Introduction

This chapter presents WSDOT's procedures and acceptable methodologies for hydraulics and hydrologic analyses for roadway hydraulic features design. The procedures and methodologies presented in this chapter assume that the PEO has a basic understanding of the science of hydrology and its principles. Additionally, the PEO should be familiar with the regulations and requirements of various state and federal agencies that regulate water-related construction, as they may be applicable to proposed improvements.

WSDOT uses several methods for determining runoff rates and/or volumes. Experience has shown these methods to be accurate, convenient, and economical. The following methods will be discussed in detail in subsequent sections of this chapter:

1. Rational Method
2. Santa Barbara Urban Hydrograph (SBUH) Method
3. Continuous Simulation Hydrologic Model (MGSFlood)
4. Published Flow Record
5. USGS Regional Regression Equations
6. Existing Hydrologic Studies
7. Basin Transfer of Gage Data

Two other methods—documented reporting and high-water mark observations—shall be used wherever possible to calibrate the results of the above statistical and empirical methods. Where calculated results vary from on-site observations, further investigation may be required. The additional two methods are summarized below:

8. Documented Reporting

Documented testimony of long-time residents should be given serious consideration by the PEO. The PEO must be aware of any bias that residents may have. Independent calculations should be made to verify this type of reporting and observations. The information furnished by residents of the area should include, but not be limited to, the following:

a. Dates of past floods
b. High-water marks
c. Amount of drift
d. Any changes in the river channel that may be occurring (i.e., streambed stability—is the channel widening, migrating, or meandering)
e. Estimated velocity
f. Description of flooding characteristics between normal flow to flood stage

9. High-Water Mark Observations
High-water marks can be used to reconstruct discharge from past flood events on existing structures or on the bank of a stream or ditch. These marks, along with other data, can be used to determine discharge by methods discussed in Chapter 3 or Chapter 4.

Additional hydrologic procedures are available including complex computer models, which can give the PEO accurate flood flow predictions. However, these methods, which require costly field data and large amounts of data preparation and calculation time, can rarely be justified for a single hydraulic structure. The HQ Hydraulics section shall be contacted before a procedure other than those listed above is used in a hydrologic analysis.

For simplicity and uniformity, the HQ Hydraulics section and the RHE will normally require one of the first six methods listed above. Exceptions will be permitted if adequate justification is provided and approved by the RHE.

Section 2-2 discusses how to select the appropriate method of assessing hydrology for a given site. Sections 2-3 and 2-4 discuss other important considerations, including the size of the basin and things to consider in cold climate areas. The remainder of the chapter describes each of the methods in more detail, followed by some examples in Section 2-11.

2-2 Selecting a Method

The first step in performing a hydrologic analysis is to determine the most appropriate method. The methods for determining runoff rates and volumes are summarized below, and Figure 2-1 provides a comparison table. Subsequent sections provide a more detailed description of each method. Additional guidance will be provided in future revisions to the Hydraulics Manual.

• Rational Method (Kuichling 1889): This method is used when peak discharges for basins up to 200 acres must be determined. This method does not provide a time series of flow nor flow volume. It is a simple and accurate method, especially when the basin is primarily impervious. The Rational Method is appropriate for culvert design, pavement drainage design, and storm sewer design. It is also appropriate for some stormwater facility designs in eastern Washington.

• SBUH Method (Stubchaer 1975): This method is used when estimation of a runoff hydrograph is necessary. The SBUH Method also can be used when retention and detention must be evaluated. The SBUH Method can be used for drainage areas up to 1,000 acres. The SBUH Method can be used for stormwater facility designs in eastern Washington and for culvert and storm sewer designs through the entire state.

• Continuous Simulation Hydrologic Model: For western Washington, calibrated continuous simulation hydrologic models, based on the Hydrological Simulation Program-Fortran (HSPF) routine, have been created for computing peak discharges and runoff volumes. These models are used for stormwater facility designs in western Washington and estimating seasonal runoff for temporary stream diversions. WSDOT uses the continuous simulation hydrologic model MGSFlood when calculating runoff treatment rates and volumes for stormwater facility design. Programs other than MGSFlood may be used if approved by HQ Hydraulics Section.
• **Published Flow Record**: This method shall be used whenever there is appropriate stream gauge data available. This is a collection of data rather than a predictive analysis like the other methods listed. USGS, cities, counties, and other agencies gather streamflow data on a regular basis. This collected data can be analyzed statistically to predict flood flows for the river and is typically more accurate than simulated flows. Published flow records are most appropriate for culvert and bridge design.

• **USGS Regional Regression Equations** (Mastin et. al. 2016): This method can be used when there is no appropriate stream gauge data available. It is a set of regression equations that were developed using data from streamflow gauging stations. The regression equations are simple to use but are less accurate than published flow records. USGS regression equations are appropriate for culvert and bridge design and are intended for use in rural and predominately undeveloped basin areas. PEOs should consult the USGS regression equation documentation for limitations when computing flows in urban basins (basins with greater than 5 percent impervious area).

• **Existing Hydrologic Studies**: This method uses existing studies or models of the watershed of interest, including FEMA flood insurance studies, smaller urban drainages, city- or countywide drainage master plans, and calibrated HSPF models. Often these values are accurate since they were developed from an in-depth analysis. Flood report data can be derived from FEMA and other approved sources, including the HQ Hydraulics Section. Obtained data may be appropriate for culvert and bridge design.

• **Basin Transfer of Gauge Data with Regional USGS Equations**: When a project is located on an ungauged stream, but there is a stream nearby with a substantial flow record, it is possible to extrapolate flows from one basin to the other, provided certain criteria are met. The watersheds of the gauged and ungauged streams must have similar geology and soils, elevation range, vegetation, and canopy cover, and must be roughly the same size. The concept is simple:

\[
Q_{\text{ungauged}} = Q_{\text{gauged}} \left( \frac{A_{\text{ungauged}}}{A_{\text{gauged}}} \right)
\]

Where

- \( Q \) = discharge
- \( A \) = drainage area

The USGS offers a spreadsheet called Flood Q Tools that includes the Flood Q Ratio Tool, which incorporates weighting of the ratio-based discharge. The weighting function uses the appropriate regional regression equation. Flood Q Tools can be found at: pubs.er.usgs.gov/publication/sir20165118. Pubs.er.usgs.gov/publication/sir20165118.

