Santa Fe River and Arroyo de Los Chamisos Modeling Report

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Restriction on Disclosure and Use of Data

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GLOSSARY

EPA – United States Environmental Protection Agency

GIS – Geographic Information System

HEC-HMS – US Army Corps of Engineers Hydrologic Engineering Center Hydrologic Modeling System

HEC-RAS – US Army Corps of Engineers Hydrologic Engineering Center River Analysis System

LSPC – Loading Simulation Program C

MS4 – Municipal Separate Storm Sewer System

SWMM – Stormwater Management Model

XPSWMM – A commercially available interface to the SWMM modeling system produced by XP Software

EXECUTIVE SUMMARY

This report contains the updates to the Santa Fe River and Arroyo de Los Chamisos Drainage Master Plans that were completed in 1997 and 1998 respectively. The report provides the background on development of new EPA SWMM based flood event models and LSPC based water quality models of the two watersheds. In addition, recommendations for new data collection efforts, modeling, stormwater program implementation and monitoring are provided.

As described in the scope of work, Tetra Tech has adopted a modeling approach to aid in the update of the drainage management plan for the Santa Fe River and Arroyo de Los Chamisos watersheds. Two major considerations for the modeling were flood control and water quality. Subtask 2.4 of the project describes building stormwater and flood management, and water quality models for assessing flooding conditions, erosion, and pollutant loading in the Santa Fe River and Arroyo de Los Chamisos watersheds. Pre-processing of data provided by the city was accomplished using ArcMap, and XPSWMM and LSPC models were built based on the existing and field collected data. The models were used to update the Santa Fe Watershed Plan previously developed in the late 1990's.

Based on the outputs of the XPSWMM and LSPC models, and the Arroyo Threat Assessment Report (Santa Fe Watershed Assocoation, 2016), Tetra Tech recommends four priority pilot areas for Green Infrastructure (GI) implementation:

1. The drainage areas in the City of Santa Fe downtown area are of highest priority.
2. The areas draining to the Arroyo Cloudstone and Arroyo Foothill are also of concern because of high cumulative sediment and nutrient loading from upstream subcatchments.
3. The drainage areas in Arroyo de Los Chamisos (North Fork) are currently experiencing flooding issues during storm events.
4. The areas near the mouth of the Santa Fe River are recommended for GI implementation. High runoff, sediment, and nutrient loads are predicted for some subcatchments.

The list below summarizes the team's recommendations based on the current modeling effort and ties the recommendations to other stormwater program efforts where synergies exist or where the information developed would serve multiple purposes.

- Stormwater System Infrastructure Collection – Priority 1
    - The City's record of stormwater infrastructure needs a comprehensive program to identify all street inlets, underground pipes, manholes, roadway culvert crossings and outfalls. This information is necessary for refined watershed modeling, siting water quality BMPs, determining monitoring locations, building an asset management program, and documenting maintenance concerns and compliance with MS4 program requirements.
- Detailed impervious cover database – Priority 2
    - A detailed impervious cover dataset based on the existing LiDAR data and a new high-resolution aerial image acquired for the purpose of impervious cover identification is recommended for use across several areas of the stormwater program. The detailed dataset can be used to better refine the LSPC and XPSWMM models, develop a parcel by parcel equitable stormwater utility fee (based either on impervious cover area or stormwater runoff generated per parcel), plan future expansion of the city by limiting impervious cover in sensitive areas) and identify unpermitted or unreported buildings and development across the city.
- Refine stormwater system criteria for water quality and sediment transport – Priority 1
    - The City's current stormwater criteria requires all infrastructure to meet the 100-year storm. This causes a singular focus on flood events and doesn't recognize the concerns of water quality, stream stability, sediment transport, and stormwater volume management. In concert with forthcoming water quality based requirements, the City's stormwater management criteria should

be expanded to address culvert design, stable channel design, and sediment transport to reduce flooding, maintenance and future erosion issues.

- Include stream flow monitoring in water quality monitoring program – Priority 3
    - The proposed MS4 permit requires monitoring for pollutants of concern with the City of Santa Fe's boundary. The monitoring program should address both the need for water quality information and the need for additional runoff rate and volume measurements to verify watershed scale modeling and local design parameters. The LSPC watershed models developed under this work assignment are largely uncalibrated because of limited monitoring data to aid in the parameterization of the model. The model performance for hydrology and water quality should be reviewed in the future based on streamflow and water quality monitoring data. Such an exercise will increase confidence on model estimates of sediment and nutrient loading.

The SWMM models developed in this report are intended for use by planners, designers, and agency staff who need to assess the impacts or benefits of proposed changes in the watershed. SWMM models are readily adapted to many modeling scenarios and information can be exchanged with other freely available models such as HEC-HMS and HEC-RAS.

1.0 INTRODUCTION

As described in the scope of work, Tetra Tech has adopted a modeling approach to aid in the update of the drainage management plan for the Santa Fe River and Arroyo de Los Chamisos watersheds. Two major considerations for the modeling were flood control and water quality. Subtask 2.4 of the project describes building stormwater and flood management, and water quality models for assessing flooding conditions, erosion, and pollutant loading in the Santa Fe River and Arroyo de Los Chamisos watersheds. Pre-processing of data provided by the city was accomplished using ArcMap, and XPSWMM and LSPC models were built based on the existing and field collected data. The models were used to update the Santa Fe and Arroyo de Los Chamisos Watershed Plan previously developed in the late 1990's. In the following sections, the steps taken to prepare or gather required data in support of model development, and results for stormwater and water quality modeling are summarized.

2.0 DATA PREPARATION

2.1 WATERSHED DELINEATION AND STREAM DEFINITION

The headwaters Santa Fe River (HUC ID: 130202010102, Area: 54.37 mi2) and Arroyo de Los Chamisos (HUC ID: 130202010103, Area: 26.20 mi2) watersheds are in Region 13 (Rio Grande Region) of the USGS Hydrologic Unit Map (Seaber, Kapinos, & Knapp, 1987). Watershed delineation and stream definition was based on the database provided by the City of Santa Fe and other publicly available data. An approximately 2 ft. resolution digital elevation model (DEM) data provided by Santa Fe County was available for the whole watershed and was generally used as the basis for watershed analyses. Contour lines generated from the LiDAR data acquired from Santa Fe County were used to aid in the delineation of subcatchment boundaries and identify areas susceptible to water-ponding or culverts located under highways/streets. An approximately 0.5 ft. resolution aerial image (dated 2014) was geo-referenced and used as background to identify ambiguous features that are not visible in the DEM or LiDAR data. It should be noted that Google Maps (https://www.google.com/maps) shows that some areas have experienced development/urbanization since 2014. However, in the absence of updated elevation/DEM data for these newly developed areas, it was assumed that the best source of information is provided by the combination of DEM, LiDAR, and aerial image.

A stream network shapefile (provided by the City of Santa Fe) and National Hydrography Dataset (NHD) data for the watersheds were used to guide stream network definition and connectivity of reaches. Delineation of subcatchments were generally based on the existing Drainage Management Plans for the Santa Fe River and Arroyo de Los Chamisos watersheds (City of Santa Fe, 1997; 1998). Subcatchment boundaries were however edited based on the LiDAR based contours and the DEM as deemed necessary. Newly developed properties and additional annexation areas were added to the models as well as reach connections to underground culverts and conduits to better represent contributing areas. A site visit was also performed to define (and refine) boundaries between some subcatchments that were not obvious in the DEM/contour data or street/satellite imagery. ***Figure 1*** represents watershed boundaries, delineated subcatchments, and stream definition for both watersheds used in the models.

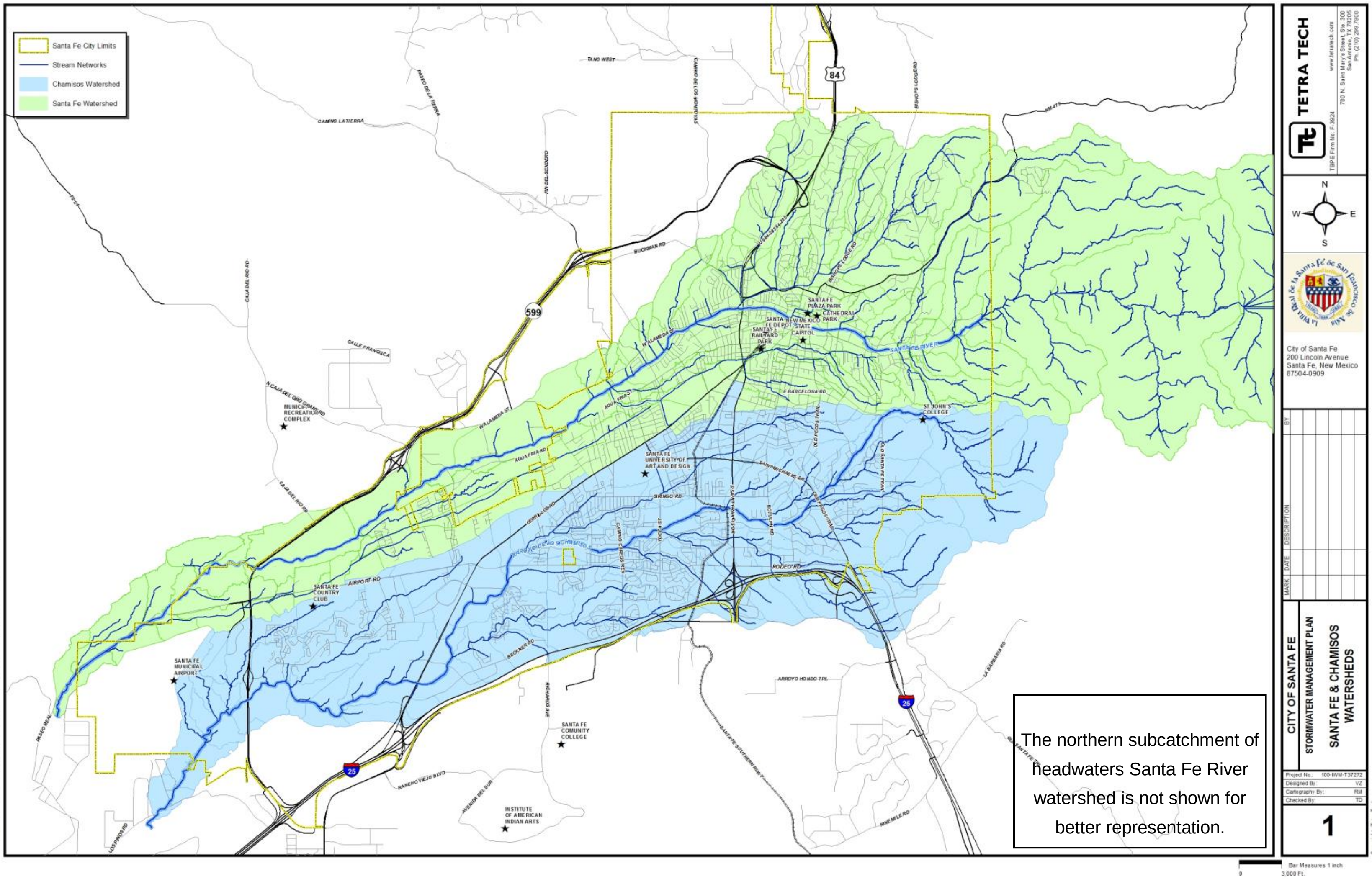


Figure 1. Headwaters Santa Fe River and Arroyo de Los Chamisos Watersheds, subcatchments, and stream networks.

2.2 SUBCATCHMENT NAMING CONVENTION

To establish a unique identifier for each individual subcatchment, the USGS Hydrologic Unit Code (HUC) numbering system was adopted. HUC 12 IDs are available for both Santa Fe River and Arroyo de Los Chamisos watersheds but further sub-classification is not available. The 12-digit numbering system for Santa Fe watershed is provided below as an example.

13: Region: Rio Grande

02: Sub-Region: Elephant Butte

02: Account Unit: Rio Grande-Elephant Butte

01: Cataloging Unit: Rio Grande-Santa Fe

01: Watershed: Santa Fe River

02: Subwatershed: Headwaters Santa Fe River

The HUC 12 IDs therefore represent the Headwaters Santa Fe River and Arroyo de Los Chamisos watersheds but not their subcatchments. Each individual tributary and subcatchment were therefore given HUC 14 and 16 IDs based on the *Federal Standards and Procedures for the National Watershed Boundary Dataset (WBD)* (USGS & USDA, 2013). In the HUC 16 numbering system, the HUC 12 ID is followed by tributary ID (13th and 14th digits) and then the subcatchment ID (15th and 16th digits). Each tributary was also assigned a name based on the effective FEMA Digital Flood Insurance Rate Map data, USDA Hydrography dataset (where available), or nearest street (***Table 1***) to facilitate identification.

Table 1. Source of the naming for tributaries.

Headwaters Santa Fe River		Arroyo de Los Chamisos	
Tributary Name	Source	Tributary Name	Source
Arroyo Barranca	FEMA Data	Arroyo de Los Amigos	FEMA Data
Arroyo de La Piedra		Arroyo de Los Chamisos	
Arroyo Del Rosario		Arroyo de Los Chamisos (North Fork)	
Arroyo Mascaras		Arroyo En Medio	
Arroyo Ranchito		NE Arroyo de Los Pinos	
Arroyo Saiz		Arroyo de La Paz	Stormwater Management Plan (City of Santa Fe, 1998)
Arroyo Torreon		Arroyo de Los Pintores	
Canada Ancha		Cloudstone Arroyo	
Canada Rincon		Foothill Arroyo	
Santa Fe River		Sawmill Arroyo	

Headwaters Santa Fe River		Arroyo de Los Chamisos	
Tributary Name	Source	Tributary Name	Source
Acequia de Los Pinos	USDA Hydrography Dataset	Sheriff's Arroyo	
Camino Carlos Real	Street closest to stream	Mesa Del Oro	Street closest to stream
Vista de Cristo		Jaguar Drive	
Calle Don Jose		N Arroyo Chamisos Urban Trail	
El Ranch Rd		Governor Miles Road	
Arroyo de Las Cruces Road		Camino Carlos Rey (Street)	
Camino de Chelly		Nizhoni Drive	
San Jose Ave		Camino Lado	
Agua Fria Road		Old Pecos Trail	
Airport Road		Calle de Sebastian	
Arroyo Tenorio		Conejo Dr	
Canyon Road		Old Santa Fe	
Camino Pequeno			
Los Arboles Drive			
Alamo Dr			
Avenida Rincon			

2.3 LAND USE, SOIL, AND CURVE NUMBER MAP

Urban Hydrology for Small Watersheds (USDA, 1986), often referred to as TR-55, represents simplified procedures for calculation of different hydrological components in small urban areas. To estimate runoff from storm events, the SCS curve number method is a broadly accepted method that relates runoff volume to rainfall depth and water abstractions in the area. The Curve Number (CN) is the most important parameter in the SCS method. CN ranges between 0 to 100 and relates land use and soil types to a number that represents potential for runoff generation. The higher a CN, the more runoff generation during storm events. TR-55 has developed several tables that estimates CN values based on the hydrologic soil group (A, B, C, or D) and land use (urban, agricultural, etc.). ***Table 2*** represents runoff curve numbers for urban areas based on the cover type and hydrological soil group. Impervious covers such as parking lots, rooftops, and streets have high CN values (80-

100), while other areas that have more pervious surfaces like residential lots and desert urban areas have lower CN values which is an indicator of less runoff generation potential.

