Chapter 22

DRAINAGE, FLOOD PREVENTION, STORMWATER QUALITY AND EROSION CONTROL

Introduction

The standards, guidelines and criteria presented herein are provided in order to facilitate the planning, design, construction and operation of both public and private drainage control, flood control, stormwater quality and erosion control facilities within the community.

The criteria are not intended as a substitute for good engineering judgment; imagination and ingenuity are encouraged. The thrust of these criteria is toward generalization in order to provide guidance for a large majority of design circumstances, but it must be understood that situations will arise in which these criteria are not appropriate.

The City Engineer or the AMAFCA Executive Engineer, as appropriate, may, in specific cases, require more stringent criteria or allow relaxation of these criteria based on his judgment and sound engineering practice.

The DRB representative from the City Engineer's office acts as the designee of the AMAFCA Executive Engineer except in review of proposals involving major arroyos or platting outside the City Limits where there is no immediately pending proposed annexation.

Summary of Documents Relating to Drainage, Flood Control, Stormwater Quality and Erosion Control

1. City Ordinances and Policies
   a. Drainage Control Ordinance
   b. Flood Hazard Control Ordinance
   c. Comprehensive Zoning Code
   d. Subdivision Ordinance
   e. Open Space Policy
2. AMAFCA Regulations and Policies
3. County Regulations
4. Agreements with other Jurisdictions

Some development plans will involve coordination with and approval by jurisdictions in addition to the City of Albuquerque, because the site drains to, or may impact, property in their jurisdiction. They are listed below:

Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA)
Bernalillo County
Office of the State Engineer Dam Safety Bureau
Middle Rio Grande Conservancy District (MRGCD)
New Mexico Department of Transportation (NMDOT)
United States Army Corps of Engineers (USACE)
Village of Los Ranchos
Rio Rancho
National Park Service (NPS)
Burlington Northern Santa Fe Railway (BNSF)
Public Service Company of New Mexico (PNM)
New Mexico Gas Company
Other jurisdictions as applicable.

Section 1. Hydrology

INTRODUCTION

AHYMO has been the primary method for hydrology calculations in Albuquerque since the DPM update in 1993, and it continues to be the basis for hydrology calculations. Other methods are allowed only if they agree closely with the AHYMO method. The “Procedures for 40 acres and Smaller Basins” is calibrated to exactly match AHYMO. In 1993, AHYMO replaced a rational method that had been derived from the SCS Curve Number method. One very specific version of the SCS Curve Number method is being allowed with this 2018 update because it agrees closely with AHYMO results.

The methods in the 1993 DPM were based on precipitation data from the NOAA Atlas 2 which has been superseded by NOAA Atlas 14. Atlas 14 Volume 1 Version 1 was published in 2001 Volume 4 in 2006 and the current Version 5 was published in 2011, and more revisions are expected as new data is collected. AHYMO- 93 and AHYMO-97 used the precipitation distributions from Atlas 2 and AHYMO- S4, released in 2009, uses precipitation distribution based on Atlas 14. The methods, graphs, and tables which follow will be used by the City of Albuquerque staff in the review and evaluation of development plans and drainage management plans.

Two basic methods of analysis are presented herein:

a) PART A - describes a simplified procedure for smaller watersheds based on the Rational Method and initial abstraction/uniform infiltration precipitation losses. The procedure is applicable to watersheds up to 40 acres in size, but the procedure may be extended to include larger watersheds with some limitations

b) PART C - describes two unit hydro graph procedures which are accomplished using computer programs. One method is the AHYMO method and the other method is the SCS Curve Number method. The AHYMO-S4 program is used for the AHYMO method and TR-20 and HEC-HMS are two of the programs that can be used for the SCS CN method and the Atlas 14 precipitation distribution. These procedures are applicable for small and large watersheds.

PART B describes the computation of time of concentration, Lag time, and time to peak which are used in PART A and PART C.

PART E contains a tabulated list of definitions of symbols used in this Section of the D.P.M. and a bibliography.

PART A - PROCEDURE FOR 40 ACRE AND SMALLER BASINS

A simplified procedure for projects with sub-basins smaller than 40 acres has been developed based on initial abstraction/uniform infiltration precipitation losses and Rational Method procedures. For this procedure, Bernalillo County has been divided into four (4) Precipitation Zones.

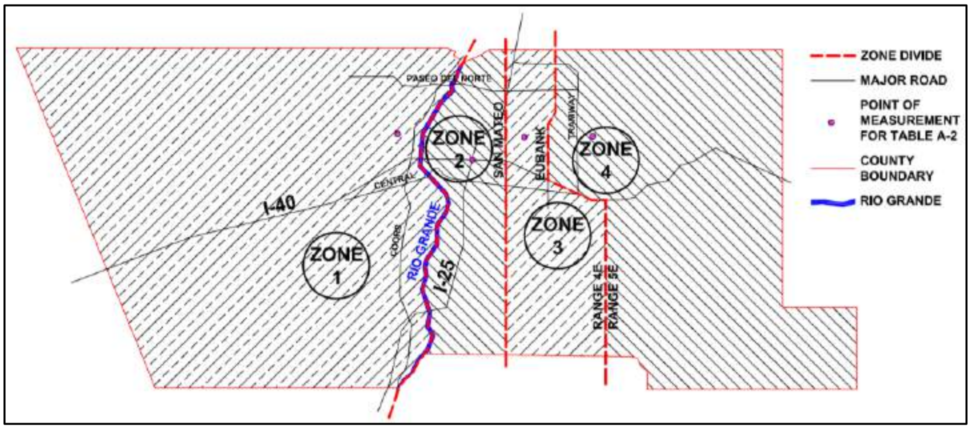
A.1 PRECIPITATION

Albuquerque's four precipitation zones are indicated in TABLE A-1 and on FIGURE A-1, and the corresponding precipitation values are in Table A-2. When modeling the storm, the standard practice is to set the peak intensity 1.5 hours into the storm when using AHYMO losses and 12 hours into the storm when using the SCS Curve Number losses Atlas 14 precipitation distributions must be used. Do not smooth the distribution and do not use the SCS precipitation distribution. The storm duration must be 24 hours and the calculation increment should be set to 5 minutes for the distribution used with the SCS method. The unit hydrograph time increment must be 0.01 hours or less. NOAA Atlas 14, available on the internet, can be used for several other frequency events, and it can be used to obtain a more precise precipitation depth for a particular location than the depths listed in Table A-2.