The Flood Q Ratio Tool puts bounds on the ungauged site – it must be within 50 percent of the area of the gauged basin and on the same stream. However, if no other tools are available, it may be used to estimate flows on a different stream, provided all other parameters (basin size, soils, elevation, etc.) are similar. This tool also has the functionality of using the regression-based weighting of the \( Q \) derived from the area ratio. Additional inputs for this technique are mean annual precipitation and percent canopy cover (for Regions 1 and 2) in the ungauged basin.
**Figure 2-1 Methods for Estimating Runoff Rates and Volumes**

<table>
<thead>
<tr>
<th>Method</th>
<th>Assumptions</th>
<th>Data Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rational</td>
<td>• Basins &lt;200 acres&lt;br&gt;• Time of concentration &lt;1 hour&lt;br&gt;• Storm duration less than or equal to concentration time&lt;br&gt;• Rainfall uniformly distributed in time and space&lt;br&gt;• Runoff is primarily overland flow&lt;br&gt;• Negligible channel storage (such as detention ponds, channels with significant volume, and floodplain storage)</td>
<td>• Time of concentration (minutes)&lt;br&gt;• Drainage area (acreage)&lt;br&gt;• Runoff coefficient (C values)&lt;br&gt;• Rainfall intensity (use m,n values to calculate inches/hour)&lt;br&gt;</td>
</tr>
<tr>
<td>Santa Barbara Urban Hydrograph</td>
<td>• Rainfall uniformly distributed in time and space&lt;br&gt;• Small to medium basins &lt;1,000 acres&lt;br&gt;• Urban type area (pavement usually suffices)&lt;br&gt;• Regional Storms (eastern Washington)&lt;br&gt;• Short-duration storm for stormwater conveyance&lt;br&gt;• Long-duration storm for stormwater volume&lt;br&gt;• Type 1A Storm (western Washington)&lt;br&gt;</td>
<td>• Curve Number (CN values)&lt;br&gt;• Drainage area (acreage)&lt;br&gt;• Digital precipitation values in the Washington State Department of Transportation GIS, National Oceanic and Atmospheric Administration Atlas, or (Isopluvials) precipitation values&lt;br&gt;</td>
</tr>
<tr>
<td>Continuous Simulation Hydrologic Model</td>
<td>• HSPF routine for stormwater best management practices for flow control facilities, such as detention and infiltration ponds, and water quality facilities, such as vegetated filter strips and bioswales.&lt;br&gt;• Elevations below 1,500 feet</td>
<td>• Drainage basin area (acreage)&lt;br&gt;• Land cover (impervious, vegetation), Soils (outwash, till, saturated)&lt;br&gt;• Climatic Region (mean annual precipitation)&lt;br&gt;</td>
</tr>
<tr>
<td>Published Flow Record</td>
<td>• Basins with stream gauge data&lt;br&gt;• Appropriate station and/or generalized skew coefficient relationship applied</td>
<td>• Ten or more years of gauged flood records (contact the HQ Hydraulics Section for additional guidance)&lt;br&gt;</td>
</tr>
<tr>
<td>U.S. Geological Survey (USGS) Regional Regression Equations</td>
<td>• Appropriate for culvert and bridge design&lt;br&gt;• Midsized and large basins&lt;br&gt;• Simple but lack accuracy of flow records for basins with more than 5% total impervious area</td>
<td>• 2016 Regional Equations&lt;br&gt;• Annual precipitation (inches)&lt;br&gt;• Drainage area (square miles)&lt;br&gt;• StreamStats web application&lt;br&gt;</td>
</tr>
<tr>
<td>Existing Hydrologic Studies</td>
<td>• Appropriate for culvert and bridge design&lt;br&gt;• Midsized and large watersheds&lt;br&gt;• Report accuracy varies so confirm level of accuracy with entity that the report derives from</td>
<td>• Available from Federal Emergency Management Agency or local flood administrative agency typically the City or County&lt;br&gt;</td>
</tr>
<tr>
<td>Basin Transfer of Gauge Data with Regional USGS equations</td>
<td>• Similar hydrologic characteristics and size ratio</td>
<td>• Discharge and area for gauged watershed&lt;br&gt;• Area for ungauged watershed&lt;br&gt;</td>
</tr>
</tbody>
</table>

**Notes:**
- HSPF = Hydrological Simulation Program-Fortran
- (1) The *Highway Runoff Manual* provides detailed guidance for design storms.
2-3 Drainage Basin

The size of the drainage basin is one of the most important parameters regardless of which method of hydrologic analysis is used.

2-3.1 Off-Site Basins

To determine the basin area, use the StreamStats web application, Quad maps, or ArcMap/GIS Workbench. These tools cannot be used in urban areas and all subbasins should be delineated by variation in soil and drainage characteristics.

All basins shall be field verified to the maximum extent feasible. Select the best available topographic map (GIS or other approved mapping software) or best available data that cover the entire area contributing surface runoff to the point of interest. In areas under urban influence, flow paths do not always follow topography due to the presence of streets, buildings, and enclosed drainage (catch basins/pipes). In most cases, drainage patterns and catchment areas cannot be deduced from an in-office terrain analysis. Field verification of how the impervious areas and pervious areas are connected or disconnected to the flow paths may be required.

2-3.2 On-Site Basins

On-site basins areas shall be determined by using the most recent survey data and being field verified by the PEO.

2-4 Cold Climate Considerations

Snowmelt and rain on snow is a complicated process and can result in greater runoff rates. There are two parts to this section: the first part focuses on calculating the impacts of snow melt and the second section provides additional considerations for PEOs when evaluating the impacts of snow melt in a project location.

2-4.1 Calculating Snow Melt

When the project is listed as a mountainous route, per the WSDOT Highway Log, or is over an elevation of 1,500 feet, the project shall consider snow melt impacts. The PEO shall apply the method described in this section, consult the RHE, the WSDOT Maintenance Office, the PEO, and historical data. Then in the hydraulic report, the PEO shall describe in detail what value (if any) was determined to most accurately represent snowmelt at a project location.

The first question PEOs should consider is whether or not snow melt effects will impact a project. In particular, PEOs should check the snow record to determine the maximum monthly average snow depths for the project location. Snow depths can be found at the following websites or by contacting the RHE or HQ Hydraulics Section:

- Washington Climate Summaries
- Washington Snow Map
The following equation uses a factor of 5, developed from the energy budget equation by the U.S. Army Corps of Engineers (USACE), and available snow for eastern Washington cities to convert depth to snow water equivalent. This amount shall be added to the 100-year, 24-hour precipitation value when designing for flood conditions for rain on snow or snowmelt. The equation below should only be applied when the average daily snow depth within the month at a project location meets or exceeds 2 inches:

\[
\text{Snow/water equivalent} = \frac{\text{Average snow depth (maximum per month (inches/day))}}{5}
\]

The snow/water equivalent shall not be greater than 1.5 inches.

### 2-4.2 Additional Considerations

Regardless of snowmelt impacting a project site, PEOs should consider the following issues to provide adequate road drainage and prevent flood damage to downstream properties.

1. **Roadside drainage:** During the design phase, consideration should be given to how roadside snow will accumulate and possibly block and erode inlets and other flow paths for water present during the thawing cycle. If it is determined that inlets could be blocked by the accumulation of plowed snow, consideration should be given to an alternate course of travel for runoff. This will help prevent the water ponding that sometimes occurs in certain areas due to snowmelt and rain not having an open area in which to drain off the roadway. This may require coordination with the WSDOT Maintenance Office.

2. **Retention ponds:** When detention or retention ponds are located near the roadway, the emergency spillway should be located outside of any snow storage areas that could block overflow passage, or an alternative flow route should be designated. This may require coordination with the WSDOT Maintenance Office.

