Cibolo Creek Watershed Holistic Master Plan

San Antonio River Authority

SAN ANTONIO RIVER AUTHORITY
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Cibolo Creek Watershed Holistic Master Plan

Phase I Report

San Antonio River Authority

July 2018 (Revised)

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Phase I Report

San Antonio River Authority

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Atkins North America, Inc.
Texas Registered Engineering Firm F-474

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Table of acronyms

ARF	Areal Reduction Factor
BCAD	Bexar County Appraisal District
BFE	Base Flood Elevations
BOD	Biochemical Oxygen Demand
BRWM	Bexar Regional Watershed Management
C2MP	Cibolo Creek Holistic Watershed Master Plan
COOP	Cooperative Observer Program (NWS)
CoSA	City of San Antonio
D2MR	Digital Data and Model Repository
DEM	Digital Elevation Model
DFIRM	Digital Flood Insurance Rate Map
EAA	Edwards Aquifer Authority
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FTABLES	hydraulic Function Tables
GBRA	Guadalupe-Blanco River Authority
GIS	Geographic Information System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HSPF	Hydrological Simulation Program – Fortran
IGCR	Intergovernmental and Community Relations
LAS	LAS File Format
LiDAR	Light Detection and Ranging
LOMR	Letter of Map Revision
NADP	National Atmospheric Deposition Program
NLCD	National Land Cover Database
NFIP	National Flood Insurance Program
NHD	National Hydraulic Dataset
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
SARA	San Antonio River Authority
SARB	San Antonio River Basin
SCS	Soil Conservation Service
SSURGO	Soil Survey Geographic database
Tc	Time of Concentration
TCEQ	Texas Commission on Environmental Quality
TNRIS	Texas Natural Resources Information System
TSDN	Technical Support Data Notebook
UH	Unit Hydrograph
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

1. Introduction

The Cibolo Creek Holistic Watershed Master Plan (C2MP) seeks to provide communities with sustainable solutions that address a variety of concerns including flooding, water quality, stream health and recreation. The solutions will be developed to consider the following objectives:

- Reduce flood risk using structural and non-structural measures,
- Reduce pollutant loadings in waterways or remove them through natural processes,
- Protect or restore riparian corridors, and
- Incorporate recreational features where feasible.

The C2MP will provide a prioritized list of implementable project alternatives and an implementation plan for the recommended alternatives.

The project consists of three phases:

- **Phase 1** – This phase evaluated the available data and what additional data needs to be collected for the C2MP. Meetings were held with local stakeholders to determine their areas of interest throughout the watershed and to collect additional available data. The collected data were reviewed and used with input of stakeholders to determine areas of interest throughout the watershed. The limits and focus of the individual study elements (Water Resources, Water Quality, Stream Health, and Human Interface/Recreation) were determined.

- **Phase 2** – This phase will include an analysis of the existing hydrology, stream hydraulics, water quality, stream health, and recreational features. “Damage centers”, which are areas where potential problems exist, will be identified based on existing and future conditions models. A preliminary list of watershed improvement alternatives will be developed. “Opportunity centers”, will be identified as areas with positive features that can potentially be preserved or enhanced.

- **Phase 3** – This phase will include an evaluation of the improvement alternatives as projects in each “damage center”. Scoring criteria, including factors such as flood damage reduction, crossing safety improvements, water quality benefits, recreational enhancements, and stream function improvements, will be used to evaluate each alternative. A prioritized list of project alternatives will be provided along with an implementation plan for the recommended alternatives.

This report documents the Phase 1 efforts for the C2MP, which included the collection and inventory of data, reports and models needed for future phases of the C2MP. This report discusses Data Collection Methods (Chapter 2), Data (Chapter 3), Reports (Chapter 4), Models (Chapter 5), and Data Gaps and Recommendations (Chapter 6). Included as part of this Phase 1 Report are a set of DVDs containing the collected data, reports and models.

The Phase 1 and Phase 2 reports are intended to be stand-alone documents.

2. Data collection methods

Data was collected for the C2MP through multiple methods, including research, stakeholder outreach and field reconnaissance. This section discusses each of these data collection methods.

2.1. Research

The majority of the data collected for the Phase 1 effort was obtained through research of readily available sources. This research included accessing websites (ex. SARA's D2MR, the National Climatic Data Center, TCEQ, etc.), contacting agencies directly, and collecting data directly from SARA.

2.2. Stakeholder Outreach

Building stakeholder consensus is a key component of any master plan. Stakeholder engagement was an important part of the Phase 1 effort. The objective was to identify key stakeholders, collect available data and conduct stakeholder meetings to discuss potential areas of interest. The identified stakeholders in the watershed were engaged through specific individual meetings. Meeting with the stakeholders individually provided a better platform to encourage data and information sharing than meeting in a group format. The individual format allowed for more of the stakeholder staff to attend and provide input in the discovery, which led to more information and historical understanding of the stakeholders' particular area of the watershed.

SARA staff along with the Atkins' team (including Ximenes and Associates) developed a stakeholder engagement plan that included an initial list of key stakeholders. The engagement plan establishes a standard approach to stakeholder coordination. This approach provides a thorough overview of the project and encourages feedback from the stakeholders. Feedback from the stakeholders had indicated support for the project and willingness to share data and information across the watershed. Stakeholder engagement and coordination will continue through Phase 2 and Phase 3 of the master plan. The stakeholder engagement in Phase 2 and 3 will be geared towards inquiries for backup data, questions from data review, and short updates as to the progress of the project. As results become available, affected stakeholders will be briefed and provided an opportunity for comments and feedback.

2.2.1. Stakeholder identification

Developing an initial list of stakeholders provided the basis for the engagement strategy. Key stakeholders with a significant interest in the plan were identified early on so that the team could allocate sufficient time to gather available data and discuss issues of relevance. A map provided to stakeholders during the discovery (included in Appendix A), shows political boundaries, city limits, council and commissioner districts, county boundaries and various other landmarks and borders. The map also identified cities and counties, political organizations, list of county judges, river authorities, and military installations. A full list of stakeholders is provided in Appendix A.

As the stakeholders were identified, they were placed in one of three categories depending on their influence.

- **Primary Stakeholders:** Large governmental entities, bigger municipalities and persons with major control or influence over portions of the watershed
- **Secondary Stakeholders:** Cities or municipalities within the watershed
- **Tertiary Stakeholders:** Environmental or recreational groups, local businesses and land owners with specific vested interests

2.2.1.1. Primary

Primary stakeholders included County Judges, County Commissioners, City Council Members, Guadalupe Blanco River Authority, City of San Antonio, Joint Base San Antonio, and SARA board members, among

others. The SARA Intergovernmental and Community Relations (IGCR) staff led coordination efforts with GBRA (Guadalupe Blanco River Authority), County Judges, Council Members, and County Commissioners. The remaining stakeholders were contacted by the project team.

2.2.1.2. Secondary

Secondary stakeholders include the cities of Boerne, Bulverde, and Selma among others. Typically, these stakeholders lie along the main stem of Cibolo Creek. Most lie outside the SARA jurisdiction and are within the GBRA boundaries. The project team engaged these stakeholders directly.

2.2.1.3. Tertiary

Tertiary stakeholders have vested interests that do not extend beyond their localities. Typical tertiary stakeholders are interest groups, land owners or committees, and scientific organizations. Tertiary stakeholders identified in the Cibolo Watershed include The Nature Conservatory, Cibolo Nature Center, and Greater Edwards Aquifer Alliance.

2.2.2. Stakeholder engagement plan

The stakeholder engagement plan establishes a standard communication framework. It consists of a list of stakeholders, contact information, communication protocol, contact schedules, and a partnering plan. The partnering plan mentions key ideas/topics of interest for each stakeholder level (i.e. tertiary, secondary, and primary) and an accompanying script to ensure that discussions with a particular stakeholder are thorough and accurate. The partnering plan and script provides a base to begin talks with the stakeholders. Actual discussions with individual stakeholders would focus on elements that were applicable to the area and that were of particular interest to the stakeholder. The stakeholder engagement plan is included in Appendix A.

2.2.3. Stakeholder meetings

Stakeholder meetings were conducted to inform interested stakeholders and the public about the planning effort, allow sharing of data, discuss key issues and collect available data for the plan. The stakeholder outreach effort started in April 2014 and lasted until September 2014. The meetings also helped identify additional stakeholders such as environmental organizations, recreational groups, local businesses and land owners. The meetings were held in-person to help foster collaboration with SARA. A total of 22 meetings were held, broken out in to eleven primary, ten secondary, and one tertiary stakeholder. Stakeholders were primarily interested in the data availability after the project was complete as well as if there was going to be project funding associated with the final recommendations. The stakeholders were informed that the final report would be made available for their review and use but the project funding would have to come from other sources not specifically related to the project.

A key objective was to gage the availability and access to the following types of data:

- FEMA Flood Hazard Identification
- Water Quality Data
- Hydrologic and Hydraulic Data
- Aquifer Studies
- High Water Marks
- Local Flooding Issues and Areas of Concern
- Future Park Plans
- Community Outreach

The following documents were developed to engage stakeholders in a consistent manner and clearly communicate the goals and objectives of the master plan:

- **Script** - A template script provides an outline of talking points to aid discussions with the stakeholders. This document includes a protocol for conducting pre-meeting outreach activities to prepare the

stakeholder for data that may be able to provide. The script formed the basis for conducting stakeholder meetings with consistency.

- **Fact Sheet** - The Cibolo Fact Sheet is a simple "leave-behind" summary sheet that informs stakeholders regarding the overall goals and objectives of the plan, the phased process and engineering and environmental aspects.

- **Map** - A map showing the Cibolo Creek watershed was included with the fact sheet. It shows county boundaries, larger cities and the Cibolo Creek watershed. This map was used during stakeholder discussions to demonstrate the magnitude of the watershed basin and the relative location of a particular stakeholder.

These documents, as well as minutes from each stakeholder meeting are included in Appendix A.

2.3. Field Reconnaissance

On January 7th and 8th of 2014 the project team toured the Cibolo Creek watershed to better understand the characteristics of Cibolo Creek, observe conditions within the watershed and visit sites, such as reservoirs, preservation areas, recreational facilities and other features that will have a bearing on the future phases of the C2MP. Photos collected from the tour are discussed in Section 3.1.7.

3. Data

This chapter discusses the data that was collected as part of Phase 1 and is organized based upon the primary use of the collected data: General, Flood Risk, Water Quality, Stream Restoration, and Project Development and Nature-Based Park Planning. Data discussed in this Chapter is included on the attached DVD as Appendix B and follows the organization of this chapter.

3.1. General

Some data may have more than one use (Flood Risk, Water Quality, Stream Restoration, and Project Development and Nature-Based Park Planning) for the C2MP. Data that falls under this category was considered "general" data and is discussed in this section.

3.1.1. Soils

SSURGO (Soil Survey Geographic database) soil data was collected for Bandera, Kendall, Bexar, Comal, Guadalupe, Karnes and Wilson counties from the NRCS. The collected county soil data is in a GIS polygon shapefile format and identifies the limits of each soil type within the county. The raw soil spatial data does not come populated with the hydrologic soil group classifications (Hydrologic Soil Group A, B, C, or D. To obtain the soil classifications, the individual County GIS soil coverages were joined with the County water feature attribute table using the MUSYM field. After all soil fields were correctly attributed, the counties were merged and clipped using the Cibolo Creek watershed boundary with 2,000 ft buffer to create a single soil coverage for the project

The Hydrologic Soil Group information will be used in future phases of the C2MP to calculate SCS curve number loss rate parameters for individual sub-basins in HEC-HMS and HSPF. Table 3-1 identifies the soil shapefiles included with this report.

Table 3-1 GIS Soil Coverages

GIS Coverage	Source	Date Published	Description
Cib_Soil_Grp (polygon)	Atkins	5/7/2015	SSURGO soil coverage, including Hydrologic Soil Groups for the entire Cibolo Creek watershed.

3.1.2. Land use coverage

Multiple land use shapefiles that cover at least portions of the Cibolo Creek watershed were collected from SARA and are listed below:

- **Bexar County 2007 Land Use** – This land use shapefile covers only the Bexar County portion of the Cibolo Creek watershed and reflects 2007 conditions. The shapefile provides land use categories that are sufficient to develop SCS Curve Numbers (CN) and percent impervious values.

- **DFIRM Future Land Use –** This land use shapefile covers only a portion of the Cibolo Creek watershed, as parts of Kendall, Guadalupe, Wilson and Karnes counties have no data. The projected date of this land use is unknown and the shapefile only provides a "GRIDCODE" identifier for each feature. The relationship between the GIRDCODE and the SARB land use categories was not determined.

- **COSA Future Land Use –** This land use shapefile covers only the portion of the Cibolo Creek watershed within the City of San Antonio and the date of this land use is unknown. The shapefile provides land use categories that are sufficient to develop SCS Curve Numbers (CN) and percent impervious values.

- **SARB Land Use Cibolo –** This land use shapefile covers the entire Cibolo Creek watershed, but the date of the land use is unknown. The shapefile provides land use categories that follows the USGS Land Use and Land Cover Classification Codes. Therefore, SCS Curve Numbers (CN) and percent impervious values can be developed from this dataset. However, the land use shapefile is very coarse, as it provides only 671 land use features within the entire Cibolo Creek watershed.

- **Wilson County 2013 Land Use –** This land use shapefile covers Wilson County with the Cibolo Creek watershed and reflects 2013 conditions. The shapefile provides land use categories that follows the State of Texas Landuse Category Codes. Therefore, SCS Curve Numbers (CN) and percent impervious values can be developed from this dataset. There are gaps in the shapefile, so significant effort would be required to develop a complete land use shapefile for Wilson County.

- **Master Development Plans –** This shapefile provides the boundaries of planned and completed master planned developments within, and just outside of, Bexar County. The shapefile is current through November 2014.

- **Bexar Master Development Plan (January 2012) –** This shapefile provides the boundaries of planned and completed master planned developments inside the Cibolo Creek watershed and Bexar County. It is assumed that they data is current through January 2012; however, this shapefile presents inconsistencies when compared against the “Master Development Plans” shapefile.

- **National Land Cover Database 2011 –** This coverage was created by the Multi-Resolution Land Characteristics Consortium to show the landcover across the entire United States. The GIS coverage included with this report was clipped to the boundary of the Cibolo Creek watershed, including a buffer.

- **SARB LU Cibolo –** This GIS land use coverage, which is in a raster format, was provided by SARA and is assumed to have been created in 2006. The land use coverage includes the entire limits of the Cibolo Creek watershed and identifies 18 different SARB land use categories. Each category has a representative impervious percentage and cover description (Open, Meadow, Brush, or Woods) for the purpose of calculating Curve Numbers. It should be noted that although the coverage includes the entire Cibolo Creek watershed, areas within Bexar County appear to be much more accurate. It is assumed that areas inside Bexar County were delineated using parcel maps, while areas outside Bexar County were created from the NLCD coverage.

3.1.3. Aquifer

An Edwards Aquifer shapefile was collected for SARA. The shapefile, which is shown on the General Workmaps, delineates the various zones of the Edwards Aquifer, including the:

- Recharge Zone
- Drainage Zone
- Contributing Zone within the Transition Zone
- Artesian Zone

In addition, records of Edwards Aquifer daily levels were collected for a time period between November 1932 and June 2011. The levels, which were recorded for the J-17 Index Well, can be used to estimate daily mean spring discharges into Cibolo Creek (see Section 5.2.1).

3.1.4. Terrain

A terrain model for the entire Cibolo Creek watershed was created as part of Phase 1. The terrain model, which will be called the C2MP terrain model, was created from several LiDAR sources provided by SARA, including:

- **Bexar County 2010 LiDAR** – This LiDAR grid has a cell size of 1-meter.

- **TNRIS 2013 LiDAR –** The raw point data was collected from TNRIS. A stand-alone LiDAR grid was not produced from the TNRIS 2013 LiDAR.

Atkins Team member 3cGeo created the C2MP terrain model by cleaning and combining the LAS points of the two LiDAR sources, creating a terrain for the watershed, exporting the terrain to a 5-meter grid size DEM, and generating a hydro-conditioned DEM.

The C2MP DEM, which has a 5-meter grid size and elevations in feet (NGVD 88), is included in Appendix B.

3.1.4.1. Comparison of existing LiDAR data

The LiDAR grid produced for the C2MP (5-meter grid size) and the Bexar County 2010 LiDAR grid (1-meter grid size) were compared. A difference grid was created by subtracting the Bexar County 2010 LiDAR grid from the C2MP LiDAR grid. As seen in Figure 3-1, the differences are minor in flatter areas. However, in steeper areas, such as channel banks, the differences are more pronounced. This is a direct result of the coarser grid size of the C2MP LiDAR grid versus the 2010 Bexar County grid.

The Middle Cibolo Creek HEC-RAS (see Section 5.1.2.3) cross sections and the cross sections generated from the C2MP LiDAR were compared in Figure 3-2 and Figure 3-3. The HEC-RAS cross sections (in black) generally have the same shape as the C2MP cross sections; however, there are significant differences in steeper areas between channel banks.

