Chapter 3
Calculating the WQCV and Runoff Reduction

Contents

1.0 Introduction ...................................................................................................................................... 1

2.0 Hydrologic Basis of the WQCV ...................................................................................................... 1
  2.1 Development of the WQCV ...................................................................................................................... 1
  2.2 Optimizing the Capture Volume ............................................................................................................... 3
  2.3 Attenuation of the WQCV (Control Measure Drain Time) ....................................................................... 3
  2.4 Excess Urban Runoff Volume (EURV) and Full Spectrum Detention ..................................................... 4

3.0 Calculation of the WQCV................................................................................................................ 4

4.0 Quantifying Volume Reduction ...................................................................................................... 7
  4.1 Conceptual Model for Volume Reduction Control Measures—Cascading Planes ................................. 7
  4.2 Watershed/Master Planning-level Runoff Reduction Method .................................................................. 8
  4.3 Site-level Runoff Reduction Methods ................................................................................................... 9
    4.3.1 SWMM Modeling Using Cascading Planes ................................................................................ 10
    4.3.2 Runoff Reduction Spreadsheets .................................................................................................. 10

5.0 Conclusion ....................................................................................................................................... 11

6.0 References ....................................................................................................................................... 14

Figures

Figure 3-1. Map of the Average Runoff Producing Storm's Precipitation Depth in the United States ...... 2
Figure 3-2. Water Quality Capture Volume (WQCV) Based on Control Measure Drain Time ............. 6

Tables

Table 3-1. Number of Rainfall Events in the Denver Area ......................................................................... 2
Table 3-2. Drain Time Coefficients for WQCV Calculations .................................................................... 5
1.0 Introduction

This chapter presents the hydrologic basis and calculations for the Water Quality Capture Volume (WQCV) and discusses the benefits of attenuating this volume and that of the Excess Urban Runoff Volume (EURV). This chapter also describes various methods for quantifying volume reduction when using LID practices. Use of these methods should begin during the planning phase for preliminary sizing and development of the site layout. The calculations and procedures in this chapter allow the engineer to determine effective impervious area, calculate the WQCV, and more accurately quantify potential volume reduction benefits of control measures.

2.0 Hydrologic Basis of the WQCV

2.1 Development of the WQCV

The purpose of designing control measures based on the WQCV is to improve runoff water quality and reduce hydromodification and the associated impacts on receiving waters. Although some control measures can remove pollutants and achieve modest reductions in runoff for frequently occurring events in a "flow through" mode (e.g., grass swales, grass buffers or wetland channels), to address hydrologic effects of urbanization, a control measure must be designed to control runoff, either through storage, infiltration, evapotranspiration or a combination of these processes (e.g., rain gardens, extended detention basins or other storage-based control measures). This section provides a brief background on the development of the WQCV.

The WQCV for the metro Denver area is based on an analysis of rainfall and runoff characteristics for 36 years of record at the Denver Stapleton Rain Gage (1948-1984) conducted by Urbonas, Guo, and Tucker (1989) and documented in Sizing a Capture Volume for Stormwater Quality Enhancement (available at the UDFCD website.) This analysis showed that the average storm for the Denver area, based on a 6-hour separation period, has duration of 11 hours and an average time interval between storms of 11.5 days. However, the great majority of storms are less than 11 hours in duration (i.e., median duration is less than average duration). The average is skewed by a small number of storms with long durations.

Table 3-1 summarizes the relationship between total storm depth and the annual number of storms. As the table shows, 61% of the 75 storm events that occur on an average annual basis have less than 0.1 inches of precipitation. These storms produce practically no runoff and therefore have little influence in the development of the WQCV. Storm events between 0.1 and 0.5 inches produce runoff and account for 76% of the remaining storm events (22 of the 29 events that would typically produce runoff on an average annual basis). Urbonas et al. (1989) identified the runoff produced from a precipitation event of 0.6 inches as the target for the WQCV, corresponding to the 80th percentile storm event. The WQCV for a given watershed will vary depending on the imperviousness and the drain time of the control measure, but assuming 0.1 inches of depression storage for impervious areas, the maximum capture volume required is approximately 0.5 inches over the area of the watershed. Urbonas et al. (1989) concluded that if the volume of runoff produced from impervious areas from these storms can be effectively treated and detained, water quality can be significantly improved.