3. **Frozen ground:** Frozen ground coupled with snowmelt or rain on snow can cause unusually adverse conditions. These combined runoff sources are generally reflected in the USGS regression equations and in the historic gauge records. No corrections or adjustments typically need to be made to these hydrology methods for frozen ground or snowmelt. For smaller basins, the SBUH Method and the Rational Method are typically used to determine peak volume and peak runoff rates. The curve number (CN) value for the SBUH Method and the runoff coefficient for the Rational Method typically do not need to be increased to account for frozen ground in snowy or frozen areas as consideration has been given to this in the normal precipitation amounts and in deriving the snowmelt equation.
2-5 Rational Method

2-5.1 General

The Rational Method is used to predict peak flows for small drainage areas, which can be either natural or developed. The Rational Method can be used for culvert design, pavement drainage design, storm sewer design, and some eastern Washington stormwater facility design. The greatest accuracy is obtained for areas smaller than 100 acres and for developed conditions with large portions of impervious surface (pavement, roof tops, etc.).

Basins up to 200 acres may be evaluated using the rational formula (Equations 2-1a and 2-1b); however, results for large basins often do not properly account for effects of infiltration and thus are less accurate. PEOs should never perform a Rational Method analysis on a mostly undeveloped basin that is larger than the lower limit specified for the USGS regression equations, since the USGS regression equations will yield a more accurate flow prediction for that size of basin. The formula for the Rational Method is as follows:

\[ Q = \frac{CIA}{K_c} \]  

(2-1a)

Where:

- \( Q \) = Runoff in cubic feet per second (cfs)
- \( C \) = Runoff coefficient in dimensionless units
- \( I \) = Rainfall intensity in inches per hour
- \( A \) = Drainage area in acres
- \( K_c \) = Conversion factor of 1 for English

When several subareas within a drainage basin have different runoff coefficients, the rational formula can be modified as follows:

\[ Q = \frac{\sum CA}{K_c} \]  

(2-1b)

Where:

\[ \sum CA = C_1 \times A_1 + C_2 \times A_2 + \ldots + C_n \times A_n \]

Hydrologic information calculated by the Rational Method shall be submitted as a calculation package within the hydraulic report using this spreadsheet (link below), or other similar forms approved by the HQ Hydraulics Section that best describes the project’s hydraulic information (www.wsdot.wa.gov/publications/fulltext/hydraulics/programs/hydrology.xls).

This spreadsheet contains all the required input information and the resulting discharge. The description of each area should be identified by name or station so the area may be easily located. A plan sheet or map showing the delineation of these areas shall be included with the hydraulic report along with the appropriate calculations.

2-5.2 Runoff Coefficients

The runoff coefficient "C" represents the percentage of rainfall that becomes runoff. The Rational Method implies that this ratio is fixed for a given drainage basin. In reality, the coefficient may vary with respect to prior wetting and seasonal conditions. The use of an average coefficient for various surface types is quite common, and it is assumed to stay constant through the duration of the rainstorm.
When considering frozen ground, PEOs should review Section 2-4.2, No. 3. In a high growth rate area, runoff factors should be projected that will be characteristic of developed conditions 20 years after project construction. Even though local stormwater practices (where they exist) may reduce potential increases in runoff, prudent engineering should still make allowances for predictable growth patterns.

The coefficients in Figure 2-2 are applicable for peak storms of 10-year frequency. Less frequent, higher intensity storms will require the use of higher coefficients because infiltration and other losses have a proportionally smaller effect on runoff. Generally, when designing for a 25-year frequency, the coefficient shall be increased by 10 percent; when designing for a 50-year frequency, the coefficient shall be increased by 20 percent; and when designing for a 100-year frequency, the coefficient shall be increased by 25 percent. The runoff coefficient shall not be increased above 0.95, unless approved by the RHE. Higher values may be appropriate for steeply sloped areas and/or longer return periods, because in these cases infiltration and other losses have a proportionally smaller effect on runoff.

Figure 2-2  Runoff Coefficients for the Rational Method – 10-Year Return Frequency

<table>
<thead>
<tr>
<th>Cover Type</th>
<th>Flat</th>
<th>Rolling (2% to 10%)</th>
<th>Hilly (Over 10%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement and Roofs</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>Earth Shoulders</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Drives and Walks</td>
<td>0.75</td>
<td>0.80</td>
<td>0.85</td>
</tr>
<tr>
<td>Gravel Pavement</td>
<td>0.50</td>
<td>0.55</td>
<td>0.60</td>
</tr>
<tr>
<td>City Business Areas</td>
<td>0.80</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>Suburban Residential</td>
<td>0.25</td>
<td>0.35</td>
<td>0.40</td>
</tr>
<tr>
<td>Single Family Residential</td>
<td>0.30</td>
<td>0.40</td>
<td>0.50</td>
</tr>
<tr>
<td>Multi Units, Detached</td>
<td>0.40</td>
<td>0.50</td>
<td>0.60</td>
</tr>
<tr>
<td>Multi Units, Attached</td>
<td>0.60</td>
<td>0.65</td>
<td>0.70</td>
</tr>
<tr>
<td>Lawns, Very Sandy Soil</td>
<td>0.05</td>
<td>0.07</td>
<td>0.10</td>
</tr>
<tr>
<td>Lawns, Sandy Soil</td>
<td>0.10</td>
<td>0.15</td>
<td>0.20</td>
</tr>
<tr>
<td>Lawns, Heavy Soil</td>
<td>0.17</td>
<td>0.22</td>
<td>0.35</td>
</tr>
<tr>
<td>Grass Shoulders</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Side Slopes, Earth</td>
<td>0.60</td>
<td>0.60</td>
<td>0.60</td>
</tr>
<tr>
<td>Side Slopes, Turf</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Median Areas, Turf</td>
<td>0.25</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Cultivated Land, Clay and Loam</td>
<td>0.50</td>
<td>0.55</td>
<td>0.60</td>
</tr>
<tr>
<td>Cultivated Land, Sand and Gravel</td>
<td>0.25</td>
<td>0.30</td>
<td>0.35</td>
</tr>
<tr>
<td>Industrial Areas, Light</td>
<td>0.50</td>
<td>0.70</td>
<td>0.80</td>
</tr>
<tr>
<td>Industrial Areas, Heavy</td>
<td>0.60</td>
<td>0.80</td>
<td>0.90</td>
</tr>
<tr>
<td>Parks and Cemeteries</td>
<td>0.10</td>
<td>0.15</td>
<td>0.25</td>
</tr>
<tr>
<td>Playgrounds</td>
<td>0.20</td>
<td>0.25</td>
<td>0.30</td>
</tr>
<tr>
<td>Woodland and Forests</td>
<td>0.10</td>
<td>0.15</td>
<td>0.20</td>
</tr>
<tr>
<td>Meadows and Pasture Land</td>
<td>0.25</td>
<td>0.30</td>
<td>0.35</td>
</tr>
<tr>
<td>Pasture with Frozen Ground</td>
<td>0.40</td>
<td>0.45</td>
<td>0.50</td>
</tr>
<tr>
<td>Unimproved Areas</td>
<td>0.10</td>
<td>0.20</td>
<td>0.30</td>
</tr>
</tbody>
</table>
2-5.3 Time of Concentration

Time of concentration ($T_c$) is defined as the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest in the watershed. Travel time ($T_t$) is the time it takes water to travel from one location to another in a watershed. $T_t$ is a component of $T_c$, which is computed by summing all the travel times for consecutive components of the drainage flow path. This concept assumes that rainfall is applied at a constant rate over a drainage basin, which would eventually produce a constant peak rate of runoff.

