CITY OF SAN ANTONIO

TRANSPORTATION & CAPITAL IMPROVEMENTS

JANUARY 2016

STORM WATER DESIGN CRITERIA MANUAL

Revised April 2019

OLMOS DAM

SAN ANTONIO RIVER TUNNEL INLET

SAN ANTONIO RIVER – ESPADA PARK

Table of Contents

FIGURES

TABLES

CHAPTER 1
INTRODUCTION

1.1 PREFACE

The purpose of this Storm Water Design Criteria Manual (SWDCM) is to provide the design engineer with the criteria necessary to design drainage facilities in and around the San Antonio area. This SWDCM establishes the standard principles and practices for the planning, design, construction, maintenance, and management of drainage facilities. It is not the intent of this SWDCM to limit the design capabilities or engineering judgment of the design engineer.

Should an error be found within the manual or changes are needed within a section of the manual, please submit these errors and changes to Director of TCI for consideration and inclusion into the next manual update.

1.2 ACRONYMS AND ABBREVIATIONS

A14	Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 11, Version 2.0: Texas (as published by NOAA)
AASHTO	American Association of State Highway Officials
AC	Asphalt Concrete
ACPA	American Concrete Pipe Association
ADA	Americans with Disabilities Act
AEP	Annual Exceedance Probability
ASTM	American Society for Texting Materials
BFE	Base Flood Elevation
BMP	Best Management Practice
CFR	Code of Federal Regulations
cfs	cubic feet per second
CIP	Capital Improvements Program
CIPP	Cast-in-Place Pipe
City	City of San Antonio
CLOMR	Conditional Letter of Map Revision
CLOMR-F	Conditional Letter of Map Revision – Fill
CMP	Corrugated Metal Pipe
CoSA	City of San Antonio
CRS	Community Rating System
CWA	Clean Water Act
DSD	Development Services Department

EARZ	Edwards Aquifer Recharge Zone
EGL	Energy Grade Line
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FILO	Fee in Lieu of Detention
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
fps	feet per second
Fr	Froude Number
GIS	Geographic Information System
gpm	gallons per minute
HDPE	High Density Polyethylene
HEC-RAS	Hydraulic Engineering Center, River Analysis System
HGL	Hydraulic Grade Line
hp	horsepower
ICL	Inside City Limits
ID	Inside Diameter
ITS	Intelligent Transportation System
Inv.	Invert
JD	Jurisdictional Delineation
LID	Low Impact Development
LOMA	Letter of Map Amendment
LOMR	Letter of Map Revision
LOMR-F	Letter of Map Revision – Fill
MBC	Multi Box Culvert
MDP	Master Development Plan
MCC	Motor Control Center
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Intent
NOT	Notice of Termination
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resource Conservation Service
OD	Outside Diameter
OSHA	Occupational Safety and Health Administration
PCCP	Portland Cement Concrete Pavement
pcf	pounds per cubic foot
PLC	Programmable Logic Controller
PMF	Probable Maximum Flood

PMP	Probable Maximum Precipitation
PMR	Physical Map Revision
PUD	Planned Unit Development
RCBC	Reinforced Concrete Box Culvert
RCP	Reinforced Concrete Pipe
ROW	Right of Way
RSWF	Regional Storm Water Facilities
RSWMP	Regional Storm Water Management Program
SARA	San Antonio River Authority
SAWS	San Antonio Water System
SCS	Soil Conservation Service (changed to NRCS)
SFHA	Special Flood Hazard Area
SWMP	Storm Water Management Plan
TAS	Texas Accessibility Standards
TCI	Transportation & Capital Improvements
TCEQ	Texas Commission on Environmental Quality
TPDES	Texas Pollutant Discharge Elimination System
Typ.	Typical
TxDOT	Texas Department of Transportation
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USDOT	United States Department of Transportation
USFW	United States Fish & Wildlife Agency
USGS	United States Geological Survey
VFD	Variable Frequency Drives
V.T.C.A.	Vernon's Texas Codes Annotated
WOUS	Waters of the United States

CHAPTER 5
HYDROLOGY

5.1 INTRODUCTION

Hydrology is the study of water, its source, distribution, quantity, quality, and movement. For the purpose of this Storm Water Design Criteria Manual (SWDCM), the hydrology guidance will be limited to surface hydrology; the portion of the hydrologic cycle that deals specifically with precipitation, infiltration, and surface runoff.

This chapter describes the specific precipitation data which has been defined by federal and state agencies and regionalized to Bexar County. This chapter will also address infiltration and surface runoff by providing guidance on Methods of Analysis (Chapter 5.3) that range from small local analysis (i.e. Rational Method) to the hydrograph methods as well as guidance on probable maximum precipitation, with equation parameters specific for this region. The selection of these methods will be determined by drainage area size and purpose of the study. The proper application of these methods will generate discharge values that may be used for planning, design, mitigation, or regulation. Other methods of proven engineering use may be used with approval from the Director of TCI or his authorized representative.

5.2 METHOD OF ANALYSIS

5.2.1 Basin Delineation

A watershed or drainage basin is an area that drains storm water runoff to a designated point. Drainage basins are defined by its geographical terrain. The basin delineation is one of the most important parameters in the hydrologic model. When defining the basin boundary the design engineer should use the most recent topography data. In San Antonio and its ETJ, this may include:

- High accuracy LiDAR based contours, as generated by public or private agencies
- On-the-ground topographic survey data
- Historical topography maps, including USGS Quad. maps for pre-developed conditions
- Roadway construction plans
- Aerial Photos
- Underground infrastructure plans

The design engineer should follow standard engineering practice when delineating basin boundaries.

All basin delineation should consider previously defined drainage basins as found by the regions DFIRM data sets, Master Development Plans, or previous approved drainage studies.

While the DFIRM data set was defined for the regions FEMA re-study, errors that may be found should be corrected. These basins can be accessed on-line at the San Antonio River Authority's Digital Data & Modeling Repository website (D2MR, website link may change, please refer to SARA staff for access to system).

Basin delineations defined by computer software should be reviewed carefully. Software including AutoCAD, Microstation, ESRI – GIS, and others have the capability to define basins. These basins are created by source data such as a Digital Elevation Model (DEM), a Triangular Irregular Network (TIN) or Raster grid files. The data set should be detailed enough to define the basin; it may require the use of break lines or fault lines to create certain features. Generally when DEM or Raster is used to generate basin delineation the resulting basin will create jagged or zigzagged basin boundary. The design engineer should verify that this resulting basin has the correct level of accuracy for the individual study.

5.2.2 Selection of Rational or Hydrograph Method

For drainage areas less than 200 hundred (200) acres, the basis for computing runoff shall be the rational formula (as defined in Section 5.3) or some other method provided it is acceptable to the Director of TCI.

For drainage areas 200 hundred (200) acres or greater, the basis for computing runoff shall be a unit hydrograph method (as defined in Section 5.6), preferably the Soil Conservation Service (SCS) Dimensionless Unit Hydrograph method as contained in the U.S. Army Corps of Engineers Hydrologic Engineering Center HEC-HMS "Hydrologic Modeling Systems".

5.2.3 Selection of Method for Detention Ponds

For detention ponds with drainage areas of twenty (20) acres or less, the basis for computing runoff shall be the modified rational method. When the drainage area of a detention pond is greater than twenty (20) acres the unit hydrograph method shall be used. The unit hydrograph method shall be used when multiple detention ponds within a watershed are being modeled, regardless of drainage area, unless approved by the Director of TCI.

5.3 RATIONAL METHOD

The Rational Method is appropriate for estimating peak discharge for small areas up to (200) acres with no significant flood storage. This method provides a peak discharge value but no time-series of flow or flow volume:

(Equation 5.3.1)

$$Q = C\ I\ A$$

Q = Peak Discharge (cfs)
C = Runoff coefficient
I = Average rainfall intensity (in./hr.)
A = Drainage area (acres)

Runoff coefficients (C) may need to be calculated as a weighted runoff coefficient where multiple values are present in one drainage area.

To determine the intensity (I) it is necessary to calculate the Time of Concentration (Tc). This value is used to identify the rainfall intensity found in Figures 5.5.1.A through Figures 5.5.1.E of this manual.

5.4 TIME OF CONCENTRATION

The following methods are recommended for time of concentration calculation:

(Equation 5.4)

$$T_c = T_t + T_{sc} + T_{ch}$$

T_c = Time of Concentration
T_t = Sheet flow over plane surface
T_{sc} = Shallow Concentrated Flow
T_{ch} = Open Channel Flow

5.4.1 Overland Flow

Flow over plane surfaces: Maximum allowable time is twenty (20) minutes. Minimum is five (5) minutes.