Figure 3-1 LiDAR Grid Comparison (C2MP LiDAR vs. 2010 Bexar County LiDAR)

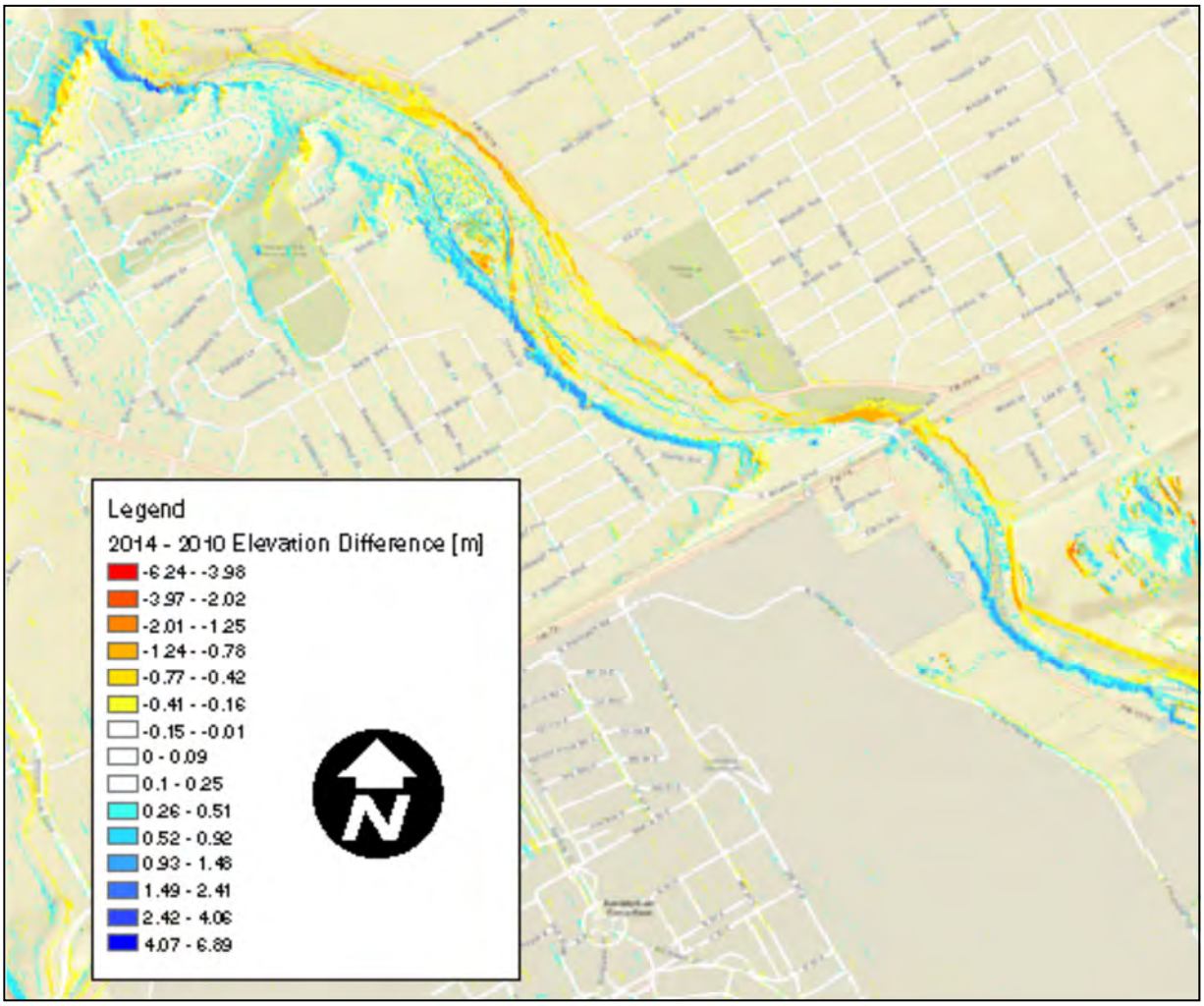


Figure 3-2 LiDAR Comparison in Mid-Cibolo Creek, Section 482,020

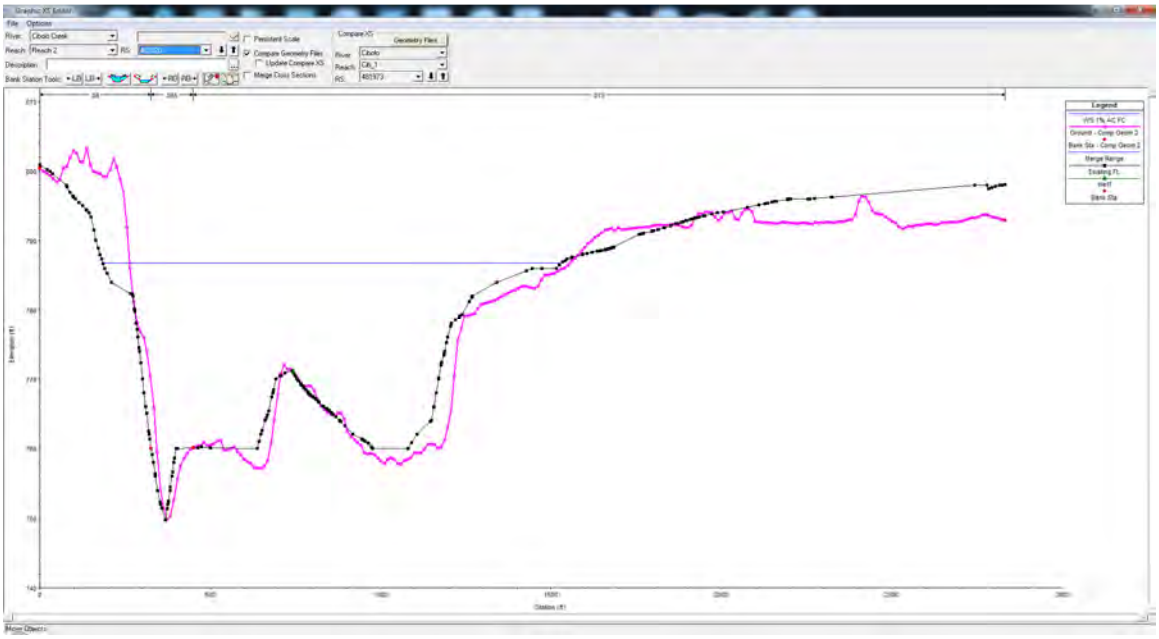
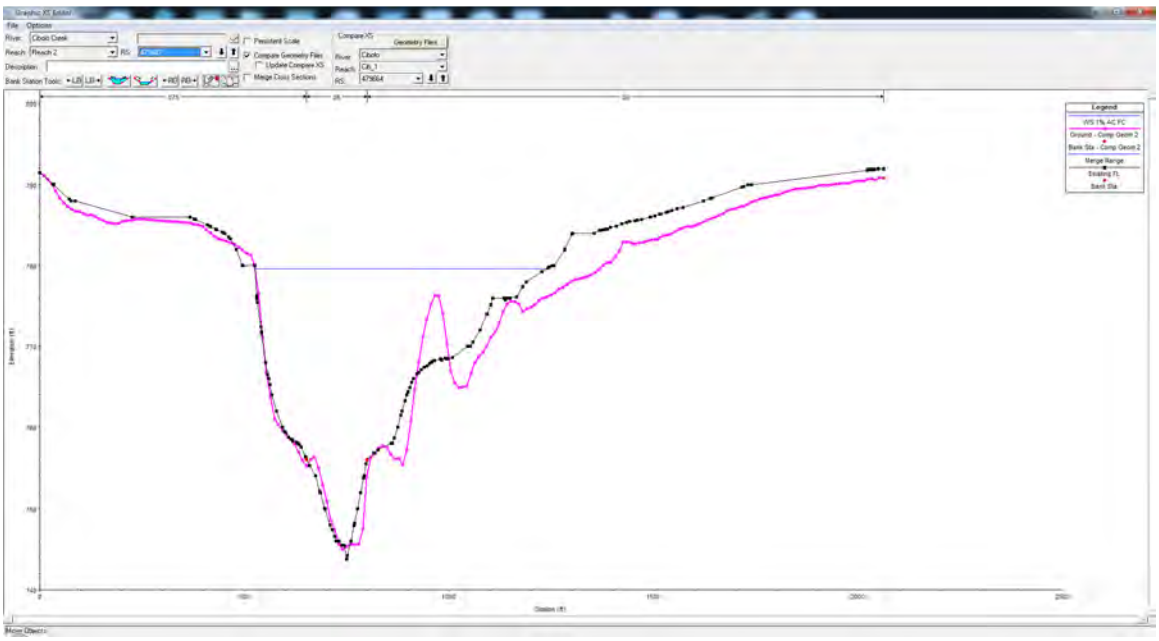


Figure 3-3 LiDAR Comparison in Mid-Cibolo Creek, Section 479,687



3.1.5. Rainfall gage

There are four (4) sources of rainfall data that were considered for the data collection effort:

- **Edwards Aquifer Authority (EAA)** – The EAA has 2 weather stations within the Cibolo Creek watershed that collect the following data at 15-minute intervals: air temperature, relative humidity, barometric pressure, precipitation, solar radiation, dew point, wind direction, wind speed, and soil moisture. Atkins was unable to collect rainfall data for the two rainfall gages beyond the near-term rainfall that is available from the EAA website.

- **United States Geological Society (USGS)** – Rainfall records with a 15-minute interval are available from the USGS website. The website provides data for the most recent 60-day period. Mr. Michael Nyman of the USGS was contacted directly to collect rainfall data beyond the most recent 60 days. Mr. Nyman noted that the data he provided is "regarded as temporary and PROVISIONAL". He further stated that, "the temporary classification means that documented, routine inspections and other quality assurance measures are not performed that would make the data acceptable for archival, retrieval, or future use in general scientific or interpretive studies."

- **National Climatic Data Center (NCDC)** – The National Weather Service collects precipitation data that is provided through the National Climatic Data Center (NCDC). Two types of precipitation data are available: official data and US daily surface data (COOP) data. Official data is endorsed by the NWS. COOP data is often collected by state universities, state or federal agencies, or private individuals whose stations are managed and maintained by the NWS. COOP data may contain as little as one parameter. The NWS recommends using the official data instead of the COOP data.

- **National Atmospheric Deposition Program (NADP)** – This program collects precipitation data but focuses on the chemical composition of the rainwater. Rainfall depth data was not collected from the NADP since there are no NADP sites within a close proximity of the Cibolo Creek watershed. The NADP data may be useful for the purpose of water quality analysis. As a result the NADP is discussed in Section 3.3.2.3.

Table 3-2 lists rainfall gage information that was collected. The table documents the gage identifier, owner of each gage, location, rainfall measurement interval, and the dates of operation of the gage. A shapefile that displays the location of all USGS gages (rainfall and stream flow) was collected. The shapefile was dated 2011 and, as a result, did not include the location of gage 08183978 (added in 2014) or 08184050. Atkins truncated the original shapefile to include only USGS gage locations in the general vicinity of the Cibolo Creek watershed and then added the location for gage 08183978 and 08184050 based upon latitude and longitude values provided on the USGS website. Atkins also collected from SARA a shapefile for NCDC/NWS gages in the vicinity of Cibolo Creek, but the shapefile only included a portion of the gages listed in Table 3-2. Atkins determined the location (latitude and longitude) of the missing gages (411434, 417945, 417947 and 418544) from internet searches and added these to the shapefile. Please see the General Workmaps for the location of gages that had rainfall data collected for this effort.

Table 3-2 Rainfall Gages

Gage Number	Owner	Location	Measurement Interval	Begin Date	End Date
08183200	USGS	San Antonio River near Floresville, TX	15-minute	6/4/2006	3/1/2015
08183900	USGS	Cibolo Creek near Boerne, TX	15-minute	5/10/2011	3/1/2015
08183978	USGS	Cibolo Creek at Specht Rd near Bulverde	15-minute	9/3/2014	3/1/2015
08185000	USGS	Cibolo Creek near Selma,TX	15-minute	10/1/2000	3/1/2015
08185065	USGS	Cibolo Creek near St Hedwig, TX	15-minute	12/2/2005	3/1/2015
08185100	USGS	Martinez Creek near St Hedwig, TX	15-minute	11/16/2005	3/1/2015
08185500	USGS	Cibolo Creek near Sutherland, TX	15-minute	12/20/2005	3/1/2015
08188570	USGS	San Antonio River near McFaddin, TX	15-minute	11/23/2005	3/1/2015
411434	NWS-COOP	Canyon Dam Number 4, TX	15-minute	1/1/1984	12/1/2013
417422	NWS-COOP	Randolph AFB, TX	Hourly	11/20/1940	11/25/2013
417945	NWS-COOP	San Antonio International Airport, San Antonio, TX	Hourly	1/13/1941	11/26/2013
417947	NWS-COOP	San Antonio 8 NNE, TX	15-minute	1/1/1999	12/1/2013
417947	NWS-COOP	San Antonio 8 NNE, TX	Hourly	5/1/1997	11/25/2013
418544	NWS-COOP	Spring Branch 2 SE, TX	15-minute	5/1/1988	12/1/2013
418653	NWS-COOP	San Antonio Stinson Municipal Airport, TX	Hourly	8/1/2002	11/26/2013

3.1.6. Stream gage

USGS stream gage data was collected for the Cibolo Creek watershed. Table 3-3 lists stream gages that have continuous discharge and stage records available at 15-minute intervals. The table documents the gage number (ID), location, dates the detailed records are available and type of record available from each gage. The earliest date that detailed discharge information is available is November 1, 2005, which may limit the use of the gage records in historical event calibration of hydrologic models. Although not available as continuous records, historical peak discharge and stage data is available for these gages prior to the “begin dates” listed in Table 3-3. Table 3-4 shows the beginning and end dates that peak discharge and peak stage measurements are available for each gage location. The location of each gage is shown on the General Workmaps.

Table 3-3 USGS stream gages (continuous records)

Gage Number	Location	Begin Date	End Date	Data Available
8183890	Cibolo Creek at Nature Preserve near Boerne, TX	11/1/2005	12/6/2013	Discharge, Stage
8183900	Cibolo Creek near Boerne, TX	8/22/2011	8/20/2014	Discharge, Stage
8183978	Cibolo Creek at Specht Rd near Bulverde	9/2/2014	6/6/2015	Stage
8184050	Cibolo Creek at Smithson Valley Road near Bulverde,TX	12/07/2010	6/8/2015	Stage
8185000	Cibolo Creek near Selma,TX	1/1/2005	8/21/2014	Discharge, Stage
8185065	Cibolo Creek near St Hedwig, TX	12/8/2005	8/21/2014	Discharge, Stage
8185100	Martinez Creek near St Hedwig, TX	11/7/2005	8/20/2014	Discharge, Stage
8185500	Cibolo Creek near Sutherland, TX	12/21/2005	8/21/2014	Discharge, Stage
8186000	Cibolo Creek near Falls City, TX	1/1/2005	8/21/2014	Discharge, Stage

Table 3-4 USGS stream gages (peak records only)

Gage Number	Location	Begin Date	End Date	Begin Date	End Date
		Peak Flow		Peak Stage	
8183890	Cibolo Creek at Nature Preserve near Boerne, TX	11/9/2005	12/5/2013	11/10/2005	12/5/2013
8183900	Cibolo Creek near Boerne, TX	3/3/1962	Present	3/3/1962	Present
8183978	Cibolo Creek at Specht Rd near Bulverde	n/a	n/a	9/2/2014	Present
8184050	Cibolo Creek at Smithson Valley Road near Bulverde,TX	n/a	n/a	12/7/2010	Present
8185000	Cibolo Creek near Selma,TX	9/27/1946	Present	5/17/1946	Present
8185065	Cibolo Creek near St Hedwig, TX	12/8/2005	Present	12/3/2005	Present
8185100	Martinez Creek near St Hedwig, TX	11/17/2005	Present	11/17/2005	Present
8185500	Cibolo Creek near Sutherland, TX	6/23/1924	Present	6/23/1924	12/28/2014
8186000	Cibolo Creek near Falls City, TX	9/30/1930	Present	9/30/1930	Present

3.1.7. Field Reconnaissance

As discussed in Section 2.3, a watershed tour was performed by various team members on January 7th and 8th, 2014. Tour notes, photos and tour route exhibits are included in Appendix B in a digital format.

3.2. Flood Risk

The section discusses data that was collected with the purpose of identifying flood risk and includes historical flooding, modeling support, and damage assessment data.

3.2.1. Historical Flooding Data

Historical flooding data will be used to calibrate hydrologic and hydraulic models in future phases of the C2MP. Atkins collected highwater marks, flooding claims and complaints, and known flooding issues identified by stakeholders.

3.2.1.1. High Water Marks

Atkins was not able to locate and collect recent surveyed highwater mark information. Atkins was able to collect a shapefile from SARA that lists two highwater marks in the Cibolo Creek watershed dated 1913 and 1967. The location of the highwater marks are shown on the Flood Risk (Hydraulics) Workmap.

Given the lack of highwater mark data, the peak flood stages of several historic flooding events were extracted from the following types of USGS gage records:

- Continuous stage gage records (15-minute reporting intervals)
- Continuous stage gage records (daily reporting intervals)
- Reported peak stages
- Field measurements

As shown in Table 3-5, peak stage information was extracted for five significant events within the watershed. The events include the October 1998, July 2002, July 2007, August 2007, and May 2013 storms. This information will be used in Phase 2 to calibrate/verify hydraulic model results. The highwater mark locations (USGS gages) are identified on the General Workmap.

Table 3-5 USGS Highwater Mark Summary

			Observed High Water Marks (NGVD29)				
Location	**USGS Gage**	**Stream Sta.**	**Oct 17-22, 1998**	**June 30 - July 6, 2002**	**July 22-23, 2007**	**Aug 16-17, 2007**	**May 25-27, 2013**
Cibolo Creek							
SH 123	08186000	56391	304.12	294.54	290.75	-	-
FM 539	08185500	202165	-	-	457.67	-	438.87
IH 10	08185065	380709	-	-	-	614.24	606.03
Lookout Road	08185000	471196	763.71	750.65	-	750.47	741.26
Smithson Valley Road	08184050	589245	-	-	-	-	1016.46
Cibolo Nature Center	08183890		-	-	-	1373.1	1365.21
D/S of Boerne	08183900		-	-	-	-	1348.36
Martinez Creek							
N. Gable Road	08185100	16602	-	-	-	-	541.07

3.2.1.2. Measured Peak Flows

The USGS provides the following types of stream flow records at selected USGS gages that can be used to determine peak flow, and in some cases, flow hydrographs for historic flooding events:

- Continuous flow gage records (15-minute reporting intervals)
- Continuous flow gage records (daily reporting intervals)
- Reported peak flows
- Field measurements

Atkins extracted, when available, peak flow data for the October 1998, July 2002, July 2007, August 2007, and May 2013 storm events (see Table 3-6). Highlighted values in the table indicate that observed hydrograph data is available for that gage location and event. The observed flow locations are identified on the General Workmap.

Table 3-6 USGS Measured Flows

			Observed Flows (cfs)				
Location	**USGS Gage**	**Stream Sta.**	**Oct 17-22, 1998**	**June 30 - July 6, 2002**	**July 22-23, 2007**	**Aug 16-17, 2007**	**May 25-27, 2013**
Cibolo Creek							
SH 123	08186000	56391	51200	2090	14000	-	*2850*
FM 539	08185500	202165	-	-	*16100*	*13400*	*2800*
IH 10	08185065	380709	-	-	*7730*	*20100*	*6940*
Lookout Road	08185000	471196	98100	39000	*25400*	*38300*	*12000*
Smithson Valley Road	08184050	589245	-	-	-	-	-
Cibolo Nature Center	08183890		-	-	*3940*	*6630*	*888*
D/S of Boerne	08183900		-	-	-	-	*2980*
Martinez Creek							
N. Gable Road	08185100	16602	-	-	1970	1730	1270

Note: Highlighted values have measured hydrographs available in addition to peak flow values.

3.2.1.3. Claims and Complaints

SARA provided Atkins with FEMA repetitive loss property data for all the counties in the Cibolo Creek watershed. The repetitive loss data identifies properties that have a history of flood loss claim payments as part of the NFIP. These locations should be investigated as part of the Phase 2 C2MP effort.

The repetitive loss data for the Cibolo watershed was taken from FEMA's sharepoint data site and lists the address of the repetitive loss property and information (date and payout) relating to each loss event. A GIS point shapefile was created with features for each loss location within the Cibolo Creek watershed. The repetitive loss shapefile does not present any owner information, only the address of each repetitive loss and the county in which the loss is located. The repetitive loss locations are shown on the Flood Risk (Hydraulics) Workmap.

3.2.1.4. Stakeholder Identified Issues

As part of the Stakeholder engagement plan, each stakeholder was asked if they had any flood risk concerns or issues related to the Cibolo Creek watershed. Typically, the secondary stakeholders (smaller cities and counties) had the most concerns and were primarily concerned with flood damage reduction. Listed below are the specific issues and concerns identified by the stakeholders at the individual meetings:

- **Universal City** - There is significant erosion at the City Golf Course at Selma Creek.
- **Universal City** - The City would like to have and extension of Kitty Hawk across Cibolo Creek to FM 1518 using a pier bridge.
- **Kendall County** - Kendall County expressed interest in SARA providing LOMR delegation support to the County.
- **City of Shertz** - City of Shertz indicated the Union Pacific Rail Road bridge over Cibolo Creek bridges cause backwater and flooding.
- **City of Selma** - City of Selma said that Lookout Road currently has a very narrow bridge that is planned to be widened. This bridge is causing backwater flooding issues.
- **City of Bulverde** – The City identified the following development/drainage/flooding issues:
    i) Singing Hills
    ii) Walmart (SH 46 and US 281)
    iii) Johnson Ranch
    iv) Oak Village North and Demonte Ranch – flooding issues along Indian Creek
    v) Luciano Park – Obst Road
    vi) CR 1863 floods frequently
    vii) Community Park in floodway
    viii) Bulverde lane

3.2.2. Modeling Support Data

This section discusses data that will support the development of flood risk modeling and mapping in future phases of the C2MP. Collected models are not discussed in this section, but instead are discussed in Chapter 5. Much of the "general" data presented in Section 3.1 will also be used to update or develop flood risk modeling for the C2MP. For example, the SSURGO soil and land use shapefiles will be used to develop SCS Curve Number loss rate parameters. The terrain data will be used to refine drainage boundaries and to populate station-elevation data for hydraulic model updates. Rainfall and stream gage data will be used to calibrate hydrologic and hydraulic model results.

