2.6 COMBINED SEWER SYSTEM AND RECEIVING WATER MODELING

Section 2.6 summarizes the use of mathematical models to characterize CSSs and evaluate CSO control alternatives and CSO impacts to receiving waters. This section discusses modeling objectives, as well as model selection and application, for the CSS and receiving water. As with other sections of this chapter, the intent is to provide an introduction to the information presented in greater detail in EPA's guidance on monitoring and modeling (1995d).

2.6.1 Combined Sewer System Modeling

This section briefly summarizes CSS modeling objectives, model selection strategy, and model development and application, including model calibration and validation and the different types of model simulations (e.g., long-term continuous versus storm event simulations).

2.6.1.1 CSS Modeling Objectives

The primary objective of CSS modeling is to understand the hydraulic response of the CSS to a variety of precipitation and drainage area inputs. CSS modeling can also be used to predict pollutant loadings to receiving waters. Once the model is calibrated and verified, it can be used for numerous applications that support CSO planning efforts, including (EPA, 1995d):

- To predict overflow occurrence, volume, and, in some cases, quality for rain events other than those which occurred during the monitoring phase. These can include a storm event of large magnitude (long recurrence period) or numerous storm events over an extended period of time.

- To predict the performance of portions of the CSS that have not been extensively monitored.

- To develop CSO statistics, such as annual number of overflows and percent of combined sewage captured in response to the presumption approach of the CSO Control Policy.

- To optimize CSS performance as part of NMC implementation. In particular, modeling can assist in locating storage opportunities and hydraulic bottlenecks and demonstrate that system storage and flow to the POTW are maximized.

- To evaluate and optimize control alternatives, from simple controls described under the NMC to more complex controls proposed in a municipality's LTCP. An example of a simple control would be to raise weir heights to increase in-line storage. The model can be used to evaluate the resulting reductions in CSO volume and frequency.

CSS Modeling and the CSO Control Policy

The CSO Control Policy "*...supports the proper and effective use of models, where appropriate, in the evaluation of the nine minimum controls and the development of the long-term CSO control plan*" (II.C.1.d). Every CSS does not need to be analyzed using complex computer models. In simple systems, computation of hydraulic profiles using basic equations (e.g., Manning's equation) and spreadsheet programming might be sufficient for identifying areas where certain measures can be implemented and for evaluating their hydraulic effect. Mathematical simulation can play an important role in credibly predicting the performance of any CSS, however. In many cases, especially in complex CSSs that have looped networks or sections that surcharge, a hydraulic computer model will be a useful tool to assess both NMC and LTCP options.

As discussed in the CSO Control Policy, continuous simulation refers to the use of long-term rainfall records (from several months to several years) rather than rainfall records for individual storms (design storms). Continuous simulation has several advantages: (1) simulations are based on a sequence of storms so that the additive effect of storms occurring close together can be examined, (2) storms with a range of characteristics are included, and (3) in cases where the municipality intends to use the presumption approach to WQS attainment, long-term simulations enable the development of performance criteria based on long-term averages, which are not readily determined from design storm simulations. Continuous simulation need not involve the application of extremely complex models. Models that simulate runoff without complex simulation of sewer system hydraulics (e.g., STORM, SWMM RUNOFF) might be appropriate if rough estimates are acceptable or for CSSs with simple basic hydraulics.

Modeling can support either the demonstration or presumption approach of the CSO Control Policy. The demonstration approach requires demonstration that a control plan is adequate to meet CWA requirements. Meeting this requirement can necessitate detailed CSS modeling to define inputs to receiving water impact analyses. The presumption approach, however, involves numeric limits on the number or volumes of CSOs. This approach may require less modeling of receiving water impacts. However, the presumption approach is acceptable only if "*...the permitting authority determines that such presumption is reasonable in light of the data and analysis conducted in the characterization, monitoring and modeling of the system and the consideration of sensitive areas...*" (II.C.4.a).