For application of this concept at a national level, analysis by Driscoll et al. (1989), as shown in Figure 3-1, regarding average runoff producing events in the U.S. can be used to adjust the WQCV.
### Table 3-1. Number of Rainfall Events in the Denver Area
(Adapted from Urbonas et al. 1989)

<table>
<thead>
<tr>
<th>Total Rainfall Depth (inches)</th>
<th>Average Annual Number of Storm Events</th>
<th>Percent of Total Storm Events</th>
<th>Percentile of Runoff-producing Storms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 to 0.1</td>
<td>46</td>
<td>61.07%</td>
<td>0.00%</td>
</tr>
<tr>
<td>0.1 to 0.5</td>
<td>22</td>
<td>29.21%</td>
<td>75.04%</td>
</tr>
<tr>
<td>⩽ 0.6</td>
<td>69</td>
<td>91.61%</td>
<td>80.00%</td>
</tr>
<tr>
<td>0.5 to 1.0</td>
<td>4.7</td>
<td>6.24%</td>
<td>91.07%</td>
</tr>
<tr>
<td>1.0 to 1.5</td>
<td>1.5</td>
<td>1.99%</td>
<td>96.19%</td>
</tr>
<tr>
<td>1.5 to 2.0</td>
<td>0.6</td>
<td>0.80%</td>
<td>98.23%</td>
</tr>
<tr>
<td>2.0 to 3.0</td>
<td>0.3</td>
<td>0.40%</td>
<td>99.26%</td>
</tr>
<tr>
<td>3.0 to 4.0</td>
<td>0.19</td>
<td>0.25%</td>
<td>99.90%</td>
</tr>
<tr>
<td>4.0 to 5.0</td>
<td>0.028</td>
<td>0.04%</td>
<td>100.00%</td>
</tr>
<tr>
<td>&gt; 5.0</td>
<td>0</td>
<td>0.00%</td>
<td>100.00%</td>
</tr>
<tr>
<td>TOTAL:</td>
<td>75</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

![Map of the Average Runoff Producing Storm's Precipitation Depth in the United States In Inches](source: Driscoll et.al., 1989)
Based on rainfall data collected in the Fountain Creek watershed as described in the Fountain Creek Rainfall Characterization Study (Carlton, 2011), a similar analysis was completed. This analysis showed that the rainfall patterns associated with small, frequent events in the Fountain Creek watershed are very similar to those in the metro Denver area. Therefore, the requirements for WQCV used in metro Denver can be applied within the Fountain Creek watershed. The analysis and its results are described in a memorandum by WWE (May, 2012).

2.2 Optimizing the Capture Volume

Optimizing the capture volume is critical. If the capture volume is too small, the effectiveness of the control measure will be reduced due to the frequency of storms exceeding the capacity of the facility and allowing some volume of runoff to bypass treatment. On the other hand, if the capture volume for a control measure that provides treatment through sedimentation is too large, the smaller runoff events may pass too quickly through the facility, without the residence time needed to provide treatment.

Small, frequently occurring storms account for the predominant number of events that result in stormwater runoff from urban catchments. Consequently, these frequent storms also account for a significant portion of the annual pollutant loads. Capture and treatment of the stormwater from these small and frequently occurring storms is required to satisfy the City’s MS4 Permit conditions.

The analysis of precipitation data at the Denver Stapleton Rain Gage revealed a relationship between the percent imperviousness of a watershed and the capture volume needed to significantly reduce stormwater pollutants (Urbonas, Guo, and Tucker, 1990). Subsequent studies (Guo and Urbonas, 1996 and Urbonas, Roesner, and Guo, 1996) of precipitation resulted in a recommendation by the Water Environment Federation and American Society of Civil Engineers (1998) that stormwater quality treatment facilities (i.e., post-construction control measures) be based on the capture and treatment of runoff from storms ranging in size from "mean" to "maximized" storms. The "mean" and "maximized" storm events represent the 70th and 90th percentile storms, respectively. As a result of these studies, water quality facilities for the Colorado Front Range are recommended to capture and treat the 80th percentile runoff event. Capturing and properly treating this volume should remove between 80 and 90% of the annual TSS load, while doubling the capture volume was estimated to increase the removal rate by only 1 to 2%.