TABLE A-1. PRECIPITATION ZONES

Zone	**Location**
1	West of the Rio Grande
2	Between the Rio Grande and San Mateo
3	Between San Mateo and Eubank, North of Interstate 40; and between San Mateo and the East boundary of Range 4 East, South of Interstate 40
4	East of Eubank, North of Interstate 40; and East of the East boundary of Range 4 East, South of Interstate 40, Not including the Cibola National Forest

FIGURE A-1



**Where a watershed extends across a zone boundary, use the zone which contains the largest portion of the watershed.*

Table A-2. Precipitation for Zones 1-4

Zone 1 (Lat 35.1282° Long -106.7221° Elev 5140)

Partial Duration		500-Year		100-Year		10-Year		2-Year	
		Depth (in)	Intensity in/hr	Depth (in)	Intensity in/hr	Depth (in)	Intensity in/hr	Depth (in)	Intensity in/hr
olu	olu	Colum	Colum	Colum	Colum	Colum	Colum	Columr	Columr
5	min.	0.701	8.41	0.538	6.46	0.335	4.02	0.207	2.48
10	min.	1.070	6.42	0.819	4.91	0.511	3.07	0.315	1.89
12	min.		5.96		4.58		2.85		1.76
15	min.	1.320	5.28	1.020	4.08	0.633	2.53	0.390	1.56
30	min.	1.780	3.56	1.370	2.74	0.852	1.70	0.525	1.05
60	min.	2.200	2.20	1.690	1.69	1.060	1.06	0.650	0.65
2	hr.	2.530	1.27	1.920	0.96	1.190	0.60	0.746	0.37
3	hr.	2.760	0.92	2.000	0.67	1.250	0.42	0.800	0.27
6	hr.	2.780	0.46	2.170	0.36	1.400	0.23	0.920	0.15
24	hr.	3.090	0.13	2.490	0.10	1.680	0.07	1.160	0.05
4	day	3.780	0.04	3.120	0.03	2.190	0.02	1.560	0.02
10	day	4.680	0.02	3.900	0.02	2.760	0.01	1.970	0.01

Zone 2 (Lat 35.1064° Long -106.6294° Elev 5040)

Partial Duration		500-Year		100-Year		10-Year		2-Year	
		Depth (in)	Intensity in/hr	Depth (in)	Intensity in/hr	Depth (in)	Intensity in/hr	Depth (in)	Intensity in/hr
olu	olu	Colum	Colum	Colum	Colum	Colum	Colum	Columr	Columr
5	min.	0.731	8.77	0.565	6.78	0.355	4.26	0.220	2.64
10	min.	1.110	6.66	0.860	5.16	0.540	3.24	0.335	2.01
12	min.		6.20		4.81		3.01		1.87
15	min.	1.380	5.52	1.070	4.28	0.669	2.68	0.415	1.66
30	min.	1.860	3.72	1.440	2.88	0.901	1.80	0.559	1.12
60	min.	2.300	2.30	1.780	1.78	1.120	1.12	0.692	0.69
2	hr.	2.660	1.33	2.030	1.02	1.260	0.63	0.797	0.40
3	hr.	2.730	0.91	2.100	0.70	1.320	0.44	0.844	0.28
6	hr.	2.980	0.50	2.290	0.38	1.480	0.25	0.977	0.16
24	hr.	3.210	0.13	2.590	0.11	1.760	0.07	1.220	0.05
4	day	3.590	0.04	2.960	0.03	2.070	0.02	1.470	0.02
10	day	4.330	0.02	3.620	0.02	2.560	0.01	1.830	0.01

Table A-2. Precipitation for Zones 1-4

Zone 3 (Lat 35.1261° Long -106.5607° Elev 5354)

Partial Duration		500-Year		100-Year		10-Year		2-Year	
		Depth (in)	Intensity in/hr	Depth (in)	Intensity in/hr	Depth (in)	Intensity in/hr	Depth (in)	Intensity in/hr
olu	olu	Colum	Colum	Colum	Colum	Colum	Colum	Columr	Columr
5	min.	0.753	9.04	0.584	7.01	0.368	4.42	0.228	2.74
10	min.	1.150	6.90	0.889	5.33	0.560	3.36	0.348	2.09
12	min.		6.41		4.96		3.12		1.94
15	min.	1.420	5.68	1.100	4.40	0.693	2.77	0.431	1.72
30	min.	1.910	3.82	1.480	2.96	0.934	1.87	0.580	1.16
60	min.	2.370	2.37	1.840	1.84	1.160	1.16	0.718	0.72
2	hr.	2.810	1.41	2.150	1.08	1.340	0.67	0.845	0.42
3	hr.	2.890	0.96	2.220	0.74	1.400	0.47	0.895	0.30
6	hr.	3.090	0.52	2.430	0.41	1.570	0.26	1.040	0.17
24	hr.	3.570	0.15	2.840	0.12	1.900	0.08	1.300	0.05
4	day	4.000	0.04	3.290	0.03	2.290	0.02	1.620	0.02
10	day	4.940	0.02	4.100	0.02	2.890	0.01	2.060	0.01

Zone 4 (Lat 35.116° Long -106.4749° Elev 7518)

Partial Duration		500-Year		100-Year		10-Year		2-Year	
		Depth (in)	Intensity in/hr	Depth (in)	Intensity in/hr	Depth (in)	Intensity in/hr	Depth (in)	Intensity in/hr
olu	olu	Colum	Colum	Colum	Colum	Colum	Colum	Columr	Columr
5	min.	0.798	9.58	0.624	7.49	0.398	4.78	0.249	2.99
10	min.	1.210	7.26	0.950	5.70	0.606	3.64	0.380	2.28
12	min.		6.77		5.31		3.38		2.12
15	min.	1.510	6.04	1.180	4.72	0.751	3.00	0.471	1.88
30	min.	2.030	4.06	1.590	3.18	1.010	2.02	0.634	1.27
60	min.	2.510	2.51	1.960	1.96	1.250	1.25	0.784	0.78
2	hr.	3.010	1.51	2.330	1.17	1.470	0.74	0.933	0.47
3	hr.	3.120	1.04	2.420	0.81	1.530	0.51	0.991	0.33
6	hr.	3.340	0.56	2.640	0.44	1.730	0.29	1.150	0.19
24	hr.	4.490	0.19	3.600	0.15	2.400	0.10	1.640	0.07
4	day	5.910	0.06	4.750	0.05	3.200	0.03	2.200	0.02
10	day	7.760	0.03	6.270	0.03	4.260	0.02	2.950	0.01

The principal design storm is the 100-year event defined by the NOAA Atlas 14 Volume 1 Version 5, and subsequent updates. Tables A-2, A-8, and A-9 will be updated when NOAA Atlas 14 precipitation depths are updated. For certain applications (e.g., street drainage, low flow channels and sediment transport) storms of greater frequency than the 100-year storm must be considered and the 500-year storm is used for some floodplains.

A.3 LAND TREATMENTS

All land areas are described by one of four basic land treatments or by a combination of the four land treatments.

Land treatments are given in TABLE A-4.

