TETRA TECH

Technical Memorandum

DATE: February 29, 2012

TO: Karin Graves, EPA Region 9 Water Division

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SUBJECT: Appendix B – Wet Weather Bacteria Loads to the Long Beach City Beaches and the Los Angeles River Estuary

The Long Beach City beaches (LBC beaches) were listed as impaired by the U.S. Environmental Protection Agency (USEPA) due to elevated concentrations of indicator bacteria in 2006. This impairment stretches 4.7 miles along the coastline between the Los Angeles River (LAR) Estuary and the San Gabriel River (SGR) Estuary and Alamitos Bay. Moreover, a recent review of available bacteria data identified an impairment of the LAR Estuary from Willow Street to the mouth of the estuary (Appendix A). These impaired segments are both located in Los Angeles County in southern California (Figure 1); the general area of the beaches is further defined by hydrological unit 405.12 in the Los Angeles Regional Water Quality Control Board (Regional Board) Basin Plan. This memo presents the approach used to estimate wet weather loading from the direct drainages to the LBC beaches and LAR Estuary.

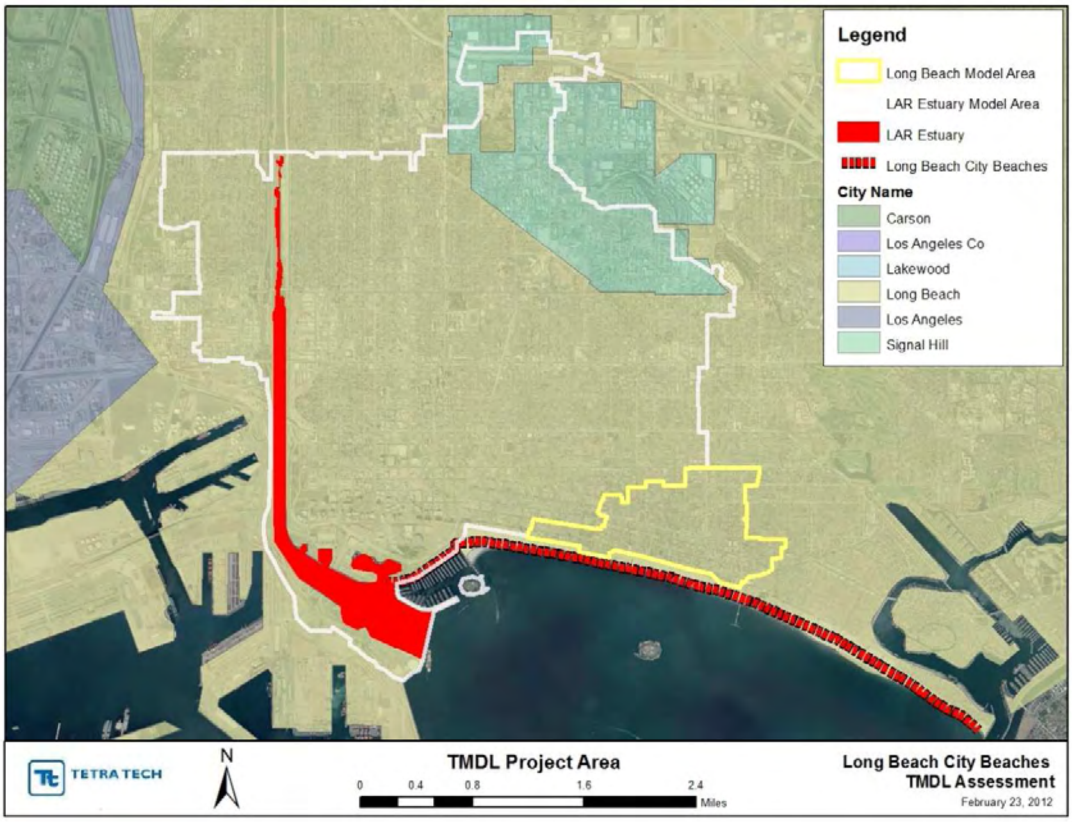


Figure 1. Long Beach City beaches and LAR Estuary location and jurisdictions

Long Beach City Beaches Environmental Setting

Along the LBC beaches, impaired locations include the beach areas at: 3rd Place, 5th, 10th, 16th, 36th, 54th, 55th, 62nd, and 72nd Streets, Coronado Avenue, Granada Avenue, Molino Avenue, and Prospect Avenue. Figure 2 defines the drainage areas based on subwatershed boundaries developed by the City of Long Beach. As shown in the figure, only a small area drains directly to the beaches; this area is referred to as the *LBC beaches direct drainage*. In total, the direct drainage covers an area of approximately 505 acres, and is entirely within the jurisdiction of the City of Long Beach. Within the LBC beaches direct drainage, there are five sewersheds, or storm drain basins. Corresponding to discharge locations, the five storm drain basins are: Molino Avenue, Redondo Street, 9th Place, 36th Place, and West Belmont Pier. Stormwater, and dry weather flows, within these basins are conveyed and discharged through storm drains to the impaired beaches. Figure 2 identifies each of the five sewersheds in the LBC beaches direct drainage.

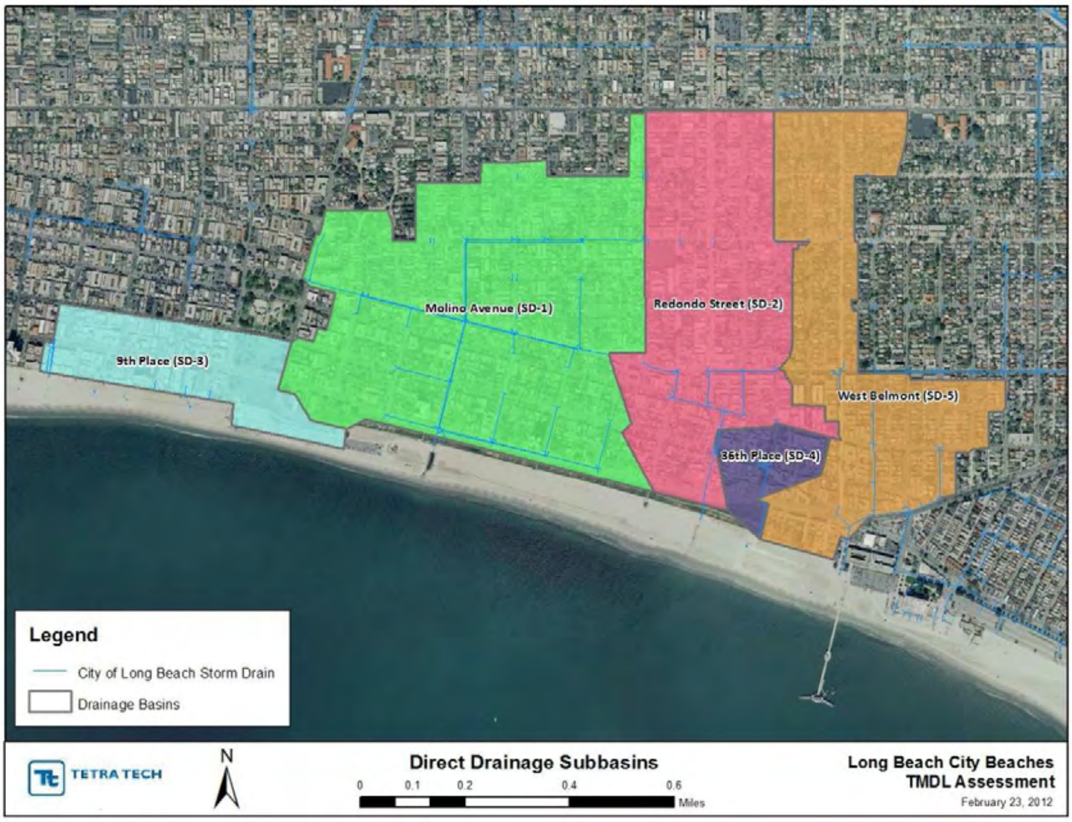


Figure 2. Direct drainage delineation of storm drain basins to the LBC beaches

Over a 30-day period during the fall of 2007, the City of Long Beach conducted a microbial source tracking study within the LBC beaches direct drainage. Storm drains within the direct drainage were identified as SD-1 through SD-5, but it should be noted that SD-4 had little to no flow and was, therefore, not sampled. Results from this study showed that, during dry weather, the storm drains within the direct drainage contribute considerable bacteria loads to the LBC beaches (City of Long Beach, 2009). Because these drains are confirmed sources during dry weather, it is assumed that they also deliver bacteria directly the beach area during wet weather conditions.