2.6.1.2 CSS Model Selection

Several guidance documents present strategies for selecting the appropriate CSS model (EPA, 1995d; Shoemaker et al., 1992; Donigian and Huber, 1991; WPCF, 1989). This section briefly summarizes the model selection process.

CSS modeling involves two distinct elements—hydraulics and water quality:

- Hydraulic modeling consists of predicting flow characteristics in the CSS. These characteristics include the different flow rate components (i.e., sanitary, infiltration, and runoff), the flow velocity and depth in the interceptors and sewers, and the CSO flow rate and duration.
- CSS water quality modeling consists of predicting the quality of the combined sewage in the system, particularly at CSOs and at the treatment plant. Water quality is measured in terms of critical parameters, such as bacterial counts, and concentrations of constituents, such as BOD, suspended solids, nutrients, and toxic contaminants.

Some models include both hydraulic (e.g., number and magnitude of overflows) and water quality components, while others are limited to one or the other. The type and complexity of modeling depends on the aspect of the CSO Control Policy being evaluated. Exhibit 2-15 shows the different combinations of hydraulic and contaminant simulation that might be appropriate under different circumstances.

Exhibit 2-15. Relevant CSS Hydraulic and Contaminant Transport Modeling for the CSO Control Policy

	CSS Hydraulic Modeling	CSS Contaminant Transport Modeling
Nine Minimum Controls		
Demonstrate implementation of the nine minimum controls	Simple to complex models of duration and peak flows	Limited - Not usually performed
Presumption Approach		
Limit number of overflow events per year	Long-term continuous simulations (preferred) or design storm simulation	Limited - Not usually performed
Capture at least 85% of wet weather combined sewage volume per year	Same	Limited - Not usually performed
Eliminate or reduce mass of pollutants equivalent to 85% capture requirement	Same	Use measured concentrations or simplified transport modeling
Demonstration Approach		
Demonstrate that a selected control program is adequate to meet the water quality-based requirements of the CWA	Design storm simulations or long-term continuous simulations	Use measured concentrations or contaminant transport simulations

Source: EPA, 1995d

Hydraulic Models

The hydraulic models appropriate for CSS simulations can be divided into three main categories (EPA, 1995d):

- **Water-budget models** based on Soil Conservation Service (SCS) curve numbers, runoff coefficients, or other similar method for the generation of flow. These models can estimate runoff flows influent to the sewer system and, to a lesser degree, flows at different points in the system. However, these models do not actually simulate flow in the CSS and, therefore, do not predict such parameters as the flow depth, which frequently control CSO occurrence.

- **Models based on the kinematic wave approximation** of the hydrodynamic equations. These models can predict flow depths and, therefore, overflows in systems not subject to surcharging or backups (backwater curves).

- **Complete, dynamic models** are based on the full hydrodynamic equations and can simulate surcharging, backwaters, or looped systems.

Examples of these three classes of models are the RUNOFF, TRANSPORT and EXTRAN blocks, respectively, of the EPA Storm Water Management Model (SWMM). EPA's guidance on monitoring and modeling lists the capabilities and limitations of these models (1995d). The following list provides criteria for selecting a CSS hydraulic model:

- Ability to accurately represent the physical characteristics and flow processes relevant to CSS performance
- Extent of monitoring activity underway
- Need for long-term simulations
- Needs for CSS water quality simulations
- Needs for receiving water quality analysis
- Ability to assess the effects of control alternatives
- Use of the presumption or demonstration approach
- Ease of use and cost.

Water Quality Models. CSS water quality models can be divided into the following categories:

- **Land Use Loading Models**—These models provide pollutant loadings as a function of the distribution of land uses in the watershed. Although there are variations, the basic approach is to attribute to each land use a concentration for each water quality parameter. The overall runoff quality is then calculated as a weighted sum of these concentrations. Pollutant concentrations for the different land uses can be derived from local data bases or the NURP studies, if local data are not available (local data are strongly recommended).
- **Statistical Methods**—A more sophisticated version of the previous method is based on a derived frequency distribution for Event Mean Concentrations (EMCs), usually based on lognormality assumptions. Documents on NURP discuss the use of statistical methods to characterize CSO quality in detail (Hydroscience, Inc., 1979) and in summary form (EPA, 1983).
- **Buildup/Washoff Models**—These models attempt to deterministically simulate the basic processes that control the quality of runoff. This approach can consider such factors as time periods between events, rainfall intensity and best management practices. Calibration is required, however.