TABLE A-4. LAND TREATMENTS

Treatment	Land Condition
A (CN=77)	Soil uncompacted by human activity with 0 to 10 percent slopes. Native grasses, weeds and shrubs in typical densities with minimal disturbance to grading, ground cover and infiltration capacity.
B (CN=79)	Irrigated lawns, parks and golf courses with 0 to 10 percent slopes. Native grasses, weeds and shrubs, and soil uncompacted by human activity with slopes greater than 10 percent and less than 20 percent.
C (CN=86)	Soil compacted by human activity. Minimal vegetation. Unpaved parking, roads, trails. Most vacant lots. Gravel or rock (desert landscaping). Irrigated lawns and parks with slopes greater than 10 percent. Native grasses, weeds and shrubs, and soil uncompacted by human activity with slopes at 20 percent or greater. Native grass, weed and shrub areas with clay or clay loam soils and other soils of very low permeability as classified by SCS Hydrologic Soil Group D.
D (CN=98)	Impervious areas, pavement and roofs. Ponds, channels and wetlands, even if seasonally dry.

Most watersheds contain a mix of land treatments. To determine proportional treatments, measure respective subareas. For large developed basins the areal percentages in TABLE A-5 may be used. instead of specific measurement for treatment D

TABLE A-5. PERCENT TREATMENT D (Impervious)	
Land Use	**Percent**
Commercial*	90
Single Family Residential N=units/acre, N≤6	$7\sqrt{(N^2) + (5N)}$ (a-4)
Multiple Unit Residential Detached* Attached*	 60 70
Industrial Light* Heavy*	 70 80
Parks, Cemeteries	7
Playgrounds	13
Schools	50
Collector & Arterial Streets	90
*Includes local streets	

TABLE A-5 does not provide areal percentages for land treatments A, B and C. Use of TABLE A-5 will require additional analysis to determine the appropriate areal percentages of these land treatments.

A.4 ABSTRACTIONS

Initial abstraction is the precipitation depth which must be exceeded before direct runoff begins. Initial abstraction may be intercepted by vegetation, retained in surface depressions, or absorbed on the watershed surface. Initial abstractions are shown in TABLE A-6.

TABLE A-6. INITIAL ABSTRACTION (IA)	
Treatment	**Initial Abstraction (inches)**
A	0.65
B	0.50
C	0.35
D	0.10

Infiltration is the only significant abstraction after the initial abstraction. After initial abstraction is satisfied, treat infiltration as a constant loss rate as specified in TABLE A-7.

TABLE A-7. INFILTRATION (INF)	
Treatment	**Loss Rate (inches/hour)**
A	1.67
B	1.25
C	0.83
D	0.04*
* Treatment D infiltration rate is applicable from 0 to 3 hours; use uniform reduction from 3 to 6 hours, with no infiltration after 6 hours.	

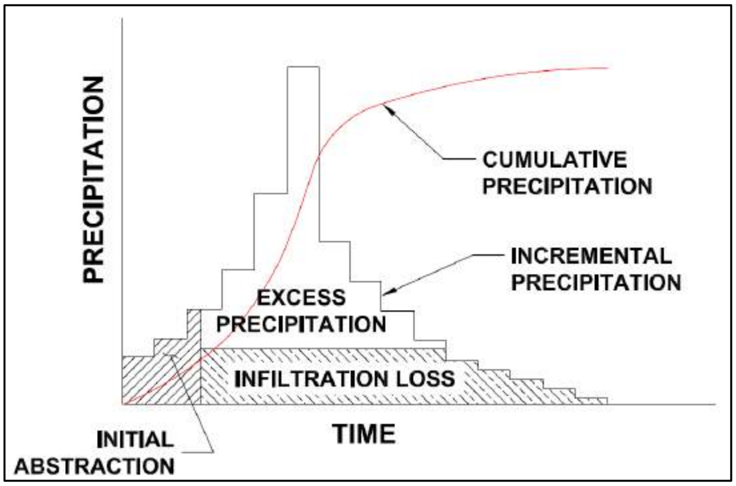
Runoff from a previous event can saturate a channel bed or pond bottom, rendering it minimally pervious for several days. Do not anticipate additional bed losses for design purposes.

A.5 EXCESS PRECIPITATION & VOLUMETRIC RUNOFF

Excess precipitation, E, is the depth of precipitation remaining after abstractions are removed. Excess precipitation does not depend on watershed area.

Excess precipitation is determined by subtracting the initial abstraction and infiltration from the design storm hydro graph. FIGURE A-2 illustrates the development of excess precipitation.

FIGURE A-2



The 6 hour excess precipitation, E, by zone and treatment is summarized in TABLE A-8.

Table A-8 - 6 Hr. Excess, 'E'

100-YR Excess Precipitation, E (in.)

Zone	Land Treatment			
	A	B	C	D
1	0.55	0.73	0.95	2.24
2	0.62	0.80	1.03	2.33
3	0.67	0.86	1.09	2.58
4	0.76	0.95	1.20	3.34

2-YR Excess Precipitation, E (in.)

Zone	Land Treatment			
	A	B	C	D
1	0.00	0.01	0.13	0.92
2	0.00	0.02	0.16	0.98
3	0.00	0.05	0.19	1.05
4	0.00	0.28	0.87	1.39

10-YR Excess Precipitation, E (in.)

Zone	Land Treatment			
	A	B	C	D
1	0.11	0.26	0.43	1.43
2	0.15	0.30	0.48	1.51
3	0.18	0.34	0.52	1.64
4	0.25	0.41	0.59	2.15

To determine the volume of runoff,

1) Determine the area in each treatment, A_A, A_B, A_C, A_D
2) Compute the weighted excess precipitation, E

$$\text{Weighted } E = \frac{E_A A_A + E_B A_B + E_C A_C + E_D A_D}{A_A + A_B + A_C + A_D} \qquad \text{(a-5)}$$

3) Multiply the weighted E by the watershed area.

$$V_{360} \text{ (as volume)} = \text{weighted } E^* (A_A + A_B + A_C + A_D) \qquad \text{(a-6)}$$

EXAMPLE A-3

Find the 100-year V_{360} for 30 acres in zone 1. Eight acres are treatment A, 10 acres are treatment B, 5 acres are treatment C, and 7

acres are treatment D.
Weighted E = ((8 * 0.55) + (10 * 0.73) + (5 * 0.95) + (7 * 2.24)) / 30 = 1.071 inches
Volume = (0.965 * 30) / 12 = 2.68 acre-ft. = V_{360}

For ponds which hold water for longer than 6 hours, longer duration storms are required to establish runoff volumes. Since the additional precipitation is assumed to occur over a long period, the additional volume is based on the runoff from the impervious areas only.

For 24-hour storms:

$$V_{1440} = V_{360} + A_D * (P_{1440} - P_{360}) / 12 \text{ in/ft} \qquad \text{(a-7)}$$

For 4-day storms:

$$V_{4DAYS} = V_{360} + A_D * (P_{4DAYS} - P_{360}) / 12 \text{ in/ft} \qquad \text{(a-8)}$$

For 10-day storms:

$$V_{10DAYS} = V_{360} + A_D * (P_{10DAYS} - P_{360}) / 12 \text{ in/ft} \qquad \text{(a-9)}$$

EXAMPLE A-4

Find the 100-year 24-hour and 4-day runoff volume, V_{1440} and V_{4days}, for the area in Example A-3.

