respectively, and the maximum and minimum cell lengths (J direction) are 288 meters and 762 meters, respectively. The grid has dimensions of I=35, J=15 in the horizontal plane and consists of a single layer in the vertical plane.

Bathymetry for the model domain was based on data obtained from from Space and Naval Warfare Systems (SPAWAR). The average depth for the course grid was 7 meters (minimum was 6 meters and maximum was 8 meters).

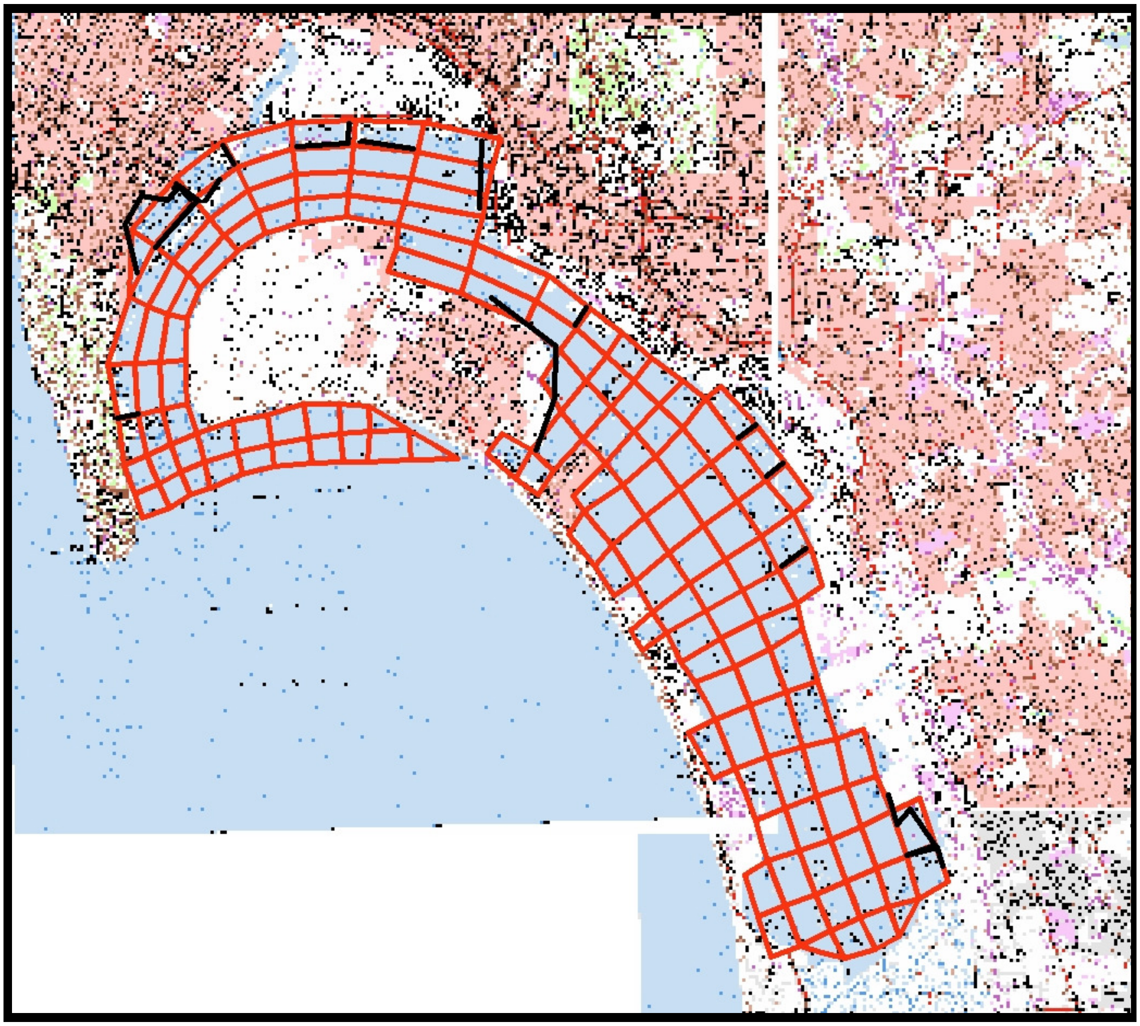

Figure F-15. Coarse Resolution Grid for San Diego Bay

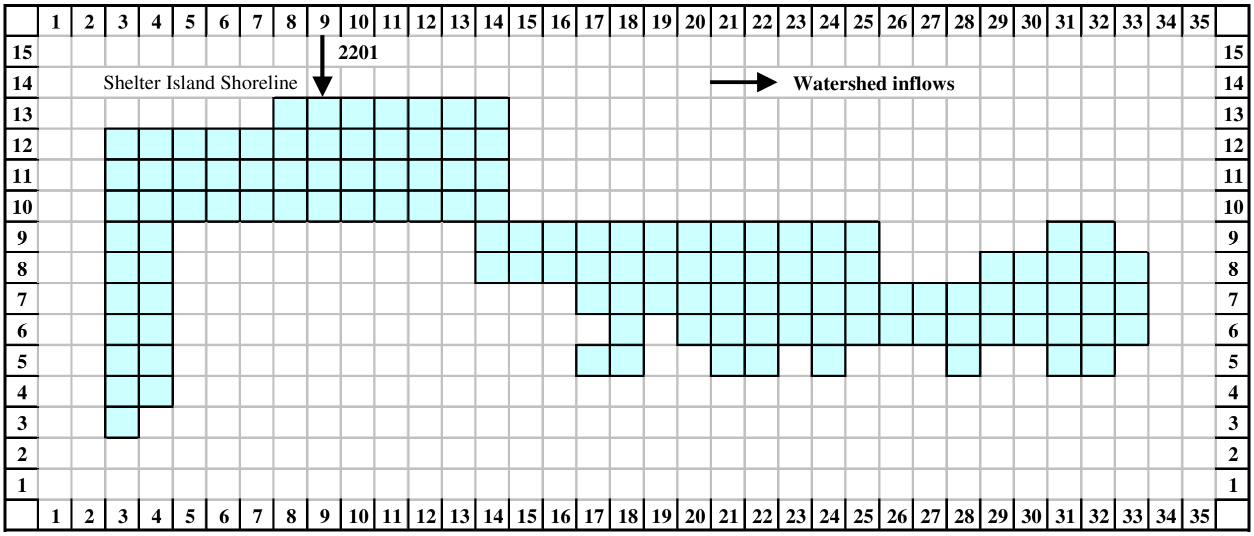

Figure F-16. Open Ocean and Lateral Boundary Locations for San Diego Bay Model

F.3.1.2 Boundary Conditions

F.3.1.2.1 Open ocean boundary conditions

The mouth of SDB opens to the Pacific Ocean. Ten grids in the model (Figure F-16) were configured as the open ocean boundary and were assigned time-variable water levels, temperature, and salinity. Real-time hourly water level data was available from the National Oceanic and Atmospheric Administration Centers for Operational Oceanographic Products and Services (NOAA-COOPS) for station #9410230, located in La Jolla, CA. Data were processed and an EFDC-compatible tidal time series dataset was created.

Two Scripps Institution of Oceanography stations with continuous surface temperature observations were utilized to obtain temperature for the open ocean boundary. The closest station to SDB is station #091, located 8.5 miles west of Point Loma. However, this station is a seasonal buoy and is operated from approximately February to August of each year. Station #095, located 3.8 miles west of La Jolla, operates year-round. Temperature data from these two stations were compared for 180 overlapping days in 2001. The comparison resulted in good correlation between the two stations with an R^2 = 0.92. Therefore, temperature data from La Jolla (station #095) were selected to build the time series at the open ocean boundary. Initially, the hourly data at La Jolla was directly used as the boundary condition. However, this caused model instability at certain times during the simulation period. The suspected cause of this instability is a short-term signal in the time series. Because the temperature at La Jolla is not exactly the same as the mouth of the bay, hourly data were averaged to daily values. This filtered out the impact of any short period temperature signals that may not be representative of conditions at the mouth.

