



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

Table of Contents	i
FIGURES	xviii
TABLES	xxi
Chapter 1 INTRODUCTION	1
1.1 Preface	1
1.2 Acronyms And Abbreviations	1
Chapter 2 DRAINAGE POLICY	2.1
2.1 Introduction.....	2.1
2.2 Statement Of Policy	2.1
2.3 Principles	2.2
2.4 Basic Knowledge	2.2
2.5 Planning	2.2
2.6 Technical Criteria	2.3
2.7 Floodplain Management	2.3
2.8 Implementation	2.3
2.9 References.....	2.4
Chapter 3 DRAINAGE LAW	3.1
3.1 INTRODUCTION	3.1
3.2 FEDERAL LAWS AND REGULATIONS.....	3.1
3.2.1 The Code of Federal Regulations	3.1
3.2.2 National Flood Insurance Program	3.1
3.2.3 National Environmental Policy Act.....	3.1
3.2.4 Rivers And Harbors Act	3.1
3.2.5 The Federal Water Pollution Control Act.....	3.1
3.2.6 Section 402 of the CWA.....	3.2
3.2.7 Section 404 of the CWA.....	3.2
3.2.8 Endangered Species Act (ESA)	3.2
3.3 STATE STATUTES AND RULES.....	3.2
3.3.1 Texas Water Code – Section 11.086.....	3.2

3.3.2	Texas Water Code – Section 16.236.....	3.3
3.3.3	Texas Commission on Environmental Quality – Chapter 213	3.3
3.3.4	Texas Commission on Environmental Quality – Chapter 299	3.3
3.4	LOCAL CODES/ORDINANCES/COURT ORDERS.....	3.3
3.4.1	City of San Antonio Texas Unified Development Code.....	3.3
3.4.2	City of San Antonio Flood Plain Ordinance 57969	3.3
3.4.3	Bexar County Flood Damage Prevention	3.3
3.4.4	Aquifer Protection Ordinance 81491	3.3
3.4.5	(Ord. No. 97568 § 2) Storm Water Management Plan Checklist	3.4
3.4.6	(Ord. No. 2006-11-30-1333, § 2, 11-30-06) Maintenance.....	3.4
3.4.7	(Ord. No. 2009-08-20-0661, § 3, 8-20-09) Amendments to Chapter 19 and 35.....	3.4
3.4.8	Ordinance No. 2010-11-18-0985.....	3.4
3.4.9	(Ord. No. 2013-01-31-0074) Amending FILO Ordinance of 1997	3.4
3.4.10	(Ord. No. 2014-06-19-0472) Amendments to Chapter 34.....	3.4
Chapter 4 PLANNING		4.1
4.1	Introduction.....	4.1
4.2	Regional Drainage Master Plan (Watershed Master Plan)	4.1
4.3	Regional Storm Water Management Program (RSWMP).....	4.2
4.3.1A	RSWMP Overview	4.2
4.3.1B	RSWMP Participation.....	4.2
4.3.1C	Adverse Impact	4.3
4.3.1D	Fee In Lieu Of.....	4.5
4.3.2	System Criteria	4.5
4.3.3	Responsibility to Accept Storm Water	4.5
4.3.4	Positive Overflow Pathways	4.5
4.3.5	Maintenance.....	4.5
4.3.6	Inspection.....	4.6
4.3.7	New Development	4.6
4.3.8	Redevelopment	4.6
4.3.9	Low Impact Development	4.6
4.4	Subdivision/Development.....	4.6

4.4.1	Major Plat	4.6
4.4.2	Minor Plat	4.7
4.4.3	Replat	4.7
4.4.4	Amending Plat	4.7
4.4.5	Master Development Plan (MDP)	4.7
4.4.6	Planned Unit Development (PUD)	4.7
4.4.7	Enclave	4.8
4.4.8	Master Plan Community District (MPCD)	4.8
4.4.9	Master Development Pattern Plan (MDPP)	4.8
4.4.10	Inner City Reinvestment/Infill Policy (ICRIP)	4.8
4.4.11	Infill Development Zone (IDZ)	4.8
4.4.12	Redevelopment Projects	4.8
4.5	Planning For The Floodplain	4.9
4.6	Planning For Drainage Systems	4.9
4.6.1	Storm Water Management Plan Checklist	4.10
4.7	Planning For Storage	4.10
4.8	Planning For Transportation	4.11
4.9	Planning For Open Space	4.11
4.10	Planning For LID	4.11
4.11	Planning For Dams	4.11
4.12	Maintenance Standards	4.12
4.13	References	4.14
Chapter 5 HYDROLOGY		5.1
5.1	Introduction	5.1
5.2	Method of Analysis	5.1
5.2.1	Basin Delineation	5.1
5.2.2	Selection of Rational or Hydrograph Method	5.2
5.2.3	Selection of Method for Detention Ponds	5.2
5.3	Rational Method	5.3
5.4	Time of Concentration	5.3
5.4.1	Overland Flow	5.3

5.4.2	Shallow Concentrated Flow.....	5.6
5.4.3	Channel Flow.....	5.8
5.5	Rainfall Data.....	5.8
5.5.1	Rainfall Intensity-Duration.....	5.10
5.5.2	Rainfall Depth-Duration-Frequency.....	5.16
5.5.2.1	Design Rainfall.....	5.16
5.5.2.2	Areal Reduction Factor	5.18
5.5.3	Runoff Coefficient	5.20
5.6	Hydrograph Method.....	5.20
5.6.1	Sub-Basin.....	5.20
5.6.1.1	Loss Method.....	5.20
5.6.1.1.1	SCS Curve Number Loss.....	5.20
5.6.1.2	Transform Method.....	5.21
5.6.1.2.1	SCS Unit Hydrograph.....	5.21
5.6.1.2.2	Snyder Unit Hydrograph.....	5.23
5.6.1.2.3	Clark Unit Hydrograph.....	5.24
5.6.1.3	Baseflow Method	5.24
5.6.1.3.1	None.....	5.24
5.6.1.3.2	Constant Monthly Baseflow	5.24
5.6.2	Reach – Routing.....	5.24
5.6.2.1	Muskingum	5.25
5.6.2.2	Muskingum-Cunge 8 Point Cross Section	5.25
5.6.2.3	Modified Puls.....	5.25
5.6.2.4	Kinematic Wave.....	5.25
5.7	Probable Maximum Flood	5.25
5.8	References.....	5.26
Chapter 6 PAVEMENT DRAINAGE.....		6.1
6.1	Introduction.....	6.1
6.2	Design Guidelines.....	6.1
6.2.1	Design Frequency and Spread	6.1
6.2.1.1	Street Classification – Primary and Secondary Arterial Streets.....	6.1