V_{360} = 2.68 acre-feet
V_{1440} = 2.68 + 7 ac * (2.49 - 2.17) / 12 = 2.87 acre-feet
V_{4DAYS} = 2.68 + 7 ac * (3.12 - 2.17) / 12 = 3.23 acre-feet

A.6 PEAK DISCHARGE RATE FOR SMALL WATERSHEDS

The peak discharge rate is given in Table A-9 for small watersheds, less than or equal to 40 acres, where the time of concentration is assumed to be 12 minutes.

Table A-9 Peak Discharge

100-YR Peak Discharge (CFS/ACRE)

	Land Treatment			
Zone	A	B	C	D
1	1.54	2.16	2.87	4.12
2	1.71	2.36	3.05	4.34
3	1.84	2.49	3.17	4.49
4	2.09	2.73	3.41	4.78

2-YR Peak Discharge (CFS/ACRE)

	Land Treatment			
Zone	A	B	C	D
1	0.00	0.02	0.50	1.56
2	0.00	0.08	0.61	1.66
3	0.00	0.15	0.71	1.73
4	0.00	0.28	0.87	1.88

10-YR Peak Discharge (CFS/ACRE)

	Land Treatment			
Zone	A	B	C	D
1	0.30	0.81	1.46	2.57
2	0.41	0.95	1.59	2.71
3	0.51	1.07	1.69	2.81
4	0.70	1.28	1.89	3.04

To determine the peak rate of discharge,

1) Determine the area in each treatment, A_A, A_B, A_C and A_D.

2) Multiply the peak rate for each treatment by the respective areas and sum to compute the total Q_P.

$$\text{Total } Q_P = Q_{PA}A_A + Q_{PB}A_B + Q_{PC}A_C + Q_{PD}A_D \qquad \text{(a-10)}$$

Example A-5

Find 100-year Q_P for 14 acres in zone 1. The four land treatments are: 3 acres in treatment A, 5 acres in treatment B, 2 acres in treatment C and 4 acres in treatment D.

Total $Q_P = (1.54 * 3) + (2.16 * 5) + (2.87 * 2) + (4.12 * 4) = 37.64$ cfs

3) Approximately the same results can be achieved by a Rational Method solution. The 0.2-hour (12-minute) peak intensities, I, are given in TABLE A-2 and Rational Method coefficients, C, are given in TABLE A-11.

$$\text{Total } Q_P = (C_A * I * A_A) + (C_B * I * A_B) + (C_C * I * A_C) + (C_D * I * A_D) \qquad \text{(a-11)}$$

Table A-11 Coeficient C

100-YR Peak Discharge (CFS/ACRE)

	Land Treatment			
Zone	A	B	C	D
1	0.34	0.47	0.63	0.90
2	0.36	0.49	0.63	0.90
3	0.37	0.50	0.64	0.91
4	0.39	0.51	0.64	0.90

2-YR Peak Discharge (CFS/ACRE)

	Land Treatment			
Zone	A	B	C	D
1	0.00	0.01	0.28	0.89
2	0.00	0.04	0.33	0.89
3	0.00	0.08	0.37	0.89
4	0.00	0.13	0.41	0.89

10-YR Peak Discharge (CFS/ACRE)

	Land Treatment			
Zone	A	B	C	D
1	0.11	0.28	0.51	0.90
2	0.14	0.32	0.53	0.90
3	0.16	0.34	0.54	0.90
4	0.21	0.38	0.56	0.90

(Note the quote from the ASCE Manual and Report on Engineering Practice No. 37 (1969): The commonly reported Rational C values "are applicable for storms to 5- to 10-yr. frequencies. Less frequent, higher intensity storms will require the use of higher coefficients because infiltration and other losses have a proportionally smaller effect on runoff." Thus higher C's realized under heavy precipitation might be expected.)

Example A-6

Recompute Example A-5 using the Rational Method.

Q = C I A

= (0.27 * 4.02 *3) + (0.43 * 4.02 * 5) + (0.61 * 4.02* 2) + (0.93 * 4.02 * 4)

= 37.13 cfs

A.7 USE OF RATIONAL METHOD FOR WATERSHEDS LARGER THAN 40 ACRES

Peak rates of discharge may be computed for watersheds larger than 40 acres by using the Rational Method Coefficients (C's) from TABLE A-11 and modifying the Intensity (in/hr) for a larger time of concentration (t_C). This method may be used to establish peak flow rates for off-site flow areas when sizing channels, pipes and road crossings. On-site areas should be divided into 40 acre or smaller sub- basins and should not use this procedure. For watersheds larger than 40 acres, the rational method should not be used to establish allowable historic flow rates since it will tend to give somewhat larger values than those computed by unit hydro graph procedures.

The procedures outlined in PART B should be used to compute the time of concentration (t_C).

Then compute the Intensity (in/hour), using the time of concentration, t_C and linear interpolation between the intensities given in Table A-2 to get the intensity corresponding to the t_c calculated using the procedures in Part B.

Do not use this formula for t_c larger than 2.0 hours.

EXAMPLE A-7

Find Q_P for a 100-year storm at a 120 acre watershed in zone 3, with a 2600 feet shallow concentrated flow upper subreach at 0.015 ft/ft slope and 1200 feet natural channel lower subreach at 0.02 ft/ft slope. The watershed is 50 percent treatment A, 20 percent treatment B, 10 percent treatment C and 20 percent treatment D.

Compute the time of concentration using Table B-1 from PART B as follows:

With a reach length longer than 2000 feet, use K = 3 for the portion below the first 2000 feet.

Since total reach length (2600 + 1200) is less than 4000 feet use equations b-1 and b-2 from PART B

$t_c \quad = \quad ((2000 / (10 * 2 * (0.015^{0.5}))) + (600 / (10 * 3 (0.015^{0.5}))) +$

$(1200 / (10 * 3 * (0.02^{0.5})))) / 60 = 21$ min.

Compute the Intensity, I, using linear interpolation between the 15 min and 30 min 100 year intensities of 4.40 and 2.96 in/hr from Table A-2 as follows:

$I=4.40-[(21-15)/(30-15)*(4.40-2.96)]$

$=3.82$ inches/hour

Using equation a-11 and the percentage of treatment types:

$A_A = 120 * 0.50 = 60$ acres $\quad A_B = 120 * 0.20 = 24$ acres
$A_c = 120 * 0.10 = 12$ inches $\quad A_D = 120 * 0.20 = 24$ acres

