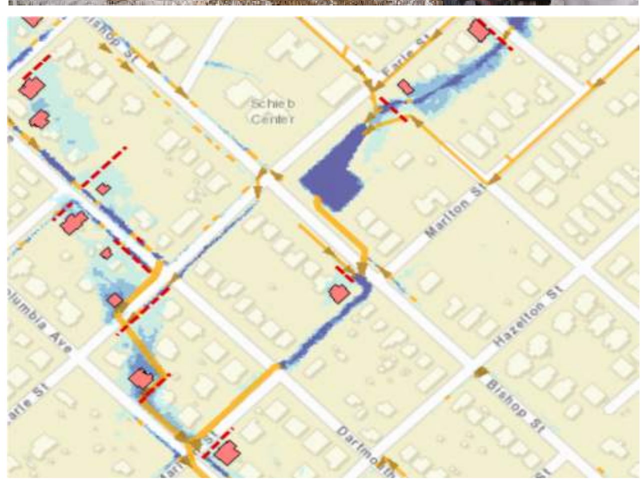
Purgatory Creek Watershed

Phase I Drainage Study | City of San Marcos

8/10/2018

LAN Project No. 120-12062-000



Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY
TBPE Firm No. 2614

Purgatory Creek Watershed

Phase I Drainage Study
August 10, 2018

STATE OF TEXAS
LAURA McKAY CASSET
99387
LICENSED
PROFESSIONAL ENGINEER
8/10/2018

Prepared for:
City of San Marcos
630 E. Hopkins Street
San Marcos, TX 78666

Prepared by:
Lockwood, Andrews, and Newnam, Inc.
TBP Firm No. 2614
407 S Stagecoach Trail, Suite 207
San Marcos, TX 78666

Project No. 120-12062-000

Executive Summary

The City of San Marcos has identified the need to address flooding issues in the Purgatory Creek Watershed. The project includes the initial setup of a detailed InfoWorks ICM model for approximately two square miles of the Purgatory Creek Watershed and an assessment of existing flood conditions in this area. The primary intent of the Phase I Drainage Study is to identify areas that do not currently meet the City's design storm criteria which requires that all drainage facilities (including street curbs, gutters, inlets and storm drains) be designed to intercept and transport runoff from a 25-year frequency storm.

The purpose of this report is to document the methodology and results of the hydrologic and hydraulic analyses used to assess existing flood conditions of the plan area. Hydrologic and hydraulic analyses were performed according to the City of San Marcos' Stormwater Technical Manual (STM), February 2014. InfoWorks Integrated Catchment Modeling (ICM) two-dimensional (2D) modeling guidelines drafted by Lockwood, Andrews, and Newnam (LAN) are provided as Appendix B.

The hydrologic analysis was performed using the U.S. Army Corps of Engineers' Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) version 4.2.1. The rain-on-mesh method was used within InfoWorks ICM to simulate the runoff and conveyance characteristics throughout the study area for the 25-year storm event. An input hydrograph was also used to simulate the inflow into Purgatory Creek from the dam upstream of the study area. InfoWorks ICM version 8.0 was used to complete the one-dimensional (1D) and 2D hydrodynamic simulation. Surveyed storm sewer sizes and flowlines were added to the City's GIS data and imported into InfoWorks ICM. The model was validated with the April 11, 2017 storm event.

The existing conditions 25-year design storm model shows that the primary sources of flooding in the study area are undersized storm drain systems and flow leaving the drainage easements, channels, and right-of-way as overland flow in up to 90 areas. There are up to 85 structures potentially at risk of flooding within the study area for the 25-year frequency storm. Phase II of the Purgatory Creek Drainage Study will include solutions development to address these drainage infrastructure inefficiencies.

Table of Contents

Appendices

1. Purpose

This project is a one-dimensional (1D)/two-dimensional (2D) storm drain analysis of the Purgatory Creek watershed in San Marcos, Texas. A Project Location Map is provided as Figure 1.

The purpose of this report is to document the methodology and results of the hydrologic and hydraulic analyses used to assess existing flood conditions within the study area from localized flooding. Hydrologic and hydraulic analyses were performed according to the City of San Marcos' Stormwater Technical Manual (STM), February 2014. InfoWorks Integrated Catchment Modeling (ICM) 2D modeling guidelines drafted by Lockwood, Andrews, and Newnam (LAN) are provided as Appendix B.

1.1 Project Description

The City of San Marcos has identified the need to address existing flooding issues due to inadequate storm drain collection systems in the Purgatory Creek Watershed. The project includes the initial setup of a detailed InfoWorks ICM 2D model for approximately two square miles of the Purgatory Creek Watershed and an assessment of existing flood conditions in this area. The primary intent of this project is to identify areas that do not currently meet the City's 25-year design storm criteria.

1.2 Data Collection and Field Study

The primary data source for the existing stormwater system in the study area is field survey by McGray and McGray Land Surveyors performed to support this analysis, dated Spring 2018. This data was integrated into the City's geographic information system (GIS) data and verified with a site visit by LAN engineers in April 2018. The City's GIS geodatabase was updated with project field survey in a manner which maintained the integrity of the original data set and only emphasized adding data to reflect survey and input values necessary to perform the ICM modeling tasks. LAN worked closely with City GIS data management staff to ensure the additional data sets would adhere to the city's quality of data management.

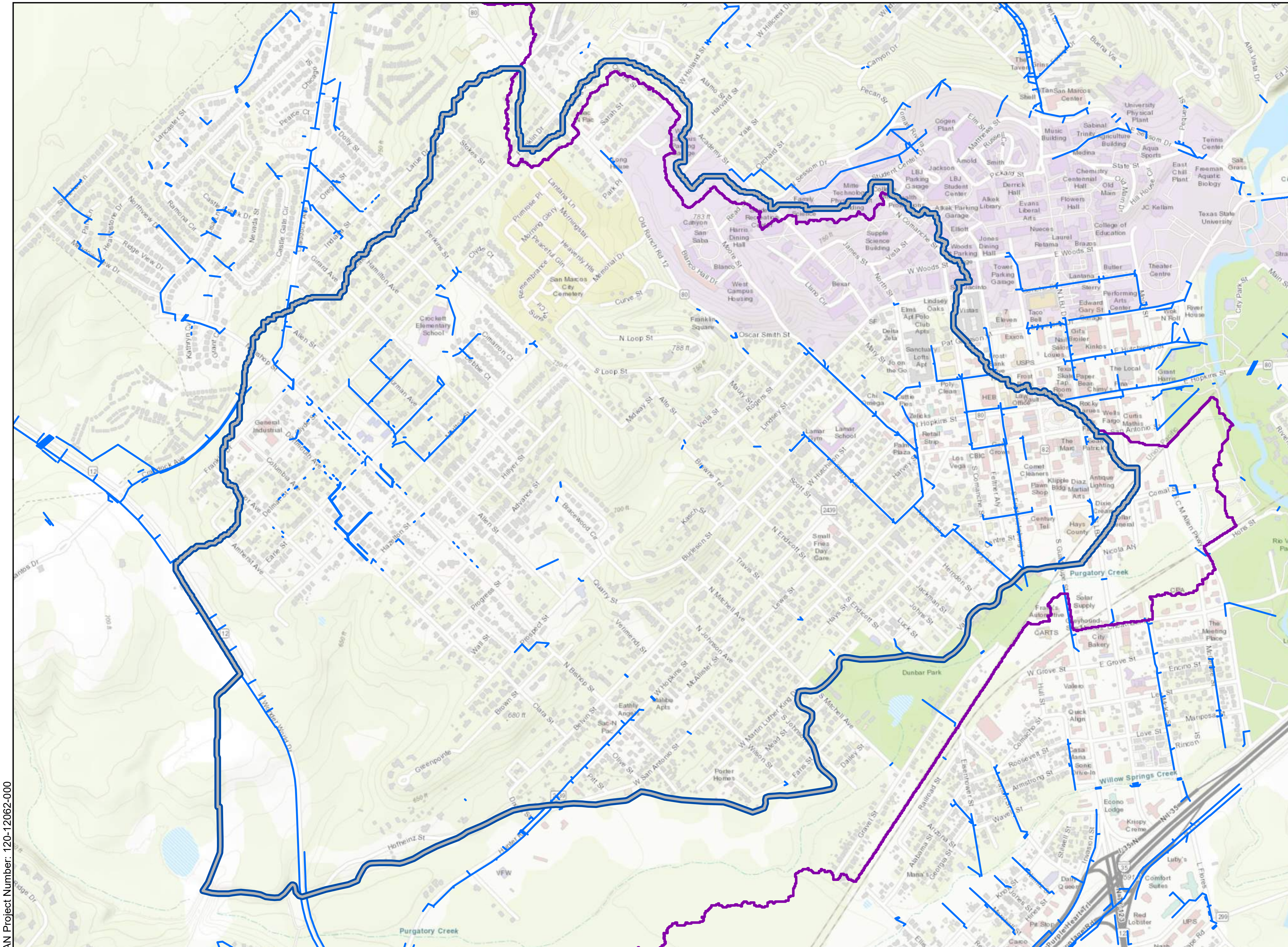
Multiple site visits were performed by LAN staff to field verify the survey data and anomalies in the storm sewer system. Field photos can be found in Appendix C. The City also provided additional GIS data that was used in the study including zoning, right-of-way, and building footprints. Texas Natural Resources Information System (TNRIS) 2017 LiDAR data was also provided by the City.

Figure 2: High water mark, April 2017 flood

Historic flood photos, videos, and high-water mark information (as shown in Figure 2) gathered during the April 11, 2017 flood event were provided by the City. Flow and flood level measurements are not available.

1.3 Project Datum

The datum for the 2017 LiDAR data obtained from the City is the Texas Coordinate System, South Central Zone of 1983 (NAD83). NAD83 (2011) was used for the project survey.



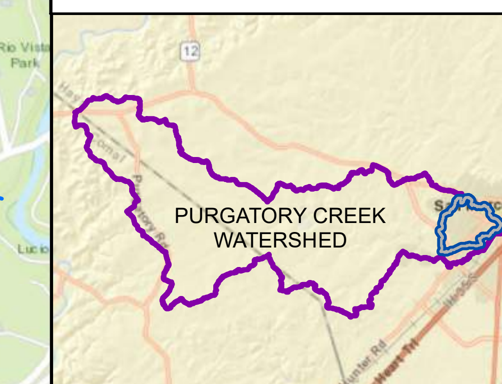
THE CITY OF SAN MARCOS

PURGATORY CREEK WATERSHED DRAINAGE STUDY

PROJECT LOCATION

Legend

- STUDY AREA
- PURGATORY CREEK WATERSHED
- STORM DRAINS



0 500 1,000
Feet

FIGURE 1

Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY

LAN Project Number: 120-12062-000

Lockwood, Andrews & Newnam Inc. makes no representations or warranties regarding accuracy or completeness of the information depicted on this map or the data from which it was produced.
This map is NOT suitable for survey purposes and does not purport to depict or establish boundaries between land owners or locations of utility infrastructure where survey data is available and field locations have been established.

2. Hydrologic Analysis

The Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service) hydrologic methods were used to model rainfall-runoff. A full description of the methodology can be found in SCS Technical Release 55 (TR-55). The rain-on-mesh method was used within InfoWorks ICM to simulate the runoff and conveyance characteristics throughout the study area for the 25-year (4% chance of occurrence) design storm. An input hydrograph was also used to simulate the inflow into Purgatory Creek from the NRCS dam located on Purgatory Creek just upstream of the study area. This hydrograph was taken from the Upper San Marcos Watershed (USM) HEC-HMS model created by Halff Associates for the San Marcos Comprehensive Master Plan Update (November 2017).

2.1 Rain-on-Mesh

The 2 square mile study area was delineated using the subbasins from the USM in the City of San Marcos Comprehensive Watershed Master Plan Update completed by Halff Associates in November 2017 and was verified with two-foot contours generated from LiDAR data.

Per the City of San Marcos STM, a frequency storm method was used with a 24-hour storm duration for the 25-year storm event. Precipitation values were obtained from U.S. Geological Survey Scientific Investigations Report 2004-5041 (Asquith and Roussel, 2004) which is consistent with the InFRM report dated September 2016. The rainfall depths are summarized in Table 2-1.

Table 2-1: Rainfall Depths (inches)

Duration	Recurrence Interval		
	10-year	25-year	100-year
15 min	1.47	1.79	2.31
1 hour	2.74	3.31	4.39
2 hour	3.47	4.14	5.54
3 hour	3.81	4.66	6.29
6 hour	4.29	5.26	7.00
12 hour	4.91	6.07	8.33
1 day	6.22	7.62	10.26

Infiltration losses can be accounted for in InfoWorks ICM by using the rainfall excess for the rain-on-mesh or through infiltration zones. Infiltration zones require extensive calibration and testing of loss coefficients for the Horton Infiltration Method used in InfoWorks ICM and were not for this study. The use of total rainfall or rainfall excess is dependent on study area conditions, since the rainfall is dropped on both pervious and impervious surfaces. Curve number and impervious cover calculations can be found in Table D-1 in Appendix D.

Time-series data from U.S. Army Corps of Engineers' Hydrologic Engineering Center Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) version 4.2.1 was used to create the rainfall event for the rain-on-mesh in InfoWorks ICM. The rain-on-mesh method in InfoWorks ICM uniformly applies rainfall to a land surface model derived from LiDAR terrain data. The time-series data output from HEC-HMS and the rainfall event data input into InfoWorks ICM are shown in Table D-2 in Appendix D.

2.2 Input Hydrograph

The 25-year outflow from the NRCS Dam Number 5 from the USM HEC-HMS model (version 3.5) created by Halff Associates was used as the inflow for the input hydrograph in InfoWorks ICM. The point source in InfoWorks ICM was placed in the creek directly downstream of the dam. Outflow depths are shown in Table D-3 in Appendix D.

2.3 Historic Flood Event

Rainfall data from the San Marcos Area Precipitation Analysis, April 11, 2017 – April 12, 2017 by Halff Associates was used to create the historic rainfall event. HRAP ID 164571 was found to most closely cover the project study area. The historic rainfall depths for this area are shown in Table 2-2 and the historic rainfall event used in InfoWorks ICM is shown in Table D-4 in Appendix D. The maximum frequency of the April 11, 2017 storm event for this area was found to be between a 10-year and a 25-year event (as shown in the San Marcos Area Precipitation Analysis by Halff Associates in Appendix D), therefore the 25-year input hydrograph at the dam was used to best model the storm conditions.