6.2.1.2	Street Classification – Local "B" and Collector Streets	6.2
6.2.1.3	Street Classification – Local "A" Streets	6.2
6.2.1.4	Street Classification – Alleys	6.3
6.2.1.5	Street Classification – Traditional Street Design	6.3
6.2.2	Street Capacity	6.3
6.2.3	High Velocity Flow	6.6
6.2.4	Longitudinal Slope.....	6.6
6.2.4.1	Minimum.....	6.6
6.2.4.2	Maximum	6.6
6.2.5	Cross Slope	6.6
6.2.5.1	Minimum.....	6.6
6.2.5.2	Maximum	6.6
6.2.6	Inverted Crown	6.7
6.2.6.1	Maximum Flow Depth	6.7
6.2.8	Flow In Sag – Vertical Curves.....	6.7
6.2.9	Unflooded Public Road Access	6.7
6.3	References.....	6.7
Chapter 7 STORM DRAIN SYSTEMS.....		7.1
7.1	Introduction.....	7.1
7.2	Hydraulics Of Storm Drainage Systems	7.1
7.2.1	Flow Type Assumptions	7.1
7.2.2	Partial Flow vs. Pressure Flow	7.1
7.2.3	Hydraulic Capacity	7.2
7.2.4	Hydraulic Grade Line and Energy Grade Line.....	7.3
7.2.5	Storm Dain Inlets and Outfalls	7.3
7.2.5.1	Inlets	7.3
7.2.5.2	Outfalls.....	7.3
7.2.6	Energy Losses	7.4
7.2.6.1	Pipe Friction Losses	7.4
7.2.6.2	Exit Losses	7.5
7.2.6.3	Bend Losses	7.5

7.2.6.4	Transition Losses.....	7.5
7.2.6.5	Junction Losses	7.9
7.2.6.6	Inlet and Manhole Losses.....	7.10
7.2.6.6.1	Missouri Charts.....	7.10
7.2.6.6.2	FHWA Inlet and Access Hole Energy Loss	7.10
7.2.6.6.3	Energy Loss Method (FHWA HEC-22, 2 nd Edition).	7.11
7.3	Design Guidelines.....	7.15
7.3.1	Design Frequency	7.15
7.3.2	Time of Concentration and Discharge	7.15
7.3.3	Velocity and Grade Considerations	7.16
7.3.4	Pipe/Box Size and Placement	7.16
7.3.5	Multiple Conduits Spacing and Placement	7.17
7.3.6	Access Spacing	7.17
7.3.7	Manholes.....	7.17
7.3.8	Junction Boxes.....	7.17
7.3.9	Materials and Specifications	7.17
7.3.9.1	Pipe Material	7.17
7.3.9.2	Minimum Structural Loads	7.18
7.3.9.3	Mud Slab	7.18
7.3.10	Outfalls	7.18
7.3.10.1	Velocity Controls	7.18
7.3.11	French Drains.....	7.18
7.4	Maintenance Considerations.....	7.19
7.5	References.....	7.19
Chapter 8 INLETS.....		8.1
8.1	Introduction.....	8.1
8.2	Inlet Types	8.1
8.2.1	Curb Inlet	8.1
8.2.2	Grate Inlet	8.1
8.2.3	4-Way Inlet	8.1
8.2.4	Combination Curb Inlet and Grate Inlet	8.1

8.2.5	Combination Grate and 4-Way Inlet.....	8.1
8.2.6	Drop Curb Opening	8.2
8.2.7	Sidewalk Drains.....	8.2
8.2.8	Slotted Drain	8.2
8.3	Design Guidelines.....	8.3
8.3.1	Curb Inlets on Grade.....	8.3
8.3.2	Curb Inlets in Sump	8.7
8.3.3	Grate Inlets on Grade.....	8.8
8.3.4	Grate Inlets In Sump	8.12
8.3.5	4-Way Inlet	8.12
8.3.6	Combination Curb Inlet and Grate Inlet	8.12
8.3.7	Combination Grate and 4-Way Inlet.....	8.13
8.3.8	Drop Curb Opening on Grade.....	8.13
8.3.9	Drop Curb Opening in Sump	8.13
8.3.10	Sidewalk Drains.....	8.13
8.3.11	Slotted Drain	8.13
8.4	Materials and Specifications	8.14
8.4.1	Cast In Place	8.14
8.4.2	Pre Cast.....	8.14
8.4.3	Minimum Structural Loads.....	8.14
8.4.4	Grate	8.14
8.4.5	Sidewalk plates	8.14
8.4.6	Sidewalk Pipe Railing.....	8.14
8.4.7	Mud Slab.....	8.14
8.5	References.....	8.15
Chapter 9 OPEN CHANNELS		9.1
9.1	Introduction.....	9.1
9.2	Hydraulics Of Open Channel Flow.....	9.1
9.2.1	Energy.....	9.2
9.2.2	Specific Energy.....	9.3
9.2.3	Flow Classification	9.4

9.2.3.1	Types of Flow in Open Channels	9.4
9.2.3.2	Critical Flow.....	9.4
9.2.3.3	Subcritical Flow	9.7
9.2.3.4	Supercritical Flow	9.7
9.2.4	Uniform Flow	9.7
9.2.4.1	Manning’s Equation	9.7
9.2.5	Gradually Varied Flow	9.9
9.2.6	Rapidly Varied Flow.....	9.9
9.2.7	Hydraulic Jump.....	9.9
9.2.7.2	Types of Hydraulic Jump	9.10
9.2.7.3	Hydraulic Jump In Horizontal Channels.....	9.12
9.3	Design Guidelines.....	9.13
9.3.1	Design Frequency	9.13
9.3.2	Natural Channels.....	9.13
9.3.3	Constructed Channels	9.13
9.3.3.1	Earthen	9.13
9.3.3.2	Concrete	9.14
9.3.4	Channel Geometry	9.15
9.3.5	Channel Slope	9.16
9.3.6	Channel Drops	9.16
9.3.6.1	Earthen Channels with Drops.....	9.16
9.3.6.2	Concrete Channels with Drops.....	9.17
9.3.7	Baffle Chutes	9.17
9.3.8	Channel Velocity	9.18
9.3.9	Low Flow Channels	9.19
9.3.10	Interceptor Channel.....	9.19
9.3.11	Channel Transitions	9.20
9.3.12	Channel Linings.....	9.20
9.3.12.1	Grass.....	9.20
9.3.12.2	Turf Reinforcement	9.20
9.3.12.3	Rubble Rip Rap	9.20