For some pollutants, chemical reactions and transformations within the CSS might be important. Few models address this topic, and calibration is difficult because loading into the CSS is never exactly known. If a CSS water quality model is warranted, criteria for the selection of a model for the LTCP include the following (EPA, 1995d):

- Needs of the receiving water quality simulation
- Ability to assess control and best management practice (BMP) alternatives
- Ability to accurately represent significant characteristics of pollutants of concern
- Capability for pollutant routing
- Expense and ease of use.

EPA and Army Corps of Engineers have developed numerous hydraulic and water quality models, ranging from simple to complex, which are available for use. A description of these models and their characteristics is beyond the scope of this guidance. EPA's guidance on monitoring and modeling provides detailed information (EPA, 1995d).

2.6.1.3 CSS Model Application

In modeling terminology, the model's level of discretization (i.e., coarse versus fine scale) determines the accuracy with which it will represent the geometry of the CSS or the land characteristics of the drainage basin. In determining the appropriate level of discretization, the modeler must ask the following questions. What is the benefit of a finer level of detail? What is the penalty (in accuracy) in not modeling a portion of the system? For systems controlled hydraulically at their downstream ends, modeling only the larger downstream portions of the CSS might be successful. This strategy would not be wise, however, if it is known that surcharging in upstream areas of the CSS (in small pipes) occurs, limiting flows. In this case, a simulation neglecting the upstream portion of the CSS would overestimate flows in the system.

In some cases, it is difficult to determine ahead of time the appropriate level of detail. In these cases, the modeler can take a phased approach, determining the value of additional complexity or data added in the previous step.

A model general enough to fit a variety of situations typically should be adjusted to the characteristics of a particular site and situation. Modelers use model calibration and verification first to perform this adjustment and then to demonstrate the credibility of the model simulation results. Using an uncalibrated model might be acceptable for screening purposes. Without supporting evidence, however, the uncalibrated result might not be accurate. To use model simulation results for evaluating control alternatives, the modeler should supply evidence demonstrating the model's reliability.

Model Calibration

Calibration is the process of using a set of input data and then comparing the results to measurements of the system. For example, a CSS hydraulic model used to simulate overflows is calibrated by running the model using measured rainfall data to simulate attributes of CSOs, such as volume, depth, and timing. The model results are then compared to actual measurements of the overflows. The modeler then adjusts parameters, such as the Manning roughness coefficient or the percent imperviousness of subcatchments, and runs the model a second time, again comparing the results to observations. Initial calibration runs often point to features of the system, such as a connection or bypass, that might not have been evident based on the available maps. The modeler repeats this procedure until satisfied that the model produces reasonable simulations of the overflows.

Verification

Verification is the process of testing the calibrated model using one or more independent data sets. Verification is important to modeling because it assesses whether the model retains its generality (i.e., a model that has been adjusted extensively to match a particular storm exactly might lose its ability to predict the effects of other storms). In the case of the hydraulic simulation, the model is run without any further adjustment using an independent set of rainfall data. Then, the results are compared to the field measurements collected concurrently with these rainfall data. If the results are suitably close, the model is considered to be verified. The modeler can then use the model with other sets of rainfall data or at other outfalls. If verification fails, the modeler must recalibrate the model and verify it again using a third independent data set. If the model fails a verification test, the next test must use a new data set. Re-using a data set from a previous verification test does not constitute a fair test, because the modeler has already adjusted model parameters to ensure compliance.

2.6.2 Receiving Water Modeling

This section describes the use of models in evaluating CSO impacts on receiving waters.

2.6.2.1 Receiving Water Modeling Objectives

The goal of the receiving water analysis (which may include modeling) is to characterize CSO impacts on receiving water quality and to predict the improvements from different CSO controls.