Actual precipitation does not fall at a constant rate. A precipitation event usually begins with less rainfall intensity, builds to peak intensity, and eventually tapers down to no rainfall. Because rainfall intensity is variable, the time of concentration is included in the Rational Method so that the PEO can determine the proper rainfall intensity to apply across the basin. The intensity that should be used for designing is the highest intensity that will occur with the entire basin contributing flow to the flow rate location being studied. This may be a much lower intensity than the maximum intensity due to it taking several minutes before the entire basin is contributing flow; the maximum intensity lasts for a much shorter time, so the rainfall intensity that creates the greatest runoff is less than the maximum by the time the entire basin is contributing flow.

Most drainage basins consist of different types of ground covers and conveyance systems that flow must navigate. These are referred to as flow segments. It is common for a basin to have overland and open-channel flow segments. Urban drainage basins often have flow segments that flow through a storm sewer pipe in addition to overland and open-channel flow segments. A travel time (the amount of time required for flow to move through a flow segment) must be computed for each flow segment. The time of concentration is equal to the sum of all the flow segment travel times.

For a few drainage areas, a unique situation occurs where the time of concentration that produces the largest amount of runoff is less than the time of concentration for the entire basin. This can occur when two or more subbasins have dramatically different types of cover (i.e., different runoff coefficients). The most common case would be a large paved area together with a long, narrow strip of natural area. In this case, the PEO shall check the runoff produced by the paved area alone to determine if this scenario would cause a greater peak runoff rate than the peak runoff rate produced when both land segments are contributing flow based on a shorter time of concentration for the pavement-only area. The scenario that produces the greatest runoff shall be used, even if the entire basin is not contributing flow to this peak runoff rate.

The procedure for determining the time of concentration for overland flow was developed by the Natural Resources Conservation Service (NRCS; formerly known as the Soil Conservation Service [SCS]) and is described below. It is sensitive to slope, type of ground cover, and channel size. If the total time of concentration is less than five minutes, a minimum of five minutes shall be used as the duration, (see Section 2-5.4 for details). Figure 2-3 lists ground cover coefficients.
The time of concentration can be calculated as in Equations 2-2 and 2-3:

\[
T_t = \frac{L}{K \sqrt{S}} = \frac{L^{1.5}}{K \sqrt{\Delta H}} \tag{2-2}
\]

\[
T_c = T_{t1} + T_{t2} + \ldots + T_{tnz} \tag{2-3}
\]

Where:
- \(T_t\) = Travel time of flow segment in minutes
- \(T_c\) = Time of concentration in minutes
- \(L\) = Length of segment in feet
- \(\Delta H\) = Elevation change across segment in feet
- \(K\) = Ground cover coefficient in feet
- \(S\) = Slope of segment \(\frac{\Delta H}{L}\) in feet per feet

**Figure 2-3  Ground Cover Coefficients**

<table>
<thead>
<tr>
<th>Type of Cover</th>
<th>Flow depth (inches)</th>
<th>K (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest with heavy ground cover</td>
<td>--</td>
<td>150</td>
</tr>
<tr>
<td>Minimum tillage cultivation</td>
<td>--</td>
<td>280</td>
</tr>
<tr>
<td>Short pasture grass or lawn</td>
<td>--</td>
<td>420</td>
</tr>
<tr>
<td>Nearly bare ground</td>
<td>--</td>
<td>600</td>
</tr>
<tr>
<td>Small roadside ditch with grass</td>
<td>--</td>
<td>900</td>
</tr>
<tr>
<td>Paved area</td>
<td>--</td>
<td>1,200</td>
</tr>
<tr>
<td>Gutter flow</td>
<td>4</td>
<td>1,500</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>2,400</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3,100</td>
</tr>
<tr>
<td>Storm sewers</td>
<td>12-inch diameter</td>
<td>3,000</td>
</tr>
<tr>
<td></td>
<td>18-inch diameter</td>
<td>3,900</td>
</tr>
<tr>
<td></td>
<td>24-inch diameter</td>
<td>4,700</td>
</tr>
<tr>
<td>Open-Channel Flow ((n = 0.040))</td>
<td>12</td>
<td>1,100</td>
</tr>
<tr>
<td>Narrow Channel (w/d =1)</td>
<td>24</td>
<td>1,800</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>2,800</td>
</tr>
<tr>
<td>Open-Channel Flow ((n = 0.040))</td>
<td>12</td>
<td>2,000</td>
</tr>
<tr>
<td>Wide Channel (w/d =9)</td>
<td>24</td>
<td>3,100</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>5,000</td>
</tr>
</tbody>
</table>

**Notes:**
- -- = not applicable
- w/d = width/depth ratio
2-5.4 Rainfall Intensity

After the appropriate storm frequency for the design has been determined (see Chapter 1) and the time of concentration has been calculated, the rainfall intensity can be calculated. PEOs shall never use a time of concentration that is less than 5 minutes for intensity calculations, even when the calculated time of concentration is less than 5 minutes. The 5-minute limit is based on two ideas:

1. Shorter times give unrealistic intensities. Many Intensity-Duration-Frequency curves are constructed from curve-smoothing equations and not based on actual data collected at intervals shorter than 15 to 30 minutes. Making the curves shorter involves extrapolation, which is not reliable.

2. Rainfall takes time to generate runoff within a defined basin, thus it would not be realistic to have less than 5 minutes for a time of concentration.

Rainfall intensity is the average of the most intense period enveloped by the time of concentration and is not instantaneous rainfall. Equation 2-4 calculates rainfall intensity.

\[
I = \frac{m}{(T_c)^n}
\]  

(2-4)

Where:

\(I\) = Rainfall intensity in inches per hour
\(T_c\) = Time of concentration in minutes
\(m\) and \(n\) = Coefficients in dimensionless units (Figure 2-4)

The coefficients \((m \text{ and } n)\) have been determined for all major cities for the 2-, 5-, 10-, 25-, 50-, and 100-year MRI. The coefficients listed in Figure 2-4 are accurate from 5-minute durations to 1,440-minute durations (24 hours). These equations were developed from the 1973 National Oceanic and Atmospheric Administration Atlas 2, *Precipitation-Frequency Atlas of the Western United States*, Volume IX-Washington (Miller et al.).