Los Angeles River Estuary Environmental Setting

The LAR Estuary connects the Los Angeles River to San Pedro Bay. It begins where the concrete-lined river ends near Willow Street and flows to Queensway Bay before entering San Pedro Bay. Receiving most of its flow from either the LAR or San Pedro Bay (during high tide), a relatively small area along either bank drains directly to the LAR Estuary. This area, referred to as the *LAR Estuary direct drainage*, is shown in Figure 3. In total, the drainage includes 6,065 acres of land, predominately draining from the east side of the estuary. Within this drainage, storm water is collected, conveyed, and discharged to the estuary through the MS4 system shown in Figure 3. MS4 jurisdictions in this area include the cities of Long Beach and Signal Hill (Figure 1).

Although a Total Maximum Daily Load (TMDL) has been developed for the LAR watershed (LARWQCB, 2010), that TMDL does not address lands draining directly to the estuary and so, unaddressed discharges to the LAR Estuary could continue to cause or contribute to impairment of the estuary itself, or the LBC beaches. For this reason, a TMDL is required to address elevated indicator bacteria (*Escherichia coli* [*E. coli*], fecal coliform, total coliform, and/or *enterococcus*) at the LBC beaches and LAR Estuary.

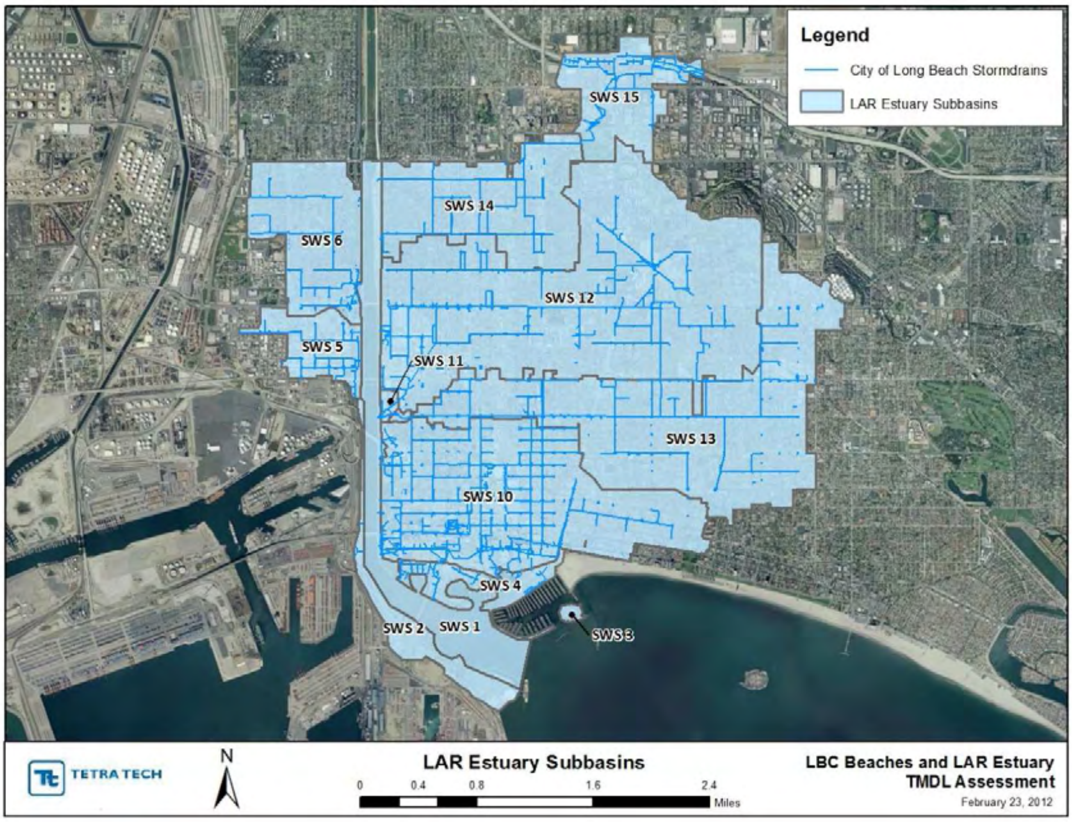


Figure 3. Direct drainage delineation of storm drain basins to the LAR Estuary

B.1 WET WEATHER MODELING APPROACH

Although sources of bacteria are similar during wet and dry conditions, their means of transport to receiving waters vary between the conditions. To accurately account for the variability between weather conditions, Tetra Tech developed and utilized different technical approaches for both conditions. This process is consistent with other TMDLs adopted in the Los Angeles Region (Los Angeles Regional Water Quality Control Board [LARWQCB], 2002, 2005a, 2005b, 2011). This technical memorandum provides a summary of the approach used for the estimation of bacteria (*E. coli*) loading from the direct drainages, to the LBC beaches and the LAR Estuary during wet weather conditions (these conditions apply to all wet weather days, as described in the TMDL report). The process used for quantification of bacteria loads to the beaches during dry weather conditions is discussed in Appendix C. The wet and dry weather technical approaches are both focused on freshwater loadings from the watersheds draining to the impaired marine segments. Therefore, *E. coli* was selected as the representative indicator bacteria to quantify freshwater loadings because it can be directly compared to the available freshwater water quality objectives and percent reductions can be calculated to support implementation actions (note: freshwater water quality objectives are not available for *enterococcus*, fecal coliform, and total coliform; however, marine water quality objectives are available for these indicator bacteria).

Wet weather sources of bacteria are generally associated with wash-off of loads accumulated on the land surface. During storm events, bacteria loads are delivered to the waterbody through creeks and stormwater collection systems. Specific to the beaches, wet-weather flows are delivered directly through the five storm drain basins identified above (Figure 2), while wet-weather flows in the LAR Estuary direct drainage are delivered to that the receiving water through 12 storm drain basins shown in Figure 3. To assess the link between sources of bacteria and the impaired waters, and since monitoring data from these basins is limited to dry-weather, a detailed modeling approach was used to calculate wet weather bacteria loads delivered from the direct drainage to the beaches.

Modeling was based on the understanding that the loading of bacteria can be linked to specific land use types that have higher relative accumulation rates or are more likely to deliver pollutants to waterbodies due to delivery through stormwater collection systems. To assess the link between sources of bacteria to the impaired segments, a modeling system was utilized to simulate land-use based sources of bacteria and the hydrologic / hydraulic processes that affect delivery. The particular model, the U.S. Environmental Protection Agency's (USEPA) Loading Simulation Program C++ (LSPC) (Shen et al., 2004; USEPA, 2003a), was ultimately used to represent the hydrologic and water quality conditions in the direct drainage watersheds contributing to the beaches.

LSPC is a component of the USEPA's TMDL Modeling Toolbox (USEPA, 2003b), which has been developed through a joint effort between USEPA and Tetra Tech, Inc. The LSPC model has been successfully applied and calibrated in Southern California for the LAR, the SGR, Dominguez Creek (DC) (original model by the Southern California Coastal Water Research Project [SCCWRP]), the nearshore watersheds draining to Los Angeles/Long Beach Harbors (LAH), the San Jacinto River, and multiple watersheds draining to impaired beaches in the San Diego Region. The model integrates a comprehensive data storage and management capability, a dynamic watershed model (a re-coded version of EPA's Hydrological Simulation Program – FORTRAN [HSPF] [Bicknell et al., 2001]), and a data analysis/post-processing system into a convenient PC-based windows interface that dictates no software requirements. LSPC is capable of representing loading and both flow and water quality from non-point and point sources as well as simulating in-stream processes. Additionally, the model can simulate flow and bacteria as well as other parameters such as sediment, metals, nutrients, pesticides, and other conventional pollutants for pervious and impervious lands and waterbodies.

