Storm Drainage Design and Technical Criteria Manual

City of Brookings, SD

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Ecological Resource Consultants, Inc.

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This manual presents the storm drainage design and technical criteria for the analysis and preparation of development plans for storm drainage facilities in the City of Brookings, South Dakota (City).

1. General

The City has adopted the following design standards, criteria, and policies for all storm drainage management, which should be used in the design and analysis of all storm drainage facilities. The City reserves the right to issue and enforce more stringent criteria. Also, occasions may arise where the minimum standards presented within this chapter are either inappropriate or cannot be justified economically. In these special cases, the City may issue a variance. All designs that vary from the standards and criteria presented in this manual shall obtain approval from the City Engineer prior to completing construction plans and/or analysis reports.

The provisions for adequate drainage are necessary to preserve and promote the general health, welfare and economic well being of the City. Drainage is a regional feature, which affects all governmental jurisdictions and all parcels of property. When planning drainage facilities, the following policies and criteria are to be used in directing your effort.

Standards and technical criteria not specifically addressed in this manual shall follow the provisions of The City of Sioux Falls Engineering Design Standards for Public Improvements, Chapter 11: Drainage Improvements, and the Urban Drainage and Flood Control District (UD&FCD) "Urban Storm Drainage Criteria Manual" (Manual). These resources are available electronically free of charge. The Sioux Falls Engineering Design Standards can be downloaded from:

http://www.siouxfalls.org/PublicWorks/Contractors/design_standards.aspx

The Urban Storm Drainage Criteria are available at:

http://www.udfcd.org/

In addition, the engineer should refer to the South Dakota Department of Transportation Standard Plans for additional design details not covered in this manual.

2. Required Design Submittals

Drainage plans submitted to the City for review shall contain a detailed hydrologic analysis and comprehensive drainage design in accordance with these criteria and other applicable standards (local, state, and federal). Prior to

receiving approval, the final Drainage Plans must be sealed by a South Dakota Registered Professional Engineer who has extensive knowledge of the project being submitted for review. Drawings submitted without being sealed, or by a party not responsible for the work, WILL NOT be reviewed. Final drainage plans and reports shall include certification statements regarding engineered plans and construction. The certification statement for the final drainage report shall indicate:

"**Certification**

I hereby certify that this Drainage Study for the _____ was prepared by me or under my direct supervision in accordance with the City of Brookings Storm Drainage Design and Technical Manual, latest edition. I understand that the City of Brookings does not assume liability for drainage facilities designed by others."

This statement shall be signed and sealed by a registered Professional Engineer.

The following paragraphs summarize the minimum level of storm drainage study to be prepared and submitted to the City for approval. Based on the point in the design process, the level of analysis and design detail required varies. Three levels of study are conducted, as outlined below. Details required in various levels of storm drainage study are presented in checklists in **Figures A1- A5** in **Appendix A**. All required information is to be submitted for City review prior to receiving an approved application or permit. Applicants are encouraged to prepare the required submittals with as much detail as possible to minimize possible confusion and to cut down on overall processing time. Should there be questions regarding the required submittals, please contact the City Engineer.

A Sketch Storm Drainage Study (SDS) must be completed and submitted along with the sketch development plan. This submittal shall include a conceptual level storm drainage plan, which presents a general overview of the proposed project. The site layout is provided with spot elevations/available topography, drainage directions, natural features, and expected extent of the development. Existing and proposed drainage structures, impervious surfaces, and utilities must be identified. A formal report is not necessary at this time. See **Figure A1** in **Appendix A** for a complete checklist of items to be completed.

A Preliminary Storm Drainage Study is to be completed and submitted along with the preliminary development plan. This submittal shall include a drainage plan as well as a drainage report. The plan includes all items presented in a Sketch SDS, with the site plan view drawn to scale, and providing greater topographical detail. Furthermore, approximate plans must be provided for proposed conveyance structures and road layouts. The Preliminary Storm Drainage Report must present a complete description of the project, design methods applied, storm water improvements, drainage improvements, and erosion and sedimentation

impacts. A preliminary hydrological and hydraulic analysis is required, and must include scaled pre- and post-development basin maps with drainage structures and storm water courses indicated. Runoff summary tables for design points, and preliminary sizing for storm water storage facilities are to be included. See **Figures A2** and **A3** in **Appendix A** for complete checklists of items to be completed.

A Final Storm Drainage Study includes a detailed drainage plan and report. Both the plan and report shall be completed and submitted with the final development plans. The drainage plan shall present a comprehensive site plan with complete descriptions of the topography, utilities, site layout, storm drainage structures, natural features, and proposed structures. The source and quantity of fill must be specified, along with demolition items. Also required in the drainage plan are profile drawings of storm drainage structures, surface grades, and proposed utilities, as well as cross section drawings of roadways, streets, channels, and basins. The plan must bear the seal of a Professional Engineer. The Final Storm Drainage Report must present a complete description of the project including land use, site improvements, and construction of impervious surfaces. The existing conditions and developed site drainage conditions must be presented, in addition to a detailed vicinity map and basin maps of the project area, including upstream and downstream basins. A hydrological analysis of the project area is necessary, as well as a downstream drainage analysis. The report must also include a geotechnical report, hydraulic design computations, and a description of erosion and sedimentation control. A signed statement from the project engineer and developer are also to be included in the report. See **Figures A4 and A5** in **Appendix A** for complete checklists of items to be completed.

2.1 Policies

2.1.1 Space Planning

Storm water management facilities serve both a conveyance and storage function. When a channel is planned as a conveyance feature, an outlet as well as a downstream storage structure is required. Therefore, during the review process and prior to approval, the City will require the submission of all appropriate information to ensure:

- Adequate space is properly allocated for drainage facilities
- There are no conflicts with other land uses that result in downstream water damage or impairment of runoff from upstream properties
- There is no impairment with the functionality of other urban systems.

2.1.2 Jurisdictional Boundaries

Since drainage considerations and problems are regional in nature, and do not respect jurisdictional boundaries, the City will emphasize regional cooperation in all submitted designs, as appropriate.

2.2 Master Planning

As previously stated, drainage boundaries are non-jurisdictional and regional cooperation is required to receive approval for all new development or re-development projects. Therefore, the City may undertake future regional master plans to define the major drainageway facilities. Whenever a City approved master plan exists, its recommendations shall be followed to the maximum extent possible.

2.2.1 Floodplain Management

As part of its zoning resolutions, the City has adopted floodplain regulations necessary to preserve and promote the general health, welfare, and economic well being of the region. The general purposes of floodplain regulations are summarized as follows:

1. To reduce the hazard of floods to life and property;
2. To protect and preserve hydraulic characteristics of watercourses used for conveyance of floodwaters;
3. To protect the public from the extraordinary financial expenditures for flood control and relief; and
4. To promote the multipurpose resource concept, with the intent to provide and preserve quality open space, trails, and tree lines.

These regulations are presented in Chapter 38 of the Brookings Municipal Code of Ordinances, available electronically at:

http://www.municode.com/resources/gateway.asp?pid=10484&sid=41

Flood design and flood proofing shall be completed according to floodplain zoning presented by FEMA in the “Flood Insurance Study for the City of Brookings” dated April, 1978. This report is available electronically at:

http://store.msc.fema.gov

Up-to-date floodplain mapping with community panel numbers can be obtained from the Federal Emergency Management Agency (FEMA). It is the responsibility of the developer to ensure design plans are consistent with the most current regulations.

2.2.2 Storm Runoff Detention

The City considers storm runoff detention to be the desired method for reducing overall (construction and maintenance) urban drainage costs. Temporarily detaining a few acre-feet of runoff can significantly reduce downstream flood hazards as well as pipe and channel requirements in urban areas. In addition, the storage of runoff provides for sediment and debris collection, which enhances downstream water quality. However, all benefits can only be obtained through consistent administration of detention policies. Therefore, during the review process and prior to approval, the City will require all new development and/or redevelopment projects to include some form of detention. Exceptions will only be granted for redevelopment of areas less then 5,000 square feet as specified in Section 9. The minimum detention capacity and maximum release rates for the 5-year and 100-year recurrence interval storms will be determined by procedures and criteria presented in section 9 of this manual.

2.2.3 Retention

In those areas of the City where no outlet presently exists for positive drainage to a major drainage system, the City will require retention of the runoff from a 24-hour, 100-year storm event plus one foot of freeboard until such connection becomes available. In addition, no parking lot retention will be accepted without specific approval of the City Engineer. Design criteria are discussed in section 10.

2.2.4 Operations and Maintenance

Key issues in the long-term performance of all storm drainage systems are the proper operations and continued maintenance of the facility (i.e. debris and sediment removal). Therefore, prior to issuing final project approval, the City will require the submission of an Operations and Maintenance Plan that briefly outlines procedures for periodic inspections and maintenance, and a plan showing the facility easement and proposed access locations to all detention/retention facilities.

3. Storm Design Criteria

In addition to land use, all drainage systems being designed within the City shall take into account both the minor (5-year) and the major (100-year) storm. The objectives of drainage system planning for the minor storm are to allow for the proper design of minor drainage systems (i.e. curb and gutters, storm sewers, open channels and detention ponds) while minimizing minor damage and maintenance costs. The objective of drainage planning for the major storm are to allow for proper design of major drainage systems (i.e. bridges, storm sewers,

open channels and detention ponds) while minimizing the possibility of major damage and/or loss of life.

It is the responsibility of the design engineer to develop, justify, and submit values used in the preparation of drainage plans prepared for City review and approval.

3.1 Storm Drainage Planning

When determining design storm flow, the engineer shall follow appropriate criteria and guidelines to assure minimum design standards and a regional based drainage solution is developed. The information presented below shall be used by the engineer in the development of design storm runoff for both onsite and offsite flows.

3.1.1 Onsite Flow Analysis

When performing analysis on the onsite basin to determine peak volumes and time to concentrations, the engineer shall used the proposed fully developed land use plan to determine runoff coefficients and consider changes in flow patterns (from the undeveloped site conditions) caused by the proposed plan (including street alignments). When evaluating the estimated time to concentrations, the proposed lot grading shall be used to calculate the time to concentration. The proposed project shall in no way change historic runoff rates off the property, cause downstream damage, or adversely impact adjacent properties. In addition, phased or partial development analysis will not be accepted. The entire platted parcel shall be analyzed for full build-out in order to properly site and size detention/ retention areas and conveyance systems.

Different levels of onsite analysis may be required depending on the size of project or as directed by the City Engineer.

3.1.2 Offsite Flow Analysis

The analysis of offsite runoff is dependent on regional drainage characteristics and the existing/proposed land use and topographic features. If an existing Storm Drainage Master Plan is available for the area being developed, the engineer shall used this as a baseline document (prior approval from the City on the Master Plan is required) and update with proposed information. However, should no offsite information be available for fully developed flows (5- and 100-year), the engineer must perform a regional analysis to ensure the proposed development does not change historic runoff values, cause downstream damage, or adversely impact adjacent properties.

3.2 Storm Return Period

The minor storm return period shall be the 5 year event and the major storm return period shall be the 100-year event for all vital drainage structures or critical points of surface water flow.

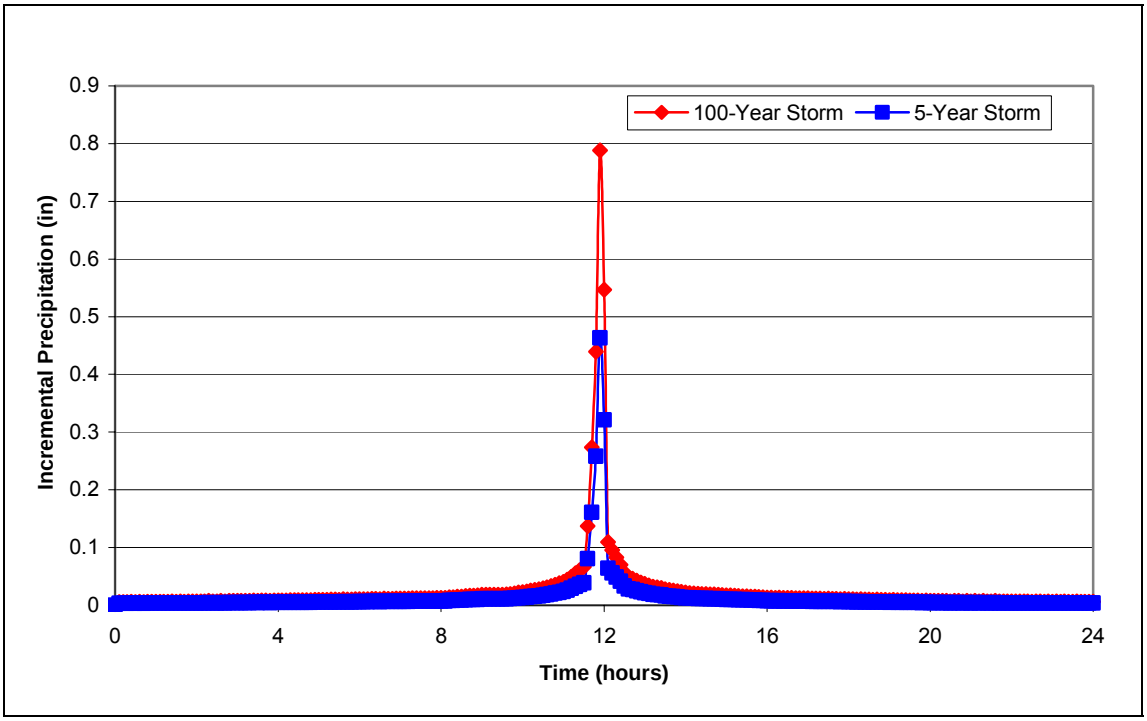
3.3 Rainfall

Presented in this section are guidelines for the development of rainfall data to be used in preparing a hydrological analysis (storm runoff) for proposed development within the City. Rainfall data from the Rainfall Frequency Atlas published by the NOAA Central Weather Service and the U.S. Weather Bureau were used to develop storm totals for the 1, 2, 5, 10, 25, 50 and 100-year storms with durations of 0.25, 0.5, 1, 2, 3, 6, 12, and 24- hours.

3.3.1 Major and Minor Design Storms

Storm totals were distributed into incremental rainfall values using an SCS- Type II storm distribution. Data for the 5- and 100-year 24-hour storms are presented in tabular format in **Tables B1** and **B2** in **Appendix B** and graphically in **Figure 1**. These data are to be used as precipitation input values when modeling basins using a method other than the Rational Method. These data are not to be used in Rational Method calculations.

Figure 1. 100-year and 5-year 24-hour Storm Distributions



3.3.2 Intensity- Duration- Frequency Curves

Intensity-duration-frequency (IDF) curves were developed for the City by using 0.25 to 24-hour point rainfall values for the 2 to 100-year storms obtained from the Rainfall Frequency Atlas. Point rainfall values were converted to intensities based upon the duration of the storm, and are given in **Table 1**. Rainfall intensities for various storms are plotted in **Figure 2**. A portion of **Figure 2**, displaying rainfall intensities for durations up to 60 minutes is shown in **Figure 3**. These figures are to be used in determining the appropriate rainfall intensity, given a time to concentration calculated as shown in section 3.6, for use in the Rational Equation.

Table 1. Point Rainfall Values for Various Return Periods & Storm Durations

Return Period (years)	Storm Duration (hours)	Storm Duration (min)	Total Precipitation (in)	Precipitation Intensity (in/hr)	Return Period (years)	Storm Duration (hours)	Storm Duration (min)	Total Precipitation (in)	Precipitation Intensity (in/hr)
2	0.08	5	0.43	5.10	25	0.08	5	0.69	8.32
2	0.17	10	0.67	4.02	25	0.17	10	1.15	6.87
2	0.25	15	0.84	3.36	25	0.25	15	1.46	5.84
2	0.5	30	1.15	2.30	25	0.5	30	2.10	4.19
2	1	60	1.47	1.47	25	1	60	2.76	2.76
2	2	120	1.65	0.83	25	2	120	2.90	1.45
2	3	180	1.75	0.58	25	3	180	3.13	1.04
2	6	360	1.93	0.32	25	6	360	3.50	0.58
2	12	720	2.30	0.19	25	12	720	4.13	0.34
2	24	1440	2.65	0.11	25	24	1440	4.65	0.19
5	0.08	5	0.52	6.27	50	0.08	5	0.77	9.26
5	0.17	10	0.85	5.07	50	0.17	10	1.28	7.69
5	0.25	15	1.07	4.28	50	0.25	15	1.64	6.55
5	0.5	30	1.51	3.01	50	0.5	30	2.36	4.73
5	1	60	1.96	1.96	50	1	60	3.12	3.12
5	2	120	2.15	1.08	50	2	120	3.27	1.64
5	3	180	2.30	0.77	50	3	180	3.38	1.13
5	6	360	2.63	0.44	50	6	360	4.10	0.68
5	12	720	3.00	0.25	50	12	720	4.55	0.38
5	24	1440	3.38	0.14	50	24	1440	5.25	0.22
10	0.08	5	0.59	7.11	100	0.08	5	0.85	10.20
10	0.17	10	0.97	5.81	100	0.17	10	1.42	8.51
10	0.25	15	1.23	4.92	100	0.25	15	1.81	7.25
10	0.5	30	1.75	3.50	100	0.5	30	2.63	5.26
10	1	60	2.29	2.29	100	1	60	3.48	3.48
10	2	120	2.60	1.30	100	2	120	3.70	1.85
10	3	180	2.70	0.90	100	3	180	4.00	1.33
10	6	360	3.08	0.51	100	6	360	4.50	0.75
10	12	720	3.50	0.29	100	12	720	5.20	0.43
10	24	1440	3.88	0.16	100	24	1440	5.75	0.24