A station operated by the Port of San Diego and located within SDB provided salinity data for the open ocean boundary. Continuous salinity observations were available from March 7, 2001 to December 13, 2001 and January 13, 2002 to February 7, 2002. The January to February 2002 data were used to fill the data gap in 2001 and the March to December 2001 data were used to fill the data gap in 2002. Although not comprehensive, the Port of San Diego data were the only available salinity data at the time the model was configured.

F.3.1.2.2 Lateral boundary conditions

Contributions from one subwatershed (2201) was included as a lateral boundary condition for SDB. Dynamic wet weather and steady-state dry weather flow rates from this subwatershed was applied to the corresponding inflow grid cells in the EFDC model. In total, the model has two lateral inflow boundary conditions (one for wet weather and one for dry weather watershed runoff).

Continuous surface temperature observations from NOAA station #9410170, located within the SDB shoreline, were used to specify the temperature for the watershed inflows. Although temperature of the bay waters can be different from the incoming tributary flows, temperature measurements for incoming streams were not available. Since watershed flows only account for a negligible portion of the total flow balance in the bay, the uncertainty associated with the inflow temperature values has minimal impact on the model results. In addition, salinity data for the inflows were not available and were thus set to zero. This is also expected to have a negligible impact on the model results because the inflows account for such a small portion of the volume of the bay.

F.3.1.2.3 Meteorological boundary conditions

Five airway stations in close proximity to SDB were evaluated for potential inclusion in the model. The stations were evaluated based on their proximity to the model domain, period of record, parameters measured, and completeness of data. Data for 1990 through 2004 were obtained from the National Climatic Data Center (NCDC). The results of the evaluation indicated that the Lindbergh Field Airway Station in San Diego was the most appropriate weather station and was thus used to create the meteorological file. This station had data for most of the required parameters, provided the most complete temporal data record, and is located in close proximity to SDB. Data for dry and wet bulb temperature, dew point temperature, relative humidity, wind speed, wind direction, sea level pressure, and sky conditions for 1990 to 2004 were obtained for the Lindbergh Field station. Sky condition was converted to "percent cloud cover" and solar radiation was estimated by calculating the clear sky solar radiation using latitude and longitude and adjusting the values based on the estimated cloud cover.