- The overland flow time chart from "Design" by Elwyn E. Seelye may be used to calculate overland flow times. Note that the minimum time has been reduced to five (5) minutes.

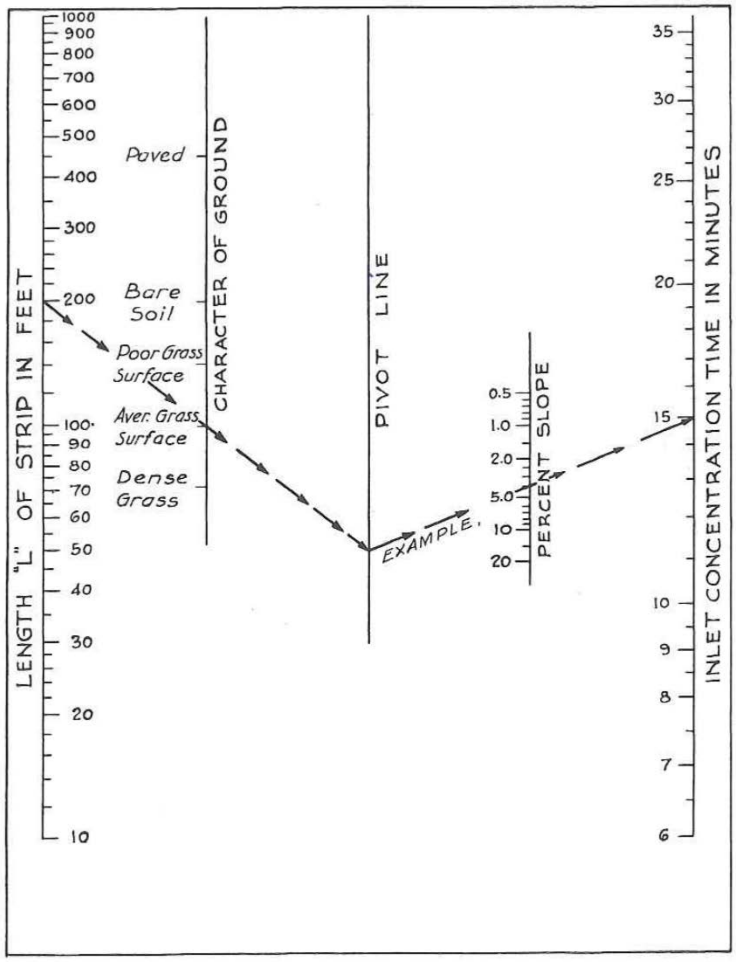


Figure 5.4.1 – Overland Flow Time *(Source: "DESIGN" by Elwyn Seelys Figure. H)*

- TR-55 "Urban Hydrology for Small Watersheds," SCS 1986 may be used, please consider the maximum (20 min.) and minimum (5 min.) when defining the flow length (L).

(Equation 5.4.1)

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} s^{0.4}}$$

T_t = travel time (hr.)
n = Manning's roughness coefficient
L = flow length (ft.)
P_2 = 2-year, 24-hour rainfall*
s = slope of hydraulic grade line (land slope, ft/ft)
*****in San Antonio and its ETJ please use 4.44 inches for the two (2) -year, twenty-four (24)-hour rainfall value

Table 5.4.1 - Roughness Values for sheet flow

Roughness Coefficient (Manning's n) for sheet flow	
Surface Description	n[1]
Smooth surface (concrete, asphalt, gravel or baresoil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses [2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods[3]:	
Light underbrush	0.40
Dense underbrush	0.80

1. The n values are composite of information compiled by Engman (1968)
2. Included species such as weeping lovegrass, bluegrass, bufallo grass, blue gamma grass, and native grass mixtures
3. When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

5.4.2 Shallow Concentrated Flow

Overland flow usually becomes shallow concentrated flow after a maximum of three hundred (300) feet: Use Manning's equation to estimate travel time for defined swales, bar ditches, street sections, etc. or Figure 5.4.2 from TR-55 "Urban Hydrology for Small Watersheds," SCS 1986, may be used where a geometric section has not been defined.

(Equation: 5.4.2)

$$\mathbf{T}_{sc} = \frac{L_{sc}}{3600\ K\ S_{sc}^{0.5}}$$

$\mathbf{T}_{sc}$ = shallow concentrated flow time (hr.)
$\mathbf{L}_{sc}$ **=** shallow concentrated flow length (ft.)
K = 16.13 for unpaved surface; 20.32 for paved surface
$\mathbf{S}_{sc}$ = shallow concentrated flow slope (ft./ft.)

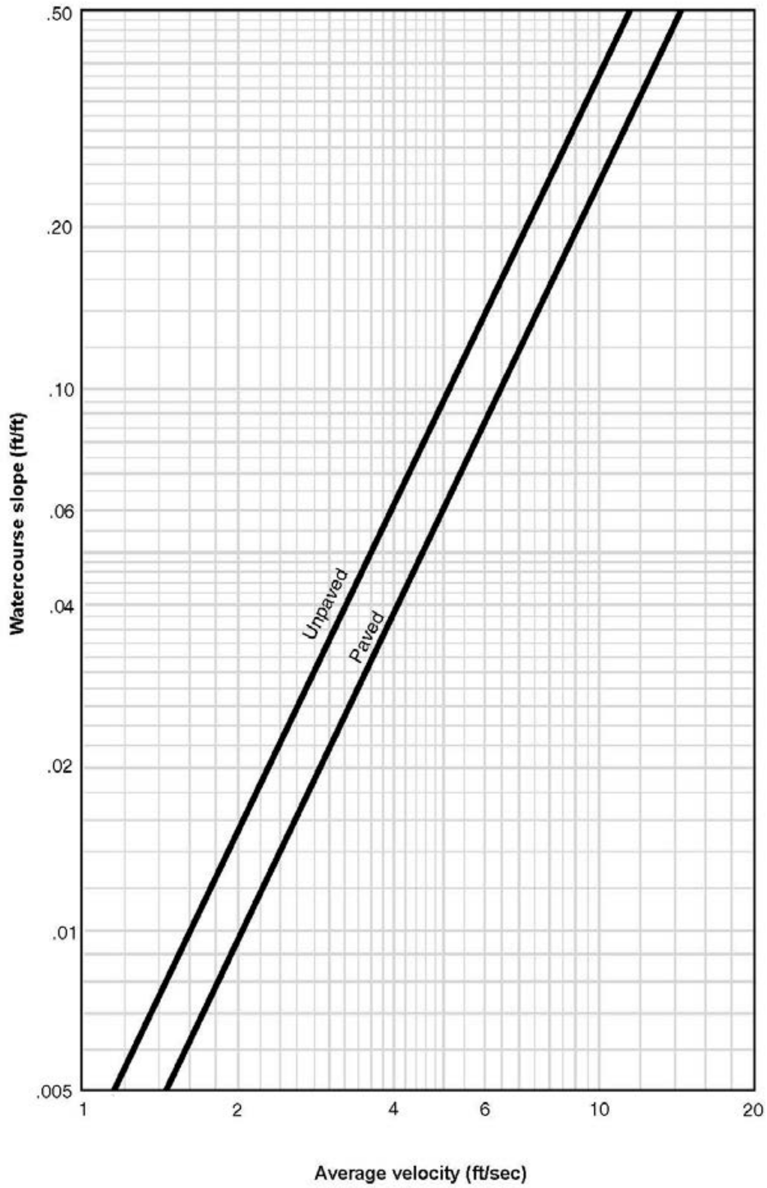


Figure 5.4.2 - Average Velocities for Estimating Travel Time for Shallow Concentrated Flow (Source: NRCS Technical Release 55 – Figure 3-1)

5.4.3 Channel Flow

Use existing computer models where available or Manning's equation if the data is not available. When estimating the time of concentration, non-floodplain channel velocities for ultimate watershed development should not be less than six (6) fps.

(Equation 5.4.3)

$$\mathbf{T}_{ch} = \frac{L_{ch}}{3600\ 1.49/n\ R^{2/3}\ S_{ch}^{\ 1/2}}$$

$\mathbf{T}_{ch}$ = channel flow time (hr.)
$\mathbf{L}_{ch}$ **=** channel flow length (ft.)
$\mathbf{S}_{ch}$ = channel flow slope (ft. /ft.)
n = Manning's roughness coefficient
R = channel hydraulic radius (ft.) and is equal to a/P_w
a = cross sectional area ($ft.^2$)
$\mathbf{P}_{w}$ **=** wetted perimeter (ft.)