Table 2-2: April 11, 2017 Rainfall Depths

Time	Rainfall (inches)
12:00 AM	0
1:00 AM	0
2:00 AM	0.01
3:00 AM	0.01
4:00 AM	0.01
5:00 AM	0
6:00 AM	0
7:00 AM	0
8:00 AM	0.02
9:00 AM	0.05
10:00 AM	0.08
11:00 AM	0.22
12:00 PM	1.97
1:00 PM	1.76
2:00 PM	0.65

3. Hydraulic Analysis

The Purgatory Creek watershed drainage study was completed using InfoWorks ICM version 8.0. The hydraulic methods used for this study are in accordance with the to the City of San Marcos' STM and LAN InfoWorks ICM 2D modeling methods (located in Appendix B). InfoWorks ICM has full integration of 1D and 2D hydrodynamic simulation techniques, which models both the above- and below-ground elements of catchments and accurately represents all flow paths.

3.1 Mesh Creation

A 2D triangular mesh is generated to model surface flows using built-in InfoWorks mesh creation processes. Because of the varied elevation changes in this area the maximum triangle area was set to 1,000 square feet and the minimum set to 10 square feet for the overall mesh. The maximum height variation was set to 0.5 feet to ensure that the mesh correctly displays curb and gutters. Mesh zones were used with a maximum triangle size of 20 square feet to define channels within the study area. Mesh zones make the mesh more detailed in a set area using data from the ground model. Elevations at the vertices of the generated mesh elements are interpolated from the 2017 LiDAR provided by the City. Roughness values are incorporated into the 2D mesh surface to account for variations in surface roughness for overland flow. The City's right-of-way, building footprints, and zoning GIS data, as well as areal imagery and field observations were used to create the roughness zones. Manning's n-values used (for flow than 3 feet) are shown in Table 3-1.

Table 3-1: Roughness Values for Flow Less Than 3 Feet

Manning's "n"	Land Use
0.016	Streets, paved areas
0.085	Generic Residential
0.12	Dense Grass Areas (Lawns)
0.14	Generic Undeveloped Area
10	Buildings/Structures

3.2 Infrastructure Data Import

All storm sewer within the project study area (excluding Texas State University) was evaluated for the 25-year design storm. Storm sewer sizes and flowlines from the surveyor were added to the City's GIS data and imported into InfoWorks ICM. Where flowline or size information was not available from the survey, it was supplemented with as-built information from the City's GIS data or assumed from surrounding similar pipes. Manning's Roughness parameters for conduits were established as 0.012 for precast concrete pipe and 0.024 for corrugated metal pipe.

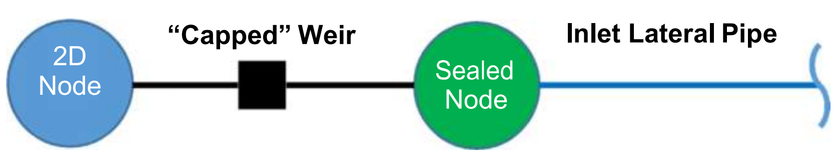


Figure 3: Inlet Capacity Setup in InfoWorks ICM

Inlets were modeled as a three-part element consisting of two nodes and one link as shown in Figure 3. The upstream node, or 2D node, is set to "2D" flood type; this allows the 1D storm sewer system to interact with the 2D mesh. The 2D node is connected to a "capped" weir that sets the inlet capacity parameters by defining the inlet crest elevation, opening width, and opening height. Weir parameters were assigned based on the survey. The "capped" weir represents both the weir regime of flow to the inlet and the orifice regime of inlet flow after the inlet opening height has been exceeded and is submerged. InfoWorks ICM uses different weir equation than the City's STM dictates. Equivalent coefficients were calculated for the primary and secondary coefficients in the "capped" weir parameters. Table 3-2 shows the InfoWorks ICM equivalent coefficients. All inlet capacity simulated results were checked for appropriateness. This "capped" weir is connected to a sealed node which is connected to the downstream storm sewer system.

Table 3-2: ICM Equivalent Coefficients

Coefficient Type	STM Coefficient	ICM Equivalent Coefficient
Weir	3.0	0.53
Orifice	0.67	0.95

3.3 Historic Event Calibration

The model was validated using photos and videos from the April 11, 2017 event, as well as comments from the City on the results from the 25-year event project meeting on June 22, 2018. Based on the result of the calibration, mesh level zones were added in some areas to better define channels that the ground model (LiDAR) did not fully define. Mesh level zones change the elevation of the mesh to be different than the ground model for a set area. Survey flowlines, field photos and measurements were used to verify channel geometry.

Break lines define lines along which the mesh triangle boundaries will be created as shown in Figure 4. Break lines were added to better define the top of curb in locations where the mesh was not picking it up. For example, video from the corner of Girard Street and Earle Street showed that at 11:46 am two curb inlets were capturing the flow and the curb was not overtopping. This was confirmed in the model with the addition of a break line. Additionally, a high water mark of two feet in the garage of 1207 Belvin Street was verified in the model. Photos from the April 11, 2017 event can be found in Appendix B.

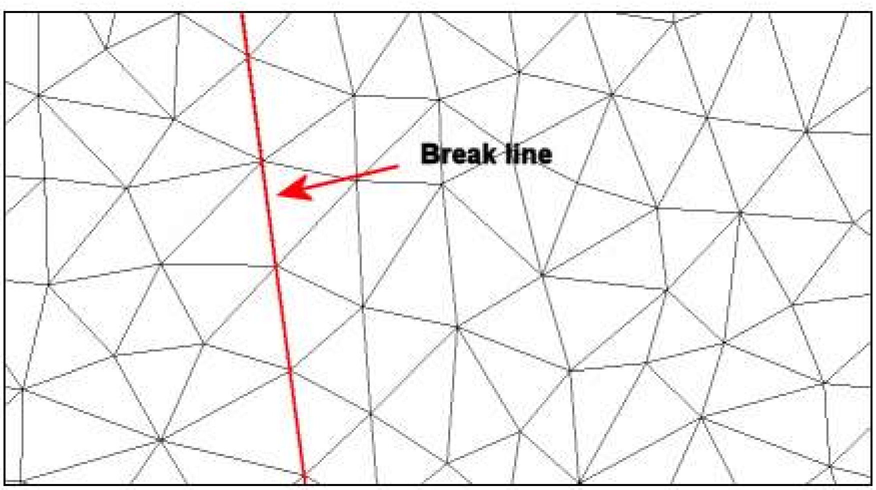


Figure 4: Triangle Boundaries Defined by Break Line, Source: InfoWorks ICM Help

4. Results

The existing conditions model depicts the extent of flooding issues in the Purgatory Creek Watershed that do not meet the City's 25-year design storm.

4.1 Inundation Map

The 25-year inundation was exported from InfoWorks ICM with a minimum depth of 0.5 feet and represents the maximum elevation throughout the event. There are some areas with ponding less than 0.5 foot not shown on this exhibit. The reason that flooding below 0.5 feet has been excluded from the inundation mapping is a function of the input data of which the analysis is based on and the nature of flooding in the study area. Namely, the accuracy of LiDAR is within two to six inches; therefore, flooding depths less than six inches (0.5 feet) may not be accurate. Flow depths less than 0.5 feet are still acceptable for use in determining flow patterns and inundation. The 25-year inundation is shown on Exhibit 2 of Appendix A.

4.2 Flood Risk Structures and Flow Leaving Right-of-Way

The number of structures potentially at risk of flooding during the 25-year event were estimated based on assumed finish floor elevations. Assumed finished floor elevations were determined with Google Street View (Summer 2017) and were assigned per neighborhood block as the minimum elevation within that block. Once computed, finish flood assumptions for the at risk structures were spot checked for accuracy. Future phases of the analysis shall include survey of these critical structures potentially at risk of flooding. Flow leaving the right-of-way was determined using velocity arrows within InfoWorks ICM. Structures potentially at risk of flooding and locations where flow is leaving the right-of-way are shown for the 25-year event on Exhibit 2 of Appendix A.

4.3 Sources of Flooding

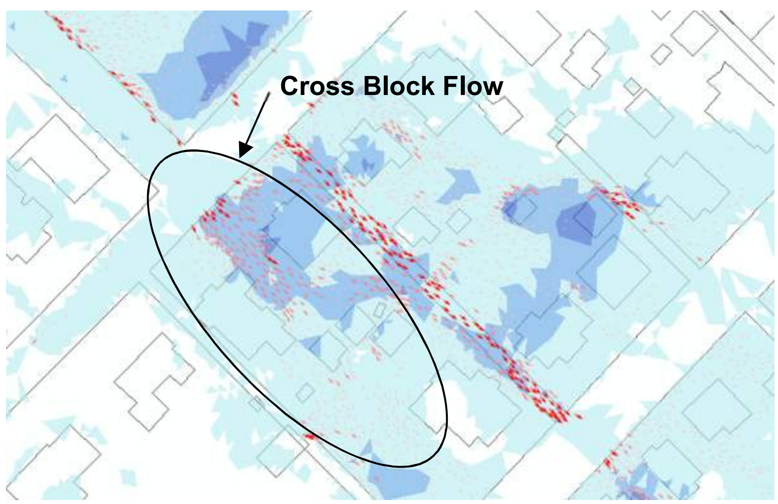


Figure 5: Example of Cross Block Flow

The primary source of flooding in the study area are undersized storm drain systems and flow leaving the drainage easements, channels, and right-of-way as overland flow. Flow that overtops a curb and then flows perpendicular to the curb and is no longer contained within the right-of-way (shown in Figure 5) is referred to as cross block flow. For the 25-year storm, there are up to 85 structure potentially at risk of flooding in the study area. For the purpose of discussing the results from the existing conditions InfoWorks ICM model, the study area was divided into four areas (A, B, C, and D). These areas are shown on Exhibit 2 and 3 of Appendix A. All discussions are of the 25-year storm event.

The pipe surcharge state/capacity for all pipes within the study area is shown on Exhibit 3 of Appendix A. InfoWorks ICM calculates surcharge state using the methodology shown in Table 4-1. The InfoWorks ICM Surcharge State defines the approximate capacity for the 25-year event. Note, capacity is defined as pipe full capacity. As hydraulic head stacks on the pipe and the HGL rises flow may be maintained within the gutter and/or channel and therefore, the surcharged pipe may still convey the 25-year event. Surcharge state along with the 25-year inundation mapping will be used in Phase II to identify strategic storm sewer sections to upsize.

Table 4-1: InfoWorks ICM Surcharge State Definitions

Surcharge State	Definition
Less than 1	Water is below the soffit at both ends of the pipe. State is set to the depth/height.
1	Water is above the soffit at the upstream and/or the downstream end, and the flow is less than or equal to pipe full capacity.
2	Water is above the soffit at the upstream and/or the downstream end, and the flow is greater than pipe full capacity.

4.3.1 Drainage System A

Drainage System A contains four moderate sized storm sewer systems and a network of drainage channels and ditches that flow southeast towards Purgatory Creek. The western-most system carries flow from the intersection of Craddock Avenue and Furman Avenue southeast towards the intersection of Franklin Drive and North Bishop Street where it outfalls into a ditch on the southside of North Bishop Street. This storm sewer system conveys the 25-year storm event.

To the east, overland flow occurs from the intersection of Stokes Street and Dale Drive southeast to the intersection of Clyde Court and Perkins Street and the beginning of the northern-most system in this area. The northern-most system begins north of Crockett Elementary School at the intersection of Perkins Street and Clyde Court and carries flow southeast to a drainage channel south of the elementary school. This system is made up of pipes ranging from 18-inch Reinforced Concrete Pipe (RCP) to 48-inch RCP and includes sections of pipe that are surcharged for the 25-year event. There is also inundation around the elementary school in this area indicating lack of sufficient localized grading and inlets to collect runoff from the 25-year storm event.

The system south of the elementary school is made up of four storm sewer trunklines that flow southwest down Clyde Street, Delmar Street, Earle Street, and Marlton Street to a regional detention pond located at the intersection of Earle Street and North Bishop Street. There is a channel located between the homes on Earle Street and Marlon Street that runs parallel to the four trunklines that does not contain the 25-year event. The trunkline located on Earle Street is a 60-inch RCP that is partially surcharged in the 25-year event. The other three trunklines in this system appear to convey the 25-year design storm.

The southern-most system flows from the intersection of Franklin Drive and North Bishop Street southeast to the intersection of Columbia Avenue and Hazelton Street then continues in a channel southeast to Purgatory Creek. This system is made up of driveway culverts, ditches, and three 4-foot by 2-foot RCP boxes that run from Dartmouth Avenue to the channel outfall. Cross block flooding occurs southwest from the intersection of Clyde Street and North Bishop Street towards Marlton Street.

The primary source of flooding in Drainage System A is select sections of undersized storm drain pipes, lack of storm drain, and an undersized channel. These inefficiencies in the stormwater conveyance system lead to flow leaving the drainage easements and right-of-way. There are up to 15 structures potentially at risk of flooding during the 25-year event and inundation around Crockett Elementary. There are three potential projects for evaluation in the Phase II analysis in this area, namely: Crockett Elementary storm drain, channel improvements between Earle Street and Marlton Street, and lack of storm drain along Dartmouth Avenue to capture cross block flow.

4.3.2 Drainage System B

Drainage System B is primarily composed of a channel that flows southeast from the intersection of Perkins Street and Marlton Street down towards Purgatory Creek. Near Verimendi Street flow leaves the channel and continues past Belvin Street as cross block flow. The primary source of flooding in this area is an undersized drainage channel allowing flow to leave the drainage easements and right-of-way as overland flow. Inundation in this area is also caused by lack of storm drain infrastructure south of Belvin Street. There are up to 30 structures potentially at risk of flooding during the 25-year event in this area. Channel improvements and/or addition of storm drain infrastructure to collect the cross block flow will be evaluated as potential projects in the Phase II analysis.

4.3.3 Drainage System C

Drainage System C flows southeast from the intersection of Midway Street and Alto Street to the storm sewer system that begins on Burleson Street between Scott Street and Blanco Street. At this point approximately 20% of the flow enters the storm sewer system and outfalls into the western-most system in Drainage System D. The remaining 80% of flow follows the curb east down Burleson Street or goes around the curb and continues southwest to Martin Luther King Drive and Purgatory Creek as cross block flow. The primary source of flooding in this area is the lack of storm infrastructure to capture runoff (inlets and culverts), once captured the undersized storm drain system that begins on Burleson Street (the western-most system of Drainage System D) causes flow to leave the drainage easements, channels, and right-of-way as overland flow.