F.3.1.3 Initial Conditions

A uniform temperature of 15ºC and a salinity of 33 parts per thousand (ppt) were included as initial conditions throughout in the water column. This temperature was verified using data from Scripps Institution of Oceanography stations #091 and #095 and was determined reasonable considering that the models began on January 1st. The initial water velocity was set to 0.0 meters per second (m/s) and the initial water surface elevation was 0.0 meters above mean sea level.

F.3.1.4 Model Calibration and Validation

The hydrodynamic model of SDB was calibrated using observed surface elevation, temperature, and salinity data from within the bay. Specifically, the model-computed hourly water surface elevations were compared with hourly real-time data from NOAA-COOPS station #9410170, located within the SDB shoreline. Figure I-1 in Appendix I illustrates the model-data comparison for 2001. The model has captured the phase and amplitude of the data well. The mean error[1] for the model-computed hourly water surface elevation for 2001 is -0.008 meters. The root mean square error[2] is 0.1 meters.

The model-predicted hourly water column temperature was compared with hourly observations from NOAA-COOPS station #9410170. Figures I-2 and I-3 of Appendix I show the model-data comparison for 2001 and 2002, respectively. The model simulates the seasonal variation in temperature well. The mean error for the model-predicted hourly temperature for 2001 is 0.39ºC and the root mean square error is 1.03ºC.

Through a sampling effort conducted in the bay by Space and Naval Warfare Systems, salinity and temperature measurements were available for January 30, May 11, and September 19, 2001, and January 27 and May 14, 2002 (see Figure I-4 of Appendix I for a map of sampling locations). Figures I-5 through I-30 of Appendix I illustrate the results of the temperature calibration to the SPAWAR data, while Figures I-31 through I-56 of the same appendix illustrate the salinity calibration. Overall, the model predicts both salinity and temperature very well.

F.3.2 Fine Grid Receiving Water Model for Shelter Island Shoreline Park

F.3.2.1 Grid Generation

The fine resolution grid developed for the Shelter Island Shoreline Park shoreline segment extends 900 meters from Shelter Island across (in J direction) to the opposite side of the bay and spans a length (in I direction) of 1750 meters along SDB (Figure F-17). The grid has dimensions of I=11, J=9 in the horizontal plane and contains a single layers in the vertical plane. The model domain is represented by 35 computation cells. Bathymetry for the model was based on data obtained from SPAWAR. Cell depths throughout most of the fine grid were identical to those in the course grid: 7 meters (minimum was 6 meters and maximum was 8 meters). Very shallow depths were assigned to the grid cells directly along the impaired shoreline to more accurately represent the natural conditions.

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[1] *Mean error = Sum (model-data)/n*; *n*=number of model-data points
[2] Root Mean Square Error = square root [{Sum (model-data)^2}/n]

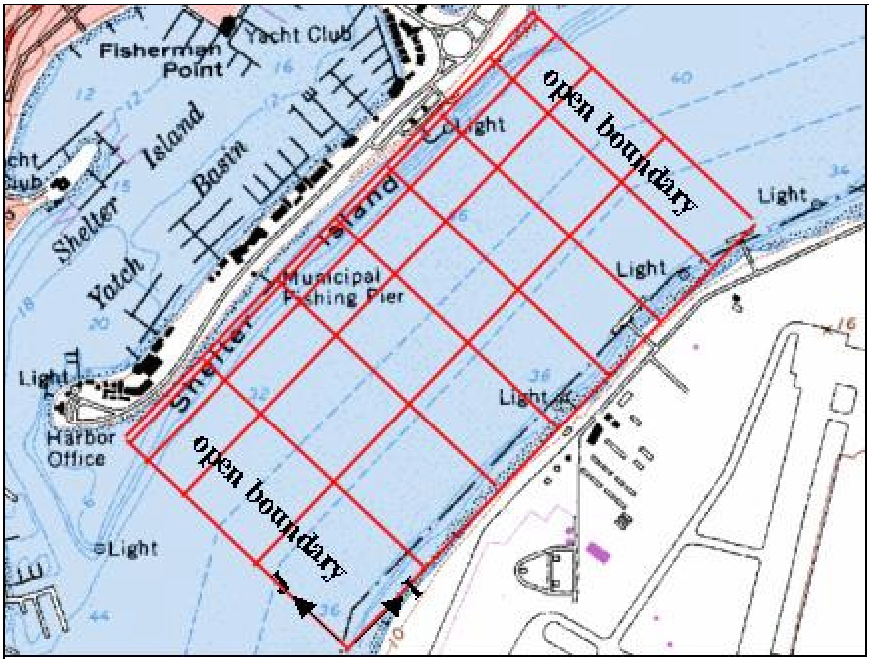

Figure F-17. Fine Resolution Grid for Shelter Island

F.3.2.2 Boundary Conditions

F.3.2.2.1 <u>Open ocean boundary conditions</u>

Two sides of the grid (see Figure F-17) were configured as the open boundary. These were assigned time-variable water levels, temperature, and salinity values. Predicted hourly water levels, daily temperature, and daily salinity from the calibrated coarse grid model were used to develop the open ocean boundary conditions. Predictions were extracted from the appropriate grids in the coarse grid model and then applied to the fine resolution open boundary grids. Available bacteria water quality data collected in the area had minimal TC, FC, and ENT bacteria densities (10 MPN/100ml, 10 MPN/100 ml, and 5 MPN/100 ml, respectively). Assuming that these values represent background bacteria densities from the other large-scale sources, they were incorporated in the model as the open ocean boundary conditions for TC, FC, and ENT.