5.5 RAINFALL DATA

Rainfall data in this section is based on NOAA Atlas 14, Volume 11 (A14) precipitation frequency estimates. A14 data indicates that precipitation depths vary across the region for each storm frequency. For the purposes of storm water and floodplain design and analysis, the region is broken into five (5) Precipitation Areas (PAs). Figure 5.5 shows the limits of each PA relative to Bexar County, major highways, and major watersheds. Properties within each respective PA will use the corresponding data from Tables 5.5.1.A-E and 5.5.2.1.A-E.

Refer to the San Antonio River Basin (SARB) Regional Modeling Standards for more information on how the A14 precipitation estimates were converted to Intensity-Duration-Frequency (IDF) and Depth-Duration-Frequency (DDF) tables. To complement Figure 5.5, the SARB Regional Modeling Standards indicate which sub-basins, streams, creeks, and tributaries fall within each PA. In the event that it is unclear whether a property or project is in a specific PA, contact the floodplain administrator for determination.

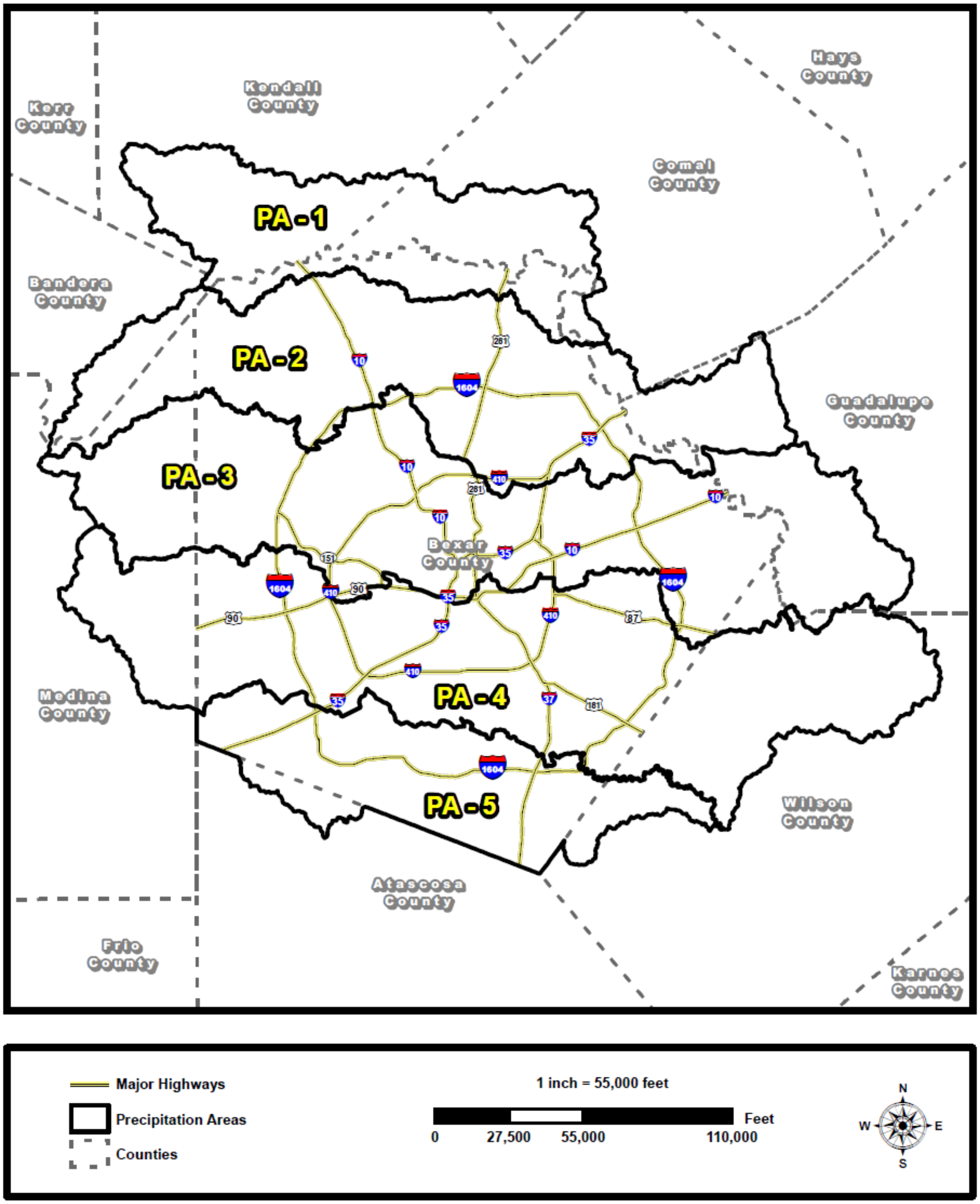


Figure 5.5- Precipitation Area (PA) Map for Major San Antonio River Watersheds *(Precipitation Areas are available in GIS format at https://www.sanantonio.gov/GIS)*

5.5.1 Rainfall Intensity-Duration

Use Tables 5.5.1.A through 5.5.1.E to determine rainfall intensity.

Table 5.5.1.A – Intensity-Duration-Frequency (IDF) Values for PA-1

Time (minutes)	Atlas 14 Rainfall Intensity (inches/hour) by Storm Frequency						
	2-YEAR	5-YEAR	10-YEAR	25-YEAR	50-YEAR	100-YEAR	500-YEAR
5	6.34	7.96	9.31	11.22	12.72	14.26	18.19
6	5.98	7.53	8.81	10.64	12.06	13.53	17.14
7	5.70	7.17	8.40	10.16	11.52	12.91	16.30
8	5.45	6.87	8.05	9.74	11.04	12.37	15.58
9	5.24	6.61	7.73	9.36	10.60	11.88	14.95
10	5.05	6.36	7.44	9.00	10.20	11.43	14.38
11	4.87	6.13	7.17	8.66	9.82	11.00	13.85
12	4.70	5.92	6.91	8.34	9.46	10.59	13.35
13	4.54	5.71	6.67	8.03	9.11	10.19	12.88
14	4.39	5.51	6.43	7.73	8.77	9.81	12.43
15	4.24	5.32	6.20	7.44	8.44	9.43	11.99
16	4.10	5.14	5.99	7.18	8.14	9.10	11.57
17	3.98	4.98	5.80	6.95	7.88	8.80	11.20
18	3.86	4.84	5.63	6.75	7.64	8.53	10.86
19	3.76	4.71	5.47	6.56	7.42	8.29	10.56
20	3.66	4.58	5.33	6.39	7.22	8.07	10.28
21	3.58	4.47	5.20	6.23	7.04	7.86	10.03
22	3.50	4.37	5.08	6.08	6.87	7.67	9.79
23	3.42	4.27	4.96	5.95	6.71	7.50	9.57
24	3.35	4.18	4.86	5.82	6.57	7.34	9.37
25	3.28	4.10	4.76	5.70	6.43	7.19	9.18
26	3.22	4.02	4.67	5.59	6.31	7.04	9.01
27	3.16	3.94	4.58	5.49	6.18	6.91	8.84
28	3.10	3.87	4.49	5.39	6.07	6.78	8.68
29	3.05	3.81	4.42	5.29	5.96	6.66	8.53
30	3.00	3.74	4.34	5.20	5.86	6.55	8.39
31	2.95	3.68	4.27	5.11	5.76	6.44	8.25
32	2.90	3.62	4.20	5.03	5.67	6.33	8.12
33	2.85	3.56	4.13	4.95	5.58	6.23	8.00
34	2.81	3.51	4.07	4.88	5.49	6.14	7.88
35	2.77	3.45	4.01	4.80	5.41	6.05	7.77
36	2.72	3.40	3.95	4.73	5.33	5.96	7.66
37	2.68	3.35	3.89	4.66	5.25	5.87	7.55
38	2.65	3.30	3.83	4.60	5.18	5.79	7.45
39	2.61	3.25	3.78	4.53	5.11	5.71	7.35
40	2.57	3.21	3.73	4.47	5.04	5.63	7.26
41	2.53	3.16	3.68	4.41	4.97	5.56	7.17
42	2.50	3.12	3.63	4.35	4.90	5.48	7.08
43	2.46	3.08	3.58	4.29	4.84	5.41	6.99
44	2.43	3.04	3.53	4.24	4.78	5.34	6.90
45	2.40	3.00	3.48	4.18	4.72	5.28	6.82
46	2.36	2.96	3.44	4.13	4.66	5.21	6.74
47	2.33	2.92	3.39	4.08	4.60	5.15	6.66
48	2.30	2.88	3.35	4.02	4.54	5.08	6.58
49	2.27	2.84	3.31	3.97	4.48	5.02	6.51
50	2.24	2.80	3.27	3.92	4.43	4.96	6.43
51	2.21	2.77	3.22	3.88	4.38	4.90	6.36
52	2.18	2.73	3.18	3.83	4.32	4.84	6.29
53	2.15	2.70	3.14	3.78	4.27	4.79	6.22
54	2.12	2.66	3.11	3.73	4.22	4.73	6.15
55	2.10	2.63	3.07	3.69	4.17	4.68	6.08
56	2.07	2.59	3.03	3.64	4.12	4.62	6.02
57	2.04	2.56	2.99	3.60	4.07	4.57	5.95
58	2.01	2.53	2.95	3.56	4.02	4.51	5.89
59	1.99	2.49	2.92	3.51	3.98	4.46	5.82
60	1.96	2.46	2.88	3.47	3.93	4.41	5.76
120	1.21	1.55	1.85	2.29	2.64	3.03	4.13
180	0.90	1.16	1.40	1.77	2.07	2.41	3.37
360	0.53	0.69	0.85	1.09	1.30	1.54	2.21
720	0.30	0.40	0.50	0.64	0.77	0.92	1.35
1440	0.17	0.23	0.29	0.37	0.45	0.54	0.80

