# Chapter 5: Hydrology Standards

## Contents

# 1.0 Overview

This Chapter presents information that is specific to the City of Fort Collins and may be a significant deviation from the information presented in the UDFCD Manuals. Utilizing UDFCD methodologies for hydrology calculations may not be accepted by FCU.

## 1.1 Storm Runoff Determination

The runoff analysis for a development must be based on the proposed land use for that area. Contributing runoff from upstream areas must be based on the existing land use and the topographic characteristics of those areas.

All runoff calculations, requirements and assumptions must be based on the Master Drainage Plan for the area that is being developed.

Natural topographic features are the basis of location for drainage easements and future runoff calculations. Average land slopes may be utilized in runoff computations unless better data is available. The drainage facilities designed must be able to handle the design flows with minimal erosion damage to the system.

## 1.2 Design Storm Frequencies

All drainage system design and construction must take into consideration three separate and distinct drainage problems. The first is the eightieth ($80^{th}$) percentile storm event or the rain event for which 80% of all rain events have an equal or smaller depth of rain. This storm event is often referred to as the "water quality storm" and is used to design water quality components of storm drainage systems.

The second is the "minor storm" or "initial storm", which is the 2-year storm in the City of Fort Collins. This is the storm that has a probability of occurring, on the average, once every two (2) years, or one that has a fifty percent (50%) probability of exceedance every year.

The third is the "major storm", which is the 100-year storm in the City of Fort Collins. This is the storm that has a probability of occurring, on the average, once every one hundred (100) years, or one that has a one percent (1%) probability of exceedance every year.

**RUNOFF CALCULATIONS**

BOTH THE 2-YEAR AND THE 100-YEAR STORM EVENTS MUST BE INCLUDED IN ALL DRAINAGE SYSTEM ANALYSES AND REPORTS

## 1.3 Water Quality Storm Provisions

Water quality drainage system, as a minimum, must be designed to address initial water quality considerations. The water quality storm shall be used in calculating the water quality capture volume (WQCV) for standard water quality and volume-based Low Impact Development (LID) systems. These are discussed in more detail in Chapter 5: Detention, and in Appendix C: LID Implementation Manual.

## 1.4 Design Storm Return Periods

The 100-year drainage system, as a minimum, must be designed to convey stormwater runoff from the 100-year recurrence flood to minimize life hazards and health, damage to structures, and interruption to traffic and services. Runoff from the 100-year storm can be conveyed in the urban street system, channels, storm sewers and other facilities, provided the conveyance is done within acceptable criteria as specified in this Manual.

All new public and private improvements must plan, design, and construct drainage systems that account for the 2-year storm event as well as the 100-year storm. The 100-year storm event is the standard level of protection in the City of Fort Collins unless otherwise specified by the applicable Master Drainage Plan. Storms with recurrence intervals greater than 100-year, may still need to be considered in the drainage analysis, if only on a qualitative basis.

### 1.4.1 Minor Storm (2-Year) Provisions

The 2-year drainage system, as a minimum, must be designed to transport stormwater runoff from the 2-year recurrence interval storm event with minimal disruption to the urban environment. The 2-year storm runoff can be conveyed in the curb and gutter area of the street or roadside ditch (subject to street classification and capacity), by a storm sewer, a channel, or other conveyance facility. See Chapter 8: Streets, Inlets and Conveyance for more detail.

The design objectives for the minor storm drainage system are to minimize inconvenience, to protect against recurring minor damage and to reduce maintenance costs in order to create an orderly drainage system at a reasonable cost. The 2-year storm drainage system may include such facilities as curb and gutter, storm sewer, open channels, drainage ways, ponds, rivers, streams and detention facilities.

### 1.4.2 Major Storm (100-Year) Provisions

The design objectives of the 100-year storm drainage system are to eliminate loss of life and prevent and/or minimize property damage. Major drainage systems may include storm sewers, curb, gutter and streets, open channels, drainage ways, ponds, rivers, streams and detention facilities. A comprehensive storm drainage system must incorporate the design objectives for both the minor and major storms.