F.3.2.2.2 <u>Lateral boundary conditions</u>

The contribution from subwatershed 2201was included in the Shelter Island Shoreline Park receiving water model as a lateral boundary condition. Time variable wet weather and constant dry weather flow rates and bacteria loads were applied to the corresponding inflow grid cells. The model had two lateral inflow boundary conditions (one for wet weather and one for dry weather watershed runoff). Bacteria loads were computed based on TC, FC, and ENT bacteria densities output from the wet and dry weather watershed models.

Continuous surface temperature observations from NOAA station #9410170 located within the SDB shoreline were used to specify temperature for the watershed inflows. Salinity of the inflow water was set to zero.

Initially the receiving water model was run only with the wet and dry weather watershed modeled bacteria loading sources. Available water quality data collected from the Shelter Island Shoreline Park shoreline segment indicated that bacteria levels varied significantly, both temporally and spatially. Comparing the initial receiving water model-predicted bacteria densities with observed data (see Figure F-18 for a map of locations with available water quality monitoring data), the results indicated that the wet weather and dry weather watershed sources do not account for the magnitude and variability of bacteria densities observed in this area. The difference in the magnitude of bacteria densities between the initial receiving water model output and observed bacteria levels suggests that additional unquantified sources, other than watershed inflows, may contribute significantly to bacteria loading along the shoreline. Therefore, in addition to the lateral bacteria loading from the wet and dry weather watershed models, an additional loading source was included for each of the fine resolution cells along the shoreline to represent other unquantified bacteria sources such as waterfowl, beach sediment sources, and other unidentified sources within the water. These unquantified sources were lumped together as "lumped sources" and included in the in the receiving water model to account for additional wet and dry weather sources that were not sufficiently captured by the traditional watershed sources.

Additionally, it was assumed that there was a corresponding temporal variability present to generate the observed bacteria density fluctuations. The lowest observed bacteria density was considered as the background bacteria density. The days on which the observed bacteria density was equal to the background bacteria density were considered as "*background days*". As an initial estimate, the TC and ENT bacteria loadings for *background days* were set to a base value. The base value was determined using the daily loading rate applied in a Malibu Creek Watershed Study (Los Angeles Water Board, 2003). The loading for days other than *background days*, was estimated by scaling the base values using the ratio between the observed bacteria density and the background density. Since the observed FC densities are similar to TC densities, the FC bacteria loading from the lumped sources was set to be equal to the TC bacteria loading from the lumped sources. These initial estimates were then systematically rescaled for the overall magnitude and fine-tuned for certain specific dates through an iterative modeling process to obtain predictions for bacteria densities closer to the observed patterns.