9.3.12.4	Gabions	9.20
9.3.12.5	Concrete	9.21
9.3.13	Channel Stability.....	9.21
9.3.14	Freeboard.....	9.21
9.3.15	Super Elevation.....	9.21
9.3.16	Utilities – Scour And Buoyancy	9.22
9.3.16.1	Scour	9.22
9.3.16.2	Buoyancy.....	9.23
9.4	Maintenance Considerations.....	9.24
9.4.1	Access.....	9.24
9.4.2	Schedule.....	9.24
9.5	References.....	9.25
9.5.1	Reference Citations.....	9.25
9.5.2	References.....	9.25
Chapter 10 CULVERTS.....		10.1
10.1	Introduction.....	10.1
10.2	Hydraulics Of Culverts	10.1
10.3	Design Guidelines.....	10.2
10.3.1	Design Frequency	10.2
10.3.2	Inlet Control.....	10.2
10.3.3	Outlet Control	10.3
10.3.4	Energy Losses through Culvert.....	10.5
10.3.4.1	Free Surface Flow – Type A	10.5
10.3.4.2	Full Flow in Conduit – Type B	10.5
10.3.4.3	Full Flow at Outlet and Free Surface Flow at Inlet – Type BA	10.7
10.3.4.4	Free Surface at Outlet and Full Flow at Inlet – Type AB	10.8
10.3.5	Energy Balance at Inlet.....	10.8
10.3.6	Determination of Outlet Velocity	10.11
10.3.7	Depth Estimation Approaches	10.12
10.3.8	Direct Step Backwater Method.....	10.12
10.3.9	Subcritical Flow and Steep Slope	10.13

10.3.10	Supercritical Flow and Steep Slope	10.13
10.3.11	Hydraulic Jump in Culverts	10.13
10.3.12	Sequent Depth.....	10.14
10.3.13	Roadway Overtopping	10.15
10.3.14	Performance Curves.....	10.18
10.3.15	Exit Loss Considerations	10.19
10.3.16	Materials and Specifications	10.19
10.3.16.1	Pipe Material	10.19
10.3.16.2	Minimum Structural Loads	10.19
10.3.16.3	Mud Slab	10.20
10.3.17	Railing.....	10.20
10.3.17.1	Hand Rail	10.20
10.3.17.2	Traffic Rail	10.20
10.3.17.3	Guard Rail	10.20
10.4	Velocity Protection And Control Devices	10.20
10.4.1	Excess Velocity.....	10.20
10.4.2	Velocity Protection Devices	10.20
10.4.3	Velocity Control Devices.....	10.21
10.4.3.1	Broken Back Design.....	10.23
10.4.3.2	Stilling Basin.....	10.23
10.4.3.3	Contra Costa Basin.....	10.31
10.4.3.4	USBR Type VI Impact Basin.....	10.34
10.4.3.5	Baffle Blocks.....	10.38
10.5	Special Applications - Detours	10.39
10.5.1	Detour culverts.....	10.39
10.5.2	Risk	10.39
10.5.3	Engineering Requirements.....	10.40
10.6	References.....	10.40
10.6.1	Reference Citations.....	10.40
10.6.2	References.....	10.41
Chapter 11 BRIDGES		11.1

11.1	Introduction.....	11.1
11.2	Hydraulics Of Bridges	11.1
11.2.1	Low Flow.....	11.2
11.2.2	High Flow	11.3
11.2.2.1	Energy Equation.....	11.3
11.2.2.2	Pressure and Weir Flow	11.3
11.3	Design Guidelines.....	11.6
11.3.1	Design Frequency	11.6
11.3.2	Freeboard	11.6
11.3.3	Supercritical Flow.....	11.7
11.3.4	Scour	11.7
11.3.5	Minimum Clear Height.....	11.7
11.3.6	Bridge Deck Drains	11.7
11.3.6.1	Constant Grade Bridges	11.8
11.3.6.2	Flat Bridges	11.9
11.3.7	Roadway Overtopping	11.10
11.3.8	Bridge Railing.....	11.10
11.3.9	Structural Loads.....	11.10
11.3.9.1	Deck	11.10
11.3.9.2	Piers/Columns	11.10
11.4	References.....	11.10
11.4.1	Reference Citation	11.10
11.4.2	References.....	11.10
Chapter 12 PUMP STATIONS.....		12.1
12.1	Introduction.....	12.1
12.1.1	Purpose of a Pump Station.....	12.1
12.1.2	Security and Access Considerations	12.3
12.1.2.1	Security	12.3
12.1.2.2	Access	12.3
12.1.3	Safety and Environmental Considerations.....	12.3
12.1.3.1	Safety.....	12.3

12.1.3.2	Hazardous Spills.....	12.3
12.2	Pump Station Components.....	12.3
12.2.1	Overview of Components	12.3
12.3	Pump Station Hydrology	12.6
12.3.1	Methods for Design	12.6
12.3.2	Procedure to Determine Mass Inflow	12.6
12.4	Pump Station Hydraulic Design Guidelines	12.6
12.4.1	Storage Design Guidelines.....	12.6
12.4.2	Pump Selection	12.9
12.5	Maintenance Considerations.....	12.9
12.5.1	Operation	12.9
12.5.2	Maintenance Schedule	12.9
12.6	References.....	12.10
12.6.1	Reference Citations.....	12.10
12.6.2	References.....	12.10
Chapter 13 STORAGE FACILITIES.....		13.1
13.1	Introduction.....	13.1
13.1.1	Security, Access, and Safety Considerations.....	13.2
13.1.1.1	Security	13.2
13.1.1.2	Access	13.2
13.1.1.3	Safety.....	13.2
13.2	Sink Holes.....	13.2
13.3	Detention Basins	13.2
13.3.1	Design types.....	13.3
13.3.2	Design Guidelines.....	13.3
13.3.2.1	Location.....	13.4
13.3.2.2	Design Frequencies	13.4
13.3.2.3	Features	13.4
13.3.2.4	Routing Methods	13.4
13.3.2.5	Freeboard.....	13.4
13.3.2.6	Layouts.....	13.5