There is also a lack of stormwater infrastructure at, and south of, West Hopkins Street. In the existing conditions cross block flow occurs along West Hopkins Street between Travis Street and North Endicott Street and between Scott Street and Blanco Street. There are up to 10 structures potentially at risk of flooding during the 25-year event in this area. Phase II will incorporate drainage improvements being prepared by others into the post-project model to determine if additional measures will need to be identified to reduce structural flooding and ROW flooding in the area of Drainage System C.

4.3.4 Drainage System D

Drainage System D contains two major storm sewer outfalls into Purgatory Creek just southeast of the intersection of Shady Lane and Valley Street. The eastern-most system carries flow southwest from University Drive west of Fredericksburg Street to an outfall into Purgatory Creek. This storm sewer system appears to convey the 25-year storm event.

The western-most system carries flow from both Drainage System C and flows southeast from the intersection of West Holland Street and Old Ranch Road 12 towards the storm sewer system that starts at the intersection of Rogers Street and Moore Street (Old Ranch Road 12). The main trunkline of this system is made up of pipes ranging from 36-inch RCP to 96-inch RCP and is surcharged for the 25-year event. This is a potential project for Phase II of the analysis. Flows that are not captured by this system continue southeast as both channel and overland flow to Purgatory Creek. The flow is conveyed through drainage infrastructure and as localized overland flow. The primary source of flooding in this area is select locations of undersized storm drain pipes that lead to flow leaving the drainage easements and right-of-way. There are up to 30 structures potentially at risk of flooding during the 25-year event.

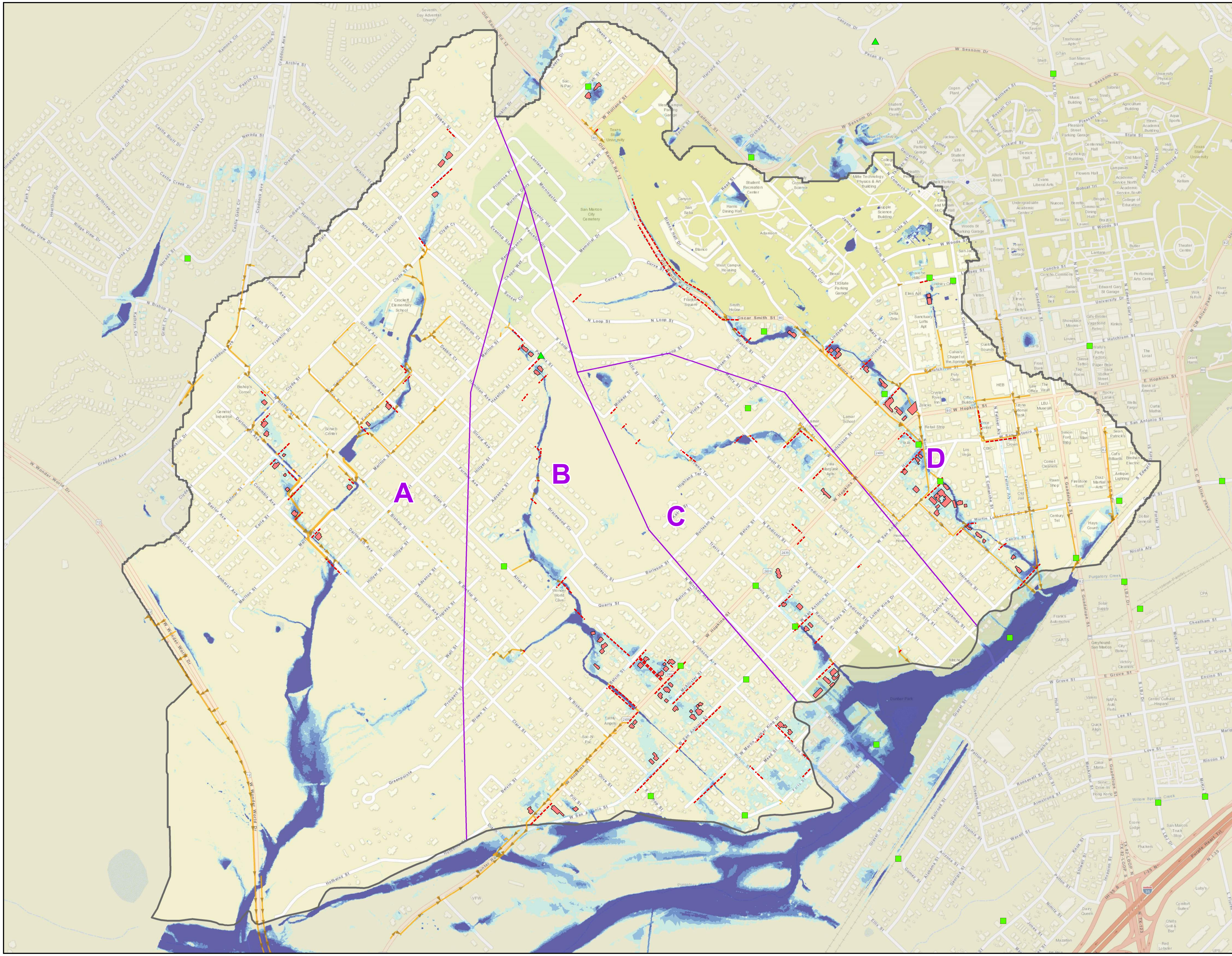
5. Conclusion

Based on the 2D InfoWorks ICM modeling effort performed, lack of storm drain and undersized storm drains within the two square mile study area of the Purgatory Creek watershed cause threat of roadway and structural flooding for the City's 25-year design storm event. Approximately 15% of the existing storm sewer system within the study area appears to be undersized for the design storm. Because of the insufficient stormwater conveyance infrastructure there are potentially 85 homes at potential risk of flooding during the 25-year event. Additionally, more than 90 locations were defined where the existing ROW is insufficient at conveying the 25-year event. Approximately 7,500 linear feet of storm sewer analyzed appears to be undersized to convey the 25-year event which contributes to cross block flow and threat of flood to roadways and existing structures. Phase II of this analysis will include solutions to address these drainage inefficiencies. The Phase II analysis will include solutions development to include evaluation of strategically upsizing critical portions of the existing storm drain system, modification of existing channel networks within the basin, addition of minor storm drain systems, incorporation of on-going storm sewer upgrades being prepared by others, addition of green space lots and/or regional detention upgrades, purchase of additional drainage easements, and/or right-of-way/roadway upgrades.

Appendix A – Exhibits

Exhibit 1: 25-Year Inundation

Exhibit 2: 25-Year Storm Sewer Surcharge State/Capacity



THE CITY OF SAN MARCOS

PURGATORY CREEK WATERSHED DRAINAGE STUDY
25-YR INUNDATION

Legend

- MASTER PLAN PROJECT SITE
- LOCAL DRAINAGE HOT SPOT
- 25-YR FLOOD RISK STRUCTURES*
- FLOW LEAVING ROW
- STORM SEWER
- STUDY AREA
- DRAINAGE SYSTEMS

INUNDATION PONDING DEPTH (FT)

- 0.5 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- >2.00

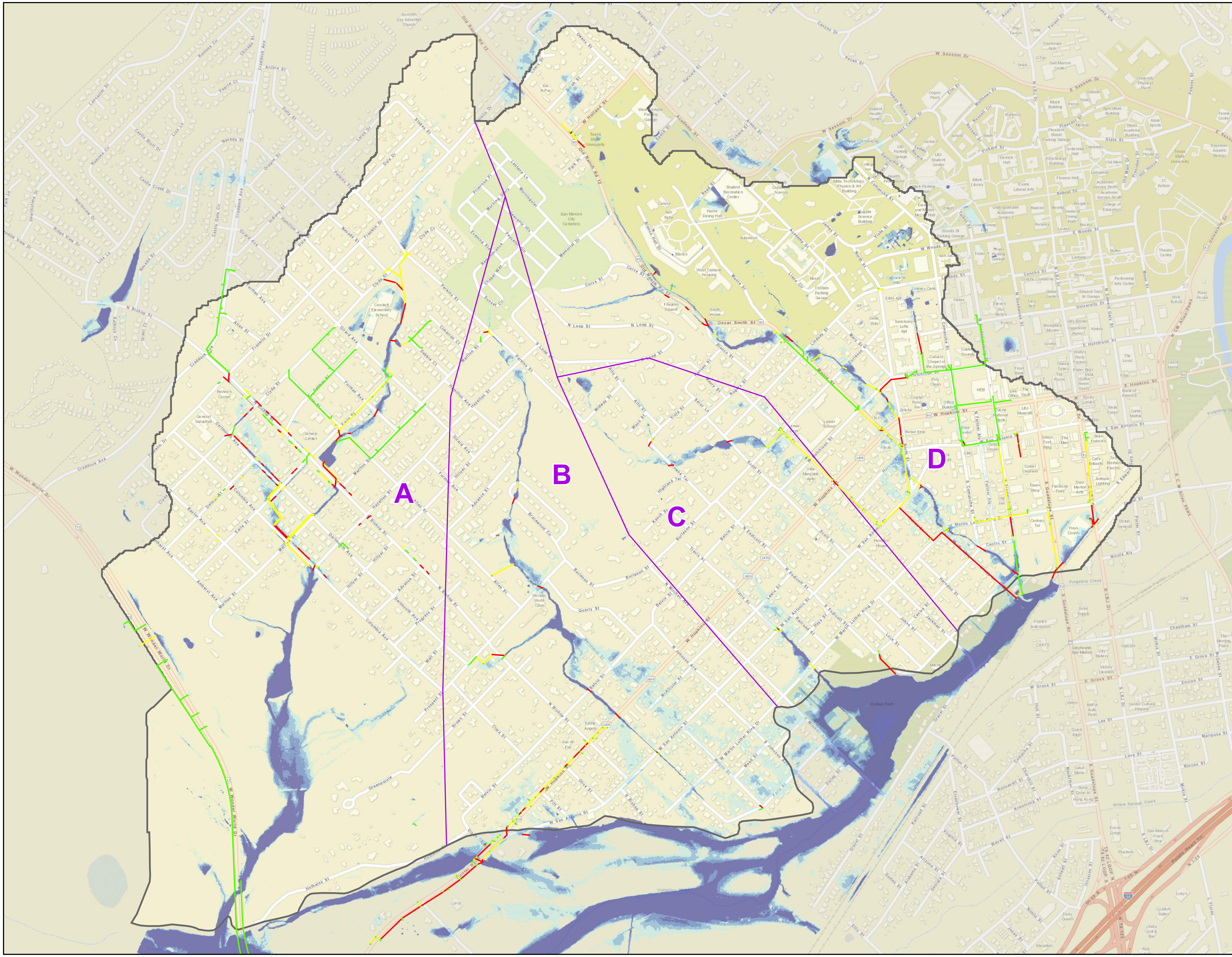
*Based on assumed finished floor elevations.

EXHIBIT 1

Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY
407 S. Stagecoach Trl, Suite 207
San Marcos, TX 78666

DATE: JULY 2018

0 800 1,600
Feet



THE CITY OF SAN MARCOS

PURGATORY CREEK WATERSHED DRAINAGE STUDY

25-YR STORM DRAIN SURCHARGE STATE/ CAPACITY

LEGEND

- STUDY AREA
- DRAINAGE SYSTEMS

INNUNDATION PONDING DEPTH (FT)

- 0.5 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- >2.00

25-YEAR STORM SEWER SURCHARGE STATE*

- <1: NO SURCHARGE, HAS CAPACITY
- 1: PARTIAL SURCHARGE, MAY HAVE CAPACITY
- 2: FULL SURCHARGE, NO CAPACITY

*InfoWorks ICM definitions in Table 4-1 of the report.

EXHIBIT 2

Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY
407 S. Stagecoach Trl, Suite 207
San Marcos, TX 78666

DATE: JULY 2018

0 800 1,600
Feet

Appendix B – 2D Modeling Methods

Purgatory Creek Watershed:
2D Modeling Methods

8/10/18

Prepared by

Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY

Table of Contents

1. Introduction

The purpose of this document is to supplement the City of San Marcos's Stormwater Technical Manual (STM) by providing additional guidance on two-dimensional (2D) hydraulic modeling as applied on the Purgatory Creek Watershed: Phase 1 Drainage Study. The STM does not currently define specific methods or standards for 2D modeling. Various methods and approaches are available for planning and design level analysis that can result in a wide range of modeling outcomes. This document will assist with defining best practices for consistency on this study and future studies.

2. Hydrologic Methods

There are two methods for calculating discharges within a 2D model. The first is rain-on-mesh which involves draping rainfall, represented by a hyetograph, directly onto the 2D mesh. Hydrologic inputs are minimal since the approximated terms of time of concentration and basin storage are calculated directly based on terrain, land use, and infiltration rates. This method was used for the Purgatory Creek Watershed: Phase I Drainage Study.

The second method is applied hydrology represented by hydrographs. Hydrographs can be applied to the model in various ways including directly into a one-dimensional (1D) network, applied as boundary conditions, or a simple runoff node. Hydrographs that are developed inside of or outside of the 2D model must be calculated using accepted City methods. This method was used at a single location for the Purgatory Creek Watershed: Phase 1 Drainage Study. Namely, the Purgatory Creek boundary condition placed in the creek just downstream of NRCS Dam Number 5.

Hydrology used for either planning or design must be checked against other methods for reasonableness. This must be documented in the reports submitted and a detailed explanation for any adjustments and methods shall be provided.

2.1 Runoff Addition

Runoff can be introduced in a variety of ways into a 1D/2D model. The consultant will utilize consistent documented methodology throughout a model for introducing runoff into the system. Where it is necessary to deviate in a particular area of a model, the change in methodology must be documented. Total rainfall and/or rainfall excess may be applied directly to the mesh. Hydrographs are to be computed outside of InfoWorks ICM using HEC-HMS following accepted City criteria.

2.2 Rainfall

A 24-hour frequency storm will be utilized for hydrograph development. Rainfall depths will be obtained from U.S. Geological Survey Scientific Investigations Report 2004-5041 (Asquith and Roussel, 2004) using the centroid of the project area.

2.3 Rainfall Losses

Infiltration losses can be accounted for in InfoWorks ICM by using the rainfall excess for the rain-on-mesh or through infiltration zones (which require extensive calibration and testing of loss coefficients for the Horton Infiltration Method used in InfoWorks ICM). Since rainfall is dropped on both pervious and impervious surfaces in the rain-on-mesh, the consultant must decide if total rainfall or rainfall excess is the best fit for the study area conditions. The National Resources Conservation Service (NRCS) method will be utilized to estimate rainfall losses.