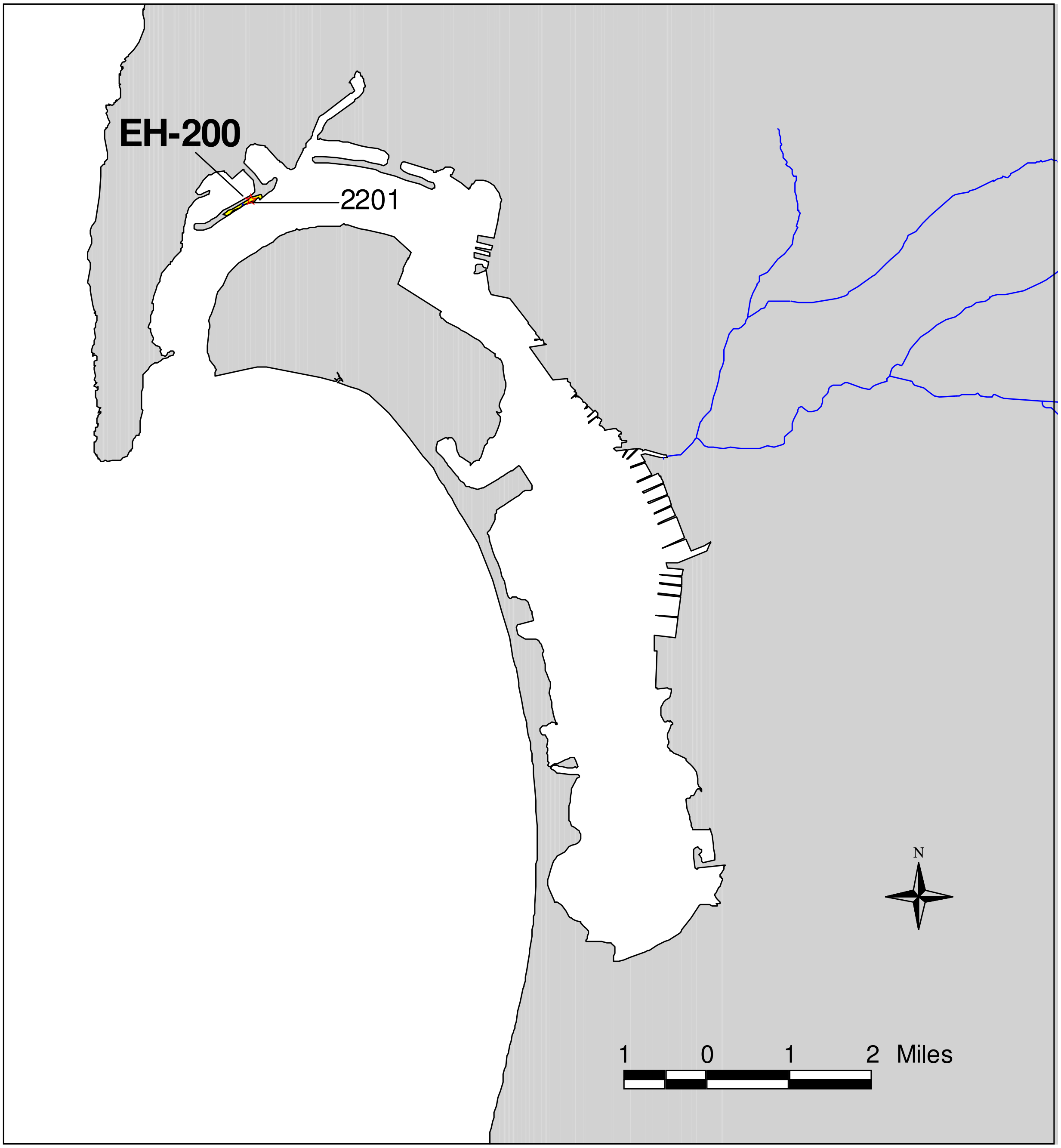

Figure F-18. Bacteria Monitoring Stations Along the San Diego Bay Shoreline

F.3.2.2.3 <u>Meteorological Boundary Conditions</u>

Meterological data from the Lindbergh Field Airway Station in San Diego were used to specify the water surface boundary conditions. Section F.3.1.2.3 provides a detailed description on the weather data required to perform the EFDC model simulations and the data processing that was necessary to obtain the appropriate format.

F.3.2.3 Initial Conditions

A uniform temperature of 15ºC and a salinity of 33 ppt were included as the initial conditions throughout the water column. The initial velocity was set to 0.0 m/s and the water surface elevation was set to 0.0 meters above mean low sea level.

F.3.2.4 Inverse Loading Identification

In conventional water quality modeling practices, an important component of model development is the calibration of model parameter values based on observed receiving water quality and well-defined source/sink functions. However, this conceptual framework does not apply to this model since the quantification of major bacteria sources is not available. On the other hand, the kinetics impacting bacteria concentrations in water is relatively simple, where die-off is the dominant process controlling bacteria dynamics. Therefore, among all the major factors impacting bacteria densities in water, the kinetic parameter values contribute significantly less uncertainty than the unquantifiable sources. In other words, it is reasonable to set values commensurate to literature values for the bacteria die-off rate and subsequently use the model to inversely estimate the external sources that produce the observed temporal variability in bacteria concentration. This type of method represents a research field known as “inverse method”, which is widely applied in the areas of air quality modeling, ocean modeling, geo-hydrology, and other environmental research areas. In air quality modeling, the model is configured with reasonable parameter values and then applied to inversely estimate pollutant rates from different sources at different locations. This approach is justified when the key component of model uncertainty is from sources rather than from parameter values.

The receiving water model was used to simulate the fate and transport of TC, FC, and ENT within the near-shore zone. The base die-off rate of the three bacteria indicators were set to 0.8/day consistent with a typical value reported by Chapra (1997). In addition to the base die-off rate, temperature and salinity dependence ratios were applied. Salinity can contribute to the die-off rate at a ratio of 0.02day^{-1}ppt^{-1} (Chapra, 1997). There is no conclusive research to show that the die-off rates of the bacteria indicators are highly temperature dependent. Therefore, a low value of 1.01 day^{-1} ºC^{-1} was included and was assumed to represent weak temperature dependence.

Using these parameter settings, the Shelter Island Shoreline Park receiving water model was run for the period from March 25, 2001 through October 30, 2002, and the simulated results were compared with observed data. For the dates that the receiving water model results did not correspond with the order of magnitude or trend of the observed data, the loading rate of the lumped sources (unquantified sources, which are assumed to be composed largely of bird sources) was fined tuned until a reasonable agreement between the receiving water model results and the observed data were achieved. Figure I-57 of Appendix I graphs the simulated bacteria density against the observed data. As shown, with the inversely derived lumped source loading, the receiving water model was able to reproduce the observed bacterial level near the shoreline relatively well. The adjusted lumped source loading for the simulation period is shown in Figure I-58 of Appendix I. No other fine-tuning was performed to further improve the goodness-of-fit. Since the uncertainty associated with bacteria water quality data can be significant, the objective of the modeling was to follow the general trend and estimate the order of magnitude present in the observed data.