Previous wet-weather watershed modeling and TMDL efforts by Tetra Tech and SCCWRP have led to the development of a regional watershed modeling approach to simulate hydrology and pollutant transport in the Los Angeles Region. The regional modeling approach assumes that pollutant (i.e. bacteria) loadings can be dynamically simulated based on hydrology and pollutant transported from land uses in a watershed. Development of the regional modeling approach resulted from the application and testing of multiple models of both small-scale land use sites and larger watersheds in the Los Angeles Region. SCCWRP developed watershed models, based on HSPF (Bicknell et al., 2001), of multiple homogeneous land use sites in the region. Sufficient stormflow and water quality data were available at these locations to facilitate calibration of land-use-specific HSPF modeling parameters. These parameters were validated in an additional HSPF model of Ballona Creek (Ackerman et al., 2005; SCCWRP, 2004), and similar models of LAR (Tetra Tech, Inc., 2004), SGR (Tetra Tech, Inc., 2005), and LAH (Tetra Tech, Inc., 2011) using LSPC. These models were used to calculate TMDLs for each of these waterbodies (LARWQCB, 2005a, 2005b, 2006, 2011).

Building off of these efforts, previously configured LSPC models were used to simulate bacteria concentrations and, ultimately, determine watershed loading from the direct drainages to the beaches and estuary. Consistent with the three seasons identified for TMDL development, wet-weather days were designated as those days receiving equal to, or greater than, 0.1” of precipitation, as well as the following three days. The following sections describe the wet-weather model configuration, and application as well as any modifications to existing models that were necessary to simulate wet-weather bacteria loading to the LBC beaches and LAR Estuary.

B.2 MODEL CONFIGURATION

Through dynamic representation of hydrology and land practices, the model represented the variability of wet-weather runoff source contributions. Any point and non-point source contributions were also considered. Key components of the watershed modeling that are discussed below are:

- Watershed segmentation/delineation
- Meteorological data
- Land use representation
- Soils
- Reach characteristics
- Point source discharges
- Hydrology representation
- Pollutant representation

B.2.1 Watershed Segmentation/Delineation

To evaluate sources contributing to the impaired waterbodies and to represent the spatial variability of these sources, the contributing drainage areas (direct drainages) were represented by a series of subbasins (or sewersheds). To delineate the direct drainages, Tetra Tech obtained the Geographic Information System (GIS) coverage of the direct drainages (total freshwater portion) and associated storm drains from the City of Long Beach. The original small subwatersheds in this coverage were simulated; however, they were combined into model subbasins discharging to discrete points along the impaired waterbodies (i.e., storm drain outfalls) for model evaluation. In total, for appropriate hydrologic connectivity and representation, the LBC beaches direct drainage was divided into five subbasins and the LAR Estuary direct drainage contained 12 subbasins; direct drainages modeled are shown in Figure 2 and Figure 3 above.

B.2.2 Meteorological Data

Meteorological data are a critical component of the watershed model. LSPC requires appropriate representation of precipitation and potential evapotranspiration (ET). 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. Rainfall-runoff processes for each subbasin were driven by precipitation data from the most representative station. These data provide necessary input to LSPC algorithms for hydrologic and water quality representation.

National Climatic Data Center (NCDC) precipitation data were reviewed based on geographic location, period of record, and missing data to determine the most appropriate meteorological stations to represent the beaches model domain. Hourly rainfall data were obtained from the Long Beach weather station (CA5085) located in the Los Cerritos Channel watershed. Precipitation data were obtained for January1, 1980 through December 31, 2010.

Because rainfall gages are not always in operation and accurately recording data, the resulting dataset may contain various intervals of accumulated, missing, or deleted data. Missing or deleted intervals are periods over which either the rainfall gage malfunctioned or the data records were somehow lost. Accumulated intervals represent cumulative precipitation over several hours, but the exact hourly distribution of the data is unknown. To address the incomplete portions of CA5085 data, it was necessary to patch the rainfall data with information from nearby gages using normal-weighted hourly distributions. Because the normal ratio considers the long-term average rainfall as the weighting factor, this method is adaptable to regions where there is large orographic precipitation variation since elevation differences will not bias the predictive capability of the method (Dunne & Leopold, 1978).

Specifically, the normal-ratio method (Dunne & Leopold, 1978) was used to patch missing data with hourly rainfall distributions at nearby gages. To apply this normal-ratio method, a composite hourly distribution was first estimated for CA5085 (where accumulated, missing, or deleted data exist). This distribution was determined by using a weighted average from surrounding *n* stations with similar rainfall patterns and where unimpaired data were measured for the same time period.

Potential evapotranspiration, which is also required by the LSPC model, was calculated from data obtained from NCDC. Specifically, long-term hourly wind speed, cloud cover, temperature, and dew point data available for the Los Angeles International Airport (WBAN #23174) were used to calculate potential evapotranspiration for the weather station representing watershed.

B.2.3 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. It is also necessary to represent variability in pollutant loading, which is highly correlated with land practices. The basis for this distribution was provided by the land use coverage of the entire watershed. The land use data used to represent watershed was the Southern California Association of Governments (SCAG) 2008 land use dataset that covers Los Angeles 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 six categories for modeling: commercial, high-density residential, industrial, mixed urban, roads and open. Selection of these land use categories was based consistency with previous studies (Tetra Tech Inc., 2011) and literature values that could be used to characterize individual land use contributions and critical bacteria-contributing practices associated with different land uses. The distributions of the land uses (urban land uses were further separated into pervious and impervious areas, as described below) in the direct drainages are shown in Figure 4 and Figure 5 and summarized in Table 1.

Table 1. Land Use Areas within Direct Drainages to the Long Beach City Beaches and the Los Angeles River Estuary

Land Use									
Subbasin ID	**Commercial (acres)**	**High Density Residential (acres)**	**Industrial (acres)**	**Mixed Urban (acres)**	**Roads (acres)**	**Open (acres)**	**Total Area (acres)**	**Total Area (km^2)**	**Total Urban Area (km^2)**
LBC Beaches Storm Drain Subbasins									
9th Place (SD-3)	4.4	14.5	0.7	0	13.2	13.9	46.7	0.19	0.13
Molino Avenue (SD-1)	11.1	119.4	1.4	0	66	4.9	202.7	0.82	0.8
Redondo Street (SD-2)	14.9	60.6	0.4	8.7	38.3	0.6	123.6	0.5	0.5
36th Place (SD-4)	0.9	9.3	0	0	6	1.6	17.8	0.07	0.07
West Belmont (SD-5)	7.4	68.5	0.1	1.7	35.8	0.4	113.9	0.46	0.46
LBC Beaches Total	38.7	272.3	2.5	10.5	159.2	21.3	504.7	2.04	1.96
LAR Estuary Storm Drain Subbasins									
LARE-1	8.2	0.1	27.1	0.0	21.1	6.3	62.8	0.25	0.23
LARE-2	0.0	0.0	142.7	0.0	12.2	0.6	155.5	0.63	0.63
LARE-3	0.0	0.0	11.0	0.0	0.0	0.0	11.0	0.04	0.04
LARE-4	66.6	0.5	0.0	0.0	15.0	46.6	128.6	0.52	0.33
LARE-5	5.5	0.0	93.2	0.0	74.3	0.9	173.9	0.70	0.70
LARE-6	49.8	218.4	3.1	0.0	149.9	3.2	424.4	1.72	1.71
LARE-10	361.4	293.7	20.2	11.0	365.1	39.0	1090.4	4.42	4.26
LARE-11	0.0	0.2	7.7	0.0	2.4	4.1	14.3	0.06	0.04
LARE-12	328.4	739.3	181.2	5.7	504.7	103.6	1862.9	7.54	7.13
LARE-13	220.5	614.2	45.0	11.8	355.0	13.0	1259.4	5.10	5.05
LARE-14	77.4	291.4	15.7	0.0	175.4	7.9	567.8	2.30	2.27
LARE-15	48.5	2.9	128.3	4.6	85.9	44.0	314.2	1.27	1.09
LAR Estuary Total	1,166.4	2,160.6	675.1	33.1	1,760.9	269.2	6,065.3	24.5	23.5