Receiving Water Quality Modeling and the CSO Policy

Under the CSO Control Policy, a municipality should develop an LTCP that adopts either the demonstration or the presumption approach to attainment of WQS. The demonstration approach is based on adequately demonstrating that the selected CSOs will provide for the attainment of WQS, including designated uses in the receiving water. The presumption approach does not explicitly call for analysis of receiving water impacts. The presumption approach usually involves at least screening-level models of receiving water impacts, however, because the approach will not apply if the NPDES permitting authority determines that the LTCP will not result in attainment of CWA requirements.

2.6.2.2 *Receiving Water Model Selection*

Three factors need to be considered when selecting a receiving water model:

- The type and physical characteristics of the receiving water body. Rivers, estuaries, coastal areas, and lakes typically require different models.
- The water quality parameters that need to be modeled, which include bacteria, dissolved oxygen, suspended solids, toxics, and nutrients. These parameters are affected by hydrodynamics and by other processes (e.g., die-off for bacteria, settling of solids, biodegradation for DO, adsorption for metals), which have different time scales (e.g., hours for bacterial die-off, days for biodegradation) and different kinetics. The time scale in turn affects the extent of the receiving water modeled (e.g., a few hundred feet for bacteria to a few miles for dissolved oxygen).
- The number and geographical distribution of discharge points and the need to simulate sources other than CSOs.

Receiving water modeling may consist of hydrodynamic modeling (to assess flow conditions) and/or water quality modeling. Both hydrodynamic and water quality receiving water models can be *steady-state* or *transient*. Steady-state models assume that conditions do not change over time, while transient models can simulate time varying conditions. Depending on the application, various combinations of steady-state and transient models can be used for receiving water models.

Hydrodynamic Models

For simple cases, hydrodynamic conditions can be determined from the receiving water monitoring program; otherwise, flow conditions are calculated using a hydrodynamic model. The main purpose of a hydrodynamic model is to provide the flow conditions, characterized by the water depth and velocity, for which water quality must be predicted. Because the same basic transport equations apply, the major models for receiving waters can generally simulate more than one type of receiving water body (i.e., rivers, estuaries, coastal areas, lakes). Whether a model can be used with a particular hydraulic regime depends upon several factors: whether the model is a one-, two-, or three-dimensional simulation; the ability of the model to handle specific boundary conditions, such as tidal boundaries; whether the model assumes steady-state conditions or allows for time varying pollutant loading. In general, steady-state loading models cannot accurately model CSO problems that require analysis of far-field effects.

Water Quality Models

Because CSO loads are typically delivered in short pulses during storm events, the selection of appropriate time scales for receiving water modeling depends upon the time and space scales necessary to evaluate the WQS. If analysis requires determining the concentration of a toxic at the edge of a relatively small mixing zone, a steady-state mixing zone model might be satisfactory. When using a steady-state mixing zone model in this way, the modeler should apply appropriately conservative assumptions about instream flows during CSO events. For pollutants such as oxygen demand, which could result in an impact over a period of several days and often several miles downstream of the CSO, incorporating the pulsed nature of the loading might be warranted. Assuming a constant loading is much simpler (and less costly) to model, however, it is conservative (i.e., leads to impacts larger than expected). For pollutants such as nutrients where the response time of the receiving water body might be slow, simulating only the average loading rate might suffice.

Detailed receiving water simulation models do not need to be implemented in all situations (EPA, 1995d). In some cases, the use of dilution and mixing zone calculations or simulation with simple spreadsheet models is sufficient to assess the magnitude of potential impacts or to evaluate the relative merit of various control options. EPA's guidance on monitoring and modeling discusses the simulation of different water quality parameters in rivers, lakes, and estuaries and summarizes available water quality models (EPA, 1995c).

2.6.2.3 Receiving Water Model Application

The application of receiving water models for CSO programs includes the following steps:

- Development of the model
- Model calibration and verification

- Model analysis
- Interpretation of results.