$Q_P \quad = \quad (0.37 * 3.82 * 60) + (0.50 * 3.82 * 24) + (0.64 * 3.82 * 12)$

$+ \ (0.91 * 3.82 * 24) = 243.41$ cfs

A.8 HYDROGRAPH FOR SMALL WATERSHED

Base time, t_B, for a small watershed hydrograph is

$$t_B = (2.107 * E * A_T / Q_P) - (0.25 * A_D / A_T) \tag{a-13}$$

Where t_B is in hours, E is the excess precipitation in inches (from TABLE A-8), Q_P is the peak flow in cfs, A_D is the area in treatment D, and A_T is the total area in acres. Using the time of concentration, t_c (hours), the time to peak in hours is

$$t_P = (0.7 * t_C) + ((1.6 - (A_D / A_T)) / 12) \tag{a-14}$$

FIGURE A-3

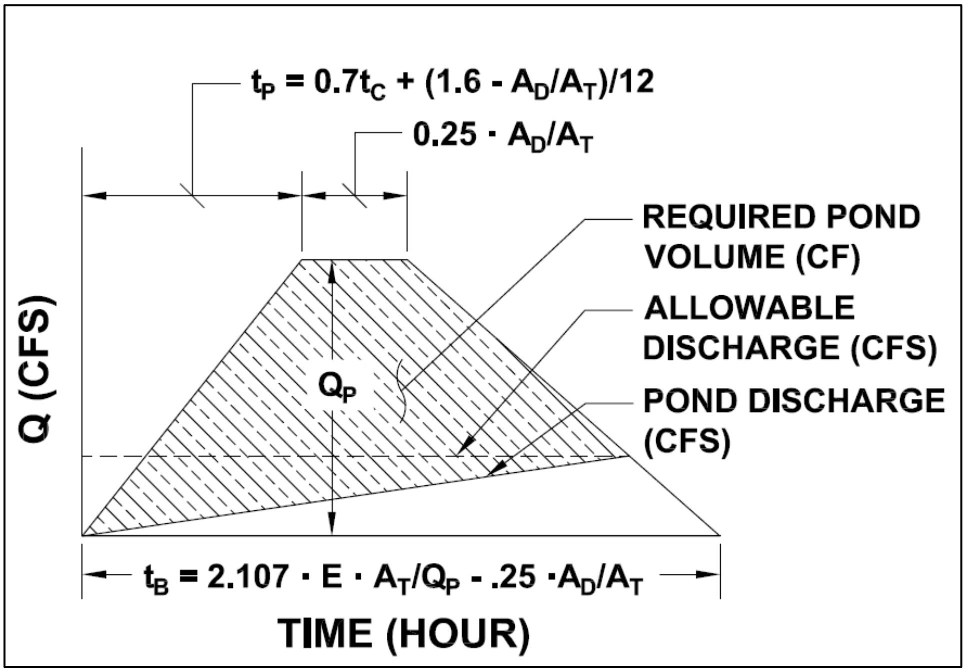
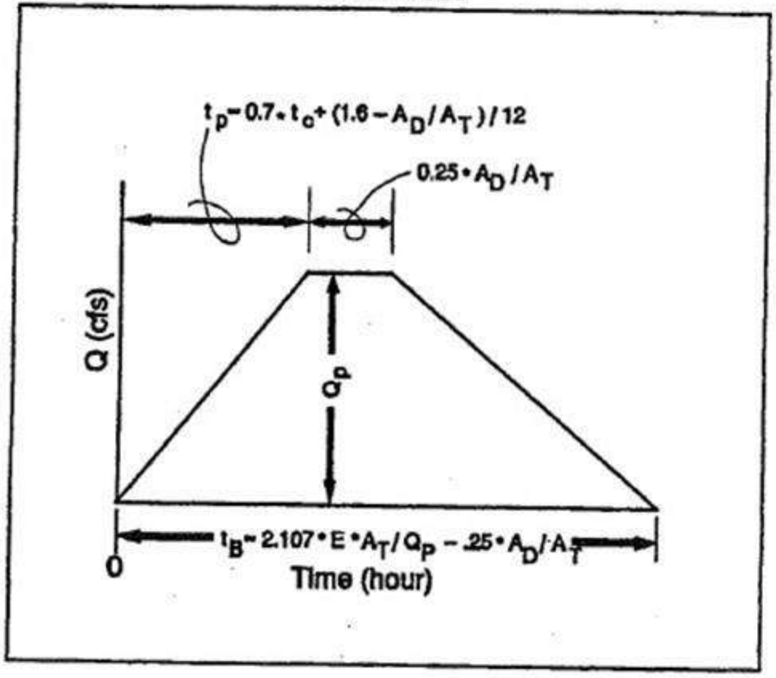


FIGURE A-3



PART B - TIME OF CONCENTRATION, LAG TIME, AND TIME TO PEAK

There is a delay, after a brief heavy rain over a watershed, before the runoff reaches its maximum. The length of time it takes for runoff from a watershed to reach an analysis point affects the peak runoff rate, with shorter times producing higher peak flow for a constant runoff volume. The velocity at which water can flow through a watershed and the length of flow path are used to determine the time factors. Time of concentration, lag time, and time to peak are three related watershed parameters that are used to determine peak rates of runoff.

B.1 DEFINITIONS

The three time parameters used are defined as follows:

time of concentration (t_c) = time it takes for runoff to travel from the hydraulically most distant part of the watershed basin to the basin outlet or point of analysis

Lag time (L_G) = time from the center of unit rainfall excess to the time of the peak flow of the unit runoff hydrograph.

time to peak (t_p) = time from the beginning of unit rainfall excess to the time of the peak flow of the unit runoff hydrograph.

The three time parameters can be computed using the procedures identified in this section. The peak discharge rates and intensity factors identified in TABLES A-9 and A-10 (PART A) were computed using a time of concentration (t_c) of 0.2 hour. The procedures in Part C require the computation of time to peak (t_p) as specified herein.

B.2 COMPUTATION OF TIME OF CONCENTRATION

Two different equations are used to compute time of concentration (tc) for larger watersheds. For subbasin reach lengths shorter than 4000 feet the SCS Upland Method is used;. A transition equation is used for subbasin reach lengths between 4000 and 12000 feet. . For subbasin reach lengths longer than 12000 feet, divide the subbasin into smaller subbasins. Use of the USDI Bureau of Reclamation lag time equation is not recommended, instead the subbasins should be routed.

Consideration should be given to splitting large watersheds into smaller subbasins with reach lengths less than 4000 feet. Smaller subbasins will allow more accurate modeling of channels and basin topography, and should provide for greater modeling accuracy.

1) For subbasin reach lengths less than 4000 feet:

Compute time of concentration, t_c (hours), for the entire (pervious and impervious) watershed by the SCS Upland Method, the sum of the travel times in the subreaches comprising the longest flow path to the watershed outlet.

$$t_c = \left[{}^{L_1}/_{V_1} + {}^{L_2}/_{V_2} + \cdots + {}^{L_n}/_{V_n}\right]/3600 \quad \text{(b-1)}$$

and, $L_1 + L_2 + \cdots + L_n < 4000ft$ (b-2) where:

t_c = time of concentration for the subbasin, in hours. If t_c is computed to be less than 0.2 hours, use t_c = 0.2 hours.