Table 5.5.1.B – Intensity-Duration-Frequency (IDF) Values for PA-2

Time (minutes)	Atlas 14 Rainfall Intensity (inches/hour) by Storm Frequency						
	2-YEAR	5-YEAR	10-YEAR	25-YEAR	50-YEAR	100-YEAR	500-YEAR
5	6.34	7.94	9.29	11.14	12.60	14.01	17.68
6	5.98	7.52	8.80	10.53	11.94	13.30	16.67
7	5.70	7.17	8.39	10.03	11.40	12.69	15.85
8	5.45	6.87	8.04	9.61	10.92	12.16	15.15
9	5.24	6.60	7.73	9.23	10.48	11.68	14.54
10	5.05	6.36	7.44	8.88	10.08	11.23	13.98
11	4.87	6.13	7.17	8.56	9.70	10.81	13.46
12	4.70	5.92	6.91	8.25	9.34	10.41	12.98
13	4.54	5.71	6.67	7.96	8.99	10.02	12.52
14	4.39	5.51	6.43	7.67	8.65	9.64	12.08
15	4.24	5.32	6.20	7.40	8.32	9.27	11.65
16	4.10	5.14	5.99	7.14	8.03	8.94	11.24
17	3.98	4.98	5.79	6.91	7.77	8.64	10.88
18	3.86	4.83	5.62	6.71	7.53	8.38	10.55
19	3.76	4.69	5.46	6.52	7.32	8.14	10.26
20	3.66	4.57	5.32	6.35	7.12	7.92	9.99
21	3.58	4.46	5.19	6.19	6.94	7.72	9.74
22	3.50	4.35	5.06	6.04	6.78	7.53	9.51
23	3.42	4.26	4.95	5.91	6.62	7.36	9.30
24	3.35	4.17	4.84	5.78	6.48	7.20	9.10
25	3.28	4.08	4.74	5.66	6.34	7.05	8.92
26	3.22	4.00	4.65	5.55	6.22	6.91	8.74
27	3.16	3.93	4.56	5.44	6.10	6.78	8.58
28	3.10	3.85	4.48	5.34	5.99	6.65	8.43
29	3.05	3.79	4.40	5.25	5.88	6.53	8.28
30	3.00	3.72	4.32	5.16	5.78	6.42	8.14
31	2.95	3.66	4.25	5.07	5.68	6.31	8.01
32	2.90	3.60	4.18	4.99	5.59	6.21	7.89
33	2.85	3.54	4.11	4.91	5.50	6.11	7.77
34	2.81	3.49	4.05	4.84	5.42	6.02	7.65
35	2.77	3.43	3.99	4.76	5.34	5.93	7.54
36	2.72	3.38	3.93	4.69	5.26	5.84	7.43
37	2.68	3.33	3.87	4.63	5.18	5.76	7.33
38	2.64	3.28	3.81	4.56	5.11	5.68	7.23
39	2.61	3.24	3.76	4.50	5.04	5.60	7.14
40	2.57	3.19	3.71	4.43	4.97	5.52	7.04
41	2.53	3.14	3.65	4.37	4.90	5.45	6.95
42	2.50	3.10	3.60	4.31	4.83	5.38	6.87
43	2.46	3.06	3.56	4.26	4.77	5.31	6.78
44	2.43	3.02	3.51	4.20	4.71	5.24	6.70
45	2.40	2.98	3.46	4.15	4.65	5.17	6.62
46	2.36	2.94	3.42	4.09	4.59	5.11	6.54
47	2.33	2.90	3.37	4.04	4.53	5.04	6.46
48	2.30	2.86	3.33	3.99	4.48	4.98	6.39
49	2.27	2.82	3.29	3.94	4.42	4.92	6.31
50	2.24	2.79	3.24	3.89	4.37	4.86	6.24
51	2.21	2.75	3.20	3.84	4.31	4.80	6.17
52	2.18	2.72	3.16	3.79	4.26	4.75	6.10
53	2.15	2.68	3.12	3.75	4.21	4.69	6.03
54	2.12	2.65	3.08	3.70	4.16	4.64	5.97
55	2.09	2.61	3.05	3.66	4.11	4.58	5.90
56	2.06	2.58	3.01	3.61	4.06	4.53	5.84
57	2.04	2.55	2.97	3.57	4.01	4.48	5.77
58	2.01	2.51	2.93	3.53	3.96	4.42	5.71
59	1.98	2.48	2.90	3.48	3.92	4.37	5.65
60	1.96	2.45	2.86	3.44	3.87	4.32	5.59
120	1.21	1.54	1.84	2.26	2.60	2.98	4.02
180	0.89	1.15	1.39	1.75	2.04	2.37	3.28
360	0.52	0.69	0.84	1.07	1.28	1.51	2.15
720	0.30	0.40	0.49	0.63	0.76	0.90	1.31
1440	0.17	0.23	0.28	0.36	0.44	0.52	0.77