	13.3.2.7	Overflow	13.5
	13.3.2.8	Auxiliary/ Emergency Spillways.....	13.5
13.4	Retention Basins		13.8
	13.4.1	Design Guidelines.....	13.9
	13.4.1.1	Design Frequencies	13.9
	13.4.1.2	Routing Methods	13.9
	13.4.1.3	Freeboard.....	13.9
	13.4.1.4	Overflow	13.9
13.5	Downstream Flow Analysis.....		13.9
13.6	Structures		13.9
	13.6.1	Dams	13.9
	13.6.1.1	Existing Dam.....	13.9
	13.6.1.2	Proposed Dam	13.9
	13.6.1.3	Breach Analysis.....	13.9
	13.6.1.4	Emergency Action Plan.....	13.9
	13.6.1.5	Approval of TCEQ Dam Safety Program	13.10
	13.6.2	Inflow Structure	13.11
	13.6.3	Outfall Structure	13.11
	13.6.3.1	Primary Spillway.....	13.11
	13.6.3.2	Secondary Spillway (Auxiliary Spillway).....	13.12
	13.6.4	Pumps	13.12
	13.6.4.1	Condition 1.....	13.12
	13.6.4.2	Condition 2.....	13.12
	13.6.4.3	Condition 3.....	13.12
	13.6.4.4	Condition 4.....	13.12
	13.6.4.5	Condition 5.....	13.12
13.7	Maintenance Considerations.....		13.12
	13.7.1	Operation	13.12
	13.7.2	Maintenance Schedule	13.12
	13.7.2.1	Regional Detention Facilities.....	13.12
	13.7.2.2	On-Site Storm Water Management Features.....	13.13

13.8	Certification	13.13
13.8.1	Detention Pond Plan Conformance Form	13.13
13.8.2	As-Built Plans for Dams	13.13
13.9	References.....	13.13
13.9.1	Reference Citation	13.13
13.9.2	References.....	13.13
Chapter 14 DRAINAGE EASEMENTS		14.1
14.1	Introduction.....	14.1
14.2	Storm Drain Systems	14.2
14.3	Open Channels.....	14.2
14.3.1	Constructed Channels	14.2
14.3.1.1	Improved Earth Channels.....	14.2
14.3.1.2	Concrete Channels.....	14.3
14.3.1.3	Interceptor Channels	14.4
14.3.1.4	Concrete Flumes.....	14.5
14.3.2	Natural Channels.....	14.5
14.3.3	Maintenance Access Drainage Easement	14.5
14.4	Pump Stations	14.6
14.5	Storage Facilities.....	14.6
Chapter 15 LOTS / UNFLOODED ACCESS		15.1
15.1	Introduction.....	15.1
15.2	Standard Lot Grading.....	15.1
15.3	Unflooded Access	15.2
15.3.1	Proposed Development.....	15.2
15.3.2	Unflooded Access Distance on Existing Public Street	15.2
15.3.3	Exception	15.2
15.4	Interceptor Channels	15.2
15.5	Lot and Property Line Crossings	15.2
Chapter 16 VEGETATION		16.1
16.1	Introduction.....	16.1
16.2	General Guidelines For Recommended Vegetation.....	16.1

16.2.1	Grasses	16.1
16.2.2	Woody Plantings.....	16.1
16.2.2.1	Trees	16.1
16.2.2.2	Shrubs.....	16.2
16.3	Tree Preservation Requirements	16.2
16.4	Preparation Of A Planting Plan.....	16.2
16.5	References.....	16.2
Chapter 17 SOFTWARE		17.1
17.1	Introduction.....	17.1
Chapter 18 DATA SOURCES		18.1
18.1	Introduction.....	18.1
18.2	City of San Antonio	18.1
18.3	Bexar County	18.1
18.4	San Antonio River Authority	18.1
18.5	Federal Emergency Management Agency.....	18.1
18.6	U.S. Army Corps of Engineers	18.1
18.7	Texas Natural Resources Information System.....	18.2
18.8	U.S. Department of Agriculture – Natural Resources Conservation Service	18.2
18.9	U.S. Fish & Wildlife Service	18.2
Chapter 19 DEFINITIONS.....		19.1
19.1	Introduction.....	19.1
APPENDIX A CHECKLIST		1
A.1	Storm Water Management Plan Checklist.....	1
CITY OF SAN ANTONIO, DEPARTMENT OF PUBLIC WORKS		1
Storm Water Engineering Review Team		1
Submittal Review Checklist / Comments		1
3.	Adverse Impact Statement: <i>“The increased runoff resulting from proposed development will not produce a significant adverse impact to other properties, habitable structures or drainage infrastructure systems to a point 2,000 feet downstream. Downstream conditions (including actual curb depth) in this reach have been field verified by myself or members of my staff. Therefore, the owner requests to participate in the Regional Storm Water Management Program by paying a fee- in-lieu-of onsite detention.”</i>	
		2

7. Grading Plan (Also required in construction plans).....	2
• Lots grading properly according to FHA Lot Grading Type (A, B, C) 2	
• Driveway Detail, reference to critical Type “C” lots	2
• To expedite review, delineate site boundaries, point 2,000 ft downstream, all downstream storm water facilities and other pertinent physiographic information.	2
• Show Time of Concentration (Tc) pathways	3
• Show individual and overall drainage areas for the site. Indicate area of each watershed.....	3
• Show computation points and points of discharge; Table of hydrologic calculations for each individual and cumulative drainage area and points of discharge. Include acreage, runoff coefficients, Tc values, and rainfall intensities for the 5, 25, & 100-yr storm events, as applicable.	3
10. Overall Drainage Area Map(s) (to scale) for Existing, Proposed, and Ultimate Conditions:	3
• Include point 2,000 ft downstream (For lots less than three (3) acres in size adverse impact analysis need only extend to where tributary drainage areas equal to 100 acres).....	3
• Show Time of Concentration (Tc) pathways	3
• Show individual and overall drainage areas for the site. Indicate area of each watershed.....	3
• Show computation points and points of discharge.....	3
• Table of hydrologic calculations for each individual and cumulative drainage area and points of discharge. Include acreage, runoff coefficients, Tc values, and rainfall intensities for the 5, 25, & 100-yr storm events, as applicable 3	
5. Provide required storage for the 5, 25, and 100 yr (proposed, ultimate)	7
B. DRAINAGE PLANS	10
1. Grading Plan:	12
A. GENERAL	13
5. Overall Aerial Drainage Area Map(s) (signed and sealed):	15
5. Detailed Map Revision Study:	17
APPENDIX B MISSOURI CHARTS	2