# 2.0 Runoff Methodologies

There are two runoff analysis methodologies that are approved by the City: the Rational Method and the Stormwater Management Model (SWMM). In general, the chosen methodology should follow the basin size limitations listed in **Table 2.0-1** below. SWMM must also be used to assess the performance of multiple detention basins in parallel or in series in a particular watershed. The City is the determining authority with respect to the appropriate methodology to use under uncertain circumstances. Please note that the Colorado Urban Hydrograph Procedure (CUHP) is not allowed to be utilized for hydrology analysis for Fort Collins area projects because this procedure is calibrated using Denver/Boulder rainfall data.

**Table 2.0-1: Runoff Calculation Method**

| Project Size | Runoff Calculation Method |
|---|---|
| < 5 acres | Rational Method Required |
| 5-20 acres | Rational Method or SWMM Accepted |
| ≥ 20 acres | SWMM Required |

Reference: Drainage Report submittal requirements must be prepared in accordance with the criteria set forth in Chapter 2: Development Submittal Requirements.

# 3.0 Rational Method

## 3.1 Rational Formula

The methodology and theory behind the Rational Method is not covered in this Manual as this subject is well described in many hydrology reference books. However, the Rational Method procedure is generally provided in the following sections. Runoff coefficient calculations, rainfall data, and the time of concentration formula are specific to the City and are included below.

The Rational Formula is represented by the following equation:

$$\mathbf{Q = CIA} \qquad \textbf{Equation 5-1}$$

Where: Q = Peak Rate of Runoff, cfs
C = Runoff Coefficient, dimensionless
I = Rainfall Intensity, in/hr
A = Area of the Basin or Sub-basin, acres

## 3.2 Runoff Coefficients

Runoff coefficients used for the Rational Method are determined based on either overall land use or surface type across the drainage area. For Overall Drainage Plan (ODP) submittals, when surface types may not yet be known, land use shall be used to estimate flow rates and volumes. **Table 3.2-1** lists the runoff coefficients for common types of land uses in the City.

**Table 3.2-1. Zoning Classification - Runoff Coefficients**

| Land Use | Runoff Coefficient (C) |
|---|---|
| **Residential** | |
| Urban Estate | 0.30 |
| Low Density | 0.55 |
| Medium Density | 0.65 |
| High Density | 0.85 |
| **Commercial** | |
| Commercial | 0.85 |
| Industrial | 0.95 |
| **Undeveloped** | |
| Open Lands, Transition | 0.20 |
| Greenbelts, Agriculture | 0.20 |

Reference: For further guidance regarding zoning classifications, refer to the Land Use Code, Article 4.

For a Project Development Plan (PDP) or Final Plan (FP) submittals, runoff coefficients must be based on the proposed land surface types. Since the actual runoff coefficients may be different from those specified in **Table 3.2-1, Table 3.2-2** lists coefficients for the specific types of land surfaces.

**Table 3.2-2. Surface Type - Runoff Coefficients**

| Surface Type | Runoff Coefficients |
|---|---|
| **Hardscape or Hard Surface** | |
| Asphalt, Concrete | 0.95 |
| Rooftop | 0.95 |
| Recycled Asphalt | 0.80 |
| Gravel | 0.50 |
| Pavers | 0.50 |
| **Landscape or Pervious Surface** | |
| Lawns, Sandy Soil, Flat Slope < 2% | 0.10 |
| Lawns, Sandy Soil, Avg Slope 2-7% | 0.15 |
| Lawns, Sandy Soil, Steep Slope >7% | 0.20 |
| Lawns, Clayey Soil, Flat Slope < 2% | 0.20 |
| Lawns, Clayey Soil, Avg Slope 2-7% | 0.25 |
| Lawns, Clayey Soil, Steep Slope >7% | 0.35 |

### 3.2.1 Composite Runoff Coefficients

Drainage sub-basins are frequently composed of land that has multiple surface types or zoning classifications. In such cases a composite runoff coefficient must be calculated for any given drainage sub-basin.