3.2.2.1. Stream network

Stream network data was provided by SARA in a GIS polyline shapefile format. The shapefile was originally extracted from the USGS National Hydraulic Dataset (NHD). Refer to Flood Hazard Workmaps for more detail on the stream network in Cibolo. It should be noted that stream centreline information is also available from the collected FEMA flood hazard information (see Section 3.2.2.3).

3.2.2.2. Basin

Previously developed watershed and subbasin boundaries were collected from SARA for the Cibolo Creek watershed. The boundaries were collected in a GIS shapefile format and include:

- **Cibolo Creek Lower Subbasins** – These subbasins cover the lower Cibolo Creek watershed. These subbasins match those of the "WKG_Lower Cibolo" HEC-HMS model discussed in Section 5.1.1.

- **Cibolo Creek Lower Subbasins (Smoothed)** – These subbasins match the "Cibolo Creek Lower Subbasins", except the subbasin polygons were smoothed. These subbasins are included on the Flood Risk (Hydrology) Workmaps.

- **Cibolo Creek Lower (Smoothed)** – This this boundary for the entire Lower Cibolo Creek watershed.

- **Full Cibolo** – This shapefile includes boundary for the entire Cibolo Creek watershed (Upper and Lower).

- **Cibolo Mainstem Subbasins** – This shapefile includes the subbasins boundaries for the upper Cibolo Creek watershed and matches the Upper Cibolo Creek watershed HEC-HMS model discussed in Section 5.1.1. These subbasins are included on the Flood Risk (Hydrology) Workmaps.

GIS subbasin boundaries were also collected from SARA for the individual hydrologic models for tributaries to Cibolo Creek developed as part of the Bexar County DFIRM. In addition to subbasin boundaries, GIS shapefiles for centroids, curve number coverages, and impervious cover coverages were also collected. This data was collected for the following tributary watersheds:

- Balcones Creek
- Borgfeld Creek
- Clear Springs Creek
- Dry Hollow Creek
- Martinez Creek
- Selma Creek
- Evans Creek
- Green Mountain Creek

3.2.2.3. FEMA Flood Hazard

Effective FEMA flood hazard data was collected for areas within the Cibolo Creek watershed. For areas within SARA's jurisdiction (Bexar, Wilson and Karnes counties) SARA provided the floodplain coverage in GIS shapefile format. For the remaining counties (Bandera, Kendall, Comal, and Guadalupe counties) the floodplain information was obtained from FEMA in the form of a DFIRM database. The collected data includes:

- Floodhazard Areas (S_FLD_HAZ_AR)
- Structures (S_GEN_STRUCT)
- Political Boundaries (S_POL_AR)
- Channel Centerlines (S_WTR_LN)
- Modeled Cross Sections (S_XS)
- Based Flood Elevations (S_BFE)

The individual county shapefiles were compiled into a single shapefiles that cover the entire Cibolo Creek watershed. The Flood Risk (Hydraulics) Workmaps show the 100-year floodplain and hydraulic model cross sections shapefiles that were collected.

3.2.2.4. LOMRs

LOMRs that have been submitted to FEMA and accepted as of November 30, 2014 were collected from Bexar and Wilson Counties and the cities of Converse, Fair Oaks Ranch, Selma and Universal City. The collected data, in most cases, includes the LOMR Determination Document, revised FIRM panel, and supporting HEC-RAS models. Table 3-7 lists the collected LOMRs that affect hydraulic modeling of a significant length of channel within the Cibolo Creek Watershed. The location of the LOMRs, including the LOMR Case Number, is shown on the Flood Risk (Hydraulics) Workmap.

Table 3-7 LOMRs affecting stream modeling

LOMR Case Number	Community	Effective Date of LOMR	Impacted Stream	Approximate Length of Study
12-06-1691X	Bexar County	9-Aug-12	Unnamed Tributary to Tributary F to Martinez Creek B	3,500 LF
13-06-0667P	Bexar County	11-Jul-13	Unnamed Tributary 67 to Martinez Creek B	7,200 LF
11-06-0362P	Converse	29-Jun-12	East Salitrillo Creek	2,000 LF
11-06-4481P	Fair Oaks Ranch	28-May-13	Cibolo Creek and Diversion Channel	12,000 LF
09-06-3178P	Selma	20-Mar-11	Selma Creek	2,500 LF
11-06-0764P	Selma	16-Dec-11	Selma Creek	7,000 LF
12-06-3821P	Universal County	15-Jul-13	East Fork Salitrillo Creek	2,000 LF
12-06-2559P	Wilson County	20-Dec-12	Dry Hollow Creek	11,500 LF
10-06-3101P	Bexar County	30-Sep-10	Borgfeld Creek	6,500 LF
11-06-0038P	Bexar County	30-Nov-10	Escondido Creek	2,700 LF
11-06-2938P	Bexar County	21-Jun-11	Tributary E to Martinez Creek B	2,000 LF
Granite Shoals	Bexar County	18-Oct-12	Unnamed Tributary 60 of Tributary E of Martinez Creek B	4,000 LF

3.2.2.5. Dams

GIS shapefiles were collected that show the location of dams within the Cibolo Creek watershed. These shapefiles include:

- **SARB Dams – Cibolo (2012)** – This shapefile includes the location of 24 dams within the upper and lower Cibolo Creek watershed. The SARB Dams are shown on the Flood Risk (Hydrology) Workmap
- **TxDOT Dams** – This shapefile shows the location of TxDOT dams within Bexar County.

3.2.2.6. Low Water Crossings

SARA provided a GIS shapefile that displays low water crossings within the Cibolo Creek watershed. The source and date of this shapefile is unknown. The shapefile includes only three low water crossings along Cibolo Creek near Schertz (see the Flood Risk (Hydraulics) Workmap). The shapefile is obviously not a complete representation of the low water crossings along Cibolo Creek or within the Cibolo Creek watershed.

3.2.2.7. Ellipsoidal Distribution Reduction Factors

SARA provided a GIS shapefile that displays ellipsoidal reduction factors for the lower Cibolo Creek watershed. The original source and date of the shapefile is unknown. However, it is presumed that the shapefile was developed as part of the U.S. Army Corps of Engineers (USACE) hydrologic analysis of the lower Cibolo Creek watershed.

3.2.3. Damage Assessment

3.2.3.1. Appraisal Data

Appraisal parcel data was collected in a GIS shapefile format for the portions of Bandera, Bexar, Comal, Karnes, Kendall and Wilson counties that are located within the Cibolo Creek watershed. It is intended that this parcel information be used in future phases of the C2MP to develop a structure database from which

flooding damage estimates will be created. To develop the structure database, at a minimum, the following data is required for each parcel: property ID number, total property value, land value and a structure value. Unfortunately, not all of the collected appraisal shapefiles include the minimum required information. Table 3-8 identifies the data that is available in each of the county parcel shapefiles and includes the date of the data.

Table 3-8 Appraisal data by county

County	Date	Property ID	Total Property Value	Land Value	Structure Value
Bandera	2011	X	X		
Bexar	2013	X	X	X	X
Comal	2012	X			
Karnes	2012				
Kendall	2011	X			
Wilson	2013	X			

3.2.3.2. Building Footprints/Planimetrics

SARA provided several building footprint shapefiles that are intended to assist with the development of a structural database for flood damage estimates:

- **Bexar Building Parts – Cibolo** – This shapefile includes the outline of structures within Bexar County and the Cibolo Creek watershed. Structures and their components, such as garages and covered porches, are included in the shapefile. Appraisal data is attached to each feature. The source of the original data is unknown and the shapefile appears to have been developed in 2012.

- **Bexar Building Outlines – Cibolo** – This shapefile appears to be the same as the "Bexar Building Parts – Cibolo" shapefile, except the individual structure components are combined into a single feature. In addition the shapefile only includes features in the Converse / Universal City area. Appraisal data is attached to each feature. The source of the original data is unknown and the shapefile appears to have been developed in 2011.

- **Bexar-Cibolo Creek Planimetrics** – Although this shapefile has "Bexar" in its name, it provides building footprints in a limited portion of Guadalupe, Comal and Bexar County. The source and date of the original data is unknown.

3.3. Water quality

The Phase 2 and Phase 3 water quality effort will focus on modeling baseline and proposed water quality conditions using Hydrological Simulation Program-Fortran (HSPF). During Phase 1 water quality data was collected to support the creation of a defensible HSPF models for the Cibolo watershed per the San Antonio River Basin Regional Modeling Standards for Water Quality Modeling (March 2014). The following describes the key water quality data that was collected.

3.3.1. Historical

3.3.1.1. Monitoring data

The TCEQ Surface Water Quality Monitoring (SWQM) Program coordinates the collection of physical, chemical, and biological samples for more than 1,800 surface water stations. Table 3-9 shows the SWQM stations within the Cibolo Creek watershed.

Table 3-9 TCEQ SWQM stations in Cibolo Creek

Station ID	Stream	Station Location
12786	Alum Creek	at CR 332 Southeast Of Sutherland Springs
12797	Cibolo Creek	at FM 81 East Of Panna Maria
12798	Cibolo Creek	at SH 123 At Cestohowa
12800	Cibolo Creek	at FM 887 West Of Pawelekville
12801	Cibolo Creek	at Plummer Crossing North Of Kosciusko
12802	Cibolo Creek	at FM 541 West Of Kosciusko
12803	Cibolo Creek	28 Meters Downstream From Fm 537 On West Bank
12804	Cibolo Creek	at SH 97 Near Stockdale
12805	Cibolo Creek	at FM 539
12853	Cibolo Creek	2.5 Miles SE of Boerne
12854	Cibolo Creek	at Herff Road In Boerne
12857	Cibolo Creek	at IH 10 & US 87 NW of Boerne
12919	Cibolo Creek	40 Meters Downstream From IH 10/US 90 on East Bank
12921	Cibolo Creek	137 Meters Upstream From Weir Rd on North Bank
12924	Cibolo Creek	at Schaeffer Rd 3 Mi East Of Randolph Air Force Base
12925	Cibolo Creek	at Upstream Side Of Cibolo City Park
12927	Cibolo Creek	at South End of River Rd
14197	Cibolo Creek	at Scull Crossing
14211	Cibolo Creek	at CR 389 near Cestohowa, Texas
14212	Cibolo Creek	Upstream of Odo J. Riedel Regional WWTP (off River Road)
15126	Cibolo Creek	Immediately Downstream of Menger Creek Confluence
16702	Cibolo Creek	1608 m. Downstream Of SH46 in Nature Reserve
17998	Town Creek	at Arizpe Rd Second Stream Crossing
17999	Town Creek	at Pfannstiel Ln First Stream Crossing
20777	Cibolo Creek	at FM 2724 3.9 Kilometers NE of Panna Maria

The TCEQ stores SWQM measurements for stations based upon their TCEQ basin or segment ID. The measurements are stored in two related file formats:

- **Event File** – Provides station information, sample date and time, sample depth, and the sampling entity.
- **Results File** – Provides each monitoring parameter code, date and measurement for each event and station.

Atkins downloaded the event and result files for TCEQ segments 1902 (Lower Cibolo Creek), 1902A (Martinez Creek), 1902B (Salitrillo Creek), 1908 (Upper Cibolo Creek) and 1913 (Mid Cibolo Creek) and for TCEQ basin 19 (San Antonio River Basin) for the period between 2003 and 2013. The TCEQ has SWQM measurements available for some basins and segments dating back to 1968.

A shapefile of all TCEQ SWQM stations within the San Antonio River Basin (Basin 19) was collected from the TCEQ. The location of the SWQM stations and their station IDs are displayed on the Water Quality Workmaps.

3.3.1.2. Documented Issues

The 2012 Texas Integrated Report of Surface Water Quality is the primary source for identifying known water quality issues within the Cibolo Creek watershed. This report, which was collected from the TCEQ, presents the following information for natural water bodies throughout Texas:

- **Water Bodies Evaluated** – List of all water bodies with their segment identifier, limit description, flow type and source, and Aquatic Life Use information (ALU).
- **Water Body Assessment** – Assesses each water body for up to seven (7) beneficial uses (aquatic life, recreation, recreational beaches, general, fish consumption, public water supply, and oyster waters)
- **Index of Impaired Waters** – Lists all water bodies that were identified as Category 4 and 5.
- **Concerns** - List water bodies that do not meet water quality standards, describes the area and pollutants that cause standards to not be met, and lists the level of concern for the water body.
- **Sources of Pollution for Impairments and Concerns** – Lists water bodies that do not meet water quality standards, identifies the offending pollutants, and lists the potential sources of the pollutants.
- **New Listings** – Lists new segments that were newly added into "Category 5" for the current evaluation.
- **De-Listings** – Lists segments that removed from "Category 5" based upon the current evaluation.
- **Categories by Segment** – Lists all segments and identifies their water body type, category, and support required.

A GIS coverage that shows the location of impaired and threatened waters (stream/river segments, lakes) was collected from the TCEQ. The shapefile identifies TCEQ surface water segments where required pollution controls are not sufficient to attain or maintain applicable water quality standards. As seen in Table 3-10, the lower, mid and upper reaches of Cibolo Creek are identified as impaired (category 4 or 5) based upon the 2012 report. These stream reaches are shown on the Water Quality Workmaps.

Table 3-10 TCEQ segment categories

Segment ID	Name	Category	Pollutant / Condition of Concern
1902	Lower Cibolo Creek	5	Bacteria, Impaired fish community
1902A	Martinez Creek	3	-
1902B	Salitrillo Creek	2	-
1908	Upper Cibolo Creek	5	Bacteria, Chloride
1913	Mid Cibolo Creek	4	Depressed dissolved oxygen

3.3.1.3. Stakeholder Identified Issues

As part of the Stakeholder engagement plan, each stakeholder was asked to identify any issues or concerns related to water quality. Below are some of the issues identified by stakeholders:

- **City of Boerne** - Upper Cibolo Creek has recently been listed as impaired due to chloride. The TCEQ target of 50 mg/L was set for Boerne. The City feels that this target is excessive compared to other entities (approximately 3 times lower for Boerne). Boerne is trying to identify the source of the constituent; possibly effluent from a WWTP or drought related. Boerne would be interested in the C2MP addressing the impairment.

- **Wilson County -** Wilson County Judge Quinney indicated that the community had voted on concerns for the County. Water quality and stream health was of significant importance to his constituents. He indicated that water quality issues may stem from the population of feral hogs within the watershed.

3.3.2. Modeling support

This section discusses data that was collected to support the development of baseline and future condition HSPF modeling for C2MP. Previously developed water quality models for the Cibolo Creek watershed were collected and are discussed later in Chapter 5.

3.3.2.1. Basins

The following GIS shapefile was collected to support the water quality modeling effort:

- **Cibolo Creek Upper** – This shapefile includes the subbasins for the Upper Cibolo Creek watershed. This shapefile appears to match the HSPF basin delineation that was used in "Simulation of Streamflow and Estimation of Ground-Water Recharge in the Upper Cibolo Creek Watershed, South-Central Texas, 1992–2004" (see Section 5.2.2).

3.3.2.2. National Climatic Data Center (NCDC) weather data

The NCDC maintains a record of hourly weather observations from weather stations across the country. The hourly observations include precipitation, sky conditions, visibility, temperature, humidity, dewpoint, wind speed, wind direction and air pressure. The hourly weather observations for the stations listed in Table 3-11 were collected. A GIS shapefile showing the location of these gages was not located.

Table 3-11 National Climatic Data Center Meteorologic Gages

Station ID	Station Location Description	Start Date	End Date
12911	Randolph Air Force Base Airport	11/1/2012	Current
12921	San Antonio International Airport	7/1/2011	Current
12961	Kerrville Municipal/Luis Shrer Fd Airport	1/1/2005	Current
12970	Stinson Municipal Airport	7/1/2011	Current
12971	New Braunfels Municipal Airport	1/1/2005	Current

3.3.2.3. Atmospheric deposition data

The National Atmospheric Deposition Program (NADP) collects data on the quantity and chemical composition of rainwater. Rainfall data that can be applied to the Cibolo Creek watershed was obtained from the NADP web site, and included rainfall pH, conductance, and Ion concentrations of Ca, Mg, K, Na, NH_4, NO_3, Cl and SO_4. Table 3-12 below lists the locations and availability data for the NADP.

Table 3-12 National Atmospheric Deposition data stations

Station ID	Station Location Description	County	Start Date	Stop Date
TX03	Beeville	Bee	2/7/1984	Active
TX10	Attwater Prairie Chicken National Wildlife Refuge	Colorado	7/3/1984	Active
TX16	Sonora	Edwards	6/26/1984	Active
TX39	Texas A&M University-Corpus Christi	Nueces	1/2/2002	12/26/2006
TX53	Victoria	Victoria	4/15/1980	9/27/1988

3.3.2.4. Diversion data

Water diversion data was collected from the TCEQ for the Cibolo Creek watershed for the period from March 1991 to December 2013. The diversion data contains:

- Water Rights Number
- Diversion Use (Municipal, Domestic & Livestock, Irrigation, etc.)
- County in which the diversion is located
- Diversion owner's name
- River Basin of the Diversion (San Antonio River)
- Specific River Location (Cibolo Creek, Martinez Creek or Salitrillo Creek)
- Monthly diversion volumes (acre-feet) by the owner

Table 3-13 summarizes the collected diversion data and documents the permitted diversions within the Cibolo Creek watershed dating back to 1991. The table shows the permitted use, diversion location, diversion start and end dates, and total diversion volume (in acre-feet) between the dates. A GIS shapefile was collected that shows the location of permitted diversions within Texas; however, the shapefile only has one discharge point located in the Cibolo Creek watershed.

Table 3-13 Water diversion data in Cibolo Creek watershed

Permittee	Use	River Location	Total Diversion Volume (ac-ft)	Start Date	End Date
City of Boerne	Municipal	Cibolo Creek	13,248	3/1/1991	12/31/2013
City of Boerne	Domestic	Cibolo Creek	363	1/1/1992	2/1/1996
Canyon Regional Water Authority	Municipal	Cibolo Creek	46	9/30/2011	10/31/2011
Individual	Irrigation	Cibolo Creek	57	8/3/2011	8/3/2011
Individual	Irrigation	Cibolo Creek	15	4/5/2000	8/13/2009
Individual	Irrigation	Cibolo Creek	283	5/11/2010	6/22/2012
Individual	Irrigation	Cibolo Creek	6	10/2/1997	10/2/1997
Individual	Irrigation	Cibolo Creek	223	8/28/1992	6/1/1196
Individual	Irrigation	Cibolo Creek	8	6/16/1998	4/24/2000
Individual	Irrigation	Cibolo Creek	572	3/6/2006	8/12/2013
Individual	Irrigation	Martinez Creek	7	4/26/1996	8/7/1996
Individual	Irrigation	Martinez Creek	34	4/19/1996	5/1/1996
Individual	Irrigation	Martinez Creek	3	8/12/2008	8/15/2008
City of Converse	Irrigation	Salitrillo Creek	6	1/1/2013	12/31/2013

A list of the water right permits (both active and inactive) dating back to 1914 was collected. The list includes, among other things:

- Water Rights Number and issue date and length of contract
- Diversion Use (Municipal, Domestic & Livestock, Irrigation, etc.)
- County in which the diversion is located
- Diversion owner's name
- River Basin of the Diversion (San Antonio River)
- Specific River Location (Cibolo Creek, Martinez Creek or Salitrillo Creek)
- Monthly diversion volumes (acre-feet) by the owner

3.3.2.5. Discharge data

Information relating to permitted wastewater discharges within the Cibolo Creek watershed were collected. The following tables were collected in a Microsoft Excel format:

- **Wastewater Treatment Plant Outfalls** – TCEQ permit information and coordinates for each outfall.
- **Wastewater Treatment Permits** – TCEQ permit information and permitted flow and loading values.