Table 2. Runoff curve numbers for urban areas (USDA, 1986).

Cover description: Cover type and hydrologic condition	Average percent impervious area 2/	hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) 3/:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) 4/		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) 5/		77	86	91	94

The existing parcels file (available from the Santa Fe County Assessor's Office) has a column labeled "Property_C" which specifies the classification of each parcel in the city. However, the land use classification specified in the parcels file is more aligned with tax purposes and does not classify lots and parcels in a way that can be readily refined for hydrologic modeling. In addition, several thousand parcels in Santa Fe ranging from a few hundred square feet to tens of acres are missing any type of property classification.

To prepare the parcels file for estimating CN values, large unclassified lots were first compared with areal imagery or National Land Cover Dataset (NLCD) to identify land use class. However, there are many small unclassified lots and visual inspection was not possible for all of them. Any unclassified lot smaller than 3 acres was therefore assumed as residential. Other types of classes that were not aligned with hydrologic purposes (such as CITY or EXEM) were converted to the closest class that matched the nature of their activity. The parcels were reclassified into the following classes: Commercial, Forest, Industrial, Open space (good and poor condition), Residential, and Road (***Table 3***). Each land use class was subsequently assigned a unique code ***Table 4***. Residential 1 to 6 classes are defined based on their size and are classified as shown in ***Table 5*** (recommended method by TR-55).

Table 3. Land use classification of parcels data.

Property Classification	Land Use Class
Vacant (VAC)	Open Space (Poor)
Common Areas (COMA)	
Open Space (OPEN)	Open Space (Good)
Parks (PARK)	
Single Residential (SRES)	Residential
Multi Residential (MRES)	
Residential Lot (LOTR)	
CRES	
CITY and EXEM	Other classes based on their usage
Unclassified	
Commercial (COMM)	Commercial

Table 4. land use coding based on the classes.

Land Use Class	Land Use Code
Residential1	1
Residential2	2
Residential3	3
Residential4	4
Residential5	5
Residential6	6
Commercial	7
Forest	8
Industrial	9
Open Space (Good)	10
Open Space (Poor)	11
Road	12

Note - Forest class was chosen based on the "*Woods (good condition)*" in TR-55 for northern areas in both watersheds.

Table 5. Residential areas classification based on their size.

Residential Class	Reported Areas in TR-55 (acre)	Suggested Areas (acre)
Residential1	1/8 or less	1/8 or less
Residential2	1/4	1/8 to 1/4
Residential3	1/3	1/4 to 1/3
Residential4	1/2	1/3 to 1/2
Residential5	1	1/2 to 1
Residential6	2 or more	1 or more

The Soil Survey Geographic Database (SSURGO) contains physical and chemical properties associated with soils covering most of the Continental US produced by the National Cooperative Soil Survey (NRCS, Soil Survey Staff, 2017). SSURGO data was used to classify most soils in the study area except areas upstream of McClure Reservoir in Headwaters Santa Fe River watershed that did not have SSURGO coverage. For those areas, the Digital General Soil Map of the United States (STATSGO2) (NRCS, Soil Survey Staff, 2017) data was used to create a combined soil map (***Figure 2***). The land use coverage (***Figure 3***) was eventually used in conjunction with combined soils dataset to generate curve numbers for each subcatchment (***Figure 4***). Also, TR-55 has average percent of impervious cover for each of the urban districts that are listed in ***Table 2*** and ***Figure 4***.

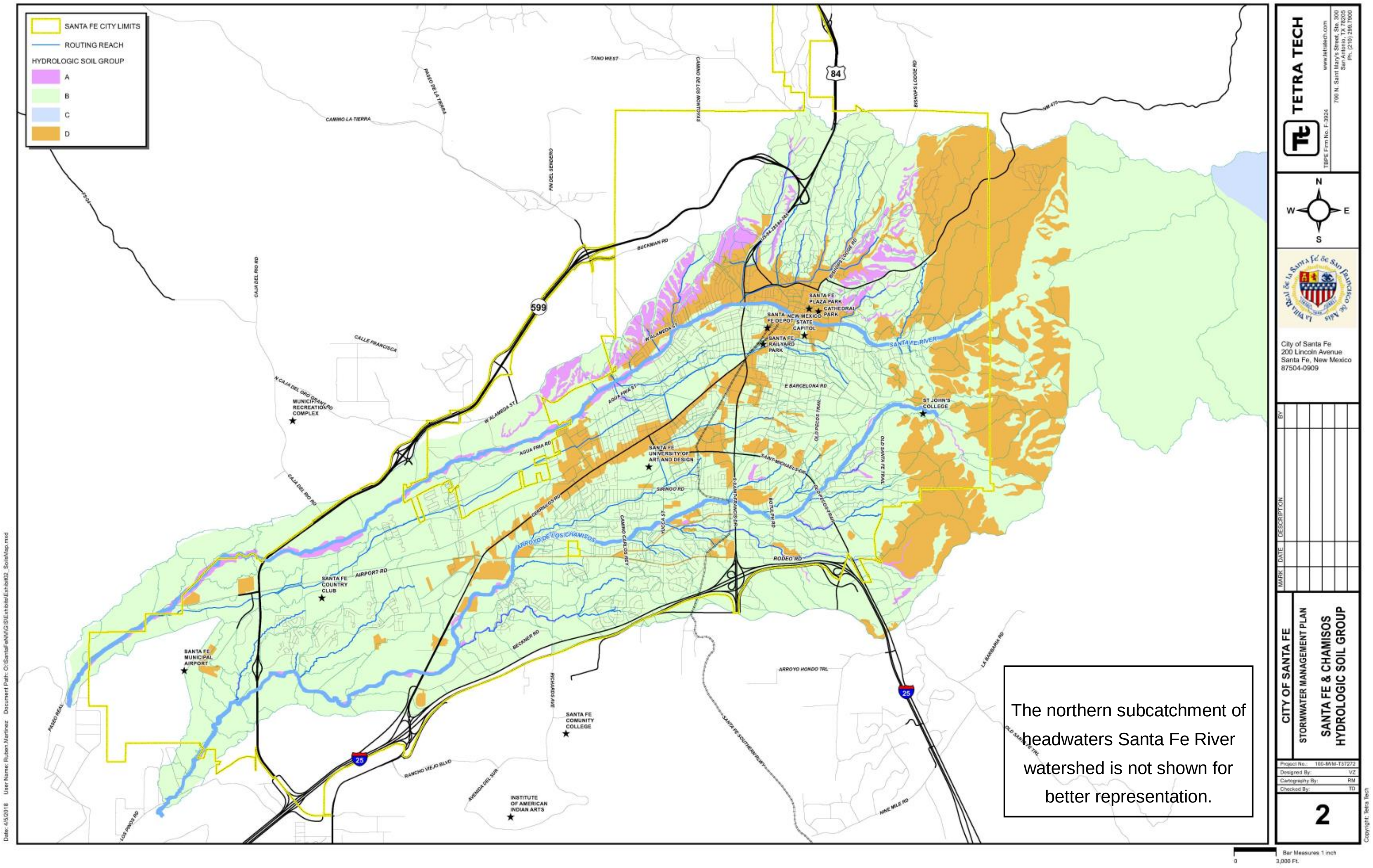
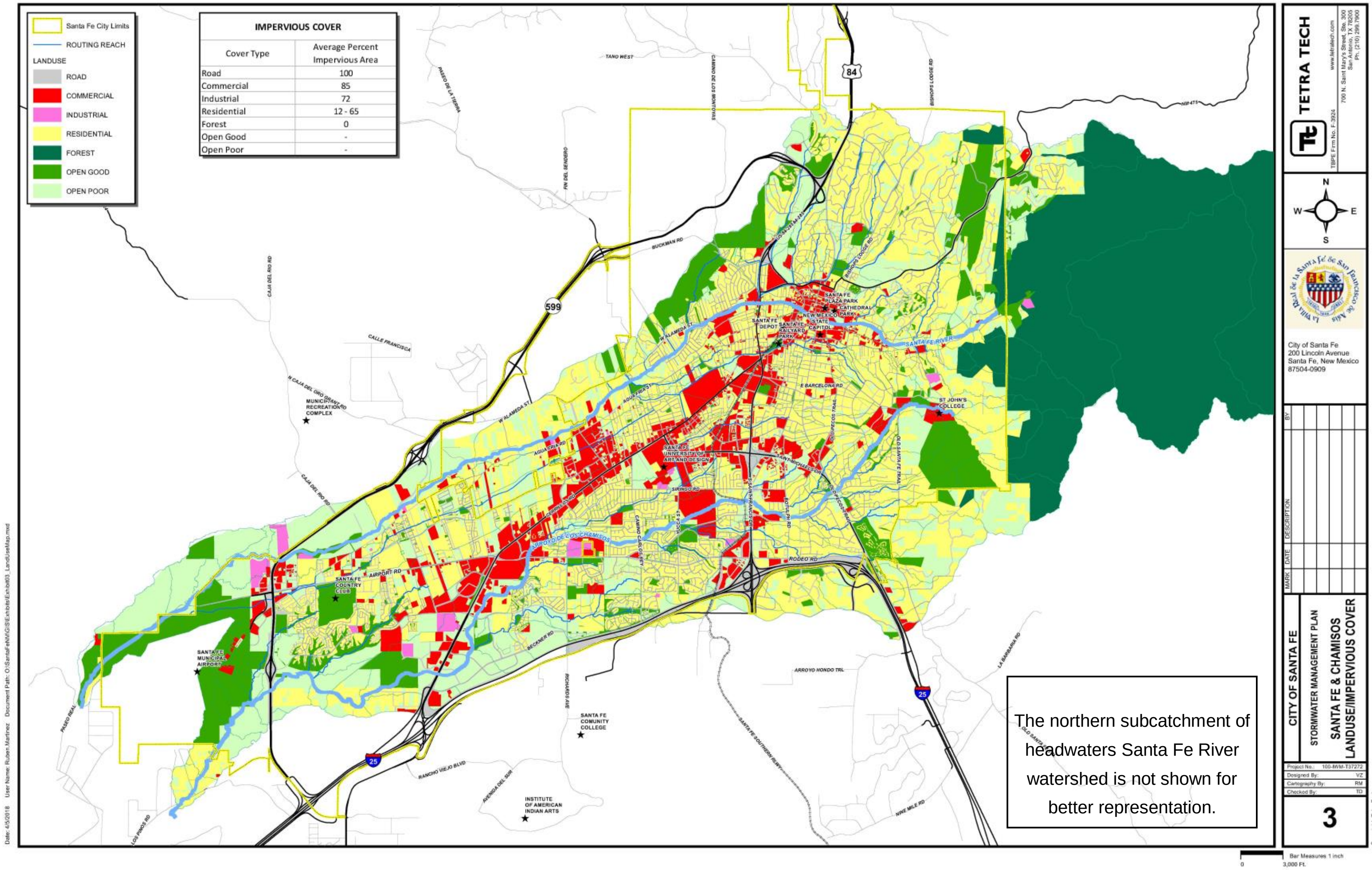


Figure 2. Soil map for headwaters Santa Fe River and Arroyo de Los Chamisos watersheds.



Cover Type	Average Percent Impervious Area
Road	100
Commercial	85
Industrial	72
Residential	12 - 65
Forest	0
Open Good	-
Open Poor	-

Figure 3. Land use map for headwaters Santa Fe River and Arroyo de Los Chamisos watersheds.

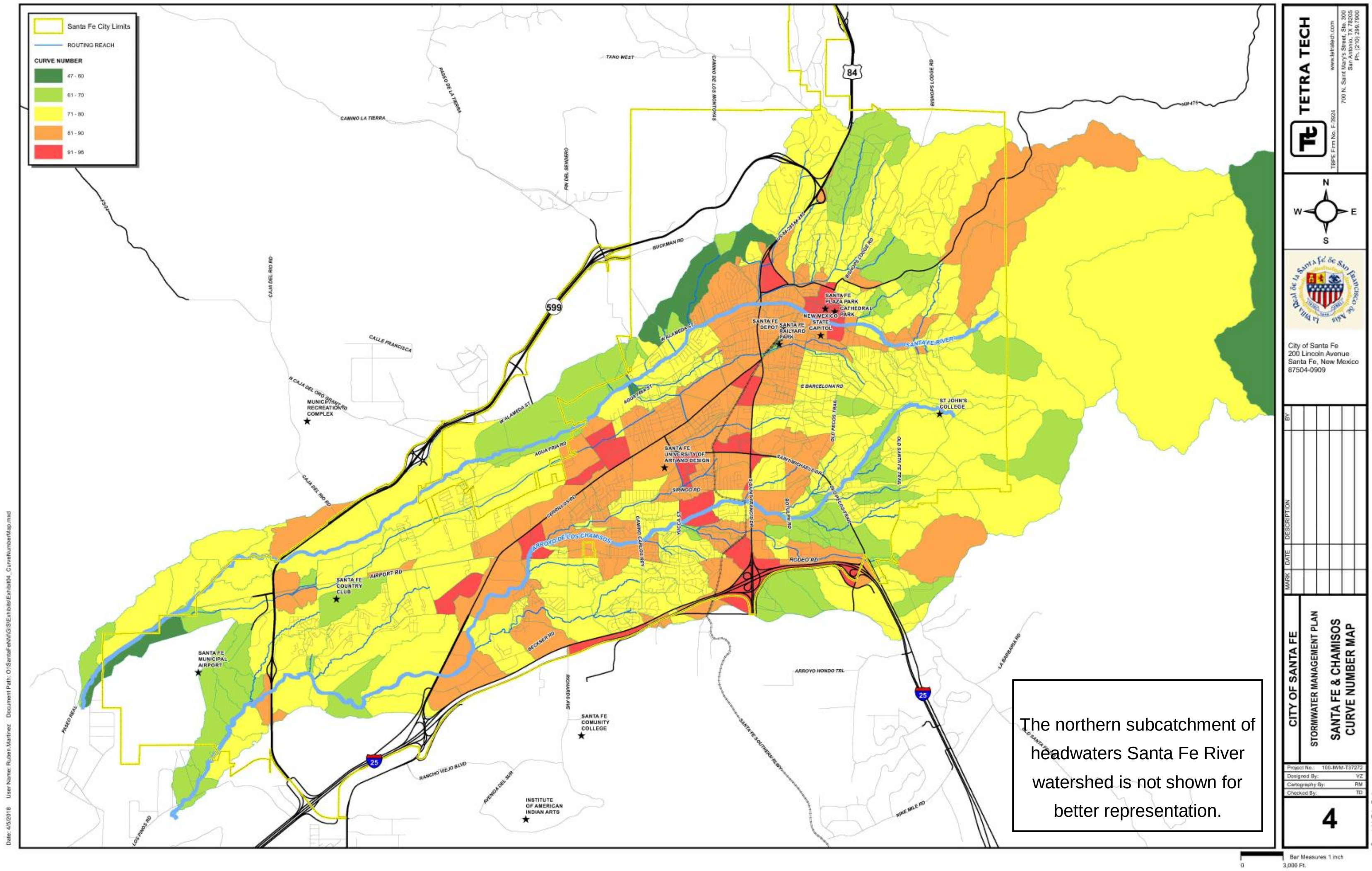


Figure 4. Curve number map for headwaters Santa Fe River and Arroyo de Los Chamisos watersheds.