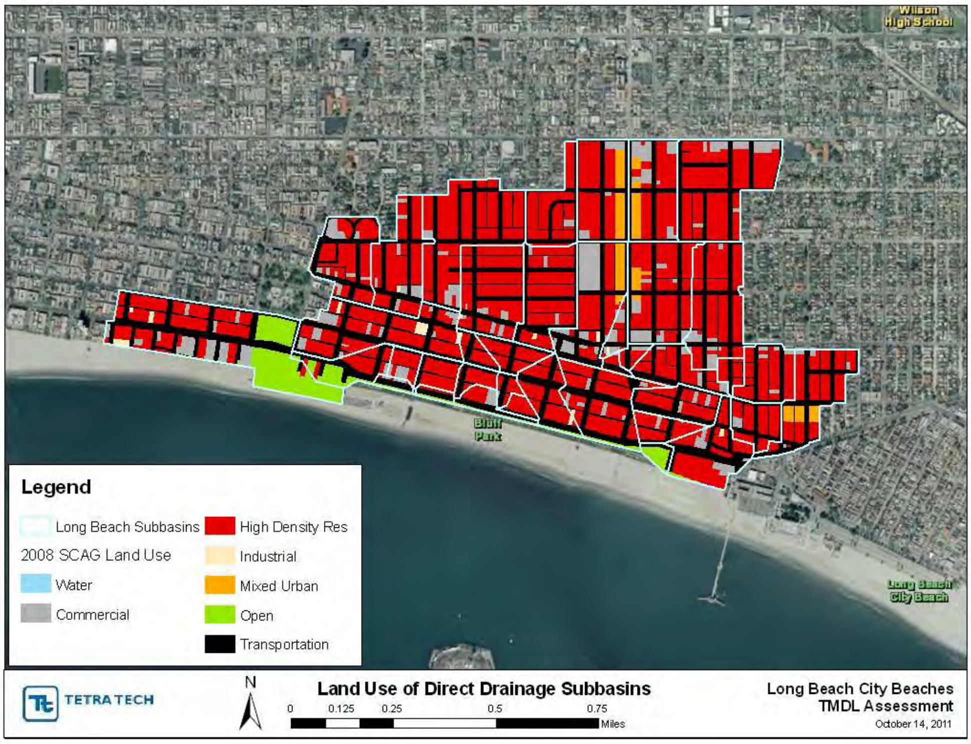


Figure 4. Land use distribution within the LBC beaches direct drainage

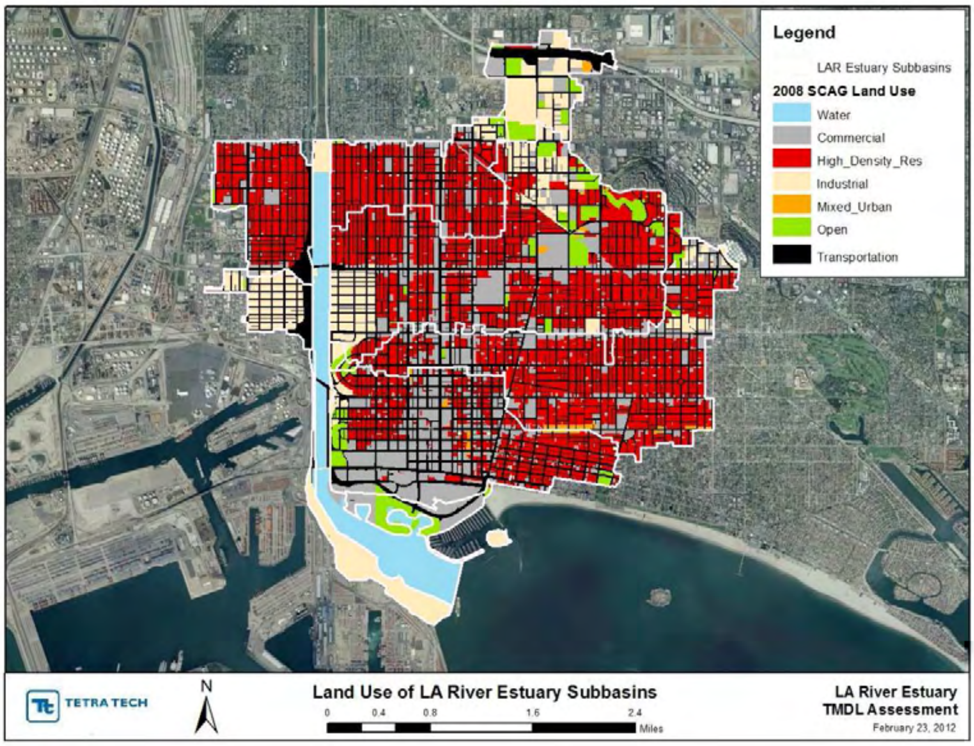


Figure 5. Land use distribution within the LAR Estuary direct drainage

LSPC algorithms require that land use categories be divided into separate pervious and impervious land units for modeling. The division of the six land use categories identified above to represent impervious and pervious areas in the model was based on typical impervious percentages associated with different land use types as defined in the TR-55 Manual (USDA, 1986) (shown in Table 2). The TR-55 values were visually compared to the 2001 Impervious Surface layer of the National Land Cover Dataset (NLCD) (downloaded from http://seamless.usgs.gov/website/seamless/viewer.htm). This analysis showed that the land uses that would be classified as low density residential in the direct drainages actually had impervious cover more similar to the high density residential land use. Therefore, the low density residential was grouped with high density residential land use to result in a value more representative of land use and imperviousness within the direct drainages.

Table 2. Percent Impervious of each Land Use Type

Urban Land Cover Type	Imperviousness (%)
Commercial	85
High Density Residential	65
Industrial	75
Mixed Urban	65
Roads	95
Open (non-urban)	3

B.2.4 Soils

There are four main Hydrologic Soil Groups (Groups A, B, C, and D), each summarized below. These groups range from soils with low runoff potential to soils with high runoff potential (USDA, 1986). Due to large amounts of disturbed soils in urbanized areas and the high percentage of urban land uses in the watershed, only one generic soil grouping was used in the model, which is consistent with previous studies (Tetra Tech, Inc., 2011). This had an infiltration rate consistent with Group B/C soils. In addition, the model domain is represented by a single soil mapping unit identification number (CA638) and the State Soil Geographic (STATSGO) Database soil layer includes a single category for urban areas (USDA, 2006). The STATSGO database is a national soil GIS layer distributed by the Natural Resources Conservation Service (NRCS) - National Cartography and Geospatial Center (NCGC). More recent data layers are available, such as the more detailed Soil Survey Geographic (SSURGO) soil layer (also distributed by the NRCS-NCGC) and a layer distributed by the County of Los Angeles. The SSURGO data layer does not cover highly urban areas, such as those areas found in the direct drainages, while the County of Los Angeles layer, which has more detail than the other national data layers, does not provide a direct linkage to the hydrologic soil groups required for modeling. Because of the limitations associated with these more recent data, the STATSGO data is the only available dataset with adequate information on hydrologic soil groups for application of the regional modeling approach.

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.

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.

B.2.5 Reach Characteristics

Each delineated subbasin was represented with a single reach assumed to be a completely mixed, one-dimensional segment with a trapezoidal cross-section. The reaches are based on storm sewer systems, since much of the flow in the watershed drains through storm sewers. Once the representative reach was identified for each subbasin, slopes were calculated based on Digital Elevation Model (DEM) data, and stream lengths measured from the GIS reach coverage. Mean stream depth and channel width were estimated using regression curves that relate upstream drainage area to stream/sewer dimensions.

The Manning's *n* values for the model reaches were estimated based on the normal value (0.015) for closed conduit flow in a concrete sewer pipe (Chow, 1959). Stormwater conduit construction material was specified in the City of Long Beach GIS Storm Drain System shapefile. Where a model subbasin did not have a stormwater pipe, Mannnig's *n* was estimated to capture the conveyance characteristics of street curb-gutter systems, which can be represented by the normal value (0.017) for concrete lined constructed channels.

B.2.6 Point Source Discharges

During watershed model configuration, National Pollutant Discharge Elimination System (NPDES) discharges can be incorporated into the model as point sources of flow and pollutants. There were no major point sources of flow located in the direct drainages (other than the MS4 system); therefore, this step was excluded during model development.