The PEO, with RHE assistance, shall interpolate between the two or three nearest cities listed in Figure 2-4 when working on a project in an unlisted location. Consult with the HQ Hydraulics Section if help is needed with interpolating which values to use.
### Figure 2-4  Inches to Rainfall Coefficients

<table>
<thead>
<tr>
<th>Location</th>
<th>2-Year MRI</th>
<th>5-Year MRI</th>
<th>10-Year MRI</th>
<th>25-Year MRI</th>
<th>50-Year MRI</th>
<th>100-Year MRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aberdeen and Hoquiam</td>
<td>5.10</td>
<td>0.488</td>
<td>6.22</td>
<td>0.488</td>
<td>7.06</td>
<td>0.487</td>
</tr>
<tr>
<td>Bellingham</td>
<td>4.29</td>
<td>0.549</td>
<td>5.59</td>
<td>0.555</td>
<td>6.59</td>
<td>0.559</td>
</tr>
<tr>
<td>Bremerton</td>
<td>3.79</td>
<td>0.480</td>
<td>4.84</td>
<td>0.487</td>
<td>5.63</td>
<td>0.490</td>
</tr>
<tr>
<td>Centralia and Chehalis</td>
<td>3.63</td>
<td>0.506</td>
<td>4.85</td>
<td>0.518</td>
<td>5.76</td>
<td>0.524</td>
</tr>
<tr>
<td>Clarkston and Colfax</td>
<td>5.02</td>
<td>0.628</td>
<td>6.84</td>
<td>0.633</td>
<td>8.24</td>
<td>0.635</td>
</tr>
<tr>
<td>Colville</td>
<td>3.48</td>
<td>0.558</td>
<td>5.44</td>
<td>0.593</td>
<td>6.98</td>
<td>0.610</td>
</tr>
<tr>
<td>Ellensburg</td>
<td>2.89</td>
<td>0.590</td>
<td>5.18</td>
<td>0.631</td>
<td>7.00</td>
<td>0.649</td>
</tr>
<tr>
<td>Everett</td>
<td>3.69</td>
<td>0.556</td>
<td>5.20</td>
<td>0.570</td>
<td>6.31</td>
<td>0.575</td>
</tr>
<tr>
<td>Forks</td>
<td>4.19</td>
<td>0.410</td>
<td>5.12</td>
<td>0.412</td>
<td>5.84</td>
<td>0.413</td>
</tr>
<tr>
<td>Hoffstadt Cr. (SR 504)</td>
<td>3.96</td>
<td>0.448</td>
<td>5.21</td>
<td>0.462</td>
<td>6.16</td>
<td>0.469</td>
</tr>
<tr>
<td>Hoodsport</td>
<td>4.47</td>
<td>0.428</td>
<td>5.44</td>
<td>0.428</td>
<td>6.17</td>
<td>0.427</td>
</tr>
<tr>
<td>Kelso and Longview</td>
<td>4.25</td>
<td>0.507</td>
<td>5.50</td>
<td>0.515</td>
<td>6.45</td>
<td>0.509</td>
</tr>
<tr>
<td>Leavenworth</td>
<td>3.04</td>
<td>0.530</td>
<td>4.12</td>
<td>0.542</td>
<td>5.62</td>
<td>0.575</td>
</tr>
<tr>
<td>Metaline Falls</td>
<td>3.36</td>
<td>0.527</td>
<td>4.90</td>
<td>0.553</td>
<td>6.09</td>
<td>0.566</td>
</tr>
<tr>
<td>Moses Lake</td>
<td>2.61</td>
<td>0.583</td>
<td>5.06</td>
<td>0.618</td>
<td>6.63</td>
<td>0.633</td>
</tr>
<tr>
<td>Mt. Vernon</td>
<td>3.92</td>
<td>0.542</td>
<td>5.25</td>
<td>0.552</td>
<td>6.26</td>
<td>0.557</td>
</tr>
<tr>
<td>Naselle</td>
<td>4.57</td>
<td>0.432</td>
<td>5.67</td>
<td>0.441</td>
<td>6.14</td>
<td>0.432</td>
</tr>
<tr>
<td>Olympia</td>
<td>3.82</td>
<td>0.466</td>
<td>4.86</td>
<td>0.472</td>
<td>5.62</td>
<td>0.474</td>
</tr>
<tr>
<td>Omak</td>
<td>3.04</td>
<td>0.583</td>
<td>5.06</td>
<td>0.618</td>
<td>6.63</td>
<td>0.633</td>
</tr>
<tr>
<td>Pasco and Kennewick</td>
<td>2.89</td>
<td>0.590</td>
<td>5.18</td>
<td>0.631</td>
<td>7.00</td>
<td>0.649</td>
</tr>
<tr>
<td>Port Angeles</td>
<td>4.31</td>
<td>0.530</td>
<td>5.42</td>
<td>0.531</td>
<td>6.25</td>
<td>0.531</td>
</tr>
<tr>
<td>Poulsbo</td>
<td>3.83</td>
<td>0.506</td>
<td>4.98</td>
<td>0.513</td>
<td>5.85</td>
<td>0.516</td>
</tr>
<tr>
<td>Queets</td>
<td>4.26</td>
<td>0.422</td>
<td>5.18</td>
<td>0.423</td>
<td>5.87</td>
<td>0.423</td>
</tr>
<tr>
<td>Seattle</td>
<td>3.56</td>
<td>0.515</td>
<td>4.83</td>
<td>0.531</td>
<td>5.62</td>
<td>0.530</td>
</tr>
<tr>
<td>Sequim</td>
<td>3.50</td>
<td>0.551</td>
<td>5.01</td>
<td>0.569</td>
<td>6.16</td>
<td>0.577</td>
</tr>
<tr>
<td>Snoqualmie Pass</td>
<td>3.61</td>
<td>0.417</td>
<td>4.81</td>
<td>0.435</td>
<td>6.56</td>
<td>0.459</td>
</tr>
<tr>
<td>Spokane</td>
<td>3.47</td>
<td>0.556</td>
<td>5.43</td>
<td>0.591</td>
<td>6.98</td>
<td>0.609</td>
</tr>
<tr>
<td>Stevens Pass</td>
<td>4.73</td>
<td>0.462</td>
<td>6.09</td>
<td>0.470</td>
<td>8.19</td>
<td>0.500</td>
</tr>
<tr>
<td>Tacoma</td>
<td>3.57</td>
<td>0.516</td>
<td>4.78</td>
<td>0.527</td>
<td>5.70</td>
<td>0.533</td>
</tr>
<tr>
<td>Vancouver</td>
<td>2.92</td>
<td>0.477</td>
<td>4.05</td>
<td>0.496</td>
<td>4.92</td>
<td>0.506</td>
</tr>
<tr>
<td>Walla Walla</td>
<td>3.33</td>
<td>0.569</td>
<td>5.54</td>
<td>0.609</td>
<td>7.30</td>
<td>0.627</td>
</tr>
<tr>
<td>Wenatchee</td>
<td>3.15</td>
<td>0.535</td>
<td>4.88</td>
<td>0.566</td>
<td>6.19</td>
<td>0.579</td>
</tr>
<tr>
<td>Yakima</td>
<td>3.86</td>
<td>0.608</td>
<td>5.86</td>
<td>0.633</td>
<td>7.37</td>
<td>0.644</td>
</tr>
</tbody>
</table>
2-6 Single-Event Hydrograph Method: Santa Barbara Urban Hydrograph

The SBUH Method is best suited for WSDOT projects where conveyance systems are being designed and for some stormwater treatment facilities in eastern Washington. The SBUH Method was developed to calculate flow occurring from surface runoff and is most accurate for drainage basins smaller than 100 acres, although it can be used for drainage basins up to 1,000 acres. The SBUH Method should not be used where groundwater flow can be a major contributor to the total flow. While not all WSDOT projects are in urban basins, typically the paved surfaces (similar to urban areas) that generate the majority of the total flow may make use of SBUH applicable for highway projects.