2.3 Attenuation of the WQCV (Control Measure Drain Time)

The WQCV must be released over an extended period to provide effective pollutant removal for post-construction control measures that use sedimentation (i.e., extended detention basin, retention ponds and constructed wetland ponds). A field study of basins with extended detention in the Washington, D.C. area identified an average drain time of 24 hours to be effective for extended detention basins. This generally equates to a 40-hour drain time for the brim-full basin. Retention ponds and constructed wetland basins have reduced drain times (12 hours and 24 hours, respectively) because the hydraulic residence time of the effluent is essentially increased due to the mixing of the inflow with the permanent pool.

When pollutant removal is achieved primarily through filtration, such as in a sand filter or rain garden control measure, an extended drain time is required to promote stability of downstream drainageways. In addition to counteracting hydromodification, attenuation in filtering control measures can also improve

---

1 The term "maximized storm" refers to the optimization of the storage volume of a BMP. The WQCV for the "maximized" storm represents the point of diminishing returns in terms of the number of storm events and volume of runoff fully treated versus the storage volume provided.
pollutant removal by increasing contact time, which can aid adsorption/absorption processes depending on the media. The minimum required drain time for a post-construction control measure is 12 hours for control measures that do not rely fully or partially on sedimentation for pollutant removal.

### 2.4 Excess Urban Runoff Volume (EURV) and Full Spectrum Detention

Capture and treatment of the EURV is required as part of the Full Spectrum Detention criteria that is required in accordance with Chapter 3 – Drainage Policies in Volume 1. The EURV represents the difference between the developed and pre-developed runoff volume for the range of storms that produce runoff from pervious land surfaces (generally greater than the 2-year event). The EURV is relatively constant for a given imperviousness over a wide range of storm events. This is a companion concept to the WQCV. The EURV is a greater volume than the WQCV and is detained over a longer time. It typically allows for the recommended drain time of the WQCV and is used to better replicate peak discharge in receiving waters for runoff events exceeding the WQCV. The EURV is associated with Full Spectrum Detention, a simplified sizing method for both water quality and flood control detention. Designing a detention basin to capture the EURV and release it slowly (at a rate similar to WQCV release rates) results in storms smaller than the 2-year event being reduced to flow rates much less than the threshold value for erosion in most drainageways. In addition, by incorporating an outlet structure designed per the criteria in this manual including an orifice or weir that limits 100-year runoff to the allowable release rate, the storms greater than the 2-year event will be reduced to discharge rates and hydrograph shapes that approximate pre-developed conditions. This reduces the likelihood that runoff hydrographs from multiple basins will combine to produce greater peak discharges than pre-developed conditions.

For the EURV and Full Spectrum Detention criteria and requirements, including calculation procedures, please refer to the Storage chapter of Volume 1.

### 3.0 Calculation of the WQCV

The first step in estimating the magnitude of runoff from a site is to estimate the site's total imperviousness. The total imperviousness of a site is the weighted average of individual areas of like imperviousness. For instance, according to the Hydrology chapter of Volume 1 of this manual, paved streets (and parking lots) have an imperviousness of 100%; drives, walks and roofs have an imperviousness of 90%; and lawn areas have an imperviousness of 0%. The total imperviousness of a site can be determined taking an area-weighted average of all of the impervious and pervious areas. These impervious areas are assumed to be directly connected to the receiving systems beyond the site. When measures are implemented to minimize directly connected impervious area (MDCIA), the effects of the total imperviousness on the calculated WQCV can be represented by using an "effective imperviousness". Sections 4 and 5 of this chapter provide guidance, requirements, and examples for calculating effective imperviousness and adjusting the WQCV using this value.