B.2.7 Hydrology Representation

Watershed hydrology plays an important role in the determination of nonpoint source flow and ultimately nonpoint source loadings to a waterbody. The watershed model must appropriately represent the spatial and temporal variability of hydrologic characteristics within a watershed. Key hydrologic characteristics include interception storage capacities, infiltration properties, evaporation and transpiration rates, and watershed slope and roughness. LSPC's algorithms are identical to those in HSPF. The LSPC/HSPF modules used to represent watershed hydrology for TMDL development included PWATER (water budget simulation for pervious land units) and IWATER (water budget simulation for impervious land units). A detailed description of relevant hydrological algorithms is presented in the HSPF User's Manual (Bicknell et al., 2001). Key hydrologic parameters in the PWATER and IWATER modules are infiltration, groundwater flow, and overland flow. The model was populated using regionally calibrated, land use-specific hydrologic parameters that were used in the LAH model (Tetra Tech, Inc., 2011).

B.2.8 Watershed Runoff Pollutant Representation

Loading processes for bacteria (*E. coli*) were represented for each subbasin 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. Consistent with the LAR freshwater bacteria TMDL, event mean concentrations for *E. coli*, based on historical monitoring, were applied as SOQC (surface outflow) and IOQC (interflow) concentrations (LARWQCB, 2010). Values input for SOQC and IOQC are shown in Table 3.

Table 3. Model Event Mean Concentrations for *E. coli*

Urban Land Cover Type	Surface Outflow (#/100mL)	Interflow (#/100mL)
Commercial	40,000	40,000
High Density Residential	6,600	6,600
Industrial	2,300	2,300
Mixed Urban	19,000	19,000
Roads	1,000	1,000
Open (non-urban)	1,000	1,000

Additionally, the decay, or die-off, of *E. coli* can be dependent on a number of factors, including sunlight and temperature. Consistent with recent studies (Cleaner Rivers through Effective Stakeholder TMDLs [CREST], 2010), a decay rate of 0.2 per day was applied to bacteria concentrations, which is similar to the average decay rate observed during winter (light) conditions (which generally overlaps with the wetter months for the region).

B.3 MODEL VALIDATION

Since model validation has been completed on the regional modeling approach a number of times for both hydrology and bacteria, and due to the lack of wet-weather monitoring data, the model was not validated further. Refer to previous modeling efforts for validation results (Tetra Tech, Inc., 2004, 2005, 2011).

B.4 MODEL ASSUMPTIONS

Assumptions are inherent to the modeling process as the model user attempts to represent the actual system as accurately as possible. The assumptions associated with the LSPC model and its algorithms are described in the HSPF User's Manual (Bicknell et al., 2001). There were several additional assumptions used in the model of the beaches, each are described below.

- *Bacteria Loading Rates* – Bacteria loading rates associated with various land use categories are constant. Rates estimated for current loading are accurate for establishing total allowable loading for each land use category. Land use practices are consistent for all that fall within a given category and associated modeling parameters are transferable between subbasins.
- *First-order Bacteria Die-off* – Each stream is modeled assuming an apparent first-order die-off of bacteria. Bacteria die-off rates for wet weather are assumed to be 0.2/day.
- *In-stream Bacteria Re-growth* – The LSPC model assumes no in-stream regrowth of bacteria. No data or literature were located to provide indication that such sources are significant during wet weather or could be estimated for model input.
- *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. (2001).

- *Land Use* – The 2008 SCAG 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.
- *Lumped Parameter Model Characteristic* – LSPC is a lumped-parameter model and is assumed to be sufficient for modeling transport of flows and bacteria loads from watersheds in the region. For lumped parameter models, transport of flows and bacteria 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. Although this limitation could result in mistiming of peak flows or under-prediction of bacteria die-off because overland losses are not simulated, impacts are assumed minimal.
- *Calibration / Validation* - No further calibration or validation was required for flow or bacteria in the model due to the prior use of the regional modeling approach.

B.5 MODEL APPLICATION AND CONCLUSIONS

Building off of previous modeling efforts conducted in the Los Angeles region (Tetra Tech, Inc., 2004, 2005, 2011; LARWQCB, 2010), the regional modeling approach allowed for the calculation of wet weather bacteria loadings to the LBC beaches and LAR Estuary during wet weather conditions. The wet weather model output can be used in various ways to support TMDL development and implementation. For instance, the results were summarized to evaluate the spatial distribution of bacteria loadings within the direct drainage. Table 4 presents results from the modeled daily wet weather bacteria loading rates in number of bacteria (MPN) per day (note: only the total loading to the LAR Estuary is presented here because the modeled loads are cumulative to the final discharge point). Allowable loads and required reductions are also presented (note: the allowable loads are based on modeled flow and the single sample maximum WQS of 235 MPN/100mL; single sample maximum value was used because wet weather events are generally considered instantaneous).

Table 4. Existing Daily Wet-Weather *E. coli* Load (Modeled) within Direct Drainage Subbasins

Direct Drainage	Subbasin	Existing Wet Weather Load[a] (MPN/day)	Allowable Wet Weather Load[b] (MPN/day)	Percent Reduction
LBC Beaches	9th Place	4.40×10^{10}	1.25×10^{9}	97.2%
	Molino Avenue	1.66×10^{11}	6.92×10^{9}	95.8%
	Redondo Street	1.50×10^{11}	4.35×10^{9}	97.1%
	36th Place	1.12×10^{10}	5.87×10^{8}	94.7%
	West Belmont Pier	1.03×10^{11}	3.97×10^{9}	96.2%
LAR Estuary	Total Direct Drainage	1.21×10^{14}	2.14×10^{11}	99.8%

[a] *Existing load calculated based on average model* for wet days.
[b] *Allowable load calculated with WQS of 235 CFU/100 mL paired with modeled flow.*

A gradient of loading by subbasin is illustrated in Figure 6 and Figure 7 for the LBC beaches and LAR Estuary, respectively. As shown in the LBC beaches direct drainage, the model quantified the greatest wet weather loadings from the Molino Avenue subbasin (darker shading). The Molino Avenue subbasin comprises the largest area in that direct drainage and also has the highest flow; therefore, this watershed is expected to produce the greatest bacteria load of the five subbasins in the direct drainage to the LBC beaches. Alternatively, the 36th Place drainage represents the smallest area in the direct drainage to the LBC beaches and least amount of flow and is modeled to produce the smallest wet weather bacteria load of the five drainages. The total existing load to the LAR Estuary is approximately three orders of magnitude above LBC beaches drainages, which is expected given its larger size (and therefore, higher flow) and greater proportion of commercial land, which had the highest *E. coli* EMC values based on historical monitoring (Table 3). Figure 7 illustrates the cumulative loads throughout the LAR Estuary direct drainage, which includes the highest loads at the mouth of the estuary.

