APPENDIX 4E

Continuous Simulation Modeling

List of Tables

4E-1 Hydrologic Analysis Methods for Designing BMPs in Western Washington: HSPF versus SBUH

This section provides a brief description and in-depth discussion of the methodologies used for calculating stormwater runoff from a project site. It includes a discussion on estimating stormwater runoff with continuous simulation models versus single-event models such as the Santa Barbara Urban Hydrograph (SBUH).

The Hydrologic Simulation Program – Fortran (HSPF) model is a U.S. EPA program for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. The HSPF model uses information such as the time history of rainfall, temperature, and solar radiation, and land surface characteristics such as land use patterns and land management practices to simulate the hydrologic processes that occur in a watershed. The result of this simulation is a time history of the quantity and quality of runoff from an urban, forested, or agricultural watershed. Flow rate and sediment load, as well as nutrient and pesticide concentrations, can be predicted.

Unlike intensity-duration models, which are sensitive to the peak rainfall intensity, the SBUH method models runoff by analyzing a given time period of rainfall to generate a hydrograph sensitive to variations in the rainfall preceding and following the peak. It was specifically developed to model runoff from urbanized areas that have mostly impervious land usage.

4E-1.1 Hydrologic Analysis for Runoff Treatment

When designing a flow rate-based runoff treatment BMP, use a calibrated, approved continuous simulation hydrologic model based on HSPF. This is because single-event models, such as SBUH, tend to underestimate the time of concentration, and the peak flow rate occurs too early. This affects treatment BMPs that are designed to achieve a specified flow residence time (the resulting designs are more conservative). Calculation of the flow residence time is sensitive to the shape of the inflow hydrograph. The inflow hydrograph is also of fundamental importance when designing an infiltration or filtration BMP, as these BMPs are sized based on a routing of the inflow hydrograph through the BMP.

When designing a volume-based runoff treatment BMP, use a calibrated, approved continuous simulation hydrologic model based on HSPF such as MGSFlood or the Washington State Department of Ecology’s (Ecology’s) Western Washington Hydrology Model (WWHM).

4E-1.2 Hydrologic Analysis for Flow Control

Because of single-event hydrologic model limitations, use an approved continuous simulation model, rather than a single-event model such as SBUH, to design flow control BMPs for WSDOT projects in western Washington. While SBUH may give acceptable estimates of total runoff volumes, it tends to overestimate peak flow rates from pervious areas, because it cannot adequately model subsurface flow (which is a dominant flow regime for predevelopment conditions in western Washington basins). One reason SBUH overestimates the peak flow rate for a pervious area is that the actual time of concentration is typically greater than what is assumed. Better flow estimates could be made if a longer time of concentration was used. This would change both the peak flow rate (it would be lower) and the shape of the hydrograph (peak occurs somewhat later), and the hydrograph would better reflect actual predeveloped conditions.

Another reason that SBUH overestimates the peak rates of runoff from undeveloped land is the curve numbers (CN) presented for single-event modeling in the 1995 *Highway Runoff Manual*. These curve numbers were developed by the U.S. Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS), and published as the Western Washington Supplemental Curve Numbers. These CN values are typically higher than the standard CN values published in NRCS Technical Release 55 (1986). In 1995, the NRCS recalled the use of the western Washington CNs for floodplain management and found that the standard CNs better describe the hydrologic conditions for rainfall events in western Washington. However, based on runoff comparisons with the King County Runoff Time Series (KCRTS), which is a continuous simulation model, better estimates of runoff are obtained when using the western Washington CNs for developed pervious areas such as parks, lawns, and other landscaped areas. Consequently, the CNs in this manual are changed to those in NRCS Technical Release 55, except for the open spaces category for the developed areas, which include lawns, parks, golf courses, cemeteries, and landscaped areas. For these areas, the western Washington CNs are used. ***Note:*** These changes are intended to provide better runoff estimates using the SBUH method. For CN values, see Appendix 4B.

When the SBUH is used to estimate runoff rates in a 24-hour storm event, it is not capable of simulating soil moisture characteristics that have a significant impact on generation of runoff. Sizing of stormwater BMPs based on 24-hour storms does not reflect the effects of longer-term storms in western Washington. The use of a longer-term (such as 3- or 7-day) storm is perhaps better suited for western Washington and could better capture the hydrologic effect of back-to-back storm events.

HSPF is a continuous simulation model capable of simulating a wider range of hydrologic responses than the single-event models like SBUH. For use in western Washington, WSDOT has developed the continuous simulation hydrologic model MGSFlood, based on HSPF. MGSFlood uses multiyear inputs of hourly precipitation and evaporation to compute a multiyear timeseries of runoff from the site. Use of precipitation input that is representative of the site under consideration is critical for the accurate computation of runoff and the design of stormwater facilities. Precipitation and evaporation timeseries have been assembled for most areas of western Washington and are stored in a database file accessed by the program.

Default HSPF model parameters that define rainfall interception, infiltration, and movement of moisture through the soil are based on work by the USGS and King County and have been included in MGSFlood. Pervious areas have been grouped into three land cover categories: forest, pasture, and lawn; and three soil/geologic categories: till, outwash, and saturated/wetland soil—for a total of seven land cover/soil type combinations (as shown in Table 4E-1). The combinations of soil type and land cover are called pervious land segments, or PERLNDS, in HSPF. Default runoff parameters for PERLNDS are loaded automatically by the program for each project and should not be changed. If you change these values, the changed values are noted in the project documentation report. If a basin or watershed has been calibrated, you can use those PERLNDS values, since they are site specific.

Table 4E-1 Pervious land cover/soil type combinations used with HSPF model parameters.