Table 3-14 summarizes some of the information found in the collected tables. It was determined that there are 17 facilities with a TCEQ "Permit To Discharge Wastes". It should be noted that only 16 of these facilities discharge directly into Cibolo Creek or its tributaries. One facility (Johnson Ranch WWTF) discharges by a subsurface drip irrigation system. These facilities and their permit numbers are shown on the Water Quality Workmap.

Information on active, cancelled and withdrawn TCEQ permits (Permit to Discharge Wastes) were collected from SARA. Only 11 of the active, cancelled and withdrawn wastewater discharge locations are within the Cibolo Creek watershed.

Self-reporting wastewater flow and loading rates were collected from the TCEQ for 12 of the 17 facilities listed in Table 3-14. Five (5) of the17 facilities, including the Graytown Road WWTP and the Johnson Ranch WWTF, do not have wastewater flow and loading rate information available. In the case of the Graytown Road WWTP it is not yet constructed and in the case of the Johnson Ranch WWTF it does not discharge into a channel.

Table 3-14 Permitted wastewater facilities

Permittee	Facility	TPDES Permit No.	NPDES No.	County	Receiving Stream
City Of Marion	City of Marion WWTP	10048-001	0022675	GUADALUPE	Unnamed Tributary of Santa Clara Creek
San Antonio River Authority	Upper Martinez Creek WWTF	10749-003	0024082	BEXAR	Martinez Creek
City Of Boerne	City of Boerne WWTP	10066-001	0024465	KENDALL	Currey Creek
City Of La Vernia	City of La Vernia WWTP	11258-001	0052850	WILSON	Lower Cibolo Creek
San Antonio River Authority	Salitrillo Creek WWTP	10749-001	0053074	BEXAR	Salatrillo Creek
City Of Stockdale	City of Stockdale WWTP	10292-001	0054232	WILSON	Unnamed Tributary of Stockdale Branch
Cibolo Creek Municipal Authority	Odo J. Riedel Regional WWTP	11269-001	0077232	BEXAR	Cibolo Creek
San Antonio River Authority	Martinez II WWTP	10749-004	0095583	BEXAR	Martinez Creek
San Antonio River Authority	Martinez III WWTP	14042-001	0117536	BEXAR	Escondido Creek
City Of Schertz	City of Schertz WWTF	14667-001	0128384	BEXAR	Woman Hollering Creek
South Central Water Co	Quail Run WWTP	14672-001	0128449	WILSON	Unnamed Tributary of Cibolo Creek
Lerin Hills MUD	Lerin Hills WWTP	14712-001	0128767	KENDALL	Unnamed Tributary of Deep Hollow Creek

San Antonio River Authority	Graytown Road WWTF	10749-007	0129861	BEXAR	Martinez Creek
City Of Boerne	Boerne WWT and Recycling Center	10066-002	0131831	KENDALL	Menger Creek
South Central Water Co	Cibolo Valley WWTF	14988-001	0132837	COMAL	Unnamed Tributary of Cibolo Creek
DHJB Development LLC	Johnson Ranch WWTF	14975-001	0133825	COMAL	N/A - No Discharge
Judson ISD	Evans Road High School WWTF	15141-001	0134775	BEXAR	Unnamed Tributary of Cibolo Creek

Collected flow and loading rate tables generally provide monthly measurements for each wastewater outfall. The tables provide loading rate measurements for carbonaceous BOD (5-day), chlorine, fecal coliform, e. coli, dissolved oxygen, pH, total suspended solids (TSS), ammonia (NH_3), and phosphorus. Table 3-15, Table 3-16, and Table 3-17 document the time periods that have flow and loading rate data available for each facility.

Table 3-15 Permitted wastewater plant outflow data (BOD, chlorine, and fecal coliform)

Site	Flow		BOD		Chlorine	
	Start date	**End date**	**Start date**	**End date**	**Start date**	**End date**
City of Marion WWTP	May-05	Jan-14	May-05	Jan-14	May-05	Jan-14
Upper Martinez Creek WWTP	Jan-02	Jan-14	Jan-02	Jan-14	-	-
City of Boerne WWTP	Jan-02	Jan-14	Jan-02	Jan-14	-	-
City of La Vernia WWTP	Feb-09	Jan-14	Feb-09	Jan-14	Feb-09	Jan-14
Salitrillo Creek WWTP	Jan-02	Jan-14	Jan-02	Jan-14	-	-
City of Stockdale WWTP	Jan-04	Jan-14	Jan-04	Jan-14	-	-
Odo J. Riedel Regional WWTP	Jan-02	Jan-14	Jan-02	Jan-14	Jan-02	Jan-14
Martinez II WWTP	Jul-05	Jan-14	Jul-05	Jan-14	-	-
Martinez III WWTP	Mar-02	Jan-14	Mar-02	Jan-14	Mar-02	Jan-14
City of Schertz WWTF	Dec-10	Jan-14	Dec-10	Jan-14	Dec-10	Jan-14
Quail Run WWTP	Nov-11	Jan-14	Nov-11	Jan-14	Nov-11	Jan-14
Lerin Hills WWTP	-	-	-	-	-	-
Graytown Road WWTF	-	-	-	-	-	-
Boerne WWT and Recycling Center	Feb-13	Jan-14	Feb-13	Jan-14	-	-
Cibolo Valley WWTF	-	-	-	-	-	-
Johnson Ranch WWTF	-	-	-	-	-	-
Evans Road High School WWTF	-	-	-	-	-	-

Table 3-16 Permitted wastewater plant outflow data (E. coli, flow, and dissolved oxygen)

Site	Fecal Coliform		E. Coli		Dissolved Oxygen	
	Start date	**End date**	**Start date**	**End date**	**Start date**	**End date**
City of Marion WWTP	-	-	May-13	Jan-14	May-05	Jan-14
Upper Martinez Creek WWTP	Jan-02	Mar-10	Apr-10	Jan-14	Jan-02	Jan-14
City of Boerne WWTP	Jan-02	Mar-10	Apr-10	Jan-14	Jan-02	Jan-14
City of La Vernia WWTP	-	-	Jun-13	Jan-14	Feb-09	Jan-14
Salitrillo Creek WWTP	Jan-02	Apr-10	May-10	Jan-14	Jan-02	Jan-14
City of Stockdale WWTP	-	-	-	-	Jan-04	Jan-14
Odo J. Riedel Regional WWTP			Dec-10	Jan-14	Jan-02	Jan-14
Martinez II WWTP	Jul-05	Jul-11	Aug-11	Jan-14	Jul-05	Jan-14
Martinez III WWTP	-	-	Feb-13	Jan-14	Mar-02	Jan-14
City of Schertz WWTF	-	-	Dec-10	Jan-14	Dec-10	Jan-14
Quail Run WWTP	-	-	Jan-12	Jan-14	Nov-11	Jan-14
Lerin Hills WWTP	-	-	-	-	-	-
Graytown Road WWTF	-	-	-	-	-	-
Boerne WWT and Recycling Center	-	-	Feb-13	Jan-14	Feb-13	Jan-14
Cibolo Valley WWTF	-	-	-	-	-	-
Johnson Ranch WWTF	-	-	-	-	-	-
Evans Road High School WWTF	-	-	-	-	-	-

Table 3-17 Permitted wastewater plant outflow data (pH, TSS, ammonia, and phosphorus)

Site	pH		TSS		Ammonia (NH3)		Phosphorus	
	Start date	**End date**	**Start date**	**End date**	**Start date**	**End date**	**Start date**	**End date**
City of Marion WWTP	May-05	Jan-14	May-05	Jan-14	-	-	-	-
Upper Martinez WWTP	Jan-02	Jan-14	Jan-02	Jan-14	Jan-02	Jan-14	-	-
City of Boerne WWTP	Jan-02	Jan-14	Jan-02	Jan-14	Jan-02	Jan-14	-	-
City of La Vernia WWTP	Feb-09	Jan-14	Feb-09	Jan-14	-	-	-	-
Salitrillo Creek WWTP	Jan-02	Jan-14	Jan-02	Jan-14	Jan-02	Jan-14	-	-
City of Stockdale WWTP	Jan-04	Jan-14	Jan-04	Jan-14	-	-	-	-
Odo J. Riedel Regional WWTP	Jan-02	Jan-14	Jan-02	Jan-14	Jan-02	Jan-14	-	-
Martinez II WWTP	Jul-05	Jan-14	Jul-05	Jan-14	Jul-05	Jan-14	-	-
Martinez III WWTP	Mar-02	Jan-14	Mar-02	Jan-14	-	-	-	-
City of Schertz WWTF	Dec-10	Jan-14	Dec-10	Jan-14	Dec-10	Jan-14	-	-
Quail Run WWTP	Nov-11	Jan-14	Nov-11	Jan-14	Nov-11	Jan-14	-	-
Boerne WWT and Recycling Center	Feb-13	Jan-14	Feb-13	Jan-14	Feb-13	Jan-14	Feb-13	Jan-14

3.3.2.6. Hazardous Materials

Atkins collected from SARA various GIS shapefiles locating areas within the watershed that may contain hazardous materials. These shapefiles include:

- Bexar Hazardous Materials Sites (Cibolo)
- Bexar Leaking Petroleum Tanks (Cibolo)
- Texas Concentrated Feeding Operations
- Livestock Points of Interest
- Texas Landfills (Cibolo)
- Texas Municipal Solid Waste Sites (Cibolo)

These shapefiles, except the Texas Landfills (Cibolo) shapefile, are displayed on the Water Quality Workmaps. The Texas Landfills (Cibolo) shapefile was not shown as it appears to duplicate information shown in the Texas Municipal Solid Waste Sites (Cibolo) shapefile.

3.4. Stream restoration

The stream health element of the C2MP is being performed by Michael Baker International (Baker) under contract with SARA. The stream restoration potential assessment being conducted by Baker will be limited to Bexar County due to budget limitations. URS has completed the assessment for the stream restoration potential of Cibolo Creek within Wilson and Karnes Counties as part of the Lower San Antonio River Basin study. Atkins will review the results from the URS analysis and provide comments. Once these comments are addressed, the document and data will be incorporated into the Phase 2 results as part of the damage center analysis. The Stream Restoration Potential Assessment by Baker is scheduled to be completed in Summer of 2015.

As part of the Stakeholder engagement plan, each stakeholder was asked to identify concerns related to stream stability and stream restoration. The City of Selma identified erosion issues in Cibolo Creek and Selma Creek at the Olympia Hills/Forum Development.

3.5. Project Development and Nature-Based Park Planning

Data for the Human Interface and Recreation is comprised of GIS coverages that document existing and planned parks, habitats, and known historic sites that could influence the development of potential improvements recommended in later phases of this study.

3.5.1. Parks

SARA provided two GIS shapefiles that document existing parks within Bexar County:

- **Park Boundaries** – This shapefile shows the boundaries of all parks, including community parks, greenways, historic resources, urban parks, nature areas, neighbourhood parks, and sports complexes. The date this shapefile is unknown.

- **Park Trails** – This shapefile shows the location of trails associated with parks in Bexar County. The shapefile shows the type of trail (access, bike lane, internal road, etc.) and the trail surface (gravel, asphalt, concrete, etc.). The date this shapefile is unknown.

3.5.2. Habitat

Two GIS shapefiles related to wildlife habitat were provided by SARA:

- **SARB Mussels (Cibolo)** – This shapefile presumably shows the location of known mussel habitats within the Cibolo Creek watershed. The date this shapefile is unknown.

- **Element Occurrence (05-26-2011) (Cibolo)** – This shapefile presumably shows the location where various species of wildlife were identified in the watershed. The shapefile shows the scientific name, common name, and group of the animal or plant, as well as the last date the animal or plant was observed in the field. The shapefile has a date of May 26, 2011.

3.5.3. Historic sites

SARA supplied several GIS shapefiles that provide information related to historic sites within the Cibolo Creek watershed:

- **Texas Archeologic Project Areas (Cibolo)** – This shapefile shows the boundaries of archeologic projects within the Cibolo watershed. The shapefile details the project type (survey, test, etc.), the project date, the agency in charge of the project (TNRCC, TxDOT, COE, etc.) and the TAC number. The date of this shapefile is unknown.

- **Texas National Register of Historic Districts** – This shapefile shows the historic districts on the national register that are located within the Cibolo Creek watershed. The shapefile includes the boundaries of the Panna Maria Historic District and the Randolph Field Historic District.

- **Texas National Register Sites** – This shapefile shows the national register sites that are located within the Cibolo Creek watershed. The shapefile includes the Panna Maria Historic District and the Polley Mansion (Whitehall).

- **Historic Monuments** – This shapefile includes the location of 16 historic monuments within the Cibolo Creek watershed.

3.5.4. Stakeholder Identified Issues and Opportunities

As part of the Stakeholder engagement plan, each stakeholder was asked about concerns or issues related to human interface and recreation. Listed below are the identified issues and concerns:

- **Universal City –** The City is interested in linear parks along Cibolo Creek and recommends contacting the City of Shertz for connection of parks along Cibolo.

- **Wilson County** – The City discussed the potential for developing Jackson Park (owned by SARA), particularly the amphitheatre. The City thinks the park could be used for education. The City said that a new powerplant is being built at FM 475 and may provide a potential funding source to help in improving the park (as part of community relations with the new plant).

4. Reports

This chapter discusses the reports and maps that were collected as part of Phase 1. The discussion is organized into four sections: Flood Risk, Water Quality, Stream Restoration, and Project Development and Nature-Based Park Planning. Reports and maps discussed in this Chapter are included on the attached DVD as Appendix C and follows the organization of this chapter.

4.1. Flood risk

Reports and maps relating to the flood risk of Cibolo Creek watershed were collected and are listed below with a brief description:

- **Hydraulics & Work Map Technical Support Data Notebook for the Bexar County Tributaries to Cibolo Creek (Final Submittal - December 2006) -** Support data notebook for FEMA submittal detailing the hydraulic methods and results from the Bexar County Map Modernization Effort within Cibolo Creek.

- **Bexar County, Texas Phase I, Technical Support Data Notebook, Section III, Engineering Analysis-Hydraulics/Mapping Cibolo Creek (November 2006) -** Support data notebook for FEMA submittal detailing the hydraulic methods and results for the Cibolo Creek main stem model and mapping upstream of IH-10.

- **Hydrology Technical Support Data Notebook for the Bexar County Tributaries to Cibolo Creek - (Final Submittal) - July 2006 by Pape Dawson Engineers, Inc.** - Support data notebook for FEMA submittal detailing the hydrologic methods and results from the Bexar County Map Modernization Effort within the Cibolo Creek watershed.

- **Hazard Mitigation Plan Update: Protecting the Region Against all Hazards (2011)** – This report provides flood hazard information within the GBRA's jurisdiction. Information include, floodzones, discussion of historical flooding, estimated historic damages, and estimated future losses.

- **Flood Insurance Study, Bexar County, Texas** – FEMA (September 29, 2010)

- **Flood Insurance Study, Comal County, Texas** – FEMA (September 9, 2009)

- **Flood Insurance Study, Guadalupe County, Texas** – FEMA (October 2, 2007)

- **Flood Insurance Study, Karnes County, Texas** – FEMA (October 19, 2010)

- **Flood Insurance Study, Kendall County, Texas** – FEMA (December 7, 2010)

- **Flood Insurance Study, Wilson County, Texas** – FEMA (November 26, 2010)

4.2. Water quality

Reports relating to the water quality of the Cibolo Creek watershed were collected and are listed below with a brief description:

- **Conduits and Turbulent Flow in the Edwards Aquifer by Worthington Groundwater (December 2003)** – This report evaluated the affect that conduits in the limestone bedrock, which are a result of dissolution of the bedrock, have upon groundwater flow in the Edwards Aquifer.

- **Evaluation of the Aquifer and Springflow Impacts Associated with the Cibolo Creek Transfer Rules by LBG-Guyton Associates (April 2006) -** Report detailing the MODFLOW modeling results of groundwater flow and the impacts to springflow caused by withdrawal from the aquifer.

- **Tracing Groundwater Flowpaths in the Edwards Aquifer Recharge Zone, Panther Springs Creek Basin, Northern Bexar County, Texas by the Edwards Aquifer Authortity (May 2010)** - This report presents the findings of investigations by the Edwards Aquifer Authority (Authority) of groundwater flowpaths, velocities, and hydrostratigraphy in the Panther Springs Creek groundwater basin, in northern Bexar County, Texas.

- **2011 Edwards Aquifer Hydrologic Data Fact Sheet by the Edwards Aquifer Authority (2012) –** This document gives and overview of the well, spring, and stream sampling results collected in 2011.

- **Cow Creek Groundwater Conservation District Groundwater Management Plan (December 2009)** - Management plan update identifying groundwater and surface water resources and usage with a planning period of fifty years.

- **Cow Creek Groundwater Conservation District Groundwater Management Plan (June 2004)** - Management plan update identifying groundwater and surface water resources and usage with a planning period of fifty years.

- **Instream Flow Study of the Lower San Antonio River and Lower Cibolo Creek by Texas Instream Flow Program and the San Antonio River Authority (March 2012)** - Report detailing the flow-habitat and flow-ecological relationships within the lower San Antonio Rive subbasin.

- **Simulation Streamflow, Evapotranspiration, and Groundwater Recharge in the Lower San Antonio River Watershed, South-Central Texas, 2000-2007 (USGS Scientific Investigations Report 2010-5027)** - Report detailing the development of HSPF models for the lower San Antonio River watershed to model streamflow, Evapotranspiration, and groundwater recharge for 2000-2007.

- **Simulation of Streamflow and Estimation of Ground-Water Recharge in the Upper Cibolo Creek Watershed, South-Central Texas, 1992-2004 (USGS Scientific Investigations Report 2007-5202)** - Report detailing the development, calibration and testing of an HSPF watershed model to simulate streamflow and estimate ground-water recharge in the upper Cibolo Creek watershed for a time period from 1992 to 2004.

- **Simulation of Hydrologic Conditions and Suspended-Sediment Loads in the San Antonio River Basin Downstream from San Antonio, Texas, 2000-12 (USGS Scientific Investigations Report 2014-5182) -** Report detailing the development of an HSPF model to simulate hydrologic conditions and suspended-sediment loads for four watersheds in the lower San Antonio River Basin for a time period from 2000 to 2012.

- **Cibolo Creek, San Antonio, Texas (April 2012) by US Army Corps of Engineers, Fort Worth District** - Interim Feasibility Report to assess flood damages and ecosystem degradation plans and to provide economic justification for the feasibility level design. This report focuses on the Upper Cibolo Creek watershed, an area downstream of IH-10 in Kendall County to the lower IH-10 crossing in Bexar and Guadalupe Counties.

- **One Total Maximum Daily Load for Dissolved Oxygen in Mid Cibolo Creek, Segment Number 1913 (July 2007) by the TCEQ** - Report describing total maximum daily load that can be received in Mid Cibolo Creek to address low levels of dissolved oxygen and still allow support of the aquatic life.

- **Improving Water Quality in Mid Cibolo Creek (December 2011) by the TCEQ** – Memorandum describing total maximum daily load developed for Mid Cibolo Creek to address low levels of dissolved oxygen.