2.4 STORMWATER CONVEYANCE SYSTEM

To assess the capacity of the current stormwater collection system, accurate data regarding size and type of culverts and conduits are necessary, and is of vital importance in stormwater modeling. Data associated with some culverts were available in *Drainage Management Plan* reports (City of Santa Fe, 1997; 1998) but others were missing. City staff indicated that most improvements identified in the drainage management plans were complete so the proposed culvert sizing table was used to assign the culvert size within the model. The database made available to Tetra Tech by the City of Santa Fe, consists of many shapefiles associated with stormwater infrastructure but they do not cover the entire watershed and attribute tables are often lacking size, material type, and length information necessary for modeling.

Two separate site surveys were therefore completed by Tetra Tech staff to collect information regarding the type and sizes of main roadway crossing culverts located in the watersheds, and upstream and downstream pictures were taken to assess the condition of culverts. ***Figure 5*** shows the location of both surveyed and collected data and ***Appendix A*** and ***Appendix B*** summarize collected information - culvert location, material, size, and number of barrels. The GIS datasets collected for this study will be submitted as part of a separate data deliverable of the storm drainage system

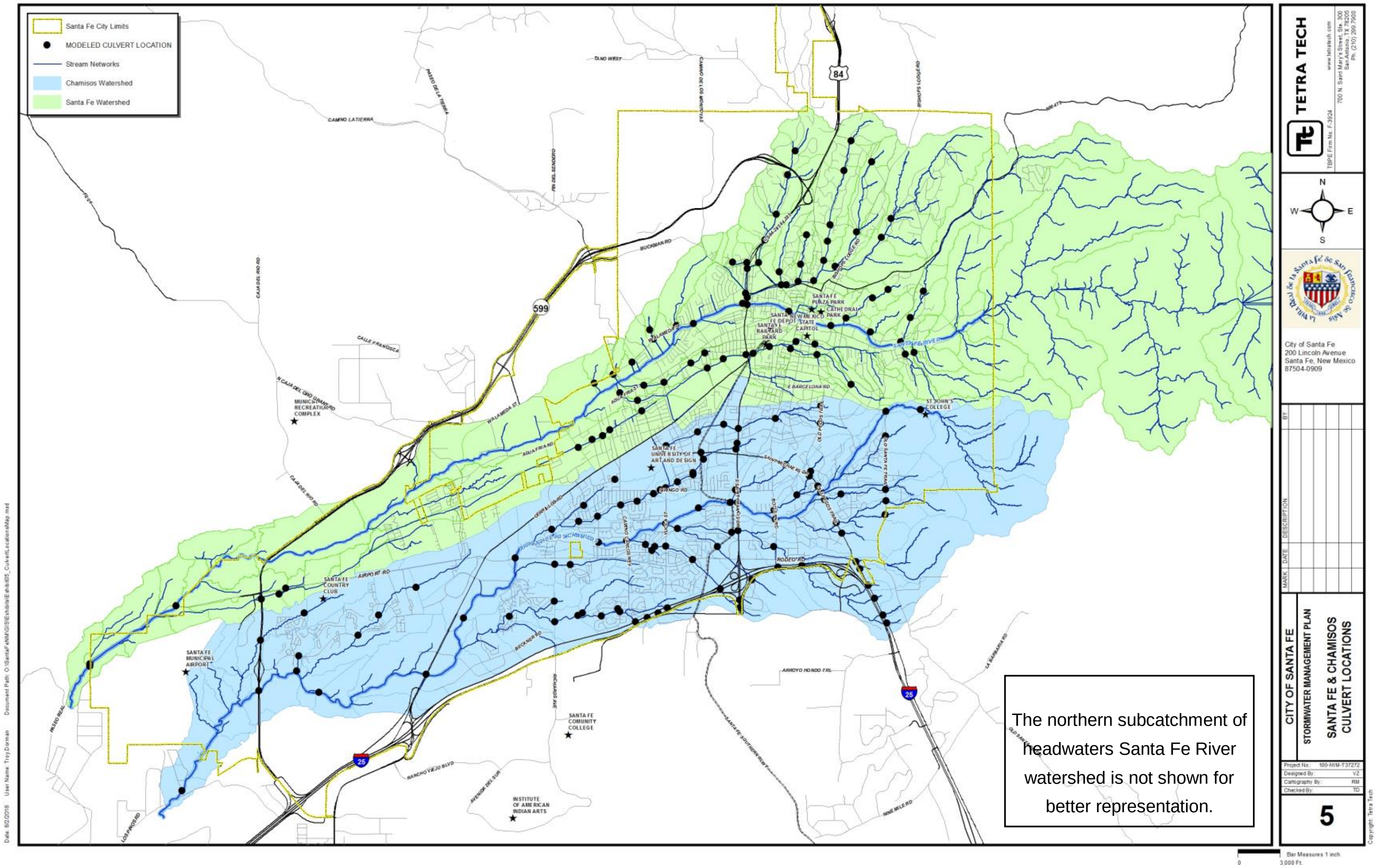


Figure 5. Location of data points (surveyed and collected) for pipes and culverts.

3.0 HYDROLOGIC AND HYDRAULIC MODELING

3.1 PRECIPITATION DATA

Precipitation data for the modeling was extracted from NOAA Atlas 14 online server for the area of City of Santa Fe (NOAA, 2011). The 10-year and 100-year design storms for a 24-hour duration were selected for modeling purposes and entered into the model as the source of rainfall (***Table 6***). These design storms are typically used for sizing culvert and storm drain systems as well as mapping floodplains.

Table 6. Design storm values for Santa Fe area (inches)

Duration	Average recurrence interval (years)	
	10	100
24 hour	2.15	3.16

3.2 RAINFALL-RUNOFF GENERATION

Snyder's unit hydrograph (Snyder, 1938) was selected as the rainfall-runoff routing method. It is a synthetic unit hydrograph based on a study of ungauged watersheds in the Appalachian Highlands in US. More importantly, there are relationships in this method to estimate the unit hydrograph parameters from watershed characteristics. Area of the subcatchments (in acres), lag time (tp), and storage coefficient (Cp) are the parameters required for unit hydrograph generation in XPSWMM. Lag time was calculated based on the CN lag method for each subcatchment (NRCS, National Engineering Handbook, 1972). Initial Cp values were adopted based on the development condition and average slope of the basin using the information in ***Table 7***.

Table 7. Typical values of Cp (iSWM, 2010).

Typical Drainage Area Characteristics	C_p
Undeveloped Areas w/ Storm Drains	
Flat Basin Slope (less than 0.50%)	0.55
Moderate Basin Slope (0.50% to 0.80%)	0.58
Steep Basin Slope (greater than 0.80%)	0.61
Moderately Developed Area	
Flat Basin Slope (less than 0.50%)	0.63
Moderate Basin Slope (0.50% to 0.80%)	0.66
Steep Basin Slope (greater than 0.80%)	0.69
Highly Developed/Commercial Area	
Flat Basin Slope (less than 0.50%)	0.70
Moderate Basin Slope (0.50% to 0.80%)	0.73
Steep Basin Slope (greater than 0.80%)	0.77

To categorize development and slope condition of each subcatchment in order to match the classes in ***Table 7***, a methodology was applied based on the average CN and Slope of each subcatchment. Development condition was identified based on CN value and steepness was calculated based on average Slope value for each subcatchment (***Table 8***).

Table 8. Curve Number and Slope classification.

Development Classification	Curve Number Value		Slope Classification	Slope Value
Undeveloped	CN < 65		Flat	Slope < 0.1
Moderately Developed	65 ≤ CN < 80		Moderate	0.1 ≤ Slope < 0.2
Highly Developed	CN ≥ 80		Steep	Slope ≥ 0.2

3.3 XPSWMM MODEL

XPSWMM is listed as a "*Nationally Accepted Hydrologic and Hydraulic*" model in FEMA's website (FEMA, 2018). It handles hydrologic and hydraulic modeling based on a collection of nodes, links, and rivers. Subcatchment data are directly served to nodes which handle routing and hydrology tasks (XPSWMM, 2014). For hydraulic modeling of the stream network, well-defined channels were selected for importing into the XPSWMM model which includes the majority of FEMA floodplains (***Figure 6***). In the upstream subcatchments, the longest flow paths including shallow channel sections were represented in the hydrologic analysis of Time of Concentration. Representative cross-sections were selected to define the shape of natural channels and the associated roughness for hydraulic modeling and hydrologic routing. Data were imported directly into XPSWMM from HEC-RAS software. The hydraulic cross-sections are not intended for mapping floodplains but rather to get a general sense of the shape, velocity, and erosivity of the major reaches.

There are two reservoirs located at the headwaters of the Santa Fe River watershed and both are incorporated into the XPSWMM model. They control streamflow from mountainous areas and allow the City of Santa Fe to capture and manage its water resources for water supply. ***Figure 6*** shows the location and ***Table 9*** summarizes basic information for each reservoir. It should be noted that there was another reservoir (Two-mile) downstream of Nichols reservoir but it was breeched in 1994 due to potential failure of the dam (Lewis & Borchert, 2009). ***Appendix C*** and ***Appendix D*** represent Elevation-Area-Storage information used for modeling the reservoirs inside XPSWMM model (Lewis & Borchert, 2009).

Table 9. Reservoirs in Headwaters Santa Fe River watershed.

Reservoir name	Longitude	Latitude	Establishment year	Capacity (ac-ft)
McClure	-105.831	35.689	1926	3255.6
Nichols	-105.877	35.691	1943	684.2

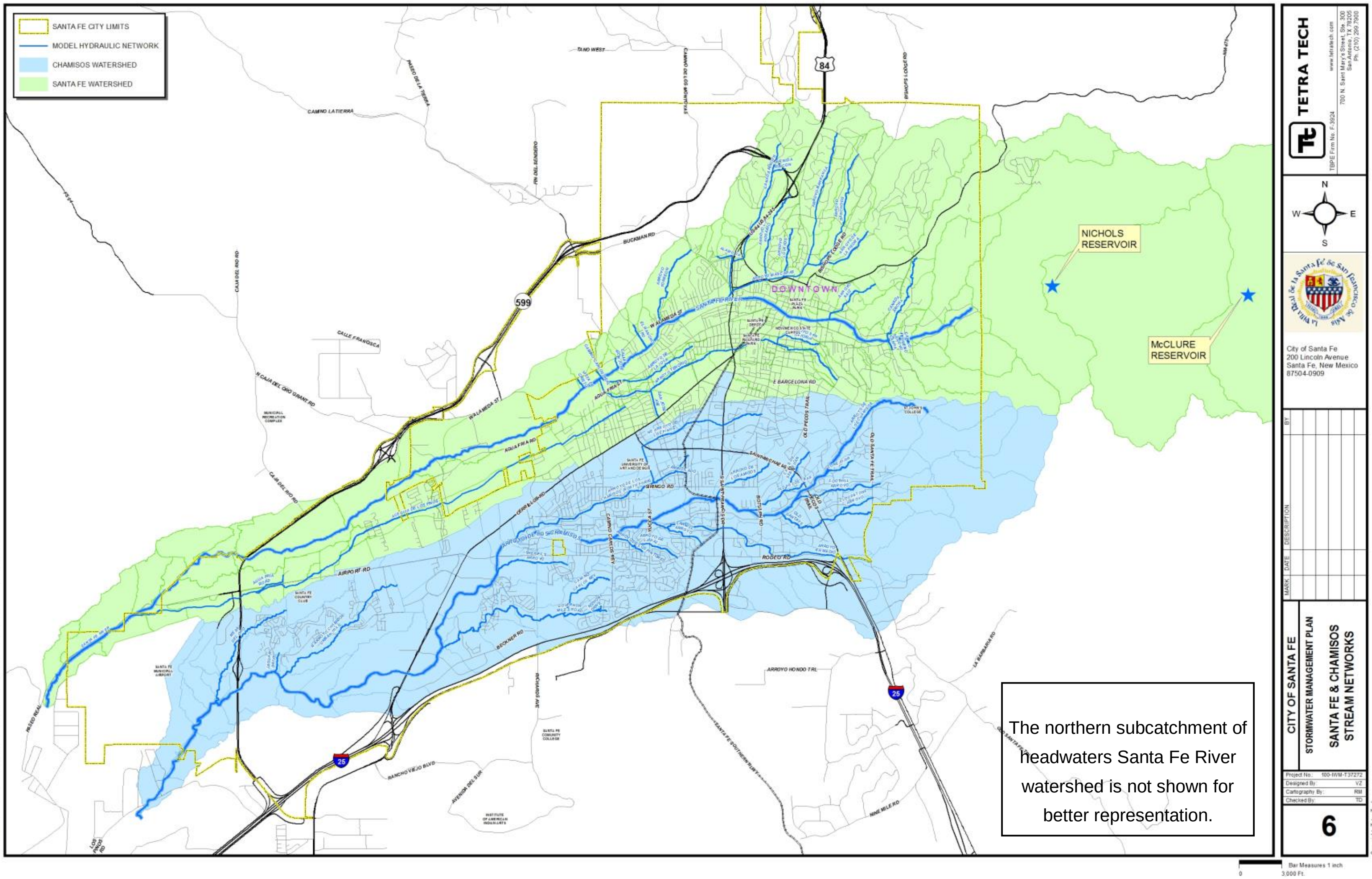


Figure 6. Stream networks selected for hydraulic modeling inside XPSWMM.