The composite runoff coefficient is obtained using the following formula:

$$C = \frac{\sum_{i=1}^{n}(C_i x A_i)}{A_t}$$

**Equation 5-2**

Where: C = Composite Runoff Coefficient

$C_i$ = Runoff Coefficient for Specific Area ($A_i$), dimensionless

$A_i$ = Area of Surface with Runoff Coefficient of $C_i$, acres or square feet

n = Number of different surfaces to be considered

$A_t$ = Total Area over which C is applicable, acres or square feet

### 3.2.2 Runoff Coefficient Frequency Adjustment Factor

The runoff coefficients provided in **Table 3.2-1** and **Table 3.2-2** are appropriate for use with the 2-year storm event. For any analysis of storms with higher intensities, an adjustment of the runoff coefficient is required due to the lessening amount of infiltration, depression retention, evapotranspiration and other losses that have a proportionally smaller effect on high-intensity storm runoff. This adjustment is applied to the composite runoff coefficient. These frequency adjustment factors, $C_f$, are found in **Table 3.2-3**.

**Table 3.2-3. Frequency Adjustment Factors**

| Storm Return Period (years) | Frequency Adjustment Factor ($C_f$) |
|---|---|
| 2, 5, 10 | 1.00 |
| 25 | 1.10 |
| 50 | 1.20 |
| 100 | 1.25 |

**CxCF**

PRODUCT OF CxCF CANNOT EXCEED THE VALUE OF 1

## 3.3 Time of Concentration

### 3.3.1 Overall Equation

The next step to approximate runoff using the Rational Method is to estimate the Time of Concentration, $T_c$, or the time for water to flow from the most remote part of the drainage sub-basin to the design point under consideration.

The Time of Concentration is represented by the following equation:

$$\mathbf{T_c = T_i + T_t} \qquad \textbf{Equation 5-3}$$

Where: $T_c$ = Total Time of Concentration, minutes
$T_i$ = Initial or Overland Flow Time of Concentration, minutes
$T_t$ = Channelized Flow in Swale, Gutter or Pipe, minutes

### 3.3.2 Overland Flow Time

Overland flow, $T_i$, can be determined by the following equation:

$$\mathbf{T_i = \frac{1.87(1.1 - CxC_f)\sqrt{L}}{\sqrt[3]{S}}} \qquad \textbf{Equation 3.3-2}$$

Where: C = Runoff Coefficient, dimensionless
$C_f$ = Frequency Adjustment Factor, dimensionless
L = Length of Overland Flow, feet
S = Slope, percent

**OVERLAND FLOW LENGTH**

L=200’ MAX IN DEVELOPED AREAS
L=500’ MAX IN UNDEVELOPED AREAS

### 3.3.3 Channelized Flow Time

Travel time in a swale, gutter or storm pipe is considered "channelized" or "concentrated" flow and can be estimated using the Manning's Equation:

$$\mathbf{V = \frac{1.49}{n} R^{2/3} S^{1/2}}$$ **Equation 5-4**

Where: V = Velocity, feet/second
n = Roughness Coefficient, dimensionless
R = Hydraulic Radius, feet (Hydraulic Radius = area / wetted perimeter, feet)
S = Longitudinal Slope, feet/feet

And:

$$\mathbf{T_t = \frac{L}{Vx60}}$$ **Equation 5-5**

### 3.3.4 Total Time of Concentration

A minimum $T_c$ of 5 minutes is required. The maximum $T_c$ allowed for the most upstream design point shall be calculated using the following equation:

$$\mathbf{T_c = \frac{L}{180} + 10}$$ **Equation 3.3-5**

The Total Time of Concentration, $T_c$, is the lesser of the values of $T_c$ calculated using $T_c = T_i + T_t$ or the equation listed above.

**TC**

- A MINIMUM $T_C$ OF 5 MINUTES IS REQUIRED IN ALL CASES.
- A MAXIMUM $T_C$ OF 5 MINUTES IS TYPICAL FOR SMALLER, URBAN PROJECTS.