An SBUH analysis requires the PEO to understand certain characteristics of the project site, such as drainage patterns, predicted rainfall, soil type, area to be covered with impervious surfaces, type of drainage conveyance, and—for eastern Washington—the flow-control BMPs that are to be provided. The physical characteristics of the site and the design storm determine the magnitude, volume, and duration of the runoff hydrograph. Other factors, such as the conveyance characteristics of channel or pipe, merging tributary flows, and type of BMPs, will alter the shape and magnitude of the hydrograph. The key elements of a single-event hydrograph analysis are listed below and described in more detail in this section:

- Design storm hyetograph
- Runoff parameters
- Hydrograph synthesis
- Hydrograph routing
- Hydrograph summation

There are several commercially available computer programs that include the SBUH Method. See Chapter 1.

2-6.1 Design Storm Hyetograph

The SBUH Method requires the input of a rainfall distribution or a design storm hyetograph. The design storm hyetograph is rainfall depth versus time for a given design storm frequency and duration. For this application, it is presented as a dimensionless table of unit rainfall depth (incremental rainfall depth for each time interval divided by the total rainfall depth) versus time. The type of design storm used depends on the project locations as noted below:

- **Eastern Washington:** For projects in eastern Washington, the design storms are usually the short-duration storm for conveyance design and the regional storm for volume-based stormwater facilities. (Design storms are discussed further in the *Highway Runoff Manual*.) However, occasionally with large basins and long concentration periods, the long duration regional (or Type 1A) storm will produce larger flow (Qs).

- **Western Washington:** For projects in western Washington, the design storm for conveyance is the Type 1A storm. For designs other than conveyance, see Section 2-7 for a description of the Continuous Simulation Method.

Along with the design storm, precipitation depths are needed and shall be selected for the city nearest to the project site using PRISM data available from ArcGIS Workbench as the primary data source for the most accurate results from its interpolation methodology, followed by utilizing an isopluvial map that clearly identifies the location within the map contours (see Appendix 2A).
2-6.2 Runoff Parameters

The SBUH Method requires input of parameters that describe physical drainage basin characteristics. These parameters provide the basis from which the runoff hydrograph is developed. This section describes the three key parameters (contributing drainage basin areas, runoff CN, and runoff time of concentration) that, when combined with the rainfall hyetograph in the SBUH Method, develop the runoff hydrograph.

The proper selection and delineation of the contributing drainage basin areas to the BMP or structure of interest is required in the hydrograph analysis. The contributing basin area(s) used should be relatively homogeneous in land use and soil type. If the entire contributing basin is similar in these aspects, the basin can be analyzed as a single area. If significant differences exist within a given contributing drainage basin, it must be divided into subbasin areas of similar land use and soil characteristics. Hydrographs should then be computed for each subbasin area and summed to form the total runoff hydrograph for the basin. Contributing drainage basins larger than 100 acres shall be divided into subbasins. By dividing large basins into smaller subbasins and then combining calculated flows, the timing aspect of the generated hydrograph is typically more accurate.

2-6.2.1 Curve Numbers

The NRCS has conducted studies into the runoff characteristics of various land types. The NRCS developed relationships between land use, soil type, vegetation cover, interception, infiltration, surface storage, and runoff. The relationships have been characterized by a single runoff coefficient called a curve number. CNs are chosen to depict average conditions—neither dry, nor saturated. The PEO shall use the CNs listed in the *Highway Runoff Manual*, or the NRCS website, or the GIS workbench.

The factors that contribute to the CN value are known as the soil-cover complex. The soil-cover complexes have been assigned to one of four hydrologic soil groups, according to their runoff characteristics. These soil groups are labeled Types A, B, C, and D, with Type A generating the least amount of runoff and Type D generating the most. The *Highway Runoff Manual* shows the hydrologic soil groups of most soils in Washington State. The different soil groups can be described as follows:

- **Type A** – Soils having high infiltration rates, even when thoroughly wetted, and consisting chiefly of deep, well drained to excessively drained sands or gravels. These soils have a high rate of water transmission.
- **Type B** – Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
- **Type C** – Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water or soils with moderately fine to fine textures. These soils have a slow rate of water transmission.
- **Type D** – Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a hardpan or clay layer at or near the surface, and shallow soils over bedrock or other nearly impervious material. These soils have a very slow rate of water transmission and typically comprise areas such as wetlands.
The HQ Materials Laboratory can also perform a soil analysis to determine the soil group for the project site. This should be done only if an NRCS soils map cannot be located for the county in which the site is located, the available SCS map does not characterize the soils at the site (many NRCS maps show "urban land" in highway ROWs and other heavily urbanized areas where the soil properties are uncertain), or there is reason to doubt the accuracy of the information on the NRCS map for the particular site.

When performing an SBUH analysis for a basin, it is common to encounter more than one soil type. If the soil types are similar (within 20 CN points), a weighted average can be used. If the soil types are significantly different, the basin should be separated into smaller subbasins (previously described for different land uses). Pervious ground cover and impervious ground cover should always be analyzed separately. If the computer program StormShed3D is used for the analysis, pervious and impervious land segments will automatically be separated, but the PEO will have to combine and manually weigh similar pervious soil types for a basin.

2-6.2.2 Antecedent Moisture Condition

The moisture condition in a soil at the onset of a storm event, referred to as the antecedent moisture condition (AMC), has a significant effect on both the volume and rate of runoff. Recognizing this, the SCS developed three AMCs: I, II, and III.

- AMC I: Soils are dry but not to the wilting point.
- AMC II: Average conditions.
- AMC III: Heavy rainfall, or light rainfall and low temperatures, has occurred within the last five days, and soil is near saturated or saturated.

Figure 2-5 gives seasonal rainfall limits for the three AMCs. These derive from the amount of rainfall in any five days.

<table>
<thead>
<tr>
<th>Antecedent Moisture Condition</th>
<th>Dormant Season (inches)</th>
<th>Growing Season (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Less than 0.5</td>
<td>Less than 1.4</td>
</tr>
<tr>
<td>II</td>
<td>0.5 to 1.1</td>
<td>1.4 to 2.1</td>
</tr>
<tr>
<td>III</td>
<td>Over 1.1</td>
<td>Over 2.1</td>
</tr>
</tbody>
</table>

The CN values generally listed are for AMC II, if the AMC falls into either group I or III, the CN value will need to be modified to represent project site conditions. The Highway Runoff Manual provides further information regarding when the AMC should be considered and conversions for the CN for different AMCs for the case of Ia = 0.2S. For other conversions, see the National Engineering Handbook (NRCS 2010).

2-6.2.3 Time of Concentration

Time of concentration \( (T_c) \) is defined as the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest in the watershed. Travel time \( (T_t) \) is the time it takes water to travel from one location to another in a watershed. \( T_t \) is a component of \( T_c \), which is computed by summing all the travel times for consecutive components of the drainage flow path. While this section starts the same as Section 2-5.3, the analysis described in this section is more detailed because water traveling through a basin is classified by flow type.
The different flow types include: sheet flow; shallow, concentrated flow; open-channel flow; or some combination of these. Classifying flow type is best determined by field inspection and using the parameters described below:

- **Sheet flow** is flow over plane surfaces. It usually occurs in the headwater areas of streams and for short distances on evenly graded slopes. With sheet flow, the friction value (ns, which is a modified Manning’s roughness coefficient) is used. These ns values are for shallow flow depths up to about 0.1 foot and are used only for travel lengths up to 150 feet on impervious surfaces without curb and 100 feet on pervious surfaces. The *Highway Runoff Manual* provides the Manning’s n values for sheet flow at various surface conditions.