B.1	General Instructions for use of Design Charts	2
B.2	CHART 2 –Rectangular Inlet With Grate Flow Only	6
B.3	CHART 3 – Flow Straight Through Any Junction.....	8
B.4	CHART 4 – Rectangular Inlet With Through Pipeline and Grate Flow.....	10
B.5	CHART 5 – Rectangular Inlet With In-line Upstream Main and 90° Lateral Pipe (With or Without Grate Flow).....	12
B.6	CHART 6 – Rectangular Inlet With In-Line Opposed Lateral Pipes Each at 90° to Outfall (With or Without Grate Flow)	15
B.7	CHART 7 - Rectangular Inlet With Offset Opposed Lateral Pipes Each at 90° to Outfall (With or Without Grate Flow)	18
B.8	CHART 8 – Junction Box (manhole) 90° Deflection – Lateral Coefficient.....	20
B.9	CHART 8 and CHART 9.....	24
B.10	CHART 10 - Square or Round Manhole on Through Pipe Line at Junction of 90° Lateral Pipe (Smaller Size Laterals $D_L / D_O < 0.6$)	29
B.11	References.....	32

FIGURES

Figure 4.3.1C – Roadway Flow Depth vs. Velocity.....	4.4
Figure 5.4.1 – Overland Flow Time.....	5.4
Figure 5.4.2 - Average Velocities for Estimating Travel Time for Shallow Concentrated Flow..	5.7
Figure 5.5 – Precipitation Area (PA) Map for Major San Antonio River Watersheds.....	5.9
Figure 6.2.1.1 - Gutter Flow.....	6.2
Figure 6.2.2.1 - Storm Drainage, Flow Velocities & Capacities for Typical Conventional Street Sections.....	6.5
Figure 7.2.4 - Hydraulic and Energy Grade Line in a conduit.....	7.3
Figure 7.2.6.4 - Angle of Cone for change in pipe diameter.....	7.6
Figure 7.2.6.5 - Interior angle for pipe junction without manhole.....	7.9
Figure 7.2.6.6.2 Sketch of FHWA access hole method	7.11
Figure 7.2.6.6.3.A - Deflection angle.....	7.12
Figure 7.2.6.6.3.B - Relative flow effect.....	7.13
Figure 7.2.6.6.3.C - Manhole benching methods	7.15
Figure 8.3.1 - Gutter Cross-Section Diagram.....	8.4
Figure 9.2.1 Total energy in open channels.....	9.3
Figure 9.2.3.2 - Curves for Determining the Critical Depth in Open Channels.....	9.6
Figure 9.2.7 - Hydraulic Jump	9.10
Figure 9.2.7.2 - Jump Forms Related to Froude Number	9.11
Figure 9.2.7.3. Hydraulic Jump in a Horizontal Channel.....	9.12
Figure 9.3.6.1 - Retard Spacing Criteria.....	9.16
Figure 9.3.7 USBR Type IX Baffled Apron Peterka, 1978.....	9.17
Figure 9.3.10 - Standard for interceptor drains for intercepting sheet flow.....	9.19
Figure 10.3.4.1 - Outlet Control Headwater for Culvert with Free Surface	10.5
Figure 10.3.4.2 - Outlet Control, Fully Submerged Flow	10.6
Figure 10.3.4.3 - Point at Which Free Surface Flow Begins	10.7
Figure 10.3.4.4 - Headwater due to Full Flow at Inlet and Free surface at Outlet.....	10.8

Figure 10.3.6.A - Cross Sectional Area based on the Higher of Critical Depth and Tailwater....	10.11
Figure 10.3.6.B - Cross Sectional Area Based on Full Flow.....	10.12
Figure 10.3.11 - Momentum Function and Specific Energy	10.14
Figure 10.3.12 - Determination of Angle β	10.15
Figure 10.3.13.A - Culvert with Overtopping Flow	10.16
Figure 10.3.13.B - Over-Embankment Flow Adjustment Factor	10.17
Figure 10.3.13.C - Roadway Overtopping with High Tailwater	10.17
Figure 10.3.13.D - Cross Section of Flow over Embankment	10.18
Figure 10.3.14 - Typical Performance Curve	10.18
Figure 10.4.3.1.A - Three Unit Broken Back Culvert.....	10.23
Figure 10.4.3.1.B - Three Unit Broken Back Culvert	10.23
Figure 10.4.3.2.A - SAF Stilling Basin	10.24
Figure 10.4.3.2.B - Dimensionless Rating Curves for the Outlets of rectangular Culverts on Horizontal and Mild Slopes.....	10.25
Figure 10.4.3.2.C - Dimensionless Rating Curves for the Outlets of Circular Culverts on Horizontal and Mild Slopes.....	10.26
Figure 10.4.3.3.A - Contra Costa Basin (Source FHWA, Hydraulic Design of Energy Dissipaters for Culverts and Channels.....	10.31
Figure 10.4.3.4.A - USBR Type VI Impact Basin	10.34
Figure 10.4.3.4.B - Design Curve for USBR Type VI Impact Basin	10.35
Figure 10.4.3.4.C - Energy Loss of USBR Type VI Impact Basin versus Hydraulic Jump	10.38
Figure 10.5.2 - Flood Frequency vs. Risk.....	10.40
Figure 11.2 - Cross Section Locations at Bridge or Culvert.....	11.2
Figure 11.2.1 - Bridge Profile with Cross Section Location.....	11.3
Figure 11.2.2.2.A - Sluice Gate Type Pressure Flow.....	11.4
Figure 11.2.2.2.B - Orifice Type Pressure Flow	11.5
Figure 11.2.2.2.C - Pressure and Weir Flow	11.6
Figure 11.3.6.A Constant Grade Bridge.....	11.8
Figure 11.3.6.B - Horizontal Bridge.....	11.9