## 3.4 Intensity-Duration-Frequency Curves for Rational Method

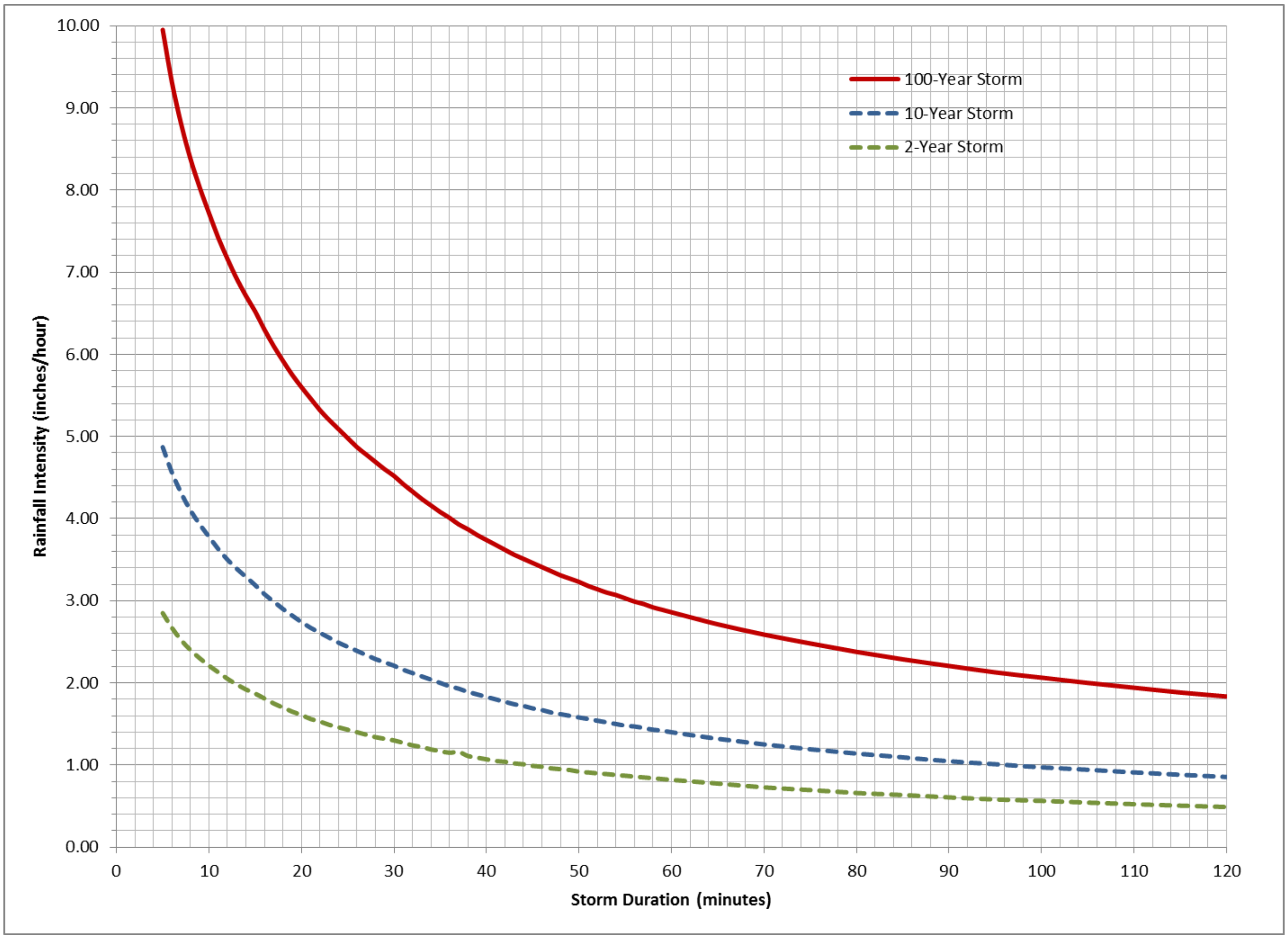
The two-hour rainfall Intensity-Duration-Frequency curves for use with the Rational Method is provided in **Table 3.4-1 and Figure 3.4-1**.