4.0 WATER QUALITY MODELING

4.1 LSPC MODEL DEVELOPMENT

LSPC watershed models were developed for the Santa Fe River and Arroyo de Los Chamisos watersheds to establish existing levels of sediment and nutrient loading at the subwatershed scale. The LSPC model for the Arroyo de Los Chamisos watershed consists of 180 subwatersheds while the Santa Fe River watershed is comprised of 176 subwatersheds. Each subwatershed in an LSPC model is comprised of smaller entities known as deluids. A deluid is the identification number assigned to the smallest landuse units in an LSPC model for which all physical processes like infiltration, runoff generation, sediment and nutrient load generation are simulated. A deluid is a unique combination of properties like land cover, soil properties, geology, slope, etc. The deluids in the Santa Fe River and Arroyo de Los Chamisos LSPC models are based on a combination of land cover and HSG. Loads generated by the deluids in a subwatershed are routed through the associated stream and downstream reaches at the model simulation time-step (hourly in this case). The LSPC models for the watersheds are setup for hourly simulation of hydrology, sediment and nutrients from 1/1/2005 to 12/31/2017.

LSPC is a hydrologic model and not a hydraulic model. Reach segments in an LSPC model are represented as one-dimensional fully mixed reactors which maintain mass balance but do not explicitly conserve momentum. The simulation of hydrographs in response to storm events in the model is dictated by Functional Tables (FTables) or depth-area-volume-discharge relationships. FTables in the models are based on physiographic region-specific regression relationships against drainage area (Bieger et al., 2015). The following equations were used for bankfull width (Wm, in meters) and bankfull depth (Ym, in meters) based on drainage area (DA, in square kilometers) we used in the LSPC for automated generation of FTables during runtime.

$$W_m = 2.56(DA)^{0.351}$$

$$Y_m = 0.38(DA)^{0.191}$$

It should be noted that FTable details primarily have an impact on the shape of a storm hydrograph but not the total flow volume.

Gridded products have been used to develop meteorological time-series forcings for the watershed models. Precipitation in the models is based on daily gridded PRISM (Parameter-elevation Relationships on Independent Slopes Model) data disaggregated to an hourly time-step using NLDAS (North American Land Data Assimilation System) version 2 gridded data. PRISM because of a finer spatial resolution is expected to provide better estimates of rainfall in these watersheds compared to NLDAS which are coarser. Other meteorological forcings (air temperature, solar radiation, wind speed and dew point temperature) are based on hourly gridded NLDAS data. Potential evapotranspiration in the model is based on the Penman Pan method with a pan evaporation coefficient appropriate for this region of the US.

5.0 RESULTS AND DISCUSSION

5.1 XPSWMM MODEL

5.1.1 Model Calibration

The hydrologic and hydraulic results of the XPSWMM modeling were compared to the effective FEMA model results for Headwaters Santa Fe River and Arroyo de Los Chamisos watersheds (***Table 10*** and ***Figure 9***). The results were reasonable and compare well with the USGS gage data and Regional Regression equations used to develop the FIS #35049CV001B dated December 4, 2012 (FEMA, 2012). The City of Santa Fe requires all stormwater systems to meet the 100-year storm event design criteria. As a result, all storm evens up to the 100-year would be expected to have similar model parameters and calibration comparisons.

Table 10. 100-year flow comparison between FEMA and XPSWMM data.

Location	Longitude	Latitude	100-yr Flow FEMA FIS (cfs)	100-yr Flow XPSWMM (cfs)
Headwaters Santa Fe River Watershed				
Canada Ancha at Confluence with Santa Fe River	-105.917	35.681	1,150	978
Santa Fe River at The Confluence of Arroyo Mascaras	-105.955	35.688	4,190	4,286
Santa Fe River at approximately 0.46 mile downstream of Alejandro Street	-105.985	35.673	4,390	5,587
Santa Fe River at the Confluence of Arroyo Calabasas	-106.117	35.610	5,930	5,915
Arroyo de Los Chamisos Watershed				
Arroyo de Los Amigos at Confluence with Arroyo de Los Chamisos	-105.958	35.65	600	404
Ne Arroyo de Los Pinos at Upstream of St. Michaels Drive	-105.976	35.66	570	604
Arroyo de Los Chamisos – North Fork	-106.006	35.642	1,800	1,674
Above Confluence with Arroyo Hondo (Cross Section 0A)	-106.095	35.588	4,400	4,898

Model calibration is the process of modifying effective model parameters to match model results with measured data. In order to calibrate model parameters (specially Cp), measured streamflow data are required at the outlet or certain locations of watersheds. Four USGS streamflow gauges are located at the upstream of headwaters Santa Fe River watershed (before and after reservoirs) but since their drainage area are mountainous with woods in good condition, it is not necessarily representative of urban areas (which contain most of the subcatchments). Currently, there are no streamflow measurements in either watershed that are appropriate for calibration. Adjacent watersheds were explored to find subcatchments with similar characteristics in order to calibrate model parameters using their data but no streamflow gauge was found in urbanized areas that could represent development condition in subcatchments. Since flow comparison of XPSWMM model with FEMA data provides reasonable results and no other type of data is available for calibration, we determined that the XPSWMM model is calibrated and ready to be used for further analysis.

5.1.2 Slope Analysis

Digital Elevation Model data was used to calculate the slope of each individual reach segment that has been modeled inside XPSWMM. The output of this analysis identifies reach segments and culverts with low slope that are vulnerable for sediment deposition and pipe clogging during storm events. ***Figure 7*** represents slope analysis results for modeled reach segments and displays them as assorted colors. Comparing results of slope analysis with ***Figure 10*** reveals that most of flood reported locations and pipe surcharges happen in areas with low to moderate slope. Mountainous regions with high slopes located at the upstream of both watersheds drain stormwater faster to flat areas and result in culvert surcharge or flooding when culverts are undersized or plugged. Arroyo Cloudstone, Arroyo Foothills (south-east of Arroyo de Los Chamisos watershed), and Arroyo Mascaras (north of Santa Fe Downtown) are examples of this issue. Also, the Arroyo Threat Assessment Report (Santa Fe Watershed Assocoation, 2016) listed these Arroyo as high priority areas for channel improvement and infrastructure damage.

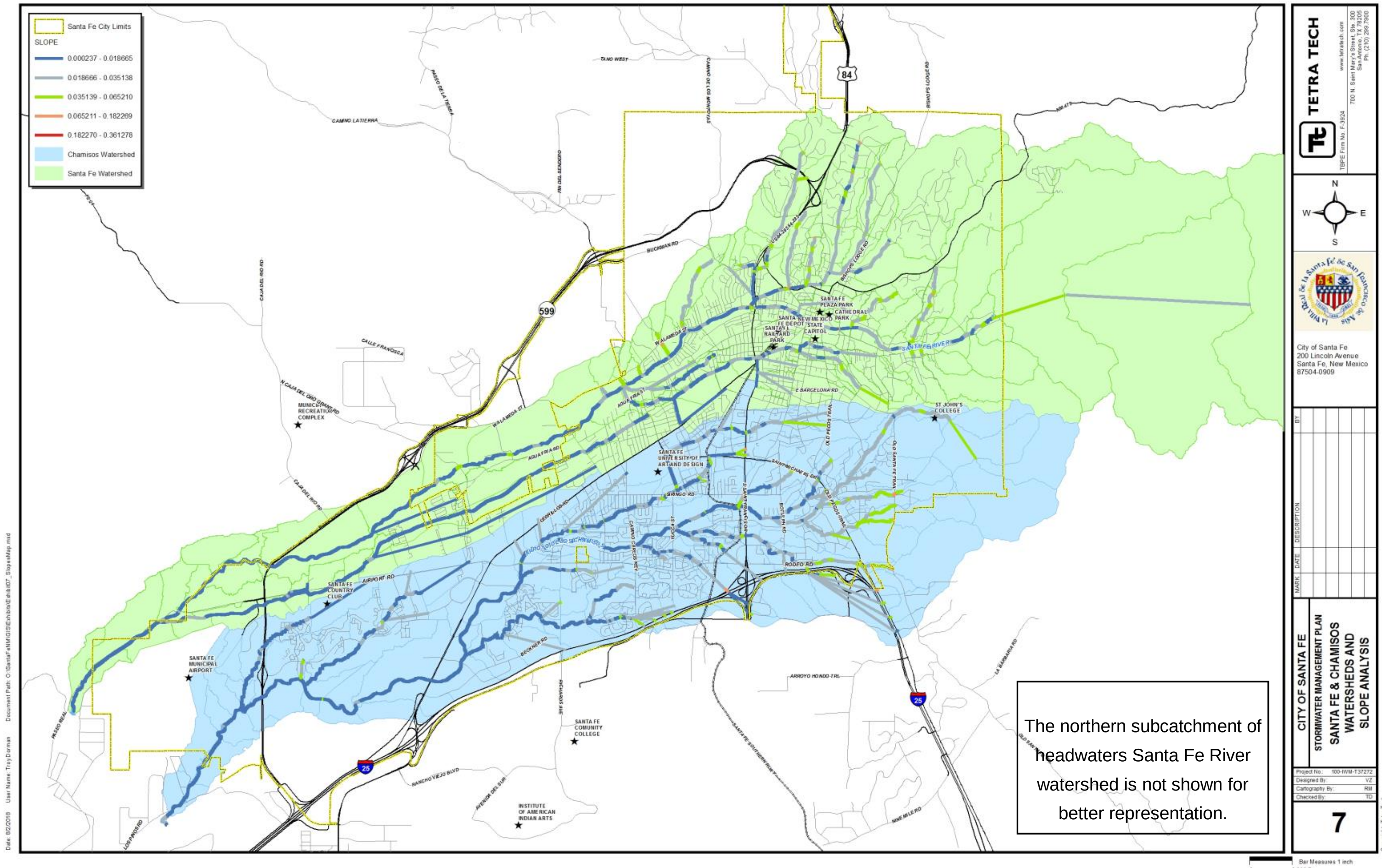


Figure 7. Average slope in reach segments.

5.1.3 Velocity Analysis

The XPSWMM model was run for the 100-year storm event precipitation and velocity profile was generated for each of the reach segments. ***Figure 8*** represents maximum velocity in reach segments. It ranges from 0.01 to 46 ft/s which depends on the slope and geometric characteristics of the reach cross-section. Areas with high velocity are potential for erosion and scour of bridge piers.

Overlaying maximum velocity with slope map reveals valuable information regarding channelization of some reaches. In the high slope areas, higher velocity values are expected but there are some culverts that have moderate or flat slope with high velocity. This issue is due to decreasing cross-section area and forcing flow to pass through the culvert which causes upstream flooding and increased velocity downstream, leading to higher erosion potential. In addition, culverts that have a flat slope or multiple openings at the same elevation cause lower flows to spread out and drop sediments. The combination of factors will create deposition and plugging upstream of a culvert and accelerate erosion downstream of the culvert even during frequent smaller events that produce runoff several times per year.

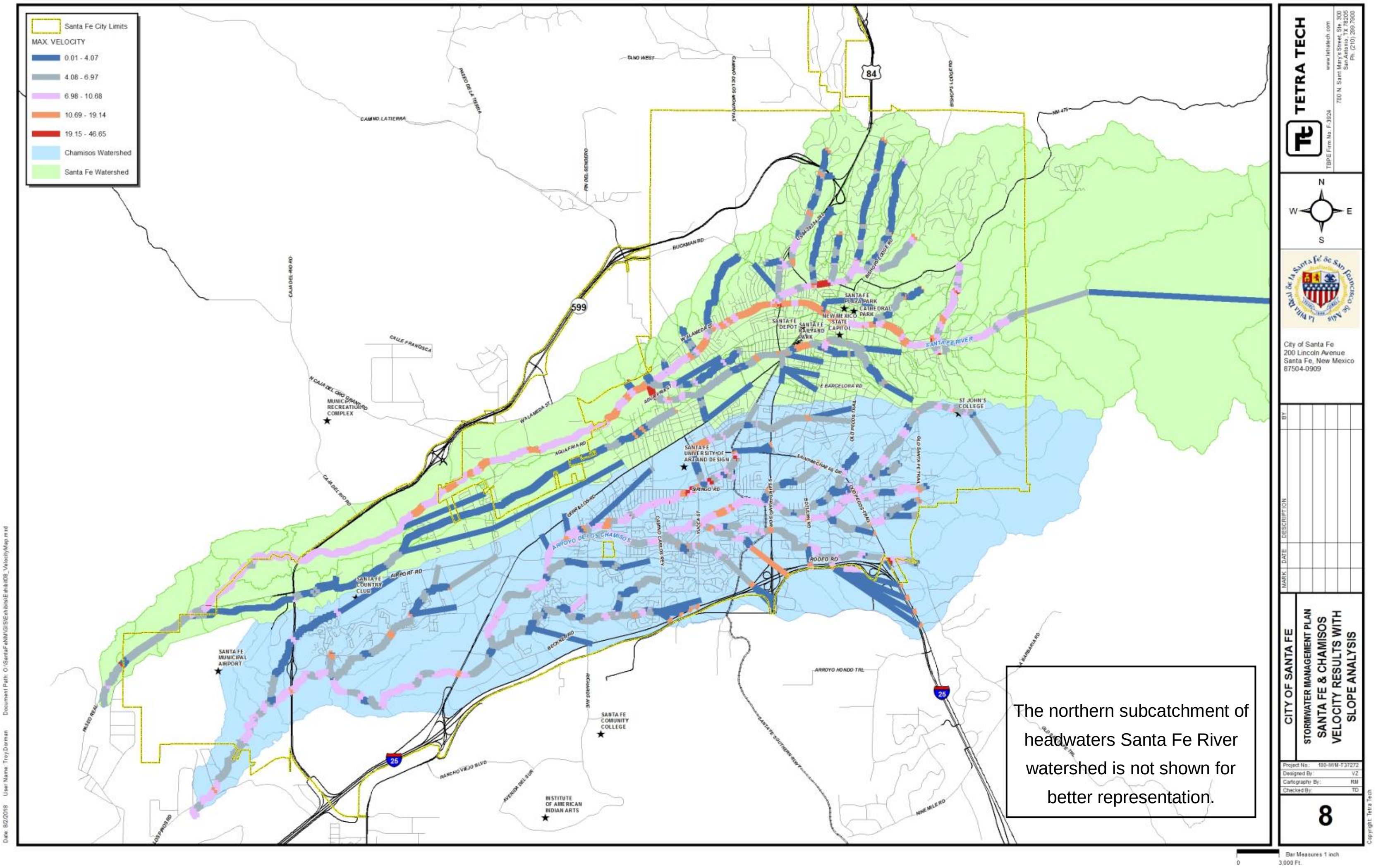
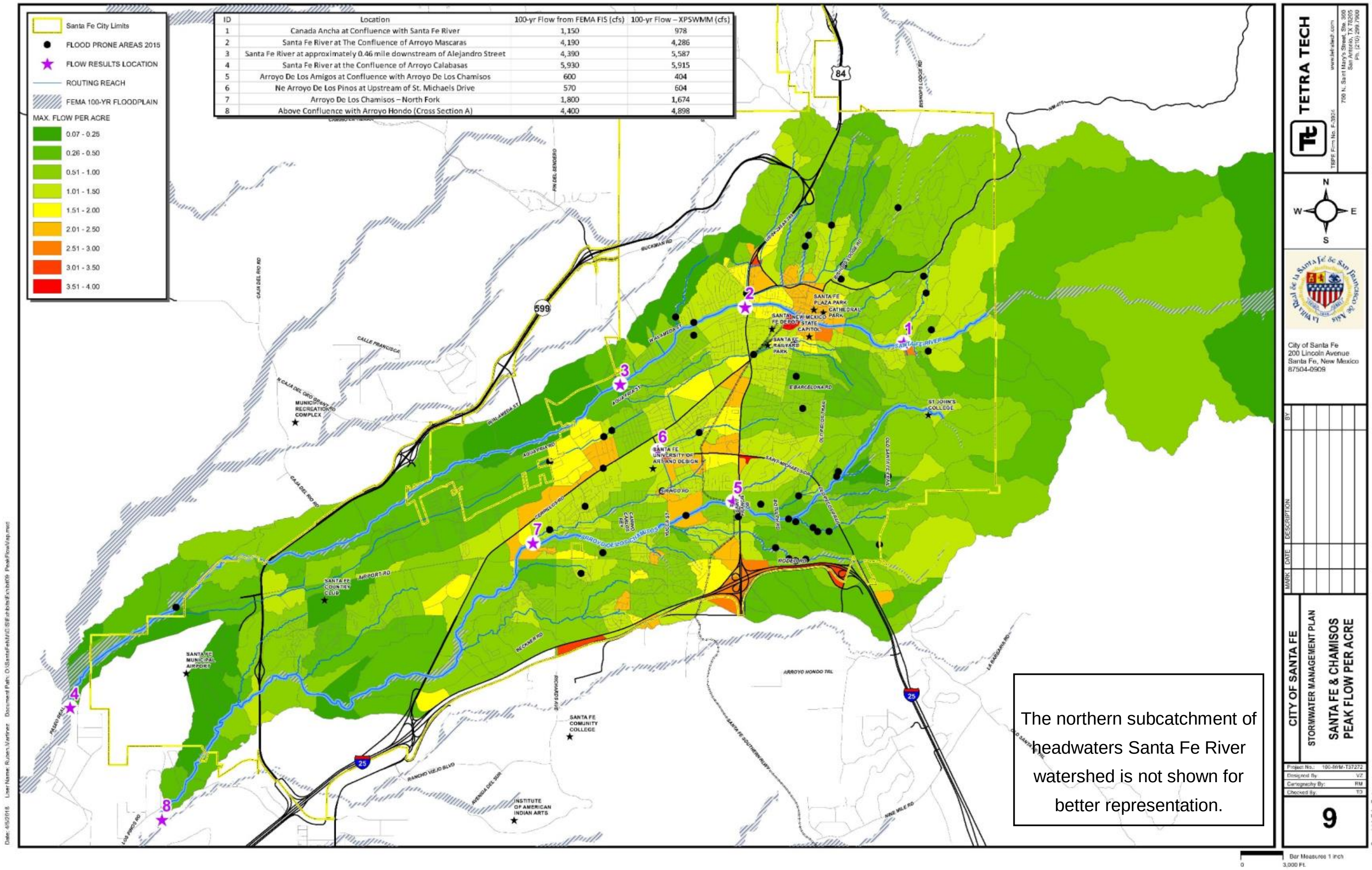