Figure 2. IDF Curves for Storms to 4 Hour Durations

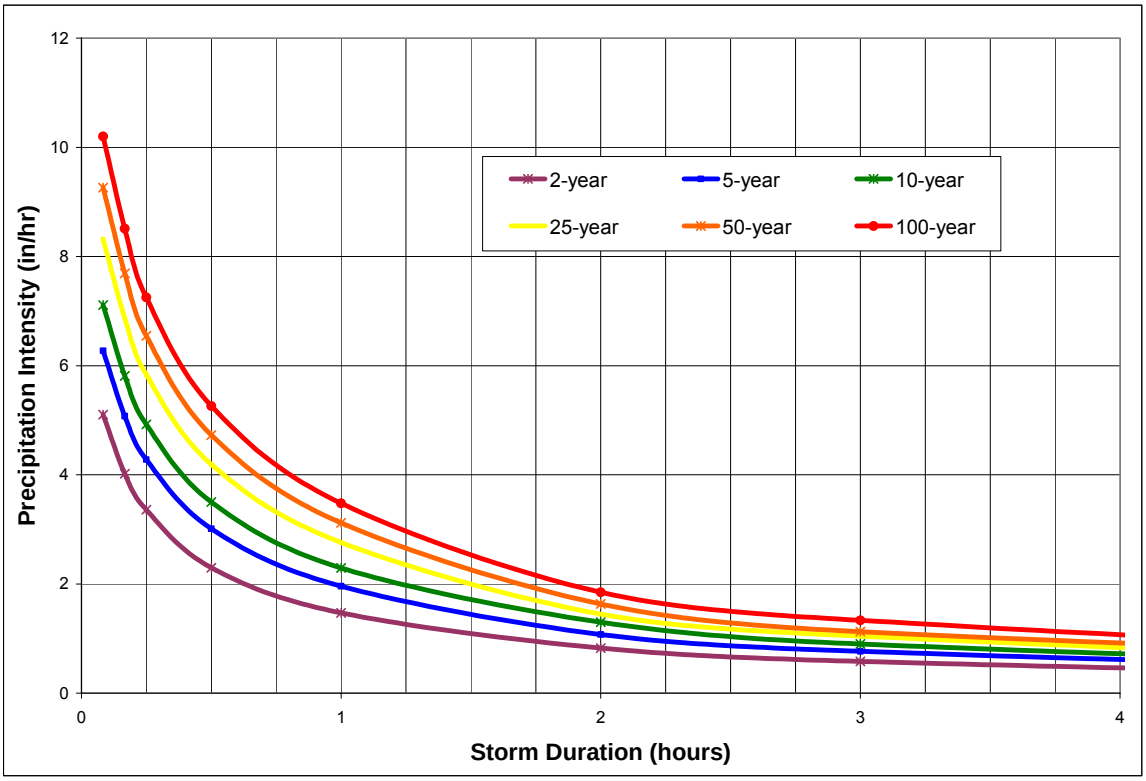
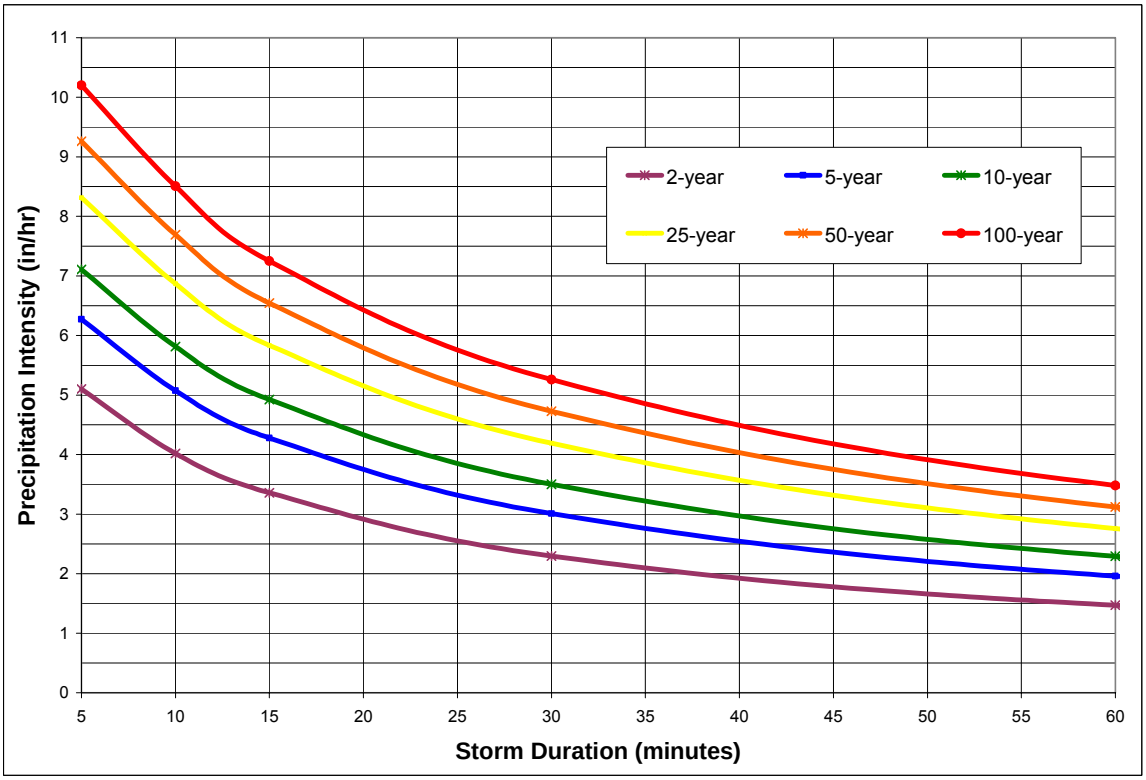


Figure 3. IDF Curves for Storms to 60 Minute Durations



3.4 Storm Flow Analysis

The engineer may use the Rational Method for basins less than 120 acres, or the computer programs WinTR-55, HEC- HMS or SWMM for basins larger or smaller than 120 acres. Other approved hydrologic models may be used with prior approval from the City.

Regardless of the basin size, the percent impervious area is an important parameter than must be quantified. All parts of a watershed can be considered either pervious or impervious. The pervious part is that area where water can readily infiltrate into the ground. The impervious part is the area that does not readily allow water to infiltrate into the ground, such as areas that are paved or covered with buildings and sidewalks or compacted, unvegetated soils. When analyzing a watershed for design purposes, the probable future percent of impervious area must be estimated. A complete tabulation of recommended values of the total percent of imperviousness is provided in **Table 2** and **Figures 4** through **6**. **Appendix C** contains a worksheet for calculating weighted average "I" values for basins with multiple land use types.

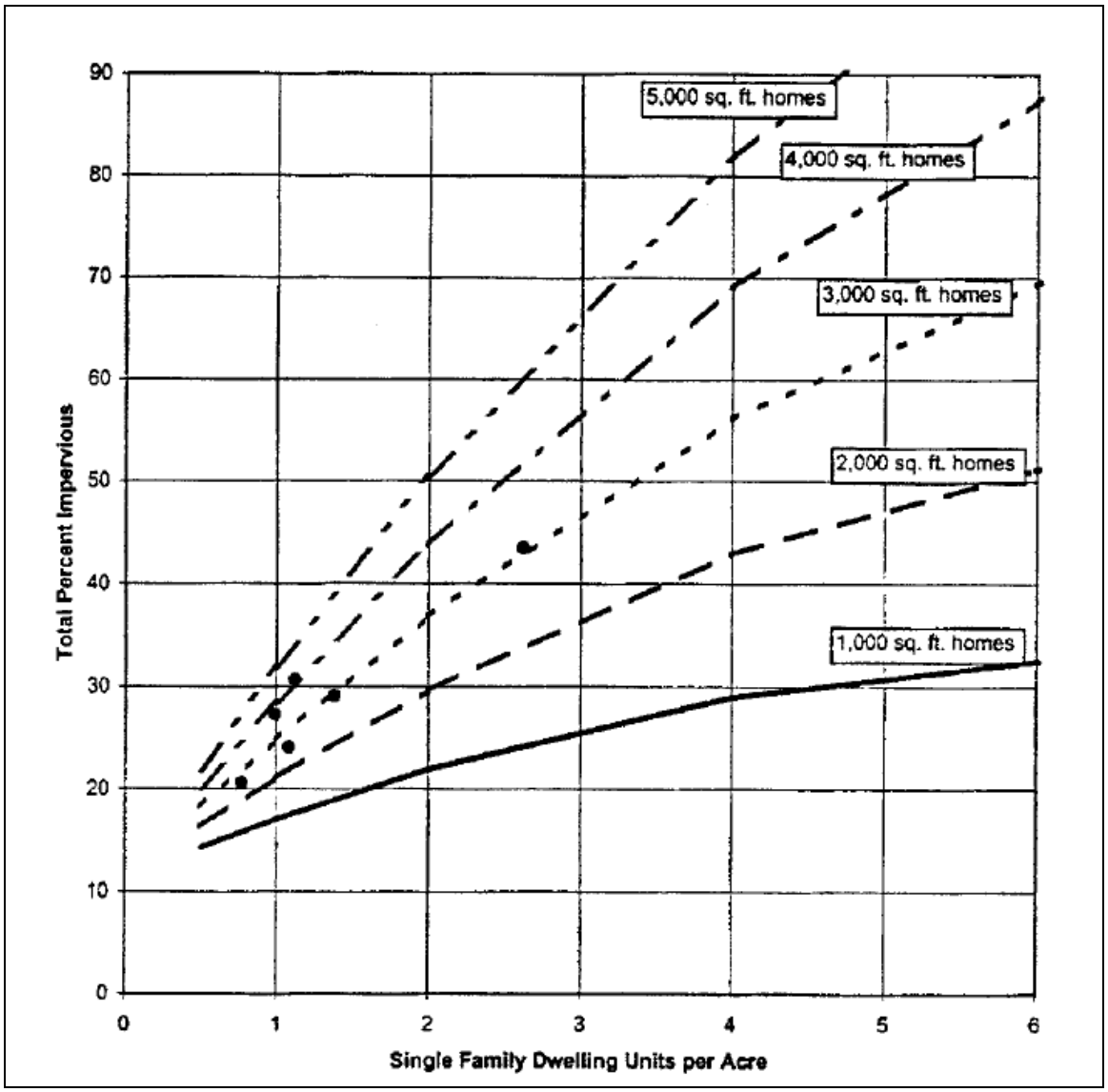
Table 2. Recommended Percentage Imperviousness Values

Land Use or Surface Characteristics	Percentage Imperviousness
Business:	
Commercial areas	95
Neighborhood areas	85
Residential:	
Single-family	*
Multi-unit (detached)	60
Multi-unit (attached)	75
Half-acre lot or larger	*
Apartments	80
Industrial:	
Light areas	80
Heavy areas	90
Parks, cemeteries	5
Playgrounds	10
Schools	50
Railroad-yard Areas	15
Undeveloped Areas	
Historic flow analysis	2
Greenbelts, agricultural	2
Off-site flow analysis (when land use not defined)	45
Streets:	
Paved	100
Gravel (packed)	40
Drives and walks	90
Roofs	90
Lawns, sandy soil	0
Lawns, clayey soil	0

*See **Figures 4** through **6** for percentage imperviousness

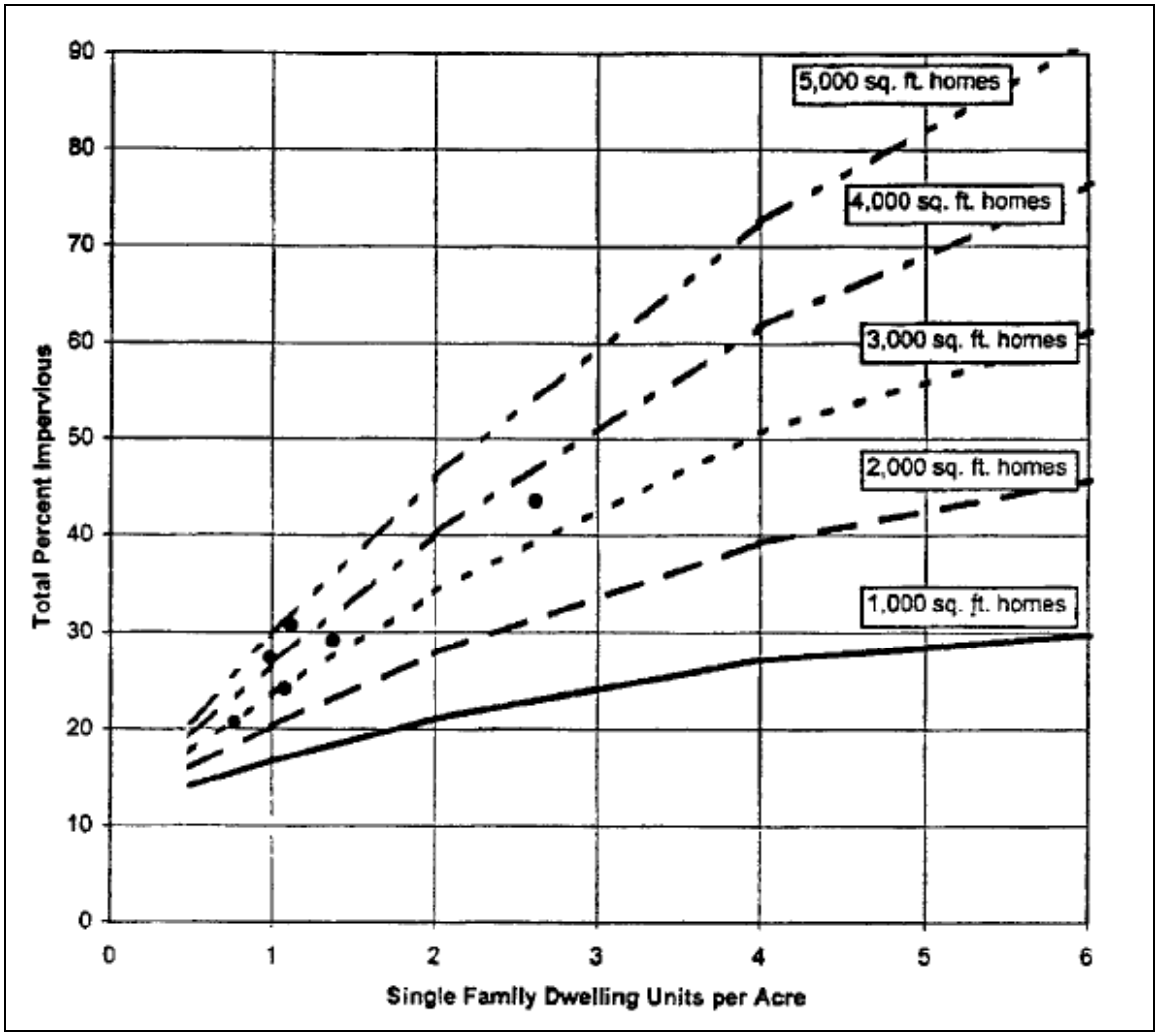
(Reference: Urban Drainage and Flood Control District)

Figure 4. Imperviousness, Single-Family Residential Ranch Style Houses



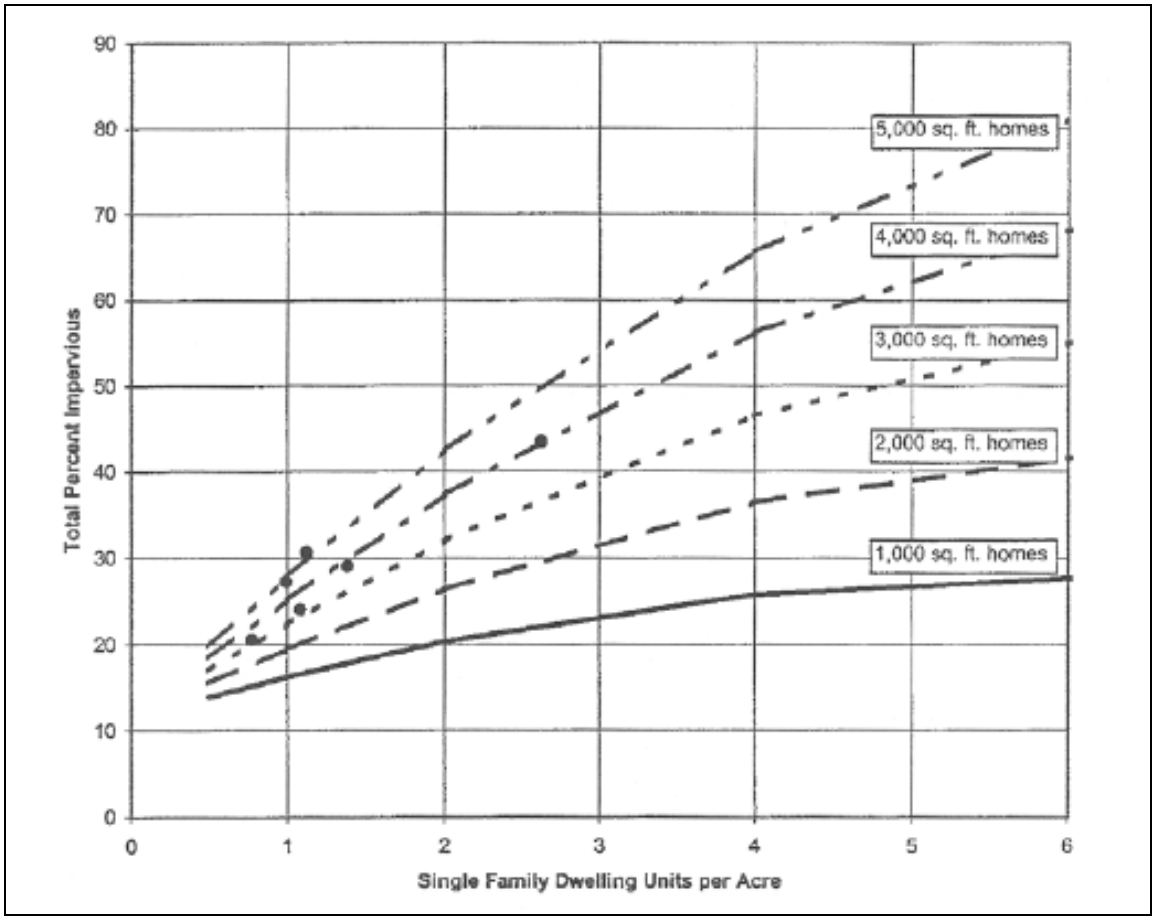
(Reference: Urban Drainage and Flood Control District)
*Square Footage Excludes Basement Area

Figure 5. Imperviousness, Single-Family Residential Split-Level Houses



(Reference: Urban Drainage and Flood Control District)
*Square Footage Excludes Basement Area

Figure 6. Imperviousness, Single-Family Residential Two-Story Houses



(Reference: Urban Drainage and Flood Control District)
*Square Footage Excludes Basement Area

3.4.1 Rational Method

The Rational Method is based on the assumption that rainfall of intensity *i* begins instantaneously and continues indefinitely, causing an increase in the rate of runoff until the time of concentration, T_c, when the entire watershed is contributing to flow at the outlet. The peak rate of flow, which occurs at time T_c, is expressed in the Rational Formula:

$$Q = C*i*A$$

Where: Q = maximum rate of runoff (cfs)
C = runoff coefficient (see section 3.5)
i = average intensity of rainfall (inches/hour) for a duration equal to the time to concentration
A = total area of basin (acres)

From the above formula, Q has units of inches per hour per acre (in/hr/ac). However, since this rate of in/hr/ac differs from cubic feet per second (cfs) by less than one percent, the more common unit of cfs is used.