**Table 3.4-1. IDF Table for Rational Method**

| Duration (min) | Intensity 2-year (in/hr) | Intensity 10-year (in/hr) | Intensity 100-year (in/hr) |
|---|---|---|---|
| 5 | 2.85 | 4.87 | 9.95 |
| 6 | 2.67 | 4.56 | 9.31 |
| 7 | 2.52 | 4.31 | 8.80 |
| 8 | 2.40 | 4.10 | 8.38 |
| 9 | 2.30 | 3.93 | 8.03 |
| 10 | 2.21 | 3.78 | 7.72 |
| 11 | 2.13 | 3.63 | 7.42 |
| 12 | 2.05 | 3.50 | 7.16 |
| 13 | 1.98 | 3.39 | 6.92 |
| 14 | 1.92 | 3.29 | 6.71 |
| 15 | 1.87 | 3.19 | 6.52 |
| 16 | 1.81 | 3.08 | 6.30 |
| 17 | 1.75 | 2.99 | 6.10 |
| 18 | 1.70 | 2.90 | 5.92 |
| 19 | 1.65 | 2.82 | 5.75 |
| 20 | 1.61 | 2.74 | 5.60 |
| 21 | 1.56 | 2.67 | 5.46 |
| 22 | 1.53 | 2.61 | 5.32 |
| 23 | 1.49 | 2.55 | 5.20 |
| 24 | 1.46 | 2.49 | 5.09 |
| 25 | 1.43 | 2.44 | 4.98 |
| 26 | 1.4 | 2.39 | 4.87 |
| 27 | 1.37 | 2.34 | 4.78 |
| 28 | 1.34 | 2.29 | 4.69 |
| 29 | 1.32 | 2.25 | 4.60 |
| 30 | 1.30 | 2.21 | 4.52 |
| 31 | 1.27 | 2.16 | 4.42 |
| 32 | 1.24 | 2.12 | 4.33 |
| 33 | 1.22 | 2.08 | 4.24 |
| 34 | 1.19 | 2.04 | 4.16 |
| 35 | 1.17 | 2.00 | 4.08 |
| 36 | 1.15 | 1.96 | 4.01 |
| 37 | 1.16 | 1.93 | 3.93 |
| 38 | 1.11 | 1.89 | 3.87 |

| Duration (min) | Intensity 2-year (in/hr) | Intensity 10-year (in/hr) | Intensity 100-year (in/hr) |
|---|---|---|---|
| 39 | 1.09 | 1.86 | 3.8 |
| 40 | 1.07 | 1.83 | 3.74 |
| 41 | 1.05 | 1.80 | 3.68 |
| 42 | 1.04 | 1.77 | 3.62 |
| 43 | 1.02 | 1.74 | 3.56 |
| 44 | 1.01 | 1.72 | 3.51 |
| 45 | 0.99 | 1.69 | 3.46 |
| 46 | 0.98 | 1.67 | 3.41 |
| 47 | 0.96 | 1.64 | 3.36 |
| 48 | 0.95 | 1.62 | 3.31 |
| 49 | 0.94 | 1.6 | 3.27 |
| 50 | 0.92 | 1.58 | 3.23 |
| 51 | 0.91 | 1.56 | 3.18 |
| 52 | 0.9 | 1.54 | 3.14 |
| 53 | 0.89 | 1.52 | 3.10 |
| 54 | 0.88 | 1.50 | 3.07 |
| 55 | 0.87 | 1.48 | 3.03 |
| 56 | 0.86 | 1.47 | 2.99 |
| 57 | 0.85 | 1.45 | 2.96 |
| 58 | 0.84 | 1.43 | 2.92 |
| 59 | 0.83 | 1.42 | 2.89 |
| 60 | 0.82 | 1.4 | 2.86 |
| 65 | 0.78 | 1.32 | 2.71 |
| 70 | 0.73 | 1.25 | 2.59 |
| 75 | 0.70 | 1.19 | 2.48 |
| 80 | 0.66 | 1.14 | 2.38 |
| 85 | 0.64 | 1.09 | 2.29 |
| 90 | 0.61 | 1.05 | 2.21 |
| 95 | 0.58 | 1.01 | 2.13 |
| 100 | 0.56 | 0.97 | 2.06 |
| 105 | 0.54 | 0.94 | 2.00 |
| 110 | 0.52 | 0.91 | 1.94 |
| 115 | 0.51 | 0.88 | 1.88 |
| 120 | 0.49 | 0.86 | 1.84 |

**Figure 3.4-1. Rainfall IDF Curve – Fort Collins**



# 4.0 SWMM

This section is for project sites that require the use of the Stormwater Management Model (SWMM) to determine storm hydrograph routing and is the only method that is able to assess the overall performance of multiple detention basins in parallel or in series in a particular project site or watershed.