Table 5.5.1.C – Intensity-Duration-Frequency (IDF) Values for PA-3

Time (minutes)	Atlas 14 Rainfall Intensity (inches/hour) by Storm Frequency						
	2-YEAR	5-YEAR	10-YEAR	25-YEAR	50-YEAR	100-YEAR	500-YEAR
5	6.30	7.88	9.20	11.00	12.36	13.79	17.20
6	5.95	7.45	8.73	10.43	11.75	13.08	16.21
7	5.66	7.11	8.33	9.95	11.24	12.49	15.41
8	5.42	6.81	7.98	9.54	10.78	11.97	14.74
9	5.21	6.54	7.67	9.17	10.35	11.49	14.14
10	5.02	6.30	7.38	8.82	9.96	11.05	13.60
11	4.85	6.08	7.11	8.50	9.58	10.64	13.10
12	4.68	5.86	6.85	8.19	9.22	10.24	12.62
13	4.53	5.66	6.60	7.89	8.87	9.85	12.17
14	4.38	5.47	6.36	7.60	8.53	9.48	11.74
15	4.24	5.28	6.12	7.32	8.20	9.12	11.33
16	4.10	5.10	5.91	7.07	7.91	8.79	10.93
17	3.97	4.94	5.72	6.84	7.66	8.50	10.58
18	3.86	4.80	5.55	6.63	7.42	8.24	10.26
19	3.75	4.66	5.40	6.45	7.21	8.00	9.97
20	3.66	4.54	5.26	6.28	7.02	7.79	9.71
21	3.57	4.43	5.13	6.12	6.84	7.59	9.46
22	3.49	4.33	5.01	5.98	6.68	7.41	9.24
23	3.41	4.23	4.90	5.84	6.53	7.24	9.04
24	3.34	4.14	4.79	5.72	6.39	7.08	8.84
25	3.27	4.06	4.70	5.60	6.26	6.93	8.66
26	3.21	3.98	4.60	5.49	6.13	6.80	8.50
27	3.15	3.90	4.52	5.38	6.02	6.66	8.34
28	3.09	3.83	4.43	5.28	5.91	6.54	8.19
29	3.04	3.76	4.35	5.19	5.80	6.42	8.04
30	2.98	3.70	4.28	5.10	5.70	6.31	7.91
31	2.93	3.64	4.21	5.01	5.60	6.21	7.78
32	2.89	3.58	4.14	4.93	5.51	6.11	7.66
33	2.84	3.52	4.07	4.85	5.43	6.01	7.54
34	2.79	3.47	4.01	4.78	5.34	5.92	7.43
35	2.75	3.41	3.95	4.71	5.26	5.83	7.32
36	2.71	3.36	3.89	4.64	5.18	5.74	7.22
37	2.67	3.31	3.83	4.57	5.11	5.66	7.12
38	2.63	3.26	3.78	4.50	5.04	5.58	7.02
39	2.59	3.22	3.72	4.44	4.97	5.50	6.93
40	2.55	3.17	3.67	4.38	4.90	5.43	6.84
41	2.52	3.13	3.62	4.32	4.83	5.35	6.75
42	2.48	3.08	3.57	4.26	4.77	5.28	6.66
43	2.45	3.04	3.52	4.20	4.70	5.21	6.58
44	2.41	3.00	3.48	4.15	4.64	5.15	6.50
45	2.38	2.96	3.43	4.09	4.58	5.08	6.42
46	2.35	2.92	3.39	4.04	4.52	5.02	6.35
47	2.32	2.88	3.34	3.99	4.47	4.96	6.27
48	2.28	2.84	3.30	3.94	4.41	4.89	6.20
49	2.25	2.81	3.26	3.89	4.36	4.83	6.13
50	2.22	2.77	3.21	3.84	4.30	4.78	6.06
51	2.19	2.73	3.17	3.79	4.25	4.72	5.99
52	2.16	2.70	3.13	3.74	4.20	4.66	5.92
53	2.13	2.66	3.09	3.70	4.15	4.61	5.85
54	2.11	2.63	3.05	3.65	4.10	4.55	5.79
55	2.08	2.59	3.02	3.61	4.05	4.50	5.72
56	2.05	2.56	2.98	3.56	4.00	4.45	5.66
57	2.02	2.53	2.94	3.52	3.95	4.39	5.60
58	1.99	2.49	2.90	3.47	3.90	4.34	5.54
59	1.97	2.46	2.87	3.43	3.86	4.29	5.48
60	1.94	2.43	2.83	3.39	3.81	4.24	5.42
120	1.19	1.52	1.81	2.22	2.55	2.90	3.88
180	0.88	1.14	1.37	1.71	1.99	2.30	3.15
360	0.51	0.67	0.82	1.05	1.24	1.46	2.06
720	0.29	0.39	0.48	0.61	0.73	0.86	1.25
1440	0.17	0.22	0.27	0.35	0.42	0.50	0.73

Table 5.5.1.D – Intensity-Duration-Frequency (IDF) Values for PA-4

Time (minutes)	Atlas 14 Rainfall Intensity (inches/hour) by Storm Frequency						
	2-YEAR	5-YEAR	10-YEAR	25-YEAR	50-YEAR	100-YEAR	500-YEAR
5	6.30	7.85	9.14	10.92	12.24	13.65	16.83
6	5.94	7.40	8.66	10.36	11.62	12.96	15.87
7	5.66	7.05	8.26	9.89	11.11	12.37	15.09
8	5.42	6.75	7.92	9.48	10.65	11.85	14.43
9	5.21	6.48	7.61	9.11	10.23	11.38	13.84
10	5.02	6.24	7.32	8.76	9.84	10.95	13.31
11	4.84	6.02	7.05	8.43	9.47	10.54	12.82
12	4.68	5.81	6.79	8.12	9.12	10.14	12.36
13	4.53	5.61	6.55	7.82	8.78	9.76	11.92
14	4.38	5.42	6.31	7.53	8.44	9.39	11.49
15	4.24	5.24	6.08	7.24	8.12	9.03	11.09
16	4.10	5.06	5.87	6.99	7.84	8.71	10.70
17	3.97	4.91	5.68	6.76	7.58	8.42	10.35
18	3.86	4.76	5.51	6.56	7.35	8.16	10.04
19	3.75	4.63	5.36	6.37	7.14	7.93	9.75
20	3.65	4.51	5.22	6.21	6.95	7.71	9.50
21	3.57	4.40	5.09	6.05	6.78	7.52	9.26
22	3.48	4.30	4.97	5.91	6.61	7.34	9.04
23	3.41	4.21	4.86	5.77	6.46	7.17	8.84
24	3.33	4.12	4.75	5.65	6.32	7.01	8.65
25	3.27	4.04	4.65	5.53	6.19	6.86	8.47
26	3.20	3.96	4.56	5.42	6.07	6.73	8.31
27	3.14	3.88	4.48	5.32	5.95	6.60	8.15
28	3.08	3.81	4.39	5.22	5.84	6.48	8.00
29	3.03	3.74	4.31	5.13	5.74	6.36	7.87
30	2.98	3.68	4.24	5.04	5.64	6.25	7.73
31	2.93	3.62	4.17	4.96	5.55	6.14	7.61
32	2.88	3.56	4.10	4.87	5.45	6.04	7.49
33	2.83	3.50	4.03	4.80	5.37	5.95	7.37
34	2.79	3.45	3.97	4.72	5.28	5.86	7.26
35	2.74	3.39	3.91	4.65	5.20	5.77	7.16
36	2.70	3.34	3.85	4.58	5.13	5.68	7.05
37	2.66	3.29	3.80	4.51	5.05	5.60	6.96
38	2.62	3.25	3.74	4.45	4.98	5.52	6.86
39	2.58	3.20	3.69	4.39	4.91	5.44	6.77
40	2.55	3.15	3.64	4.33	4.84	5.37	6.68
41	2.51	3.11	3.59	4.27	4.78	5.30	6.59
42	2.47	3.07	3.54	4.21	4.71	5.23	6.51
43	2.44	3.02	3.49	4.15	4.65	5.16	6.43
44	2.40	2.98	3.44	4.10	4.59	5.09	6.35
45	2.37	2.94	3.40	4.04	4.53	5.02	6.27
46	2.34	2.90	3.35	3.99	4.47	4.96	6.20
47	2.31	2.86	3.31	3.94	4.41	4.90	6.12
48	2.27	2.83	3.26	3.89	4.36	4.84	6.05
49	2.24	2.79	3.22	3.84	4.30	4.78	5.98
50	2.21	2.75	3.18	3.79	4.25	4.72	5.91
51	2.18	2.71	3.14	3.75	4.20	4.66	5.84
52	2.15	2.68	3.10	3.70	4.15	4.61	5.78
53	2.12	2.64	3.06	3.65	4.09	4.55	5.71
54	2.10	2.61	3.02	3.61	4.04	4.50	5.65
55	2.07	2.57	2.98	3.56	4.00	4.44	5.58
56	2.04	2.54	2.95	3.52	3.95	4.39	5.52
57	2.01	2.51	2.91	3.48	3.90	4.34	5.46
58	1.98	2.47	2.87	3.43	3.85	4.29	5.40
59	1.96	2.44	2.84	3.39	3.81	4.24	5.34
60	1.93	2.41	2.80	3.35	3.76	4.19	5.28
120	1.18	1.51	1.79	2.19	2.51	2.85	3.76
180	0.87	1.13	1.36	1.69	1.95	2.25	3.05
360	0.51	0.67	0.81	1.03	1.21	1.41	1.98
720	0.29	0.38	0.47	0.60	0.71	0.83	1.19
1440	0.16	0.22	0.27	0.34	0.41	0.48	0.70