It should be noted that the inversely estimated loading is not fictitious, but rather consistent with reality. Observed data show that there is a peak of TC bacteria density on July 29, 2002 (maximum value of 250,250 MPN/100 ml); however, the wet weather and dry weather watershed bacteria loads did not show significant loading during that time period. The only explanation for such high bacteria levels is the presence of significant additional bacteria loading source(s) during that time period. Two days later on July 31, 2002, it was also observed that the TC bacteria density at the same location was 10 MPN/100 ml. This type of rapid change in bacteria concentrations demonstrates the unique local relationship between bacteria loadings and densities. As shown through the receiving water model results (Figure I-57 of Appendix I), the model was able to predict sharp changes in bacteria concentrations caused by loading rates and tidal conditions within a short period of time.

F.3.3 Dana Point Harbor Receiving Water Model

F.3.3.1 Grid Generation

The DPH receiving water model includes the harbor up to the outer barrier and then extends approximately 5 kilometers in the south-east direction into the open ocean. The grid consists of 62 computation cells in the horizontal plane (Figure F-19) and each cell is represented by a single vertical layer. Six additional barrier features were setup to represent the grid cells that have one or more flow faces blocked from marina breakwaters (Figure F-20). All six barriers were assigned to the western face of each cell. Bathymetry for the model domain was based on data obtained from the US Army Corps of Engineerings (USACE). The average grid depth was 5 meters (minimum was 1 meter and maximum was 9 meters).