2.4 Routing

Routed hydrographs are not necessary within the 1D/2D study area. Flood routing is directly simulated within the dynamic 2D model.

3. Hydraulic Methods

1D/2D hydrodynamic models rely upon the use of two separate but inter-related networks. The 1D network consists primarily of subsurface storm drainage networks; however, they can be used to represent defined open channels. A 2D mesh is used to represent the surface where runoff is collected or where surcharge from the underlying 1D network is relieved. The connection between the two is essential to the stability and predictability of the results.

3.1 1D Network

3.1.1 Storm Sewer Modeling

Storm sewer connectivity, sizes and flowlines will be compiled from the survey, GIS data and as-built information provided by the City. Where flowline or size information is not available from GIS data or as-built information, it will be supplemented with field measurements or assumed from surrounding similar pipes. In areas with no upstream or downstream information, pipe flowlines will be assumed to be installed at grades sufficient to provide full flow velocities at the minimum two feet-per-second. The Manning's roughness parameters for conduits will be 0.012 for precast concrete pipes and 0.024 for corrugated metal pipes where appropriate.

3.1.2 Node Types

Node types should be set according to what they physically represent. Inlets and points that are to interact with the 2D surface should be set to "2D Node" flood type. Sealed and connectivity manholes should be set to "sealed" flood type in order to not interact with the 2D surface. Storm sewer outfalls that will interact directly with 2D surfaces should be set to "2D outfall" type in order to place runoff back on to the surface at the storm sewer outfall. Traditional 1D outfalls should be set to "outfall" type. All nodes with the exception of "2D Nodes" should use the default parameters as specified per InfoWorks ICM. Parameters and values of "2D Nodes" should be set as shown below:

Ground elevation: assigned by LiDAR

Flooding Discharge Coefficient: 5, in order to not create an arbitrary restriction for the link between the 1D surface and 2D surface elements

Mesh Element Area Factor: 1, or as high as necessary to create a large enough mesh element for the subsurface system to interact with

3.1.3 Inlet Capacity Determination

Drainage inlet capacity will be evaluated to properly model the subsurface infrastructure flow. Inlets will be modeled as a three-part element consisting of two nodes and one link as illustrated below.

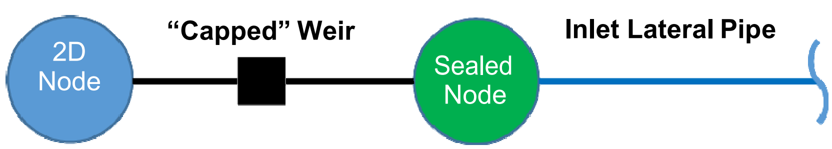


Figure 1: Inlet Capacity Configuration

The first, upstream node is a 2D node that interacts with the 2D mesh surface. The second node is a sealed node representing the connection to the downstream storm sewer system (lateral or trunk line depending on the location). The two nodes are connected via a “capped” weir to represent the losses and restrictions of an inlet. The inlet is represented as a “capped” weir, limiting the amount of flow transferred from the mesh 2D node to the storm sewer system sealed node. The ICM default weir coefficients are inappropriate for STM inlet equations due to the differences in weir equation implementation between the STM and InfoWorks ICM. Table 1 below presents the ICM equivalent coefficients.

Table 1: ICM Equivalent Coefficients

Coefficient Type	Coefficient	ICM Equivalent Coefficient
Weir	3.0	0.53
Weir	2.3	0.405
Orifice	0.67	0.95

Additional Weir parameters should be set as follows:

Length: actual length of inlet opening

Height: actual height of the inlet opening

Crest Elevation: elevation of the inlet throat set at the elevation of the LiDAR minus the height of the opening.

Primary discharge coefficient: 0.53 represents weir flow

Secondary discharge coefficient: 0.95 represents orifice flow when the inlet is overtopped.

Area inlets should be modeled like curb inlets with the weir lengths equal to the total length of sides for the area inlet. Grate inlets should also be modeled with the same approach where the weir length is equal to the total open length of the grates. Grate inlet capacity should be checked against typical STM reported capacities and discharge coefficients within ICM modified to appropriately represent the overall inlet capacity. If desired, blockages can be represented with reductions in the effective weir length or modifying the discharge coefficients to represent a reduced capacity condition.

3.1.4 Inlet Level Hydraulic Inputs

When applied hydrology is used in lieu of rain on mesh, hydrograph results will be exported from HEC-HMS using the HEC DSS-VUE program and imported to the InfoWorks ICM hydraulic model at the points of interest (manhole, inlet, creek, surface, etc.). Each individual runoff hydrograph will be associated with the appropriate node within the model based upon the drainage area and node name. It is recommended that each subbasin be named according to the node that it will contribute to in the model.

3.2 2D Network and Surface

3.2.1 LiDAR

Within ICM, a triangular mesh will be generated to perform the analysis of the surface flows using the built-in InfoWorks mesh creation process. LiDAR data will be provided by the City or acquired from survey data. This data will be imported into ICM as a high resolution ASCII ground model from which the mesh will be created. Elevations at the vertices of the generated mesh elements are interpolated from the LiDAR derived ground model. It is recommended that the raw LiDAR (LAS files) be utilized to create a high-resolution ASCII ground model. This ground model should be comprised of bare earth returns only and should be post processed into a grid of resolution sufficient to represent the area of interest. It is recommended that the grid resolution be of sub-5'x5' grids in order to appropriately represent the study area.

3.2.2 2D Simulation Area

The mesh minimum triangle size will be adjusted to provide adequate definition of the study area. The terrain-sensitive meshing will be used and a six-inch max elevation difference set to ensure that curbs are visible in the 2D mesh zone. Recommended baseline parameters for the 2D simulation area are below:

Mesh ID: 1
Maximum Triangle Area: 1500 square feet
Minimum Triangle Area: 10 square feet, subject to change depending on underlying LiDAR resolution
Boundary Type: normal; to allow flow to leave the study area Terrain Sensitive Meshing: enabled
Maximum Height Variation:
0.5-feet Roughness: standard
concrete values
Apply rainfall directly to mesh elements: enabled

Building footprints will not be placed as voids during development of the initial "rain-on-mesh" model due to the void area being removed from the mesh area artificially lowering the total volume of storm water calculated.

3.2.3 Roughness Zones

Overland roughness zones are incorporated into the 2D mesh surface to account for variations in surface roughness such as the change from concrete areas to grassed areas. City land use data will be used to specify the correct roughness value assigned to different areas within the study area. Building footprint GIS data will be input as roughness areas with a high roughness coefficient to slow the flow through buildings.

Recommended Manning's roughness coefficients for overland flow to be used in 2D modeling are shown in Table 2 below. For unique project areas and challenges, the Consultant can work with the City to establish project specific n-values, as needed, that meet the City's STM criteria and 2D modeling goals.

Table 2: Roughness Values for Flow less than 3.0 feet

Manning's "n"	Land Use
0.016	Streets, paved areas
0.085	Generic Residential
0.12	Dense Grass Areas (lawns)
0.14	Generic Undeveloped Area
10	Buildings/Structures

3.2.4 Break lines and Porous Walls/Polygons

Even with terrain sensitive meshing, it may be necessary to establish break lines in order to better represent critical topographic features such as roadway crowns, roadway curbs, and other distinct topographic transitions. Break lines should be drawn with the minimal number of vertices in order to describe the feature. Additional vertices can over complicate the mesh and create a high number of small triangles which can slow down the overall simulations. Break lines placed next to one another or directly adjacent (touching) should be drawn with snapping enabled and the end/start points of each break line exactly coincident.

Complicated overland flow regimes involving cross block flooding and fences may necessitate the need for porous walls. It is recommended that porous walls and polygons not be part of the initial simulation and only be added if the verification and validation events do not adequately represent known water surfaces or ponding extents. Porous walls and polygons have the ability to represent partially porous structures such as fences and building crawl spaces. Porous walls and polygons should be drawn with snapping enabled and with the minimal number of vertices necessary to represent the feature. Care should be taken with drawing porous walls and polygons to ensure that numerous small triangular features are not created within the mesh. If porous walls or polygons are necessary, the porosity of each feature should be estimated with field visits or other data. Porous polygons should not be used to model buildings unless approved by the City.

3.2.5 Mesh Zones and Mesh Level Zones

Mesh zones are polygons where minimum and/or maximum mesh triangle size can be set. Mesh zones should be utilized if a change in the prevailing mesh resolution of the 2D study area is necessary; for example, when areas of higher resolution are needed while keeping the overall mesh counts as low as possible to assist with shorter run times.

Mesh level zones are areas along a defined polygon where elevations are set. Mesh level zones can be utilized to better define pertinent drainage features such as channels, ponds, retaining walls, drop structures, and building foundations.

Mesh level zones and mesh zones should be utilized when LiDAR elevations do not match known field conditions. Mesh zones redefine the mesh triangle size whereas mesh level zones set specific elevations for known elements of interest. Therefore, mesh level zones should be utilized when more control is required for surface adjustments.

3.2.6 Infiltration Zones

Initial and infiltration losses accounted for as part of the HEC-HMS model shall not be “double counted” within the 2D surface. Meaning that if lumped hydrology is used, which takes into account initial and infiltration losses within HEC-HMS, it may not be distributed over a rain-on-mesh with infiltration zones.

3.3 Boundary Conditions

Storm sewer outfall locations should be evaluated in order to determine the influence of potential downstream conditions. If there is a natural or man-made drainage feature (i.e. drainage ditch, creek, river, pond, or lake) that the system outfalls into, the water surface elevation level (WSEL) of that feature will be determined. The resulting WSEL will be incorporated into the model as a Level Event that can be assigned to that outfall node or edge of the 2D mesh. If the travel time of the system being studied is significantly shorter than the system it outfalls into, a reasonably constant WSEL will be applied to the outfall node unless otherwise specified. If no detailed information can be found for the upstream or downstream drainage features, the 2D mesh zone area will be extended a distance upstream and downstream. If outfalling to a drainage feature where offsite influences are expected, a 2D inflow point or inflow line, will be applied to the upstream edge of the 2D mesh and a known level or normal depth condition at the downstream edge of the mesh.

3.4 Simulation Run Parameters

Simulation parameters form the basis for how InfoWorks ICM runs are performed and stored. Recommended defaults are as follows:

Name: "TypeReturnPeriodDuration;" example

"ExistingConditions100yr24hr" Run Parameters

Start: 00:00 01/01/2016 or to match inflow and tailwater

start times Timestep: 1s

Results Timestep

Multiplier: 60 Gauge

Timestep Multiplier: 60

Finish

Duration: 1440 minutes, assuming a 24-hour storm

Rain Event: Blank, unless running a rain-on-mesh simulation

Inflow: inflow for the specified return period and storm

duration Level: level for the specified return period and

storm duration, if tailwaters apply

Other Options:

Summary PRN Results:

enabled Exit if initialization

fails: enabled

2D Parameters/ GPU: always

enabled Diagnostics/Timestep

log: enabled

4. Calibration/Validation

Once the ICM model is built, runoff hydrographs for multiple historic flood events (if available) will be developed for each of the drainage areas based on rainfall depths or rain gages in the region. The hydrographs will be input to the 2D model and simulated to produce inundation depths for each event. The inundation results will be compared to the observed high water marks. Based on the results, the HEC-HMS and/or ICM model will be adjusted as appropriate to best simulate the historic events. Potential items to be adjusted include the following: overland roughness zones, structural block outs, porous walls, porous polygons, infiltration parameters, inlet locations, inlet losses, tailwater conditions, mesh resolution, mesh adjustment zones, and break lines.

Appendix C – Site Visit and Historic Event Photos

Figure C-1: Outfall Southeast of Intersection of Shady Lane and Valley Street

Figure C-2: Outfall South of Intersection of South Fredericksburg Street and Valley Street

Figure C-3: Typical Channel Cross Section at intersection of Girard Street and Earle Street

Figure C-4: Typical Channel Cross Section at intersection of Lindsey Street and Moore Street

Figure C-5: Girard Street and Earle Street at 11:46 am on April 11, 2017

Figure C-6: Two Feet of Water in 1207 Belvin Street after April 11, 2017 Event

Figure C-7: Remmes Field across Veramendi Street during April 11, 2017 Event

Appendix D – Hydrologic Data

Table D-1: Weighted Curve Number Calculations/Impervious Cover

Table D-2: 25-Year Rainfall Event

Table D-3: Input Hydrograph

Table D-4: April 11, 2017 Historic Rainfall Event

Halff's San Marcos Area Precipitation Analysis: April 11, 2017 – April 12, 2017

Project:	Purgatory Creek Watershed Storm Drain Study		
Subject:	Hydrologic Data for Rain on Mesh Simulations		
Task:	Hydrology		
Job #:	120-12062-000		
Engineer:	OEM	Reviewer:	LMC
Date:	1/26/2018	Date:	1/30/2018

D-1.1: Weighted Impervious Cover Calculation

Area (ac)	Zoning Code	Land Use	% Impervious
12.04	CC	Community Commercial	80%
6.75	CS*	Civic Space	40%
81.98	D	Duplex Residential District	75%
1.50	DR	Duplex Restricted District	75%
23.17	FD	Future Development District	30%
7.12	GC	General Commercial District	80%
2.39	LI	Light Industrial District	85%
13.49	MF-12	Multiple-Family Residential	75%
7.39	MF-18	Multiple-Family Residential	75%
35.01	MF-24	Multiple-Family Residential	75%
1.00	MR	Manufactured Home/Residential District	50%
26.70	MU	Mixed Use District	60%
2.58	NC	Neighborhood Commercial District	80%
2.55	OP	Office Professional District	80%
260.77	P	Public and Institutional District	80%
14.27	SF-4.5	Single Family District	60%
622.23	SF-6	Single Family District	50%
2.93	SF-R	Rural Residential District	15%
6.75	T4*	General Urban Zone	60%
73.11	T5*	Urban Center Zone	100%
14.13	TH	Townhouse Residential District	70%
			66.05%

D-1.2: Weighted Curve Number Calculation

Area (ac)	Hydrologic Soil Group	Curve Number
18.21	A	39
61.63	B	61
174.58	C	74
963.25	D	80
		77.57

Land use from City of San Marcos Zoning shapefile with percent impervious cover by zoning type as defined in Section 4.1.6 of the City of San Marcos Land Development Code