The WQCV is calculated as a function of imperviousness and control measure drain time using Equation 3-1, and as shown in Figure 3-2:

\[
WQCV = a(0.91I^3 - 1.19I^2 + 0.78I)
\]

Equation 3-1

Where:

\[
WQCV = \text{Water Quality Capture Volume (watershed inches)}
\]
Chapter 3 Calculating the WQCV and Volume Reduction

\[ a = \text{Coefficient corresponding to WQCV drain time (Table 3-2)} \]

\[ I = \text{Imperviousness (\%)} \]

**Table 3-2. Drain Time Coefficients for WQCV Calculations**

<table>
<thead>
<tr>
<th>Drain Time (hrs)</th>
<th>Coefficient, ( a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 hours</td>
<td>0.8</td>
</tr>
<tr>
<td>24 hours</td>
<td>0.9</td>
</tr>
<tr>
<td>40 hours</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Figure 3-2, which illustrates the relationship between imperviousness and WQCV for various drain times, is appropriate for use in Colorado's high plains near the foothills. For other portions of Colorado or United States, the WQCV obtained from this figure can be adjusted using the following relationships:

\[
WQCV_{\text{other}} = d_6 \left( \frac{WQCV}{0.43} \right) 
\]

Equation 3-2

Where:

\[
WQCV = \text{WQCV calculated using Equation 3-1 or Figure 3-2 (watershed inches)}
\]

\[
WQCV_{\text{other}} = \text{WQCV outside of Denver region (watershed inches)}
\]

\[
d_6 = \text{depth of average runoff producing storm from Figure 3-1 (watershed inches)}
\]

Once the WQCV in watershed inches is found from Figure 3-2 or using Equation 3-1 and/or 3-2, the required control measure storage volume in acre-feet can be calculated as follows:

\[
V = \left( \frac{WQCV}{12} \right) A
\]

Equation 3-3

Where:

\[
V = \text{required storage volume (acre-ft)}
\]

\[
A = \text{tributary catchment area upstream (acres)}
\]

\[
WQCV = \text{Water Quality Capture Volume (watershed inches)}
\]
Figure 3-2. Water Quality Capture Volume (WQCV) Based on Control Measure Drain Time
4.0 Quantifying Volume Reduction

Volume reduction is an important part of the Four Step Process and is fundamental to effective stormwater management. Quantifying volume reduction associated with MDCIA, LID practices and other control measures is important for watershed-level master planning and also for conceptual and final site design. It also allows the engineer to evaluate and compare the benefits of various volume reduction practices. This section describes the conceptual model for evaluating volume reduction and provides tools for quantifying volume reduction using three different approaches, depending on the size of the watershed, complexity of the design, and experience level of the user. In this section, volume reduction is evaluated at the watershed level and at the site level.

4.1 Conceptual Model for Volume Reduction

Control Measures—Cascading Planes

The hydrologic response of a watershed during a storm event is characterized by factors including shape, slope, area, imperviousness (connected and disconnected) and other factors (Guo 2006). As previously discussed, total imperviousness of a watershed can be determined by delineating roofs, drives, walks and other impervious areas within a watershed and dividing the sum of these impervious areas by the total watershed area. In the past, total imperviousness was often used for calculation of peak flow rates for design events and storage requirements for water quality and flood control purposes. This is a reasonable approach when much of the impervious area in a watershed is directly connected to the drainage system; however, when the unconnected impervious area in a catchment is significant, using total imperviousness will result in over-calculation of peak flow rates and storage requirements.

To evaluate the effects of MDCIA and other LID practices, UDFCD has performed modeling using SWMM to develop tools for planners and designers, both at the watershed/master planning level where site-specific details have not been well defined, and at the site level, where plans are at more advanced stages. Unlike many conventional stormwater models, SWMM allows for a relatively complex evaluation of flow paths through the on-site stormwater control measure layout. Conceptually, an urban watershed can be divided into four land use areas that drain to the common outfall point as shown in Figure 3-3, including:

- Directly Connected Impervious Area (DCIA)
- Unconnected Impervious Area (UIA)
- Receiving Pervious Area (RPA)
- Separate Pervious Area (SPA)

Defining Effective Imperviousness

The concepts discussed in this section are dependent on the concept of effective imperviousness. This term refers to impervious areas that contribute surface runoff to the drainage system. For the purposes of this manual, effective imperviousness includes directly connected impervious area and portions of the unconnected impervious area that also contribute to runoff from a site. For small, frequently occurring events, the effective imperviousness may be equivalent to directly connected impervious area since runoff from unconnected impervious areas may infiltrate into receiving pervious areas; however, for larger events, the effective imperviousness is increased to account for runoff from unconnected impervious areas that exceeds the infiltration capacity of the receiving pervious area. This means that the calculation of effective imperviousness is associated with a specific return period.