The general procedure for Rational Method calculations for a single catchment is as follows:

1. Delineate the catchment boundary and determine catchment area
2. Define the flow path from the upper-most portion of the catchment to the design point. This flow path should be divided into reaches of similar flow type (i.e. overland flow, shallow swale flow, gutter flow, etc.). The length and slope of each reach should be measured.
3. Determine the time to concentration, T_c, for the catchment. (See section 3.6 of this manual)
4. Find the rainfall intensity, i, for the design storm using the calculated T_c and the rainfall intensity-duration-frequency curve. (See section 3.3.2 of this manual.)
5. Determine the runoff coefficient, C. (See section 3.5 of this manual)
6. Calculate the peak flow rate from the watershed using the Rational Equation.

Appendix D contains example worksheets for calculating the peak flow for both the minor and major storm event at locations of interest using the Rational Method.

3.4.2 Computer Aided Hydrologic Models

For analyzing basins larger than 120 acres, or if desired for smaller basins the engineer may either use WinTR-55, HEC-HMS, SWMM or another appropriate hydrology/ hydraulics model.

Technical Release 55 for Windows (WinTR-55), developed by the Natural Resource Conservation Service (NRCS) is a single-event rainfall-runoff hydrologic model for small watersheds up to 25 square miles. The model generates hydrographs from both urban and agricultural areas and at selected points along the stream system. Hydrographs are routed downstream through channels and/or reservoirs. Multiple sub-areas can be modeled within the watershed. WinTR-55 is comprised of multiple windows including the Storm Data Window, the Land Use Details Window, and the Reach Data Window. Although 24-hour rainfall amounts for many counties in the US are stored within the program, using the storm values presented in this manual is recommended for consistency. Further, it is recommended to enter curve numbers and time to concentration values calculated by the methods presented in this manual for consistency.

The Hydrological Modeling System (HEC-HMS), a precipitation-runoff simulation computer program developed by the Army Corps of Engineers, calculates the magnitude and timing of the peak discharge resulting from design storm rainfall-runoff. HEC-HMS is comprised of three main components, the Basin Model, the Meteorological Model, and the Control Specifications. Within the Basin Model, the SCS Curve Number (CN) method is recommended for the Loss Rate. In applying the SCS CN method, the user must specify an initial loss, a curve number, and the percent impervious area. Initial loss is calculated as:

$$I_a = 0.2S$$

$$S = \frac{1000}{CN} - 10$$

Where: I_a = Initial abstraction (in)
S = Potential maximum retention (in)
CN = SCS Curve Number

Pre- and post development curve numbers for use with the SCS Curve Number Method are listed in **Table 6**. Listed curve numbers are based on antecedent moisture condition (AMC) II. For more detailed analysis the engineer may use CN values presented in the National Engineering Handbook.

www.wcc.nrcs.usda.gov/hydro/hydro-techref-neh-630.html

The SCS method is recommended for the Transform within the Basin Model. In applying the SCS method, the user must specify the lag time (T_p). The lag time is calculated as:

$$T_p = 0.6*T_c$$

Where: T_p = Lag time
T_c = Time to concentration (see section 3.6)

Within the Meteorological Model, the User Hyetograph is recommended. Incremental precipitation values presented in **Tables B1** and **B2** in **Appendix B** are to be entered as precipitation gage data in creating a User Hyetograph.

Where surfaces (pervious and impervious) within the basin vary in characteristics, weighted or composite coefficients for each basin must be used in development of the unit and flood hydrographs. This is typically accomplished by breaking each basin into the appropriate number of sub-basins and using the corresponding surface coefficients. Each computer-aided model has default parameters for typical surface characteristics and soil types; the selection of

these parameters is the key to a successful analysis and therefore must be submitted for City review.

3.5 Runoff Coefficients

The runoff coefficient to be used within the Rational Method is to be determined based on existing and/or proposed land use and surface characteristics, soil type, and storm return period. Soil types are defined by the Natural Resources Conservation Service (NRCS), and describe the infiltration capacity and rate of runoff of the soil. Types can be either A, B, C, or D, where the infiltration capacity decreases and rate of runoff increases from A to D. Soil types are accessible from the NRCS Soil Survey Division at the following web address:

http://websoilsurvey.nrcs.usda.gov/app/

Runoff coefficients are shown in **Tables 3-5**. **Appendix C** contains a worksheet for calculating weighted average "C" values for basins with varying land use types.

Table 3. Runoff Coefficient Values for Type A Soils

Percentage Imperviousness	Storm Return Interval					
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
0%	0.00	0.00	0.05	0.12	0.16	0.20
5%	0.00	0.02	0.10	0.16	0.20	0.24
10%	0.00	0.06	0.14	0.20	0.24	0.28
15%	0.02	0.10	0.17	0.23	0.27	0.30
20%	0.06	0.13	0.20	0.26	0.30	0.33
25%	0.09	0.16	0.23	0.29	0.32	0.35
30%	0.13	0.19	0.25	0.31	0.34	0.37
35%	0.16	0.22	0.28	0.33	0.36	0.39
40%	0.19	0.25	0.30	0.35	0.38	0.41
45%	0.22	0.27	0.33	0.37	0.40	0.43
50%	0.25	0.30	0.35	0.40	0.42	0.45
55%	0.29	0.33	0.38	0.42	0.45	0.47
60%	0.33	0.37	0.41	0.45	0.47	0.50
65%	0.37	0.41	0.45	0.49	0.51	0.53
70%	0.42	0.45	0.49	0.53	0.54	0.56
75%	0.47	0.50	0.54	0.57	0.59	0.61
80%	0.54	0.56	0.60	0.63	0.64	0.66
85%	0.61	0.63	0.66	0.69	0.70	0.72
90%	0.69	0.71	0.73	0.76	0.77	0.79
95%	0.78	0.80	0.82	0.84	0.85	0.86
100%	0.89	0.90	0.92	0.94	0.95	0.96

(Reference: Urban Drainage and Flood Control District)

Table 4. Runoff Coefficient Values for Type B Soils

Percentage Imperviousness	Storm Return Interval					
	2-yr	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**
0%	0.02	0.08	0.15	0.25	0.30	0.35
5%	0.04	0.10	0.19	0.28	0.33	0.38
10%	0.06	0.14	0.22	0.31	0.36	0.40
15%	0.08	0.17	0.25	0.33	0.38	0.42
20%	0.12	0.20	0.27	0.35	0.40	0.44
25%	0.15	0.22	0.30	0.37	0.41	0.46
30%	0.18	0.25	0.32	0.39	0.43	0.47
35%	0.20	0.27	0.34	0.41	0.44	0.48
40%	0.23	0.30	0.36	0.42	0.46	0.50
45%	0.26	0.32	0.38	0.44	0.48	0.51
50%	0.29	0.35	0.40	0.46	0.49	0.52
55%	0.33	0.38	0.43	0.48	0.51	0.54
60%	0.37	0.41	0.46	0.51	0.54	0.56
65%	0.41	0.45	0.49	0.54	0.57	0.59
70%	0.45	0.49	0.53	0.58	0.60	0.62
75%	0.51	0.54	0.58	0.62	0.64	0.66
80%	0.57	0.59	0.63	0.66	0.68	0.70
85%	0.63	0.66	0.69	0.72	0.73	0.75
90%	0.71	0.73	0.75	0.78	0.80	0.81
95%	0.79	0.81	0.83	0.85	0.87	0.88
100%	0.89	0.90	0.92	0.94	0.95	0.96

(Reference: Urban Drainage and Flood Control District)

Table 5. Runoff Coefficient Values for Type C and D Soils

Percentage Imperviousness	Storm Return Interval					
	2-yr	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**
0%	0.04	0.15	0.25	0.37	0.44	0.50
5%	0.08	0.18	0.28	0.39	0.46	0.52
10%	0.11	0.21	0.30	0.41	0.47	0.53
15%	0.14	0.24	0.32	0.43	0.49	0.54
20%	0.17	0.26	0.34	0.44	0.50	0.55
25%	0.20	0.28	0.36	0.46	0.51	0.56
30%	0.22	0.30	0.38	0.47	0.52	0.57
35%	0.25	0.33	0.40	0.48	0.53	0.57
40%	0.28	0.35	0.42	0.50	0.54	0.58
45%	0.31	0.37	0.44	0.51	0.55	0.59
50%	0.34	0.40	0.46	0.53	0.57	0.60
55%	0.37	0.43	0.48	0.55	0.58	0.62
60%	0.41	0.46	0.51	0.57	0.60	0.63
65%	0.45	0.49	0.54	0.59	0.62	0.65
70%	0.49	0.53	0.57	0.62	0.65	0.68
75%	0.54	0.58	0.62	0.66	0.68	0.71
80%	0.60	0.63	0.66	0.70	0.72	0.74
85%	0.66	0.68	0.71	0.75	0.77	0.79
90%	0.73	0.75	0.77	0.80	0.82	0.83
95%	0.80	0.82	0.84	0.87	0.88	0.89
100%	0.89	0.90	0.92	0.94	0.95	0.96

(Reference: Urban Drainage and Flood Control District)

For basins larger than 120 acres where a computer aided hydrologic model is applied, SCS curve numbers may be used. Values for developed conditions are dependent on soil type and proposed land use (City of Sioux Falls Storm Water BMP Master Plan). **Table 6** shows general curve numbers for various land uses and soil groups specific to the City of Sioux Falls.

More detailed analysis may be performed at the developer's discretion using CN values presented in the National Engineering Handbook. Chapter 9 of this reference related to curve numbers is presented in **Appendix F**.

www.wcc.nrcs.usda.gov/hydro/hydro-techref-neh-630.html

Table 6. Land Uses and General Curve Numbers for Hydrologic Soil Groups.

Land Use	Hydrologic Soil Group			
	A	B	C	D
Residential Single Family	77	85	90	92
Rural Residential	51	68	79	84
Residential Multiple Family	77	85	90	92
Manufacturing	81	88	91	93
Transportation, Communication, Utilities, Parking Facilities	98	98	98	98
General Commercial	89	92	94	95
Heavy Commercial	89	92	94	95
Offices, Churches, Institutions, Schools	81	88	91	93
Cultural Activity: Libraries, Museums, Parks	49	69	79	84
Cemetery, Landfills, Mining, Quarrying, Under Construction	68	79	86	89
Undeveloped[1]	64	74	81	85

[1]Assumes contoured row crops in good hydrologic condition

(Reference: City of Sioux Falls Storm Water BMP Master Plan)

3.6 Time to Concentration

In order to determine the rate of runoff at a designated outfall, the time to concentration must be determined. The time to concentration is the time it takes for water to flow from the most remote part of the drainage basin to the outfall of the study area. For the Rational Method, a separate time to concentration is necessary for the overall basin, each sub-basin and each design point where a hydraulic structure of conveyance element is proposed. The time to concentration (T_c) is composed of the initial or overland flow time (T_{ov}) and channel flow time (T_t). The time to concentration formula is presented below. Other methods may be used with prior approval from the City.

$$T_c = T_{ov} + T_t$$

Where: T_c = time to concentration
T_{ov} = initial or overland flow time
T_t = channel flow time

The initial or overland flow time, T_{ov}, may be calculated as follows:

$$T_{ov} = \frac{0.395(1.1 - C_5)\sqrt{L}}{S^{0.33}}$$

Where: T_{ov} = initial or overland flow time (min)
C_5 = runoff coefficient for 5-year storm
L = length of overland flow (500 ft maximum for non-urban land uses, 300 ft maximum for urban land uses)
S = average basin slope (ft/ft)

The channel flow time, T_t, is calculated using the hydraulic properties of the swale, ditch, or channel. For preliminary work, the channel flow time can be estimated with the help of the following equation:

$$V = C_v(S_w)^{0.5}$$

Where: V = velocity (ft/s)
C_v = conveyance coefficient (from **Table 7**)
S_w = watercourse slope (ft/ft)

The travel time is determined from the calculated velocity and the length of the watercourse (L_w).

Table 7. Conveyance Coefficient Values

Type of Land Surface	Conveyance Coefficient (C_v)
Heavy Meadow	2.5
Tillage/ field	5
Short pasture and lawns	7
Nearly bare ground	10
Grassed waterway	15
Paved areas and shallow paved swales	20

The time to concentration, T_c, is then the sum of the initial or overland flow time, T_{ov}, and the channel travel time T_t. A minimum value of 15 minutes is recommended for the time to concentration.

Appendix D includes a worksheet for calculating the time-of-concentration based on the method presented above.

4. Open Channels

Open channels are the cornerstone of all Major Drainage Systems, providing conveyance of floodwaters through natural and manmade conduits. Due to the complexities of open channels, there is a wide range of design options available to the engineer. Hydrologic, hydraulic, structural, financial, environmental, public safety and maintenance factors must all be considered in open channel design.

The design of open channels shall be in accordance with the UD&FCD Manual Open Channels Sections. The engineer is referred to the Manual and other references cited for additional discussion and basic design concepts.

The use of computer programs in the design of open channels is encouraged provided the model input and justifications are submitted to the City for review and approval.

5. Storm Sewers

Storm sewers are to be viewed as an integral part of all Minor Drainage Systems. The installation of storm sewer systems is required when the other parts of the minor system (i.e. curb, gutter, and roadside ditches) no longer have capacity for additional runoff and spread widths and flow depths exceed those requirements presented in section 6. The storm sewer system shall commence at the point where the maximum allowable encroachment occurs.

Structural design of City storm sewers shall conform to City of Brookings Storm Sewer Standards, March 9, 2004 except as modified herein. All hydrologic and hydraulic design shall follow the procedures specified in this updated manual, which supersedes the March 2004 standards. The use of computer programs in the design of storm sewer systems is encouraged provided the model input and justifications are submitted to the City for review and approval.

5.1 Construction Materials

Only reinforced concrete storm sewer pipes shall be used for public storm sewer systems unless written approval for alternate materials is received from the City Engineer. For all pipe materials the required pipe strength shall be determined from the actual depth of cover, true load, and proposed field conditions. All construction of pipe, joints, inlets and manholes shall be in accordance with the approved City of Brookings Standard Specifications and Standard Plates for storm drainage improvements. The minimum allowable sewer depth of cover shall be 18 inches. Depths greater than 36 inches shall be avoided due to the possibility of storm sewer lines blocking access to sanitary sewer services to the main sanitary lines. Typical design strength calculations shall be submitted as a part of the Storm Drainage Study (SDS).

5.2 Hydraulic Design

Storm sewers shall be designed to convey the minor storm runoff peaks without surcharging the sewer. Furthermore, the minimum allowable slope shall be 0.5 percent or the slope shall produce a velocity of 3 feet per second (fps) when the sewer is flowing full. The maximum velocity shall be 15 fps. To insure this objective is achieved, the hydraulic and energy gradelines shall be computed by calculating both the major and minor losses (i.e. friction, expansion, contraction, bend, and junction losses). The methods for estimating these losses are presented in the following sections. The final energy grade line shall be at or below the proposed ground surface.

5.3 Pipe Friction Losses

Manning's n-values to be used in the calculation of storm sewer capacity and velocity are to be based on the material being proposed. **Table 8** presents typical Manning's n-values.

5.4 Pipe Form Losses

Generally, between the inlet and outlet the flow encounters a variety of configurations in the flow passageway (i.e. changes in pipe size, branches, bends junctions, expansions, and contractions). These variations of configuration impose losses in addition to those resulting from pipe friction. These form loss values shall be submitted, with full justification for the values chosen, as a part of the Storm Drainage Study.

5.5 Vertical Alignment

The sewer grade shall be such that a minimum cover is maintained to withstand AASHTO HS-20 loading on the pipe. The minimum cover depends upon the pipe size, type and class, and soil bedding condition, but shall not be less than 18 inches.

5.6 Horizontal Alignment

The storm sewer alignment may be curvilinear for pipe with diameters of 48-inches or greater but only when approved by the City Engineer. The applicant must demonstrate the need for a curvilinear alignment. The limitations on the radius for pulled-joint pipe are dependent on the pipe length and diameter, and amount of opening permitted in the joint. The maximum allowable joint pull shall be ¾ inch. The minimum parameters for radius type pipe are shown in **Table 8**. The radius requirement for pipe bends is dependent upon the manufacturer's specifications.

Table 8. Storm Sewer Alignment and Size Criteria

Sewer Access Spacing:

Vertical Dimension of Pipe (in)	Maximum Allowable Distance between Manholes and/ or Cleanouts (ft):
12 to 36	400
42 and larger	500

Minimum Radius of Curvature for Diameter Pipe[1]:

Diameter of Pipe (in)	Radius of Curvature (ft)
48 to 54	28.5
57 to 72	32.0
78 to 108	38.0

[1]Short radius bends shall not be used on sewers 42 inches or less in diameter

Minimum Pipe Diameter:

Type	Minimum Equivalent Pipe Diameter (in)	Minimum Cross-Sectional Area (ft^2)
Main Trunk	18	**1.77**
Lateral from Inlet[2]	12	**0.785**

[2]Minimum size of lateral shall also be based upon a water surface inside the inlet with a minimum distance of 1 ft below the grate or throat.