*Civic Spaces, General Urban Zone and Urban Center Zone are not assigned a Percent (%) Impervious Cover in Section 4.1.6, therefore the max allowable lot coverage values from Table 1.2 and the descriptions from Table 3.4 in the City of San Marcos Land Development

Table D-2: 25-Year Rainfall Event

Time	25-yr Total Rainfall (in)	25-yr Intensity (in/hr)
0:00	0	0
0:05	0.00871	0.10452
0:10	0.00875	0.105
0:15	0.00879	0.10548
0:20	0.00883	0.10596
0:25	0.00887	0.10644
0:30	0.00891	0.10692
0:35	0.00896	0.10752
0:40	0.009	0.108
0:45	0.00905	0.1086
0:50	0.00909	0.10908
0:55	0.00914	0.10968
1:00	0.00918	0.11016
1:05	0.00923	0.11076
1:10	0.00928	0.11136
1:15	0.00932	0.11184
1:20	0.00937	0.11244
1:25	0.00942	0.11304
1:30	0.00947	0.11364
1:35	0.00952	0.11424
1:40	0.00957	0.11484
1:45	0.00963	0.11556
1:50	0.00968	0.11616
1:55	0.00973	0.11676
2:00	0.00978	0.11736
2:05	0.00984	0.11808
2:10	0.00989	0.11868
2:15	0.00995	0.1194
2:20	0.01001	0.12012
2:25	0.01007	0.12084
2:30	0.01012	0.12144
2:35	0.01018	0.12216
2:40	0.01025	0.123
2:45	0.01031	0.12372
2:50	0.01037	0.12444
2:55	0.01043	0.12516
3:00	0.0105	0.126
3:05	0.01056	0.12672
3:10	0.01063	0.12756
3:15	0.01069	0.12828
3:20	0.01076	0.12912
3:25	0.01083	0.12996
3:30	0.0109	0.1308

Time	25-yr Total Rainfall (in)	25-yr Intensity (in/hr)
3:35	0.01098	0.13176
3:40	0.01105	0.1326
3:45	0.01112	0.13344
3:50	0.0112	0.1344
3:55	0.01127	0.13524
4:00	0.01135	0.1362
4:05	0.01143	0.13716
4:10	0.01151	0.13812
4:15	0.01159	0.13908
4:20	0.01168	0.14016
4:25	0.01176	0.14112
4:30	0.01185	0.1422
4:35	0.01194	0.14328
4:40	0.01203	0.14436
4:45	0.01212	0.14544
4:50	0.01221	0.14652
4:55	0.01231	0.14772
5:00	0.01241	0.14892
5:05	0.01251	0.15012
5:10	0.01261	0.15132
5:15	0.01271	0.15252
5:20	0.01282	0.15384
5:25	0.01292	0.15504
5:30	0.01303	0.15636
5:35	0.01314	0.15768
5:40	0.01326	0.15912
5:45	0.01338	0.16056
5:50	0.0135	0.162
5:55	0.01362	0.16344
6:00	0.01374	0.16488
6:05	0.00878	0.10536
6:10	0.00888	0.10656
6:15	0.00898	0.10776
6:20	0.00909	0.10908
6:25	0.00919	0.11028
6:30	0.0093	0.1116
6:35	0.00941	0.11292
6:40	0.00953	0.11436
6:45	0.00964	0.11568
6:50	0.00977	0.11724
6:55	0.00989	0.11868
7:00	0.01002	0.12024
7:05	0.01015	0.1218
7:10	0.01029	0.12348
7:15	0.01043	0.12516
7:20	0.01057	0.12684
7:25	0.01072	0.12864
7:30	0.01088	0.13056
7:35	0.01104	0.13248
7:40	0.0112	0.1344
7:45	0.01138	0.13656

Time	25-yr Total Rainfall (in)	25-yr Intensity (in/hr)
7:50	0.01155	0.1386
7:55	0.01174	0.14088
8:00	0.01193	0.14316
8:05	0.01212	0.14544
8:10	0.01233	0.14796
8:15	0.01254	0.15048
8:20	0.01276	0.15312
8:25	0.01299	0.15588
8:30	0.01323	0.15876
8:35	0.01348	0.16176
8:40	0.01374	0.16488
8:45	0.01402	0.16824
8:50	0.0143	0.1716
8:55	0.0146	0.1752
9:00	0.01492	0.17904
9:05	0.01293	0.15516
9:10	0.01323	0.15876
9:15	0.01355	0.1626
9:20	0.01389	0.16668
9:25	0.01425	0.171
9:30	0.01463	0.17556
9:35	0.01504	0.18048
9:40	0.01547	0.18564
9:45	0.01592	0.19104
9:50	0.01641	0.19692
9:55	0.01694	0.20328
10:00	0.0175	0.21
10:05	0.0181	0.2172
10:10	0.01875	0.225
10:15	0.01946	0.23352
10:20	0.02023	0.24276
10:25	0.02107	0.25284
10:30	0.02199	0.26388
10:35	0.03829	0.45948
10:40	0.03988	0.47856
10:45	0.04166	0.49992
10:50	0.04363	0.52356
10:55	0.04584	0.55008
11:00	0.04835	0.5802
11:05	0.0567	0.6804
11:10	0.0602	0.7224
11:15	0.0643	0.7716
11:20	0.06916	0.82992
11:25	0.07505	0.9006
11:30	0.08238	0.98856
11:35	0.10943	1.31316
11:40	0.12297	1.47564
11:45	0.14207	1.70484
11:50	0.21867	2.62404
11:55	0.2743	3.2916
12:00	0.58862	7.06344

Time	25-yr Total Rainfall (in)	25-yr Intensity (in/hr)
12:05	0.58862	7.06344
12:10	0.58862	7.06344
12:15	0.24178	2.90136
12:20	0.15506	1.86072
12:25	0.13161	1.57932
12:30	0.11568	1.38816
12:35	0.08676	1.04112
12:40	0.0785	0.942
12:45	0.07196	0.86352
12:50	0.06662	0.79944
12:55	0.06216	0.74592
13:00	0.05839	0.70068
13:05	0.04974	0.59688
13:10	0.04706	0.56472
13:15	0.0447	0.5364
13:20	0.04261	0.51132
13:25	0.04075	0.489
13:30	0.03907	0.46884
13:35	0.02248	0.26976
13:40	0.02152	0.25824
13:45	0.02064	0.24768
13:50	0.01984	0.23808
13:55	0.0191	0.2292
14:00	0.01842	0.22104
14:05	0.01779	0.21348
14:10	0.01721	0.20652
14:15	0.01667	0.20004
14:20	0.01616	0.19392
14:25	0.01569	0.18828
14:30	0.01525	0.183
14:35	0.01483	0.17796
14:40	0.01444	0.17328
14:45	0.01407	0.16884
14:50	0.01372	0.16464
14:55	0.01339	0.16068
15:00	0.01308	0.15696
15:05	0.01508	0.18096
15:10	0.01476	0.17712
15:15	0.01445	0.1734
15:20	0.01416	0.16992
15:25	0.01388	0.16656
15:30	0.01361	0.16332
15:35	0.01336	0.16032
15:40	0.01311	0.15732
15:45	0.01288	0.15456
15:50	0.01265	0.1518
15:55	0.01243	0.14916
16:00	0.01222	0.14664
16:05	0.01202	0.14424
16:10	0.01183	0.14196
16:15	0.01164	0.13968

Time	25-yr Total Rainfall (in)	25-yr Intensity (in/hr)
16:20	0.01146	0.13752
16:25	0.01129	0.13548
16:30	0.01112	0.13344
16:35	0.01096	0.13152
16:40	0.0108	0.1296
16:45	0.01065	0.1278
16:50	0.0105	0.126
16:55	0.01036	0.12432
17:00	0.01022	0.12264
17:05	0.01009	0.12108
17:10	0.00996	0.11952
17:15	0.00983	0.11796
17:20	0.00971	0.11652
17:25	0.00959	0.11508
17:30	0.00947	0.11364
17:35	0.00936	0.11232
17:40	0.00925	0.111
17:45	0.00914	0.10968
17:50	0.00903	0.10836
17:55	0.00893	0.10716
18:00	0.00883	0.10596
18:05	0.01381	0.16572
18:10	0.01368	0.16416
18:15	0.01356	0.16272
18:20	0.01344	0.16128
18:25	0.01332	0.15984
18:30	0.0132	0.1584
18:35	0.01309	0.15708
18:40	0.01298	0.15576
18:45	0.01287	0.15444
18:50	0.01276	0.15312
18:55	0.01266	0.15192
19:00	0.01256	0.15072
19:05	0.01246	0.14952
19:10	0.01236	0.14832
19:15	0.01226	0.14712
19:20	0.01217	0.14604
19:25	0.01207	0.14484
19:30	0.01198	0.14376
19:35	0.01189	0.14268
19:40	0.01181	0.14172
19:45	0.01172	0.14064
19:50	0.01164	0.13968
19:55	0.01155	0.1386
20:00	0.01147	0.13764
20:05	0.01139	0.13668
20:10	0.01131	0.13572
20:15	0.01124	0.13488
20:20	0.01116	0.13392
20:25	0.01108	0.13296
20:30	0.01101	0.13212

Time	25-yr Total Rainfall (in)	25-yr Intensity (in/hr)
20:35	0.01094	0.13128
20:40	0.01087	0.13044
20:45	0.0108	0.1296
20:50	0.01073	0.12876
20:55	0.01066	0.12792
21:00	0.01059	0.12708
21:05	0.01053	0.12636
21:10	0.01046	0.12552
21:15	0.0104	0.1248
21:20	0.01034	0.12408
21:25	0.01028	0.12336
21:30	0.01021	0.12252
21:35	0.01015	0.1218
21:40	0.0101	0.1212
21:45	0.01004	0.12048
21:50	0.00998	0.11976
21:55	0.00992	0.11904
22:00	0.00987	0.11844
22:05	0.00981	0.11772
22:10	0.00976	0.11712
22:15	0.0097	0.1164
22:20	0.00965	0.1158
22:25	0.0096	0.1152
22:30	0.00955	0.1146
22:35	0.0095	0.114
22:40	0.00945	0.1134
22:45	0.0094	0.1128
22:50	0.00935	0.1122
22:55	0.0093	0.1116
23:00	0.00925	0.111
23:05	0.00921	0.11052
23:10	0.00916	0.10992
23:15	0.00911	0.10932
23:20	0.00907	0.10884
23:25	0.00902	0.10824
23:30	0.00898	0.10776
23:35	0.00894	0.10728
23:40	0.00889	0.10668
23:45	0.00885	0.1062
23:50	0.00881	0.10572
23:55	0.00877	0.10524
24:00	0.00873	0.10476

Project:	Purgatory Creek Watershed Storm Drain Study	Engineer:	OEM
Subject:	Hydrologic Data for Rain on Mesh Simulations	Date:	1/26/2018
Task:	Hydrology	Reviewer:	LMC
Job #:	120-12062-000	Date:	1/30/2018

D-3: Dam Outflow Input Hydrograph

Source: City of San Marcos Comprehensive Watershed Master Plan Update by Halff Associates, November 2017

NRCS Dam No. 5	
Date	**Outflow (in)**
1/1/2018 0:00	0
1/1/2018 0:02	0.199987
1/1/2018 0:04	1.400015
1/1/2018 0:06	3.200003
1/1/2018 0:08	5.200014
1/1/2018 0:10	7.599999
1/1/2018 0:12	10.20001
1/1/2018 0:14	13
1/1/2018 0:16	16.09999
1/1/2018 0:18	19.3
1/1/2018 0:20	22.69999
1/1/2018 0:22	26.19999
1/1/2018 0:24	29.90001
1/1/2018 0:26	33.70001
1/1/2018 0:28	37.50001
1/1/2018 0:30	41.5
1/1/2018 0:32	45.50002
1/1/2018 0:34	49.60001
1/1/2018 0:36	53.70001
1/1/2018 0:38	57.89999
1/1/2018 0:40	62.09999
1/1/2018 0:42	66.3
1/1/2018 0:44	70.59999
1/1/2018 0:46	74.8
1/1/2018 0:48	79.10002
1/1/2018 0:50	83.4
1/1/2018 0:52	87.69998
1/1/2018 0:54	91.89999
1/1/2018 0:56	95.60002
1/1/2018 0:58	98.79998
1/1/2018 1:00	101.9
1/1/2018 1:02	105.1
1/1/2018 1:04	108.3
1/1/2018 1:06	111.4
1/1/2018 1:08	114.6

NRCS Dam No. 5	
Date	**Outflow (in)**
1/1/2018 1:10	117.7
1/1/2018 1:12	120.9
1/1/2018 1:14	124
1/1/2018 1:16	127.1
1/1/2018 1:18	130.2
1/1/2018 1:20	133.3
1/1/2018 1:22	136.4
1/1/2018 1:24	139.4
1/1/2018 1:26	142.5
1/1/2018 1:28	145.5
1/1/2018 1:30	148.5
1/1/2018 1:32	151.5
1/1/2018 1:34	154.4
1/1/2018 1:36	157.3
1/1/2018 1:38	160.2
1/1/2018 1:40	163.1
1/1/2018 1:42	165.9
1/1/2018 1:44	168.7
1/1/2018 1:46	171.4
1/1/2018 1:48	174.2
1/1/2018 1:50	176.9
1/1/2018 1:52	179.5
1/1/2018 1:54	182.2
1/1/2018 1:56	184.8
1/1/2018 1:58	187.3
1/1/2018 2:00	189.9
1/1/2018 2:02	192.4
1/1/2018 2:04	194.9
1/1/2018 2:06	197.4
1/1/2018 2:08	199.8
1/1/2018 2:10	202.3
1/1/2018 2:12	204.7
1/1/2018 2:14	207.1
1/1/2018 2:16	209.4
1/1/2018 2:18	211.7

NRCS Dam No. 5	
Date	**Outflow (in)**
1/1/2018 2:20	214.1
1/1/2018 2:22	216.4
1/1/2018 2:24	218.6
1/1/2018 2:26	220.9
1/1/2018 2:28	223.1
1/1/2018 2:30	225.3
1/1/2018 2:32	227.5
1/1/2018 2:34	229.7
1/1/2018 2:36	231.8
1/1/2018 2:38	233.9
1/1/2018 2:40	236
1/1/2018 2:42	238.1
1/1/2018 2:44	240.2
1/1/2018 2:46	242.2
1/1/2018 2:48	244.2
1/1/2018 2:50	246.2
1/1/2018 2:52	248.2
1/1/2018 2:54	250.1
1/1/2018 2:56	251.7
1/1/2018 2:58	252.6
1/1/2018 3:00	253.4
1/1/2018 3:02	254.3
1/1/2018 3:04	255.2
1/1/2018 3:06	256
1/1/2018 3:08	256.8
1/1/2018 3:10	257.8
1/1/2018 3:12	259.3
1/1/2018 3:14	260.8
1/1/2018 3:16	262.3
1/1/2018 3:18	263.3
1/1/2018 3:20	264
1/1/2018 3:22	264.8
1/1/2018 3:24	264.5
1/1/2018 3:26	266
1/1/2018 3:28	267