Although the general principles of establishing the data needs for receiving water models are similar to those discussed for CSS models, the specific requirements depend upon the hydraulic regime and model employed (EPA, 1995d). For specific input data requirements, the municipality should refer to the documentation for individual models, the relevant sections of the *Guidance for State Water Monitoring and Wasteload Allocation Programs* (EPA, 1985), or to texts such as *Principles of Surface Water Quality Modeling and Control* (Thomann and Mueller, 1987).

Model Calibration and Verification

Like CSS models, receiving water models need to be calibrated and verified. This is accomplished by running the model to simulate events for which receiving water hydraulic and quality monitoring was conducted and comparing the model results with the measurements. Calibration and verification are often conducted in two steps: first for receiving water hydrodynamics and then for water quality. Calibration of a receiving water quality model typically cannot be achieved with the same degree of accuracy as that of a CSS model for the following reasons:

- Pollutant loadings, which are required input to the receiving water quality model, are typically not known accurately, whether they are determined by monitoring or modeling of the CSS system.
- Because three-dimensional receiving water models are still not commonly available and used in CSO control efforts, receiving water models involve spatial averaging (over the depth, width, or cross-section). Thus, model results are not directly comparable with measurements, unless the results have sufficient spatial resolution to allow comparable averaging.
- Loadings from non-CSO sources (such as storm water), upstream boundaries, other point sources, and atmospheric deposition, are frequently not known.
- Receiving water hydrodynamics are affected by numerous factors which are difficult to account for, including fluctuating winds, large-scale eddies, and density effects.

These uncertainties, however, make calibration all the more important to ensure that the model reasonably reflects receiving water characterization data. *Measures of Verification, Workshop on Verification of Water Quality Models* presents a detailed discussion of the validation procedure for water quality models (Thomann, 1980).

Model Analysis

Analyses can be conducted using single events or long-term simulations. Single event simulations are usually favored when using complex models, although advances in computer technology keep extending the limits of what can practically be achieved. Long-term simulations can provide predictions of water quality impacts on an annual basis.

While a general goal might be to determine the number of WQS exceedances, models allow evaluation of these exceedances using different measures, such as duration of exceedance at critical points (e.g., beaches), acre-hours of exceedance, and mile-hours of exceedance along a shore. These provide a more refined measure of CSO impacts on water quality and of the improvements that would result from implementation of different CSO controls. A frequently used approach is to conduct separate simulations for CSO loadings alone to gage the CSO impacts relative to other sources. Chapter 3 discusses the application of this approach. This procedure is appropriate because the equations governing receiving water quality are linear and, consequently, the effects are additive.

It is useful to assess the sensitivity of modeling results due to variations and changes in parameters, rate constants, and coefficients. Results of such sensitivity analyses determine the key parameters, rate constants, and coefficients that merit particular attention in evaluating CSO control alternatives. The modeling approach should accurately represent features that are fully understood and also be supported by sensitivity analyses to develop an understanding of the significance of other factors or features that are not as clearly defined. Sensitivity or uncertainty analyses can define the extent of variation in predicted future water quality conditions due to a variation of water quality parameters or factors that are not well defined or well established.

Interpretation of Results

Using averages over space and time, simulation models predict CSO volumes, pollutant concentrations, and other variables of interest. The extent of this averaging is a function of the model structure, model implementation, and resolution of the input data. The purpose of modeling generally includes assessing the attainment of WQS, the number or volume of overflow events, or other conditions proposed by the permit writer. The model's space and time resolution should match that of the necessary analysis. For instance, the applicable WQS can be expressed as a 1-hour average concentration not to exceed a given concentration more than once every 3 years on average. Spatial averaging can be represented by a concentration averaged over a receiving water mixing zone or implicitly by the specification of monitoring locations to compare results with in-stream criteria. In any case, the municipality should note whether the model predictions use the same averaging scales required in the permit or relevant WQS.

The key output of the receiving water modeling is the prediction of expected conditions due to CSO control alternatives and their associated reductions of pollutant loads. In most cases, the municipality will use the modeling results to determine which load reductions are necessary for achieving WQS.