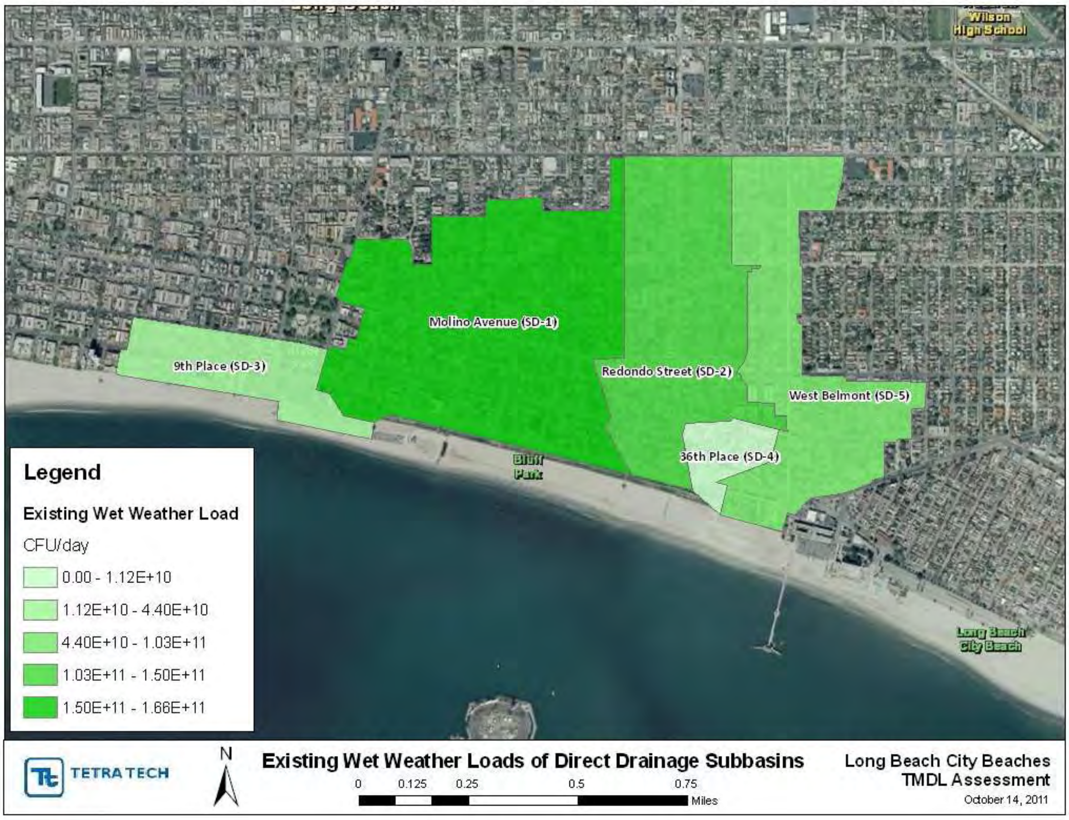


Figure 6. Existing daily wet-weather *E. coli* load (modeled) within LBC beaches direct drainage subbasins (CFU/day)

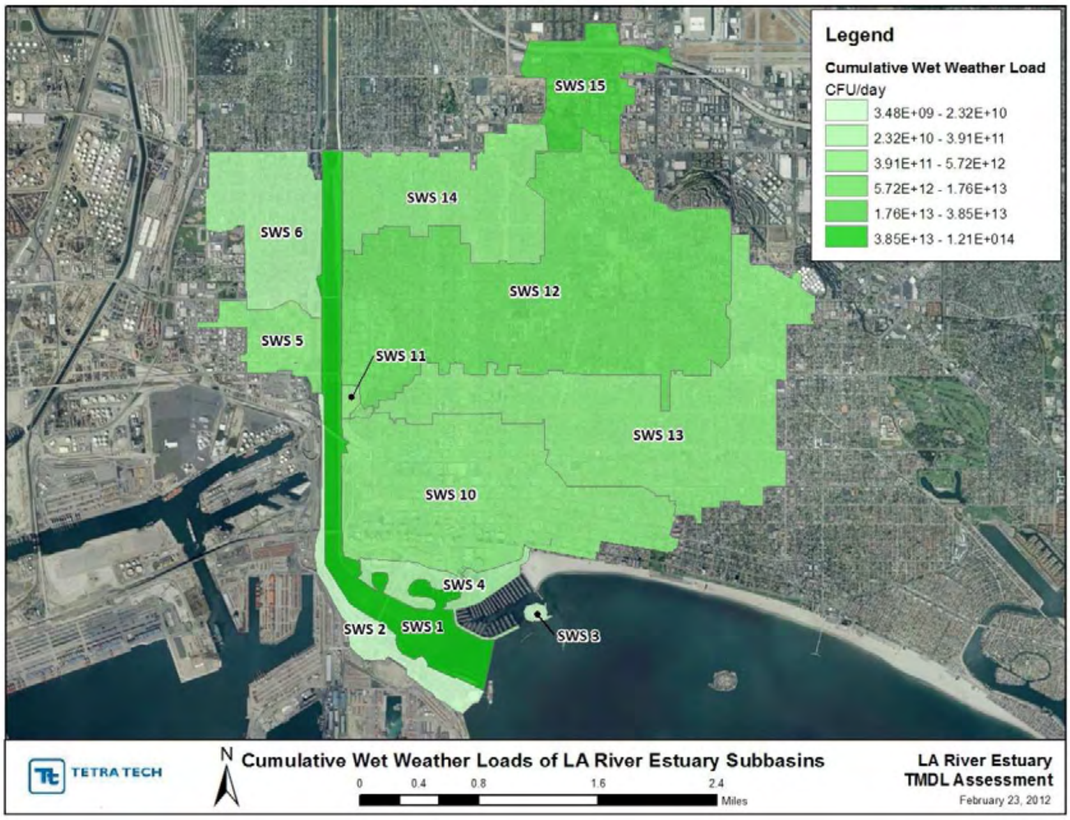
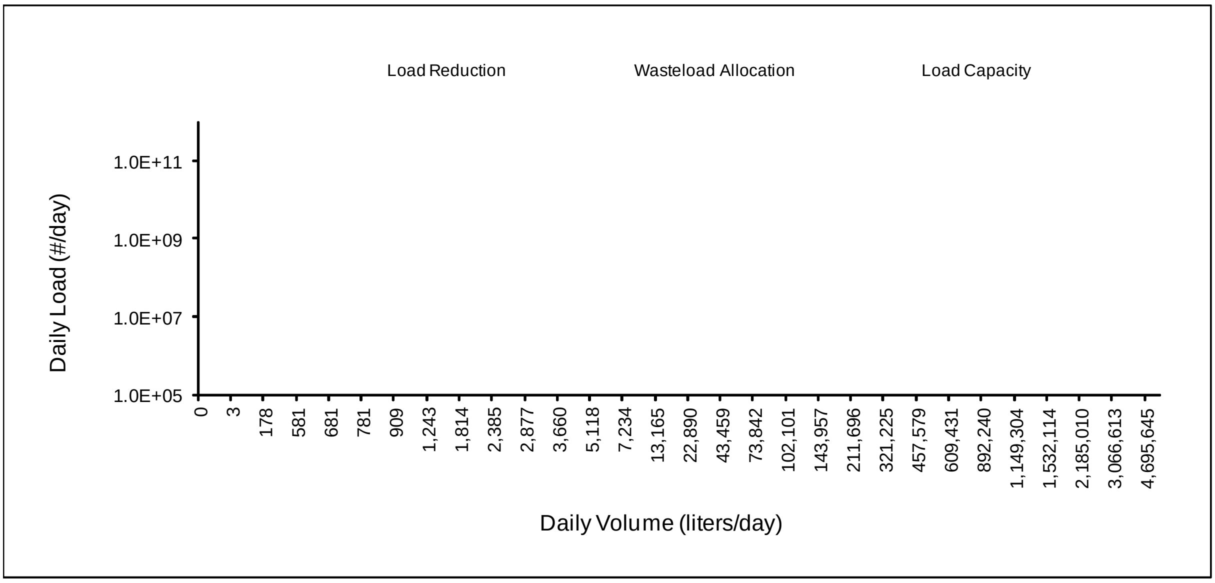


Figure 7. Existing daily wet-weather *E. coli* load (modeled) within LAR Estuary direct drainage subbasins (CFU/day)

Load duration curves, developed for each of the LBC beaches direct drainage subbasins, are shown in Figure 8 through Figure 12, and Figure 13 illustrates a similar curve for the total LAR Estuary direct drainage loading. Summary statistics for each of the subbasins, including the average annual loading rates by subbasins, are shown in the table below each figure. These curves show the simulated results for average daily load (MPN/day) on the y-axis and the daily water volume on the x-axis (liters) for the days designated as wet. As expected, the volumes and associated loads were higher at the larger LBC beaches direct drainages (Molino Avenue [Figure 9] and Redondo Street [Figure 10]); however, these sites did not have the highest simulated percent reductions. The existing loads at the LAR Estuary were higher than the LBC beaches (likely due to the larger land area) and require 99.8 percent reduction (Figure 13).