L_x is the subreach length for the nth subreach in feet

V_n = subreach velocity for the nth subreach, in feet per second

The subreach velocity V_n,is as determined by the following equation:

$$V_n = K(s \cdot 100)^{0.5} = 10K(s)^{0.5} \quad \text{(b-3)}$$

where:

K = conveyance factor, per Table B-1, unitless

s = slope, in feet/feet

TABLE B-1. CONVEYANCE FACTORS

K	Conveyance Condition
0.7	Turf, landscaped areas and undisturbed natural areas (sheet flow* only).
1	Bare or disturbed soil areas and paved areas (sheet flow* only).
2	Shallow concentrated flow (paved or unpaved).
3	Street flow, storm drains less than 48” diameter, natural channels, and that portion of subbasins (without constructed channels) below the upper 2000 feet for subbasins longer than 2000 feet.
4	Constructed channels (for example: riprap, soil cement or concrete lined channels).
7	Storm drains 48” diameter and larger.

* Sheet flow is flow over plane surfaces, with flow depths up to 0.1 feet.
Sheet flow applies only to the upper 400 feet (maximum) of a subbasin.

For composite reaches where the basin slope is <u>not</u> uniform, the composite basin conveyance condition, K, can be computed using the following equation:

$$K = \frac{L/\sqrt{s}}{L_1/(K_1\sqrt{s})} + \frac{L/\sqrt{s}}{L_2/(K_2\sqrt{s})} + \cdots + \frac{L/\sqrt{s}}{L_n/(K_n\sqrt{s})} \qquad \text{(b-4)}$$

where: $L = L_1 + L_2 + \cdots + L_n$

and, $L = L_1 + L_2 + \cdots + L_n$ (b-5)

2.) For subbasin reach lengths between 4000 and 12000 feet:

Compute the time of concentration, t_C (hours), for the entire watershed using the following equation:

$$t_c = \frac{12000-L}{72000K(s^{0.5})} + \frac{(L-4000)K_N(L_{CA}/L)^{0.33}}{552.2(s^{0.165})} \qquad \text{(b-7)}$$

where:

K = Conveyance factor from Table B-1. For composite reaches, K is computed using equation b-4.

L = distance of longest watercourse, in feet.

L_{CA} = distance along L from point of concentration to a point opposite centroid of drainage basin, in feet.

s = overall slope of L, in foot per foot. For composite reaches s is computed using equation b-5.

K_N = a basin factor based on an estimate of the weighted, by stream length, average Manning's n value for the principal watercourses in the drainage basin. For the Albuquerque area, values of K_N may be estimated from Table B-2.

TABLE B-2. LAG EQUATION BASIN FACTORS

K_N	Basin Condition
0.042	Mountain Brush and Juniper
0.033	Desert Terrain (Desert Brush)
0.025	Low Density Urban (Minimum improvements to watershed channels)
0.021	Medium Density Urban (Flow in streets, storm sewers and improved channels)
0.016	High Density Urban (Concrete and rip-rap lined channels)

B.3 COMPUTATION OF TIME TO PEAK AND LAG TIME

For the procedures outlined in PART C , the time to peak (t_P) is assumed to be a constant ratio of the time of concentration (t_C). The following equation is used to compute time to peak:

$$L_G = 0.6t_c \qquad \text{(b-8)}$$

$$t_P = \frac{2}{3}t_C \qquad \text{(b-9)}$$

Example B-1

Find the time of concentration (t_c) for a watershed with a 4000 feet desert terrain upper reach (shallow concentrated flow) at 0.015 ft/ft slope and a 3000 feet low density urban lower reach (streets and natural channels) at 0.02 ft/ft slope. The distance to the centroid point is 60% of the total reach length.

L = 4000 + 3000 = 7000 ft L_{CA} / L = 0.60

s = (0.015 * 4000 + 0.02 * 3000) / 7000 = 0.01714 foot per foot

K_N = (0.033 * 4000 + 0.025 * 3000) / 7000 = 0.030

From equation b-4:

$K = (7000 / (0.01714^{0.5})) / ((2000 / (2 * (0.015^{0.5}))) + (2000 / (3 * (0.015^{0.5})))$
$+ (3000 / (3 * (0.02^{0.5})))) = 2.59$

$t_c = ((12000 - 7000) / (72000 * 2.59 * 0.01714^{0.5})) + ((7000 - 4000)$
$* 0.030 * 0.60^{0.33} / (552.2 * 0.01714^{0.165})) = 0.2048 + 0.2694 = 0.4742$ hours

Example B-2

Find the time of concentration (t_c), lag time (L_G) and time to peak (t_p) for a watershed with a 8000 feet desert terrain upper reach at 0.015 ft/ft slope and a 6000 feet low density urban lower reach at 0.02 ft/ft slope. The distance to the centroid point is 60% of the total reach length.

$L = 8000 + 6000 = 14000$ feet
$L_{CA} = 0.60 * 14000 = 8400$ feet

Use equation b-5:

$s = (0.015 * 8000 + 0.02 * 6000) / 14000 = 0.01714$ ft/ft
$K_N = (0.033 * 8000 + 0.025 * 6000) / 14000 = 0.030$

Use equation b-7:

$L_G = 26 * 0.030 * ((14000 * 8400 / (5280^2 * (0.01714 * 5280)^{0.5}))^{0.33})$
$= 0.596$ hours
$t_c = (4/3) * 0.596 = 0.795$ hours
$t_p = (2/3) * 0.795 = 0.530$ hours

B.4 TIME OF CONCENTRATION FOR STEEP SLOPES AND NATURAL CHANNELS

The procedures used to compute time of concentration (tc) as described in Section B.2 may compute values that are too small to be sustained for natural channel conditions. In natural channels, flows become unstable when a Froude Number of 1.0 is approached. The procedures identified in Section B-2 may compute flow velocities for steep slopes that indicate supercritical flow conditions, even though such supercritical flows cannot be sustained for natural channels.

For steep slopes, natural channels will likely experience chute and pool conditions with a hydraulic jump occurring at the downstream end of chute areas; or will experience a series of cascading flows with very steep drops interspersed with flatter channel sections.

For the purposes of this section, steep slopes are defined as those greater than 0.04 foot per foot. The procedures outlined in this section should not be used for the following conditions:

a. Slopes flatter than 0.04 foot per foot.

b. Channels with irrigated grass, riprap, soil cement, gabion, or concrete lining which cannot be clearly identified as natural or naturalistic.

c. The hydraulic design of channels or channel elements. The purpose this section is to define procedures for hydrologic analysis only. The design of facilities adjacent to or within channels with chute and pool conditions cannot be analyzed with the simplified procedures identified herein. It may be necessary to design such facilities for the supercritical flows of chutes (for sediment transport, local scour, stable material size) and for the hydraulic jump of pool conditions (for maximum water surface elevation and flood protection).