Pervious Land Cover/Soil Type Combinations
1. Till/Forest
2. Till/Pasture
3. Till/Lawn
4. Outwash/Forest
5. Outwash/Pasture
6. Outwash/Lawn
7. Saturated Soil/All Cover Groups

4E-1.3 Pond Design Using Routing Table

Perform routing using the information entered in the *Pond Hydraulics Excel Spreadsheet*. You can key into and copy information from the spreadsheet and paste it into the hydrology program (MGSFlood or WHAM) using the Windows clipboard function. *Elevation* is the water surface elevation in the pond; *Area* is the pond surface area (acres); *Volume* is the pond volume (acre-feet); *Discharge* is the pond discharge (cfs); and *Infilt* is the infiltration rate (cfs) through the pond bottom. Water infiltrated through the pond bottom does not contribute to the computed pond outflow. (See Appendix 4A for a web link to example problems that will provide suggestions for manipulating the design to achieve matching predeveloped and postdeveloped durations.)

4E-1.4 Pond Design Using Optimization

The proprietary version of MGSFlood includes routines for computing pond hydraulics and automatically sizing detention pond and outlet works to meet the duration-based flow control standard (see Table 3-6). Designing stormwater ponds to this standard is a laborious, iterative process, whereby the runoff timeseries (typically 40 years or more) is routed through the pond, and flow-duration statistics are computed and compared with predeveloped flow-duration statistics. The automatic pond-sizing routine in MGSFlood performs this pond design procedure.

The automatic pond-sizing optimization routine in the MGSFlood Hydraulic Structures add-in module will determine the pond size and outlet configuration for three pond types: (1) a detention pond with no infiltration, (2) a detention pond with minor infiltration, and (3) an infiltration pond. The characteristics of these pond types are listed in Table 4E-2.

MGSFlood also has the following features:

1. Option for simulating multiple structures to allow the designer to account for infiltration that occurs upstream of a detention facility and to analyze sites with multiple treatment facilities.

2. Determines whether the runoff treatment volumes can be infiltrated in 36 hours. Under this premise, the storm/runoff ends 12 hours after the runoff period midpoint and combines with the 24-hour drain criteria; therefore, it would take 36 hours to drain the pond.

3. Subroutine that provides water surface elevation magnitude-frequency statistics and reports these in the project report.

4. Subroutine that computes varying infiltration rates as a function of pond depth using the Detailed Approach Method (Massmann’s) equations.

5. Subroutine to compute the volume of stormwater treated by a sand filter.

6. Subroutine that states the percentage of runoff that infiltrates through the pond bottom relative to the total pond inflow.

7. Predevelopment, 100-year line on pond performance flow duration graph.

8. Subroutine for infiltration trench design on the embankment or in the ditch line.

9. Subroutines for compost-amended vegetated filter strips (CAVFS), filter strips, and flow splitters.

Table 4E-2 Characteristics of detention and infiltration ponds sized using MGSFlood optimization routine.

Characteristic	Detention Pond	Infiltration Pond
Pond Configuration	Riser Structure With Low-Level Circular Orifice and Vertical Rectangular Upper Orifice	Overflow Riser Only
Valid Infiltration Rates	0.00–0.10 inches/hour	0.05–50 inches/hour
Optimization Levels	Quick or Full	Quick Only

Two levels of optimization are available for detention pond sizing: Quick Optimization and Full Optimization. Quick Optimization determines a “ballpark” solution in a relatively short time (usually less than one minute). Full Optimization does an exhaustive search of potential solutions, seeking a configuration for the minimum pond size required to meet the flow duration standard. The Full Optimization routine usually converges on a solution in less than ten minutes, depending on the speed and memory of the computer.

The pond-sizing optimization routine uses general input about the pond geometry, including:

1. Pond length-to-width ratio
2. Pond side slope
3. Pond floor elevation
4. Riser crest elevation
5. Pond infiltration rate

The pond-sizing routine uses this information to establish the geometric relationships for the pond configuration. The program establishes a parameter space of possible solutions by varying the pond bottom area and the sizes and elevations of hydraulic devices for the outlet structure. The program then routes the developed runoff timeseries through the pond and seeks to find a solution that provides the minimum pond size to meet the discharge flow duration requirements.

Once the optimization has determined a pond size, it is still possible to go back to the first tab under Pond/Vault Geometry and manually manipulate the pond size under the Prismatic Pond Geometry or the Elevation Volume Table for irregularly shaped ponds.

The standard outlet configuration used for detention ponds consists of a circular low-level orifice and a vertical rectangular orifice (slot). If you desire a different outlet configuration, you can set the volume-discharge characteristics of the desired configuration c to match the volume-discharge characteristics returned by the program for the orifice/slot weir configuration. The low-level circular orifice is assumed to be free of tailwater effects. If tailwater conditions are present, first use the optimization routine to determine the pond configuration without consideration of tailwater. Then, include the tailwater rating table and manually adjust the pond configuration to meet the flow duration design criteria.

There is a wide variety of combinations of hydraulic devices, device sizes and invert heights, and pond configurations you can use to match the flow duration standard. However, it is difficult to find a pond configuration that minimizes the pond volume and meets the duration standard using a manual trial-and-error approach. The automatic pond-sizing routine searches the parameter space of possible solutions and seeks to find the minimum pond size to meet the flow duration standard.

In some situations, usually when there are “outliers” in the precipitation data or precipitation data of poor quality are used, the pond design may not meet all design criteria. In these cases, the pond design determined by the MGSFlood program is returned to the Hydraulic Structures and Pond/Vault Geometry tabs for manual refinement. You can make modifications to the design and route flows through the pond using manual mode.