NRCS Dam No. 5	
Date	Outflow (in)
1/1/2018 3:30	267.8
1/1/2018 3:32	268.5
1/1/2018 3:34	269.2
1/1/2018 3:36	269.2
1/1/2018 3:38	270.7
1/1/2018 3:40	271.4
1/1/2018 3:42	272
1/1/2018 3:44	272.7
1/1/2018 3:46	273.5
1/1/2018 3:48	274.2
1/1/2018 3:50	274.8
1/1/2018 3:52	275.5
1/1/2018 3:54	275.9
1/1/2018 3:56	276.8
1/1/2018 3:58	277.3
1/1/2018 4:00	278.2
1/1/2018 4:02	278.8
1/1/2018 4:04	279.5
1/1/2018 4:06	280.1
1/1/2018 4:08	280.7
1/1/2018 4:10	281.4
1/1/2018 4:12	282
1/1/2018 4:14	282.6
1/1/2018 4:16	283.2
1/1/2018 4:18	283.8
1/1/2018 4:20	284.2
1/1/2018 4:22	285.1
1/1/2018 4:24	285.7
1/1/2018 4:26	286.3
1/1/2018 4:28	286.9
1/1/2018 4:30	287.4
1/1/2018 4:32	287.9
1/1/2018 4:34	288.6
1/1/2018 4:36	289.2
1/1/2018 4:38	289.1
1/1/2018 4:40	290.3
1/1/2018 4:42	290.5
1/1/2018 4:44	291.5
1/1/2018 4:46	292
1/1/2018 4:48	292.6
1/1/2018 4:50	292.8
1/1/2018 4:52	293.7
1/1/2018 4:54	294.2
1/1/2018 4:56	294.8
1/1/2018 4:58	295

NRCS Dam No. 5	
Date	Outflow (in)
1/1/2018 5:00	295.9
1/1/2018 5:02	296.1
1/1/2018 5:04	296.6
1/1/2018 5:06	297.4
1/1/2018 5:08	298
1/1/2018 5:10	298.5
1/1/2018 5:12	299
1/1/2018 5:14	299.4
1/1/2018 5:16	300
1/1/2018 5:18	300.5
1/1/2018 5:20	301.1
1/1/2018 5:22	301.6
1/1/2018 5:24	301.9
1/1/2018 5:26	302.2
1/1/2018 5:28	303
1/1/2018 5:30	303.5
1/1/2018 5:32	304
1/1/2018 5:34	304.5
1/1/2018 5:36	305
1/1/2018 5:38	305.5
1/1/2018 5:40	306
1/1/2018 5:42	305.2
1/1/2018 5:44	306.9
1/1/2018 5:46	307.3
1/1/2018 5:48	307.9
1/1/2018 5:50	307.6
1/1/2018 5:52	308.8
1/1/2018 5:54	309.2
1/1/2018 5:56	309.7
1/1/2018 5:58	310.2
1/1/2018 6:00	310.6
1/1/2018 6:02	311.1
1/1/2018 6:04	311.4
1/1/2018 6:06	311.6
1/1/2018 6:08	312.4
1/1/2018 6:10	312.8
1/1/2018 6:12	313.3
1/1/2018 6:14	313.4
1/1/2018 6:16	314.1
1/1/2018 6:18	314.4
1/1/2018 6:20	314.9
1/1/2018 6:22	315.4
1/1/2018 6:24	315.7
1/1/2018 6:26	316.1
1/1/2018 6:28	316.5

NRCS Dam No. 5	
Date	Outflow (in)
1/1/2018 6:30	316.9
1/1/2018 6:32	317.2
1/1/2018 6:34	317.7
1/1/2018 6:36	318
1/1/2018 6:38	318.4
1/1/2018 6:40	318.8
1/1/2018 6:42	318.8
1/1/2018 6:44	318.6
1/1/2018 6:46	319.9
1/1/2018 6:48	320
1/1/2018 6:50	320.5
1/1/2018 6:52	320.8
1/1/2018 6:54	321.1
1/1/2018 6:56	321.2
1/1/2018 6:58	321.9
1/1/2018 7:00	322.1
1/1/2018 7:02	322.5
1/1/2018 7:04	322.8
1/1/2018 7:06	322.9
1/1/2018 7:08	323.5
1/1/2018 7:10	323.5
1/1/2018 7:12	324.1
1/1/2018 7:14	324.1
1/1/2018 7:16	324.7
1/1/2018 7:18	325
1/1/2018 7:20	325.2
1/1/2018 7:22	324.9
1/1/2018 7:24	325.8
1/1/2018 7:26	326.1
1/1/2018 7:28	326.4
1/1/2018 7:30	326.7
1/1/2018 7:32	326.9
1/1/2018 7:34	327.2
1/1/2018 7:36	327.5
1/1/2018 7:38	327.7
1/1/2018 7:40	327.9
1/1/2018 7:42	328.3
1/1/2018 7:44	328.5
1/1/2018 7:46	328.8
1/1/2018 7:48	329
1/1/2018 7:50	328.7
1/1/2018 7:52	329.6
1/1/2018 7:54	329.8
1/1/2018 7:56	330.1
1/1/2018 7:58	330.3

NRCS Dam No. 5	
Date	Outflow (in)
1/1/2018 8:00	330.6
1/1/2018 8:02	330.2
1/1/2018 8:04	330.5
1/1/2018 8:06	331.3
1/1/2018 8:08	331.4
1/1/2018 8:10	331.8
1/1/2018 8:12	332.1
1/1/2018 8:14	332.3
1/1/2018 8:16	332.6
1/1/2018 8:18	332.8
1/1/2018 8:20	333.1
1/1/2018 8:22	333.3
1/1/2018 8:24	333.6
1/1/2018 8:26	333.5
1/1/2018 8:28	334.1
1/1/2018 8:30	334.3
1/1/2018 8:32	334.6
1/1/2018 8:34	334.3
1/1/2018 8:36	335.1
1/1/2018 8:38	335.3
1/1/2018 8:40	335.3
1/1/2018 8:42	334.5
1/1/2018 8:44	336.1
1/1/2018 8:46	334
1/1/2018 8:48	336.7
1/1/2018 8:50	337
1/1/2018 8:52	337.2
1/1/2018 8:54	337.6
1/1/2018 8:56	337.6
1/1/2018 8:58	338.2
1/1/2018 9:00	338.5
1/1/2018 9:02	338.8
1/1/2018 9:04	339.1
1/1/2018 9:06	339.5
1/1/2018 9:08	339.8
1/1/2018 9:10	340.2
1/1/2018 9:12	340.5
1/1/2018 9:14	340.9
1/1/2018 9:16	341.2
1/1/2018 9:18	341.6
1/1/2018 9:20	341.8
1/1/2018 9:22	342.3
1/1/2018 9:24	342.7
1/1/2018 9:26	343.1
1/1/2018 9:28	343.1

NRCS Dam No. 5	
Date	Outflow (in)
1/1/2018 9:30	343.7
1/1/2018 9:32	344.2
1/1/2018 9:34	344.6
1/1/2018 9:36	345
1/1/2018 9:38	345.5
1/1/2018 9:40	345.9
1/1/2018 9:42	346.2
1/1/2018 9:44	346.8
1/1/2018 9:46	347.3
1/1/2018 9:48	347.6
1/1/2018 9:50	348.3
1/1/2018 9:52	348.8
1/1/2018 9:54	349.1
1/1/2018 9:56	350
1/1/2018 9:58	350.6
1/1/2018 10:00	351.1
1/1/2018 10:02	351.6
1/1/2018 10:04	350.3
1/1/2018 10:06	353.2999
1/1/2018 10:08	353.9999
1/1/2018 10:10	354.8001
1/1/2018 10:12	355.4001
1/1/2018 10:14	356.3999
1/1/2018 10:16	357.3
1/1/2018 10:18	358.0999
1/1/2018 10:20	358.6999
1/1/2018 10:22	360.3
1/1/2018 10:24	361.1998
1/1/2018 10:26	362.2999
1/1/2018 10:28	363.4999
1/1/2018 10:30	355.9002
1/1/2018 10:32	351.8
1/1/2018 10:34	363.9
1/1/2018 10:36	363.3999
1/1/2018 10:38	363.4999
1/1/2018 10:40	363.9999
1/1/2018 10:42	363.2
1/1/2018 10:44	363.0002
1/1/2018 10:46	363.9999
1/1/2018 10:48	363.9
1/1/2018 10:50	362.4002
1/1/2018 10:52	363.9
1/1/2018 10:54	363.8
1/1/2018 10:56	363.9999
1/1/2018 10:58	363.9999

NRCS Dam No. 5	
Date	Outflow (in)
1/1/2018 11:00	363.9
1/1/2018 11:02	366.2
1/1/2018 11:04	368.8998
1/1/2018 11:06	371.6
1/1/2018 11:08	373.4999
1/1/2018 11:10	375.6001
1/1/2018 11:12	377.7998
1/1/2018 11:14	380.0999
1/1/2018 11:16	382.6002
1/1/2018 11:18	385.3
1/1/2018 11:20	388.1001
1/1/2018 11:22	391.2
1/1/2018 11:24	394.5001
1/1/2018 11:26	397.9998
1/1/2018 11:28	401.7001
1/1/2018 11:30	405.8001
1/1/2018 11:32	410.0001
1/1/2018 11:34	414.5998
1/1/2018 11:36	419.4002
1/1/2018 11:38	424.5999
1/1/2018 11:40	429.9999
1/1/2018 11:42	435.7
1/1/2018 11:44	441.7999
1/1/2018 11:46	448.2
1/1/2018 11:48	454.8999
1/1/2018 11:50	460.5001
1/1/2018 11:52	465.7002
1/1/2018 11:54	471.2001
1/1/2018 11:56	477.1001
1/1/2018 11:58	483.3999
1/1/2018 12:00	490.3
1/1/2018 12:02	497.6998
1/1/2018 12:04	505.9998
1/1/2018 12:06	515.1001
1/1/2018 12:08	525.2001
1/1/2018 12:10	535.5
1/1/2018 12:12	545.1998
1/1/2018 12:14	555.7999
1/1/2018 12:16	567.3001
1/1/2018 12:18	579.7001
1/1/2018 12:20	592.8001
1/1/2018 12:22	604.6002
1/1/2018 12:24	615.5
1/1/2018 12:26	626.8
1/1/2018 12:28	638.2999

NRCS Dam No. 5	
Date	Outflow (in)
1/1/2018 12:30	650.1999
1/1/2018 12:32	661.3
1/1/2018 12:34	671.1002
1/1/2018 12:36	680.9999
1/1/2018 12:38	691
1/1/2018 12:40	701.1999
1/1/2018 12:42	711.2999
1/1/2018 12:44	720.1999
1/1/2018 12:46	728.9
1/1/2018 12:48	737.4998
1/1/2018 12:50	745.9001
1/1/2018 12:52	754.2002
1/1/2018 12:54	762.2
1/1/2018 12:56	769.0002
1/1/2018 12:58	775.6001
1/1/2018 13:00	781.9999
1/1/2018 13:02	788.1001
1/1/2018 13:04	794.1001
1/1/2018 13:06	799.7999
1/1/2018 13:08	805.3001
1/1/2018 13:10	810.4999
1/1/2018 13:12	814.6998
1/1/2018 13:14	818.6999
1/1/2018 13:16	822.5001
1/1/2018 13:18	826.2
1/1/2018 13:20	829.7001
1/1/2018 13:22	833.0998
1/1/2018 13:24	836.3
1/1/2018 13:26	839.3
1/1/2018 13:28	842.2001
1/1/2018 13:30	845.0002
1/1/2018 13:32	847.6
1/1/2018 13:34	850.1
1/1/2018 13:36	852.4999
1/1/2018 13:38	854.7
1/1/2018 13:40	856.5
1/1/2018 13:42	858.2001
1/1/2018 13:44	859.7998
1/1/2018 13:46	861.3
1/1/2018 13:48	862.6999
1/1/2018 13:50	864.1001
1/1/2018 13:52	865.4
1/1/2018 13:54	866.6
1/1/2018 13:56	867.8
1/1/2018 13:58	869

NRCS Dam No. 5	
Date	Outflow (in)
1/1/2018 14:00	870.1001
1/1/2018 14:02	871.1002
1/1/2018 14:04	872.0999
1/1/2018 14:06	873.1
1/1/2018 14:08	873.9999
1/1/2018 14:10	874.8001
1/1/2018 14:12	875.6
1/1/2018 14:14	876.3998
1/1/2018 14:16	877.2001
1/1/2018 14:18	877.9
1/1/2018 14:20	878.5
1/1/2018 14:22	879.1
1/1/2018 14:24	879.7
1/1/2018 14:26	880.3
1/1/2018 14:28	880.8001
1/1/2018 14:30	881.3001
1/1/2018 14:32	881.8002
1/1/2018 14:34	882.2999
1/1/2018 14:36	882.7
1/1/2018 14:38	883.1001
1/1/2018 14:40	883.4999
1/1/2018 14:42	883.9
1/1/2018 14:44	884.2001
1/1/2018 14:46	884.5999
1/1/2018 14:48	884.9001
1/1/2018 14:50	887.5999
1/1/2018 14:52	894.5
1/1/2018 14:54	903.3001
1/1/2018 14:56	913.3001
1/1/2018 14:58	924.0001
1/1/2018 15:00	934.9999
1/1/2018 15:02	946.1001
1/1/2018 15:04	957.0999
1/1/2018 15:06	968.0001
1/1/2018 15:08	978.4998
1/1/2018 15:10	988.7001
1/1/2018 15:12	998.5
1/1/2018 15:14	1007.8
1/1/2018 15:16	1016.6
1/1/2018 15:18	1024.8
1/1/2018 15:20	1032.5
1/1/2018 15:22	1039.7
1/1/2018 15:24	1046.3
1/1/2018 15:26	1052.5
1/1/2018 15:28	1058.1