For sheet flow of up to 100 feet, use Manning’s kinematic solution (Equation 2-5) to directly compute \( T_t \):

\[
T_t = \frac{(0.42 \text{ (nsL)}0.8)}{(P2)0.527\text{(so)}0.4)
\]

Where:
- \( T_t \) = travel time (minutes)
- \( ns \) = sheet flow Manning’s coefficient (dimensionless)
- \( L \) = flow length (feet)
- \( P2 \) = 2-year, 24-hour rainfall (inches)
- \( so \) = slope of hydraulic grade line (land slope, feet/foot [ft/ft])

- **Shallow flow** – After the maximum sheet flow length, sheet flow is assumed to become shallow concentrated flow. The average velocity for this flow can be calculated using the \( k_s \) values from the *Highway Runoff Manual*. Average velocity is a function of watercourse slope and type of channel. After computing the average velocity using the Velocity Equation (Equation 2-6), the travel time (\( T_t \)) for the shallow concentrated flow segment can be computed by dividing the length of the segment by the average velocity.

- **Open channels** are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where lines indicating streams appear on USGS quadrangle maps. For developed drainage systems, the travel time of flow in a pipe is also represented as an open channel. The \( k_c \) values from the *Highway Runoff Manual* used in the Velocity Equation can be used to estimate average flow velocity. Average flow velocity is usually determined for bank full conditions. After average velocity is computed, the travel time (\( T_t \)) for the channel segment can be computed by dividing the length of the channel segment by the average velocity.

A commonly used method of computing average velocity of flow, once it has measurable depth, is the following Velocity Equation:

\[
V = (k)(so0.5)
\]

Where:
- \( V \) = velocity (feet per second [ft/s])
- \( k \) = time of concentration velocity factor (ft/s)
- \( so \) = slope of flow path (ft/ft)

Regardless of how water moves through a watershed, when estimating travel time (\( T_t \)), the following limitations apply:
2-7  Continuous Simulation Hydrologic Model  
(Western Washington Only)

When designing stormwater facilities in western Washington, the PEO must use an Ecology-approved continuous simulation hydrologic model to meet the requirements of the most current version of the Highway Runoff Manual. A continuous simulation hydrologic model captures the back-to-back effects of storm events that are more common in western Washington. These events are associated with high volumes of flow from sequential winter storms rather than high peak flow from short duration events, as is characteristic in eastern Washington.

WSDOT uses MGSFlood (see Highway Runoff Manual), which uses the HSPF routines for computing runoff from rainfall on pervious and impervious land areas. In addition, MGSFlood has the BMP design criteria built into the software and will help the sizing of the stormwater facility to meet the Highway Runoff Manual-required runoff treatment and flow control flow rates and volumes. WSDOT also uses MGSFlood to estimate seasonal flows for temporary stream diversion designs. Refer to the HQ Hydraulics Section web page for a detailed example of this modeling approach.

MGSFlood does have limitations that the PEO should understand before using the program, regarding the project location, conveyance design, and the basin size. MGSFlood is for projects in western Washington with elevations below 1,500 feet. The program does not include routines for simulating the accumulation and melting of snow, and its use should be limited to areas where snowmelt is typically not a major contributor to floods or to the annual runoff volume. MGSFlood is not used for permanent conveyance design but is capable for conveyance design when a small-time step, such as 5 or 15 minutes is used. For projects located in western Washington that fall outside the modeling guidelines described in this paragraph, contact the RHE or HQ Hydraulics Section staff for assistance.

2-7.1  Modeling Requirements

MGSFlood should be used once the PEO has selected the BMP(s) for the project site and has determined the input values for precipitation, delineated drainage basin areas, and soil characteristics. Each of these input values are further described in the sections below.

2-7.1.1  Precipitation Input

There are two methods for transposing precipitation time series that are available in the continuous simulation model: extended precipitation time series selection and precipitation station selection. The PEO will generally select the extended precipitation time series unless it is not available for a project site, then the precipitation station is selected. Both methods are further described below.

1.  **Extended Precipitation Time Series Selection** – Uses a family of prescaled precipitation and evaporation time series (Figure 2-6). These time series were developed by combining and scaling precipitation records from widely separated stations, resulting in record lengths in excess of 100 years. Extended hourly precipitation and evaporation time
series have been developed using this method for most of the lowland areas of western Washington where WSDOT projects are constructed. These time series should be used for stormwater facility design for project sites.

2. **Precipitation Station Selection** – For project sites located outside the extended time series region, a second precipitation scaling method is used (Figure 2-7). A source gauge is selected, and a single scaling factor is applied to transpose the hourly record from the source gauge to the site of interest (target site). The current approach for single-factor scaling, as recommended in Ecology’s *Stormwater Management Manual for Western Washington* (Ecology 2014), is to compute the scaling factor as the ratio of the 25-year, 24-hour precipitation for the target and source sites. Contact the RHE or HQ Hydraulics Section staff if assistance is needed in selecting the appropriate gauge.
Figure 2-6  Extended Precipitation Time Series Regions
Figure 2-7  Precipitation Station Selection Outside Extended Precipitation Time Series Regions

Determine Precipitation Station Region and 25-year, 24-hour Precipitation for Site
(Use Extended Precipitation Timeseries in Grey Shaded Area)

Precipitation Station Location and Region Boundary

Port Angeles

Precipitation (inches)

- Less than 1.0
- 1.0-1.5
- 1.5-2.0
- 2.0-2.5
- 2.5-3.0
- 3.0-3.5
- 3.5-4.0
- 4.0-5.0
- 5.0-6.0
- 6.0-7.0
- 7.0-8.0
- 8.0-9.0
- 9.0-10.0
- 10.0-12.0
- 12.0-14.0
- 14.0-16.0
- 16.0-18.0
- 18.0-20.0
- More than 20.0

Legend

North

10  20  30  40 Miles
2-7.1.2 Hydrologic Soil Groups

For each basin, land cover is defined in units of acres for predeveloped and developed conditions. Soils must be classified into one of three categories for use in MGSFlood: till, outwash, or saturated soil (as defined by the USGS). Mapping of soil types by the NRCS is the most common source of soil/geologic information used in hydrologic analyses for stormwater facility design. Each soil type defined by the NRCS has been classified into one of four hydrologic soil groups: A, B, C, or D. In western Washington, the soil groups used in MGSFlood generally correspond to the NRCS hydrologic soil groups shown in Figure 2-8.

Figure 2-8 Relationship Between NRCS Hydrologic Soil Group and MGSFlood Soil Group

<table>
<thead>
<tr>
<th>NRCS Group</th>
<th>MGSFlood Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Outwash</td>
</tr>
<tr>
<td>B</td>
<td>Till or Outwash</td>
</tr>
<tr>
<td>C</td>
<td>Till</td>
</tr>
<tr>
<td>D</td>
<td>Saturated</td>
</tr>
</tbody>
</table>

Note:
NRCS = Natural Resources Conservation Service

NRCS Type B soils can be classified as either glacial till or outwash, depending on the type of soil under consideration. Type B soils underlain by glacial till or bedrock, or that have a seasonally high water table, are classified as till. Conversely, well-drained B-type soils should be classified as outwash. It is important to work with the HQ Materials Laboratory or a licensed geotechnical engineer to confirm the soil properties and near-surface hydrogeology of the site are well understood, as they are significant factors in the final modeling results. The Highway Runoff Manual contains some soils classification information for preliminary work.