- **Kendall County and the City of Fair Oaks Ranch Water and Wastewater Planning Study (February 2011) by GBRA/TWDB** - Report detailing the facilities needed to meet future demands for water supply and wastewater requirements for a planning period of 2010 to 2040 in Kendall County and Fair Oaks Ranch.

- **Hydrologic Data Report for 2012, Report No. 13-01 (December 2013) by the EAA** - Report presenting results of the EAA's data collection program for 2012 including groundwater level data, precipitation measurement data, groundwater recharge data and usage, and water quality data.

- **Cibolo Creek Water Quality Monitoring and Modeling (February 2009) by the City of Bourne** - Study to understand current and potential water quality conditions with regard to City of Bourne's wastewater treatment plant discharge into Cibolo Creek.

- **Upper Cibolo Creek Watershed Protection Plan (September 2013) by the Upper Cibolo Creek Watershed Partnership/City of Boerne** - Report detailing the development of a watershed protection plan for Upper Cibolo Creek including identifying causes and sources of pollution, management strategies, criteria for success, and monitoring requirements.

- **Upper Cibolo Creek Watershed Protection Plan – Riparian Area Fact Sheet by the Upper Cibolo Creek Watershed Partnership/City of Boerne** – This fact sheet describes riparian areas and their benefit to Cibolo Creek.

- **Upper Cibolo Creek Watershed Partnership Fact Shee by the Upper Cibolo Creek Watershed Partnership** – This fact sheet outlines the role and goals of the Upper Cibolo Creek Watershed Partnership.

4.3. Stream restoration

The following stream restoration report was collected:

- **Riparian Restoration on Farms and Ranches in Texas by the Texas A&M AgriLife Extension, the USDA and the Texas Water Resources Institute (August 2014)** – This report documents the impacts of stream erosion, the benefits properly functioning riparian areas, and methods of riparian restoration.

4.4. Project development and nature-based park planning

Reports and maps related to project development and nature-based park planning in the Cibolo Creek watershed were collected and are listed below with a brief description:

- **Boerne Master Plan Update (September 2006)** - The document presents recommended future plans land use and development, development patterns and infrastructure within the City of Boerne.

- **City of Boerne - 2014 Economic Development Work Plan** – This document outlines some of the City's strategies, initiatives and projects to achieve its development goals. The document presents an overview of potential pedestrian enhancements, a bicycle mobility plan, and park improvements along Cibolo Creek.

- **City of Bulverde Comprehensive Plan** – The plan provides a general guide for the City's future growth. Although specific components are not presented, the plan discusses infrastructure such as pedestrian and bike trails, and parks and recreation facilities and their benefits to the City.

- **City of Schertz-Parks and Recreation Master Plan 2014: Live and Play! –** The master plan provides recommendations for parks, open space, and trails within the City of Schertz.

- **Selma Stage Stop Masterplan (Draft February 2001) –** This document presents the master plan for the restoration of the historic Stage Stop site and the development of a park surrounding the site.

- **Upper Cibolo Creek Watershed Partnership – Public Participation Plan by the City of Boerne (January 2010) –** This report presents the public participation plan for the Upper Cibolo Creek watershed protection plan.

Maps that were collected that relate to Human Interface and Recreation include:

- **City of Bulverde Hike & Bike Plan**

5. Models

This chapter discusses the models that were collected as part of Phase 1. The model discussion is organized into two sections: Flood Risk and Water Quality. Models discussed in this Chapter are included on the attached DVD as Appendix D and follows the organization of this chapter.

5.1. Flood Risk

This section presents the flood risk models that were collected. The discussion is organized into two sections: hydrologic models and hydraulic models.

5.1.1. Hydrologic models

The Cibolo Creek watershed does not have a single complete hydrologic model used to develop peak flows for the Federal Emergency Management Agency (FEMA) effective hydraulic models within the watershed. Instead, there are a total of nine (9) hydrologic models for the watershed, all of which are in the HEC-HMS format (version 3.5). The FEMA DFIRM models that are maintained by SARA and were developed for the Bexar Regional Watershed Management (BRWM) DFIRM project were obtained through the SARA's D2MR website. SARA also provided the USACE hydrologic models for upper and lower Cibolo Creek watersheds. Table 5-1 displays information relating to the coverage of all the collected HEC-HMS models, including model source, drainage area, and a description of coverage area.

Table 5-1 Hydrologic model limits

HEC-HMS Model	Source	Drainage Area (mi^2)	Coverage
Upper Cibolo	USACE	312.30	Cibolo Creek watershed upstream of IH-10
Lower Cibolo	USACE	543.66	Cibolo Creek watershed downstream of IH-10
Balcones Creek	SARA (BRWM DFIRM)	24.14	Balcones Creek Watershed
Borgfield Creek	SARA (BRWM DFIRM)	1.89	Borgfeld Creek Watershed
Clear Springs Creek	SARA (BRWM DFIRM)	7.51	Clear Springs Creek Watershed
Dry Hollow Creek	SARA (BRWM DFIRM)	20.73	Dry Hollow Creek Watershed
Martinez Creek	SARA (BRWM DFIRM)	88.63	Martinez Creek B Watershed
Meusebach Creek	SARA (BRWM DFIRM)	9.84	Meusebach Creek Watershed
Selma, Evans & Green Mtn. Creek	SARA (BRWM DFIRM)	12.20	Selma Creek, Green Mountain Creek and Evans Creek watersheds

Balcones Creek, Borgfeld Creek, Clear Springs Creek, Dry Hollow Creek, Martinez Creek B, Meusebach Creek, Evans Creek, Green Mountain Creek and Selma Creek are all tributaries to Cibolo Creek. As a result, the hydrologic models for these tributaries overlap with the two main stem USACE Cibolo Creek hydrologic models. Atkins collected the GIS shapefiles for the sub-basin boundaries of the models listed in Table 5-1 and noted that overlaps and gaps exist between the USACE and BRWM DFIRM models. There are also sub-basin delineation inconsistencies between the Upper Cibolo and Lower Cibolo Creek hydrologic models created by the USACE. The sub-basin delineation is consistent between the BRWM DFIRM models. Figure 5-1 shows an example of the sub-basin boundary delineation inconsistencies between the BRWM DFIRM and USACE hydrologic models.

The BRWM DFIRM update includes sub-basin delineations based on 5-foot contours generated from a 2003 Digital Elevation Model (DEM). The source of elevation data used to develop the USACE delineations could not be determined. However, it is clear that the USACE used a different elevation source for sub-basin delineations compared to the DFIRM project. In addition, the DFIRM models have a more detailed internal breakout of the sub-basins to achieve the DFIRM project's target drainage area size of 1- square mile for urbanized areas and 3- square miles for rural areas. Atkins verified that the DFIRM sub-basin delineations are consistent with the DEM created for the Phase 1 C2MP effort (see Section 3.1.4).

Atkins reviewed each of the collected HEC-HMS models to determine the transformation, loss and routing methods applied to each model's basin model. Table 5-2 documents these methods for each HEC-HMS model.

Table 5-2 HEC-HMS basin methodology

HEC-HMS Model	Transformation Method	Loss Method	Routing Method(s)
Upper Cibolo	Snyder UH	Initial and Constant	Modified Puls
Lower Cibolo	Snyder UH	SCS	Modified Puls & Muskingum-Cunge
Balcones Creek	Snyder UH	SCS	Modified Puls (Missing Storage Discharge Curves)
Borgfield Creek	SCS	SCS	Modified Puls
Clear Springs Creek	Snyder UH	SCS	Modified Puls
Dry Hollow Creek	SCS	SCS	Modified Puls
Martinez Creek	SCS	SCS	Modified Puls & Muskingum-Cunge
Meusebach Creek	Snyder UH	SCS	Modified Puls
Selma, Evans & Green Mtn. Creek	Snyder UH	SCS	Modified Puls

Figure 5-1 Subbasin Boundary Delineation Comparison

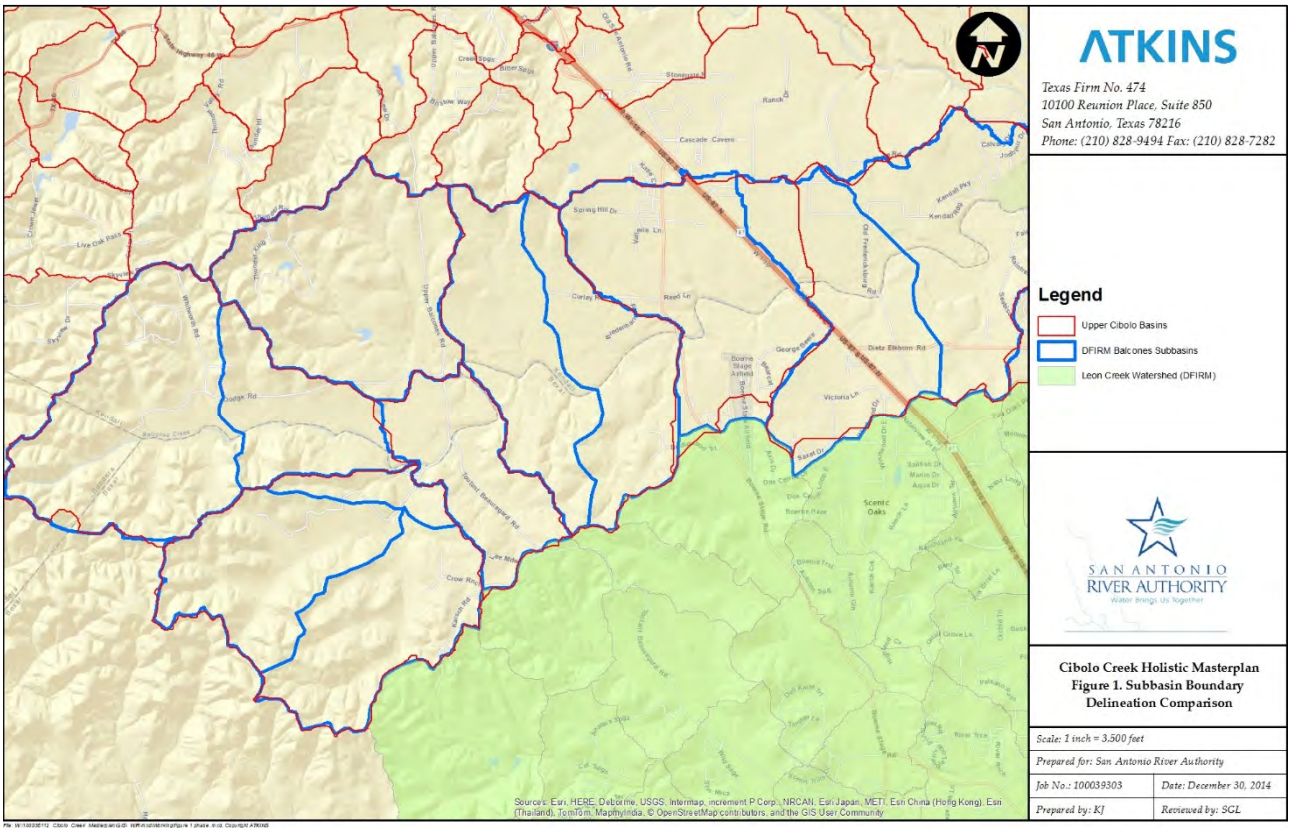


Table 5-3 documents the various precipitation methods used in the Cibolo Creek watershed HEC-HMS models. The Upper Cibolo watershed model utilizes the Bexar County rainfall design storm precipitation data, while the Lower Cibolo watershed model utilizes an ellipsoidal rainfall distribution. The HEC-HMS models for the tributaries to Cibolo Creek use either a frequency storm or hyetographs with areal reduction factors, as per the San Antonio River Basin (SARB) Regional Modeling Standards.

Table 5-3 HEC-HMS meteorologic methodology

Model	Storm Frequencies	Rainfall Distribution	Real Storm Simulations
Upper Cibolo	2-, 5-, 10-, 25-, 50-, 100-, 250- & 500-Year	Frequency Storm	1997, 1998, 2002
Lower Cibolo	10-, 25-, 50-, 100- & 500-Year	Ellipsoidal Distribution	1997, 1998, 2002
Balcones Creek	10-, 25-, 50-, 100- & 500-Year	SARB Hyetographs w/ ARF	1998 and 2002
Borgfield Creek	10-, 25-, 50-, 100- & 500-Year	Frequency Storm	1998 and 2002
Clear Springs Creek	10-, 25-, 50-, 100- & 500-Year	Frequency Storm	1998 and 2002
Dry Hollow Creek	10-, 25-, 50-, 100- & 500-Year	SARB Hyetographs w/ ARF	1998 and 2002
Martinez Creek	10-, 25-, 50-, 100- & 500-Year	SARB Hyetographs w/ ARF	1998 and 2002
Meusebach Creek	10-, 25-, 50-, 100- & 500-Year	Frequency Storm	1998 and 2002
Selma, Evans & Green Mtn. Creek	10-, 25-, 50-, 100- & 500-Year	Frequency Storm	1998 and 2002

The HEC-HMS models collected for the Cibolo Creek watershed employ the Snyder Unit Hydrograph and SCS Unit Hydrograph transform methods to estimate sub-basin runoff. Both methods require a lag time value for each sub-basin that is approximately 60% of the calculated time of concentration. Time of concentration calculations for the BRWM DFIRM hydrologic models were collected from SARA. Time of concentration calculations were provided in two formats: an excel file with the calculations of time of concentration and lag time for each sub-basin and a GIS polyline shapefile that delineates the longest flow path of each sub-basin. Time of concentration calculations were not available for the Upper Cibolo and Lower Cibolo hydrologic models created by the USACE.

5.1.2. Hydraulic models

The discussion of the collected hydraulic models is divided into three primary categories:

- Hydraulic models within SARA's jurisdiction;
- Hydraulic models outside SARA's jurisdiction; and,
- Main stem Cibolo Creek hydraulic models.

This is an important distinction because there is much less hydraulic modeling data available outside SARA's jurisdiction than within SARA's jurisdiction. In addition, with respect to enhancements or new hydraulic model development, SARA is limited in the amount of work that it can accomplish outside its jurisdiction. The locations of the detailed and approximate studied streams can be seen in the Flood Risk (Hydraulics) Workmaps.

5.1.2.1. Hydraulic models (within SARA's jurisdiction)

Hydraulic models within the Cibolo Creek watershed were developed for the Bexar County FEMA DFIRM project. All the FEMA DFIRM hydraulic models were developed using HEC-RAS (version 3.1.2). The discussion of these models is organized around the four (4) types of stream studies that were performed for the DFIRM project:

- **Detailed Models** – These studies include detailed hydraulic analyses with topographic data, ground surveyed cross sections (including underwater elevations) and detailed survey of hydraulic structures.
- **Limited Detailed Study** – These studies used models with cross sections taken from topographic data and utilized approximate survey measurements for the hydraulic structures.
- **Redelineation** – In these studies, base flood elevations (BFE) were extracted from existing models and used to delineate the floodplains on updated topographic data.
- **Conversion** – These studies consisted of digitizing the existing effective FEMA floodplain (Zone A) for streams in areas where there was minimal or no development.

Table 5-4 lists the detailed hydraulic models within the Cibolo Creek watershed that were collected from SARA's D2MR website. The 13 hydraulic models are the FEMA effective models for their respective streams as of December 29, 2010. The detailed models have a total study length of 74.69 miles, 905 cross sections and 73 structures. Since these models were developed as part of detailed FEMA DFIRM studies, the hydraulic model geometries can be used "as is" for the current master planning effort.

Table 5-4 Detailed hydraulic models within SARA's jurisdiction

Stream Name	Study Length (mi)	# of Cross Sections	# of Structures
Balcones Creek	12.44	137	10
Tributary G to Balcones	0.51	9	0
Rundale Creek	2.27	32	0
Unnamed Trib to Rundale Creek	1.29	15	0
Meusebach Creek	2.59	24	1
Selma Creek	1.79	27	3
Trib C to Selma Creek	0.5	16	1
Trib D to Selma Creek	0.5	11	1
Escondido Creek	6.99	103	8
Martinez Creek B	24.21	261	21
Trib E to Martinez Creek B	1.69	22	1
Trib F to Martinez Creek B	2.76	44	3
Woman Hollering Creek	10.88	69	7

Ten (10) of the hydraulic models within the Cibolo Creek watershed were developed as Limited Detailed Studies for the Bexar County DFIRM effort. Table 5-5 lists these models.

Table 5-5 Limited detailed models within SARA's jurisdiction

Stream Name	Study Length (mi)	# of Cross Sections	# of Structures
Borgfeld Creek	1.31	16	1
Clear Springs Ford	2.71	36	1
Unnamed Trib to Clear Springs Fork	1.26	16	0
Evans Creek	1.15	23	1
Green Mountain Creek	2.5	40	3
West Fork of Green Mountain Creek	0.83	15	1
Trib E to Selma Creek	2.1	26	1

Salitrillo Creek	6.18	69	7
Dry Hollow Creek	5.22	72	5
Trib E to Dry Hollow Creek	1.1	16	1

Table 5-6 lists the hydraulic models for streams that were "redelineated" during the Bexar County DFIRM project. There are a total of 18.49 miles of models.

Table 5-6 Redelineation models within SARA's jurisdiction

Stream Name	Study Length (mi)
Tributary G to Balcones	0.49
Unnamed Tribs to Balcones Creek	0.17
Clear Springs Fork	0.73
Selma Creek	2.4
South Branch of Selma Creek	1.36
South Fork of South Branch of Selma Creek	0.45
East Salitrillo Creek	7.01
East Branch of Salitrillo Creek	2.88
East Fork of East Branch of Satlitrillo Creek	1.76
Salitrillo Creek	1.24

Models for DFIRM digital conversion areas were not collected because, even if available, these models would require significant effort to update to current BRWM standards and to verify the model results.

The Flood Risk (Hydraulic) Workmaps show the limits of the detailed, limited detail, and approximate studies.

5.1.2.2. Hydraulic models (outside SARA's jurisdiction)

These detailed models include discrete sections in both the Main Stem Cibolo (in Boerne) and tributaries running through local cities such as the City of Shertz, City of Bulverde and the City of Stockdale. The detailed models have been requested by SARA but have not been collected as of the writing of this Phase 1 report. It is not anticipated that these models will be updated as they are outside of SARA's jurisdiction. However, the models could be used to develop routing relationships for HEC-HMS.

5.1.2.3. Hydraulic models (Main Stem Cibolo Creek)

The main stem Cibolo Creek is split into three hydraulic models. The upper model extends from Battle Intense Road (located at Fair Oaks Ranch) to the USGS gage at Selma (Lookout Road Crossing). The middle model extends from the USGS gage at Selma (Lookout Road Crossing) to just upstream of IH-10. The lower model extends from IH-10 to approximately Lupon Road. Table 5-7 displays the length, number of cross sections and number of structures in each of the models.

Table 5-7 Main stem Cibolo Creek hydraulic models

Stream Name	Study Length (mi)	# of Cross Sections	# of Structures	Project Name
Upper Cibolo (Battle Intense Road to Lookout Road Crossing)	46.35	695	11	Cibolo_Creek_Reach2.prj
Middle Cibolo (Lookout Crossing Road to IH-10)	16.41	155	7	Cibolo_Creek_Reach1.prj
Lower Cibolo (IH-10 to Lupon Road)	3.49	342	6	Lower_Cibolo_Creek.prj

Table 5-8 lists key parameters for each of the Cibolo Creek main stem hydraulic models. As seen in the table, all of the models have the same vertical datum but have differing elevation data sources. The cities of Cibolo and Schertz have made localized updates to the models for Upper and Middle Cibolo after the USACE completed their modeling efforts. These updates are included as part of the Cibolo Creek main stem model.