Figure 8. Maximum velocity in reach segments.

5.1.4 Peak Flow Analysis

Each of the subcatchments generates a hydrograph during rainfall-runoff routing and drains to the outlet. In the Snyder's unit hydrograph method, it is a function of lag time and storage coefficient that incorporates other characteristics of the watershed into these two parameters. A useful comparison of watersheds can be made, by dividing the peak of the hydrograph by subcatchment area, to reveal the potential of each subcatchment for generating high flows. ***Figure 9*** represent maximum flow per acre of each subcatchment. Most subcatchments with high flow are located in the highly urbanized part of the watersheds and in the vicinity of highways or major roads. This result is highlighted in the Curve Number map (***Figure 4***) where areas around Downtown Santa Fe, Cerrillos Rd., and S. Saint Francis Dr. have the highest Curve Number values that leads to higher runoff potential during storm events. These areas show a high potential for sediment transport due to high flow and increased erosion. Urbanization and impervious cover create additional runoff above baseline natural conditions which results in increased stream channel erosion.

Overlaying XPSWMM results for slope, velocity, and peak flow reveals that areas around Downtown Santa Fe are generating a high amount of peak flow and velocity while slope is low to moderate. On the other hand, since these areas have flat slope and are mostly channelized, velocities are increased, leading to higher risk for erosion. The Arroyo Threat Assessment report (Santa Fe Watershed Assocoation, 2016) mentioned Arroyo Mascaras (north of Downtown Santa Fe) as the highest potential for infrastructure damage and has recommended measures for channel stabilization.



ID	Location	100-yr Flow from FEMA FIS (cfs)	100-yr Flow – XPSWMM (cfs)
1	Canada Ancha at Confluence with Santa Fe River	1,150	978
2	Santa Fe River at The Confluence of Arroyo Mascaras	4,190	4,286
3	Santa Fe River at approximately 0.46 mile downstream of Alejandro Street	4,390	5,587
4	Santa Fe River at the Confluence of Arroyo Calabasas	5,930	5,915
5	Arroyo De Los Amigos at Confluence with Arroyo De Los Chamisos	600	404
6	Ne Arroyo De Los Pinos at Upstream of St. Michaels Drive	570	604
7	Arroyo De Los Chamisos – North Fork	1,800	1,674
8	Above Confluence with Arroyo Hondo (Cross Section A)	4,400	4,898

Figure 9. Maximum flow per acre of each subcatchment. Flow Comparison locations are shown by star and listed in the above table.

5.1.5 Culvert Capacity Analysis

Culverts and pipes that were incorporated into the XPSWMM model were analyzed to determine if they convey the 100-year design flow without surcharge. Surcharge occurs when the flow rate exceeds pipe capacity, which results in upstream flooding and even roadway closures when the water overtops the road surface. A list of reported areas with flooding issues was made available to Tetra Tech by City of Santa Fe. However, frequency of associated storm event, exact location of river tributary that flooding occurred, and the source of incoming water were not identified in the list. In cases where a specific culvert could not be determined from the reported flood issue, Tetra Tech staff selected the closest model each or main roadway crossing culvert for assessment. ***Figure 10*** presents the locations of surcharged pipes and culverts during 10-year and 100-year design storms, as well as flood prone areas reported by the City of Santa Fe. A 10-year storm is the minimum required frequency for design of roadside ditches and inlets (NMDOT, 2016). Based on the results, there are a total 17 culverts in both watersheds that are under sized for the 10-year storm event. The predicted number of surcharged culverts increased to 43 when the 100-year storm event was analyzed. Most of the locations are within reported flood prone areas which indicates the neighborhoods are having problems with undersized culverts or culvert blockage.

In order to identify minimum pipe and culvert size to convey flow without surcharge, XPSWMM was used to given iterative runs to with 10-year storm event to design new dimensions for undersized pipes and culverts. When a surcharge condition is encountered (flow exceeds full flow capacity), XPSWMM automatically increases the diameter of circular pipes or width of rectangular culverts in fixed increments until the structure is no longer surcharged. Conduits that are neither circular nor rectangular will be converted to circular if they need to be resized. Although, XPSWMM provides an estimate of the culvert size to convey the 10-year flow, a detailed analysis of each structure based on surveyed inverts and road elevations would be necessary to develop a final design. The results presented in the ***Table 11*** are useful for budgeting and initial project scoping for a Capital Improvements Program. The first 17 locations are in the Santa Fe River watershed and the last five are in the Arroyo de Los Chamisos Watershed.

Table 11. Designed conduit dimensions to convey 10-year storm event.

	Original			Designed		
Location	Height	Width	Barrels	Height	Width	Barrels
Old Santa Fe Trail and Arroyo Tenorio St.	1.5	6	1	1.5	8	1
Arroyo Mascaras at Rosario Blvd	3.33	5.42	2	3.33	5.42	3
El Camino Real at Airport Rd	4	4	2	4	4	4
Arroyo Mascaras at W Alameda St	6	10	7	6	10	8
Old Santa Fe Trail and Pino Rd	2	6	1	2	6	3
Paseo de Peralta and W Santa Fe Ave	3	4	1	3	6	1
Paseo de Peralta and W Santa Fe Ave	3	4	1	3	5	1
Galisteo St and W Booth St	3	4	1	3	5	1
Felipe St	2.75	4.08	3	2.75	4.08	5
Agua Fria St and Camino de Chelly	8	8	1	9	9	1
Santa Fe River at E Alameda St	4	10	1	4	10.5	1
Santa Fe River at E Alameda St	4	10	1	4	12	1
Acequia de Los Pinos at Maez Rd	2	4	1	2	5	1
Acequia de Los Pinos at Harrison Rd	2	2	2	2	2	4
Santa Fe River at Calle Debra	6	21	1	6	38	1
Acequia de Los Pinos at Clark Rd	1.55	1.55	1	1.8	1.8	5
Acequia de Los Pinos at Siler Rd	2	2	2	2	2	8
Pinos at Liano St.	3	3	3	3	3	5
Culvert at Governor Miles Rd.	2	2	1	2	2	4
Pinos at Practilliano Dr.	3.5	7.5	2	3.5	7.5	4
Pinos at Camino Carlos Rey	4	8	2	4	8	3
Culvert at Camino Carlos Rey	3	3	1	3	3	4

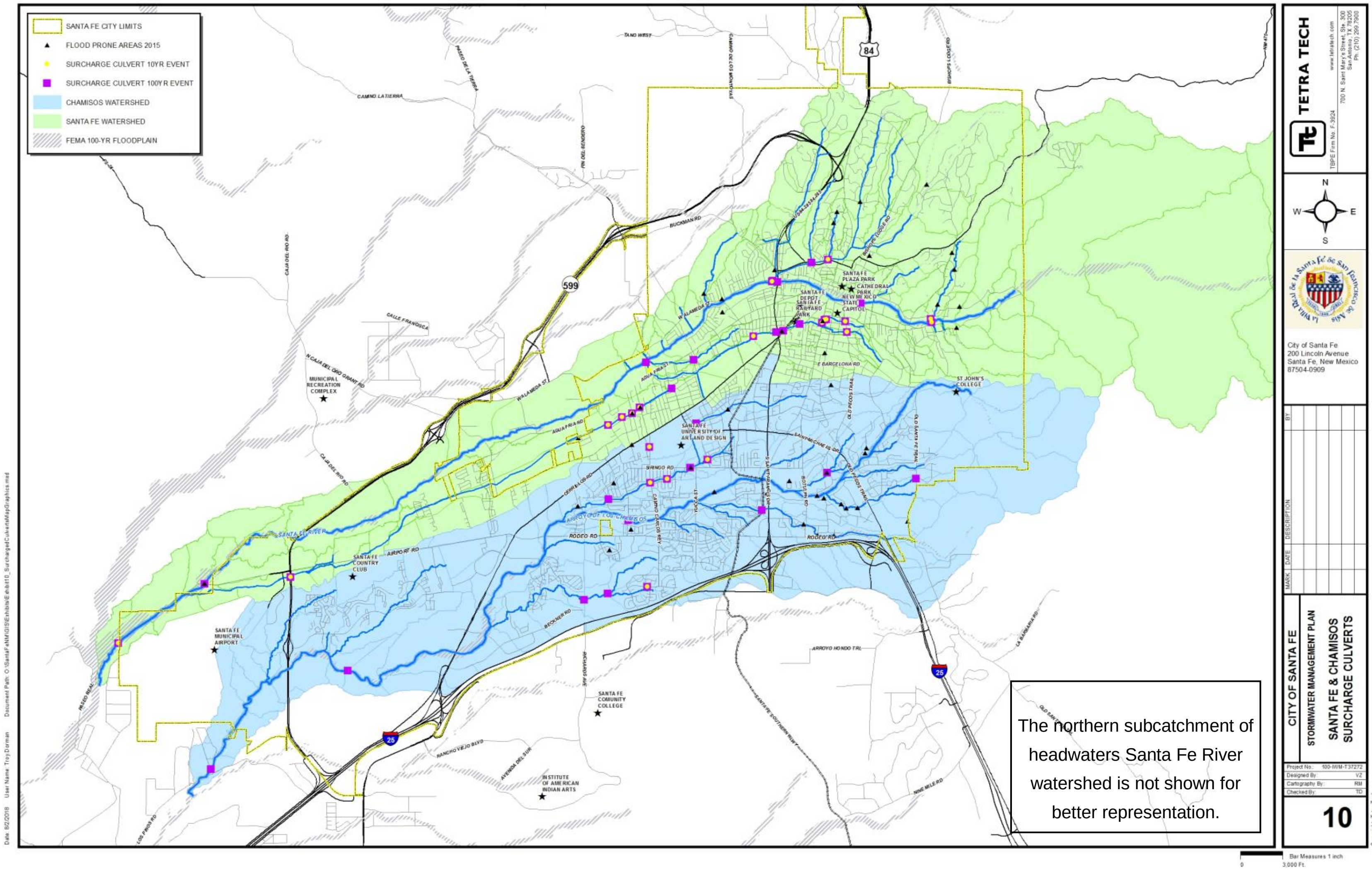


Figure 10. Location of surcharged pipes and culverts for 10-year and 100-year storm events and areas with reported flooding issues.

5.2 LSPC MODEL

5.2.1 Hydrology Simulation

As noted above, both watersheds generally lack streamflow and water quality data to enable comprehensive calibration and validation of the watershed models. Parameterization of the LSPC models was therefore based on prior HSPF (Hydrologic Simulation Program - FORTRAN) models for this region (Moltz et al., 2009; Butcher et al., 2013).

The simulated water balance for the Santa Fe River and Arroyo de Los Chamisos watersheds are shown in

Figure 11. Evapotranspiration is expected to be the largest part of the water balance and is approximately 85% of the precipitation, and in a similar range (of 80% to 99%) reported for this region by Sanford and Selnick (2013). The ratio of LSPC simulated average annual surface runoff to precipitation is shown at the subcatchment scale in ***Figure 13***. As expected, this ratio is generally higher for the more urbanized areas (with high imperviousness) of the watersheds. The flow duration curve for combined daily simulated streamflow from Santa Fe River and Arroyo de Los Chamisos (***Figure 12***) shows that the simulated streamflow generally ranges from 100 cfs to less than 1 cfs.