Wetland soils remain saturated throughout much of the year. The hydrologic response from wetlands is variable, depending on the underlying geology, the proximity of the wetland to the regional groundwater table, and the geometry of the wetland. Generally, wetlands provide some base flow to streams in the summer months and attenuate storm flows via temporary storage and slow release in the winter. Special design consideration must be considered when including wetlands in continuous simulation runoff modeling.
2-8 Published Flow Records

When available, published flow records provide the most accurate data for designing culverts and bridge openings. This is because the values are based on actual measured flows and not calculated flows. The streamflows are measured at a gauging site for several years. A statistical analysis, typically using the USGS Regression Spreadsheet, is then performed on the measured flows to predict the recurrence intervals.

USGS, Ecology, local and state municipalities, and several utility companies work together to maintain gauging sites throughout Washington State. Flood discharges for these gauging sites, at selected exceedance probabilities (based on historical data up to 2014), can be found in the following websites:

- StreamStats
- [https://pubs.er.usgs.gov/publication/sir20165118](https://pubs.er.usgs.gov/publication/sir20165118)
- USGS

2-9 USGS Regression Equations

While measured flows provide the best data for design purposes, it is not practical to gauge all rivers and streams in the state. A set of equations has been developed by USGS to calculate flows for drainage basins in the absence of a streamflow gauge. The equations were developed by performing a regression analysis on streamflow gauge records to determine which drainage basin parameters are most influential in determining peak runoff rates. In addition, StreamStats or digital precipitation values in WSDOT GIS Workbench can be used.

Estimates of the magnitude and frequency of flood-peak discharges and flood hydrographs are used for a variety of purposes, such as the design of bridges, culverts, and flood-control structures, and for the management and regulation of floodplains.

The equations divide the state into four different hydrologic regions, as shown on the map in Appendix 2B. The various hydrologic regions require different input variables, depending on the hydrologic region. Input parameters that may be required include: total area of the drainage basin; percent of the drainage basin that is in forest cover; and percent of the drainage basin that is in lakes, swamps, or ponds. These variables can be determined by the PEO through use of site maps, aerial photographs, and site inspections.

The PEO must be aware of the limitations of these equations. They were developed for natural rural basins; however, the equations have been updated with current flood events. The equations can be used in urban ungauged areas with additional back-up data (i.e., comparing results to nearest gauge data for calibration and sensitivity analysis, field inspection of high-water lines, and information from local maintenance). PEOs should contact the RHE for further guidance. Also, any river that has a dam and reservoir in it should not be analyzed with these equations. Finally, the PEO must keep in mind that, due to the simple nature of these equations and the broad range of each hydrologic region, the results of the equations contain a wide confidence interval, represented as the standard error.
The standard error is a statistical representation of the accuracy of the equations. Each equation is based on many rivers and the result represents the mean of all the flow values for the given set of basin characteristics. The standard error shows how far out one standard deviation is for the flow that was just calculated. For a bell-shaped curve in statistical analysis, 68 percent of all the samples are contained within the limits set by one standard deviation above the mean value and one standard deviation below the mean value. It can also be viewed as indicating that 50 percent of all the samples are equal to or less than the flow calculated with the equation and 84 percent of all samples are equal to or less than one standard deviation above the flow just calculated.

The PEOs shall use the mean value determined from the regression equations with no standard error or confidence interval. If the flows are too low or too high for that basin based on information that the PEO has collected, then the PEO may apply the standard error specific to the regression equation accordingly. The PEO should consult the RHE for assistance.

In addition to the worksheets at the end of this chapter, the USGS has a computation program, PeakFQ, to improve the process of estimating peak flows. The program is available for PEOs use and should be loaded by the Region IT: PeakFQ.

StreamStats is another USGS tool that not only estimates peak flows but can also delineate the basin area and determine the mean annual precipitation as well as other basin characteristics. It should be noted that StreamStats uses GIS PRISM maps and may produce a slightly different result than the map links on Appendix 2A.

2-10 Flood Reports

Flood reports have been developed for many rivers in Washington State. Most of these reports have been developed by FEMA. Other reports have been developed by the USACE and by local agencies.

Many small- and medium-sized streams within urbanizing areas have had some modeling by local government. These can be useful and appropriate to adopt for WSDOT use, following examination of model assumptions and drainage basin delineation.

These reports are a good source of flow information since they were developed to analyze the flows during flooding conditions of a particular river or stream. The types of calculations used by the agency conducting the analysis are more complex than the Rational Method or USGS regression equations and are therefore more accurate. The increased time required to perform these complex calculations is not justified for the typical structure that WSDOT is designing; however, if the analysis has already been performed by another agency, then it is in WSDOT’s best interest to use this information.

FEMA reports and USACE flood reports are available on the FEMA map service center website. HQ Hydraulics Section should be contacted for local agency reports. HQ Hydraulics Section may also have basin planning documents or action plans that could contain flow rate information.
2-11 **Examples**

Compute the 25-year runoff for the Spokane watershed shown in Figure 2-9. Three types of flow conditions exist from the highest point in the watershed to the outlet. The upper portion is 4.0 acres of forest cover with an average slope of 0.15 ft/ft. The middle portion is 1.0 acre of single family residential with a slope of 0.06 ft/ft and primarily lawns. The lower portion is a 0.8-acre park with 18-inch-diameter storm sewers with a general slope of 0.01 ft/ft.

![Figure 2-9 Rational Formula Example][1]

\[ T_c = \sum \frac{L}{K \sqrt{S}} = \frac{1800}{150 \sqrt{0.15}} + \frac{650}{420 \sqrt{0.06}} + \frac{820}{3,900 \sqrt{0.01}} \]

\[ T_c = 31 \text{ min} + 6 \text{ min} + 2 \text{ min} = 39 \text{ min} \]

\[ I = \frac{m}{(T_c)^n} = \frac{9.09}{(39)^{0.626}} = 0.93 \text{ in/hr} \]

\[ \sum CA = 0.22(4.0 \text{ acres}) + 0.44(1.0 \text{ acres}) + 0.11(0.8 \text{ acres}) = 1.4 \text{ acres} \]

\[ Q = \frac{I(\sum CA)}{K_c} = \frac{(0.93)(1.4)}{1} = 1.31 \text{ cfs} \]

2-12 **Appendices**

- **Appendix 2A** Isopluvial and MAP Web Links and Mean Annual Precipitation Data
- **Appendix 2B** USGS Regression Equation Zone Map
Appendix 2A  Isopluvial and MAP Web Links and Mean Annual Precipitation Data

The 24-hour and 2-hour Isopluvial maps and the mean annual precipitation maps for Washington are available in PDF format through the link below or by using GIS Workbench. Contact your local GIS group for how to extract digital precipitation data using ArcMap.

www.wsdot.wa.gov/Design/Hydraulics