Table 5.5.1.E – Intensity-Duration-Frequency (IDF) Values for PA-5

Time (minutes)	Atlas 14 Rainfall Intensity (inches/hour) by Storm Frequency						
	2-YEAR	5-YEAR	10-YEAR	25-YEAR	50-YEAR	100-YEAR	500-YEAR
5	6.31	7.85	9.13	10.90	12.24	13.65	16.65
6	5.96	7.41	8.66	10.32	11.62	12.95	15.70
7	5.67	7.06	8.27	9.84	11.11	12.37	14.93
8	5.43	6.76	7.93	9.42	10.65	11.85	14.27
9	5.22	6.49	7.61	9.05	10.23	11.38	13.69
10	5.03	6.24	7.32	8.70	9.84	10.95	13.17
11	4.85	6.01	7.04	8.37	9.47	10.53	12.68
12	4.69	5.80	6.78	8.07	9.12	10.14	12.23
13	4.53	5.59	6.53	7.77	8.78	9.76	11.79
14	4.38	5.39	6.28	7.48	8.44	9.39	11.38
15	4.24	5.20	6.04	7.20	8.12	9.03	10.97
16	4.10	5.03	5.83	6.95	7.84	8.71	10.59
17	3.97	4.87	5.65	6.73	7.58	8.42	10.24
18	3.85	4.73	5.48	6.53	7.35	8.16	9.94
19	3.75	4.60	5.33	6.34	7.14	7.93	9.65
20	3.65	4.48	5.19	6.18	6.95	7.71	9.40
21	3.56	4.38	5.06	6.02	6.78	7.52	9.16
22	3.48	4.28	4.94	5.88	6.61	7.34	8.95
23	3.40	4.18	4.83	5.75	6.46	7.17	8.75
24	3.33	4.09	4.73	5.62	6.32	7.01	8.56
25	3.26	4.01	4.63	5.51	6.19	6.86	8.39
26	3.20	3.93	4.54	5.40	6.07	6.73	8.22
27	3.14	3.86	4.45	5.30	5.95	6.60	8.07
28	3.08	3.79	4.37	5.20	5.84	6.47	7.92
29	3.03	3.72	4.29	5.11	5.74	6.36	7.78
30	2.97	3.66	4.22	5.02	5.64	6.25	7.65
31	2.92	3.60	4.15	4.94	5.55	6.14	7.53
32	2.88	3.54	4.08	4.86	5.45	6.04	7.41
33	2.83	3.48	4.02	4.78	5.37	5.95	7.30
34	2.78	3.43	3.95	4.70	5.28	5.85	7.19
35	2.74	3.38	3.89	4.63	5.20	5.77	7.08
36	2.70	3.33	3.84	4.56	5.13	5.68	6.98
37	2.66	3.28	3.78	4.50	5.05	5.60	6.88
38	2.62	3.23	3.73	4.43	4.98	5.52	6.79
39	2.58	3.18	3.67	4.37	4.91	5.44	6.70
40	2.54	3.14	3.62	4.31	4.84	5.37	6.61
41	2.51	3.09	3.57	4.25	4.78	5.29	6.52
42	2.47	3.05	3.52	4.19	4.71	5.22	6.44
43	2.44	3.01	3.48	4.14	4.65	5.15	6.36
44	2.40	2.97	3.43	4.08	4.59	5.09	6.28
45	2.37	2.93	3.38	4.03	4.53	5.02	6.20
46	2.34	2.89	3.34	3.98	4.47	4.96	6.13
47	2.30	2.85	3.30	3.93	4.41	4.89	6.05
48	2.27	2.81	3.25	3.88	4.36	4.83	5.98
49	2.24	2.78	3.21	3.83	4.30	4.77	5.91
50	2.21	2.74	3.17	3.78	4.25	4.71	5.84
51	2.18	2.70	3.13	3.73	4.20	4.66	5.78
52	2.15	2.67	3.09	3.69	4.15	4.60	5.71
53	2.12	2.63	3.05	3.64	4.09	4.54	5.65
54	2.09	2.60	3.01	3.60	4.04	4.49	5.58
55	2.07	2.56	2.98	3.55	4.00	4.44	5.52
56	2.04	2.53	2.94	3.51	3.95	4.38	5.46
57	2.01	2.50	2.90	3.47	3.90	4.33	5.40
58	1.98	2.46	2.87	3.42	3.85	4.28	5.34
59	1.96	2.43	2.83	3.38	3.81	4.23	5.28
60	1.93	2.40	2.80	3.34	3.76	4.18	5.22
120	1.18	1.51	1.79	2.18	2.50	2.83	3.70
180	0.87	1.12	1.35	1.68	1.94	2.23	3.00
360	0.51	0.66	0.81	1.02	1.20	1.39	1.93
720	0.29	0.38	0.46	0.59	0.69	0.81	1.15
1440	0.16	0.21	0.26	0.33	0.40	0.46	0.66

5.5.2 Rainfall Depth-Duration-Frequency

5.5.2.1 Design Rainfall

For the Design Rainfall, a twenty-four (24) hour rainfall distribution shall be applied for hydrograph based runoff calculations. Table 5.5.2.1 relates storm frequency terminology to annual exceedance probability. Rainfall intensities as adopted for the City of San Antonio are given in Tables 5.5.2.1.A through 5.5.2.1.E.

Refer to the SARB Regional Modeling Standards for more information related to rainfall distribution and hyetographs.

Table 5.5.2.1 – Design Storm Frequency vs. Annual Exceedance Probability (AEP)

	Design Storm Frequency							
	1-year	**2-year**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**	**500-year**
AEP	1.0	0.5	0.2	0.1	0.04	0.02	0.01	0.002

Table 5.5.2.1.A – Depth-Duration-Frequency (DDF) Values for PA-1

Atlas 14, Volume 11 Adjusted Rainfall Values (pre-areal reduction)								
Duration	**Design Storm Depth (inches) by Storm Frequency**							
	1-year	2-year	5-year	10-year	25-year	50-year	100-year	500-year
5 minute	0.45	0.53	0.66	0.78	0.94	1.06	1.19	1.52
10 minute	0.71	0.84	1.06	1.24	1.50	1.70	1.90	2.40
15 minute	0.90	1.06	1.33	1.55	1.86	2.11	2.36	3.00
30 minute	1.27	1.50	1.87	2.17	2.60	2.93	3.27	4.19
1 hour	1.65	1.96	2.46	2.88	3.47	3.93	4.41	5.76
2 hour	1.98	2.42	3.09	3.69	4.57	5.28	6.07	8.26
3 hour	2.15	2.69	3.48	4.21	5.30	6.21	7.24	10.10
6 hour	2.46	3.16	4.15	5.09	6.54	7.80	9.23	13.26
12 hour	2.78	3.62	4.80	5.94	7.70	9.25	11.02	16.23
24 hour	3.11	4.10	5.49	6.85	8.93	10.76	12.88	19.12

Table 5.5.2.1.B – Depth-Duration-Frequency (DDF) Values for PA-2

Atlas 14, Volume 11 Adjusted Rainfall Values (pre-areal reduction)								
Duration	**Design Storm Depth (inches) by Storm Frequency**							
	1-year	2-year	5-year	10-year	25-year	50-year	100-year	500-year
5 minute	0.45	0.53	0.66	0.77	0.93	1.05	1.17	1.47
10 minute	0.71	0.84	1.06	1.24	1.48	1.68	1.87	2.33
15 minute	0.90	1.06	1.33	1.55	1.85	2.08	2.32	2.91
30 minute	1.28	1.50	1.86	2.16	2.58	2.89	3.21	4.07
1 hour	1.65	1.96	2.45	2.86	3.44	3.87	4.32	5.59
2 hour	1.97	2.41	3.08	3.67	4.52	5.20	5.95	8.03
3 hour	2.14	2.67	3.46	4.18	5.24	6.12	7.10	9.84
6 hour	2.44	3.13	4.11	5.05	6.45	7.66	9.04	12.90
12 hour	2.76	3.58	4.75	5.87	7.58	9.06	10.76	15.73
24 hour	3.10	4.04	5.44	6.76	8.74	10.45	12.47	18.45

Table 5.5.2.1.C – Depth-Duration-Frequency (DDF) Values for PA-3

Atlas 14, Volume 11 Adjusted Rainfall Values (pre-areal reduction)								
Duration	**Design Storm Depth (inches) by Storm Frequency**							
	1-year	2-year	5-year	10-year	25-year	50-year	100-year	500-year
5 minute	0.45	0.53	0.66	0.77	0.92	1.03	1.15	1.43
10 minute	0.71	0.84	1.05	1.23	1.47	1.66	1.84	2.27
15 minute	0.90	1.06	1.32	1.53	1.83	2.05	2.28	2.83
30 minute	1.28	1.49	1.85	2.14	2.55	2.85	3.16	3.96
1 hour	1.64	1.94	2.43	2.83	3.39	3.81	4.24	5.42
2 hour	1.96	2.38	3.04	3.62	4.44	5.10	5.81	7.75
3 hour	2.12	2.64	3.43	4.11	5.14	5.98	6.91	9.46
6 hour	2.42	3.08	4.05	4.95	6.31	7.45	8.74	12.36
12 hour	2.73	3.53	4.66	5.73	7.36	8.76	10.36	14.99
24 hour	3.07	3.96	5.31	6.56	8.46	10.06	12.00	17.51