Manning's n value:

Sewer Type	Capacity Calculation	Velocity Calculation
Concrete (newer pipe)	0.013	0.011
Concrete (older pipe)	0.013	0.012
Concrete (preliminary sizing)	0.015	0.012
Plastic	0.011	0.009

5.7 Pipe Size

The minimum allowable pipe size for storm sewers is dependent upon the estimated flows and a practical diameter from a maintenance perspective. In addition, the length of the sewer affects the maintenance and, therefore, the minimum diameter. Public storm sewers shall be at least 12 inches in diameter, and trunk storm sewers must be a minimum of 18 inches in diameter. **Table 8** presents the recommended minimum pipe size and other specifications for storm sewers located in the City right-of-way.

5.8 Manholes

Manholes or maintenance access ports will be required whenever there is a change in size, direction, elevation, grade, or where there is a junction of two or more sewers. In addition, a manhole may be required at the beginning and/or the end of the curved section of storm sewer. The maximum spacing between manholes for various pipe sizes shall be in accordance with **Table 8**. Refer to **Table 9** for the required manhole size.

Table 9. Storm Sewer Manhole Size

Sewer Diameter (in)	Recommended Manhole Diameter (ft)
12 to 18	4
21 to 42	5
48 to 54	6
60 and larger	As approved by City Engineer

Larger manhole diameters or a junction structure may be required when sewer alignments are not straight or more than one sewer line goes through the manhole. Manhole diameter may be increased should conditions require such.

5.9 Storm Sewer Inlets

Presented in the following subsection is a discussion on the criteria and methodology for design and evaluation of storm sewer inlets in the City.

5.9.1 Standard Inlets

The standard inlets permitted for uses in the City are presented in **Table 10**.

Table 10. Storm Sewer Inlet Types

Inlet Type	Permitted Use
Curb Opening Inlet	All street types
Grated Inlet –Type C	All streets with a roadside or median ditch
Grated Inlet –Type 13	Alleys or private drives with a valley gutter (private areas only)
Combination Inlet –Types 13 and 16	All street types

5.9.2 Inlet Hydraulics

The procedures and basic data to define the capacities of the standard inlets under various flow conditions shall be calculated. The engineer shall submit assumptions, and calculated inlet capacities as a part of the Storm Drainage Study.

6. Streets

Urban and rural streets, specifically the curb and gutter or the roadside ditches, should be viewed as an integral part of a Minor Drainage System. When the drainage in the street exceeds allowable limits, a storm sewer system or an open channel is required to convey the excess flows. In addition, streets may be viewed as a critical part (subject to certain limitation) of the Major drainage System when it conveys nuisance flows (flows larger than minor events) quickly and efficiently to the storm sewer or open channel drainage without interference with traffic movement. However, the primary function of urban streets is for TRAFFIC MOVEMENT and therefore the drainage function is subservient to this traffic objective.

Design criteria for the collection and conveyance of surface runoff on public streets is based on a reasonable frequency and magnitude of traffic interference (see **Tables 11 - 13**). That is, depending on the classification of the street, certain traffic lanes can be fully inundated during a major storm event. However, during lesser intense storms, runoff will also inundate traffic lanes, but to a lesser degree. The limits of storm runoff encroachment for each Drainage Classification and storm condition are presented in **Tables 11** through **13**.

Table 11. Use of Streets for Minor Storm Runoff

Drainage Classification	Maximum Street Encroachment
Local	No curb overtopping, but flow may spread to crown of street (flow may spread to back of sidewalk)
Collector	No curb overtopping and flow spread must leave at least one 10-foot lane free of water for every two lanes of road (one lane for two-lane streets, two lanes for four-lane streets)
Arterial	No curb overtopping and flow spread must leave at least two 10-foot lanes free of water (10-feet each side of the street crown or median)
Freeway	No encroachment is allowed on any traffic lane

Table 12. Allowable Use of Streets for Major Storm Runoff

Drainage Classification	Maximum Depth
Local and Collector	Building structures shall not be inundated at the ground line. The depth of water at the street crown shall not exceed 18 inches
Arterial and Freeway	Building structures shall not be inundated at the ground line. To allow for emergency vehicles, the depth of water shall not exceed 6 inches at the street crown or 18 inches at the gutter flowline, whichever is more restrictive.

Cross street flow can occur by three separate means. One condition occurs when the runoff in a gutter spreads across the street crowns to the opposite gutter. The second case arises when flow from some external source, such as a drainageway or conduit exceeds the conduit capacity and overtops the crown of the street. The third cause of cross street flow is the use of cross-pans. The maximum allowable cross street flow depths based on the minor and major storms shall not exceed the limitations presented in the following table.

Table 13. Allowable Cross Street Flow

Drainage Classification	Minor Storm Maximum Depth	Major Storm Maximum Depth
Local	6 inches of depth in cross pan or at gutter flowline	18 inches of depth in cross pan or at gutter flowline
Collector	6 inches of depth at gutter flowline	18 inches of depth at gutter flowline
Arterial	None	6 inches

7. Culverts

A culvert is defined as a conduit that conveys, by gravity, surface drainage runoff under a highway, railroad, canal, or other embankment (except detention outlets). Culverts come in many shapes and sizes, and are constructed of many different types of materials. For all pipe materials, the required pipe strength shall be determined from the actual depth of cover, true load, and proposed field conditions. The procedures for selecting the appropriate culvert(s) shall be submitted to the City for review and approval as part of the Storm Drainage Study.

7.1 Structural Design

At a minimum, all culverts shall be designed to withstand an HS-20 loading (unless designated differently by the City Engineer) in accordance with the design procedures of AASHTO, “Standard Specifications for Highway Bridges”, and with the pipe manufacturer’s recommendation. Using this loading requirement, calculations shall be performed to confirm the estimated depth of cover and bearing load on the selected culvert.

7.2 Culvert Sizing Considerations

The sizing of a culvert is dependent upon two factors, the street classification and the limits of allowable culvert overtopping. These limits for the various street classifications are presented in **Table 14**. In no case, however, will approval be made for round culverts with an inside diameter less than 18 inches, or for arched or oval shaped culverts with span-rise dimensions less than 24 inches x 18 inches nominal. Culverts 12 inches or greater in diameter may be used for single family residential access drives. The minimum height of a reinforced box culvert should be three feet to facilitate cleanout and allow removal of forms during construction.

Table 14. Allowable Maximum Culvert Overtopping

Drainage Classification	Minor Drainage System Maximum Depth	Major Drainage System Maximum Depth
Local Industrial, Local Residential and Collector	No Overtopping	12 inches of depth at the gutter flowline (6 inches of depth at street crown for streets without gutters)
Major Arterial and Minor Arterial	No Overtopping	The minimum clearance between the low chord or culvert crown and energy grade line shall be 6 inches for basins less than 2 mi^2, 1 foot for basins up to 10 mi^2, and 2 feet for basins greater than 10 mi^2.
The maximum headwater for the 100-year design flows shall be 1.5 times the culvert diameter, or 1.5 times the culvert rise dimension for shapes other than round. Driveway culverts shall be designed using criteria outlined in Tables 9-11.		

7.3 Inlet and Outlet Configuration

Within the City, all culvert inlets shall be designed to minimize entrance and friction losses. To accomplish this objective, all culverts are to be designed with headwalls and wingwalls, or with flared-end sections at the inlet and outlet. Projecting ends will not be acceptable. Flared-end sections are only allowed on pipes with diameter of 42 inches (or equivalent) or less. Additional protection at the inlet and outlet may be required to minimize the potential of channel erosion. Refer to section 11 for erosion and sedimentation protection design guidelines

7.4 Culvert Hydraulics

The procedures and basic data to be used for the hydraulic evaluation of culverts being proposed for installation in the City shall be in accordance with the Urban Drainage Criteria Manual, Volume 2, Culverts, except as modified herein.

The use of computer programs developed for the design of culverts will be permitted, provided the model input, justifications and related had calculations are submitted to the City for review and approval.

7.4.1 Hydraulic Data

The computed culvert capacities must never exceed manufacturer's recommendations or best engineering practices. The assumptions and/ or model

input shall be submitted as part of the Storm Drainage Study for City review and approval.

Culverts shall be analyzed to determine whether discharge is controlled by inlet or outlet conditions for both the minor storm discharge and the major storm discharge. The value of the roughness coefficient (Manning's n) used shall not be less than that specified by documentation of the culvert manufacturer. Computations for selected culvert sizes shall be submitted for review.

7.5 Velocity Considerations

In designing culverts, both the minimum and maximum velocities must be considered. Based on many publications, a flow velocity greater than approximately 3 feet per second (fps) is required to assure self-cleaning conditions exist and therefore reducing long-term maintenance costs. In addition, a velocity less than approximately 12-fps minimizes possible culvert damage due to scouring and downstream channel erosion.

7.6 Trash and Debris Deflector

When, in the opinion of the City Engineer, debris accumulation for a particular drainageway appears to pose a significant probability of culvert plugging or potential safety hazard, trash racks or debris deflectors will be required. Further, racks or grates shall be required for safety purposes at the City Engineer's discretion.

8. Bridges

The hydraulic design of bridges within the City shall be in accordance with the USDOT Federal Highway Administration "Hydraulics of Bridge Waterways". Other City approved resources shall also be used to determine the possible impacts on the drainageway (both upstream and downstream), scour potential, and mitigation techniques for a proposed bridge structure. Based upon federal and state requirements, under no circumstance shall a proposed structure adversely impact the existing floodway or change the depth of the floodway due to the proposed bridge. Therefore, the engineer is encouraged to communicate with the City Engineer prior to proposing the placement of a bridge structure within the City to obtain written approval.

9. Detention

As stated in section 2.2.2, onsite detention is required for all development, expansion and redevelopments projects. Requirements for detention storage of

storm runoff shall be based on the location of the development within its major drainage basin as determined by hydrological modeling and surface characteristics. Early communication with the City is encouraged for the determination of the appropriate method and level of detail required for submission.

Developments within the area where Master Drainage Plans have been developed shall release storm runoff in accordance with the plan. In cases where the Master Drainage Plan has been approved but not yet implemented or facilities constructed, temporary detention facilities shall be required until such time the facilities are constructed. In basins where Master Drainage Plans have not been developed, the City requires detention storage in accordance with this section to protect existing natural structures and downstream developments.

Detention storage facilities shall be sized to hold the 5-year runoff volume, and 100-year runoff volume. Surface water shall not be released from the development at rates greater than provided for in **Table 15** in section 9.1.1 when detention design capacity is performed using the Rational Method for basins smaller than 120 acres. For basins larger than 120 acres, release rates shall not exceed pre-development conditions as calculated by a City-approved hydrologic model.

Exemptions from these detention requirements may only be granted by the City Engineer for redevelopment and in-fill areas where the increase in impervious area covers less than 5,000 square feet. Onsite detention requirements for the control of runoff rates will be waived where regional detention facilities are sized and constructed with the capacity to accommodate 100-year storm event flows from a fully developed basin and are publicly owned and maintained.

9.1 Allowable Release Rate

9.1.1 Release Rates- Rational Method Design

For basins smaller than 120 acres where the Rational Method is applied, surface water shall not be released from the development at rates greater than those shown in **Table 15**. When using the Rational Method, the predominate soil group for the total basin area contributing runoff to the detention facility will be used in determining the allowable release rate.

Table 15. Allowable Release Rates (cfs/acre)

Control Frequency	Dominant Soil Group		
	A	B	C & D
5- year	0.07	0.13	0.17
100- year	0.50	0.85	1.00

9.1.2 Release Rates- Computer Aided Design

For basins larger than 120 acres, release rates shall not exceed pre-development conditions as calculated by a City-approved hydrologic model. When designing a facility using a computer aided model, the engineer shall select the soil group that best represents the surface characteristics of each sub-basin. The selected soil group(s) will be submitted as part of the Storm Drainage Study for City review and approval.

9.2 Volume Calculations

9.2.1 Volume Calculations (FAA Method)

The volume available for detention storage for tributary catchments of 120 acres or less shall be determined using the Federal Aviation Administration (FAA) Method. This method is based upon the Rational Formula and provides storage volume requirements for one level of peak control. The input required for the FAA volume calculation procedure includes:

A = Area of the catchment tributary to the storage facility (acres)

C = Runoff coefficient (presented in **Tables 2-4**)

Q_{po} = Allowable maximum release rate from detention facility (presented in **Table 15**)

T_c = Time to concentration (minutes) (see section 3.6)

The calculations are best set up in a tabular (spreadsheet) form with each 5-minute increment in duration being entered in rows and the following variables being entered, or calculated in each column:

1. T = Storm duration time (minutes)

2. I = Rainfall intensity (in/hr) (see IDF curves in section 3.3.2)

3. V_i = Inflow volume (ft^3), calculated as the cumulative volume at the given storm duration using the equation:

$$V_i = CIA(60T)$$

4. m = Outflow adjustment factor

$$m = \frac{1}{2}\left(1 + \frac{T_c}{T}\right)$$

Where: $0.5 \leq m \leq 1$ for $T \geq T_c$
For $T < T_c$, $m = 1$

5. Q_{av} = Calculated average outflow rate (cfs) over the duration T

$$Q_{av} = mQ_{po}$$

6. V_o = Calculated outflow volume (ft^3) during the given duration given the adjustment factor at that duration, calculated using the equation:

$$V_o = Q_{av}(60T)$$

7. V_s = Required storage volume (cubic feet), calculated using the equation:

$$V_s = V_i - V_o$$

The value of V_s increases with time, reaches a maximum value, and then starts to decrease. The maximum value of V_s is the required storage volume for the detention facility.

The required storage volume must be determined for both the minor and major design storms. Therefore, the above methodology must be applied twice, once for the 5-year storm, and once for the 100-year storm.

Detention Sizing Spreadsheet, presented in **Appendix E** provides an example of parameters to be calculated in using the FAA Method.

9.2.2 Volume Estimates (Computer Aided Method)

The volume available for detention storage for tributary catchments greater than 120 acres shall be determined using a City-approved computer aided hydrology/hydraulics model. Within the model, a hydrograph shall be generated and hydrologic routing shall be used to route flows to and away from the proposed detention facility. The routed or inflow hydrograph will represent the total volume of runoff from that particular rain event(s) while the outflow hydrograph represents the maximum allowable release rate, which shall not exceed pre-development conditions. The difference between the inflow and outflow hydrographs represents the total storage volume of the detention facility. The following paragraphs outline the procedure used in determining the storage volume.

Using initial shape and size parameters of the proposed detention facility, an elevation-storage relationship shall be developed using the storage-area curve method. The storage-area curve is determined from water surface elevations and

the associated surface areas contained at each elevation. This approach calculates incremental storage values with the following equation:

$$S_{j+1} = S_j + \frac{(h_{j+1} - h_j)(A_j + A_{j+1})}{2}$$

Where: S_{j+1} = Storage at level j + 1 (ft^3)
S_j = Storage at level j (ft^3)
h_{j+1} = Elevation j + 1 (ft)
h_j = Elevation j (ft)
A_{j+1} = Surface area at level j + 1 (ft^2)
A_j = Surface area at level j (ft^2)

Given the detention facility outlet type and parameters, an elevation-outflow rating curve shall be developed. The elevation-outflow rating curve is merged with the elevation-storage curve and can be input in to the approved hydrology/ hydraulics model.

It will be the responsibility of the engineer to document and justify the model input and output parameters. These parameters and a detailed discussion on the method used for this design will be submitted as part of the Storm Drainage Study for City review and approval.

9.3 Detention Basin Outlet/Outfall

Selecting the most appropriate outlet configuration requires a detailed design, which ensures the maximum release rate meets the requirements of the project and includes proper provisions for maintenance and reliability. In addition, care shall be taken as to ensure the designed outlet will not cause downstream erosion or damage during the largest storm event. The engineer shall select the preferred outlet structure based on criteria presented in this section or other references and will prevent back up information in the Storm Drainage study. The following lists five typical outlet structures for use in the design of a detention facility depending on the conditions, storage structure design and discharge rates:

1. Circular Culverts
2. Rectangular Culverts
3. Orifices
4. Weirs
5. Stand Pipe Weirs

The outlet shall be designed to minimize unauthorized modifications, which affect proper function. To assist in this effort, a sign with a minimum area of 0.75

square feet shall be attached to the outlet or posted nearby with the following message:

"WARNING
Unauthorized modification of
this structure is a code violation
and subject to the penalties as
provided by law."

9.4 Additional Design Standards for Detention

The following section presents additional design standards (depth of freeboard, location planning, grading, and revegetation) for an open space detention facility. The location, size, and landscaping should be properly coordinated with the proposed project and surrounding areas.

9.4.1 Location Planning

The planning of a detention facility is very critical in assuring the facility meets the volume requirements for the proposed project and is properly located for long term operations and maintenance. The facility should be constructed in an area that best fits the existing and proposed topography and facilitates the coordination with other regional facilities.

As part of the submitted project plans, the engineer shall accurately represent the location of the facility including limits of grading, approximate embankment slopes, and invert elevations for the outlet. In addition, a larger scale or regional map shall be supplied to show where the facility will discharge and how it interacts with existing or proposed regional facilities.

9.4.2 Depth of Freeboard

The minimum required freeboard for open space detention facilities is 1 foot above the computed 100-year water surface elevation.

The property corner elevation of properties abutting a detention pond shall be 1 foot above the 100-year design storm elevation. Recommended minimum ground elevations for homes abutting or affected by the detention pond shall be 2 feet above the overflow elevation. If an overflow system is not available, recommended minimum ground elevation for homes abutting or affected by detention ponds will be a minimum of 4 feet above the 100-year pond high water elevation, or at an elevation that provides an additional 50 percent storage.

9.4.3 Grading

Slopes on earthen embankments less than 5 feet in height shall not be steeper than 4 (horizontal) to 1 (vertical). For embankment heights 5 feet and greater, the slopes shall not be steeper than 3 (horizontal) to 1 (vertical), but the horizontal distance of the slope shall not be less than 20 feet. Any dam constructed for the purpose of storing water or having a surface area, volume, or dam height as specified in Administrative Rules of South Dakota (ARSD) chapter 74:02:08:01 (7), shall require the approval (in writing) of the State Engineer's Office prior to submission to the City. According to the ARSD, a jurisdictional dam is described as a structure that is greater than 25 feet in height and stores 50 acre-feet of water or more. A dam is not considered jurisdictional if it is less than 6 feet in height regardless of its storage capacity, or if the storage capacity is less than 15 acre-feet regardless of its height.