The slope of steep natural watercourses should be adjusted to account for the effective slope that can be sustained. The slope adjustment procedures identified in the Denver - Urban Drainage and Flood Control District (UDFCD) Urban Storm Drainage Criteria Manual (Figure 4-1, Runoff chapter, 1990) are applicable for the slope adjustment identified herein. In addition, channel conveyance factors (K) should be checked to make sure that appropriate equivalent Froude Numbers are maintained. The UDFCD Figure 4-1 can be approximated by the following equation:

$$s' = 0.052467 + (0.063627 * s) - 0.18197 * e\,(^{-62.375} * s) \qquad \text{(b-10)}$$

where: s = measured slope (foot per foot)

and, s' = adjusted slope (foot per foot)

The conveyance factors (K) for the upland method should be checked to make sure that appropriate Froude Numbers are maintained. To accomplish this, it is necessary to estimate the peak flow rate from the watershed. Using estimated conveyance factors (K) from Table B-1 and the procedures outlined in Part A, an estimated peak flow rate for the basin (Q_P) can be computed. The following formulas are then used to compute conveyance factor adjustment:

$$K' = 0.302 * s'^{\,(-0.5)} * Q_p^{\,(0.18)} \qquad \text{(b-11)}$$

$$K'' = 0.207 * s'^{\,(-0.5)} * Q_p^{\,(0.18)} \qquad \text{(b-12)}$$

An adjusted conveyance factor (K) is then obtained based on the following:

if $K > K'$ then $K = K'$

if $K' \geq K \geq K''$ then $K = K$ (no adjustment)

if $K < K''$ then $K = K''$

Recompute Q_P based on the revised conveyance factor (K) using the procedures in Part A or Part C as appropriate. If the recomputed Q_P is within 10 percent of the Q_P used to compute K' and K", the estimate is sufficiently accurate. If the recomputed Q_P is more than 10 percent from the Q_P used to compute K' and K", repeat the process using the revised Q_P.

The Lag Equation Basin Factors, K_N, from, TABLE B-2 remain applicable when using equations b-6 and b-7 with the adjusted slope computed by equation b-10.

Example B-3

Compute the time of concentration (t_c) for a natural basin having a length of 4,000 feet and a uniform slope of 0.12 foot per foot. The basin is estimated to have a peak flow of 600 cfs using the procedures in PART A .

$s = 0.12$ foot per foot $Q_P = 600$ cfs

Compute the adjusted slope using equation b-10.

$s' = 0.052467 + 0.063627 * 0.12 - 0.18197 * (e^{(-62.375 * 0.12)})$

$= 0.052764 + 0.007635 - 0.000102 = 0.0603$ ft/ft

Compute conveyance factors from Table B-1 and equation b-3

$K = 4000 / (300 / 0.7 + 1700 / 2.0 + 2000 / 3.0) = 2.056$

From equations b-11 and b-12

$K' = 0.302 * (.0603)^{(-0.5)} * (600)^{0.18} = 3.89$

$K'' = 0.207 * (.0603)^{(-0.5)} * (600)^{0.18} = 2.66$

Since $K < K''$ then use $K = 2.66$

From equation b-1 and b-2

$V = 10 * 2.66 * (0.0603^{0.5}) = 6.53$ ft/sec

$t_C = (4000 / 6.53) / 3600 = 0.170$ hour (Use 0.200 hour minimum.)

The Q_P should then be recomputed using the revised t_c and the procedures in PART A or PART C.

B.5 CHANNEL ROUTING FOR STEEP SLOPES AND NATURAL CHANNELS

The procedures outlined to compute time of concentration for steep natural channels in Section B.4 are also applicable for hydrologic routing of hydrographs through channel segments. The restrictions which limit the procedure only to natural channels with slopes steeper than 0.04 foot per foot are also applicable here. The procedures are not applicable to the hydraulic design of channel structures.

Equation b-10 can be used to obtain an adjusted slope for the channel segment. The Manning's roughness (n) for the channel should be checked to make sure that appropriate Froude Numbers are maintained. It is necessary to estimate the peak flow rate (Q_P) for the watershed channel segment to perform this check. An analysis without a Manning's roughness adjustment may be used for the initial estimate. The following formula is then used to compute the Manning's roughness adjustment:

$$n' = 0.122 * s'^{(0.5)} * Q_P^{(0.06)} \qquad \text{(b- 13)}$$

An adjusted Manning's roughness (n) is then obtained based on the following:

if $n < n'$ then $n = n'$

if $n \geq n'$ then $n = n$ (no adjustment)

Recompute the Q_p based on the revised Manning's roughness (n). If the recomputed Q_p is within 30 percent of the Q_p used to compute n', the estimate is sufficiently accurate. If the recomputed Q_p is more than 30 percent from the Qp used to compute n'', repeat the process using the revised Q_p.

Example B-4

A channel segment immediately downstream of the basin in Example B-3 has a slope of 0.08 foot per foot. The channel has an apparent Manning’s roughness of 0.035. Compute the equivalent channel slope and Manning’s roughness for use in hydrologic routing.

$s = 0.08$ foot per foot $\quad Q_p = 600$ cfs

$s' = 0.052467 + 0.063627 * 0.08 - 0.18197 * e^{(-62.375*0.08)}$

$= 0.052467 + 0.005090 - 0.001238 = 0.0563$ ft/ft

Use equivalent slope = 0.0563 ft/ft in routing computation.

From equation b-13

$n' = 0.122 * (.0563)^{0.5} * (600)^{0.06} = 0.0425$

Since $n < n'$, then use $n = 0.0425$

PART C - PROCEDURE FOR SMALL AND LARGE WATERSHEDS

A unit hydrograph procedure is used for major drainage area analysis and for sub-basins larger than 40 acres. The PART C procedure may also be utilized for small watersheds (40 acres or less) in place of the procedures specified in PART A. AHYMO is the primary method of hydrograph computation using losses described in Tables 6 and 7 for Land Treatments as described in Table A-4 and a rainfall distribution with peak intensity 1.5hours after the beginning of the storm. The SCS Curve Number method is also allowed using Curve Numbers listed in Table A-4 with a 24 hour rainfall distribution based on Atlas 14 (smoothing should not be applied to the Atlas 14 data points) with the peak intensity at 12 hours. The unit hydrograph calculation increment is to be 0.01 hours or less for both the AHYMO and the SCS methods.

C.1 COMPUTER PROGRAMS

The unit hydrograph calculations must be accomplished using computer programs that are acceptable to the City of Albuquerque. Consult the User’s Manual for direction on how to use each program. Program data files must be included with applications to hydrology. A list of acceptable programs is available on the Hydrology web page of the City of Albuquerque along with requirements for procedures to be used and the format of the printout to be contained in the application for each program.

C.2 ZONES

The unit hydrograph procedure should not utilize precipitation zones from TABLE A-1 or FIGURE A-1 of PART A. The precipitation amounts are obtained for a specific location near the center of the watershed being analyzed from the NOAA Atlas 14. The Latitude and Longitude and Elevation of the “Point Precipitation Frequency Estimates and map showing the location of the point should be included in the documentation. Program parameters are obtained based on basin characteristics and precipitation quantities.