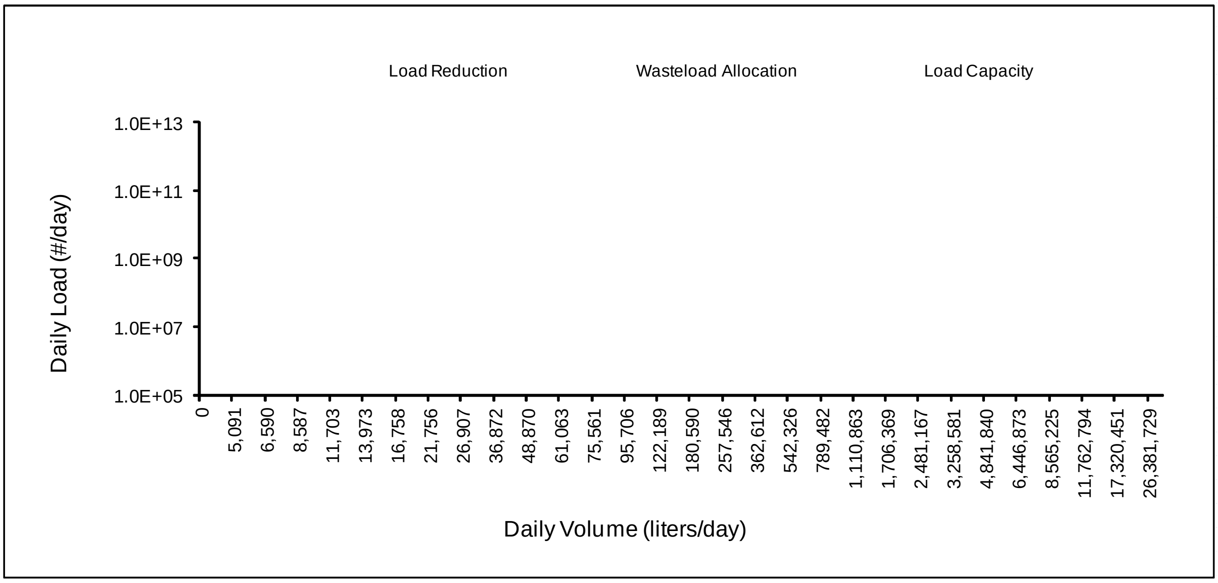
Long Beach City Beaches - 9th Place (*freshwater*), 1990-2010 Model Simulation



Computed Load Indicators	Value	Units
Total Wet Days Over 20-Year Period	1179	none
Total Below Load Capacity Curve	1.25E+09	#/day
Existing Condition (Red and Blue)	4.40E+10	#/day
Existing Load Below Load Capacity Curve (Blue)	1.25E+09	#/day
Existing Load Above Load Capacity Curve (Red)	4.28E+10	#/day
TMDL Wasteload Reduction	97.2%	none

Summary of Annual Average Loads	Value	Units
Average Annual Volume	31	million liters
Average Annual Existing Load	2.60E+12	#/year
Average Annual Exceedance Load	2.52E+12	#/year
Average Annual Load Capacity	7.35E+10	#/year
% Reduction	97.2%	none

Figure 8. *E. coli l*oad duration curve for wet-weather in 9th Place drainage

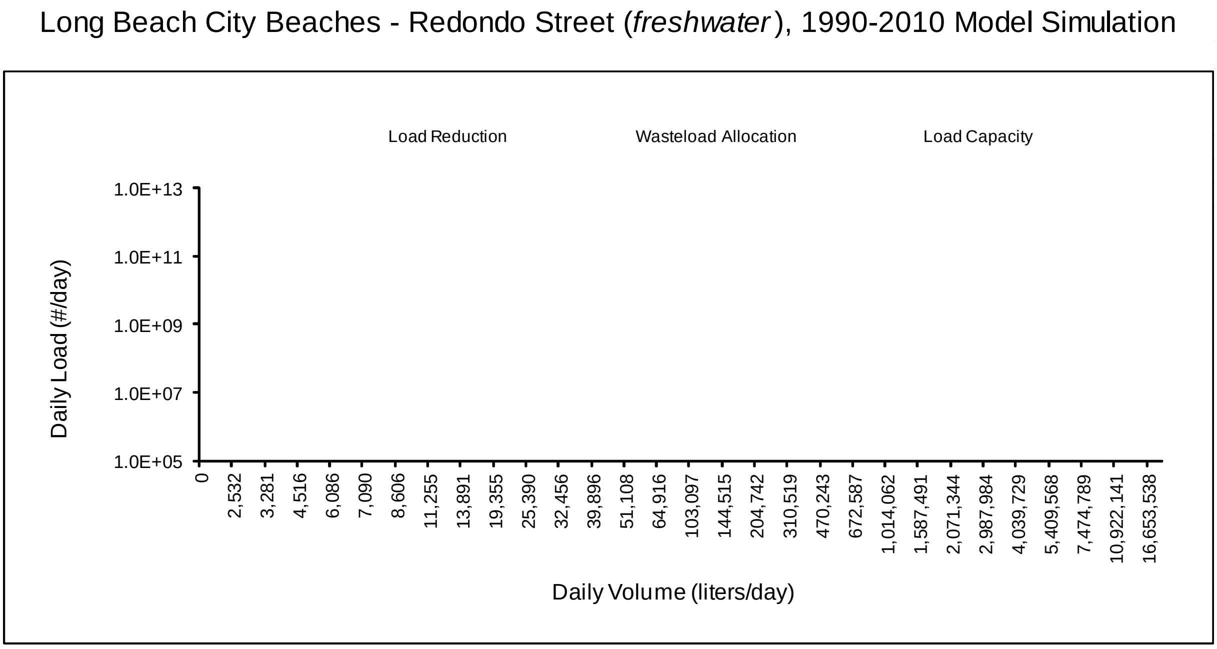


Long Beach City Beaches - Molino Avenue (*freshwater*), 1990-2010 Model Simulation

Computed Load Indicators	Value	Units
Total Wet Days Over 20-Year Period	1179	none
Total Below Load Capacity Curve	6.92E+09	#/day
Existing Condition (Red and Blue)	1.66E+11	#/day
Existing Load Below Load Capacity Curve (Blue)	6.92E+09	#/day
Existing Load Above Load Capacity Curve (Red)	1.59E+11	#/day
TMDL Wasteload Reduction	95.8%	none

Summary of Annual Average Loads	Value	Units
Average Annual Volume	174	million liters
Average Annual Existing Load	9.78E+12	#/year
Average Annual Exceedance Load	9.37E+12	#/year
Average Annual Load Capacity	4.08E+11	#/year
% Reduction	95.8%	none

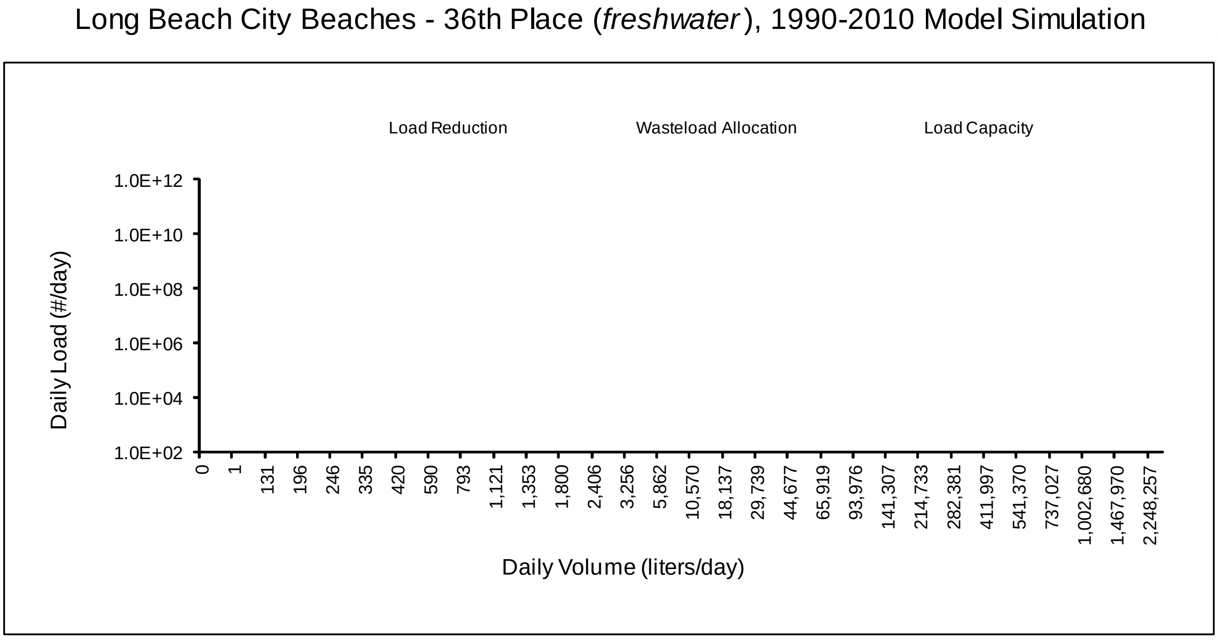
Figure 9. ***E. coli l*****oad duration curve for wet-weather in Molino Avenue drainage**