All detention facility embankments shall be protected from catastrophic failure due to overtopping. Overtopping can occur when the pond outlets become obstructed or when an event larger than the 100-year storm occurs. Failure protection for the embankment must be provided in the form of a buried heavy riprap layer on the entire downstream face of the embankment or a separate emergency spillway having a minimum capacity of twice the maximum release rate for the 100-year flood. Structures shall not be permitted in the path of the emergency spillway or overflow. The invert of the emergency spillway should be set equal to the 100-year water surface elevation.

For all detention facilities, the minimum bottom slope shall be 0.5 percent measured perpendicular to the trickle channel.

9.4.4 Revegetation

All detention facilities shall be revegetated. In addition, a geotextile fabric shall be place to maintain the slopes prior to vegetation maturation. The engineer shall submit the proposed revegetation plan to the City for review and approval.

9.5 Maintenance Easements

A drainage maintenance easement shall be granted to the City to ensure that emergency maintenance and access can be legally provided to keep the facility operable.

10. Retention

As stated in section 2.2.3, onsite retention will only be allowed where ALL possible means of storage and/or conveyance has been exhausted for a particular development, expansion, or redevelopment project. Further, retention

is recommended only as a temporary solution to drainage issues until a formal system is developed downstream. Requirements for retention storage runoff shall be based on the criteria presented in this section and compared to hydrological modeling. The City will require retention of the runoff from a 24-hour, 100-year storm even under fully developed conditions (including runoff from adjacent streets whether they are existing or proposed).

Acceptable alternatives to these requirements may include:

1. When written agreements among landowners wherein historic flow rates are exceeded by upstream landowners and will be accepted by downstream landowners. Such agreements are subject to review by the City Engineer.
2. The developer is providing offsite drainage improvements to convey storm water to acceptable outfall points.

10.1 Minimum Retention Volume

The minimum retention volume shall be equal to 1.5 times the 100-year 24-hour storm plus 1-foot freeboard. The facility also must be situated and designed so that when it overtops, no human-occupied or critical structures (e.g., electrical vaults) will be flooded and no catastrophic failure at the facility (e.g., loss of dam embankment) will occur. It is also recommended that retention facilities be as shallow as feasible to encourage infiltration and other losses of the captured urban runoff.

10.2 Emergency Spillway

An overflow section shall be provided for the retention facility that will protect embankments from overflow resulting from a 100-year storm assuming the retention basin is full and the tributary area is fully developed.

10.3 Pond Design

Side slopes shall not be steeper than four (4) horizontal to one (1) vertical.

10.3.1 Freeboard

One (1) foot of minimum freeboard shall be added to the maximum retention volume water surface.

10.4 Revegetation

All retention facilities shall be revegetated. In addition, a geotextile fabric shall be placed to maintain the slopes prior to vegetation maturation. The engineer shall submit the proposed revegetation plan to the City for review and approval.

10.5 Effects on Local Groundwater

The engineer must evaluate or assess the impacts of the retention facility on local groundwater levels and the potential for damage to nearby properties. In addition, increasing local groundwater levels to a point where standing water within the retention facility occurs may create a wetland area that requires additional permitting and long-tem maintenance requirements.

10.6 Maintenance Easements

A drainage maintenance easement shall be granted to the City to ensure that emergency maintenance and access can be legally provided to keep the facility operable. This easement may only be reduced when the retention pond is converted to detention due to downstream conveyance availability.

11. Erosion and Sedimentation Protection Design Guidelines

A comprehensive Erosion and Sedimentation plan must be developed that minimizes the risk of environmental damage. The plan should be primarily based upon the nature of the construction activity and the conditions that exist at the construction site. The plan should:

- Minimize the amount of disturbed soil
- Prevent runoff from offsite areas from flowing across disturbed areas
- Slow down the runoff flowing across the site
- Remove sediment from onsite runoff before it leaves the site
- Save existing vegetation
- Meet or exceed local or State requirements for sediment and erosion control plans.

Construction should be planned to minimize the amount of disturbed land exposed at any one time, thus limiting the overall erosion potential of the site. Once an effective, phased development plan has been prepared, individual erosion control practices can be selected an implemented on site. These individual practices are inventoried and described in Volume 3 of the Urban Drainage and Flood Control District Manual.

It should be noted that the EPA administers a storm water program as a part of the National Pollutant Discharge Elimination System (NPDES) that regulates discharges from Municipal Separate Storm Water Systems (MS4s). Brookings is a small, or Phase 2 MS4 community.

An Erosion and Sedimentation Control Plan must be submitted and completely integrated with the Storm Drainage and Storm Water Quality Study for City approval when a Preliminary Storm Drainage Study is submitted. The extent and

detail of the plan may be a function of the site area, the extent of grading being proposed, and the point in the design process. Submittal requirements are outlined in **Figures A1 – A5** in **Appendix A**. The engineer should contact the City Engineer for project-specific submittal requirements.

12. References

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Adams County, Colorado Development Standards and Regulations. Storm Drainage and Erosion Control Design and Technical Criteria. (2004). Available at: http://www.co.adams.co.us/index.cfm?d=standard&b=1&c=26&s=134&p=349

Administrative Rules of South Dakota. Chapter 74:02:08:01. Available at: http://legis.state.sd.us/rules/index.aspx

Brookings, South Dakota Municipal Code of Ordinances. Chapter 38: Floods. (2002). Available at: http://www.municode.com/resources/gateway.asp?pid=10484&sid=41

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City of Sioux Falls, South Dakota Engineering Design Standards for Public Improvements. Chapter 11: Drainage Improvements. Available at: http://www.siouxfalls.org/PublicWorks/Contractors/design_standards.aspx

FEMA Flood Insurance Study for the City of Brookings. (1978). Available at: http://store.msc.fema.gov

Natural Resources Conservation Service. (2004). National Engineering Handbook Chapter 9: Hydrologic Soil Cover Complexes. Available at: http://policy.nrcs.usda.gov/scripts/lpsiis.dll/H/H_210_630_9.pdf

Natural Resources Conservation Service Web Soil Survey. Available at: http://websoilsurvey.nrcs.usda.gov/app/

NOAA Central Weather Service. Precipitation Frequency Information and Publications for South Dakota. Available at: http://hdsc.nws.noaa.gov/hdsc/pfds/other/sd_pfds.html

US Department of Transportation, Federal Highway Administration. (1978). Hydraulics of Bridge Waterways. Available at: http://www.fhwa.dot.gov/engineering/hydraulics/pubs/hds1.pdf

USEPA Region 8 Storm Water and Municipal Storm Water Systems website. Available at: http://www.epa.gov/region08/water/stormwater/municipal.html

USEPA Storm Water Phase II Final Rule: Small MS4 Storm Water Program Overview. (2005). Available at: http://www.epa.gov/npdes/pubs/fact2-0.pdf

Urban Drainage and Flood Control District. Urban Storm Drainage Criteria Manual volumes 1,2,3. (1999). Available at: http://www.udfcd.org/

Appendix A: Checklists for Submittal

Figure A1. Sketch Storm Drainage Study: Plan Checklist

Item No.	Submitted[1]	City Use Only			
		Rejected	Accepted	N/A	
1	☐	☐	☐	☐	Sheet Size - 24" x 36" or 11" x 17" or 8 1/2" x 11"
2	☐	☐	☐	☐	Project Title Sheet
3	☐	☐	☐	☐	Project Site Plan
4	☐	☐	☐	☐	Title Block - including name and address of proposed project/development
5	☐	☐	☐	☐	North arrow indicator, Section-Township-Range, Drawing Scale, Legend
6	☐	☐	☐	☐	Name, address and telephone number of the applicant, agent or owner
7	☐	☐	☐	☐	Name, address and telephone number of the person preparing the plan
8	☐	☐	☐	☐	Site Layout - including property boundaries, dimensions, areas, adjoining street names and right-of-way widths
9	☐	☐	☐	☐	Contour Lines - from the best available source, spot elevations or indications of direction and steepness of slopes with the source clearly identified
10	☐	☐	☐	☐	Drainage Structures - including existing and proposed structures (pipes, catch basins, channels, ponds, irrigation ditches, etc) and impervious surfaces (parking lots, roads, driveways, patios, building, etc)
11	☐	☐	☐	☐	Utilities - existing and/or proposed with easements identified
12	☐	☐	☐	☐	Natural Features - including drainage channels, wetlands, water bodies, areas of natural vegetation and floodplains
Developer's Comments (please reference the item number for each comment)					
City's Comments					

[1] To be checked by the Developer. If a "submitted" box is not checked, the Applicant must explain (in comment box above) or the application may be rejected for insufficient information.

Reference: Adams County, Colorado Development Standards and Regulations

Figure A2. Preliminary Storm Drainage Study: Plan Checklist

Item No.	Submitted[1]	City Use Only			
		Rejected	Accepted	N/A	
1	☐	☐	☐	☐	Sheet Size - 24" x 36" or 11" x 17"
2	☐	☐	☐	☐	Project Title Sheet
3	☐	☐	☐	☐	Project Site Plan
4	☐	☐	☐	☐	Title Block - including name and address of proposed project/development
5	☐	☐	☐	☐	North arrow indicator, Section-Township-Range, Drawing Scale, Legend
6	☐	☐	☐	☐	Drawing Scale-- Plan view must be drawn at a scale legible enough for review. Must use standard engineering scale.
7	☐	☐	☐	☐	Topography-- Include contour lines at a maximum of 2' intervals with source to datum identified. Extend past the project limits as appropriate to show downstream effects.
8	☐	☐	☐	☐	Utilities - existing and/or proposed with easements identified
9	☐	☐	☐	☐	Site Layout - including property boundaries, dimensions, areas, adjoining street names and right-of-way widths
10	☐	☐	☐	☐	Drainage Structures - including existing and proposed structures (pipes, catch basins, channels, ponds, irrigation ditches, etc) and impervious surfaces (parking lots, roads, driveways, patios, building, etc)
11	☐	☐	☐	☐	Natural Features - including drainage channels, wetlands, water bodies, areas of natural vegetation and floodplains
12	☐	☐	☐	☐	Proposed Conveyance Structures-- including approximate plans for collection and conveyance of storm water through the project site. As a minimum, show by flow arrows the direction of proposed storm water flow and indicate the method for conveyance (pipe, ditch, overland flow, etc.)
13	☐	☐	☐	☐	Preliminary Road Layouts-- including existing grade and proposed finished grade.
14	☐	☐	☐	☐	Erosion and Sedimentation Control-- including location and type of erosion and sedimentation control measure proposal.
15	☐	☐	☐	☐	General Construction Notes-- include notes for clarification
16	☐	☐	☐	☐	Professional Engineer's Seal-- including signature and date
Developer's Comments (please reference the item number for each comment)					
City's Comments					

[1] To be checked by the Developer. If a "submitted" box is not checked, the Applicant must explain (in comment box above) or the application may be rejected for insufficient information.

Reference: Adams County, Colorado Development Standards and Regulations

Figure A3. Preliminary Storm Drainage Study: Report Checklist (1 of 2)

Item No.	Submitted[1]	City Use Only			
		Rejected	Accepted	N/A	
1	☐	☐	☐	☐	Signed certification statements of the Engineer and Developer
2	☐	☐	☐	☐	Description of project location
3	☐	☐	☐	☐	Description of pre-development site conditions
4	☐	☐	☐	☐	Description of proposed development, including description of proposed developed site
5	☐	☐	☐	☐	Description of proposed storm water improvements, including conveyance, storm water quantity control facilities, and storm water quality control facilities.
6	☐	☐	☐	☐	Description of the design method utilized, names of any computer software routines utilized in the design process, and reference any design standards utilized (other than City ordinances).
7	☐	☐	☐	☐	Preliminary hydrological and hydraulic analysis, including pre-development and post-development runoff hydrographs for the project site.
8	☐	☐	☐	☐	Preliminary sizing of storage facilities proposed for storm water quantity and/ or quality control
9	☐	☐	☐	☐	Preliminary report addressing potential erosion and sedimentation impacts during construction, and general proposals for the mitigation of these impacts. Address erosion control during and after construction.
10	☐	☐	☐	☐	Vicinity Map-- including Section, Township and Range
11	☐	☐	☐	☐	Professional Engineer's Seal-- including signature and date
12	☐	☐	☐	☐	Downstream and adjacent property Drainage Impact Analysis and Mitigation Measures.

Reference: Adams County, Colorado Development Standards and Regulations

Figure A3, continued. Preliminary Storm Drainage Study: Report Checklist (2 of 2)

13	☐	☐	☐	☐	Pre-development and post-development basin maps, showing boundaries of project, any off-site contributing drainage basins, on-site drainage basins, time of concentration routes, approximate locations of all major drainage structures within the basins, and
14	☐	☐	☐	☐	Other resource material such as soils maps, isopluvial maps, nomographs, charts, figures, tables, etc.
15	☐	☐	☐	☐	Surface/ subsurface soil test results and test locations (when retention/ infiltration is proposed).
16	☐	☐	☐	☐	Identify all easements
17	☐	☐	☐	☐	Include runoff summary table at design points
18	☐	☐	☐	☐	Indicate proposed drainage improvements
Developer's Comments (please reference the item number for each comment)					
City's Comments					

[1] To be checked by the Developer. If a "submitted" box is not checked, the Applicant must explain (in comment box above) or the application may be rejected for insufficient information.

Figure A4. Final Storm Drainage Study: Plan Checklist (1 of 3)

Item No.	Submitted[1]	City Use Only			
		Rejected	Accepted	N/A	
					General Requirements for all Storm Drainage Study Plans and Details:
1	☐	☐	☐	☐	Sheet Size-- 24" x 36" or 11" x 17"
2	☐	☐	☐	☐	Project Title Sheet
3	☐	☐	☐	☐	Project Site Plan
4	☐	☐	☐	☐	Title Block-- Include name and address of proposed project/ development, submittal date, title of drawing, and sheet number.
5	☐	☐	☐	☐	North arrow indicator, Section-Township-Range, Drawing Scale, Legend
6	☐	☐	☐	☐	Drawing Scale-- 1" = 50' or 100'. Larger scales may be required where necessary to clearly present details.
					Site Plan:
7	☐	☐	☐	☐	Topography-- include existing and final contour lines at a maximum of 2' intervals (with source to datum) for the site extended beyond project limits as appropriate to show downstream effects and adjacent property interaction. (Insufficient extension of contours will be cause for rejection.) In addition, contour lines for adjacent rights-of-way must be included for the full width of right-of-way. Slopes steeper than 10% shall be identified by shading or cross-hatching.
8	☐	☐	☐	☐	Utilities-- existing and proposed with easements identified
9	☐	☐	☐	☐	Site Layout-- including property boundaries (bearings, dimensions, and area), adjoining streets and centerlines (with name and ROW widths), access locations, and existing structures (curb, gutter, sidewalks, etc.).
10	☐	☐	☐	☐	Storm Drainage Structures-- including existing and proposed structures (curb, gutter, pipes, inlets, channels, culverts, irrigation ditches, detention/ retention basins, etc.) clearly identifying invert, flowline elevations, limits of erosion protection, and direction of flow. Number, size and materials of construction for each structure shall be presented in tabulation form. In addition, notes shall be included referencing details, cross-sections, profiles, etc.
11	☐	☐	☐	☐	Natural Features-- including drainage channels, wetlands, water bodies, areas of natural vegetation, and floodplains. For natural drainage features, show direction of flow and 100 year floodplain boundary (if applicable).
12	☐	☐	☐	☐	Demolition-- including all items to be removed (culverts, storm sewers, trees, curb, gutter, sidewalk, etc.), presented in tabulation form.

Reference: Adams County, Colorado Development Standards and Regulations

Figure A4, continued. Final Storm Drainage Study: Plan Checklist (2 of 3)

13	☐	☐	☐	☐	Proposed Structures-- including new roads and road improvements, parking surfaces, building footprints, walkways, landscape areas, maintenance access, etc. Exact lines, grades and gradients of proposed public roadways shall be shown. If a cul-de-sac is proposed as a part of the roadway system, show spot flowline elevations at 25' intervals along the perimeter of the cul-de-sac. Spot elevations at flowlines may also be necessary at intersections.
14	☐	☐	☐	☐	Fill Source and Quantity-- including source and quantity of selected off-site material and locations and quantity of designated on-site borrow pits and pertinent information showing where each type of fill is to be placed.
					Profiles:
15	☐	☐	☐	☐	Storm Drainage Structure Profiles-- including pipe sizes, pipe types and materials, lengths of runs, gradients and exact locations of pipes or channels, structure identifier (e.g. catch basin/ manhole number), type of structure (e.g. Type 16 CB), exact location of structures (e.g. station and offset, or dimensioning), invert elevations in/out of structures, outlet configuration, and top elevations of structures. In addition, hydraulic gradelines will be shown for all storm sewer collection systems.
16	☐	☐	☐	☐	Surface Grades-- existing and finish surface grades.
17	☐	☐	☐	☐	Proposed Utilities, showing exact line and grade of all proposed utilities at crossings with the proposed drainage system.
					Cross Sections:
18	☐	☐	☐	☐	Spacing-- roadways, streets, channels and basins-- 50' intervals (< 1 mile) or 100' intervals (>= 1 mile), changes in section or at critical areas.
19	☐	☐	☐	☐	Roadways-- including new, existing, improved, and maintenance access roads.
20	☐	☐	☐	☐	Detention/ Retention Basins-- including slope, depth, and erosion protection techniques.
21	☐	☐	☐	☐	Modified/ Newly Developed Channels-- including proposed channels, ditches and swales.
					Details:
22	☐	☐	☐	☐	Details shall be provided for all proposed drainage structures for which there is insufficient information in the plan or profile views (i.e. outlet configurations, headwall/ wingwall, etc.). Details are not required for structures included in the SDDOT Standard Plans, provided that the specific SDDOT Standard Plans are referenced in the construction notes.
					Additional Requirements:
23	☐	☐	☐	☐	Indicate any proposed phasing of construction.
24	☐	☐	☐	☐	Professional Engineer's Seal-- including signature and date.

