Appendix A4

Model Calibration

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A4.1 Model Calibration

Calibration is used for nearly every kind of scientific modeling. Physically based models generally have some parameters that can be directly measured and others that cannot. During calibration, the values of non-measurable parameters are adjusted to satisfy the input/output relationship of the modeled system. This is accomplished by running the model using incremental iterations of values for one or more of the unknown parameters. Model calibration entailed adjusting the model parameters that control the magnitude and shape of simulated I/I flows. The outputs from successive model iterations were compared with measured values for the output parameters (such as flow, for a hydrologic model). When the modeled output closely and consistently matches the measured output, the model is considered calibrated.

The procedure for selecting parameter values to calibrate each flow components is complex. It requires a detailed understanding of the relationship between parameter values defined in MOUSE and the resulting simulated flow response. The Danish Hydraulic Institute developed MOUSE, or Modeling of Urban Sewers, for continuous simulation of rainfall-dependent I/I and for quantifying the I/I entering the sewer system basins. The calibration procedure typically begins by first defining the less variable components of flow, such as dry weather flow. Therefore, the initial steps of calibration involve comparing and calibrating model simulations to records collected during periods of dry weather. After dry weather calibration is completed, the effort focuses on matching simulation results to recorded wet weather flows. In general, the procedure involves targeting particular periods of the observed flow record to first match hydrograph volume, then matching peak flow and shape.

A4.1.1 Calibration Flow Time Series

MOUSE model “runs” (a run is defined as a single iteration of model calculations, representing a single parameter combination) is compared to the collected flow data. The flow data is collected at several monitoring sites and generally can be directly compared with modeling results for various basins. Sometimes, the calibration process for a basin is based upon the addition or subtraction of data between two or more different meters.

Subtraction and addition is completed by comparing upstream and downstream measured flow hydrographs. Flow travel time lags are corrected for as well as any other effects that might inhibit the subtraction. The final subtracted data is averaged over a 60-minute moving interval. Note that when calibration relies on addition or subtraction of data, the data is considered valid only for time periods when valid data was collected at all required meters.

A4.1.2 Dry Weather Calibration

The first step in the calibration process for each model basin is to match simulated flows with flows measured during dry weather. The dry weather flows measured at the beginning of each monitoring period are used to define and calibrate dry weather flow input into the model. Dry weather flows are represented in MOUSE using three components (see Figure A4-1 for additional detail):

1. The daily diurnal pattern above the daily minimum flow
2. The portion of the daily minimum flow estimated to be wastewater (the remaining flow below the daily minimum flow was assumed to be base infiltration)

The portion of the daily minimum flow estimated to be dry weather infiltration (base infiltration)

To calibrate each basin to existing conditions, the amount of dry weather flow is derived from the available measured flow data. King County had monitoring data available from dry periods, so it was not necessary to use population to determine the wastewater contribution in each basin (population can provide an estimate of the wastewater contribution in the absence of flow data collected over dry periods).