NRCS Dam No. 5	
Date	Outflow (in)
1/1/2018 15:30	1063.4
1/1/2018 15:32	1068.2
1/1/2018 15:34	1072.6
1/1/2018 15:36	1076.6
1/1/2018 15:38	1080.3
1/1/2018 15:40	1083.7
1/1/2018 15:42	1086.8
1/1/2018 15:44	1089.7
1/1/2018 15:46	1092.3
1/1/2018 15:48	1094.7
1/1/2018 15:50	1096.8
1/1/2018 15:52	1098.6
1/1/2018 15:54	1100.2
1/1/2018 15:56	1101.5
1/1/2018 15:58	1102.5
1/1/2018 16:00	1103.2
1/1/2018 16:02	1103.7
1/1/2018 16:04	1104
1/1/2018 16:06	1103.9
1/1/2018 16:08	1103.7
1/1/2018 16:10	1103.2
1/1/2018 16:12	1102.4
1/1/2018 16:14	1101.5
1/1/2018 16:16	1100.4
1/1/2018 16:18	1099.1
1/1/2018 16:20	1097.6
1/1/2018 16:22	1095.9
1/1/2018 16:24	1094.1
1/1/2018 16:26	1092.1
1/1/2018 16:28	1090
1/1/2018 16:30	1087.8
1/1/2018 16:32	1085.5
1/1/2018 16:34	1083
1/1/2018 16:36	1080.5
1/1/2018 16:38	1077.9
1/1/2018 16:40	1075.1
1/1/2018 16:42	1072.3
1/1/2018 16:44	1069.5
1/1/2018 16:46	1066.5
1/1/2018 16:48	1063.5
1/1/2018 16:50	1060.4
1/1/2018 16:52	1057.3
1/1/2018 16:54	1054.2
1/1/2018 16:56	1051
1/1/2018 16:58	1047.8

NRCS Dam No. 5	
Date	Outflow (in)
1/1/2018 17:00	1044.5
1/1/2018 17:02	1041.3
1/1/2018 17:04	1038
1/1/2018 17:06	1034.7
1/1/2018 17:08	1031.4
1/1/2018 17:10	1028.1
1/1/2018 17:12	1024.8
1/1/2018 17:14	1021.5
1/1/2018 17:16	1018.2
1/1/2018 17:18	1015
1/1/2018 17:20	1011.7
1/1/2018 17:22	1008.5
1/1/2018 17:24	1005.3
1/1/2018 17:26	1002.1
1/1/2018 17:28	998.9001
1/1/2018 17:30	995.8001
1/1/2018 17:32	992.6999
1/1/2018 17:34	989.6
1/1/2018 17:36	986.6
1/1/2018 17:38	983.5
1/1/2018 17:40	980.6
1/1/2018 17:42	977.6
1/1/2018 17:44	974.7
1/1/2018 17:46	971.7999
1/1/2018 17:48	968.9998
1/1/2018 17:50	966.2001
1/1/2018 17:52	963.4
1/1/2018 17:54	960.6998
1/1/2018 17:56	958
1/1/2018 17:58	955.4002
1/1/2018 18:00	952.7999
1/1/2018 18:02	950.3
1/1/2018 18:04	947.8001
1/1/2018 18:06	945.3002
1/1/2018 18:08	942.8998
1/1/2018 18:10	940.6001
1/1/2018 18:12	938.3001
1/1/2018 18:14	936.1
1/1/2018 18:16	933.9998
1/1/2018 18:18	931.9
1/1/2018 18:20	929.9002
1/1/2018 18:22	927.9999
1/1/2018 18:24	926.0999
1/1/2018 18:26	924.3999
1/1/2018 18:28	922.5999

NRCS Dam No. 5	
Date	Outflow (in)
1/1/2018 18:30	921.0002
1/1/2018 18:32	919.3001
1/1/2018 18:34	917.7999
1/1/2018 18:36	916.3001
1/1/2018 18:38	914.8999
1/1/2018 18:40	913.6
1/1/2018 18:42	912.3
1/1/2018 18:44	911.0001
1/1/2018 18:46	909.8001
1/1/2018 18:48	908.7001
1/1/2018 18:50	907.6999
1/1/2018 18:52	906.6998
1/1/2018 18:54	905.7001
1/1/2018 18:56	904.7999
1/1/2018 18:58	904
1/1/2018 19:00	903.2001
1/1/2018 19:02	902.3999
1/1/2018 19:04	901.7
1/1/2018 19:06	901
1/1/2018 19:08	900.4
1/1/2018 19:10	899.8001
1/1/2018 19:12	899.3
1/1/2018 19:14	898.7999
1/1/2018 19:16	898.2999
1/1/2018 19:18	897.9001
1/1/2018 19:20	897.5
1/1/2018 19:22	897.0999
1/1/2018 19:24	896.8001
1/1/2018 19:26	896.4
1/1/2018 19:28	896.2001
1/1/2018 19:30	895.8999
1/1/2018 19:32	895.6001
1/1/2018 19:34	895.3998
1/1/2018 19:36	895.2
1/1/2018 19:38	895.1
1/1/2018 19:40	894.9001
1/1/2018 19:42	894.6999
1/1/2018 19:44	894.6
1/1/2018 19:46	894.5
1/1/2018 19:48	894.4001
1/1/2018 19:50	894.3001
1/1/2018 19:52	894.1999
1/1/2018 19:54	894.0999
1/1/2018 19:56	894.0999
1/1/2018 19:58	894

NRCS Dam No. 5	
Date	Outflow (in)
1/1/2018 20:00	893.9
1/1/2018 20:02	893.9
1/1/2018 20:04	893.8001
1/1/2018 20:06	893.8001
1/1/2018 20:08	893.7001
1/1/2018 20:10	893.7001
1/1/2018 20:12	893.5999
1/1/2018 20:14	893.5999
1/1/2018 20:16	893.4999
1/1/2018 20:18	893.4
1/1/2018 20:20	893.4
1/1/2018 20:22	893.3
1/1/2018 20:24	893.2001
1/1/2018 20:26	893.1002
1/1/2018 20:28	892.9999
1/1/2018 20:30	892.8999
1/1/2018 20:32	892.8
1/1/2018 20:34	892.7
1/1/2018 20:36	892.5002
1/1/2018 20:38	892.3999
1/1/2018 20:40	892.2999
1/1/2018 20:42	892.1
1/1/2018 20:44	892.0001
1/1/2018 20:46	891.7999
1/1/2018 20:48	891.6
1/1/2018 20:50	891.4001
1/1/2018 20:52	891.1999
1/1/2018 20:54	891
1/1/2018 20:56	890.8001
1/1/2018 20:58	890.5999
1/1/2018 21:00	890.4
1/1/2018 21:02	890.2001
1/1/2018 21:04	889.9999
1/1/2018 21:06	889.7001
1/1/2018 21:08	889.5002
1/1/2018 21:10	889.2
1/1/2018 21:12	889.0001
1/1/2018 21:14	888.6999
1/1/2018 21:16	888.5001
1/1/2018 21:18	888.1999
1/1/2018 21:20	888
1/1/2018 21:22	887.6998
1/1/2018 21:24	887.4
1/1/2018 21:26	887.2001
1/1/2018 21:28	886.9

NRCS Dam No. 5	
Date	Outflow (in)
1/1/2018 21:30	886.7001
1/1/2018 21:32	886.3999
1/1/2018 21:34	886.2
1/1/2018 21:36	886.0001
1/1/2018 21:38	885.7
1/1/2018 21:40	885.5001
1/1/2018 21:42	885.4001
1/1/2018 21:44	885.1999
1/1/2018 21:46	885.1
1/1/2018 21:48	885
1/1/2018 21:50	885
1/1/2018 21:52	885
1/1/2018 21:54	885
1/1/2018 21:56	884.9001
1/1/2018 21:58	884.9001
1/1/2018 22:00	884.9001
1/1/2018 22:02	884.9001
1/1/2018 22:04	884.8001
1/1/2018 22:06	884.8001
1/1/2018 22:08	884.8001
1/1/2018 22:10	884.8001
1/1/2018 22:12	884.6999
1/1/2018 22:14	884.6999
1/1/2018 22:16	884.6999
1/1/2018 22:18	884.6999
1/1/2018 22:20	884.5999
1/1/2018 22:22	884.5999
1/1/2018 22:24	884.5999
1/1/2018 22:26	884.5999
1/1/2018 22:28	884.5
1/1/2018 22:30	884.5
1/1/2018 22:32	884.5
1/1/2018 22:34	884.5
1/1/2018 22:36	884.4
1/1/2018 22:38	884.4
1/1/2018 22:40	884.4
1/1/2018 22:42	884.3001
1/1/2018 22:44	884.3001
1/1/2018 22:46	884.3001
1/1/2018 22:48	884.3001
1/1/2018 22:50	884.2001
1/1/2018 22:52	884.2001
1/1/2018 22:54	884.2001
1/1/2018 22:56	884.0999
1/1/2018 22:58	884.0999

NRCS Dam No. 5	
Date	Outflow (in)
1/1/2018 23:00	884.0999
1/1/2018 23:02	883.9999
1/1/2018 23:04	883.9999
1/1/2018 23:06	883.9999
1/1/2018 23:08	883.9
1/1/2018 23:10	883.9
1/1/2018 23:12	883.9
1/1/2018 23:14	883.8
1/1/2018 23:16	883.8
1/1/2018 23:18	883.8
1/1/2018 23:20	883.7001
1/1/2018 23:22	883.7001
1/1/2018 23:24	883.7001
1/1/2018 23:26	883.6002
1/1/2018 23:28	883.6002
1/1/2018 23:30	883.6002
1/1/2018 23:32	883.4999
1/1/2018 23:34	883.4999
1/1/2018 23:36	883.4999
1/1/2018 23:38	883.3999
1/1/2018 23:40	883.3999
1/1/2018 23:42	883.3999
1/1/2018 23:44	883.3
1/1/2018 23:46	883.3
1/1/2018 23:48	883.2
1/1/2018 23:50	883.2
1/1/2018 23:52	883.2
1/1/2018 23:54	883.1001
1/1/2018 23:56	883.1001
1/1/2018 23:58	883.1001
1/2/2018 0:00	883.0002
1/2/2018 0:02	883.0002
1/2/2018 0:04	883.0002
1/2/2018 0:06	882.8999
1/2/2018 0:08	882.8999
1/2/2018 0:10	882.7999
1/2/2018 0:12	882.7999
1/2/2018 0:14	882.7999
1/2/2018 0:16	882.7
1/2/2018 0:18	882.7
1/2/2018 0:20	882.6
1/2/2018 0:22	882.6
1/2/2018 0:24	882.6
1/2/2018 0:26	882.5001
1/2/2018 0:28	882.5001

NRCS Dam No. 5	
Date	Outflow (in)
1/2/2018 0:30	882.4002
1/2/2018 0:32	882.4002
1/2/2018 0:34	882.4002
1/2/2018 0:36	882.2999
1/2/2018 0:38	882.2999

Table D-4: April 11, 2017 Historic Rainfall Event

Time	Historic Event (in)	Historic Event (in/hr)
0:00	0	0
0:05	0	0
0:10	0	0
0:15	0	0
0:20	0	0
0:25	0	0
0:30	0	0
0:35	0	0
0:40	0	0
0:45	0	0
0:50	0	0
0:55	0	0
1:00	0	0
1:05	0.00083	0.01
1:10	0.00167	0.02
1:15	0.00250	0.03
1:20	0.00333	0.04
1:25	0.00417	0.05
1:30	0.00500	0.06
1:35	0.00583	0.07
1:40	0.00667	0.08
1:45	0.00750	0.09
1:50	0.00833	0.1
1:55	0.00917	0.11
2:00	0.01	0.12
2:05	0.01	0.12
2:10	0.01	0.12
2:15	0.01	0.12
2:20	0.01	0.12
2:25	0.01	0.12
2:30	0.01	0.12
2:35	0.01	0.12
2:40	0.01	0.12
2:45	0.01	0.12
2:50	0.01	0.12
2:55	0.01	0.12
3:00	0.01	0.12
3:05	0.01	0.12
3:10	0.01	0.12
3:15	0.01	0.12
3:20	0.01	0.12
3:25	0.01	0.12
3:30	0.01	0.12

Time	Historic Event (in)	Historic Event (in/hr)
3:35	0.01	0.12
3:40	0.01	0.12
3:45	0.01	0.12
3:50	0.01	0.12
3:55	0.01	0.12
4:00	0.01	0.12
4:05	0.00917	0.11
4:10	0.00833	0.1
4:15	0.00750	0.09
4:20	0.00667	0.08
4:25	0.00583	0.07
4:30	0.00500	0.06
4:35	0.00417	0.05
4:40	0.00333	0.04
4:45	0.00250	0.03
4:50	0.00167	0.02
4:55	0.00083	0.01
5:00	0	0
5:05	0	0
5:10	0	0
5:15	0	0
5:20	0	0
5:25	0	0
5:30	0	0
5:35	0	0
5:40	0	0
5:45	0	0
5:50	0	0
5:55	0	0
6:00	0	0
6:05	0	0
6:10	0	0
6:15	0	0
6:20	0	0
6:25	0	0
6:30	0	0
6:35	0	0
6:40	0	0
6:45	0	0
6:50	0	0
6:55	0	0
7:00	0	0
7:05	0.00167	0.02
7:10	0.00333	0.04
7:15	0.00500	0.06
7:20	0.00667	0.08
7:25	0.00833	0.1
7:30	0.01000	0.12
7:35	0.01167	0.14
7:40	0.01333	0.16
7:45	0.01500	0.18