Reference: Adams County, Colorado Development Standards and Regulations

Figure A4, continued. Final Storm Drainage Study: Plan Checklist (3 of 3)

25	☐	☐	☐	☐	General Construction Notes-- include notes for clarification
26	☐	☐	☐	☐	Drainage maintenance plan
27	☐	☐	☐	☐	All drainage easements and maintenance access points identified on plans. Submittal includes a copy of final plat to verify easements.
Developer's Comments (please reference the item number for each comment)					
City's Comments					

[1] To be checked by the Developer. If a "submitted" box is not checked, the Applicant must explain (in comment box above) or the application may be rejected for insufficient information.

Reference: Adams County, Colorado Development Standards and Regulations

Figure A5. Final Storm Drainage Study: Report Checklist (1 of 3)

Item No.	Submitted[1]	City Use Only			
		Rejected	Accepted	N/A	
1	☐	☐	☐	☐	Cover sheet-- including project name, proponent's name, address, and telephone number, Project Engineer, and date of submittal.
2	☐	☐	☐	☐	Table of contents-- Show the page numbers for each section of the report, including appendices.
					Project Description:
3	☐	☐	☐	☐	Describe the type of permit(s) for which the applicant is applying, the size and location of the project site, address or parcel number, and legal description of the property, property zoning, etc.
4	☐	☐	☐	☐	Describe other permits required
5	☐	☐	☐	☐	Describe the project, including proposed land use, site improvements, construction of impervious surfaces, and landscaping.
6	☐	☐	☐	☐	Existing Conditions-- Include references to relevant reports such as basin plans, flood studies, groundwater studies, wetland designation, sensitive area designation, environmental impact statements, water quality reports, etc.
7	☐	☐	☐	☐	Existing Conditions-- Where such reports impose additional conditions on the applicant, those conditions shall be included in the report. In addition, an existing drainage report or master plan (City approved source) may be used as a baseline and updated with the proposed information.
8	☐	☐	☐	☐	Developed site drainage conditions-- Describe the land cover resulting from the proposed project; describe the potential storm water quantity and quality impacts resulting from the proposed project; describe the proposal for the collection and conveyance of site runoff from the project site, for the control of any increase in storm water quantity resulting from the project, and for the control of storm water quality.
9	☐	☐	☐	☐	Hydrological Analysis-- including assumptions, computations, and results.
10	☐	☐	☐	☐	Describe the drainage basin(s) to which the project site contributes runoff, and identify the receiving waters for each of these drainage basins.
11	☐	☐	☐	☐	Soils hydrological group(s)
12	☐	☐	☐	☐	Description of upstream basin(s)-- Identify any sources of runoff to the project site. This should be based on a field investigation. Any existing drainage or erosion problems upstream which may have an impact on the proposed development should be noted.
13	☐	☐	☐	☐	Downstream Drainage Analysis-- The initial drainage report submittal shall include a Level I Downstream Drainage Analysis. Any further analysis of downstream conditions required beyond the Level I analysis shall be submitted as part of this Drainage Report.

Reference: Adams County, Colorado Development Standards and Regulations

Figure A5, continued. Final Storm Drainage Study: Report Checklist (2 of 3)

13	☐	☐	☐	☐	Geotechnical Report-- either supervised or prepared by a registered professional engineer (sealed, signed and dated)
14	☐	☐	☐	☐	Basin map(s)-- Show boundaries of project, any offsite contributing drainage basins, onsite drainage basins, approximate locations of all major drainage structures within the basins, and depict the course of storm water origination from the subject property and extending all the way to the closest receiving body of water. Reference the source of the topographic base map, the scale of the map, and include a north arrow.
15	☐	☐	☐	☐	Hydraulic design computations-- supporting the design of proposed conveyance, quantity and quality control facilities, and verifying the capacity of existing drainage facilities. These computations may include capacity and backwater analyses required either as part of the proposed drainage design or as a part of the downstream drainage investigation, and flood routing computations required for the design of detention/ retention storage facilities, for wetland impact analysis, or for floodplain analysis.
16	☐	☐	☐	☐	Erosion and Sedimentation Control-- Include a description of proposed erosion control objectives and strategies; a description of erosion control facilities and other temporary water quality facilities proposed; a description of the revegetation plan for the project site; identification of areas of concern regarding soil stability and/ or water quality impacts; computations for the sizing of temporary storm water conveyance and quantity control facilities; computations for the design and sizing of proposed sediment containment facilities, etc.
17	☐	☐	☐	☐	Appendices-- Include copies of any additional relevant reports, prepared by others, which support or corroborate the findings, conclusions, or assumptions contained in the Drainage Report; copies of any additional permits (or completed permit applications) required for the project.
					Vicinity Map:
18	☐	☐	☐	☐	Sheet Size-- 11' x 17" or 8 1/2" x 11"
19	☐	☐	☐	☐	Project Title Sheet
20	☐	☐	☐	☐	Project Title Plan
21	☐	☐	☐	☐	Title Block-- Include name and address of proposed project/ development, submittal date, title of drawing, and page number.
22	☐	☐	☐	☐	Drawing Information-- Include North arrow indicator, Section-Township-Range, Drawing Scale, Symbol Legend
23	☐	☐	☐	☐	Drawing Scale-- as necessary to clearly present details.

Reference: Adams County, Colorado Development Standards and Regulations

Figure A5, continued. Final Storm Drainage Study: Report Checklist (3 of 3)

24	☐	☐	☐	☐	Project site topography, land cover and land use; abutting property land cover and land use.
25	☐	☐	☐	☐	Offsite drainage to the property; creeks, lakes, ponds, wetlands, ravines, gullies, steep slopes, springs, and other environmentally sensitive areas on or adjacent to the project site.
26	☐	☐	☐	☐	General soils conditions present within the project site.
27	☐	☐	☐	☐	Existing natural and manmade drainage facilities within and immediately adjacent to the project site.
28	☐	☐	☐	☐	Points of discharge for drainage from the project site.
29	☐	☐	☐	☐	Impact on adjacent properties. Location(s) of downstream outfall points.
30	☐	☐	☐	☐	Signed statement from engineer, developer.
Developer's Comments (please reference the item number for each comment)					
City's Comments					

[1] To be checked by the Developer. If a "submitted" box is not checked, the Applicant must explain (in comment box above) or the application may be rejected for insufficient information.

Reference: Adams County, Colorado Development Standards and Regulations

Appendix B: Major and Minor Design Storm Criteria

Table B1. 5-year 24-hour Storm Incremental Precipitation Values.

Time (min)	Time (hr)	Incremental Precipitation (in)	Time (min)	Time (hr)	Incremental Precipitation (in)	Time (min)	Time (hr)	Incremental Precipitation (in)	Time (min)	Time (hr)	Incremental Precipitation (in)
0	0	0.000	360	6	0.006	720	12	0.321	1080	18	0.006
6	0.1	0.003	366	6.1	0.006	726	12.1	0.064	1086	18.1	0.006
12	0.2	0.003	372	6.2	0.006	732	12.2	0.056	1092	18.2	0.006
18	0.3	0.003	378	6.3	0.006	738	12.3	0.049	1098	18.3	0.006
24	0.4	0.004	384	6.4	0.006	744	12.4	0.041	1104	18.4	0.006
30	0.5	0.003	390	6.5	0.006	750	12.5	0.033	1110	18.5	0.006
36	0.6	0.004	396	6.6	0.007	756	12.6	0.028	1116	18.6	0.005
42	0.7	0.003	402	6.7	0.006	762	12.7	0.027	1122	18.7	0.006
48	0.8	0.004	408	6.8	0.006	768	12.8	0.025	1128	18.8	0.005
54	0.9	0.004	414	6.9	0.007	774	12.9	0.023	1134	18.9	0.005
60	1	0.004	420	7	0.007	780	13	0.022	1140	19	0.005
66	1.1	0.004	426	7.1	0.007	786	13.1	0.020	1146	19.1	0.005
72	1.2	0.004	432	7.2	0.007	792	13.2	0.019	1152	19.2	0.005
78	1.3	0.004	438	7.3	0.007	798	13.3	0.018	1158	19.3	0.005
84	1.4	0.004	444	7.4	0.007	804	13.4	0.018	1164	19.4	0.005
90	1.5	0.004	450	7.5	0.007	810	13.5	0.016	1170	19.5	0.005
96	1.6	0.004	456	7.6	0.007	816	13.6	0.016	1176	19.6	0.005
102	1.7	0.004	462	7.7	0.007	822	13.7	0.015	1182	19.7	0.005
108	1.8	0.004	468	7.8	0.007	828	13.8	0.014	1188	19.8	0.004
114	1.9	0.004	474	7.9	0.007	834	13.9	0.014	1194	19.9	0.005
120	2	0.004	480	8	0.007	840	14	0.013	1200	20	0.004
126	2.1	0.004	486	8.1	0.007	846	14.1	0.013	1206	20.1	0.004
132	2.2	0.004	492	8.2	0.008	852	14.2	0.012	1212	20.2	0.004
138	2.3	0.004	498	8.3	0.008	858	14.3	0.012	1218	20.3	0.004
144	2.4	0.004	504	8.4	0.009	864	14.4	0.011	1224	20.4	0.004
150	2.5	0.004	510	8.5	0.009	870	14.5	0.011	1230	20.5	0.004
156	2.6	0.004	516	8.6	0.009	876	14.6	0.011	1236	20.6	0.004
162	2.7	0.004	522	8.7	0.010	882	14.7	0.011	1242	20.7	0.004
168	2.8	0.004	528	8.8	0.010	888	14.8	0.011	1248	20.8	0.004
174	2.9	0.004	534	8.9	0.010	894	14.9	0.010	1254	20.9	0.004
180	3	0.004	540	9	0.011	900	15	0.010	1260	21	0.004
186	3.1	0.004	546	9.1	0.011	906	15.1	0.010	1266	21.1	0.004
192	3.2	0.004	552	9.2	0.011	912	15.2	0.010	1272	21.2	0.004
198	3.3	0.004	558	9.3	0.011	918	15.3	0.009	1278	21.3	0.004
204	3.4	0.005	564	9.4	0.011	924	15.4	0.009	1284	21.4	0.004
210	3.5	0.004	570	9.5	0.011	930	15.5	0.009	1290	21.5	0.004
216	3.6	0.005	576	9.6	0.011	936	15.6	0.009	1296	21.6	0.004
222	3.7	0.005	582	9.7	0.011	942	15.7	0.009	1302	21.7	0.004
228	3.8	0.004	588	9.8	0.012	948	15.8	0.008	1308	21.8	0.004
234	3.9	0.005	594	9.9	0.013	954	15.9	0.008	1314	21.9	0.004
240	4	0.005	600	10	0.013	960	16	0.008	1320	22	0.004
246	4.1	0.005	606	10.1	0.014	966	16.1	0.008	1326	22.1	0.004
252	4.2	0.005	612	10.2	0.015	972	16.2	0.007	1332	22.2	0.004
258	4.3	0.005	618	10.3	0.016	978	16.3	0.008	1338	22.3	0.004
264	4.4	0.005	624	10.4	0.016	984	16.4	0.007	1344	22.4	0.004
270	4.5	0.005	630	10.5	0.017	990	16.5	0.007	1350	22.5	0.004
276	4.6	0.005	636	10.6	0.018	996	16.6	0.007	1356	22.6	0.004
282	4.7	0.005	642	10.7	0.020	1002	16.7	0.007	1362	22.7	0.004
288	4.8	0.005	648	10.8	0.021	1008	16.8	0.007	1368	22.8	0.004
294	4.9	0.005	654	10.9	0.022	1014	16.9	0.007	1374	22.9	0.004
300	5	0.005	660	11	0.024	1020	17	0.007	1380	23	0.004
306	5.1	0.005	666	11.1	0.026	1026	17.1	0.007	1386	23.1	0.004
312	5.2	0.005	672	11.2	0.029	1032	17.2	0.007	1392	23.2	0.004
318	5.3	0.006	678	11.3	0.032	1038	17.3	0.007	1398	23.3	0.004
324	5.4	0.006	684	11.4	0.036	1044	17.4	0.006	1404	23.4	0.004
330	5.5	0.005	690	11.5	0.039	1050	17.5	0.007	1410	23.5	0.004
336	5.6	0.006	696	11.6	0.080	1056	17.6	0.006	1416	23.6	0.004
342	5.7	0.006	702	11.7	0.161	1062	17.7	0.006	1422	23.7	0.004
348	5.8	0.006	708	11.8	0.258	1068	17.8	0.006	1428	23.8	0.004
354	5.9	0.006	714	11.9	0.463	1074	17.9	0.006	1434	23.9	0.004
									1440	24	0.004

Table B2. 100-year 24-hour Storm Incremental Precipitation Values.

Time (min)	Time (hr)	Incremental Precipitation (in)	Time (min)	Time (hr)	Incremental Precipitation (in)	Time (min)	Time (hr)	Incremental Precipitation (in)	Time (min)	Time (hr)	Incremental Precipitation (in)
0	0	0.000	360	6	0.010	720	12	0.547	1080	18	0.010
6	0.1	0.006	366	6.1	0.010	726	12.1	0.109	1086	18.1	0.010
12	0.2	0.006	372	6.2	0.010	732	12.2	0.095	1092	18.2	0.010
18	0.3	0.006	378	6.3	0.011	738	12.3	0.083	1098	18.3	0.010
24	0.4	0.006	384	6.4	0.011	744	12.4	0.070	1104	18.4	0.010
30	0.5	0.006	390	6.5	0.010	750	12.5	0.056	1110	18.5	0.010
36	0.6	0.006	396	6.6	0.012	756	12.6	0.048	1116	18.6	0.009
42	0.7	0.006	402	6.7	0.011	762	12.7	0.046	1122	18.7	0.010
48	0.8	0.006	408	6.8	0.011	768	12.8	0.043	1128	18.8	0.009
54	0.9	0.006	414	6.9	0.012	774	12.9	0.039	1134	18.9	0.009
60	1	0.006	420	7	0.012	780	13	0.037	1140	19	0.009
66	1.1	0.006	426	7.1	0.012	786	13.1	0.035	1146	19.1	0.009
72	1.2	0.006	432	7.2	0.011	792	13.2	0.032	1152	19.2	0.009
78	1.3	0.006	438	7.3	0.012	798	13.3	0.031	1158	19.3	0.009
84	1.4	0.007	444	7.4	0.012	804	13.4	0.030	1164	19.4	0.009
90	1.5	0.006	450	7.5	0.012	810	13.5	0.028	1170	19.5	0.008
96	1.6	0.007	456	7.6	0.012	816	13.6	0.026	1176	19.6	0.008
102	1.7	0.006	462	7.7	0.012	822	13.7	0.025	1182	19.7	0.008
108	1.8	0.007	468	7.8	0.012	828	13.8	0.024	1188	19.8	0.007
114	1.9	0.007	474	7.9	0.013	834	13.9	0.023	1194	19.9	0.008
120	2	0.007	480	8	0.013	840	14	0.022	1200	20	0.007
126	2.1	0.007	486	8.1	0.013	846	14.1	0.021	1206	20.1	0.007
132	2.2	0.007	492	8.2	0.014	852	14.2	0.021	1212	20.2	0.007
138	2.3	0.007	498	8.3	0.014	858	14.3	0.020	1218	20.3	0.007
144	2.4	0.007	504	8.4	0.015	864	14.4	0.020	1224	20.4	0.007
150	2.5	0.007	510	8.5	0.015	870	14.5	0.020	1230	20.5	0.007
156	2.6	0.007	516	8.6	0.016	876	14.6	0.019	1236	20.6	0.007
162	2.7	0.007	522	8.7	0.017	882	14.7	0.019	1242	20.7	0.007
168	2.8	0.007	528	8.8	0.017	888	14.8	0.018	1248	20.8	0.007
174	2.9	0.007	534	8.9	0.017	894	14.9	0.018	1254	20.9	0.007
180	3	0.007	540	9	0.018	900	15	0.017	1260	21	0.007
186	3.1	0.007	546	9.1	0.018	906	15.1	0.017	1266	21.1	0.007
192	3.2	0.007	552	9.2	0.018	912	15.2	0.017	1272	21.2	0.007
198	3.3	0.007	558	9.3	0.018	918	15.3	0.016	1278	21.3	0.007
204	3.4	0.008	564	9.4	0.018	924	15.4	0.016	1284	21.4	0.007
210	3.5	0.007	570	9.5	0.018	930	15.5	0.016	1290	21.5	0.007
216	3.6	0.008	576	9.6	0.019	936	15.6	0.015	1296	21.6	0.007
222	3.7	0.008	582	9.7	0.020	942	15.7	0.015	1302	21.7	0.007
228	3.8	0.007	588	9.8	0.021	948	15.8	0.014	1308	21.8	0.007
234	3.9	0.008	594	9.9	0.022	954	15.9	0.014	1314	21.9	0.007
240	4	0.008	600	10	0.022	960	16	0.013	1320	22	0.007
246	4.1	0.008	606	10.1	0.024	966	16.1	0.013	1326	22.1	0.007
252	4.2	0.008	612	10.2	0.025	972	16.2	0.013	1332	22.2	0.007
258	4.3	0.009	618	10.3	0.026	978	16.3	0.013	1338	22.3	0.007
264	4.4	0.009	624	10.4	0.028	984	16.4	0.013	1344	22.4	0.007
270	4.5	0.009	630	10.5	0.029	990	16.5	0.013	1350	22.5	0.006
276	4.6	0.009	636	10.6	0.031	996	16.6	0.013	1356	22.6	0.007
282	4.7	0.009	642	10.7	0.033	1002	16.7	0.012	1362	22.7	0.007
288	4.8	0.009	648	10.8	0.036	1008	16.8	0.012	1368	22.8	0.006
294	4.9	0.009	654	10.9	0.038	1014	16.9	0.012	1374	22.9	0.007
300	5	0.009	660	11	0.040	1020	17	0.012	1380	23	0.006
306	5.1	0.009	666	11.1	0.044	1026	17.1	0.012	1386	23.1	0.007
312	5.2	0.009	672	11.2	0.049	1032	17.2	0.012	1392	23.2	0.006
318	5.3	0.010	678	11.3	0.055	1038	17.3	0.012	1398	23.3	0.007
324	5.4	0.010	684	11.4	0.061	1044	17.4	0.011	1404	23.4	0.006
330	5.5	0.009	690	11.5	0.066	1050	17.5	0.012	1410	23.5	0.006
336	5.6	0.010	696	11.6	0.137	1056	17.6	0.011	1416	23.6	0.007
342	5.7	0.010	702	11.7	0.274	1062	17.7	0.011	1422	23.7	0.006
348	5.8	0.010	708	11.8	0.439	1068	17.8	0.010	1428	23.8	0.006
354	5.9	0.010	714	11.9	0.788	1074	17.9	0.011	1434	23.9	0.006
									1440	24	0.006

Appendix C: Percent Imperviousness and Runoff Coefficients Worksheet

Figure C1. Percent Imperviousness and Runoff Coefficient Worksheet.