CASE STUDY: LEWISTON-AUBURN, MAINE—CSO AND RECEIVING WATER MODELING

The CSSs in Auburn and Lewiston were analyzed to determine the flow quantities and pollutant loads discharged to area receiving waters from CSSs within each community. The CSO analysis was accomplished using the Storm Water Management Model (SWMM), which mathematically simulates the time varying nature of CSOs, including both quantity and quality variation over time, under various hydrologic conditions. As part of the analysis, the CSO response to short-term rainfall, including a range of design storm events, and the effects of long-term rainfall, using annual precipitation records, were evaluated for existing and future no-action conditions.

In addition, the Androscoggin and Little Androscoggin Rivers were analyzed to assess the impacts of CSOs on receiving waters. This analysis focused on *E. coli* bacteria levels in the two rivers because the wet weather monitoring program indicated that only this criterion was exceeded.

CSO MODEL DEVELOPMENT

To use SWMM to determine the CSO flows and loads discharged by each community, the physical characteristics of each CSS and their combined sewer tributary areas were discretized into individual elements for model input. For this study, a coarse level of discretization was used to characterize the CSOs. The level of discretization involved modeling the main trunk sewers, interceptors, and CSO regulators in detail and modeling the area tributary to each CSO as a single drainage area, or subcatchment, depending on land use. The discretization provided the necessary degree of accuracy for the hydraulics controlling CSOs, while maintaining an economical analysis effort for the study area.

SWMM was used to predict the quantity and quality of CSOs from both the Auburn and Lewiston CSSs under various conditions, which were not directly measured, and under proposed future conditions. First, however, the model's ability to predict such conditions was demonstrated through the following steps:

- Flow monitoring, block testing, rainfall monitoring, and quality sampling during dry weather and wet weather storm events were conducted, as described in the case study following Section 2.5.3.6.

- Necessary input data for SWMM were established by reviewing existing record information and field measurements.

- SWMM was run with data collected during one storm event, and the model results were compared to the observed field results. Physical parameters were adjusted within acceptable limits to obtain the "best fit" between observed and computed data.

- A second storm event was then run using SWMM with the same physical parameters used to model the first storm. Model results were compared with observed data, thereby establishing confidence in the model's results.

- Flow and pollutant concentration data from monitored CSOs were extrapolated to the remainder of the study area in order to model the entire area.

- Overall study area simulations were compared with block testing data from non-monitored locations to confirm accurate predictions.

CSO MODEL CALIBRATION AND VERIFICATION

The SWMM models were calibrated using the flow and quality data collected at the eight monitored CSOs and the treatment plant during September 26-28, 1993. Several parameters were used to assess the accuracy of the calibration process, including:

- Duration, peak flow, and volume of CSOs
- Hydrographs of measured flows versus predicted model results
- Magnitude and timing of peak flow and quality values.

To achieve agreement between measured values and predicted modeling results, adjustments were made to the hydraulic and hydrologic input data developed for each system. The major factor affecting the magnitude of runoff peaks and volumes was the percent of impervious area of the individual subcatchments. The initial values for percent imperviousness were based on the review of existing sewer record plans and topographical maps, which show the study area drainage patterns. Consequently, these values were considered likely candidates for adjustment during calibration. A second parameter that affected the magnitude and timing of peak flows is the subcatchment width. Other factors that could alter the timing and magnitude of peak flows included ground slope and surface storage, as well as resistance parameters. These factors were also used during calibration, although their impact on runoff peaks and volumes is significantly less than the percent of impervious area and the subcatchment width.

For the calibration of CSO quality, pollutant washoff coefficients and constituent fractions of dust and dirt were the major adjustment parameters. The pollutant washoff coefficients and constituent fractions affect the magnitude of surface runoff pollutant concentrations, while the washoff coefficients alter the distribution of the pollutant concentration over time during a storm. Once a generally close match was obtained between actual and model results, the models were verified. Verification involved running additional storms without adjusting model parameters. The models were verified using the October 12-13, 1993 storm event, which yielded 1.22 inches of rainfall over a 13-hour period, activating all of the monitored CSOs for a sustained period of time.