Note: Users should be aware that some national engineering literature defines effective imperviousness more narrowly to include only directly connected impervious area.
Calculating the WQCV and Volume Reduction

Chapter 3

Calculating the WQCV and Volume Reduction

Chapter 3

Figure 3-3. Four Component Land Use

A fundamental concept of LID is to route runoff generated from the UIA onto the RPA to increase infiltration losses. To model the stormwater flows through a LID site, it is necessary to link flows similarly to take into consideration additional depression storage and infiltration losses over the pervious landscape. One of the more recent upgrades to SWMM allows users to model overland flow draining from the upper impervious areas onto a downstream pervious area. As illustrated in Figure 3-3, the effective imperviousness is only associated with the cascading plane from UIA to RPA, while the other two areas, DCIA and SPA, are drained independently.

For a well-designed and properly constructed LID site, the effective imperviousness will be less than the total imperviousness. This difference will be greatest for smaller, more frequently occurring events and less for larger, less-frequent events. Aided by SWMM, effective imperviousness can be determined by a runoff-volume weighting method that accounts for losses along the selected flow paths. When designing a drainage system, design criteria that account for effective imperviousness can potentially reduce stormwater costs by reducing the size of infrastructure to convey and/or store the design stormwater flows and volumes. This chapter presents methods that allow the engineer to convert between total imperviousness and effective imperviousness at both the watershed and site scales.

4.2 Watershed/Master Planning-level Runoff Reduction Method

For watershed-level assessments and master planning, NRCS (TR-55) provides guidance for users to model effects of LID through adjustments to Curve Number for unconnected imperviousness.

Figure 3-4 can be used to estimate composite CNs for unconnected impervious areas. Runoff from these areas is spread over a pervious area as sheet flow. To determine CN when all or part of the impervious area is not directly connected to the drainage system, Figure 3-4 may be used if total imperviousness is less than 30 percent. Otherwise the methods for estimating effective imperviousness described elsewhere in this chapter may be used to estimate composite CNs.

Obtain the composite CN for unconnected impervious areas by entering the right half of Figure 3-4 with the percentage of total impervious area and the ratio of total unconnected impervious area to total impervious area. Then move left to the appropriate pervious CN and read down to find the composite CN. For example, for a 1.2 acre lot with 20 percent total impervious area (75 percent of which is unconnected) and pervious CN of 60, the composite CN from Figure 3-4 is 64. If all of the impervious area is connected, the composite CN would be 68. Figure 3-4 is intended for use at the planning level...
when specifics of the site conditions are not yet well established.

It is notable that the reductions in effective imperviousness shown in Figure 3-4 are relatively modest. When site-level details are still in conceptual stages, the use of effective impervious calculations and composite unconnected CNs provides a tool for a master planning/watershed level assessment of effects of disconnected impervious area. At a more advanced stage of design, when site-specific disconnected areas, receiving pervious areas, flow paths, and other design details are available, the site-level methods in Section 4.3 can be used to better quantify volume reduction, and results will typically show greater reductions in effective imperviousness for aggressive LID implementation than reflected in Figure 3-4. Even so, to ensure compliance with the City’s requirement to capture and treat the EURV, it is unlikely that conveyance-based control measures alone will provide adequate pollutant removal and volume reduction for most project sites, and a storage-based control measure will also be required.