WEIGHTED PERCENT IMPERVIOUSNESS AND RUNOFF COEFFICIENT CALCULATIONS

Use this table to determine the weighted percent imperviousness "I" & runoff coefficeints "C" of a basin

Basin ID A

1	2	3	4	5
Subbasin ID	Subbasin Area (acres)	Subbasin Imperviousness "I"	Minor Storm (5-Yr) Subbasin Runoff Coefficient "C"	Major Storm (100-Yr) Subbasin Runoff Coefficient "C"
A1	10	60	0.75	0.8
A2	20	40	0.6	0.7
A3	50	20	0.9	0.94
A4				
A5				
A6				
A7				
A8				
A9				
A10				
A11				
A12				
A13				
A14				
A15				
A16				
A17				
A18				
A19				
A20				

Total Area (acres)	**80**
Weighted Imperviousness "I"	**30**
Weighted Minor Storm Runoff Coefficient "C_5"	**0.81**
Weighted Major Storm Runoff Coefficient "C_{100}"	**0.86**

To Use This Sheet:

1. Enter subbasin ID in column 1
2. Enter area of each subbasin (in units of acres) in column 2
3. Enter the imperviousness of each subbasin in column 3.
   (This value is obtained from Table 2 and Figures 4 - 6 of Criteria Manual.)
4. Enter the runoff coefficient the 5-Year Storm of each subbasin in column 4.
   (This value is obtained from Tables 3 - 5 of the Criteria Manual and is dependent on soil type.)
5. Enter the runoff coefficient the 100-Year Storm of each subbasin in column 5.
   (This value is obtained from Tables 3 - 5 of the Criteria Manual and is dependent on soil type.)

Total Area, Weighted Imperviousness "I" and Weighted Runoff Coefficient "C"
for the basin are calculated in "Yellow" Cells

Appendix D: Runoff Calculations Worksheets

Figure D1. Time of Concentration Worksheet.

TIME OF CONCENTRATION FOR INDIVIDUAL SUBBASINS

Use this spreadsheet to calculate the time-of-concentration (Tc) from each individual subbasin
This sheet provides the Tc at the downstream end of a individual subbasin.

1	2	3	4	5	6	7	8	9	10	11	12
Sub-Basin Data			Initial/Overland (Tov)			Channel Flow (Tt)					Time-of-Concentration Tc
Subbasin ID	Area (acres)	C_5	L (ft)	S (ft/ft)	Tov (min)	L (ft)	S (ft/ft)	Cv	Vel (fps)	Tt (min)	Tc (min)
A1	10.0	0.82	100	0.02	4.0	800	0.020	2.2	0.31	42.9	46.9
A2	20.0	0.56	200	0.0025	21.8	400	0.005	16.0	1.13	5.9	27.7
A3	15.0	0.54	150	0.0031	18.2	700	0.005	20.0	1.41	8.2	26.5
A4	12.0	0.62	100	0.0041	11.6	1100	0.006	8.0	0.62	29.6	41.2
A5	6.0	0.82	200	0.002	12.2	900	0.004	12.0	0.76	19.8	31.9
A6	4.0	0.01	150	0.006	28.5	450	0.010	14.0	1.40	5.4	33.9
A7	8.0	0.88	50	0.004	3.8	200	0.010	20.0	2.00	1.7	5.5
A8											
A9											
A10											
A11											
A12											
A13											
A14											
A15											
A16											
A17											
A18											
A19											
A20											

To Use This Spreadsheet:
1. Enter subbasin IDs in column 1
2. Enter subbasin areas (acres) in column 2
3. Enter calculated C5 values for each subbasin in column 3
4. Enter the length (ft) of the overland flow in column 4. This is the distance before flows become channelized.
   (For undeveloped land the maximum length of overland flow is 500 feet, for developed flow the maximum length is 300 feet.)
5. Enter the average subbasin slope where overland flow occurs in column 5 (ft/ft)

Given this information, the overland flow time (Tov) is calculated in column 6 (minutes)

6. Enter the length (ft) of channelized flow in column 7. This is the total subbasin length minus the overland flow length.
7. Enter the average subbasin slope where channelized flow occurs in column 8.
8. Enter the conveyance coefficient (Cv) in column 9. This value can be found in Table 7 of the Criteria Manual

The average velocity in the channelized section is calculated in column 10 (fps)
The channel flow time (Tt) is calculated in column 11 (minutes).
The time-of-concentration (Tc) is calculated in column 12 (minutes).

NOTE
This spreadsheet provides calculations for computing Tc for each subbasin.
The Tc for any location within the overall basin should be determine by evaluating Tc for subbasins contributing flows to a particular point plus travel time from the downstream end of the subbason to the point of interest. Travel time downstream of the subbasin should be based on channelized flow (roads, swales, pipes etc)
The Tc should be calculated for every hydraulic structure (inlet, swale, road, pipe, detention pond etc) in the drainage system.

Figure D2. Rational Method Peak Flow Calculation Worksheet: Minor Storm

Minor Storm (5-Year) Peak Flow Calculation

Use this spreadsheet to calculate the peak 5-year flow at different hydraulic design points

1	2	3	4	5	6	7
Design Point	**Tributary Subbasin(s)**	**Tributary Area**	**C5**	**Tc**	**Rainfall Int. (i)**	**Qp**
		(acres)		**(min)**	**(inches/hr)**	**(cfs)**
DP-1	A1, A3, A4	25	0.4	20	2.6	26.0
DP-2	A2, A5	10	0.55	15	2.9	16.0
DP-3	A6	2	0.39	10	3.4	2.7
DP-4	A1,A2,A3,A4,A5,A6	40	0.47	30	2.3	43.2
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0

To use this sheet:

1. Enter the design point ID in column 1.
2. Enter the names of the different subbasins that contribute flow to the design point in column 2.
3. Enter the total area (acres) of all subbasins tributary to the design point in column 3.
4. Enter the weighted C5 value for all subbasins tributary to the design point in column 4.
5. Enter the Tc (min) for the design point in column 5.
6. Enter the rainfall intensity (i) in inches per hour in column 6 that corresponds to the Tc in column 5. Note that the 5-year rainfall intensity should be used in this sheet.

The spreadsheet calculates the peak flow (cfs) in column 7.

Figure D3. Rational Method Peak Flow Calculation Worksheet: Major Storm

Major Storm (100-Year) Peak Flow Calculation

Use this spreadsheet to calculate the peak 100-year flow at different hydraulic design points

1	2	3	4	5	6	7
Design Point	**Tributary Subbasin(s)**	**Tributary Area**	**C100**	**Tc**	**Rainfall Int. (i)**	**Qp**
		(acres)		**(min)**	**(inches/hr)**	**(cfs)**
DP-1	A1, A3, A4	25	0.4	20	2.6	26.0
DP-2	A2, A5	10	0.55	15	2.9	16.0
DP-3	A6	2	0.39	10	3.4	2.7
DP-4	A1,A2,A3,A4,A5,A6	40	0.47	30	2.3	43.2
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0

To use this sheet:

1. Enter the design point ID in column 1.
2. Enter the names of the different subbasins that contribute flow to the design point in column 2.
3. Enter the total area (acres) of all subbasins tributary to the design point in column 3.
4. Enter the weighted C100 value for all subbasins tributary to the design point in column 4.
5. Enter the Tc (min) for the design point in column 5.
6. Enter the rainfall intensity (i) in inches per hour in column 6 that corresponds to the Tc in column 5. Note that the 100-year rainfall intensity should be used in this sheet.

The spreadsheet calculates the peak flow (cfs) in column 7.

Appendix E: Detention Sizing Spreadsheets

Figure E1. Detention Sizing Spreadsheet- Minor Storm

DETENTION SIZING SPREADSHEET
FAA METHOD - 5 YEAR STORM

Use this Worksheet to Calculate the Required 5-Year Storage Volume

Area of catchment tributary to storage facility (A):	25	(acres)
Soil type:	C	
Percentage Imperviousness:	25	
Storm return period:	5	(years)
Runoff coefficient (C_5):	0.38	
Allowable Release Rate (cfs/acre)	0.13	
Allowable maximum release rate (Q_{po}):	3.25	(cfs)
Time to concentration (T_c)	32	(minutes)

Soil Type	5-Year Allowable Release (cfs/acre)
A	0.07
B	0.13
C	0.13
D	0.17

Storm Duration T (min)	Rainfall Intensity I (in/hr)	Inflow Volume V_i (ft^3)	Outflow Adjustment m	Average Outflow Q_{av} (cfs)	Calculated Outflow V_o (ft^3)	Storage Volume V_s (ft^3)
5	6.27	17,870	1.00	3.25	975	16,895
10	5.07	28,899	1.00	3.25	1,950	26,949
15	4.28	36,594	1.00	3.25	2,925	33,669
20	3.76	42,864	1.00	3.25	3,900	38,964
25	3.35	47,738	1.00	3.25	4,875	42,863
30	3.01	51,471	1.00	3.25	5,850	45,621
35	2.74	54,663	0.96	3.11	6,533	48,131
40	2.53	57,684	0.90	2.93	7,020	50,664
45	2.36	60,534	0.86	2.78	7,508	53,027
50	2.21	62,985	0.82	2.67	7,995	54,990
55	2.08	65,208	0.79	2.57	8,483	56,726
60	1.96	67,032	0.77	2.49	8,970	58,062
65	1.85	68,543	0.75	2.43	9,458	59,085
70	1.75	69,825	0.73	2.37	9,945	59,880
75	1.66	70,965	0.71	2.32	10,433	60,533
80	1.57	71,592	0.70	2.28	10,920	60,672
85	1.49	72,191	0.69	2.24	11,408	60,783
90	1.41	72,333	0.68	2.20	11,895	60,438
95	1.34	72,561	0.67	2.17	12,383	60,179
100	1.28	72,960	0.66	2.15	12,870	60,090
105	1.22	73,017	0.65	2.12	13,358	59,660
110	1.17	73,359	0.65	2.10	13,845	59,514
115	1.12	73,416	0.64	2.08	14,333	59,084
120	1.08	73,872	0.63	2.06	14,820	59,052

5-Year Storm water detention volume (ft^3) = 60,783

To Use this Sheet:
Enter the tributary basin area (acres) in cell E5
Enter the predominant soil type in cell E7
Enter the percent imperviousness in cell E9
Enter the 5-year runoff coefficient (C_5) in cell E13
Enter the calculated time of concentration is cell E19

The allowable release rate, maximum release rate and required detention volume will be calculated.

Figure E2. Detention Sizing Spreadsheet- Major Storm

DETENTION SIZING SPREADSHEET
FAA METHOD - 100 YEAR STORM

Use this Worksheet to Calculate the Required 100-Year Storage Volume

Area of catchment tributary to storage facility (A):	25	(acres)	Soil Type	100-Year Allowable Release (cfs/acre)
Soil type:	C		A	0.50
			B	0.85
Percentage Imperviousness:	25		C	0.85
			D	1.00
Storm return period:	100	(years)		
Runoff coefficient (C_{100}):	0.58			
Allowable Release Rate (cfs/acre)	0.85			
Allowable maximum release rate (Q_{po}):	21.25	(cfs)		
Time to concentration (T_c)	32	(minutes)		

Storm Duration T (min)	Rainfall Intensity I (in/hr)	Inflow Volume V_i (ft^3)	Outflow Adjustment m	Average Outflow Q_{av} (cfs)	Calculated Outflow V_o (ft^3)	Storage Volume V_s (ft^3)
5	10.20	44,370	1.00	21.25	6,375	37,995
10	8.50	73,950	1.00	21.25	12,750	61,200
15	7.30	95,265	1.00	21.25	19,125	76,140
20	6.50	113,100	1.00	21.25	25,500	87,600
25	5.75	125,063	1.00	21.25	31,875	93,188
30	5.26	137,286	1.00	21.25	38,250	99,036
35	4.80	146,160	0.96	20.34	42,713	103,448
40	4.50	156,600	0.90	19.13	45,900	110,700
45	4.25	166,388	0.86	18.18	49,088	117,300
50	3.90	169,650	0.82	17.43	52,275	117,375
55	3.60	172,260	0.79	16.81	55,463	116,798
60	3.48	181,656	0.77	16.29	58,650	123,006
65	3.25	183,788	0.75	15.86	61,838	121,950
70	3.10	188,790	0.73	15.48	65,025	123,765
75	3.00	195,750	0.71	15.16	68,213	127,538
80	2.80	194,880	0.70	14.88	71,400	123,480
85	2.60	192,270	0.69	14.63	74,588	117,683
90	2.50	195,750	0.68	14.40	77,775	117,975
95	2.40	198,360	0.67	14.20	80,963	117,398
100	2.30	200,100	0.66	14.03	84,150	115,950
105	2.10	191,835	0.65	13.86	87,338	104,498
110	2.05	196,185	0.65	13.72	90,525	105,660
115	1.95	195,098	0.64	13.58	93,713	101,385
120	1.85	193,140	0.63	13.46	96,900	96,240

100-Year Storm water detention volume (ft^3) = 127,538

To Use this Sheet:
1. Enter the tributary basin area (acres) in cell E5
2. Enter the predominant soil type in cell E7
3. Enter the percent imperviousness in cell E9
4. Enter the 100-year runoff coefficient (C_{100}) in cell E13
5. Enter the calculated time of concentration is cell E19

The allowable release rate, maximum release rate and required detention volume will be calculated.

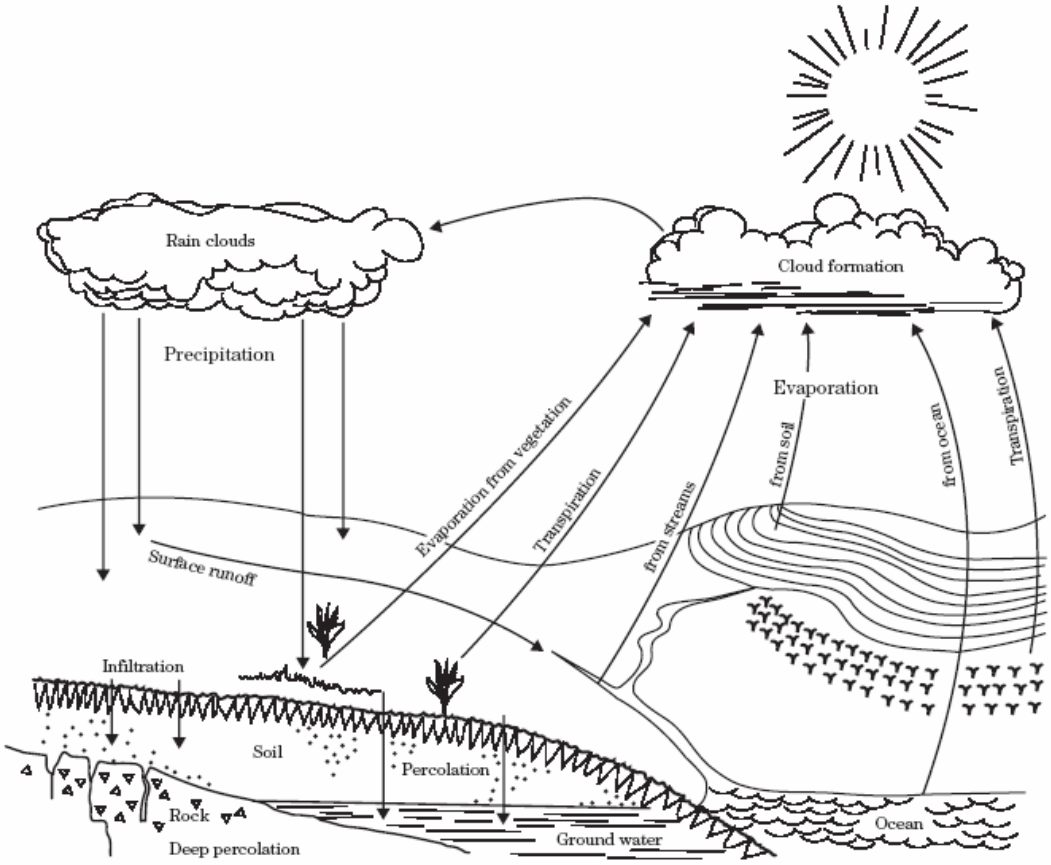
Appendix F: National Engineering Handbook Chapter 9- Curve Numbers

United States
Department of
Agriculture

Natural
Resources
Conservation
Service

Part 630 Hydrology
National Engineering Handbook

Chapter 9 Hydrologic Soil-Cover Complexes



(210-VI-NEH, July 2004)

Chapter 9 Hydrologic Soil-Cover Complexes

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Chapter 9 Hydrologic Soil-Cover Complexes

630.0900 General

A combination of a hydrologic soil group (soil) and a land use and treatment class (cover) is a hydrologic soil-cover complex. This chapter gives tables and graphs of runoff curve numbers (CNs) assigned to such complexes. This CN indicates the runoff potential of a complex during periods when the soil is not frozen. A higher CN indicates a higher runoff potential and specifies which runoff curve of appendix A or figure 10–2 in National Engineering Handbook, part 630 (NEH 630), chapter 10, is to be used in estimating runoff for the complex. Applications and further description of CNs are given in NEH 630, chapters 10 and 12.