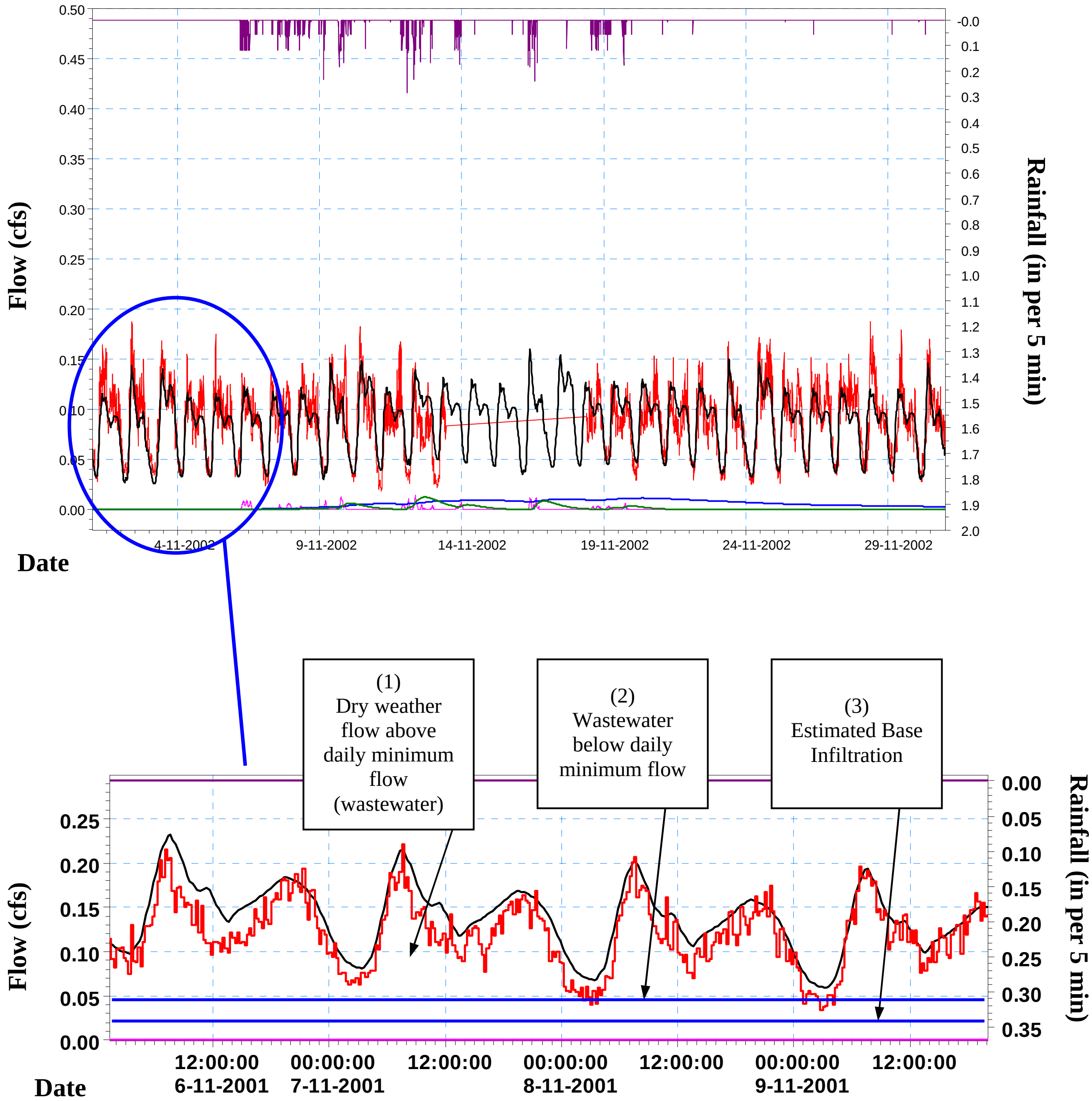

Figure A4-1. Dry Weather Flow Calibration

A4.1.3 Wet Weather Calibration

MOUSE represents wet weather I/I as three distinct responses: fast response, rapid infiltration, and slow infiltration. During the calibration process, each wet weather flow component is "tuned" (partially calibrated) individually in order (from the slow infiltration response to the fast response). Then an overall final tuning is done.

Tuning for the slow infiltration response is done by matching the diurnal dry weather flow pattern to the flow data before and after storm events as well as at the end of the monitoring season. If the slow infiltration response component is adjusted correctly, the dry weather flow pattern matches the flow data at the higher flow around the storm events. This approach is a way of separating out the component into flows that are primarily dependent on the addition of the slow infiltration component.

Tuning for the rapid infiltration component is done by matching storm event volumes and shapes with special attention to matching the flow recession of the storm events. The rapid infiltration component is primarily responsible for the recession limb of the storm event. Measured flow responses to all storms are used for calibration; however, it is typically not possible to match simulated flows to measured flow responses for all storms. In these cases, more emphasis is placed on matching flow responses to large, rather than small storms.

The last component to be tuned is the fast response component. The fast response component is tuned to match storm peaks. With regard to shape and peak, this effort involves fine-tuning the rapid infiltration response. Large storms are matched at the cost of smaller storms when there are inconsistencies.

After all components are tuned, calibration is finalized by adjusting all components together until the best model-to-flow data "fit" is achieved. Reduced emphasis is placed on periods with unreliable or inconsistent diurnal wastewater flow patterns (such as holidays). Figure A4-2 presents a plot of simulated flow (black) versus measured flow (red). Rainfall (purple) is included on the reverse second Y-axis for reference. Also included for reference are the wet weather I/I components: fast response (magenta), rapid infiltration (green), and slow infiltration (blue).

The calibration process is based on the monitored flow data. The confidence in final model parameter combinations decreases when large amounts of data are missing or not collected.