Table 5-8 Main stem Cibolo Creek hydraulic model parameters

Stream Name	Developed by	Elevation Source	Elevation Datum	Model Date
Upper Cibolo (Battle Intense Road to Lookout Road Crossing)	USACE (Updated by City of Cibolo)	2002 USGS TIN	NAVD88	1995
Middle Cibolo (Lookout Crossing Road to IH-10)	USACE (Updated by City of Schertz)	2002 USGS TIN	NAVD88	1995
Lower Cibolo (IH-10 to Lupon Road)	Halff Associates	2005 SARA LiDAR	NAVD88	2005

5.2. Water Quality

There are two (2) HSPF models for the Cibolo Creek watershed: a 2014 USGS model for the lower Cibolo Creek watershed and a 2007 USGS model for the upper Cibolo Creek watershed. SARA provided both of these models.

5.2.1. Lower Cibolo Creek Watershed HSPF model (2014)

The 2014 USGS HSPF model for Cibolo Creek was created in support of the USGS Scientific Investigations Report #2014-5182 “Simulation of Hydrologic Conditions and Suspended-Sediment Loads in the San Antonio River Basin Downstream from San Antonio Texas, 2000-12”. The limits of the 2014 USGS HSPF model for the Cibolo Creek watershed extend from the USGS stream flow gage in Selma, TX (08185000) to the confluence with the San Antonio River. The HSPF model was developed along with an upper San Antonio River, an Ecleto Creek, and lower San Antonio River HSPF models to simulate streamflow and suspended-sediments loads for the lower San Antonio River.

Key aspects from the 2014 USGS HSPF model are discussed below:

- **Channel Routing** – Channel depth and width values measured at USGS gaging stations were assumed constant for the entire reach to calculate RCHRES surface area and volume relationships. Ungaged channel reaches were assumed to have the same channel width and depth as nearby gaged channel reaches.
- **Surficial Geology** – Geologic maps from the Geologic Atlas of Texas (by the University Of Texas Bureau Of Economic Geology) were used to determine HRU (Hydrologic Response Unit) types. An HRU is a hydrologically distinct area in HSPF that drains to a stream or reservoir. An HRU is defined as either pervious (PERLND) or impervious (IMPLND).
- **Infiltration** – NRCS county soils data was used to estimate soil infiltration rates and soil erodibility/detachability.
- **Land-Cover** - The 2006 National Land Cover Database (NLCD) was the source of land-cover data. The NLCD's 15 land-cover classes were simplified to eight (8) land-cover classes.
- **Elevation** – The USGS National Elevation Dataset was used to delineate subwatersheds.
- **Precipitation** – DAYMET daily precipitation data was disaggregated to hourly totals based on the temporal distribution of rainfall measured at one or more nearby rainfall gages. USGS and NWS rainfall gages (see Table 5-9) were used in the analysis.

Table 5-9 Rainfall gages used for 2014 USGS HSPF model

Gage Number	Owner	Location	Begin Year	End Year
08183200	USGS	San Antonio River near Floresville, TX	2006	2012
08185500	USGS	Cibolo Creek near Sutherland Springs, TX	2006	2012
08188570	USGS	San Antonio River near McFaddin, TX	2006	2012
418653	NWS	San Antonio Stinson Municipal Airport, TX	2000	2012
413201	NWS	Floresville, TX	2000	2012
417422	NWS	Randolph AFB, TX	2000	2012
418658	NWS	Stockdale 6N, TX	2000	2012
417836	NWS	Runge, TX	2000	2012
413618	NWS	Goliad, TX	2000	2012

- **Evaporation & Evapotranspiration** – Daily potential evaporation and evapotranspiration were calculated using DAYMET daily maximum and minimum temperature data, the Hamon method and EPA BASINS 4.0. Table 5-10 lists the NWS temperature gages used in the modeling.

Table 5-10 Temperature gages used for 2014 USGS HSPF model

Gage Number	Owner	Location	Begin Year	End Year
413201	NWS	Floresville, TX	2000	2012
417422	NWS	Randolph AFB, TX	2000	2012
418658	NWS	Stockdale 6N, TX	2000	2012
417836	NWS	Runge, TX	2000	2012
413618	NWS	Goliad, TX	2000	2012

- **Wastewater Effluent** – Effluent from 12 wastewater treatment plants (WWTP) was included in the HSPF model. Table 5-11 summarizes the plant records that were used in the modeling.

Table 5-11 Wastewater effluent records used for 2014 USGS HSPF model

Wastewater Treatment Plant	Receiving Stream	Begin Year	End Year
Floresville WWTP	San Antonio River upstream from Cibolo Creek	2000	2012
Milam Street WWTP	San Antonio River upstream from Cibolo Creek	2000	2012
OJ Reidel WWTP	Cibolo Creek	2000	2012
Salatrillo WWTP	Martinez Creek	2000	2012
Upper Martinez WWTP	Martinez Creek	2000	2012
Martinez II WWTP	Martinez Creek	2000	2012
La Vernia WWTP	Cibolo Creek	2000	2012
Stockdale WWTP	Cibolo Creek	2000	2012
Karnes City WWTP	San Antonio River downstream from Cibolo Creek	2000	2012
Kenedy WWTP	San Antonio River downstream from Cibolo Creek	2000	2012
Runge WWTP	San Antonio River downstream from Cibolo Creek	2000	2012
Goliad WWTP	San Antonio River downstream from Cibolo Creek	2000	2012

- **Spring Discharges** – A regression equation was developed to estimate the daily mean spring discharge into Cibolo Creek. The sole variable in the equation is the daily water level of the Edwards Aquifer Authority's J-17 index well.

$$Q_{springflow} = 2\ x\ 10^{-77}\ x\ L^{27.521}$$

Where:

$Q_{springflow}$ = the daily mean spring discharge to Cibolo Creek, in cubic feet per second; and,

L = daily water level of the J-17 well, in feet above NGVD 29.

- **Surface-water Withdrawals**- Texas Commission on Environmental Quality (TCEQ) monthly irrigation withdrawal data was disaggregated to hourly values.
- **Suspended-Sediment Loads** – The 2014 HSPF model simulates suspended-sediment loads in the watershed. USGS gages that record suspended-sediment loads were used to account for sediment inflows at the model's upstream boundaries and to calibrate the model at selected in-stream locations. Table 5-12 shows the suspended-sediment loading gage records that were used in the modeling.

Table 5-12 Suspended sediment gages used for 2014 USGS HSPF model

Gage Number	Owner	Location	Begin Year	End Year
08181800	USGS	San Antonio River near Elmendorf, TX	2000	2012
08183500	USGS	San Antonio River near Falls City, TX	2000	2012
08185000	USGS	Cibolo Creek near Selma, TX	2000	2012
08186000	USGS	Cibolo Creek near Falls City, TX	2000	2012
08186500	USGS	Ecleto Creek near Runge, TX	2006	2012
08188500	USGS	San Antonio River at Goliad, TX	2000	2012

- **Streamflow –** USGS stream flow gage data (see Table 5-13) was used to estimate spring discharges, account for inflows at the model's upstream boundaries and to calibrate the model at selected in-stream locations.

Table 5-13 Streamflow gages used for 2014 USGS HSPF model

Gage Number	Owner	Location	Begin Year	End Year
08181800	USGS	San Antonio River near Elmendorf, TX	2000	2012
08183200	USGS	San Antonio River near Floresville, TX	2006	2012
08183500	USGS	San Antonio River near Falls City, TX	2000	2012
08185000	USGS	Cibolo Creek near Selma, TX	2000	2012
08185065	USGS	Cibolo Creek near St Hedwig, TX	2006	2012
08185100	USGS	Martinez Creek near St Hedwig, TX	2006	2012
08185500	USGS	Cibolo Creek near Sutherland Springs, TX	2006	2012
08186000	USGS	Cibolo Creek near Falls City, TX	2000	2012
08186500	USGS	Ecleto Creek near Runge, TX	2006	2012
08188500	USGS	San Antonio River at Goliad, TX	2000	2012
08188570	USGS	San Antonio River near McFaddin, TX	2006	2012

The 2014 USGS HSPF models for Cibolo Creek, Ecleto Creek, the upper San Antonio River and lower San Antonio River were collected. The supporting GIS data used to develop the modeling were not located.

5.2.2. Upper Cibolo Creek Watershed HSPF model (2007)

The USGS developed an HSPF model in 2007 for the upper Cibolo Creek watershed to support the USGS Scientific Investigations Report # 2007-5202 "Simulation of Streamflow and Estimation of Ground-Water Recharge in the Upper Cibolo Watershed, South-Central Texas, 1992-2004". The modeling simulated streamflow on Cibolo Creek and estimated the groundwater recharge in the upper Cibolo Creek watershed. The 2007 USGS HSPF model includes the upper basins of the watershed downstream to the USGS stream flow gaging station in Selma, TX.

Key aspects of the 2007 USGS HSPF model are discussed below:

- **Channel Routing** – Channel depth and width values measured at USGS gaging stations were assumed constant for the entire reach to calculate RCHRES surface area and volume relationships. Ungaged

channel reaches were estimated using survey data collected by the USACE

- **Surficial Geology** – Geologic maps from the Geologic Atlas of Texas (by the University of Texas Bureau of Economic Geology) were used to determine HRU types.
- **Infiltration –** Bexar, Comal and Kendall County soil surveys (NRCS, 1966; 1984, and; 1981) were used to estimate soil infiltration rates.
- **Land-Cover** – A land-cover map was initially developed by the USACE and refined by MWH Global, Inc. using 2001 satellite imagery. This map, which includes 23 land-cover categories, was used the source of land-cover data.
- **Elevation –** USGS 7.5-minute digital elevation models were used to determine watershed slopes and to delineate subwatersheds.
- **Precipitation –**The USGS and NWS rainfall gages listed in Table 5-14 were used in the analysis.

Table 5-14 Rainfall gages used for 2007 USGS HSPF model

Gage Number	Owner	Location	Begin Year	End Year
410902	NWS	near Boerne, TX	1992	2004
411215	NWS	near Bulverde, TX	1997	2002
417945	NWS	San Antonio International Airport, San Antonio, TX	1992	2004
417422	NWS	Randolph Field, TX	1992	2004
08178595	USGS	Stone Mountain drainage channel at Granite Path, San Antonio, TX (Partial Records)	1997	2001
08178627	USGS	Elm Waterhole Creek Tributary at San Antonio, TX (Partial Records)	2001	2002
08180945	USGS	Leon Creek at Scenic Loop Road near Leon Springs, TX	2001	2002
08185000	USGS	Cibolo Creek near Selma, TX	1992	2004

- **Evaporation –** Daily potential evaporation data from NWS gages was disaggregated to average hourly rates for each day. Table 5-15 lists the NWS pan evaporation gages used in the modeling.

Table 5-15 Pan evaporation gages used for 2007 USGS HSPF model

Gage Number	Owner	Location	Begin Year	End Year
418169	NWS	Sea World, San Antonio, TX	1997	2004
411429	NWS	Canyon Dam, Comal County, TX	1992	2004

- **Evapotranspiration –** Simulated evapotranspiration results were compared against measurements from USGS gages in the Honey Creek watershed near Spring Branch. Table 5-16 lists the evapotranspiration gages used to calibrate the modeling.

Table 5-16 Evapotranspiration gages used for 2007 USGS HSPF model

Gage Number	Owner	Location	Begin Year	End Year
295104098285900	USGS	Honey Creek reference ET site near Spring Branch, TX	2002	2002
295102098283200	USGS	Honey Creek treatment ET site near Spring Branch, TX	2002	2002

- **Wastewater Effluent –** Effluent from the Boerne wastewater plant was included in the HSPF model as equal hourly discharges, disaggregated from daily totals.
- **Spring Discharges –** The HSPF model does not simulate the discharge of springs into the watershed.
- **Surface-water Withdrawals-** The HSPF model does not include any irrigation withdrawals.
- **Suspended-Sediment Loads –** The 2007 HSPF model does not simulate suspended-sediment loads.
- **In-Stream Groundwater Recharge –** Modeling results show that, on average, approximately 59,000 acre-feet of water per year recharges into aquifers from stream flow. This recharge was included in the HSPF model as withdrawals from channel reaches. The withdrawals were included in the FTABLES of stream reaches as a function of stream discharge or stream volume.
- **Overland Ground-water Recharge** – On average, approximately 20,800 acre-feet of water per year recharges into aquifers from overland runoff. The Geologic Atlas of Texas (by the University of Texas Bureau of Economic Geology) was used to identify aquifer outcrops and to estimate their permeability. This information was used to simulate overland groundwater recharge from within the watershed.
- **Streamflow –** USGS stream flow gage data (see Table 5-17) was used to estimate groundwater recharge and to calibrate the model at selected in-stream locations.

Table 5-17 Streamflow gages used for 2014 USGS HSPF model

Gage Number	Owner	Location	Begin Year	End Year
08183850	USGS	Cibolo Creek at Interstate Highway 10 above Boerne, TX	1996	2004
08183900	USGS	Cibolo Creek near Boerne, TX	1992	1994
08183950	USGS	Cibolo Creek at Ralph Fair Road below Boerne, TX (Partial Records)	2001	2002
08183970	USGS	Cibolo Creek at Blanco Road above Bulverde, TX (Partial Records)	2001	2002
08183990	USGS	Cibolo Creek at Blanco Road near Bulverde, TX (Partial Records)	2001	2002
08183995	USGS	Cibolo Creek at U.S. Highway 281 near Bulverde, TX (Partial Records)	2001	2002
08184050	USGS	Cibolo Creek at Smithson Valley Road near Bulverde, TX (Partial Records)	2001	2002
08184300	USGS	Cibolo Creek at Farm Road 1863 below Bulverde, TX (Partial Records)	2001	2002
08185000	USGS	Cibolo Creek at Selma, TX	1992	2004

The 2007 USGS HSPF model for upper Cibolo Creek was collected. However, the supporting GIS data files were not located.

6. Data Gaps and Recommendations

This section discusses the data gaps that were identified during the Phase 1 effort. The discussion of gaps is organized based upon the primary use of the missing data (General, Flood Risk, and Water Quality).

6.1. General

The following data gaps were identified for data discussed under Section 3.1 (General Data):

- **Land use** –Pollutant loading varies by land use, so it can be deduced that generalized, out-of-date, or inaccurate land use will directly impact the water quality modeling results. Therefore, for the purpose of estimating pollutant loading for water quality modeling it is important to have an accurate land use coverage of the entire Cibolo Creek watershed that delineates land uses such as residential (low, medium and high density), commercial, parks, transportation, etc. None of the collected land use coverages provide the required detail over the entire watershed. Listed below are the primary shortcomings of the collected land use coverages:
    - The land use coverage within Bexar County was created from Bexar Appraisal District parcel data and defines land uses identified in the SARB Regional Modeling Standards for Hydrology and Hydraulics. Relatively minor clean-up of the collected land use coverage within Bexar County will be required to make it sufficient for the purpose of water quality modeling.
    - The collected land use coverage outside Bexar County appears to be developed from NLCD data but has land use classifications consistent with those in Bexar County. Outside Bexar County the land use is inaccurate in developed areas and is also coarsely delineated. The land use of undeveloped areas is reasonably accurate. Major clean-up of the collected land use coverage outside Bexar County will be required to make it sufficient for the purpose of water quality modeling.
- **C2MP LiDAR Grid Accuracy in Steep Areas** – Due to its coarse grid size the C2MP LiDAR grid may not accurately represent localized elevations in steep areas such as channel banks. Any new channel cross sections that need to be developed in Phase 2 should utilize the Bexar County 2010 LiDAR grid if the coverage allows.
- **Rainfall Gage** – Rainfall gage coverage is reasonable across the upper watershed but gage density is sparse in the lower watershed.

6.2. Flood risk

The following data gaps were identified for data discussed under Section 3.2 (Flood Risk Data):

- **Appraisal Values** – The collected appraisal parcel shapefiles for Comal, Karnes, Kendall and Wilson counties do not include land values or improvement (structure) values. These values will need to be extracted manually from appraisal district web sites if flood damage estimates are to be performed in Comal, Karnes, Kendall and Wilson counties.
- **Channel routing data** – The source of the HEC-HMS routing parameters is unknown for many of the collected HEC-HMS models. Furthermore, there are limited detailed hydraulic models outside Bexar County that can be used to develop routing data for major tributaries of Cibolo Creek.

- **Sub-basin boundaries** – There are overlaps and gaps in many of the HEC-HMS models. The sub-basin delineation should be updated with consideration given to smaller basin size, new topography and the sub-basin size requirements of water quality modeling.

- **Hydraulic Modeling** – As can be seen in the Flood Hazard Workmaps there are breaks in the detailed modeling:

    - Detailed model coverage of the Cibolo Creek main stem does not include the reach extending from Boerne to the Bexar County line, or the reach extending from the confluence with the San Antonio River to Lupon Road.

    - Outside of Bexar County the tributary modeling is typically completed using Approximate Methods and mapped as Zone A on the effective FIRMs.

    - Detailed models outside of Bexar County that still needed to be collected include Elm Creek, Town Creek, and Santa Clara Creek (and tributaries).

- **Highwater Marks** – Atkins was not able to locate and collect surveyed highwater marks information. However, the following stage information was collected from USGS gages to estimate peak flood stages for several historic flooding events:

    - Continuous stage gage records (15-minute reporting intervals)

    - Continuous stage gage records (daily reporting intervals)

    - Reported peak stages

    - Field measurements

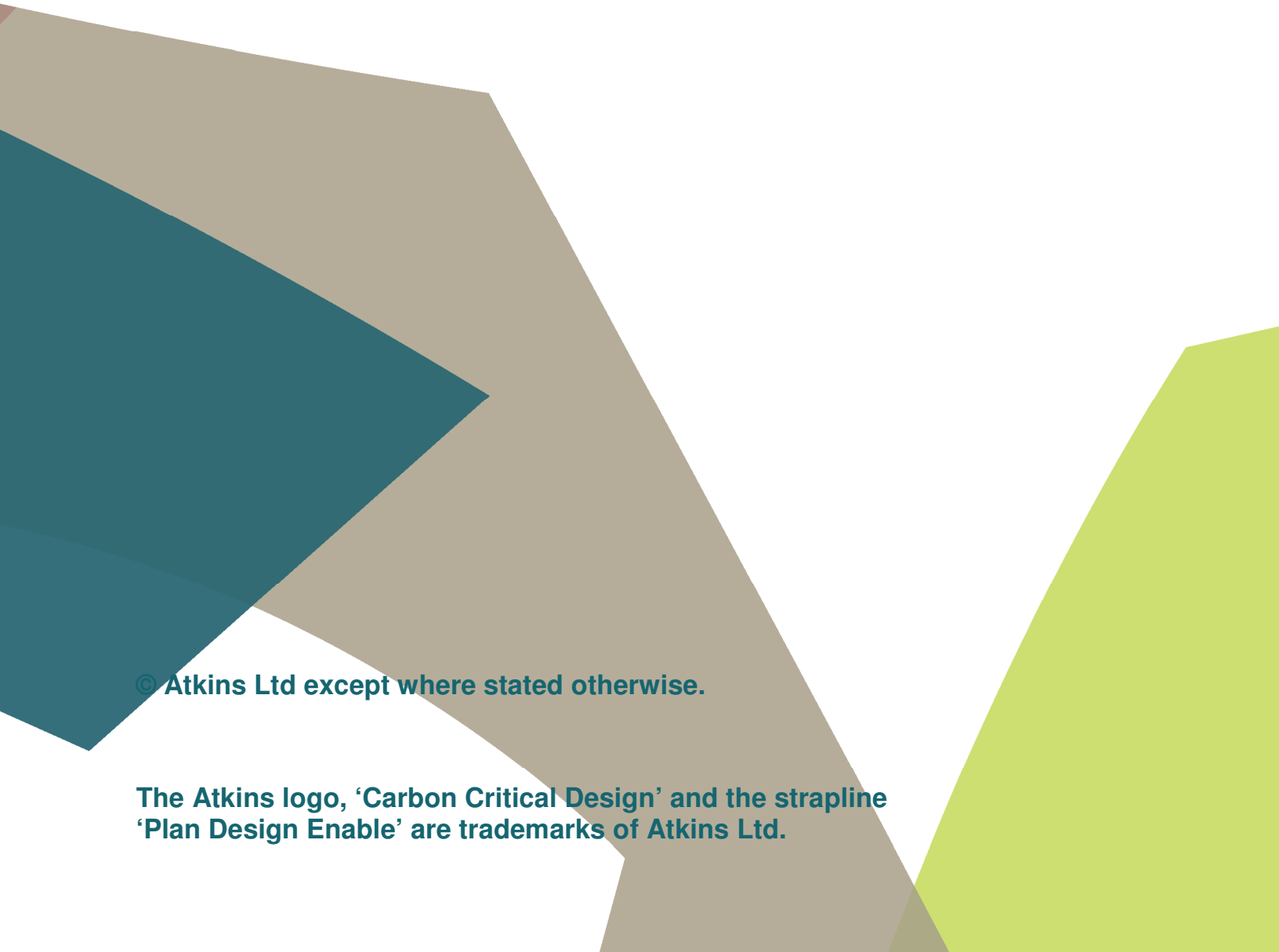
6.3. Water quality

The following data gaps were identified for data discussed under Section 3.3 (Water Quality Data):

- **Aquifer Infiltration data –** The 2007 USGS HSPF model for the Cibolo Creek watershed simulated the infiltration of Cibolo Creek channel flow into the Edwards Aquifer. The channel infiltration rating curves (FTABLES) from the HSPF model can be used to simulate the channel infiltration in the HEC-HMS model. However, overland infiltration information was not available.