Reference: The theory and methodology for reservoir routing is not covered in this Manual as this subject is well described in many hydrology reference books. The EPA SWMM Reference Manuals, dated January 2016, have been utilized in preparing the information in this section of the Manual.

## 4.1 Input Parameters

**Table 4.1-1** provides required input values to be used for SWMM modeling.

Basin and conveyance element parameters must be computed based on the physical characteristics of the site.

**Table 4.1-1. SWMM Input Parameters**

| **Depth of Storage** | |
|---|---|
| Impervious Areas | 0.1 inches |
| Pervious Areas | 0.3 inches |
| **Infiltration Parameters** | |
| Maximum | 0.51 in/hr |
| Minimum | 0.50 in/hr |
| Decay Rate | 0.0018 in/sec or 6.48 in/hr |
| **Zero Detention Depth** | 1% |
| **Manning's "n"** | |
| Pervious Surfaces | 0.250 |
| Impervious Surfaces | 0.016 |

For Overall Drainage Plan (ODP) and Project Development Plan (PDP) submittals, when surface types may not yet be known, land uses may be used to estimate impervious percentages. **Table 4.1-2** lists the percent imperviousness for common types of land uses in the City.

**Table 4.1-2. Land Use - Percent Impervious**

| Land Use | Percent Impervious (%) |
|---|---|
| **Residential** | |
| Urban Estate | 30 |
| Low Density | 50 |
| Medium Density | 70 |
| High Density | 90 |
| **Commercial** | |
| Commercial | 80 |
| Industrial | 90 |
| **Undeveloped** | |
| Open Lands, Transition | 20 |
| Greenbelts, Agriculture | 2 |
| Offsite Flow Analysis (when Land Use not defined) | 45 |

Reference: For further guidance regarding zoning classifications, refer to the Land Use Code, Article 4.

For Final Plan (FP) submittals, impervious values must be based on the proposed land surface types. Refer to **Table 4.1-3** for recommended percent impervious values.

**Table 4.1-3. Surface Type – Percent Impervious**

| Surface Type | Percent Impervious (%) |
|---|---|
| **Hardscape or Hard Surface** | |
| Asphalt, Concrete | 100 |
| Rooftop | 90 |
| Recycled Asphalt | 80 |
| Gravel | 40 |
| Pavers | 40 |
| **Landscape or Pervious Surface** | |
| Playgrounds | 25 |
| Lawns, Sandy soil | 2 |
| Lawns, Clayey soil | 2 |

The composite imperviousness is obtained using the following formula:

$$I = \frac{\sum_{i=1}^{n} \left( I_i x A_i \right)}{A_t}$$ **Equation 5-6**

Where: I = Composite Imperviousness, %

$I_i$ = Imperviousness for Specific Area ($A_i$), %

$A_i$ = Area of Surface with Imperviousness of $I_i$, acres or square feet

n = Number of different surfaces to be considered

$A_t$ = Total Area over which I is applicable, acres or square feet

### 4.1.1 Intensity-Duration-Frequency Curves for SWMM

The hyetograph input option must be selected when creating SWMM input files. Hyetographs for the 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year Fort Collins rainfall events are provided in **Table 4.1-4**.