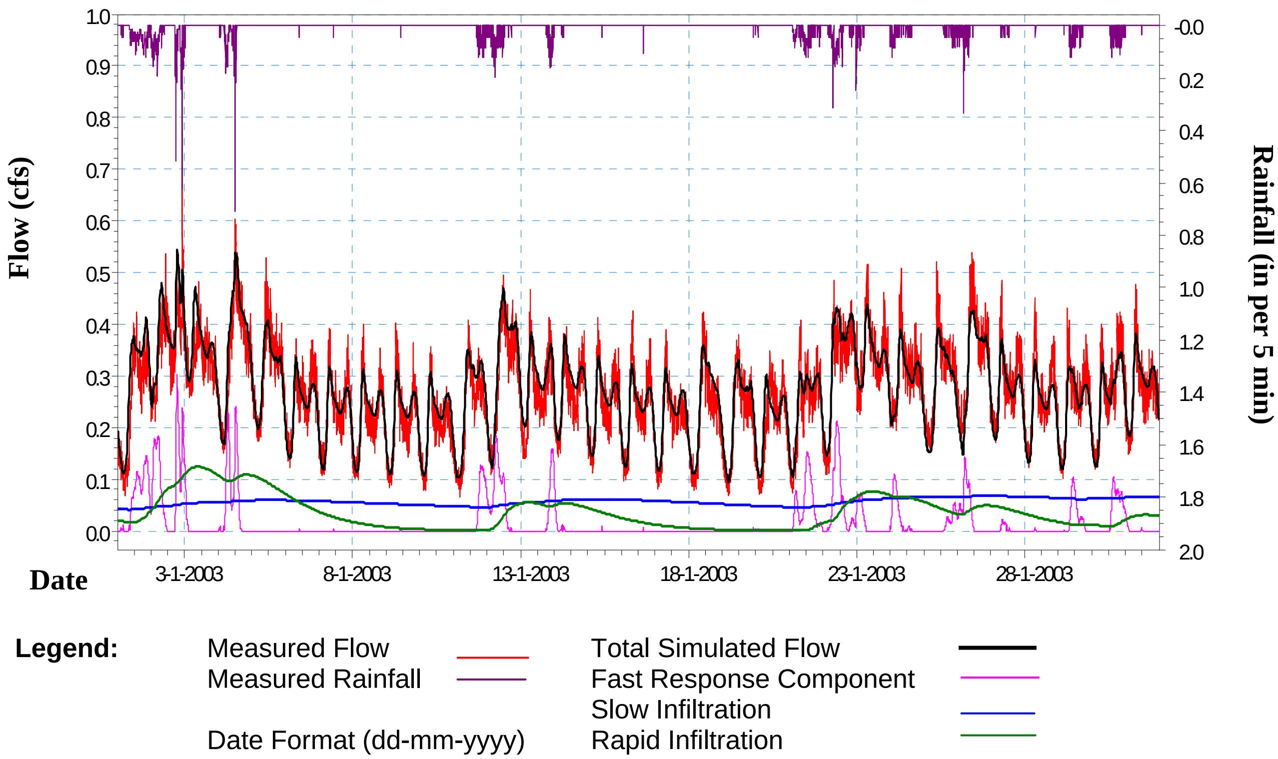

Figure A4-2. Model Calibration Example

A4.2 Estimated 20-Year Peak Flows

King County has adopted a 20-year flow capacity standard for conveyance facilities that transport wastewater from local agencies to County treatment plants. This means the facilities must have capacity for flows of a magnitude that can be expected on an average of once every 20 years (20-year return period). This corresponds to a 5-percent chance of such flows or higher occurring in any given year. To maintain consistency with King County capacity standards, the difference in the 20-year flow established for pre-rehabilitation versus post-rehabilitation is used to estimate rehabilitation effectiveness.

To estimate the benefits of I/I reduction, it is also necessary to estimate reduction in the 20-year flow achieved through system rehabilitation. It is unlikely that an event as infrequent as the 20-year flow will be measured during a short monitoring period; therefore, alternative methods were developed to estimate the 20-year flow. Many traditional methods, such as the "design storm approach," equate rainfall probability to flow probability. These methods become unreliable when flow of a given magnitude can result from a range of rainfall events. As antecedent conditions become more significant in determining flow response, it becomes increasingly difficult to correlate flow to a single rainfall event. The design storm approach lacks the ability to account for varying geographic coverage, antecedent conditions, or impacts from successive rainfall events, all of which are common in this region. An additional consideration is the sensitivity of flows resulting from rainfall received over successive days, weeks, or even months.

The method used to estimate the 20-year flow for each basin consisted of conducting an extended simulation and performing a frequency analysis on the simulated flows. Through calibration of the continuous simulation model to measured flows, the parameters describing each basin were adjusted to represent the processes that transform rainfall to infiltration and inflow. The model can then be used to simulate flow response from a long-term rainfall time series that includes large, infrequent rainfall events. By simulating a continuous, long-term period, this approach accounts for the effects of antecedent conditions.

A4.2.1 20-Year I/I Flow Estimation Procedure

After the hydrologic model for each basin is calibrated, it is simulated with a 60-year extended time series (ETS) of precipitation as input. The ETS were developed to facilitate application of continuous simulation hydrology despite variability of mean annual precipitation and infrequent rainfall event volumes throughout the study area. The ETS applicable to the King County study area were developed by adjusting the 60-year SeaTac rainfall record to match the storm statistics of the time series records at over 50 precipitation gauges located in the lowlands of western Washington. More specifically, a series of statistical scaling functions were used rather than a single scaling factor. The scaling functions provide for scaling rainfall amounts at the 2-hour, 6-hour, 24-hour, 72-hour, 10-day, 30-day, 90-day, and annual durations.