630.0901 Determinations of complexes and curve numbers

(a) Agricultural land

Complexes and assigned CNs for combinations of soil groups of NEH 630, chapter 7 and land use and treatment classes of NEH 630, chapter 8 are given in table 9–1. Also given are some complexes that make applications of the table more direct. Impervious and water surfaces, which are not listed, are always assigned a CN of 98.

(1) Assignment of CNs to complexes

Table 9–1 was developed as follows:

- The data literature was searched for watersheds in single complexes (one soil group and one cover); watersheds were found for most of the listed complexes.
- An average CN for each watershed was obtained using rainfall-runoff data for storms producing the annual floods. The watersheds were generally less than 1 square mile in size, the number of watersheds for a complex varied, and the storms were of 1 day or less duration.
- The CNs of watersheds in the same complex were averaged and all CNs for a cover were plotted. A curve for each cover was drawn with greater weight given to CNs based on data from more than one watershed, and each curve was extended as far as necessary to provide CNs for ungaged complexes. All but the last three lines of CN entries in table 9–1 are taken from these curves.
- For the complexes in the last three lines of table 9–1, the proportions of different covers were estimated and the weighted CNs computed from previously derived CNs.

Table 9–1 has not been significantly changed since its construction in 1954 although CNs for crop residue cover treatment has been added. Supplementary tables for special regions have been developed and are shown later in this chapter.

(2) Use of table 9–1

Chapters 7 and 8 of NEH 630 describe how soils and covers of watersheds or other land areas are classified in the field. After the classification is completed, CNs are read from table 9–1 and applied as described in chapter 10. Because the principal use of CNs is for estimating runoff from rainfall, the examples of applications are given in chapter 10.

Table 9–1 Runoff curve numbers for agricultural lands [1/]

Cover description: cover type	treatment [2/]	hydrologic condition [3/]	CN for hydrologic soil group: A	B	C	D
Fallow	Bare Soil	---	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C & T)	Poor	66	74	80	82
		Good	62	71	78	81
	C & T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C & T	Poor	61	72	79	82
		Good	59	70	78	81
	C & T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C & T	Poor	63	73	80	83
		Good	51	67	76	80

See footnotes at end of table.

Table 9–1 Runoff curve numbers for agricultural lands [1/] — Continued

Cover description: cover type	treatment [2/]	hydrologic condition [3/]	CN for hydrologic soil group: A	B	C	D
Pasture, grassland, or range-continuous forage for grazing [4/]		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
Meadow-continuous grass, protected from grazing and generally mowed for hay		Good	30	58	71	78
Brush-brush-forbs-grass mixture with brush the major element [5/]		Poor	48	67	77	83
		Fair	35	56	70	77
		Good	30 [6/]	48	65	73
Woods-grass combination (orchard or tree farm) [7/]		Poor	57	73	82	86
		Fair	43	65	76	82
		Good	32	58	72	79
Woods [8/]		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	30	55	70	77
Farmstead–buildings, lanes, driveways, and surrounding lots		---	59	74	82	86
Roads (including right-of-way):						
Dirt		---	72	82	87	89
Gravel		---	76	85	89	91

1/ Average runoff condition, and I_a=0.2s.

2/ Crop residue cover applies only if residue is on at least 5 percent of the surface throughout the year.

3/ Hydrologic condition is based on combinations of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥20%), and (e) degree of surface toughness.
Poor: Factors impair infiltration and tend to increase runoff.
Good: Factors encourage average and better then average infiltration and tend to decrease runoff.
For conservation tillage poor hydrologic condition, 5 to 20 percent of the surface is covered with residue (less than 750 pounds per acre for row crops or 300 pounds per acre for small grain).
For conservation tillage good hydrologic condition, more than 20 percent of the surface is covered with residue (greater than 750 pounds per acre for row crops or 300 pounds per acre for small grain).

4/ Poor: < 50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

5/ Poor: < 50% ground cover.
Fair: 50 to 75% ground cover.
Good: > 75% ground cover.

6/ If actual curve number is less than 30, use CN = 30 for runoff computation.

7/ CNs shown were computed for areas with 50 percent woods and 50 percent grass (pasture) cover. Other combinations of conditions may be computed from the CNs for woods and pasture.

8/ Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed, but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

(b) National and commercial forest: forest-range

(1) Forest-range in Western United States

In the forest-range regions of the Western United States, soil group, cover type, and cover density are the principal factors used in estimating CNs. Figures 9–1 and 9–2 show the relationships between these factors and CNs for soil-cover complexes used to date. The figures are based on information in table 2–1, part 2, of the USDA Forest Service's Handbook on Methods of Hydrologic Analysis (USDA 1959b). The amount of litter is taken into account when estimating the density of cover.

Present hydrologic conditions are determined from existing surveys or by reconnaissance, and future conditions from the estimate of cover and density changes resulting from proper use and treatment. Table 9–2 lists CNs for arid and semiarid rangelands. It is used like table 9–1.

Figure 9–1 Estimating runoff curve numbers of forest-range complexes in Western United States: herbaceous and oak-aspen complexes

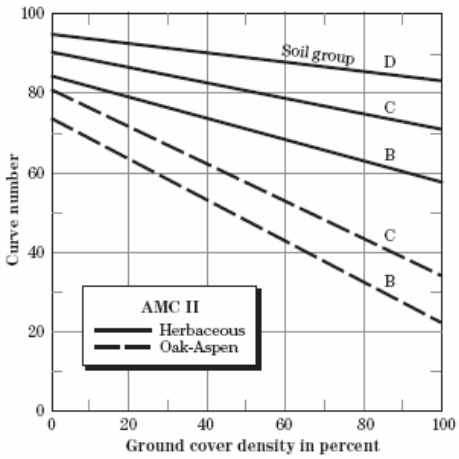


Figure 9–2 Estimating runoff curve numbers of forest-range complexes in Western United States: juniper-grass and sage-grass complexes

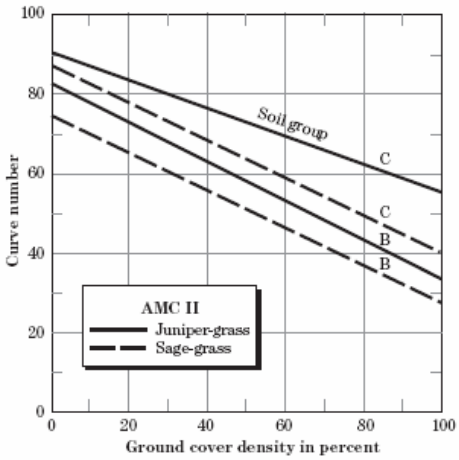


Table 9–2 Runoff curve numbers for arid and semiarid rangelands 1/

Cover description: cover type	hydrologic condition 2/	Hydrologic soil group: A 3/	B	C	D
Herbaceous—mixture of grass, weeds and low-growing brush, with brush the minor element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sage-grass—sage with an understory of grass	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, paloverde, mesquite, and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

1/ Average runoff condition, and $I_a = 0.2s$. For range in humid regions, use table 9–1.

2/ Poor: <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: >70% ground cover.

3/ Curve numbers for group A have been developed only for desert shrub.

(2) Supplementary tables of CNs

Tables 9–3 and 9–4 are supplements to table 9–1 and are used in the same way. Table 9–3 gives CNs for selected covers in Puerto Rico. The CNs were obtained using a relation between storm and annual data and the annual rainfall-runoff data for experimental plots at Mayaguez, Puerto Rico.

Table 9–4 gives CNs for sugarcane complexes in Hawaii. The CNs are tentative estimates now undergoing study.

Table 9–3 Runoff curve numbers for hydrologic soil-cover complexes in Puerto Rico 1/

Cover description: cover type and hydrologic condition	CN for hydrologic soil group: A	B	C	D
Fallow	77	86	91	93
Grass (bunchgrass or poor stand of sod)	51	70	80	84
Coffee (no ground cover, no terraces)	48	68	79	83
(with ground cover and terraces)	22	52	68	75
Minor crops (garden or truck crops)	45	66	77	83
Tropical kudzu	19	50	67	74
Sugarcane: (trash burned, straight-row)	43	65	77	82
(trash mulch, straight-row)	45	66	77	83
(in holes, on contour)	24	53	69	76
(in furrows, on contour)	32	58	72	79

1/ Average runoff condition, and $I_a = 0.2S$.

Table 9–4 Runoff curve numbers; tentative estimates for sugarcane hydrologic soil-cover complexes in Hawaii [1/]

Cover and treatment [2/]	Hydrologic soil group A	B	C	D
Sugarcane:				
Limited cover, straight row	67	78	85	89
Partial cover, straight row	49	69	79	84
Complete cover, straight row	39	61	74	80
Limited cover, contoured	65	75	82	86
Partial cover, contoured	25	59	75	83
Complete cover, contoured	6	35	70	79

1/ Average runoff condition and $I_a = 0.2S$.

2/ Degrees of cover:
Limited cover—Cane newly planted, or ratooned cane with a limited root system; canopy over less than half the field area.
Partial cover—Cane in the transition period between limited and complete cover; canopy over half to nearly the entire field area.
Complete cover—Cane from the stage of growth when full canopy is provided to the stage at harvest.
Straight-row planting is up and down hill or cross-slope on slopes greater than 2 percent.
Contoured planting is the usual contouring or cross-slope planting on slopes less than 2 percent.

(c) Urban and residential land

Several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system, should be considered in computing CNs for urban areas (Rawls et al., 1981). For example, do the impervious areas connect directly to the drainage system, or do they outlet onto lawns or other pervious areas where infiltration can occur?

The urban and residential CNs given in table 9–5 were developed for typical land use relationships based on specific assumed percentages of impervious area. These CN values were developed on the assumptions that

- pervious urban areas are equivalent to pasture in good hydrologic condition,
- impervious areas have a CN of 98 and are directly connected to the drainage system, and
- the cover types listed have assumed percentages of impervious area as shown in table 9–5.

Sheet flow is flow over plane surfaces that usually occurs in the headwater of streams immediately after the rainfall's impact. Sheet flow has very shallow flow depths of 0.05 to 0.1 foot, with laminar flow characteristics of parallel or nearly parallel flowlines and a maximum flow length of 100 feet.

Shallow concentrated flow occurs downstream from sheet flow and upstream from flow in a defined channel. In shallow concentrated flow, the water flows in nonparallel flow paths, and flow depths range from 0.1 foot to as much as 0.5 foot.

In concentrated flow the water follows definite channels that are a discernable feature on the ground surface. See NEH 630, Chapter 15, Time of Concentration, for more information on these flow types.

(1) Connected impervious areas

An impervious area is considered connected if runoff from it flows directly into the drainage system. It is also considered connected if runoff from it occurs as shallow concentrated flow that runs over a pervious area and then into a drainage system.

If all of the impervious area is directly connected to the drainage system, but the impervious area percentages in table 9–5 or the pervious land use assumptions are not applicable, use equation 9–1 or figure 9–3 to compute a composite CN.

$$CN_c = CN_p + \left(\frac{P_{imp}}{100}\right)\left(98 - CN_p\right) \qquad [9–1]$$

where:
CN_c = composite runoff curve number
CN_p = pervious runoff curve number
P_{imp} = percent imperviousness.

Figure 9–3 Composite CN with connected impervious area

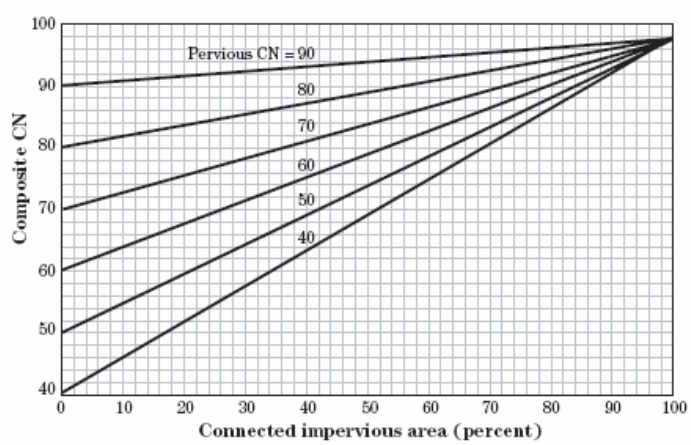


Table 9–5 Runoff curve numbers for urban areas [1/]

Cover description cover type and hydrologic condition	Average percent impervious area [2/]	-- CN for hydrologic soil group -- A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3/]					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4/]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)		77	86	91	94

1/ Average runoff condition, and $I_a = 0.2S$.

2/ The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition.

3/ CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space type.

4/ Composite CNs for natural desert landscaping should be computed using figures 9–3 or 9–4 based on the impervious area percentage (CN=98) and the pervious area CN. The pervious area CNs are assumed equivalent to desert shrub in poor hydrologic condition.

Example 9–1 Calculation of composite urban residential CN with different percentage of impervious area than that assumed in table 9–5

Given: Table 9–5 gives a CN of 70 for a ½-acre lot in HSG B with an assumed impervious area of 25 percent. The pervious area CN is 61.

Problem: Find the CN to be used if the lot has 20 percent impervious area.

Solution: **Method 1**—Solve equation 9–1 with CN_p, the pervious runoff curve number, equal to 61 and P_{imp}, the percent imperviousness, equal to 20:

$$CN_c = 61 + \left(\frac{20}{100}\right)(98 - 61)$$

$$CN_c = 61 + (.20)(37)$$

$$CN_c = 61 + 7.4$$

$$CN_c = 68.4 \text{ round to } 68$$

The CN difference between 70 in table 9–5 and 68 reflects the difference in percent impervious area.

Method 2—Enter figure 9–3 with the percentage of impervious area equal to 20 and move up to a point a little above the curve representing a pervious curve number of 60 to find the point for a pervious CN of 61. Read the Composite CN of 68 on the left axis.

The CN difference between 70 in table 9–5 and 68 reflects the difference in percent impervious area.

Example 9–2 Calculation of a composite urban residential CN with different CN for the pervious area than that assumed in table 9–5

Given: Table 9–5 gives a CN of 70 for a ½-acre lot in HSG B with an assumed impervious area of 25 percent. The pervious area CN is 61.

Problem: Find the CN to be used if the lot's pervious area has a CN of 69, indicating fair condition instead of good condition.

Solution: **Method 1**—Solve equation 9–1 with CN_p, the pervious runoff curve number, equal to 69 and P_{imp}, the percent imperviousness, equal to 25:

$$CN_c = 69 + \left(\frac{25}{100}\right)(98 - 69)$$

$$CN_c = 69 + (.25)(29)$$

$$CN_c = 69 + 7.25$$

$$CN_c = 76.25 \text{ round to } 76$$

The CN difference between 70 in table 9–5 and 76 reflects the difference in the pervious area CN.

Method 2—Enter figure 9–3 with the percentage of impervious area equal to 25 and move up to a point a little below the curve representing a pervious curve number of 70 to find the point for a pervious CN of 69. Read the Composite CN of 76 on the left axis.

The CN difference between 70 in table 9–5 and 76 reflects the difference in the pervious area CN.

(2) Unconnected impervious areas

If runoff from impervious areas occurs over a pervious area as sheet flow prior to entering the drainage system, the impervious area is unconnected. To determine CN when all or part of the impervious area is not directly connected to the drainage system:

- use equation 9–2 or figure 9–4 if the total impervious area is less than 30 percent of the total area or
- use equation 9–1 or figure 9–3 if the total impervious area is equal to or greater than 30 percent of the total area, because the absorptive capacity of the remaining pervious areas will not significantly affect runoff.

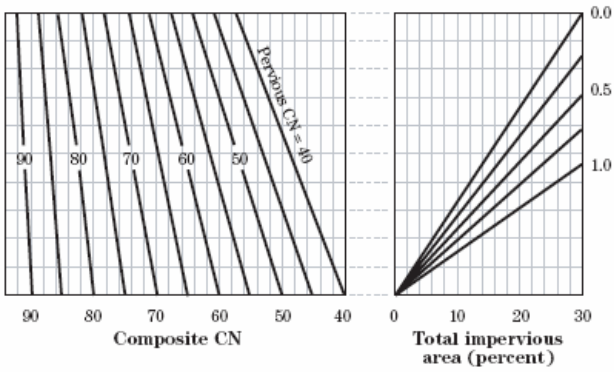
$$CN_c = CN_p + \left(\frac{P_{imp}}{100}\right)(98 - CN_p)(1 - .05R) \quad [9\text{–}2]$$

where:

CN_c = composite runoff curve number
CN_p = pervious runoff curve number
P_{imp} = percent imperviousness
R = ratio of unconnected impervious area to total impervious area

When impervious area is less than 30 percent, obtain the composite CN by entering the right half of figure 9–4 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.

Figure 9–4 Composite CN with unconnected impervious areas and total impervious area less than 30%



Example 9–3 Determine the composite CN with unconnected impervious areas and total impervious area less than 30%

Given: A ½-acre lot in HSG B has an assumed impervious area of 20 percent, 75 percent of which is unconnected. The pervious area CN is 61.

Problem: Find the CN to be used for the lot.

Solution: **Method 1**—Solve equation 9–2 with CN_p, the pervious runoff curve number, equal to 61; P_{imp}, the percent impervious area, equal to 20; and R, the ratio of unconnected impervious area to total impervious area, equal to 0.75:

$$CN_c = 61 + \left(\frac{20}{100}\right)(98-61)(1-0.5(0.75))$$

$$CN_c = 61 + (.20)(37)(1-0.375)$$

$$CN_c = 61 + (.20)(37)(0.625)$$

$$CN_c = 61 + 4.62$$

$$CN_c = 65.62 \text{ round to } 66$$

Method 2—Enter the right half of figure 9–4 with the percentage of impervious area equal to 20 and move up to the 0.75 line for the ratio of unconnected impervious area to total impervious area. Then move to the left part of the figure, left to the appropriate pervious CN 61, and read down to find the composite CN 66.

The CN considering all the impervious areas to be connected as in example 9–1 is 68. Example 9–3 shows that if 75 percent of the impervious area is unconnected, the CN is reduced to 66.

630.0902 References

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