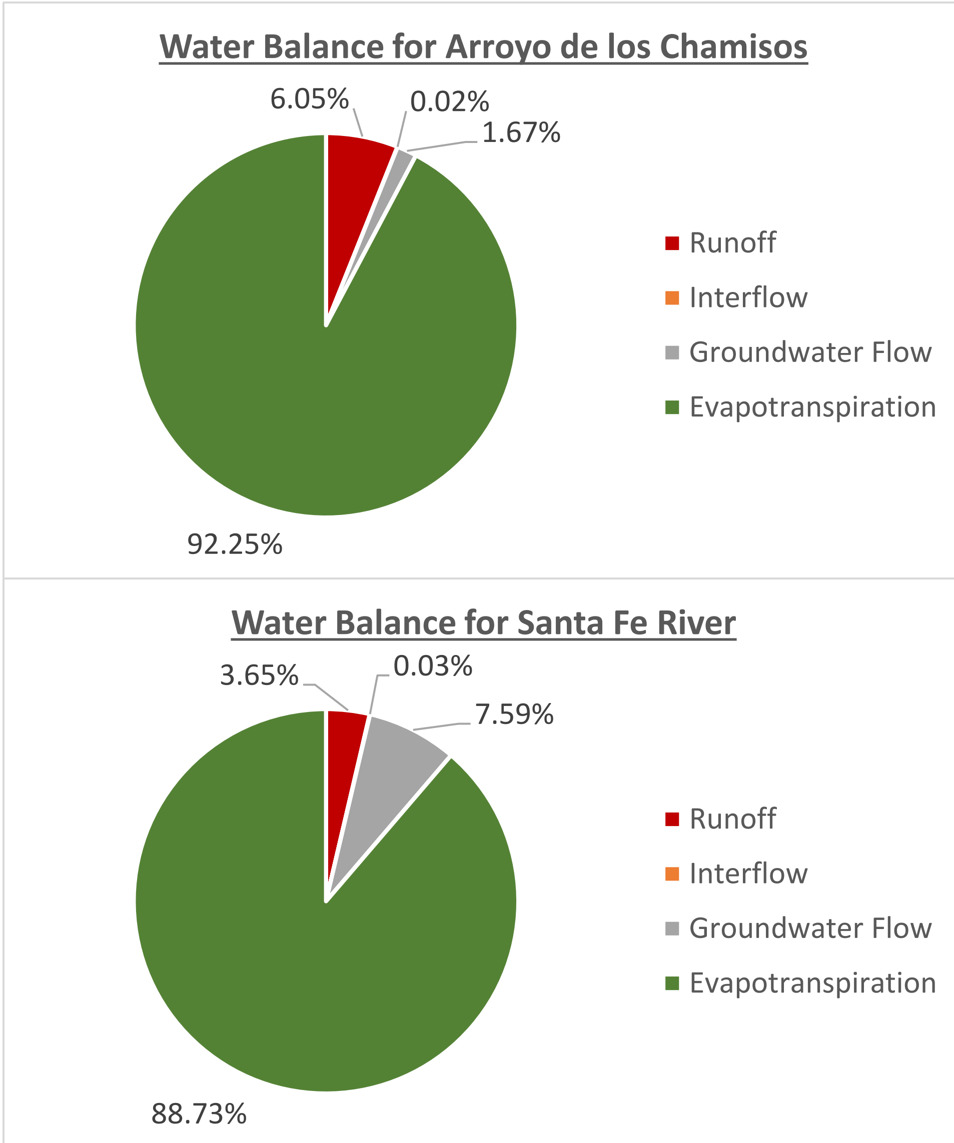


Figure 11. Simulated water balance for the Arroyo de Los Chamisos and Santa Fe River LSPC models.

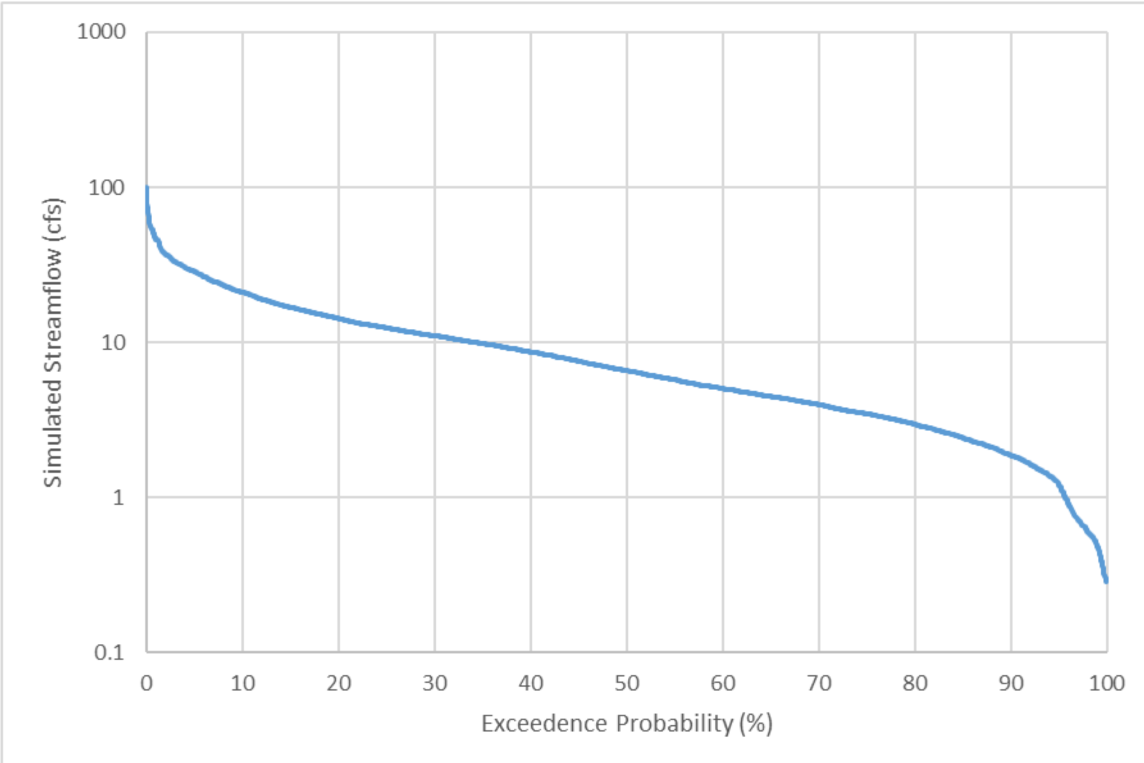


***Figure 12*.** Simulated streamflow duration for the Santa Fe River and Arroyo de Los Chamisos.

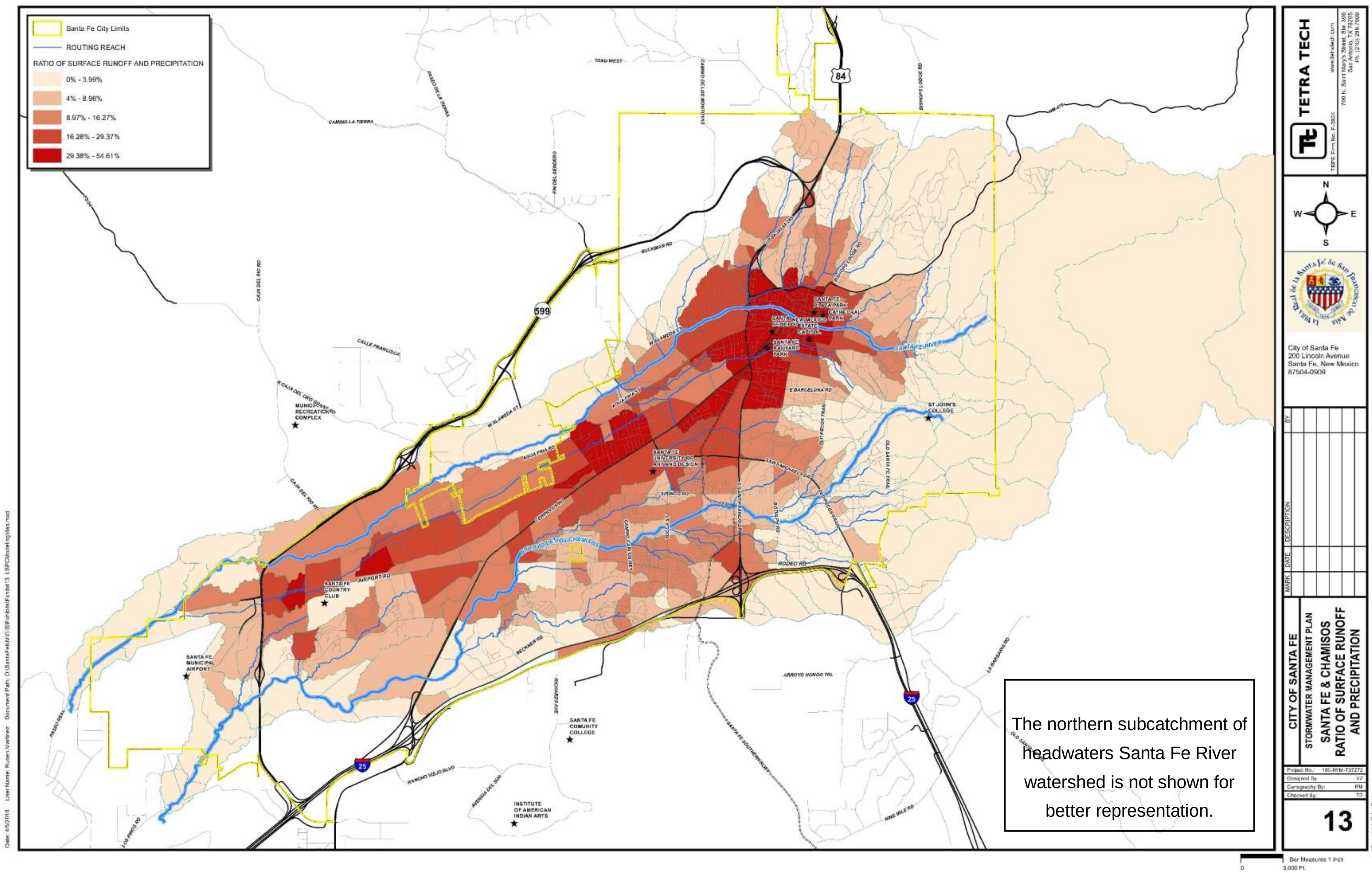


Figure 13. Ratio of LSPC simulated surface runoff to precipitation for the Santa Fe River and Arroyo de Los Chamisos watersheds.

5.2.2 Water Quality Simulation

Given limited water quality monitoring, at this time the sediment and nutrient loads predicted by the LSPC models are the best estimates of non-point source pollutant loading in the watershed. As and when more data are available, the watershed models should be re-evaluated for water quality simulation. Simulated annual average sediment, total nitrogen and total phosphorus loads simulated by the LSPC models are summarized in ***Table 12***.

Table 12. Simulated average annual sediment, total nitrogen and total phosphorus loads for the Santa Fe River and Arroyo de Los Chamisos LSPC models.

Constituent	Santa Fe River	Arroyo de Los Chamisos
Sediment (tons/yr)	2,341.7	555.1
Total Phosphorus (lbs/yr)	342.0	103.8
Total Nitrogen (lbs/yr)	5,868.5	689.5

Simulated non-point runoff associated sediment and nutrient loads at the subcatchment scale are shown in ***Figure 14*** to ***Figure 16***. The sediment and nutrient load show the same trend as runoff with higher loading rates predicted for subcatchments with higher levels of urbanization and imperviousness. Some subcatchments in the south-east part of the Arroyo de Los Chamisos watershed show high sediment and phosphorus loading rates despite being not as heavily urbanized as the rest of the watershed. The high loads are likely linked to poor soil conditions in this region of the Arroyo de Los Chamisos watershed.

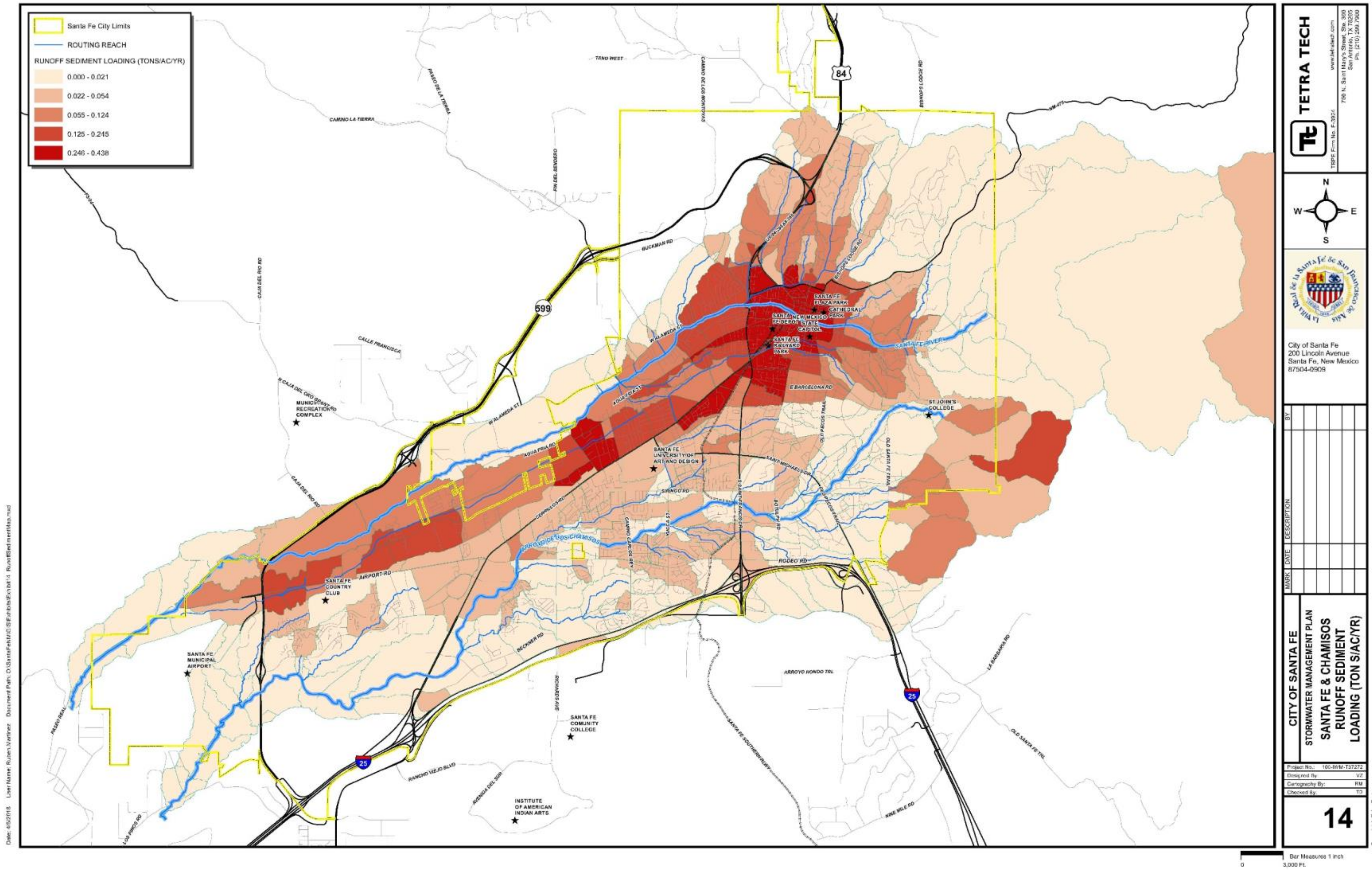


Figure 14. LSPC simulated annual average sediment load for the Santa Fe River and Arroyo de Los Chamisos watersheds.