Table 5.5.2.1.D – Depth-Duration-Frequency (DDF) Values for PA-4

Atlas 14, Volume 11 Adjusted Rainfall Values (pre-areal reduction)								
Duration	**Design Storm Depth (inches) by Storm Frequency**							
	1-year	2-year	5-year	10-year	25-year	50-year	100-year	500-year
5 minute	0.45	0.53	0.65	0.76	0.91	1.02	1.14	1.40
10 minute	0.71	0.84	1.04	1.22	1.46	1.64	1.82	2.22
15 minute	0.91	1.06	1.31	1.52	1.81	2.03	2.26	2.77
30 minute	1.28	1.49	1.84	2.12	2.52	2.82	3.12	3.87
1 hour	1.64	1.93	2.41	2.80	3.35	3.76	4.19	5.28
2 hour	1.95	2.37	3.02	3.58	4.38	5.02	5.70	7.51
3 hour	2.12	2.62	3.38	4.07	5.06	5.86	6.75	9.14
6 hour	2.41	3.05	4.01	4.88	6.18	7.27	8.49	11.87
12 hour	2.70	3.47	4.57	5.61	7.18	8.49	10.00	14.33
24 hour	3.02	3.91	5.16	6.40	8.20	9.75	11.49	16.70

Table 5.5.2.1.E – Depth-Duration-Frequency (DDF) Values for PA-5

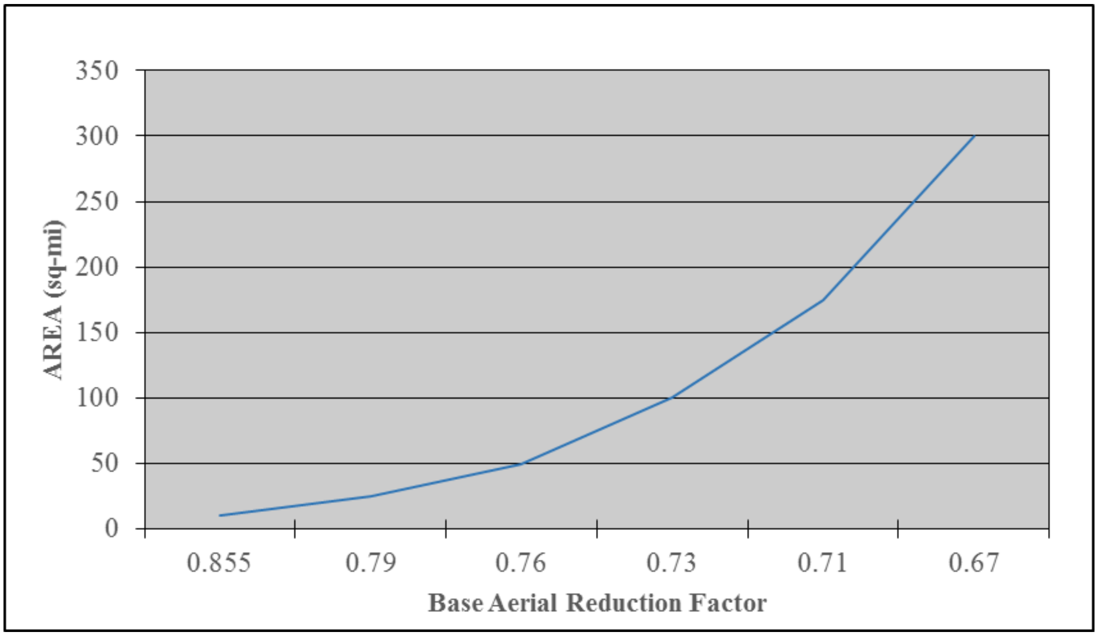
Atlas 14, Volume 11 Adjusted Rainfall Values (pre-areal reduction)								
Duration	**Design Storm Depth (inches) by Storm Frequency**							
	1-year	2-year	5-year	10-year	25-year	50-year	100-year	500-year
5 minute	0.45	0.53	0.65	0.76	0.91	1.02	1.14	1.39
10 minute	0.71	0.84	1.04	1.22	1.45	1.64	1.82	2.19
15 minute	0.91	1.06	1.30	1.51	1.80	2.03	2.26	2.74
30 minute	1.28	1.49	1.83	2.11	2.51	2.82	3.12	3.83
1 hour	1.64	1.93	2.40	2.80	3.34	3.76	4.18	5.22
2 hour	1.95	2.36	3.01	3.57	4.36	4.99	5.67	7.41
3 hour	2.12	2.61	3.37	4.05	5.03	5.82	6.69	8.99
6 hour	2.41	3.04	3.98	4.85	6.12	7.18	8.36	11.60
12 hour	2.70	3.44	4.53	5.53	7.06	8.31	9.75	13.83
24 hour	3.01	3.86	5.12	6.25	8.02	9.50	11.14	15.94

5.5.2.2 Areal Reduction Factor

Calculated storm water runoff at a given point may be reduced by factors shown in Table 5.5.2.2 based on the tributary area (in square miles) draining to said point.

Table 5.2.2.2 - Areal Reduction Factors

Areal Reduction Factors (for use in calculating Point Rainfall for Bexar County)**	
Area (sq mi)	Base ARF for Area
10	0.855
25	0.79
50	0.76
100	0.73
175	0.71
300	0.67
*****Source: San Antonio River Basin Regional Modeling Standards, on file with the San Antonio River Authority***	



5.5.3 Runoff Coefficient

Runoff coefficients (C value) for use in the rational formula shall not be less than the values shown in Table 5.5.3A, as appropriate

Table 5.5.3A - Runoff Coefficient (C value) - percentage

Character of Area	**SLOPE**			
	Up to 1%	Over 1% up to 3%	Over 3% up to 5%	Over 5%
Business or commercial areas (90% or more impervious), Existing Pavement / Buildings or Zoning Districts O, C, I-1, I-2	95	96	97	97
Densely developed areas (80% to 90% impervious) or Zoning Districts D, MX, NC, TOD, Use Pattern TND	85	88	91	95
Closely built residential areas and school sites or Zoning Districts MF, R-4	75	77	80	84
Undeveloped areas * - Present land is undeveloped and ultimate land use is unknown. C values for use in ultimate development calculations.	68	70	72	75
Large lot residential area or Zoning Districts R20, RE	55	57	62	64
Undeveloped areas * - Existing conditions.				
Average residential area or Zoning Districts R-5, R-6	65	67	69	72
Cultivated or Range (Grass Cover < 50% of Area)	44	47	53	55
Range (Grass Cover 50—75% of Area)	37	41	49	53
Forest or Range (Grass Cover > 75% of Area)	35	39	47	52

**Areas included within parks, green belts, or regulatory floodplains shall be considered to remain undeveloped per this table*

5.6 Hydrograph Method

5.6.1 Sub-Basin

5.6.1.1 Loss Method

5.6.1.1.1 SCS Curve Number Loss

The SCS curve numbers adopted for use by the City of San Antonio are shown in Table 5.6.1.1.1.1. The hydrologic soil groups are listed in the latest version of the United States Natural Resources Conservation Service [formerly the Soil Conservation Service], "Urban Hydrology for Small Watersheds," Technical Release No. 55 (TR 55); this document is hereby incorporated by this reference. Soil types that relate to the hydrologic soil group may be found in the latest version of the United States Natural Resources Conservation Service "Soil Survey-Bexar County, Texas;" this document is hereby incorporated by this reference. Soil types may also be based on a Geotechnical Engineering Report.

Table 5.6.1.1.1.1 - SCS Curve Number by Soil Type

Cover Description	Hydrologic Condition	Curve Number (CN) for Hydrologic Soil Group			
		A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, etc.)	Good	39	61	74	80
Meadow (continuous grass, protected from grazing and generally mowed for hay)		30	58	71	78
Brush (brush-weed-grass mixture with brush the major element)	Good	30	48	65	73
Woods	Good	30	55	70	77

Table 5.6.1.1.1.2 - Percent Impervious Cover by Land Use

Land Use Category		Average Percent Impervious Cover
Residential	1/8 acre Residential Lots, or Garden or townhouse apartments, or Zoning Districts R-4, R-5, RM-4, RM-5; TND/TOD Use Patterns	65—85
	¼ acre Residential Lots or Zoning District R-6, RM-6	38
	1/3 acre Residential Lots or Zoning District R-15	30
	½ acre Residential Lots or Zoning Districts R-20	25
	1 acre Residential Lots or Zoning Districts RP, RE	20
Industrial or Zoning Districts L, I-1, I-2		72—85
Business or Commercial, or Zoning Districts NC, O, C		85—95
Densely developed (apartments), or Zoning Districts MF		65—85
Streets, Roads, and Parking Areas		98

5.6.1.2 Transform Method

5.6.1.2.1 SCS Unit Hydrograph

A method developed by the Natural Resource Conservation Service (formally known as the Soil Conservation Service) for constructing unit hydrographs. This method is based on empirical data from small agriculture watersheds across the United States. For the SCS method, antecedent moisture condition II shall be used in the runoff model. Design rainfall values listed in Table 5.5.2.1 shall be used for hydrograph calculations. The method requires the determination of the SCS lag time and time to peak, the peak discharge is calculated by the following equation:

(Equation 5.6.1.2a)

$$\mathbf{Q}_p = \frac{484\ A}{t_p}$$

$\mathbf{Q}_p$ = peak discharge (cfs.)
A = drainage area (mi.^{2})
$\mathbf{t_p}$ = time to peak (hr.)