**Figure 3-4. Composite Curve Number with Unconnected Imperviousness**
(Source: TR-55, Figure 2-4)

4.3 Site-level Runoff Reduction Methods

Two options are available for quantification of volume reduction at the site level when the DCIA, UIA, RPA, and SPA fractions have been identified:

1. SWMM modeling using the cascading plane approach (must use Horton or Green Ampt for infiltration; the CN method in EPA SWMM may produce different results than the NRCS CN method), or
### 4.3.1 SWMM Modeling Using Cascading Planes

Because of complexities of modeling LID and other control measures using SWMM, the cascading planes alternative for site-level volume reduction analysis is recommended only for experienced users. Guidance for conveyance- and storage-based modeling includes these steps:

1. Each sub-watershed should be conceptualized as shown in Figure 3-3. Two approaches can be used in SWMM to achieve this:
   - Create two SWMM sub-catchments for each sub-watershed, one with UIA 100% routed to RPA and the other with DCIA and SPA independently routed to the outlet, or
   - Use a single SWMM sub-catchment to represent the sub-watershed and use the SWMM internal routing option to differentiate between DCIA and UIA. This option should only be used when a large portion of the pervious area on a site is RPA and there is very little SPA since the internal routing does not have the ability to differentiate between SPA and RPA (i.e., the UIA is routed to the entire pervious area, potentially overestimating infiltration losses).

2. Once the subwatershed is set up to represent UIA, DCIA, RPA and SPA in SWMM, the rainfall distribution should be directly input to SWMM.

3. Parameters for infiltration, depression storage and other input parameters should be selected in accordance with the guidance in the *Hydrology* chapter of Volume 1.

4. For storage-based control measures, there are two options for representing the WQCV:
   - The pervious area depression storage value for the RPA can be increased to represent the WQCV. This approach is generally applicable to storage-based control measures that promote infiltration such as rain gardens, permeable pavement systems with storage or sand filters. This adjustment should not be used when a storage-based control measure has a well-defined outlet and a stage-storage-discharge relationship that can be entered into SWMM.
   - The WQCV can be modeled as a storage unit with an outlet in SWMM. This option is preferred for storage-based control measures with well-defined stage-storage-discharge relationships such as extended detention basins.

These guidelines are applicable for EPA SWMM Version 5.0 and all later versions.

### 4.3.2 Volume Reduction Spreadsheet

Documentation regarding the “Quantifying Runoff Reduction Fact Sheet” is published separately on the UDFCD website.
5.0 Conclusion

This chapter provides the computational procedures necessary to calculate the WQCV and adjust imperviousness values used in these calculations due to implementation of LID/MDCIA in the tributary watershed. The resulting WQCV can then be combined with control measure specific design criteria in Chapter 4 to complete the control measure design(s). Adjustments to imperviousness and Curve Numbers resulting from these procedures can be used as input into methods for estimating runoff described in the Hydrology chapter of Volume 1 and for sizing storage volumes described in the Storage chapter of Volume 1.
Figure 3-7. Colorado Green Development DCIA, UIA, RPA, and SPA

<table>
<thead>
<tr>
<th>SUB-BASIN</th>
<th>SPA</th>
<th>RPA</th>
<th>UIA</th>
<th>DCIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.15</td>
<td>0.44</td>
<td>0.56</td>
<td>0.00</td>
</tr>
<tr>
<td>B</td>
<td>0.03</td>
<td>0.05</td>
<td>0.37</td>
<td>0.00</td>
</tr>
<tr>
<td>C</td>
<td>0.02</td>
<td>0.08</td>
<td>0.11</td>
<td>0.00</td>
</tr>
<tr>
<td>D</td>
<td>0.00</td>
<td>0.05</td>
<td>0.12</td>
<td>0.00</td>
</tr>
<tr>
<td>E</td>
<td>0.04</td>
<td>0.11</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>F</td>
<td>0.11</td>
<td>0.00</td>
<td>0.50</td>
<td>0.00</td>
</tr>
<tr>
<td>G</td>
<td>0.10</td>
<td>0.00</td>
<td>0.50</td>
<td>0.00</td>
</tr>
<tr>
<td>H</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>TOTALS</td>
<td>0.42</td>
<td>0.65</td>
<td>1.12</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Figure 3-12. Colorado Green IRF Conveyance-based Lookup (Sub basin E)
6.0 References