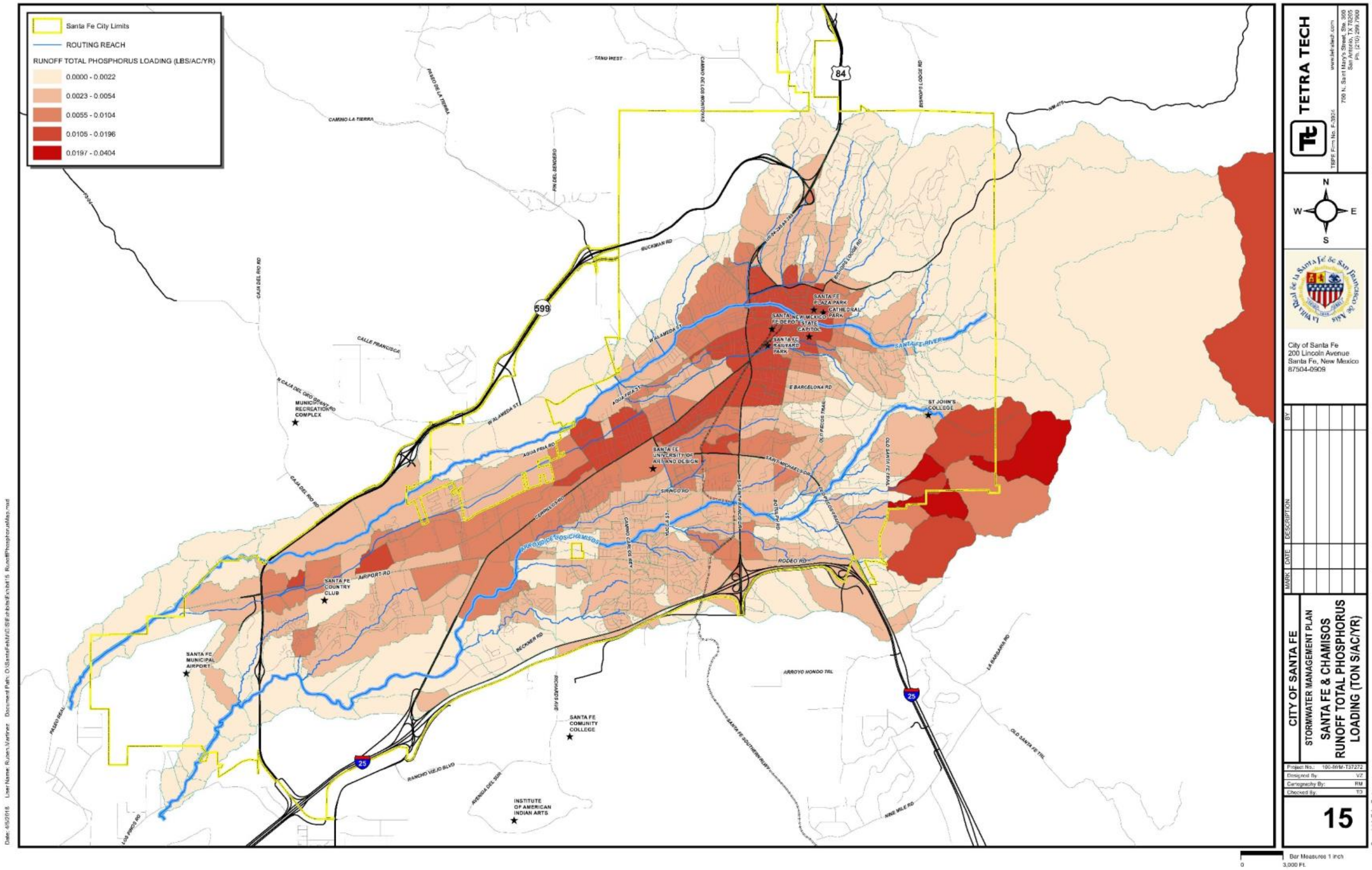


Figure 15. LSPC simulated annual average runoff phosphorus load for the Santa Fe River and Arroyo de Los Chamisos watersheds.

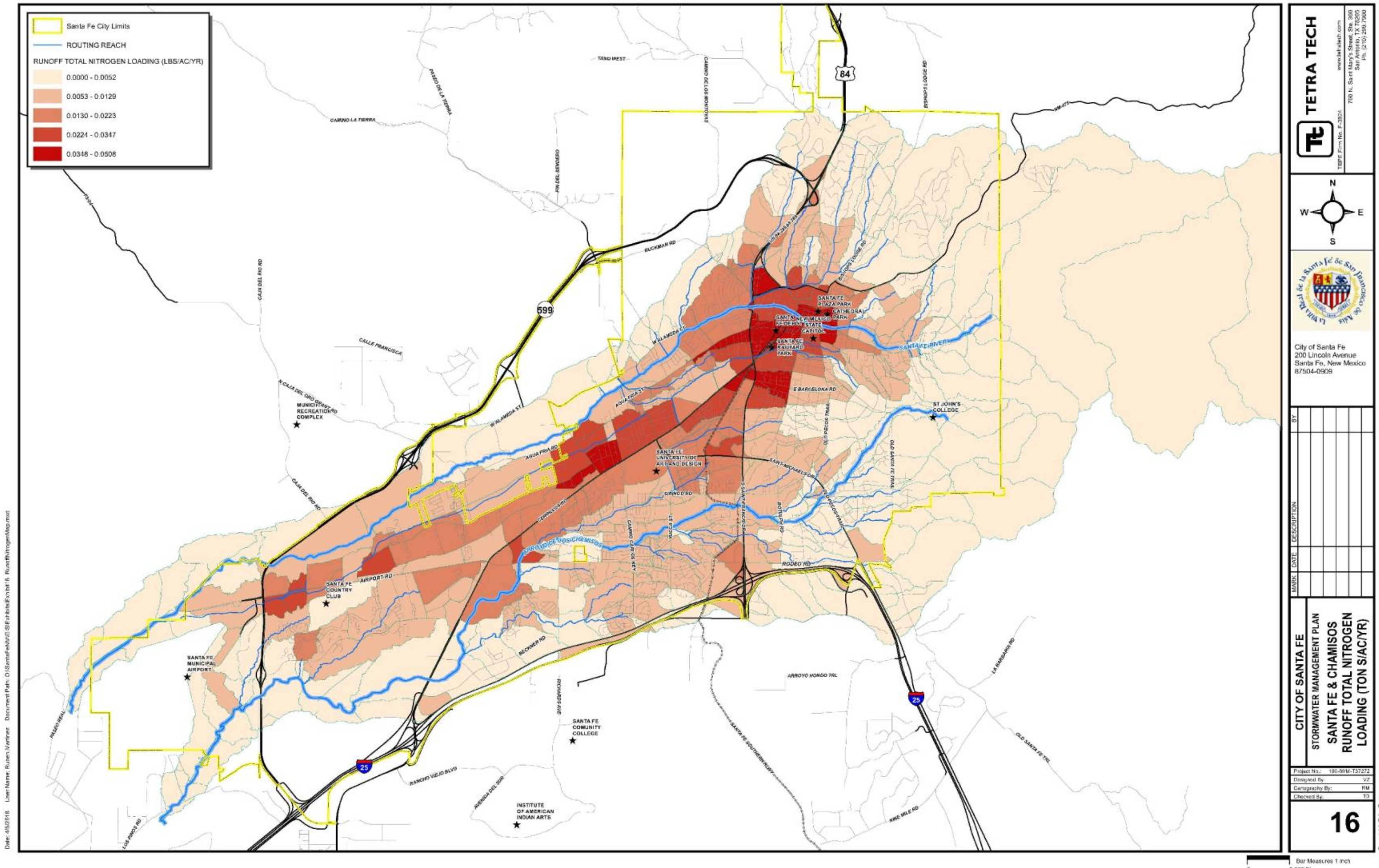


Figure 16. LSPC simulated annual average runoff nitrogen load for the Santa Fe River and Arroyo de Los Chamisos watersheds.

6.0 PRIORITY AREAS FOR GREEN INFRASTRUCTURE IMPLEMENTATION

Based on the outputs of the XPSWMM and LSPC models, and the Arroyo Threat Assessment Report (Santa Fe Watershed Assocoation, 2016), Tetra Tech recommends four priority pilot areas for Green Infrastructure (GI) implementation (***Figure 17.*** Priority areas for GI implementation.

):

1. The subcatchments in the City of Santa Fe downtown area are of highest priority. High peak flow rates, runoff volumes, sediment and nutrient loads, and pipe surcharges are simulated for these areas and flooding issues have been reported frequently. Some subcatchments in this area drain to the Arroyo Mascaras, parts of which have been rated as “high” infrastructure damage/risk in the Arroyo Threat Assessment Report.

2. The subcatchments draining to the Arroyo Cloudstone and Arroyo Foothill are also of concern because of high cumulative sediment and nutrient loading from upstream subcatchments. Also, downstream of these Arroyo have been reported as flood prone areas and based on the hydraulic modeling, some culverts are likely to surcharge during 100-year events. In addition, sections of the Arroyo Cloudstone are already identified as “high” infrastructure damage/risk.

3. The subcatchments in Arroyo de Los Chamisos (North Fork) are currently experiencing flooding issues during storm events. Although the Arroyo Threat Assessment Report generally rates the infrastructure in this region as “good”, the modeling results elaborate that some culverts are likely undersized for conveyance of 10-year and 100-year events. Sediment and nutrient loads predicted for this area are also moderately high.

4. Lastly, the areas near the mouth of the Santa Fe River are recommended for GI implementation. High runoff, sediment and nutrient loads are predicted for some subcatchments. Given the high velocity values along the Santa Fe River, it has high potential for erosion too. Also, culvert capacity analysis suggests that some culverts are likely under-sized for conveyance of 10-year and 100-year events and flooding have been a reported issue, especially in Acequia de Los Pinos.

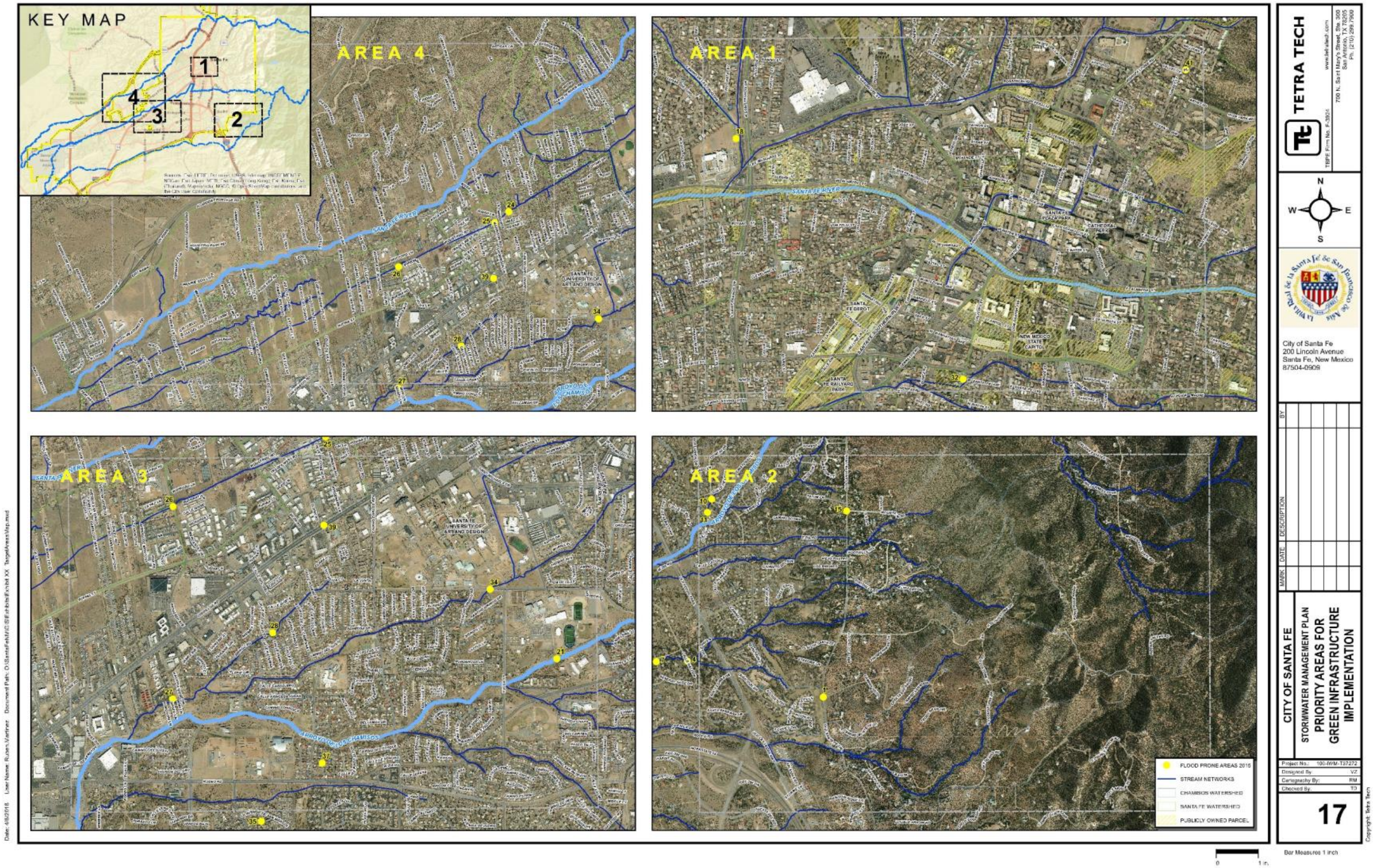


Figure 17. Priority areas for GI implementation.

7.0 FUTURE MODEL ENHANCEMENTS

The LSPC watershed models developed under this work assignment are largely uncalibrated because of limited monitoring data to aid in the parameterization of the model. The model performance for hydrology and water quality should be reviewed in the future based on streamflow and water quality monitoring data. Such an exercise will increase confidence on model estimates of sediment and nutrient loading.