The 60-year simulation produces a time series of flows at the basin outlet. This 60-year flow time series can be used to determine flow frequency, which includes estimating the 20-year peak I/I flow from each model basin. The procedure for estimating the 20-year peak I/I flow can be summarized in the following steps:

1. Develop and calibrate a basin model using rainfall and flow data measured in the basin.
2. Simulate flow response with the calibrated model using the 60-year extended time series (ETS) of precipitation as input.
3. Extract, rank, and plot the simulated peak I/I flows.
4. Estimate the 20-year I/I flow from the plot of peak flows.

The ETS simulation produces 60 years of simulated flows at the basin outlet. From this information, a plot can be made of peak flow magnitude versus return period such as the one shown in Figure A4-3. A best-fit curve is used to interpolate between the plotted points with a return period greater than 1 year. The estimated 20-year flow was determined by selecting the flow from the plotted best-fit curve with a return period of 20 years.

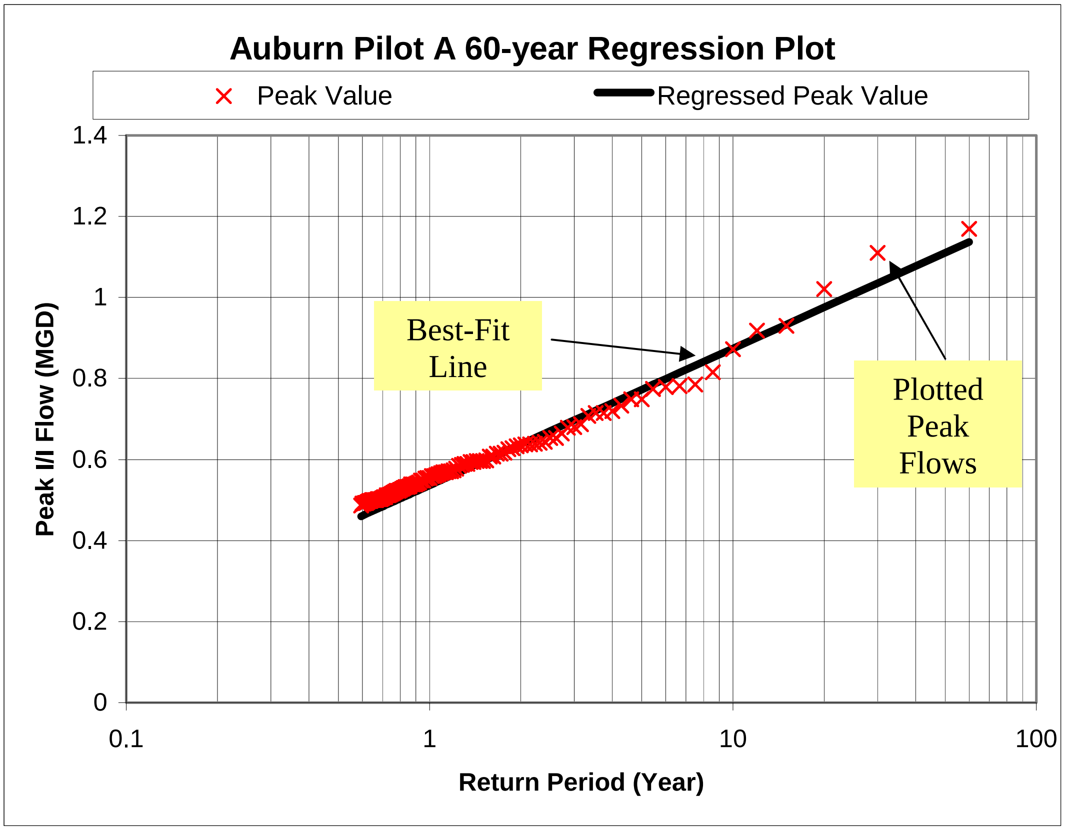

Figure A4-3. Assigning Return Intervals to Peak Simulated Flows

This process relies on several key assumptions. The ETS were derived using the SeaTac rainfall record, which is the longest continuous record of rainfall data in the eastern Puget Sound lowlands. It was assumed to be representative of rainfall patterns likely to occur in the service area, after adjustments were made to account for annual and peak rainfall differences throughout the region. Another key assumption is that a calibrated model can simulate flow response from any rainfall time series. Representation of multiple flow components and calibration to varied conditions provides a reasonable basis for such an extrapolation assuming that the events calibrated to are large enough to be able to project out to the 20-year event.