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Cibolo Creek Watershed Holistic Master Plan

Phase II Report

San Antonio River Authority

July 2018 (Revised)

SAN ANTONIO RIVER AUTHORITY
Leaders in Watershed Solutions

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Table of acronyms

ADA	Americans with Disabilities Act
ADT	Average Daily Traffic
AEP	Annual Exceedance Probability
BASINS	Better Assessment Science Integrating Points and Non-point Sources
BCI	Bat Conservation International
BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
C2MP	Cibolo Creek Holistic Watershed Master Plan
COE	Corps of Engineers
CRP	Clean Rivers Program
D2MR	Digital Data and Model Repository
DCF	Dangerous Crossing Factor
DEM	Digital Elevation Model
DFIRM	Digital Flood Insurance Rate Map
DO	Dissolved Oxygen
DSC	Distance to Safe Crossing
EAD	Estimate Annual Damage
ECHO	Enforcement and Compliance History Online
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
FTABLE	Hydraulic Function Tables
GIS	Geographic Information System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HSPF	Hydrological Simulation Program - Fortran
IMPLND	Impervious Land
LiDAR	Light Detection and Ranging
LRT	Load Reduction Tool
NAVD88	North American Vertical Datum of 1988
NCD	Natural Channel Design
NLDAS	North American Land Data Assimilation System
NOAA	National Oceanic Atmospheric Administration
NWS	National Weather Service
PERLND	Pervious Land
RCHRES	River Reach
SARA	San Antonio River Authority
SARB	San Antonio River Basin
SAWS	San Antonio Water System
SCS	Soil Conservation Service
SDR	Safe Depth Ratio

SWQM	Storm Waste Quality Monitoring
TCEQ	Texas Commission on Environmental Quality
TSDN	Technical Support Data Notebook
TSS	Total Suspended Solids
TxDOT	Texas Department of Transportation
UDC	United Development Code
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UTSA	University of Texas at San Antonio
WRC	Water Resource Center
WWTP	Waste Water Treatment Plant

1. Introduction

The Cibolo Creek Holistic Watershed Master Plan (C2MP) seeks to provide communities with sustainable solutions that address a variety of concerns including flooding, water quality, stream health and recreation. The solutions will be developed to consider the following objectives:

Reduce flood risk using structural and non-structural measures,
Reduce pollutant loadings in waterways or remove them through natural processes,
Protect or restore riparian corridors, and
Incorporate recreational features where feasible.

The C2MP will provide a prioritized list of implementable project alternatives and an implementation plan for the recommended alternatives.

The project consists of three phases:

Phase 1 – This phase evaluated the available data and what additional data needs to be collected for the C2MP. Meetings were held with local stakeholders to determine their areas of interest throughout the watershed and to collect additional available data. The collected data were reviewed and used with input of stakeholders to determine areas of interest throughout the watershed. The limits and focus of the individual study elements (Water Resources, Water Quality, Stream Health, and Human Interface/Recreation) were determined.

Phase 2 – This phase included an analysis of the existing hydrology, stream hydraulics, water quality, stream health, and recreational features. “Damage centers”, which are areas where potential problems exist, were identified based on existing and future conditions models. A preliminary list of watershed improvement alternatives were developed. “Opportunity centers”, were identified as areas with positive features that can potentially be preserved or enhanced.

Phase 3 – This phase will include an evaluation of the improvement alternatives as projects in each “damage center”. Scoring criteria, including factors such as flood damage reduction, crossing safety improvements, water quality benefits, recreational enhancements, and stream function improvements, will be used to evaluate each alternative. A prioritized list of project alternatives will be provided along with an implementation plan for the recommended alternatives.

This report documents the Phase 2 efforts for the C2MP, which included the definition of baseline conditions within the watershed, identification of damage centers, and the development of a preliminary list of watershed improvements. The Phase 2 report discusses Flood Risk (Chapter 2), Water Quality (Chapter 3), Stream Restoration (Chapter 4), and Project Development and Nature-Based Park Planning (Chapter 5). Included as part of this Phase 2 Report are a set of DVDs containing the models, mapping, and results created to define baseline conditions within the watershed.

2. Flood Risk

Flood Risk identification within the Cibolo Creek watershed focused on streams which had existing hydraulic models collected as part of the Phase 1 data collection effort. These streams included the main channel of Cibolo Creek, as well as 24 tributaries within the San Antonio River Authorities' jurisdiction. Although hydraulic modelling was not performed for many streams within the Cibolo Creek watershed, the hydrologic model of the entire watershed was updated as part of the Phase 2 effort. This chapter will discuss the update for the hydrologic model and hydraulic models for baseline conditions.

2.1. Overview

2.1.1. Software

The baseline condition hydrology for the Cibolo Creek watershed was simulated using HEC-HMS version 4.2. All hydraulic simulations were performed using HEC-RAS version 4.1.

2.1.2. Modeling Standards

The models completed as part of this analysis were developed using the "San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling, September 2013" (San Antonio River Authority, 2013), unless otherwise noted.

2.1.3. Modeling Conditions

The following watershed conditions were modelled as part of the baseline condition analysis:

- Baseline Existing Condition – This condition simulates the drainage patterns, land use, and routing as of June 2015.
- Baseline Future Condition – This condition simulates the drainage patterns and channel routing as of June 2015, but simulates the ultimate land use within the watershed.

2.1.4. Modeling Events

For the Baseline Existing and Baseline Future conditions theoretical events were simulated for the 50%, 10%, 4%, 2%, 1%, and 0.2% annual exceedance probabilities (AEP). Historic storm events, for the purpose of calibrating and verifying the results of the hydrologic model, were simulated for the Baseline Existing condition. These historic events included the May 2013 and October 2015 storms.

2.2. Hydrology

This section discusses the development of the hydrologic model for the Cibolo Creek watershed. The hydrologic modeling Subsections are included to present the basin models, meteorological models, control specifications and simulations included in the analysis.

2.2.1. Basin Models

The Cibolo Creek watershed hydrologic model contains basin models for two conditions: Baseline Existing and Baseline Future. The Baseline Existing condition reflects the drainage patterns, land use, and channel conditions within the watershed as of June 2015. The Baseline Future condition reflects the drainage patterns and channel conditions as of June 2015 and ultimate land use within the watershed.

2.2.1.1. Baseline Existing Condition

This section discusses the primary parameters of the Baseline Existing basin model.

2.2.1.1.1. Subbasin Area

HEC-HMS subbasins were delineated for the entire Cibolo Creek watershed, while, in general, maintaining effective HEC-HMS junction locations. This allowed effective routing relationships to be maintained where hydraulic models did not exist to develop updated routing relationships (see Section 2.2.1.1.4). The project's LiDAR dataset and ArcHydro were used to create GIS catchments and flowpaths for the entire watershed that were used to guide the manual delineation of the subbasins used in the Baseline Existing hydrologic model. The 853.6 mi^2 watershed includes a total of 467 subbasins with an average subbasin area of 1.8 mi^2. The Flood Risk (Hydrologic) Workmaps display the baseline subbasin delineation for the watershed used in the hydrologic model.

2.2.1.1.2. Loss Rate Parameters

The Cibolo Creek watershed HEC-HMS model uses the Green and Ampt method to simulate diffuse infiltration. Initially the SCS loss method was used; however, during historic storm events simulations (see Section 2.4) it was determined that the Green and Ampt method would more realistically reflect soil infiltration over the extended timeframe of the October 2015 and May 2013 events. Furthermore, it was determined that higher diffuse infiltration in some portions of the watershed were justified for both calibration events based upon simulated versus observed peak flows and flood stages. This finding was supported by a USGS study (Ockerman, 2007) that modelled higher diffuse infiltration rates over karst features in the upper Cibolo watershed. Atkins increased the Green and Ampt conductivity rate of subbasins over the Recharge Zone by 75% to account for the higher infiltration rates.

Atkins created a shapefile that identifies land use, landcover and corresponding impervious percentages throughout the watershed following the categories and parameters shown in Table 2-1. The shapefile provides the information necessary to produce weighted impervious percentage values for calculation of loss rates. Although not used in the Cibolo Creek watershed hydrologic model, the shapefile also provides the parameters necessary to calculate SCS Curve Numbers for the watershed.

Table 2-1 Land Use Categories

Land use Description	SARB LU Code	% IC	Land Cover
Undeveloped			
Undeveloped - Meadow	UM	0	Meadow
Undeveloped - Brush	UB	0	Brush
Undeveloped - Woods	UW	0	Woods
Residential			
Residential (Dispersed)	RD	10	Open
Residential (Low - 1/2 acre lots)	RL	25	Open
Residential (Medium - 1/3 acre lots)	RM	38	Open
Residential (High - 1/4 acre lots)	RH	65	Open
Residential (Multi-Family)	RMF	75	Open
Residential			
Commercial	C	90	Open
Commercial Low Density	CL	65	Open
Industrial			
Industrial	I	72	Open
Transportation			
Transportation	T	90	Open
Extraction			
Mining	M	0	Open
Open Space			
Open Space - Urban	OU	0	Open
Open Space - Cultivated	OC	0	Meadow
Easements	EA	10	Open
Services			
Utilities	U	80	Open
Mixed Use	MX	40	Open
Water			
Lakes, Ponds, Streams, Wetlands	W	100	Open
Mixed-Use			
Residential/Commercial Developments	MRC	51	Open

In addition to impervious percentage, the Green and Ampt method in HEC-HMS version 4.2 requires the following parameters to estimate infiltration:

- Initial Content
- Saturated Content
- Suction (in)
- Conductivity (in/hr)

Documented values of the above parameters in relation to various soil types were not available at the time of this analysis. However, the Water Research Center (Water Research Center) provides values of Average Capillary Suction, Saturated Hydraulic Conductivity and Initial Moisture Deficit by USDA Soil Texture Classification for areas where detailed soils information is not available (see Table 2-2).

Table 2-2 Soil Parameters by USDA Soil Type

USDA Soil Texture Classification	Average Capillary Suction (in)	Saturated Hydraulic Conductivity (in/hr)	Initial Moisture Deficit
Sand	1.95	9.27	0.404
Loamy Sand	2.41	2.35	0.382
Sandy Loam	4.33	0.86	0.358
Loam	3.5	0.52	0.346
Silt Loam	6.57	0.27	0.368
Sandy Clay Loam	8.6	0.12	0.25
Clay Loam	8.22	0.08	0.267
Silty Clay Loam	10.75	0.08	0.263
Sandy Clay	9.41	0.05	0.191
Silty Clay	11.5	0.04	0.229
Clay	12.45	0.02	0.203

The release notes for HEC-HMS version 3.5 (U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2010) provides guidance on converting Average Capillary Suction, Saturated Hydraulic Conductivity and Initial Moisture Deficit parameters into Initial Content, Saturated Content, Suction and Conductivity (Green and Ampt parameters used in later versions of HEC-HMS):

$$\textit{Saturated Content} = 0.46 \quad \textbf{(2-1)}$$

$$\textit{Initial Content} = 0.46 - \textit{Initial Moisture Deficit} \quad \textbf{(2-2)}$$

Table 2-3 displays the converted Green and Ampt parameters, by USDA Soil Texture Classification, that were used in the development of the Cibolo Creek watershed hydrologic modeling.

Table 2-3 Green and Ampt Loss Rate Parameters by USDA Soil Type

USDA Soil Texture Classification	Saturated Content	Initial Content	Suction (in)	Conductivity (in/hr)
Sand	0.46	0.056	1.95	9.27
Loamy Sand	0.46	0.078	2.41	2.35
Sandy Loam	0.46	0.102	4.33	0.86
Loam	0.46	0.114	3.5	0.52
Silt Loam	0.46	0.092	6.57	0.27
Sandy Clay Loam	0.46	0.21	8.6	0.12
Clay Loam	0.46	0.193	8.22	0.08
Silty Clay Loam	0.46	0.197	10.75	0.08
Sandy Clay	0.46	0.269	9.41	0.05
Silty Clay	0.46	0.231	11.5	0.04
Clay	0.46	0.257	12.45	0.02

Atkins created a separate soil shapefile that includes USDA Soil Texture Classifications. This shapefile was used to calculate the area of each USDA soil classification within each subbasin of the watershed, which, in turn, allowed weighted Green and Ampt parameters to be calculated for each subbasin. The weighted Green and Ampt parameters for the each subbasin of the Cibolo Creek watershed are displayed in Appendix A.

2.2.1.1.3. Transformation Parameters

The Synder Unit Hydrograph transformation method was used for the Cibolo Creek watershed hydrologic model. The method requires a lag time (T_{LAG}) (in hours) and a peaking coefficient (C_P). The lag time was calculated in the same manner as the Cibolo Creek watershed TSDN, using the equations below:

$$T_{LAG} = C_T \, x \, (\frac{L \, x \, L_C}{\sqrt{S}})^N \quad \textbf{(2-3)}$$

$$C_T = 1.4224 \, e^{(-0.0088X)} \quad \textbf{(2-4)}$$

Where:

N = 0.39
X = Percent Development (1.75 x %IC)
L = Length of longest flow path (miles)
L_C = Length to centroid along longest flow path (miles)
S = Slope of longest flow path (feet/mile)

The peaking coefficient (C_P) was set to 0.760 for subbasins above the Escarpment and 0.5 or 0.550 for subbasins below the Escarpment. Synder Unit Hydrograph parameters and calculations may be found in Appendix A.

2.2.1.1.4. Channel Routing

The Baseline Existing basin model uses a combination of the Modified Puls, Muskingum-Cunge and Lag Methods for channel routing. Atkins updated the Modified Puls routing parameters for routing reaches of modeled streams within SARA's jurisdiction; however, hydraulic modeling was not available to update the routing relationships for reaches outside SARA's jurisdiction. Therefore, outside SARA's jurisdiction, the effective routing relationships (Modified Puls, Muskingum-Cunge or Lag) were maintained, with one exception. The effective hydrologic models that are the source of the Modified Puls routing outside of SARA's jurisdiction have a 10-minute time step. The baseline hydrologic model has a 5-minute time step. The number of subreaches in the effective routing was doubled for compatibility with the baseline hydrologic model.

The Modified Puls routing relationships for the following streams were updated using the latest HEC-RAS models from SARA's D2MR:

- Cibolo Creek
- Balcones Creek
- Borgfeld Creek
- Clear Spring – Unnamed Tributary
- Clear Spring – West Fork
- Clear Spring Fork
- Green Mountain Creek
- Meusebach Creek
- Rundale Creek
- Dry Hollow Creek
- Escondido Creek
- Martinez Creek B
- Martinez Creek B - Tributary E
- Martinez Creek B – Tributary F
- Salitrillo Creek
- Woman Hollering Creek

The baseline condition Modified Puls routing parameters for the above streams are documented in Appendix A. As seen in the routing tables, nine routing profiles were simulated in each HEC-RAS model to create the storage volume versus discharge relationship for each routing reach. The peak flow for each profile was constant through each routing reach and was set as a percentage of the maximum 1% event peak flow expected in that reach. The profiles are typically 5%, 10%, 20%, 40%, 60%, 80%, 100%, 140%, and 275% of the maximum 1% AEP peak flow. Note that the percentage of the last profile is not consistent for all streams as the routing relationship was extended for some streams to cover the full range of simulated HEC-HMS flows.

The number of subreaches for each routing reach was determined by taking the average floodwave travel time of the nine profiles and dividing it by the HEC-HMS model's time step (15 minutes). The floodwave travel time is assumed to be 1.5 times faster than the "Trvl Time Avg" reported by HEC-RAS.

2.2.1.1.5. Channel Losses

The effective hydrologic models for the Cibolo Creek watershed do not account for loss of stream flow into the Edwards Aquifer. However, a USGS report (Ockerman, 2007) that evaluated ground water recharge in the Upper Cibolo Creek watershed showed that channel losses do indeed affect flows of Cibolo Creek and several of its tributaries. Consequently, Atkins incorporated channel losses into the Cibolo Creek watershed model.

There is very little guidance on how to apply channel losses to hydrologic models for flood hazard modeling. The "San Antonio River Basin Regional Modeling Standards for Water Quality Modeling" (San Antonio River Authority, 2014) does, however, provide guidance for the purpose of water quality modeling. The standards state in Section 4.2.4.2, "…to achieve adequate hydrologic calibration of WQ modeling, channel loss must

be considered and included in reaches within the Edwards Aquifer recharge zone…". The standards provide a channel loss equation from the USGS Water-Resources Investigations Report 2002-4241 (Ockerman, 2002):

$$\boldsymbol{Loss\ per\ mile = 0.062\ x\ streamflow + 8.3} \quad \textbf{(2-5)}$$

Equation 5, if modified, is compatible with the HEC-HMS Constant Loss/Gain method. This method applies a "flow rate" that is subtracted from the routed hydrograph and a "fraction" that defines the ratio of flow above the subtracted "flow rate" that is also subtracted from the routed hydrograph. Equation 6 and 7 convert Equation 5 into a format that is compatible with the HEC-HMS Constant Channel Loss/Gain method.

$$\boldsymbol{Flow\ Rate\ (cfs) = 8.3\ x\ Reach\ Length} \quad \textbf{(2-6)}$$

$$\boldsymbol{Fraction\ = 0.062\ x\ Reach\ Length} \quad \textbf{(2-7)}$$

Where:

Reach Length = Length of routing reach in miles

Atkins initially applied channel losses just to routing reaches within the Edwards Aquifer Recharge Zone, as seen in Figure 2-1. However, the number of channel reaches with channel losses was expanded (see Figure 2-2) to maintain consistency with previous USGS HSPF modeling of the upper Cibolo Creek watershed (Ockerman, 2007), as well as to better match observed values to historic event simulation results during the calibration effort (see Section 2.4).