Figure 12.1.1.A - Sump Area with Drywell.....	12.2
Figure 12.1.1.B - Wet Well.....	12.2
Figure 12.4.1.A - Pump Station Schematic	12.7
Figure 12.4.1.B - Typical Cross Section	12.8
Figure 13.3.2.8a - Auxiliary/Emergency Design Schematic.....	13.6
Figure 13.3.2.8b - Discharge coefficients for Spillways.....	13.7
Figure 30 TAC § 299.1(a)(2).....	13.10
Figure 14.2 - Storm Drain System Easement.....	14.2
Figure 14.3.1.1 - Earth Channel Easement.....	14.3
Figure 14.3.1.2 - Concrete Channel Easement.....	14.4
Figure 14.3.1.3 - Interceptor Channel Easement.....	14.5
Figure 14.3.2 - Natural Channel Easement.....	14.6
Figure 15.2 - Typical FHA Lot Grading.....	15.1
Figure B.1 Chart 1 - Manhole Junction Types & Nomenclature	5
Figure B.2 Chart 2 - Rectangular inlet with grate flow only	7
Figure B.3 Chart 3 - Flow Straight Through any Junction.....	9
Figure B.4 Chart 4 - Rectangular Inlet With Through Pipeline And Grate Flow	11
Figure B.5 Chart 5 - Rectangular Inlet With In-line Upstream Main And 90° Lateral Pipe	14
Figure B.6 Chart 6 - Rectangular Inlet With In-line Opposed Lateral Pipes Each at 90° To Outfall	17
Figure B.7 Chart 7 - Rectangular Inlet With Offset Opposed Lateral Pipes each at 90° To Outfall.....	19
Figure B.8 Chart 8 - Square or Round Manhole At 90° Deflection Or On Through Pipeline At Junction Of 90° Lateral Pipe	21
Figure B.9 Chart 9 - Square Or Round Manhole On Through Pipeline At Junction Of A 90° Lateral Pipe (In-line Pipe Coefficient)	28
Figure B.10 Chart 10 - Square Or Round Manhole On Through Pipeline At Junction Of A 90° Lateral Pipe (For Conditions Outside Range Of Figure B.8 Chart 8 and Figure B.9 Chart 9).....	31

TABLES

Table 5.4.1 - Roughness Values for sheet flow.....	5.5
Table 5.5.1.A – Intensity-Duration-Frequency (IDF) Values for PA-1.....	5.11
Table 5.5.1.B – Intensity-Duration-Frequency (IDF) Values for PA-2.....	5.12
Table 5.5.1.C – Intensity-Duration-Frequency (IDF) Values for PA-3.....	5.13
Table 5.5.1.D – Intensity-Duration-Frequency (IDF) Values for PA-4.....	5.14
Table 5.5.1.E – Intensity-Duration-Frequency (IDF) Values for PA-5.....	5.15
Table 5.5.2.1 – Design Storm Frequency vs. Annual Exceedance Probability (AEP).....	5.16
Table 5.5.2.1.A – Depth-Duration-Frequency (DDF) Values for PA-1.....	5.16
Table 5.5.2.1.B – Depth-Duration-Frequency (DDF) Values for PA-2.....	5.17
Table 5.5.2.1.C – Depth-Duration-Frequency (DDF) Values for PA-3.....	5.17
Table 5.5.2.1.D – Depth-Duration-Frequency (DDF) Values for PA-4.....	5.18
Table 5.5.2.1.E – Depth-Duration-Frequency (DDF) Values for PA-5.....	5.18
Table 5.2.2.2 - Areal Reduction Factors.....	5.11
Table 5.5.3A - Runoff Coefficient (C value) – percentage.....	5.12
Table 5.6.1.1.1.1 - SCS Curve Number by Soil Type.....	5.13
Table 5.6.1.1.1.2 - Percent Impervious Cover by Land Use.....	5.13
Table 5.6.1.2.1 – SCS Dimensionless Unit Coordinates	5.14
Table 6.2.2.1 - Manning's Roughness Coefficient.....	6.4
Table 7.2.3 - Manning's Roughness Coefficient.....	7.2
Table 7.2.6.4A - (Source FHWA HEC 22).....	7.6
Table 7.2.6.4B - (Source ASCE Manuals and Reports of Engineering Practice No. 77).....	7.7
Table 7.2.6.4C - (Source ASCE Manuals and Reports of Engineering Practice No. 77).....	7.7
Table 7.2.6.4D - (Source ASCE Manuals and Reports of Engineering Practice No. 77).....	7.8
Table 7.2.6.4E - (Source ASCE Manuals and Reports of Engineering Practice No. 77).....	7.8
Table 7.2.6.6.3 - Correction for Benching.....	7.14
Table 7.3 - Maximum Velocity.....	7.16
Table 8.3.3 - Splash-Over Velocity Calculation Equations (English).....	8.10
Table 8.3.a - Clogging Coefficients for Multiple Units.....	8.12
Table 9.2.4.1 - Manning's Roughness Coefficient.....	9.9

Table 9.3.8 - Velocity Control.....	9.18
Table 9.3.14 - Drainage Freeboard for Concrete Lined and Earth Channels for Twenty-Five-Year Storm.....	9.21
Table 9.3.16.1 - Tentative guide to competent velocities for erosion of cohesive materials* ...	9.23
Table 10.3.3 - Outlet Depth Conditions	10.4
Table 10.3.5 - Entrance Loss Coefficients (Ce)	10.10
Table 10.4.3 Energy Dissipaters and Limitations.....	10.22
Table 10.4.3.4. - USBR Type VI Impact Basin Dimensions (ft)	10.36
Table 13.3.2.8 - Spillway Design Parameters.....	13.8

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 (T_c). 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.