**Table 4.1-4. IDF Table for SWMM**

| Duration (min) | Intensity 2-year (in/hr) | Intensity 5-year (in/hr) | Intensity 10-year (in/hr) | Intensity 25-year (in/hr) | Intensity 50-year (in/hr) | Intensity 100-year (in/hr) |
|---|---|---|---|---|---|---|
| 5 | 0.29 | 0.40 | 0.49 | 0.63 | 0.79 | 1.00 |
| 10 | 0.33 | 0.45 | 0.56 | 0.72 | 0.90 | 1.14 |
| 15 | 0.38 | 0.53 | 0.65 | 0.84 | 1.05 | 1.33 |
| 20 | 0.64 | 0.89 | 1.09 | 1.41 | 1.77 | 2.23 |
| 25 | 0.81 | 1.13 | 1.39 | 1.80 | 2.25 | 2.84 |
| 30 | 1.57 | 2.19 | 2.69 | 3.48 | 4.36 | 5.49 |
| 35 | 2.85 | 3.97 | 4.87 | 6.30 | 7.90 | 9.95 |
| 40 | 1.18 | 1.64 | 2.02 | 2.61 | 3.27 | 4.12 |
| 45 | 0.71 | 0.99 | 1.21 | 1.57 | 1.97 | 2.48 |
| 50 | 0.42 | 0.58 | 0.71 | 0.92 | 1.16 | 1.46 |
| 55 | 0.35 | 0.49 | 0.60 | 0.77 | 0.97 | 1.22 |
| 60 | 0.30 | 0.42 | 0.52 | 0.67 | 0.84 | 1.06 |
| 65 | 0.20 | 0.28 | 0.39 | 0.62 | 0.79 | 1.00 |
| 70 | 0.19 | 0.27 | 0.37 | 0.59 | 0.75 | 0.95 |
| 75 | 0.18 | 0.25 | 0.35 | 0.56 | 0.72 | 0.91 |
| 80 | 0.17 | 0.24 | 0.34 | 0.54 | 0.69 | 0.87 |
| 85 | 0.17 | 0.23 | 0.32 | 0.52 | 0.66 | 0.84 |
| 90 | 0.16 | 0.22 | 0.31 | 0.50 | 0.64 | 0.81 |
| 95 | 0.15 | 0.21 | 0.30 | 0.48 | 0.62 | 0.78 |
| 100 | 0.15 | 0.20 | 0.29 | 0.47 | 0.60 | 0.75 |
| 105 | 0.14 | 0.19 | 0.28 | 0.45 | 0.58 | 0.73 |
| 110 | 0.14 | 0.19 | 0.27 | 0.44 | 0.56 | 0.71 |
| 115 | 0.13 | 0.18 | 0.26 | 0.42 | 0.54 | 0.69 |
| 120 | 0.13 | 0.18 | 0.25 | 0.41 | 0.53 | 0.67 |

#### 4.1.2 Conveyance Element Methodology

Embedded conveyance elements, if used, must begin at the midpoint of the sub-basin in order to appropriately represent the basin based on its actual physical characteristics. Embedded conveyance elements are only allowed in undeveloped watersheds.

#### 4.1.3 Basin Width

Traditionally, the basin width calculation requirement in Fort Collins has been calculated as the area of the basin divided by the length of the basin. The basin length is defined as the length of the concentrated flow (Equation 4-9).

$$\mathbf{W} = \frac{\mathbf{A}}{\mathbf{L_{Ch}}}$$ **Equation 5-7**

Where:

W = Width of the sub-basin
A = Area of the sub-basin
$L_{Ch}$ = Length of the concentrated flow path

This method is perhaps more appropriate for idealized, rectangular shaped basins. For basins that are irregular in shape or have a concentrated flow channel that is off center, the Design Engineer should explore one of three additional methods presented in the EPA SWMM Hydrology Manual for more accurate runoff results. Early coordination with FCU staff is encouraged to discuss the most appropriate method for determining width.

## 4.2 Flow Analysis

Conditions may arise where a dynamic wave modeling analysis may not provide sufficient information on the operation of drainage facilities. An example of this is when analyzing detention basins inter-connected by culverts or storm sewers where release rates and basin volumes may be affected. In such cases when further evaluation is required, FCU staff may require that additional analysis be provided for a complete and accurate analysis of the proposed drainage facilities. Additional analysis may include unsteady flow analysis using hydrographs generated from SWMM.

In addition, flow analysis will also need to consider any other limiting capacity factors, such as existing or proposed inlet capacities that may affect the amount of runoff that is able to contribute to a storm piping system.