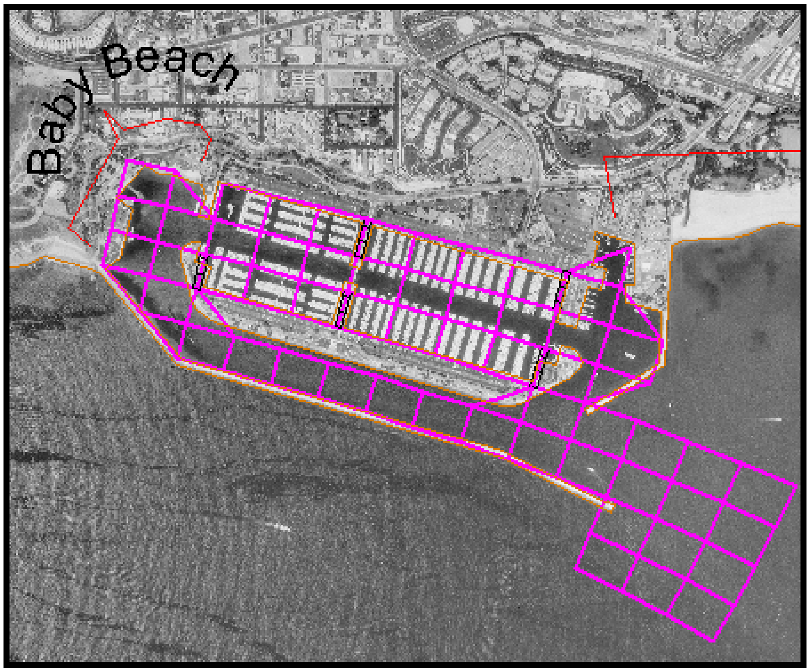

Figure F-19. Grid for the Dana Point Harbor

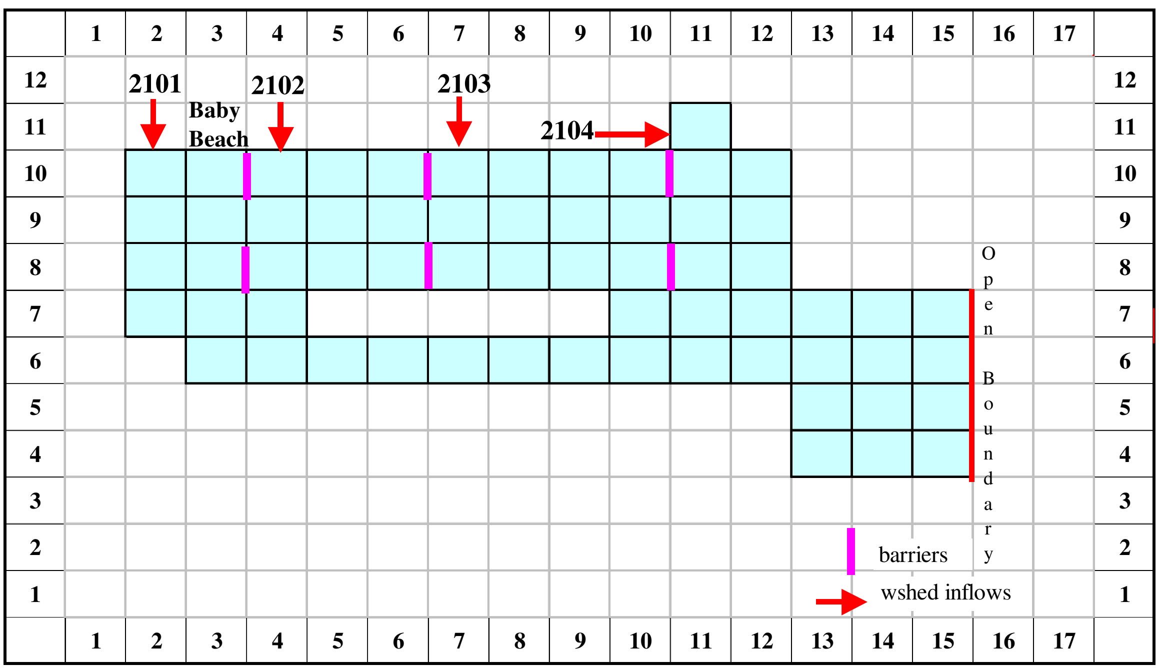

Figure F-20. Open Ocean and Lateral Boundary Locations for Dana Point Harbor Model

F.3.3.2 Boundary Conditions

F.3.3.2.1 Open ocean boundary conditions

Four grids in the eastern boundary of the model were configured as open ocean boundary conditions and were assigned time-variable water levels (Figure F-20). Real-time water level data were available through the NOAA-COOPS website for select locations in southern California. The closest station to DPH was Los Angeles, which is about 80 kilometers away. Therefore, to more accurately portray tidal fluctuations, the tidal predictions for San Clemente were used to develop the open ocean boundary conditions since this location is closer in proximity to DPH.

To predict the time-variable water levels at San Clemente, data were obtained for its assigned reference station, San Diego (Broadway). Specifically, hourly tidal predictions for San Diego (Broadway) for 2000 through 2004 were obtained from NOAA-COOPS. The phase and amplitude of the tide at San Clemente was then calculated based on these reference data. To account for the time difference between tides at San Clemente and San Diego (Broadway), an average lag time of 13 minutes was included in the calculation of the San Clemente phase (actual lag times are 15 minutes for high tide and 11 minutes for low tide). In addition, an amplitude ratio of 0.92 (as specified on the NOAA-COOPS website) was used to convert the tidal height from the San Diego (Broadway) values to corresponding heights at San Clemente. After completing these calculations, the data were processed and an EFDC-compatible tidal time series was created.

Scripps Institution of Oceanography station #096, located 3.7 miles west of Dana Point, provided temperature data for the open ocean boundary. Data with a 30-minute frequency were converted to build the EFDC-compatible temperature time series. Specifically, since temperature data from station #096 is not exactly the same as the temperature at the open ocean boundary, the 30-minute data was averaged to daily values to filter out the impact of any short period temperature signals, which may not be representative of the true condition at the boundary and may result in model instability. There were no salinity data identified for DPH. Therefore, the same salinity time series used for the SDB model (see Section F.3.1.2.1) was used for the DPH open ocean boundary.

F.3.3.2.2 Lateral boundary conditions

Contributions from subwatersheds 2101 and through 21042 were included as lateral boundary conditions for DPH. The wet weather flows and bacteria loads were configured based on simulation results from the LSPC watershed model. Nuisance runoff rates and associated bacteria loads were obtained from the steady-state dry weather watershed spreadsheet model, originally developed and calibrated for Bacteria TMDL Project I. The spatial representation of these inflow boundary conditions was determined by mapping the geographical coordinates of the watershed outlets to the model grid. Flow and bacteria loading output from the wet and dry weather watershed models were processed to build a time series for each tributary in EFDC-compatible format, which was then applied to the corresponding grid cells. In total, the model has four lateral inflow boundary conditions (two for wet weather and two dry weather watershed runoff).

Available data collected from four locations along the Baby Beach shoreline segment indicated that bacteria levels varied significantly both temporally and spatially. As with the Shelter Island Shoreline Park fine grid receiving water model, in addition to the lateral bacteria loading from the wet weather and dry weather watershed models, an additional loading source was included for each of the cells along the shoreline to represent the contribution from lumped sources (unquantified sources such as waterfowl, unidentified human sources, beach sediment sources, and other unidentified sources within the water).

Uniform bacteria densities (MPN/100ml) for TC, FC, and ENT and associated seasonally-variable surface flow rate (cms/m^2) were used to apply a lumped source loading in units of MPN/day at the computation cells adjacent to the Baby Beach shoreline segment. Seasonal variability in the unit area flow rate takes into account factors such as the seasonal bird population. To estimate the load allocation from lumped sources, the receiving water model was run with and without this lumped source load, as described in Section F.3.6.4.

There were no data identified for the temperatures of tributaries flowing into DPH. Therefore, the same temperature time series used at the open ocean boundary was used to provide temperature for all wet and dry weather watershed inflows. Salinity of the inflow waters was set to zero since no data were available.