(Equation 5.6.1.2b)

$$\mathbf{t}_p = \frac{\Delta \mathbf{t}}{2} + \mathbf{t}_{lag}$$

$\mathbf{t_p}$ = time to peak (hr.)
$\Delta\mathbf{t}$ **=** the duration of rainfall (hr.) = 0.133 $\mathbf{t}_c$
$\mathbf{t_{lag}}$ = lag time from the centroid of rainfall to peak discharge, estimated at 0.6 $\mathbf{t}_c$ (hr.)

Table 5.6.1.2.1 – SCS Dimensionless Unit Coordinates

Coordinates of SCS Dimensionless unit hydrograph			
t/t_p	Q/Q_p	t/t_p	Q/Q_p
0	0	1.4	0.750
0.1	0.015	1.5	0.660
0.2	0.075	1.6	0.560
0.3	0.160	1.8	0.420
0.4	0.280	2.0	0.320
0.5	0.430	2.2	0.240
0.6	0.600	2.4	0.180
0.7	0.770	2.6	0.130
0.8	0.890	2.8	0.098
0.9	0.970	3.0	0.075
1.0	1.000	3.5	0.036
1.1	0.980	4.0	0.018
1.2	0.920	4.5	0.009
1.3	0.840	5.0	0.004

5.6.1.2.2 Snyder Unit Hydrograph

The Synder Unit Hydrograph is a method developed from analysis of ungauged watersheds in the Appalachian Highlands in the United States. Required parameters are the standard lag (hr.) and the peaking coefficient.

(Equation 5.6.1.2.2a)

$$\mathbf{Q}_p = \frac{640\ C_p\ A}{t_{lag}}$$

$\mathbf{Q_p}$ = Snyder peak discharge (cfs.)
$\mathbf{C_p}$ = peaking coefficient; range from 0.5 – 0.9
A = Drainage Area (mi.^{2})
$\mathbf{t_{lag}}$ = Snyder lag time (hr.)

(Equation 5.6.1.2.2b)

$$\boldsymbol{T_{lag} = C_t\left(\frac{LL_{ca}}{\sqrt{S}}\right)^{0.33}}$$

$\mathbf{T_{lag}}$ = Snyder lag time (hr.)
$\mathbf{C_t}$ = basin coefficient based on the level of development in the watershed
L = length of the main stream from the outlet to the watershed divide
$\mathbf{L_{ca}}$ = length of the centroid along the flow path
S = Slope of the longest path (L)

(Equation 5.6.1.2.2c)

$$C_t = 1.4224e^{-0.0088x}$$

x = the percentage of development

Note:Typically C_t range for this area is 1.1 to 1.4.

5.6.1.2.3 Clark Unit Hydrograph

The Clark Unit Hydrograph is derived by two major parameters; the translation or movement of runoff and the attenuation or reduction of runoff as it moves through the watershed. These two parameters are defined at its basis with the following equation:

(Equation: 5.6.1.2.3)

$$\frac{dS}{dt} = I_t - O_t$$

$\frac{dS}{dt}$ = time rate of change in storage at time ($_t$)
I_t = average inflow at time ($_t$)
O_t = outflow from storage at time ($_t$)

To use this method in HEC-HMS the parameters of translation and attenuation are defined by the watersheds time of concentration (t_c) and Basin Storage coefficient (R).

- **The Translation** is derived by the time of concentration (t_c), and is defined by Equation 5.4 in this manual, the TR-55 method of calculation. The t_c is provided as a unit of time in hours (hr.)
- **The Attenuation** is the Basin Storage coefficient (R), a measure of the storage within the individual watershed. The larger the R value, the larger the attenuation. This value can be defined by calibration. R is given as a unit of time (hr.)

5.6.1.3 Baseflow Method

5.6.1.3.1 None

For a majority of the perennial streams in San Antonio and its ETJ, the hydrology models will not account for any base flow condition. It is recommended that the design engineer visit the study stream to observe average conditions.

5.6.1.3.2 Constant Monthly Baseflow

As defined in the HEC-HMS technical Manual of March 2000 "[the base flow parameter is] best estimated empirically, with measurements of channel flow when storm runoff is not occurring. In the absence of such records, field observation may help establish the average flow…for most urban channels and for smaller streams in the western and southwestern US, the baseflow contribution may be negligible."

5.6.2 Reach – Routing

Routing of the runoff hydrograph through the channel from one (1) subarea calculation point to the next in the HEC-HMS shall be computed using one (1) of the methods listed below.

Channel routing methodologies that are currently being applied in the existing HEC-HMS model of the watershed shall not be replaced with a different methodology without approval or direction from the Director of TCI.

For use in routing methods, Manning's roughness coefficients ("N" values) shall be consistent with the values listed in Table 9.2.4.1

(Equation: 5.6.2)

$$I - O = \frac{dS}{dt}$$

$\frac{dS}{dt}$ = time rate of change in storage at time t
I = average inflow
O = outflow from storage

5.6.2.1 Muskingum

If overbank/channel storage not significant, use Muskingum/normal depth channel routing.

5.6.2.2 Muskingum-Cunge 8 Point Cross Section

If overbank/channel storage is not significant and a hydraulic model is not available, use the Muskingum-Cunge eight (8) point cross section Method.

5.6.2.3 Modified Puls

Use the Modified Puls Storage Method where a hydraulic model is available to develop storage/out flow relationship.

5.6.2.4 Kinematic Wave

The Kinematic Wave Method for channel reaches where inflow from overbank runoff or multiple point sources (Example: storm drain outfalls) is significant and where hydrograph attenuation is insignificant.

5.7 PROBABLE MAXIMUM FLOOD

For information on calculating the Probable Maximum Flood (PMF), please refer to the National Oceanic and Atmospheric Administration (NOAA) Hydro-meteorological Report (HMR) 51 & 52 and the various USGS report for the probable maximum flood peak discharges in Texas. When defining the PMF please contact the City of San Antonio TCI staff and also refer to the Texas Commission on Environmental Quality (TCEQ) Dam Safety program for additional guidance.

5.8 REFERENCES

- Chow, Ven Te. (Jan. 2009). *Open-Channel Hydraulics - McGraw-Hill civil engineering series*. Caldwell, NJ: Reprint by Blackburn Press.
- NOAA. *NOAA Atlas 14 Precipitation-Frequency Atlas of the United States; Volume 11, Version 2.0: Texas.* U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, Maryland, 2018.
- Snyder, Franklin F., 1938, *Synthetic unit-graphs*: Am Geophys. Union Trans., Pt. I, p. 447-454.
- Sandrana, Shiva, P.E., PH., CFM. (Jan. 2011). *IDF curves for Bexar County*. Technical Memo, Bexar County Infrastructure Services – Flood Control Division.
- PBS&J. (May 2005). *Technical Memorandum: Snyder Unit Hydrograph Parameter Guidelines* – San Antonio River Basin, Regional Watershed Modeling System.
- USDA. *Urban Hydrology for Small Watersheds - Technical Release No. 55*. U.S. Department of Agriculture, Natural Resources Conservation Service, Conservation Engineering Division, June 1986.
- TXDOT. Hydrology. Chapter 4 in *Hydraulic Design Manual*. Texas Department of Transportation, Revised 2011. (Accessed April 2014)
- USACE. *HEC-RAS River Analysis System – Hydraulic Reference Manual Version 4.1*. U.S. Army Corp of Engineers, Hydrologic Engineering Center, Davis, California, Jan. 2010.
- Seelye, Elwyn E. (1960) *Data Book for Civil Engineers: Design Vol. 1* (3rd ed.). New York, NY: John Wiley and Sons, Inc.
- San Antonio River Authority. (September 2013) *San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling.*