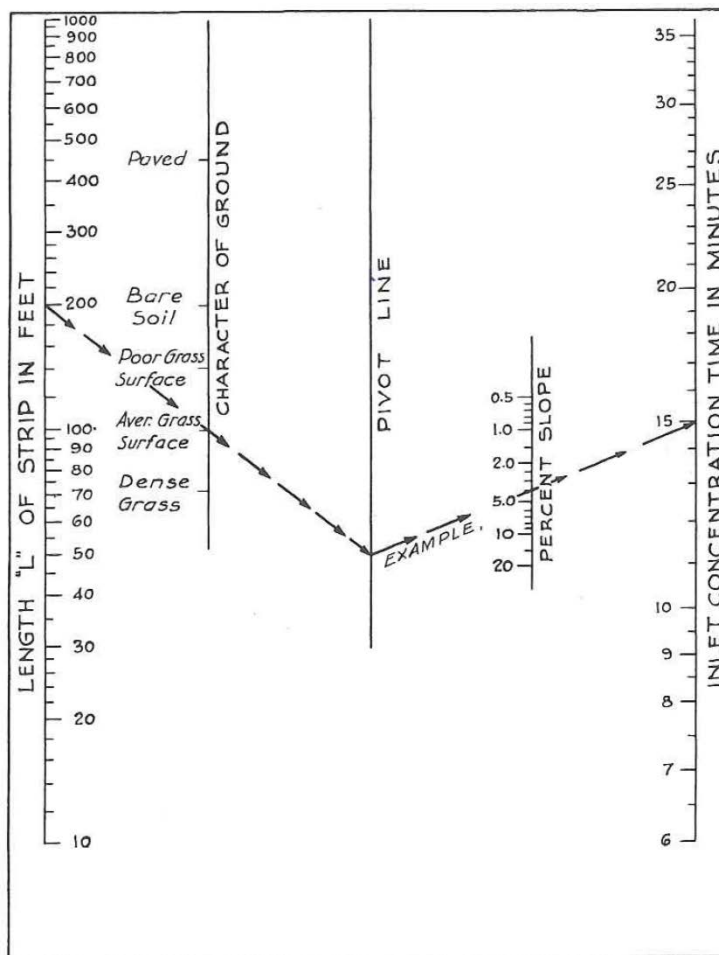


Figure 5.4.1 – Overland Flow Time (Source: “DESIGN” by Elwyn Seelys Figure. H)

- 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 $\leq$ 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, buffalo 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)

$$T_{sc} = \frac{L_{sc}}{3600 K S_{sc}^{0.5}}$$

T_{sc} = shallow concentrated flow time (hr.)

L_{sc} = shallow concentrated flow length (ft.)

K = 16.13 for unpaved surface; 20.32 for paved surface

S_{sc} = shallow concentrated flow slope (ft./ft.)

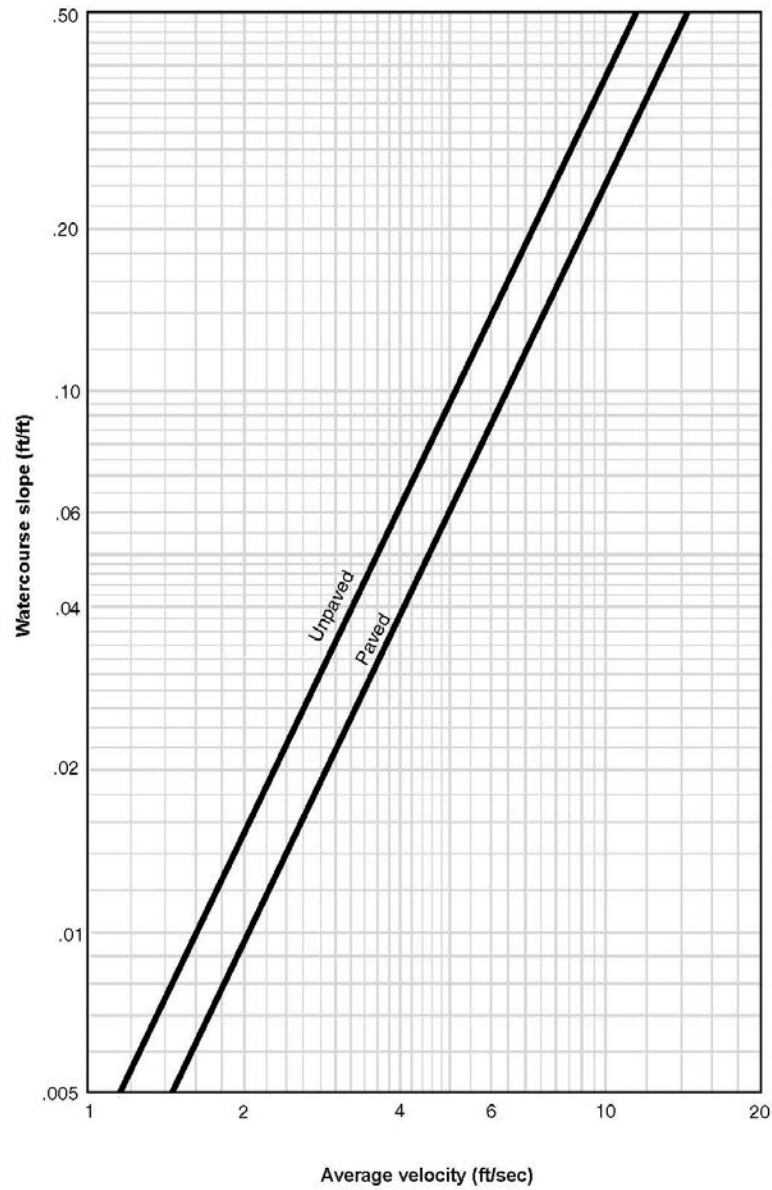


Figure 5.4.2 - Average Velocities for Estimating Travel Time for Shallow Concentrated Flow (Source: NRCS Technical Release 55 – Figure 3-1)

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)

$$T_{ch} = \frac{L_{ch}}{3600 \cdot 1.49/n \cdot R^{2/3} \cdot S_{ch}^{1/2}}$$

T_{ch} = channel flow time (hr.)

L_{ch} = channel flow length (ft.)

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)

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.