F.3.3.2.3 <u>Meteorological boundary conditions</u>

El Toro Marine Corps Air Station is the closest Airway station to DPH; however, records from the El Toro station did not extend through the calibration time period. Therefore, a meteorological file was created using data from Lindbergh Field Airway Station in San Diego. Hourly data for the El Toro and Lindbergh Field stations were compared for January to June of 1997 and were found to be very similar for several meteorological parameters. As a result, the Lindbergh Field station was used to represent dry and wet bulb temperature, relative humidity, wind speed, wind direction, sea level pressure, and sky conditions for 1990 to 2004. Sky conditions were converted to “percent cloud cover” and solar radiation was estimated by calculating the clear sky solar radiation using latitude and longitude and adjusting the values based on the estimated cloud cover.

F.3.3.3 Initial Conditions

A uniform temperature of 15ºC and a salinity of 35 psu were specified as the initial conditions throughout the water column. The initial water velocity was set to 0.0 m/s and water surface elevation was set to 0.0 meters above mean sea level.

F.3.3.4 Inverse Loading Identification

The receiving water model was used to simulate the fate and transport of TC, FC, and ENT within the near-shore zone. Bacteria kinetics (including bacteria die-off rates and the temperature and salinity impact on the die-off rate) were the same as those described for the SDB Shelter Island Shoreline Park fine grid model (see Section F.3.2.4). Bacteria water quality observations were available at four stations along the Baby Beach shoreline segment – BDP 12, 13, 14 and 15 (see Figures I-60 and I-61 of Appendix I); however, BDP 12, 13 and 14 fall within one computation cell of the DPH grid. Therefore, data at those three stations were averaged to obtain a mean value.

Initially the receiving water model was run only with the wet and dry weather watershed modeled bacteria loading sources. Bacteria die-off rates were not considered for this simulation. Comparing the initial receiving water model-predicted bacteria densities with observed data the results indicated that the wet weather and dry weather watershed sources do not account for the magnitude and variability of bacteria densities observed in this area. The difference in the magnitude of bacteria densities between the initial receiving water model output and observed bacteria levels suggests that additional unquantified sources, other than watershed inflows, may contribute significantly to bacteria loading along the shoreline.

Next, as in the SDB fine grid receiving water model for Shelter Island Shoreline Park (see Section F.3.2.2.2), the DPH receiving water model was used to inversely estimate external bacteria loading sources that would produce the observed temporal variability in bacteria densities. However, in the DPH receiving water model, loading from lumped sources was not adjusted to match individual bacteria observations. Instead, the seasonal loading rate was adjusted to match the 30-day geometric mean of the observed data. A higher load was applied between 30 to 90 days and 330 to 390 days (days are relative to the modeling starting time of January 1, 2001) since the observed bacteria densities in the region were high during those time periods. A lower load was applied during other times to correspond with the lower observed bacteria densities.

Figures I-62 through I-64 of Appendix I show the simulated bacteria densities plotted against the 30-day geometric mean for the observed data. As shown with the seasonally-variable lumped source loading, the model was able to reproduce the observed bacterial level near the shoreline relatively well. The adjusted seasonally-variable lumped source loading for the simulation period at the two cells bordering Baby Beach is shown in Figure I-65 of Appendix I.

F.4 Application of the Watershed and Receiving Water Models

The EFDC receiving water models incorporated bacteria loads and flow rates from the wet and dry weather watershed models as lateral boundary conditions. Therefore, all TMDL calculations were based on output from the comprehensive EFDC models for the corresponding impaired shoreline segment. Additional, localized sources of bacteria associated with lumped sources (unquantified sources such as waterfowl, unidentified human sources, beach sediment sources, and other unidentified sources within the water) were simulated for each shoreline segment based on model simulations to reproduce observed conditions within the waters. These loads from lumped sources, in addition to watershed sources, were used to determine existing conditions and load allocations to sources.

After completing all model simulations, the EFDC model was applied to obtain hourly and average daily output for the critical wet and dry periods described in Section 7 of the Technical Report. The maximum hourly TC, FC, and ENT densities were obtained for a 30-day critical period for each impaired shoreline model zone. These concentrations were used to determine compliance to numeric targets for TMDL calculation. If bacteria densities exceeded the selected numeric targets, bacteria loads to the receiving water from controllable sources were reduced until compliance was reached. The resulting bacteria loads were equivalent to the TMDL and associated load and wasteload allocations.

While this modeling effort was useful in calculating TMDLs for impaired shorelines in SDB and DPH, future expansion of the model can greatly increase its accuracy and utility. If data become available that quantify the bacteria loading from birds and other unknown sources (both directly to the waterbodies and to the near-shore areas), this modeling system can be modified and expanded to capture detail on all available sources. The model can also be expanded to incorporate bacteria simulations if data become available near the segments where bacteria data were unavailable. Adding any additional detail to the model would allow for more specific load and wasteload allocations. In addition, the incorporation of more data would enhance the range of scenarios that can be simulated to assist the San Diego Water Board and stakeholders with implementation of the TMDL.