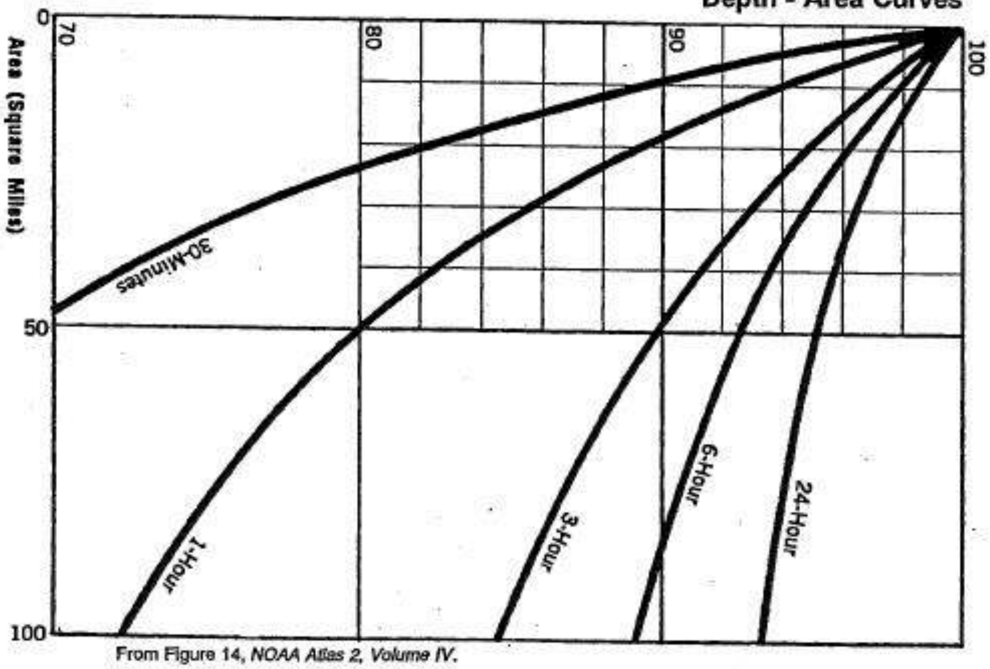
C.3 DESIGN STORM

1) The principal design storm for peak flow determination is the 100-year 24-hour event defined by the NOAA Atlas 14, Precipitation - Frequency Atlas of the United States, Vol. 1 Version 5 Semiarid Southwest or the most current version. Storms of other frequencies or durations are required for design or analysis of volume sensitive facilities, when examining sediment transport, and for complex routing conditions. The following statement from the Federal Emergency Management Agency (FEMA) should be used to provide guidance when selecting storm duration:

"FEMA's position regarding the duration of rainfall is that the storm must extend for a period long enough to include all rainfall excess when the volume of the runoff hydrograph is an important consideration. This includes conditions when detention storage is involved, when sediment processes are a significant factor, and when combining and routing subbasin hydrographs to obtain watershed runoff.

) When evaluating uncontrolled watersheds larger than five (5) square miles, the precipitation amounts may be reduced by multiplying the precipitation amounts by the "Percent of Point Precipitation" obtained from FIGURE C-4. Uncontrolled watersheds mean those areas not controlled by dams, ponds or partial diversions.

Figure C-4
Depth - Area Curves



From Figure 14, *NOAA Atlas 2, Volume IV.*

PART E - SYMBOLS AND BIBLIOGRAPHY

E.1 DEFINITIONS OF SYMBOLS

When evaluation equations use the following order of precedence: 1) parentheses, 2) functions (i.e., SIN or LOG), 3) power or square root, 4) multiplication or division, 5) addition or subtraction.

A_A area in land treatment A

A_B area in land treatment B

A_C area in land treatment C

A_D area in land treatment D

A_T total area in sub-basin

Ac Ft acre feet

C Rational Method coefficient

C_A Rational Method coefficient for treatment A

C_B Rational Method coefficient for treatment B

C_C Rational Method coefficient for treatment C

C_D Rational Method coefficient for treatment D

cfs cubic feet per second

CN SCS Curve Number

D duration in days

e base of natural logarithm system = 2.71828

E excess precipitation

E_A excess precipitation for treatment A

E_B excess precipitation for treatment B

E_C excess precipitation for treatment C

E_D excess precipitation for treatment D

EA elevation Adjustment factor for PMP_{60}

Elev elevation (feet)

Ft feet

hr hour

I Rational Method intensity (inches/hour)

IA initial abstraction (inches)

INF	infiltration (inches/hour)
K	conveyance factor for SCS Upland Method
k	recession coefficient for HYMO program
K_N	basin factor for lag time equation
K_X	conveyance factor for watershed subreach
k/t_{pA}	k divided by t_p for treatment A
k/t_{pB}	k divided by t_p for treatment B
k/t_{pC}	k divided by t_p for treatment C
k/t_{pD}	k divided by t_p for treatment D
k/t_{P40}	k divided by t_p for 40 acres or smaller area
k/t_{P200}	k divided by t_p for 200 acres or larger area
L	length of subreach (feet)
L_{CA}	distance to centroid of drainage basin (feet)
L_G	lag time (hours)
L_X	length of watershed subreach
In	natural logarithm (base e)
$\log_{10}$	base 10 logarithm
mi^2	square mile(s)
n	Manning’s roughness coefficient
P_{12}	12-minute precipitation
P_{60}	60-minute precipitation at 100-year storm
P_{60-2}	60-minute precipitation at 2-year storm
$P_{60\text{-year}}$	60-minute precipitation at “year” storm
P_{360}	360-minute precipitation at 100-year storm
P_{360-2}	360-minute precipitation at 2-year storm
P_{360-10}	360-minute precipitation at 10-year storm
P_{1440}	1440-minute (24-hr) precipitation, 100-year storm
P_{1440-2}	1440-minute (24-hr) precipitation at 2-year storm
P_D	precipitation for “D”-days duration
P_{N-100}	“n”-minute precipitation at 100-year storm

$P_{N\text{-}YEAR}$	“n”-minute precipitation at “year” storm
P_T	precipitation at any time, t
Q_P	peak discharge (cfs)
Q_{PA}	peak discharge rate (cfs/acre) for treatment A
Q_{PB}	peak discharge rate (cfs/acre) for treatment B
Q_{PC}	peak discharge rate (cfs/acre) for treatment C
Q_{PD}	peak discharge rate (cfs/acre) for treatment D
s	slope of subreach in foot per foot
t	time in minutes
t_B	base time for small watershed hydrograph
t_C	time of concentration (hours)
t_p	time to peak (hours)
v	velocity of flow in watershed (feet/sec)
v_x	velocity of flow in watershed subreach
V_{360}	runoff volume for 360-minute storm
V_{1440}	runoff volume for 1440-minute storm
V_{4days}	runoff volume for 4-day storm
V_{10days}	runoff volume for 10-day storm
y^x	y to the x power
+	addition operator
-	subtraction operator
*	multiplication operator
/	division operator
$\sqrt{\ }$	square root operator

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