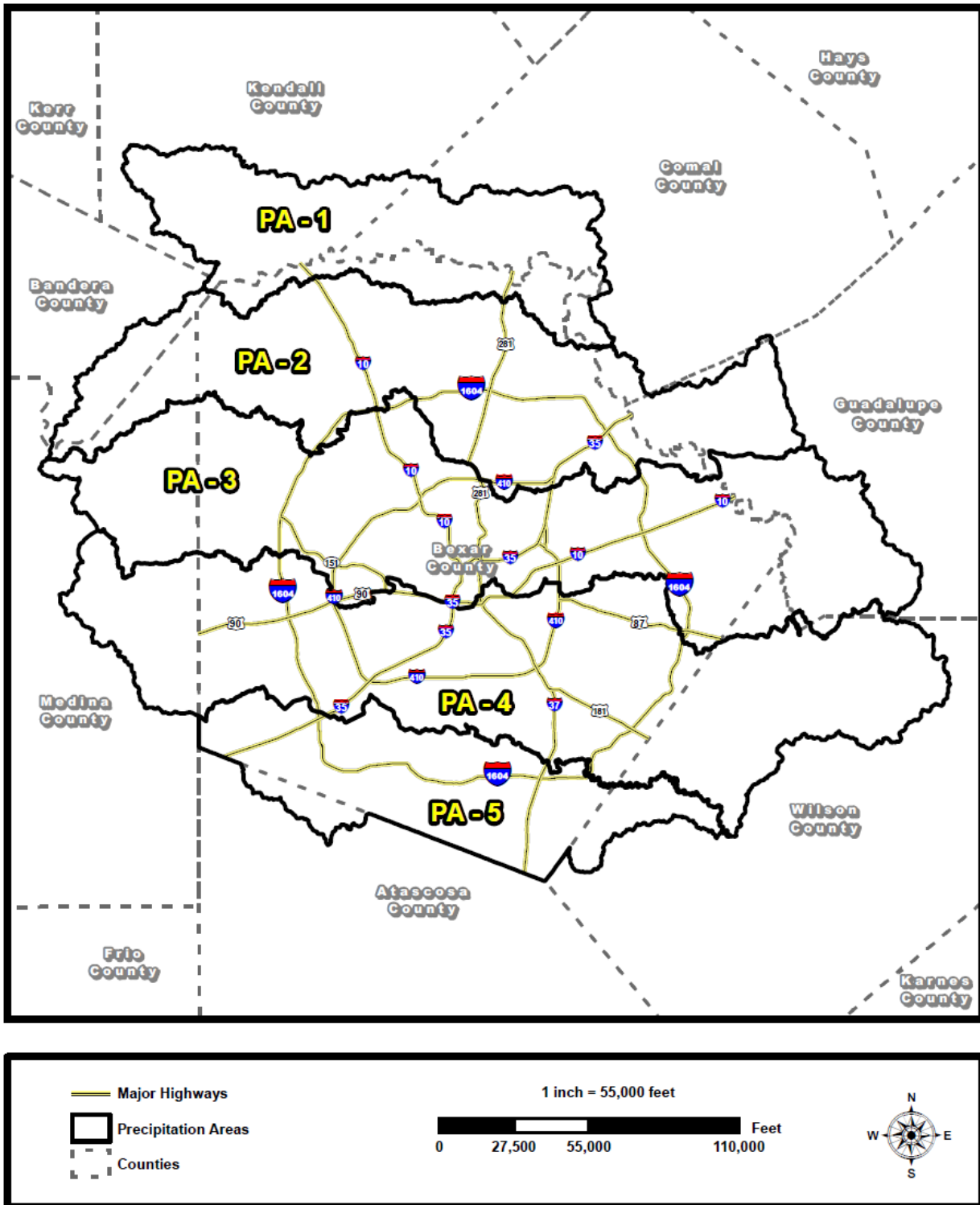


Figure 5.5- Precipitation Area (PA) Map for Major San Antonio River Watersheds (*Precipitation Areas are available in GIS format at <https://www.sanantonio.gov/GIS>*)

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

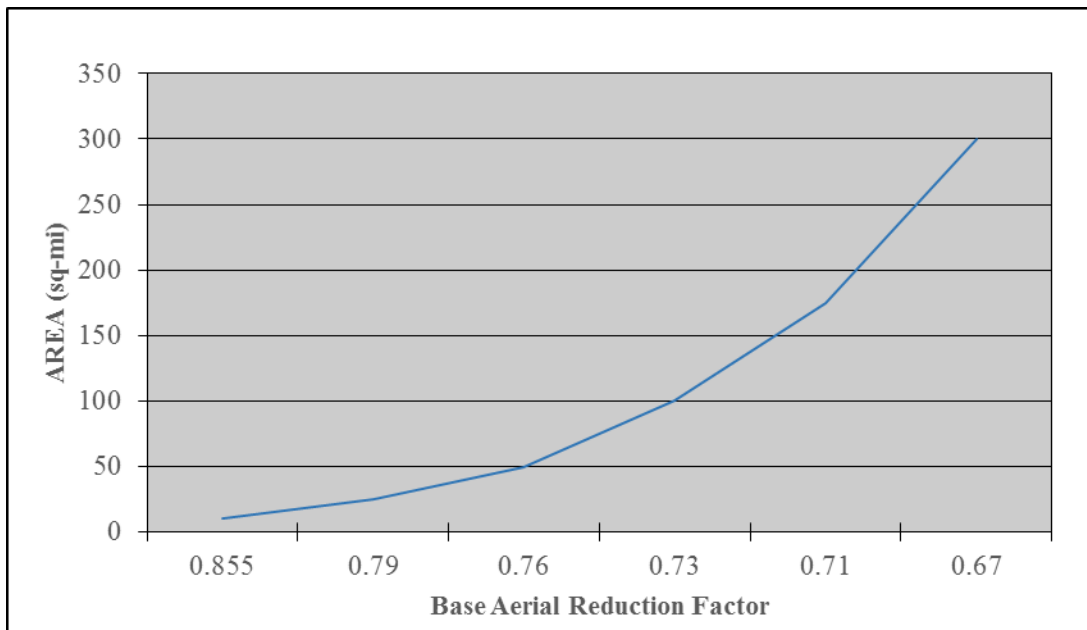
Atlas 14, Volume 11 Adjusted Rainfall Values (pre-areal reduction)								
Duration	Design Storm Depth (inches) by Storm Frequency							
	1-year	2-year	5-year	10-year	25-year	50-year	100-year	500-year
5 minute	0.45	0.53	0.65	0.76	0.91	1.02	1.14	1.39
10 minute	0.71	0.84	1.04	1.22	1.45	1.64	1.82	2.19
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)

$$Q_p = \frac{484 A}{t_p}$$

Q_p = peak discharge (cfs.)

A = drainage area (mi.²)

t_p = time to peak (hr.)

(Equation 5.6.1.2b)

$$t_p = \frac{\Delta t}{2} + t_{lag}$$

t_p = time to peak (hr.)

Δt = the duration of rainfall (hr.) = 0.133 t_c

t_{lag} = lag time from the centroid of rainfall to peak discharge, estimated at 0.6 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 Snyder 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)

$$Q_p = \frac{640 C_p A}{t_{lag}}$$

Q_p = Snyder peak discharge (cfs.)

C_p = peaking coefficient; range from 0.5 – 0.9

A = Drainage Area (mi.²)

t_{lag} = Snyder lag time (hr.)

(Equation 5.6.1.2.2b)

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

T_{lag} = Snyder lag time (hr.)

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

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*.