Computed Load Indicators	Value	Units
Total Wet Days Over 20-Year Period	1179	none
Total Below Load Capacity Curve	4.35E+09	#/day
Existing Condition (Red and Blue)	1.50E+11	#/day
Existing Load Below Load Capacity Curve (Blue)	4.35E+09	#/day
Existing Load Above Load Capacity Curve (Red)	1.45E+11	#/day
TMDL Wasteload Reduction	97.1%	none

Summary of Annual Average Loads	Value	Units
Average Annual Volume	109	million liters
Average Annual Existing Load	8.82E+12	#/year
Average Annual Exceedance Load	8.56E+12	#/year
Average Annual Load Capacity	2.56E+11	#/year
% Reduction	97.1%	none

Figure 10. *E. coli l*oad duration curve for wet-weather in Redondo Street drainage

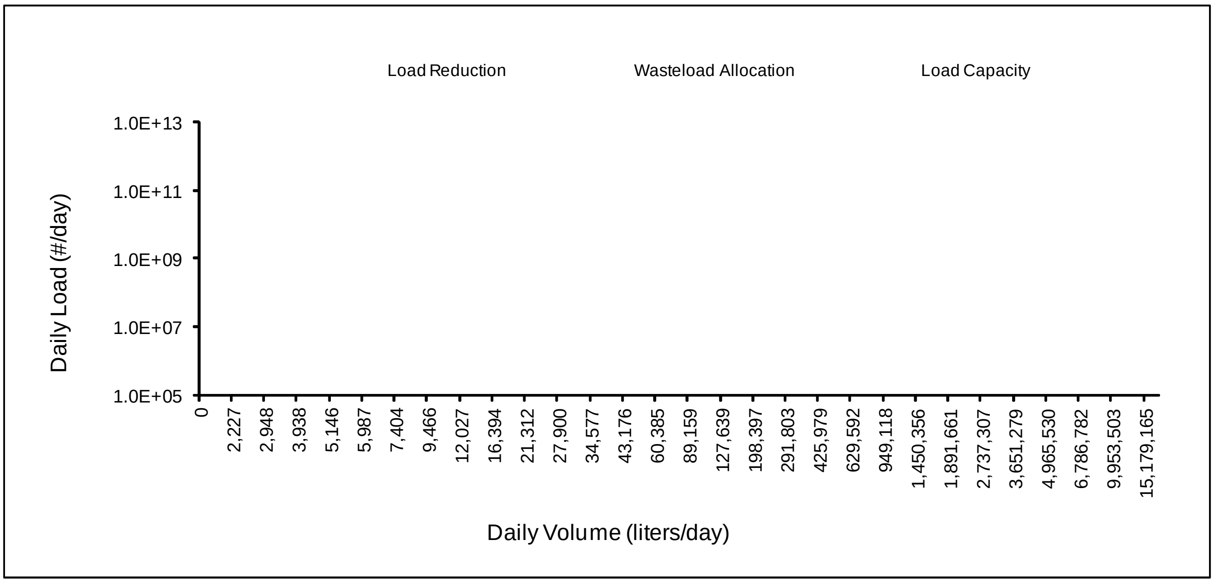


Computed Load Indicators	**Value**	**Units**
Total Wet Days Over 20-Year Period	1179	none
Total Below Load Capacity Curve	5.87E+08	#/day
Existing Condition (Red and Blue)	1.12E+10	#/day
Existing Load Below Load Capacity Curve (Blue)	5.87E+08	#/day
Existing Load Above Load Capacity Curve (Red)	1.06E+10	#/day
TMDL Wasteload Reduction	94.7%	none

Summary of Annual Average Loads	**Value**	**Units**
Average Annual Volume	15	million liters
Average Annual Existing Load	6.59E+11	#/year
Average Annual Exceedance Load	6.24E+11	#/year
Average Annual Load Capacity	3.46E+10	#/year
% Reduction	94.7%	none

Figure 11. *E. coli* load duration curve for wet-weather in 36th Place drainage

Long Beach City Beaches - West Belmont Pier (*freshwater*), 1990-2010 Model Simulation

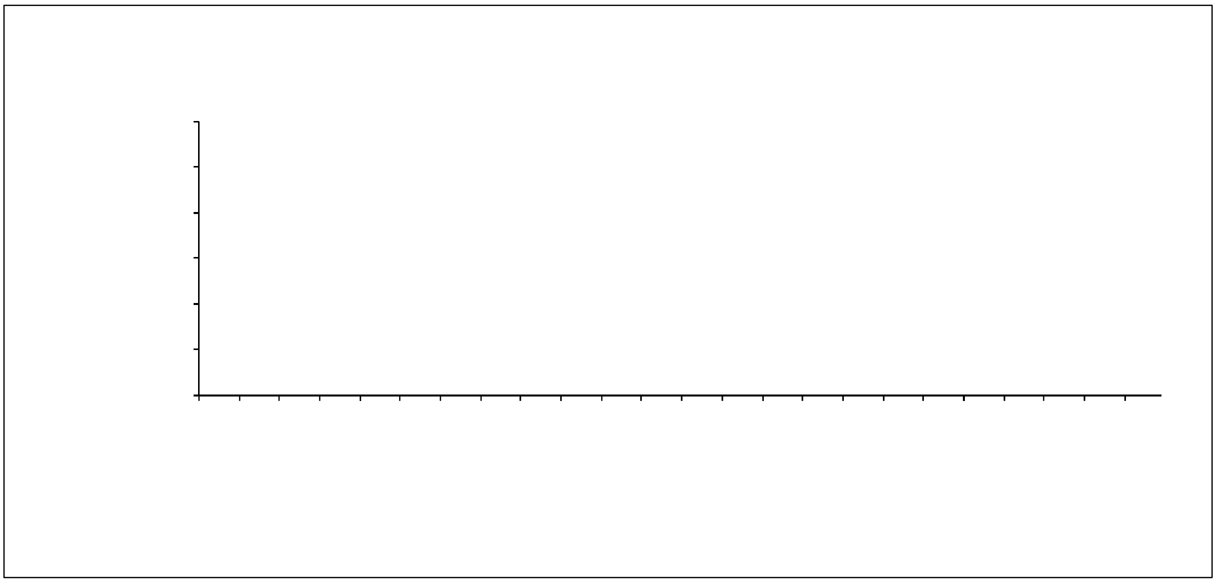


Computed Load Indicators	Value	Units
Total Wet Days Over 20-Year Period	1179	none
Total Below Load Capacity Curve	3.97E+09	#/day
Existing Condition (Red and Blue)	1.03E+11	#/day
Existing Load Below Load Capacity Curve (Blue)	3.97E+09	#/day
Existing Load Above Load Capacity Curve (Red)	9.91E+10	#/day
TMDL Wasteload Reduction	96.2%	none

Summary of Annual Average Loads	Value	Units
Average Annual Volume	100	million liters
Average Annual Existing Load	6.08E+12	#/year
Average Annual Exceedance Load	5.84E+12	#/year
Average Annual Load Capacity	2.34E+11	#/year
% Reduction	96.2%	none

Figure 12. *E. coli l*oad duration curve for wet-weather in West Belmont Pier drainage

Los Angeles River Estuary (*freshwater drainage*), 1990-2010 Model Simulation



Computed Load Indicators	Value	Units
Total Wet Days Over 20-Year Period	1179	none
Total Below Load Capacity Curve	2.14E+11	#/day
Existing Condition (Red and Blue)	1.21E+14	#/day
Existing Load Below Load Capacity Curve (Blue)	2.14E+11	#/day
Existing Load Above Load Capacity Curve (Red)	1.21E+14	#/day
TMDL Wasteload Reduction	99.8%	none

Summary of Annual Average Loads	Value	Units
Average Annual Volume	5,360	million liters
Average Annual Existing Load	7.12E+15	#/year
Average Annual Exceedance Load	7.11E+15	#/year
Average Annual Load Capacity	1.26E+13	#/year
% Reduction	99.8%	none

Figure 13. *E. coli l*oad duration curve for wet-weather in LAR Estuary direct drainage

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