CSO MODEL RESULTS

Once the model was calibrated and verified, CSO flow and pollutant loads were simulated for a range of developed design storms. Design storms with return periods of 1 week, 1 month, 3 months, 6 months, 1 year, 2 years, 5 years, and 10 years were selected for analysis. The design storms were run in SWMM to determine the storm size required to trigger CSOs under existing and future no-action conditions.

Total CSO volume and pollutant loads were estimated for the 1-week through 10-year design storms for existing conditions. These served as the basis for sizing and evaluating CSO control alternatives. Once the baseline existing conditions had been developed, the future no-action conditions were analyzed. These conditions changed from the existing condition as a result of increases in population or major projects scheduled in the study area that would affect the quantity and quality of CSOs. For the purposes of this study, the CSO analysis for future conditions was based on estimates of wastewater flows and pollutant loads for a 20-year planning period, or until the year 2015.

Values were estimated for annual population growth, domestic wastewater contribution rates, annual increase in commercial/industrial flows, and pollutant loadings for domestic and commercial/industrial wastewater. The projected incremental growth, together with the flow and load values for the baseline year, were then totaled to provide flow and load estimates for the year 2015 and project incremental growth in wastewater flow and pollutants loads between the baseline year (1992) and the planning year (2015).

In comparison, the results for this future no-action condition showed a slight increase in CSO volumes and pollutant loads over existing conditions.

In addition to the design storm study outlined, the continuous simulation mode of SWMM was used to develop annual CSO flows and loads for the study area. Hourly precipitation data for a long-term period were used to generate CSO flows and loads during wet weather periods, while pollutant buildup on subcatchment areas was calculated during dry weather periods. A historical rainfall analysis identified 1974 as the most representative year for the period of record, in which 95 storms occurred totaling 43.3 inches of rainfall. The hourly precipitation data recorded for 1974 were then input to the SWMM models for a continuous simulation of annual CSO flows and loads in the study area under existing and future no-action conditions.

RECEIVING WATER MODEL DEVELOPMENT

To assess CSO impacts on area receiving waters, the Androscoggin and Little Androscoggin Rivers were analyzed. The wet weather monitoring data indicated that the existing CSOs only result in exceedance of the criterion for *E. coli* bacteria. For this reason, the receiving water analysis conducted in this study only considered *E. coli* bacteria levels within the Androscoggin and Little Androscoggin Rivers under existing and future no-action conditions.

After reviewing available approaches to conducting the receiving water analysis, a simplified modeling effort was selected to provide a useful definition of the duration of impacts from wet weather discharges at a relatively low cost. The simplified modeling approach was used, therefore, for the analysis of the two major rivers in the study area. In addition, CSOs in Lewiston affect several small receiving waters, including Goff Brook, Gully Brook, Jepson Brook, and Stetson Brook. With the exception of Gully Brook, there is very little or, in some cases, no flow in these brooks during dry weather. Any CSO to these receiving waters causes significant exceedances of bacterial standards. Gully Brook, an extension of the Upper Canal from the Androscoggin River, flows within and normally is contained within the CSS, only discharging to the canal during a CSO event. Consequently, Gully Brook was not considered as a separate receiving water, but as part of the Androscoggin River.

Jepson Brook is also somewhat unique in the study area. Once a natural drainage brook tributary to the Androscoggin River, Jepson is now a concrete-lined trapezoidal drainage channel that receives discharges from 15 CSOs and many separate storm drains. Although designated as a Class B receiving water suitable for swimming and aquatic life, there is no evidence that either use exists in Jepson Brook. The base flow in the brook is quite low, less than 0.5 cfs, and similar to the other brooks, any CSO will cause exceedances of the water quality criteria for bacteria.

An adaptation of the CHARLESA model was used to simulate CSO and storm water impacts on the Androscoggin and Little Androscoggin Rivers. The CHARLESA model, developed by the Massachusetts Institute of Technology, is a simplified version of the one-dimensional, time-dependent QUAL2EXP water quality model. This modified version of the QUAL2EXP model only simulates the transport and first-order decay (bacterial die-off) of *E. coli* bacteria.