Since urban areas are the focus of non-point pollution in these watersheds a more detailed impervious coverage dataset should be developed for the study area. Such an enhanced impervious coverage dataset should also be used to improve the representation of urban areas in the XPSWMM and LSPC models

Lastly watershed models are most useful in providing existing pollutant loads and also for evaluation of best management practices (BMPs) to mitigate increased volume pollution. LSPC is well-designed to link to the SUSTAIN model to evaluate the impacts of BMPs on pollutant loads and associated costs. The watershed model at this time provides relative estimates of subcatchments that have high sediment and nutrient loading rates. Targeted application of BMPs using the LSPC-SUSTAIN linked model may be readily evaluated for some of these problematic subcatchments for cost effective pollution abatement.

8.0 STORMWATER PROGRAM RECOMMENDATIONS

A high-level review of the model development process and model results presented in this report provides insights into the City of Santa Fe's broader stormwater program. As described above the modeling is useful for identifying areas where urbanization, watershed characteristics and transportation features are resulting in flood prone areas. In combination with the Santa Fe Watershed Association's arroyo assessment, the model results help identify stream segments that are experiencing accelerated erosion and will result in higher maintenance and repair costs for the City. The model also indicates hotspots for water quality concerns that can be addressed as part of the upcoming Phase II MS4 permit implementation. However, there are a few model refinements that would allow a more detailed look within the watersheds and provide better certainty on the level of water quality enhancements. In addition, there are specific design criteria that are recommended to address water quality and flooding issues. The list below summarizes the team's recommendations based on the current modeling effort and ties the recommendations to other stormwater program efforts where synergies exist or where the information developed would serve multiple purposes.

- Stormwater system infrastructure collection – Priority 1
    - The City's record of stormwater infrastructure needs a comprehensive program to identify all street inlets, underground pipes, manholes, roadway culvert crossings and outfalls. This information is necessary for refined watershed modeling, siting water quality BMPs, determining monitoring locations, building an asset management program, and documenting maintenance concerns and compliance with MS4 program requirements.
- Detailed impervious cover database – Priority 2
    - A detailed impervious cover dataset based on the existing LiDAR data and a new high-resolution aerial image acquired for the purpose of impervious cover identification is recommended for use across several areas of the stormwater program. The detailed dataset can be used to better refine the LSPC and XPSWMM models, develop a parcel by parcel equitable stormwater utility fee (based either on impervious cover area or stormwater runoff generated per parcel), plan future expansion of the city by limiting impervious cover in sensitive areas) and identify unpermitted or unreported buildings and development across the city.
- Refine stormwater system criteria for water quality and sediment transport – Priority 1
    - The City's current stormwater criteria requires all infrastructure to meet the 100-year storm. This causes a singular focus on flood events and doesn't recognize the concerns of water quality,

stream stability, sediment transport, and stormwater volume management. In concert with forthcoming water quality based requirements, the City's stormwater management criteria should be expanded to address culvert design, stable channel design, and sediment transport to reduce flooding, maintenance and future erosion issues.

- Include stream flow monitoring in water quality monitoring program – Priority 3
    - The proposed MS4 permit requires monitoring for pollutants of concern with the City of Santa Fe's boundary. The monitoring program should address both the need for water quality information and the need for additional runoff rate and volume measurements to verify watershed scale modeling and local design parameters.

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APPENDIX A. SURVEYED DATA OF STORMWATER COLLECTION SYSTEM IN HEADWATERS SANTA FE WATERSHED

Name	Lat.	Long.	Material	Shape	Height [ft]	Width [ft]	# Barrels
Santa Fe River at Calle Debra	35.618	-106.112	CMP	Arch	6	20	1
Santa Fe River at Calle Debra	35.618	-106.112	CMP	Round	3	3	2
Santa Fe River at Calle Debra	35.618	-106.112	CMP	Oval	2	3	3
Santa Fe River at Paseo Real	35.630	-106.092	CMP	1/2 Round	6	12	7
Acequia de Los Pinos at Clark Rd	35.662	-105.991	CMP	Round	2	2	1
Acequia de Los Pinos at Siler Rd	35.660	-105.995	CMP	Round	2	2	2
Acequia de Los Pinos at Harrison Rd	35.663	-105.989	Concrete	Oval	1.5	2.5	2
Acequia de Los Pinos at Maez Rd	35.664	-105.987	Concrete	Oval	2.5	4.5	1
Acequia de Los Pinos at Osage Ave	35.668	-105.979	CMP	Arch	2.5	4.5	1
W Alameda St	35.673	-105.991	Concrete	Round	5	5	2
W Alameda St and Camino Carlos Rael	35.675	-105.986	CMP	Round	5	5	2
W Alameda St and Calle Nopal	35.677	-105.982	Stone & Concrete	Square	2.25	6	1
N El Rancho Rd and Paseo de Las Vistas	35.684	-105.978	Concrete	Square	1 to 2	6	1
W Alameda St and N El Rancho Rd	35.682	-105.977	Concrete	Square	4.75	8	1
El Camino Real at Airport Rd	35.631	-106.071	CMP	Round	4	4	2
Agua Fria St and Camino de Chelly	35.671	-105.985	Concrete	Round	8	8	1
Osage Ave and San Ildefonso Rd	35.670	-105.980	Concrete	Square	5	8	2
Cristobal Colon and Agua Fria St	35.677	-105.968	CMP	Arch	4	6	1

Name	Lat.	Long.	Material	Shape	Height [ft]	Width [ft]	# Barrels
Baca St and Hickox St	35.679	-105.964	CMP	Arch	2.25	4.5	1
Velarde St and Agua Fria St	35.673	-105.974	CMP	Round	3	3	1
Agua Fria St and Camino Solano	35.673	-105.979	CMP	Arch	4	6	1
Baca St and Potencia St	35.676	-105.964	CMP	Arch	3	5	2
Felipe St	35.678	-105.960	CMP	Arch	2.5	4	3
S St Francis Dr and Mercer St	35.679	-105.954	CMP	Round	4.5	4.5	2
Cerrillos Rd and Don Diego Ave	35.680	-105.949	Concrete	Round	3.5	3.5	1
Galisteo St and W Booth St	35.680	-105.944	Concrete	Square	3	5	1
Old Santa Fe Trail and Arroyo Tenorio St.	35.679	-105.937	Concrete	Square	1 to 1.5	6	1
Camino Corrales and Garcia St	35.673	-105.929	Concrete	Square	5.5	10	1
Old Santa Fe Trail and Pino Rd	35.681	-105.938	Concrete	Square	2.5	6	1
Paseo de Peralta and W Santa Fe Ave	35.681	-105.942	Concrete	Square	3	4	1
Santa Fe River and Camino Alire	35.685	-105.967	Concrete	Bridge	15	65	1
Gregg Ave and Michelle Dr	35.697	-105.958	CMP	Arch	4.5	7	1
Alamo Dr and N St Francis Dr	35.697	-105.954	Concrete	Square	4	6	1
Arroyo Mascaras at Las Mascaras St	35.690	-105.954	Concrete	Square	6	10	5
Canada Rincon at Camino Francisca	35.714	-105.944	CMP	1/2 Round	4	8	2
Canada Rincon at Avenida Rincon	35.706	-105.947	CMP	Round	4	4	7
Vera Dr and Los Lovatos Rd	35.696	-105.941	CMP	Arch	3	5.5	2
Arroyo Ranchito at Murales Rd	35.696	-105.933	CMP	Arch	3.25	4.5	2
Arroyo Barranca at Chula Vista St	35.715	-105.931	CMP	Round	6	6	1

Name	Lat.	Long.	Material	Shape	Height [ft]	Width [ft]	# Barrel s
Arroyo de La Piedra at Cam Chamisa	35.702	-105.922	CMP	Round	6	6	5
Santa Fe River at Guadalupe St	35.687	-105.944	Concrete	Bridge	15	45	1
Arroyo Saiz at E Palace Ave	35.686	-105.930	Concrete	Square	6	15.5	1
Arroyo Saiz and Avenida Primera S	35.690	-105.924	CMP	Round	4	4	1
Santa Fe River at Paseo de Peralta	35.684	-105.934	Concrete	Bridge	10	45	1
Arroyo Saiz at Avenida Primera S	35.691	-105.920	CMP	Round	3.5	3.5	1
E Palace Ave and Los Lobatos Rd	35.683	-105.925	Concrete	Square	4	10	1
Upper Canyon Rd and Canyon Rd	35.679	-105.916	Concrete	Round	5	5	1
Upper Canyon Rd and Apodaca Hill St	35.679	-105.914	Stone & Concrete	Trapezo id	8	12 to 18	1
Alarid St and Mercer St	35.679	-105.953	CMP	Round	3	3	2
Arroyo Del Rosario at Griffin St	35.695	-105.946	CMP	Round	3.5	3.5	3
Arroyo Barranca at Loma Entrada	35.701	-105.935	CMP	Arch	6	16	1
Culvert at Los Arboles Dr	35.702	-105.940	CMP	Round	3	3	1

APPENDIX B. SURVEYED DATA OF STORMWATER COLLECTION SYSTEM IN ARROYO DE LOS CHAMISOS WATERSHED

Name	Lat.	Long.	Material	Shape	Height [ft]	Width [ft]	# Barrels
Culvert at Veterans Memorial Hwy	35.62	-106.07	CMP	Round	4.5	4.5	2
Culvert on Chamisos Trib.	35.62	-106.06	CMP	Round	3	3	1
Culvert at Jaguar Dr.	35.62	-106.06	CMP	Round	5	5	1
Chamisos at Las Cuatro Milpas	35.61	-106.06	Concrete	Square	8	6	1
Chamisos at Governor Miles Rd.	35.63	-106.02	Concrete	Square	10	10	8
Pinos at Kachina Ridge Dr.	35.64	-106.00	CMP	Round	7	7	4
Chamisos at Urban Trail	35.65	-105.97	CMP	Pipe Arch	14	26	1
Chamisos at Rail Road	35.65	-105.96	Steel, concrete, wood	Bridge	~16	~35	-
Chaparral at E Sawmill Rd.	35.64	-105.95	CMP	Round	6	6	6
Culvert at Jaguar Dr.	35.62	-106.05	CMP	Round	7	7	2
Culvert at Dancing Ground Rd.	35.63	-106.01	CMP	Pipe Arch	5.5	7	7
Culvert at Pueblos Del Sol Park	35.63	-105.99	Concrete	Square w filled corners	2.5 to sand	16	1
Culvert at Governor Miles Rd.	35.63	-105.99	CMP	Round	2	2	1
Culvert at Nizhoni Dr.	35.63	-105.98	Concrete	Square w filled corners	5 to dirt	16	1
Culvert at Calle Tecolote	35.65	-105.94	CMP	Round	2	2	3
Culvert at St. Michael's Dr.	35.65	-105.94	CMP	Round	4	4	1
Chamisos at Paseo de Angel N	35.59	-106.09	CMP	Pipe Arch	7.5	26	2

Name	Lat.	Long.	Material	Shape	Height [ft]	Width [ft]	# Barrels
Culvert at South Meadows Rd.	35.63	-106.03	CMP	Pipe Arch	5	7.5	4
Culvert at Governor Miles Rd.	35.63	-105.99	CMP	Round	4	4	1
Culvert at Paseo Del Sol W	35.63	-106.06	CMP	Round	5	5	1
Culvert at Ravine Rd.	35.63	-105.99	CMP	Round	4	4	3
Chamisos at La Rambla	35.67	-105.91	CMP	Pipe Arch	7 to sand	14	1
Chamisos at Botulph Rd.	35.65	-105.95	Concrete	Square	4 to sand	10	4
Culvert at Botulph Rd.	35.65	-105.95	Concrete	Square	5.5 to sand	12	1
Pintores at W Zia Rd.	35.64	-105.98	Concrete	Round	2.5	2.5	4
Sheriff's at Paseo de Los Pueblos	35.64	-106.00	CMP	Round	3.5	3.5	2
Foothill at Calle Cacique	35.65	-105.93	CMP	Round	7	7	1
Foothill at Old Santa Fe Trail	35.65	-105.92	CMP	Pipe Arch	5	7	1

APPENDIX C. ELEVATION-AREA-STORAGE DATA FOR MCCLURE RESERVOIR

Elevation (ft)	Area (acres)	Capacity (ac-ft)
7782	0.02	0.05
7786	0.2	0.61
7790	0.57	2.46
7794	1.28	6.78
7800	3.55	23.21
7804	5.14	42.14
7806	6.02	54.18
7810	8.33	85.18
7814	10.03	123.66
7816	11.14	145.94
7820	13.54	197.71
7824	16.13	259.62
7826	18.11	295.84
7830	21.73	379.39
7834	24.84	475.57
7836	26.52	528.62
7840	30.45	646.27
7842	32.45	711.18
7844	34.64	780.46
7846	37.06	854.57
7848	39.24	933.05
7850	41.4	1015.85
7852	43.77	1103.39
7854	46.24	1192.86

Elevation (ft)	Area (acres)	Capacity (ac-ft)
7856	48.66	1293.18
7858	51.25	1395.69
7860	54.24	1504.17
7862	57.59	1619.36
7864	59.78	1738.92
7866	61.18	1861.28
7868	62.63	1986.54
7870	64.29	2115.13
7872	66.24	2247.61
7874	68.06	2383.72
7876	69.83	2523.37
7878	71.58	266.53
7880.16 (Previous Spillway)	73.49	2825.26
7882	74.28	2963.65
7884	76.8	3117.25
7885.79 (Current Spillway)	77.63	3257.45
7886	78.34	3273.93
7888	79.91	3433.75
7890	81.5	3596.76
7892	83.15	3763.01

APPENDIX D. ELEVATION-AREA-STORAGE DATA FOR NICHOLS RESERVOIR

Elevation (ft)	Area (acres)	Capacity (ac-ft)
7424	0	0
7426	0.1	0
7428	0.3	0.4
7430	0.6	1.3
7432	0.93	2.8
7434	1.34	5
7436	1.84	8.1
7438	2.5	12.3
7440	3.29	18.1
7442	4.13	25.5
7444	5.02	34.7
7446	5.93	45.6
7448	6.85	58.4
7450	7.9	73.0
7452	9.01	90.0
7454	9.98	109.0
7456	10.94	129.9
7458	12.01	152.8
7460	13.21	177.9
7462	14.56	205.6
7464	15.8	236.2
7466	16.95	268.9
7468	18.23	304.0
7470	19.69	341.8

Elevation (ft)	Area (acres)	Capacity (ac-ft)
7472	21.34	382.7
7474	22.99	427.1
7476	24.65	474.7
7478	26.44	525.7
7480	28.14	580.5
7482	29.63	638.3
7483 (Spillway)	30.36	668.3
7484	30.92	699.0
7486	32.04	761.9
7488	33.15	827.1
7490	34.22	894.5
7492	35.26	964.0
7494	36.25	1035.6