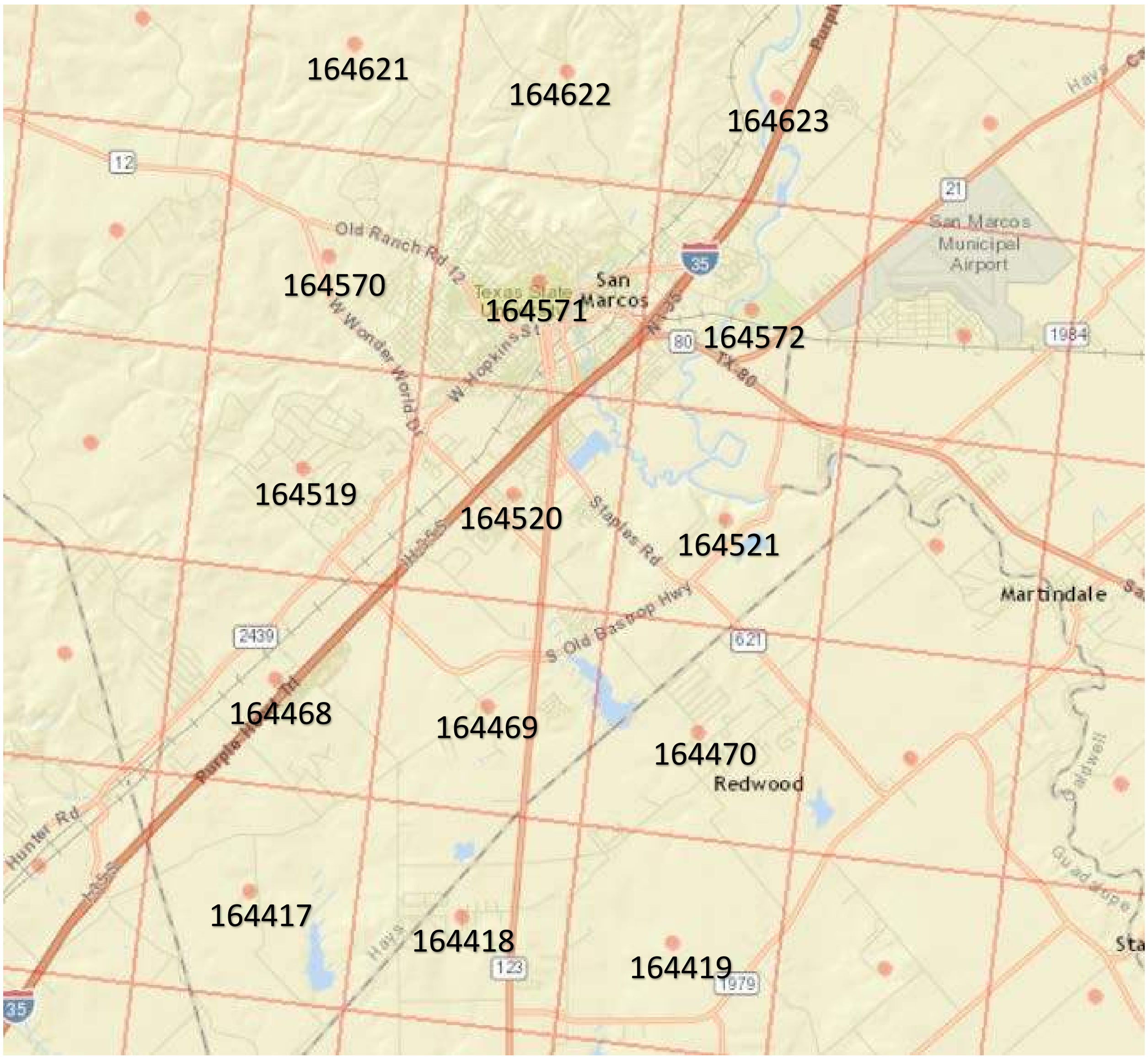
Time	Historic Event (in)	Historic Event (in/hr)
7:50	0.01667	0.2
7:55	0.01833	0.22
8:00	0.02	0.24
8:05	0.0225	0.27
8:10	0.025	0.3
8:15	0.0275	0.33
8:20	0.03	0.36
8:25	0.0325	0.39
8:30	0.035	0.42
8:35	0.0375	0.45
8:40	0.04	0.48
8:45	0.0425	0.51
8:50	0.045	0.54
8:55	0.0475	0.57
9:00	0.05	0.6
9:05	0.0525	0.63
9:10	0.055	0.66
9:15	0.0575	0.69
9:20	0.06	0.72
9:25	0.0625	0.75
9:30	0.065	0.78
9:35	0.0675	0.81
9:40	0.07	0.84
9:45	0.0725	0.87
9:50	0.075	0.9
9:55	0.0775	0.93
10:00	0.08	0.96
10:05	0.09167	1.1
10:10	0.10333	1.24
10:15	0.115	1.38
10:20	0.12667	1.52
10:25	0.13833	1.66
10:30	0.15	1.8
10:35	0.16167	1.94
10:40	0.17333	2.08
10:45	0.185	2.22
10:50	0.19667	2.36
10:55	0.20833	2.5
11:00	0.22	2.64
11:05	0.36583	4.39
11:10	0.51167	6.14
11:15	0.6575	7.89
11:20	0.80333	9.64
11:25	0.94917	11.39
11:30	1.095	13.14
11:35	1.24083	14.89
11:40	1.38667	16.64
11:45	1.5325	18.39
11:50	1.67833	20.14
11:55	1.82417	21.89
12:00	1.97	23.64

Time	Historic Event (in)	Historic Event (in/hr)
12:05	1.9525	23.43
12:10	1.935	23.22
12:15	1.9175	23.01
12:20	1.9	22.8
12:25	1.8825	22.59
12:30	1.865	22.38
12:35	1.8475	22.17
12:40	1.83	21.96
12:45	1.8125	21.75
12:50	1.795	21.54
12:55	1.7775	21.33
13:00	1.76	21.12
13:05	1.6675	20.01
13:10	1.575	18.9
13:15	1.4825	17.79
13:20	1.39	16.68
13:25	1.2975	15.57
13:30	1.205	14.46
13:35	1.1125	13.35
13:40	1.02	12.24
13:45	0.9275	11.13
13:50	0.835	10.02
13:55	0.7425	8.91
14:00	0.65	7.8
14:05	0.59583	7.15
14:10	0.54167	6.5
14:15	0.4875	5.85
14:20	0.43333	5.2
14:25	0.37917	4.55
14:30	0.325	3.9
14:35	0.27083	3.25
14:40	0.21667	2.6
14:45	0.1625	1.95
14:50	0.10833	1.3
14:55	0.05417	0.65
15:00	0	0
15:05	0	0
15:10	0	0
15:15	0	0
15:20	0	0
15:25	0	0
15:30	0	0
15:35	0	0
15:40	0	0
15:45	0	0
15:50	0	0
15:55	0	0
16:00	0	0
16:05	0	0
16:10	0	0
16:15	0	0

4/11/2017 – 4/12/2017

San Marcos Area
Precipitation Analysis

HALFF



Uses NWS Hourly MPE data and Daily QPE data
against the USGS Water Resources Report 98-4044
to establish the frequency curves.

HRAP Summary Max Frequency

Note: Durations Vary

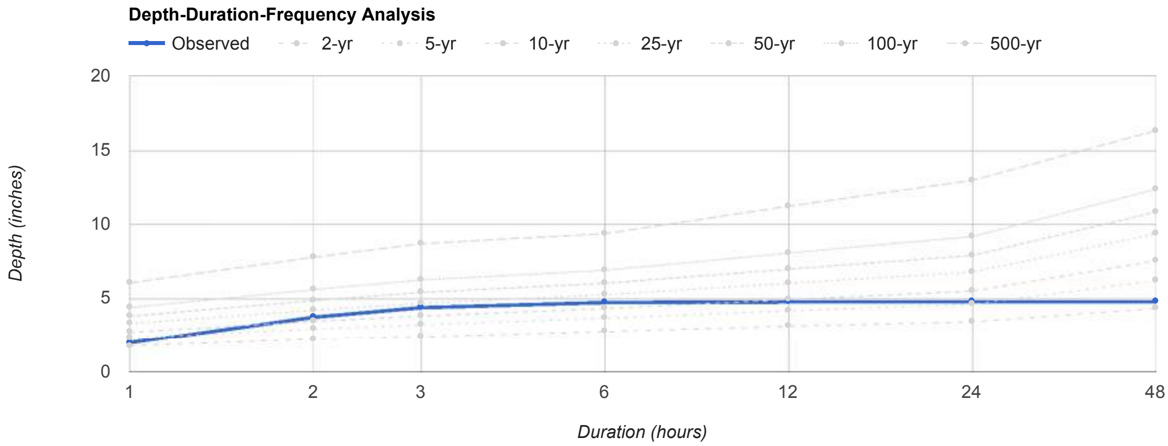
HRAP ID	Max Frequency
164570	10-year
164571	10-25-year
164572	25-50-year
164518	10-year
164519	100-yr
164520	100-500-year
164521	50-100-year
164522	10-year
164467	10-year
164468	25-year
164469	100-year
164470	10-year
164417	5-year
164418	10-year
164419	2-5-year

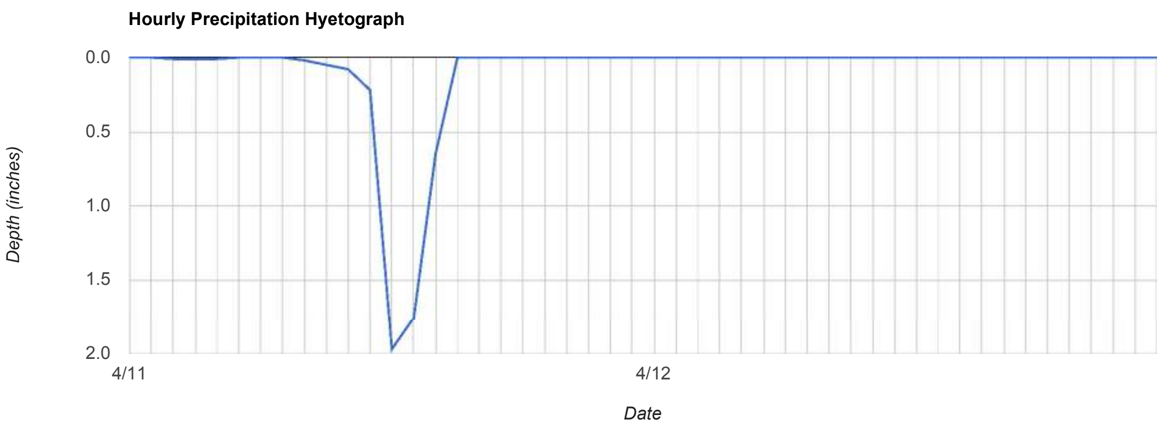
Precipitation Analysis

HRAP ID 164571

Precipitation Summary Latitude: 29.8904 Longitude: -97.9414

For Date Range: 4/11/2017 - 4/12/2017





Precipitation Source: NWS Hourly MPE data and Daily QPE data.

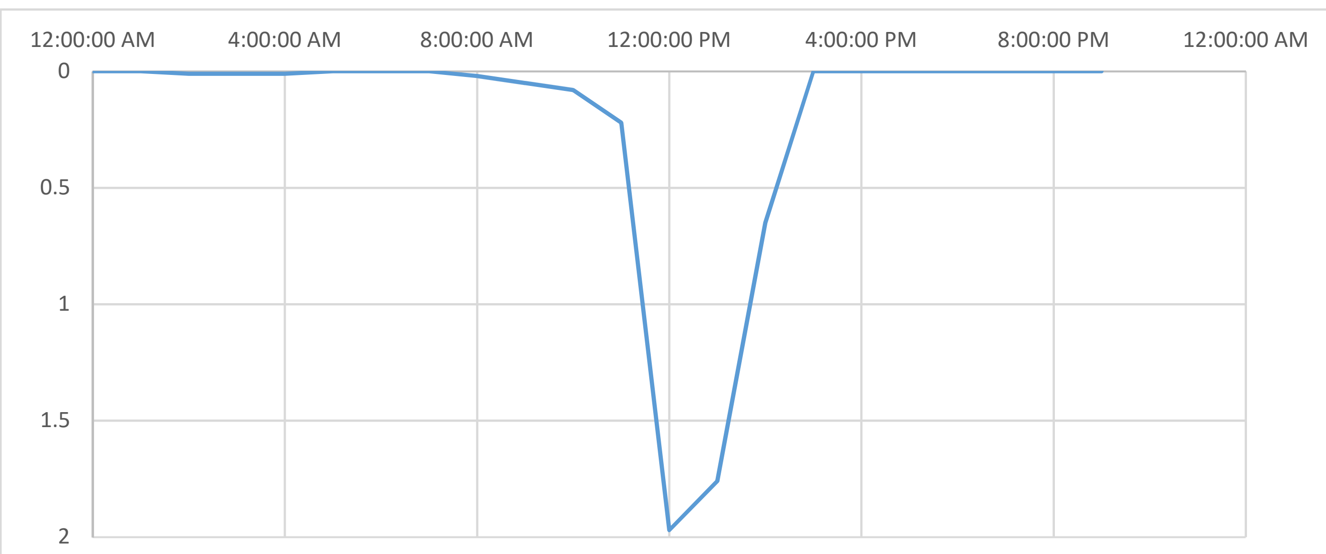
DDF Source: USGS Water Resources Report 98-4044

Precipitation Summary

Duration (hr)	1	2	3	6	12	24	48
Depth (in)	1.97	3.73	4.38	4.73	4.77	4.78	4.78
Intensity (iph)	1.97	1.87	1.46	0.79	0.40	0.20	0.10
Start Time	4/11/2017 12:00:00 PM	4/11/2017 12:00:00 PM	4/11/2017 12:00:00 PM	4/11/2017 9:00:00 AM	4/11/2017 3:00:00 AM	4/11/2017 12:00:00 AM	4/11/2017 12:00:00 AM
End Time	4/11/2017 1:00:00 PM	4/11/2017 2:00:00 PM	4/11/2017 3:00:00 PM	4/11/2017 3:00:00 PM	4/11/2017 3:00:00 PM	4/12/2017 12:00:00 AM	4/13/2017 12:00:00 AM

Rainfall Depth Verification

Time	Rainfall (inches)
12:00 AM	0
1:00 AM	0
2:00 AM	0.01
3:00 AM	0.01
4:00 AM	0.01
5:00 AM	0
6:00 AM	0
7:00 AM	0
8:00 AM	0.02
9:00 AM	0.05
10:00 AM	0.08
11:00 AM	0.22
12:00 PM	1.97
1:00 PM	1.76
2:00 PM	0.65
3:00 PM	0
4:00 PM	0
5:00 PM	0
6:00 PM	0
7:00 PM	0
8:00 PM	0
9:00 PM	0



Source: Halff San Marcos Area Precipitation Analysis 4/11/2017 - 4/12/2017

San Marcos Office
407 S. Stagecoach Trl.
Suite 207
San Marcos, TX 78666
512.338.4212

Info@lan-inc.com

Texas
Austin
College Station
Corpus Christi
Dallas
Fort Worth
Houston
San Antonio
San Marcos
Waco

Arizona
Phoenix

California
Los Angeles
Milpitas
Orange
Sacramento

Florida
Miami
Tampa Bay

Illinois
Chicago

Michigan
Flint
Lansing

www.lan-inc.com

Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY

TBPE Firm No. 2614