The receiving water model requires discretization of the river into a number of model "elements," each representing a short length of the river. The model determines the volume of water and pollutant load passed from one element to the next over short-time intervals. Pollutant loads from CSOs are added to elements that correspond to outfall locations along the river banks. Water quality is assumed to be fully mixed laterally. The hydraulic portion of the model is semi-transient with constant model element volumes but varying flows. Conservation of mass (continuity) is ensured by increased river discharge downstream of inflows. A completely transient hydraulic model was determined not to be necessary for the scope of the modeling effort in this project.

Model inputs included river segment volumes (river geometry), upstream flows and pollutant loads, and source flows and pollutant loads. River geometry was determined using cross-sections from previous hydraulic modeling efforts performed by the USGS to delineate flood zones along the river. Using these cross-sections and river discharge information recorded by the USGS gaging station in Auburn, river surface elevations were estimated for both monitored rainfall events (September 26-27 and October 12-13) and used to determine river segment volumes. Upstream flows were set equal to the measured river discharges. Upstream bacterial loads were assumed to be negligible.

CSO loads from both communities were estimated using SWMM results, discussed previously. Other source loadings included the flow and pollutant load contributions from the Little Androscoggin River and Jepson Brook, as well as dry weather overflows in Auburn during the time of the sampling and monitoring period. Pollutant loadings from the Little Androscoggin River were simulated using the receiving water model, while the dry weather overflows were estimated based on the monitoring data collected on the rivers during dry weather conditions.

RECEIVING WATER MODEL CALIBRATION AND VERIFICATION

The model was calibrated and verified to determine the optimum dispersion and decay coefficients for use in simulations of future conditions and to ensure that the model could reasonably reproduce river quality for a known rainfall event. The two storms during which water quality sampling was performed were used for calibration and verification of the model. The calibration runs were performed with a decay coefficient of 1.0 (/day) and a longitudinal dispersion coefficient of 5.0 (m^2/sec). Additional runs of the model with varied coefficients did not change model results in any significant manner. It was observed that, due to the huge variations in loadings and the relatively large volume of clean upstream flow, the modeled pollutant concentrations were dominated by advection effects (the transport of pollutants due to movement of the river water) with relatively little decay occurring within the model bounds. Simulations of the verification storm that occurred on October 12-13, 1993, confirmed the reasonable accuracy of the water quality models.

RECEIVING WATER MODEL RESULTS

Once the receiving water models were calibrated and verified, water quality simulations for the full range of design storms were performed for existing and future no-action conditions under the worst case scenario of 7-day, 10-year low flow (7Q10) conditions. Because the stages of both the Androscoggin and Little Androscoggin Rivers are regulated extensively by the various dams in the Lewiston-Auburn area, however, a true quantification of the 7Q10 flow condition was not possible. For the purpose of these simulations, therefore, the design flows for the Androscoggin and Little Androscoggin Rivers were assumed to be the minimum release requirements for the Lewiston Falls Dam on the Androscoggin River and the lower Barker Mills Dam on the Little Androscoggin River.

CSO pollutant loads, developed in the CSS analyses, were input to the water quality model for each design storm simulation. In general, water quality criteria exceedances in the Androscoggin River occurred for a longer period of time for the future condition simulations than the calibration and verification runs with similar rainfall. This indicated that water quality conditions depend greatly upon the flushing capabilities of the Androscoggin River. Whereas the design flow was only 1,000 cfs, the average flows for the calibration and verification storm events were 2,590 and 3,370 cfs, respectively. A similar trend was also observed in the modeling of the Little Androscoggin River. The design storm simulations also indicated that storms in excess of the 1-month storm do not increase significantly the period of water quality criteria exceedances. Thus, larger quantities of pollutants would be expected to increase the magnitude of exceedances, but not the duration. The analysis demonstrated that wet weather discharges cause exceedances of the WQS for bacteria in all area receiving waters.