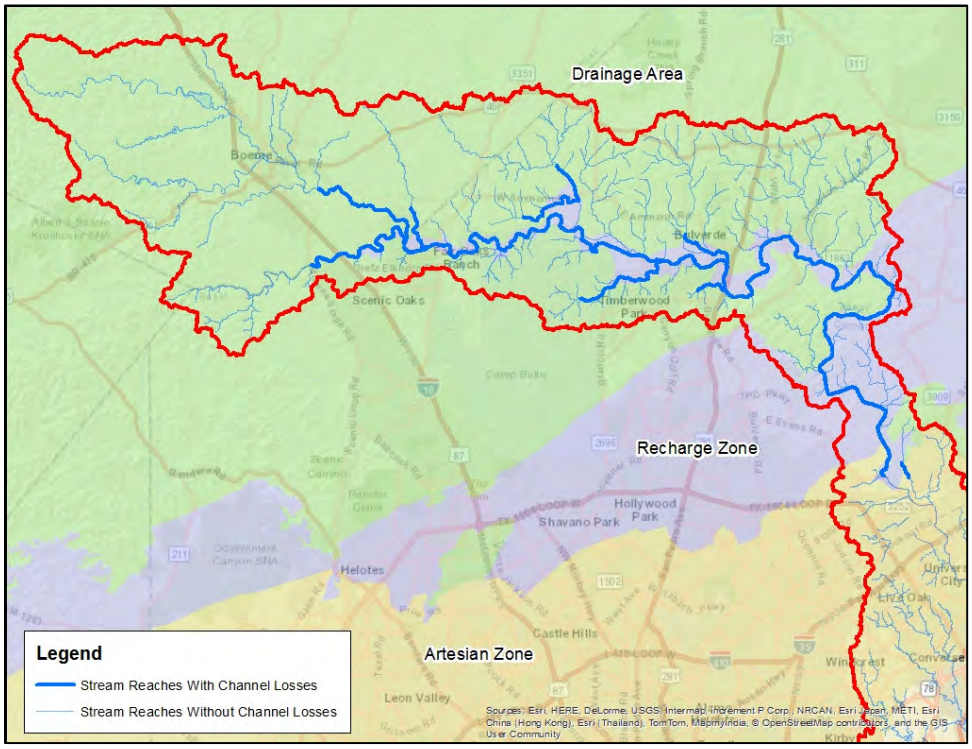


Figure 2-1 Stream Reaches with Channel Losses (Initial)

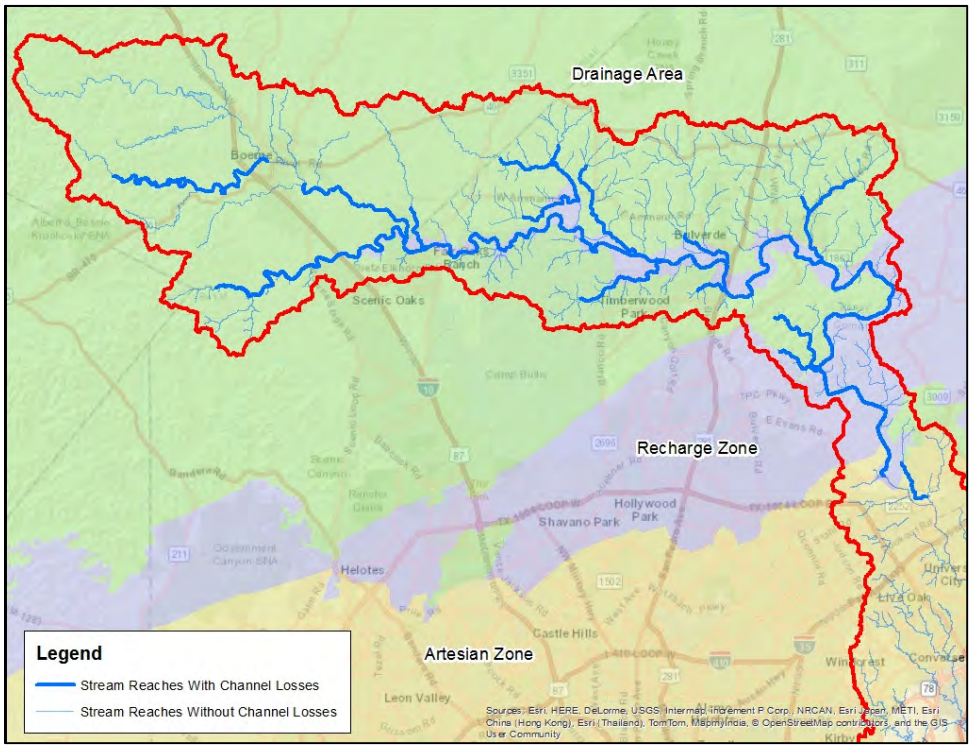


Figure 2-2 Channel Reaches with Channel Losses (Final)

In addition to the changing the limits of channel losses, the calibration effort resulted in a modification of the initial equation for "Fraction" (Equation 7) used in the HEC-HMS Constant Channel Loss/Gain method. As seen in Equation 9, the "Fraction" equation was modified to reduce the rate of channel infiltration. Below are the equations used for the Constant Channel Loss/Gain method:

$$\boldsymbol{Flow\ Rate\ (cfs) = 8.3\ x\ Reach\ Length} \quad \textbf{(2-8)}$$

$$\boldsymbol{Fraction\ = 0.01\ x\ Reach\ Length} \quad \textbf{(2-9)}$$

Where:

Reach Length = Length of routing reach in miles

Channel loss parameters (Flow Rate and Fraction) included in the Baseline Existing basin model may be found in Appendix A.

2.2.1.1.6. Reservoirs

As seen in Table 2-1, there are a total of ten reservoirs that are simulated in the Cibolo Creek watershed model. With exception of the Martinez Dam No. 1, Dam No. 2, and Dam No. 3, the Baseline Existing basin model maintains the reservoir configurations of the effective hydrologic models. The three Martinez dams were reconstructed in 2015 and the baseline hydrologic model reflects the revised dam configuration. The elevation-storage-discharge relationships for these dams were updated based upon design information provided by SARA. Appendix A contains the updated elevation-storage-discharge relationships for Martinez Dam No. 1, Dam No. 2, and Dam No. 3.

Table 2-4 Cibolo Watershed Reservoirs

Reservoir ID	Channel	Description
S4010122	Cibolo Creek	SCS Dam #1 - Boerne Lake
S4010135	Ranger Creek	SCS Dam #2
S4010151	Frederick Creek	SCS Dam #3
S4010155	Deep Hollow Creek	SCS Dam #4
Dam No. 1	Martinez Creek B	Martinez Dam No. 1
Dam No. 2	Martinez Creek B Tributary E	Martinez Dam No. 2
Dam No. 3	Escondido Creek	Martinez Dam No. 3
Dam No. 4	West Salitrillo Creek	Martinez Dam No. 4
Dam No. 5	East Salitrillo Creek	Martinez Dam No. 5
Dam No. 6-A	Salitrillo Creek	Martinez Dam No. 6A

2.2.1.1.7. Overflows

There are two overflows simulated in the baseline condition hydrologic model. The first, at node C4020234, diverts flow from Cibolo Creek, just upstream of IH-10, to a small channel (Spill 2) to the east. The second overflow diverts flow from Spill 2, just upstream of IH-10, to a second channel (Spill 3) to the east. Figure 2-3 shows the layout of these overflows.

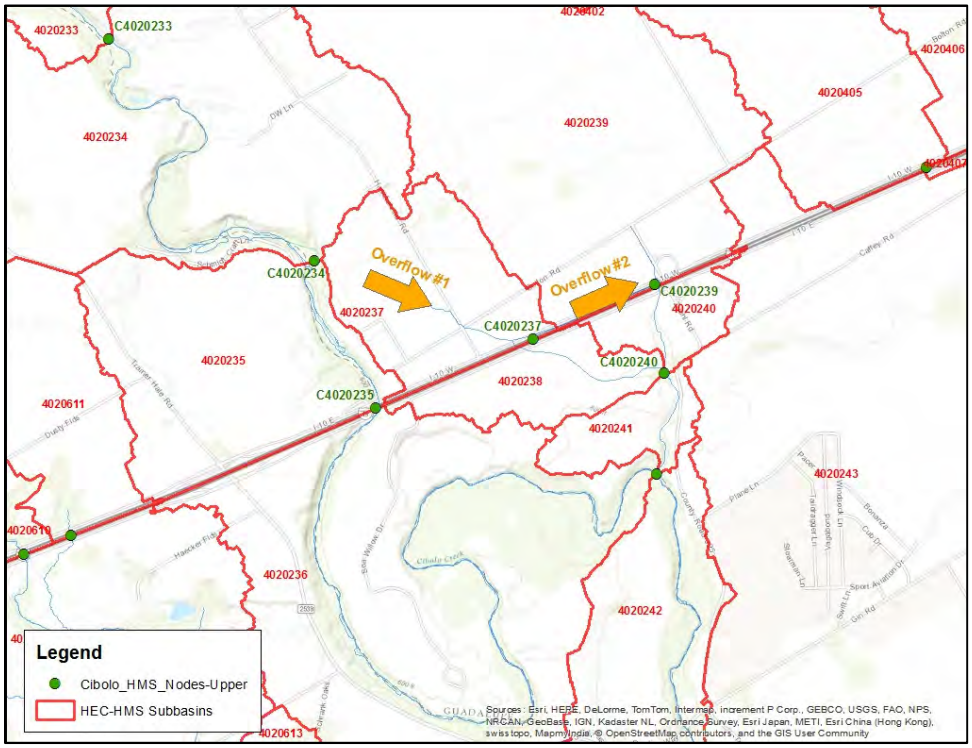


Figure 2-3 HEC-HMS Overflows

Overflow relationships were approximated by first using the available HEC-RAS models (Cibolo Creek and the IH-10 channels) to determine the stage and flow at which the overflow would initiate. Atkins assumed that 50% of all flows higher than this "initiation flow" will be diverted. Table 2-525 and Table 2-6 display the Inflow-Diversion relationships for both overflows.

Table 2-5 Diversion Relationship at Node C4020234

Main Channel Flow (cfs)	Diversion Flow (cfs)
0	0
40300	0
55000	7350
65000	12350
75000	17350
90000	24850
160000	59850

Table 2-6 Diversion Relationship at Node C4020237

Main Channel Flow (cfs)	Diversion Flow (cfs)
1000	500
2500	1250
5000	2500
10000	5000
15000	7500
20000	10000

2.2.1.2. Baseline Future Conditions

The Baseline Future condition hydrologic model reflects the effect of assumed future development. In the future currently undeveloped areas will be developed, currently developed areas will be redeveloped, drainage patterns will change because of development, and stormwater regulations will likely be modified. Predicting such changes with any accuracy is difficult, therefore, Atkins made some simplifying assumptions:

- Baseline Existing drainage patterns will not change with future development
- The Baseline Future condition land use distribution is based upon future land use shapefiles provided by SARA
- Impervious cover will increase with future development and on a subbasin-level the Baseline Future condition impervious percentage can't be lower than the Baseline Existing condition
- All development beyond the Baseline Existing Condition will require peak flow mitigation

The Baseline Existing condition basin model (see Section 2.2.1.1) was modified to create the Baseline Future condition basin model. The Baseline Future condition basin model maintains the following parameters of the Baseline Existing condition basin model:

- Subbasin Area
- Channel Routing
- Channel Losses
- Reservoirs
- Overflows

The following sections document the parameters that were updated for the Baseline Future condition or that require additional explanation.

2.2.1.2.1. Loss Rate Parameters

As with the Baseline Existing condition, the Baseline Future condition modeling uses the Green and Ampt method to estimate soil losses. Green and Ampt losses are dependent upon soil type and the amount of impervious cover. Because soil types will not change with the future condition, only changes in impervious cover need to be accounted for in the future condition.

To estimate the future impervious cover Atkins first combined several future land use shapefiles provided by SARA to create a watershed-wide future land use shapefile. The shapefile identifies future land use throughout the watershed using SARB land use categories identified in Table 2-1. Next, the future land use shapefile was intersected with the watershed subbasin boundaries to determine the amount of each land use type within each subbasin. The land use type to impervious percentage relationship shown in Table 2-1 was used to develop Baseline Future condition impervious percentages for each subbasin. However the future impervious percentage of some subbasins was calculated to be lower than the existing condition. In these cases, the future condition impervious percentage was increased to match the existing condition impervious percentage. The future condition of the Cibolo Creek watershed was calculated to have an impervious percentage of 20.6%, as opposed to 7.5% for the existing condition. Appendix A lists the Baseline Future condition impervious percentages for each subbasin.

2.2.1.2.2. Transformation Parameters

The Baseline Future condition hydrologic modeling is based upon the assumption that, although future development may increase runoff volume, peak flow mitigation (detention) requirements will ensure that on a site-level peak flows are not increased by future development. This assumption was translated to the Baseline Future condition hydrologic model by maintaining the Baseline Existing condition Synder Unit Hydrograph transformation parameters (T_{LAG} and C_P) in the Baseline Future condition hydrologic model.

2.2.2. Meteorological Model

The Cibolo Creek watershed hydrologic model has meteorological models defined for six theoretical events (50%, 10%, 4%, 2%, 1%, and 0.2% AEP events), as well for two historical events. This section discusses the development of both types of meteorological models.

2.2.2.1. Theoretical Events

The “San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling” (San Antonio River Authority, 2013) requires an areal adjustment to flows for drainage areas greater than 10 square miles using the drainage area versus reduction factor relationship shown in Table 2-7. To apply the areal reduction, individual hyetographs that correspond to a specific drainage area and reduction factor were created. The reduced hyetographs were created by multiplying each ordinate of the base (unreduced) unit hydrograph by the corresponding reduction factor. For a given exceedance event, individual meteorological models, and ultimately HEC-HMS simulations, were created for each of the hyetographs. These simulations produced peak flow results at every HEC-HMS combination point for each drainage area reduction. These results were used to interpolate peak flows at each combination point based upon the drainage area contributing to that combination point.

Table 2-7 Areal Reduction Factors

Drainage Area (mi^2)	Reduction Factor
0	1
10	1
25	0.823
50	0.775
100	0.745
175	0.72
300	0.69
450	0.655
700	0.628
1000	0.603
1500	0.575
2150	0.545

Based upon the methodology described above, each of the 6 theoretical storm events had a total of 9 meteorological models (10, 25, 50, 100, 175, 300, 450, 700 and 1,000 mi^2) and simulations to develop peak flows for the 853.6 mi^2 Cibolo Creek watershed. A total of 54 meteorological models were developed. All the meteorological models use the "specified hyetograph" method.

2.2.2.2. Historical Events

Two historic storm events were simulated to verify and calibrate the results of the modeling: the May 2013 and the October 2015 storm events.

May 2013 Event

The rainfall measurements of 11 gages were collected for May 24-27, 2013 event. The USGS and NWS gages provided rainfall measures at 15-minute intervals, while the NOAA gages provided rainfall measurements in hourly intervals. The rainfall measurements for both gage sources were converted into cumulative rainfall records with 15-minute intervals.

Initially, rainfall gage data was used with the HEC-HMS "gage weights" method to develop the historic rainfall patterns for individual subbasins. However, it was determined that the gage locations were too dispersed to produce accurate rainfall estimates with this method. Therefore, Atkins used the "specified hyetograph" method with the "total override" option for this storm event. The hyetograph for each subbasin was set to be the nearest rainfall gage but the total rainfall depth for each subbasin was calculated from radar rainfall records. Daily historic rainfall estimates in a point shapefile format were downloaded from the NWS (National Weather Service, n.d.) and converted into raster DEM for the cumulative rainfall depth in the region for May 24-27, 2013. The average cumulative rainfall depth for each subbasin was calculated from this raster and was used to override the total rainfall depth from each subbasin's associated rainfall gage. Figure 2-4 shows the radar estimated total rainfall between May 24 and May 27, 2013, as well as the total rainfall depths reported by the various rainfall gages.

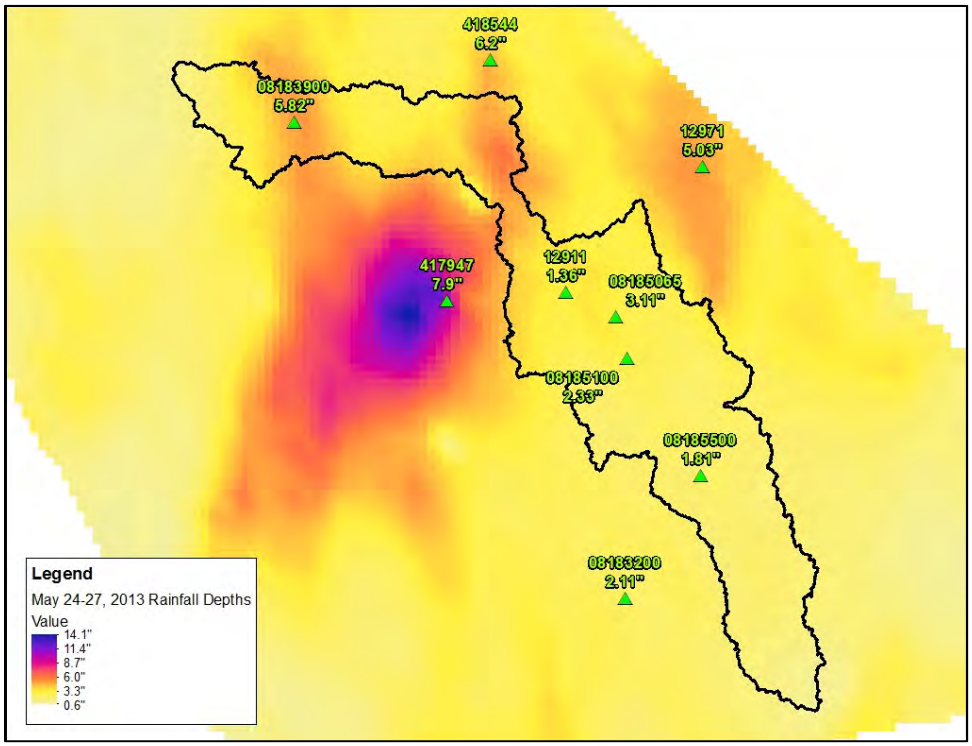


Figure 2-4 May 24-27, 2013 Rainfall Depths

October 2015 Event

The October 2015 event, in general, occurred as three separate events: October 23-24th, October 30th and October 31st. Because these three events occurred over a short timeframe Atkins covered all three events under a single simulation. The October 2015 simulation covers the period from October 15th to November 6th. Rainfall measurements were collected from 18 gages. The USGS and NWS gages provided rainfall measures at 15-minute intervals, while the NOAA gages provided rainfall measurements in hourly intervals. The rainfall measurements for both gage sources were converted into cumulative rainfall records with 15-minute intervals.

The October 2015 rainfall gage data was used with the HEC-HMS "gage weights" method to develop the historic rainfall patterns for individual subbasins. Atkins measured the distance between each gage and the centroid of each subbasin to determine the "depth weighting" that should be applied to each gage's rainfall depth for each subbasin. The depth weighting was applied based upon the closest three gages to each subbasin. The "time weighting" was based solely upon the nearest gage to each subbasin.

Figure 2-5 shows the location of the rainfall gages used in the simulation of the October 2015 storm event and the total depth of rainfall at those gages between October 15th and November 6th, 2015.

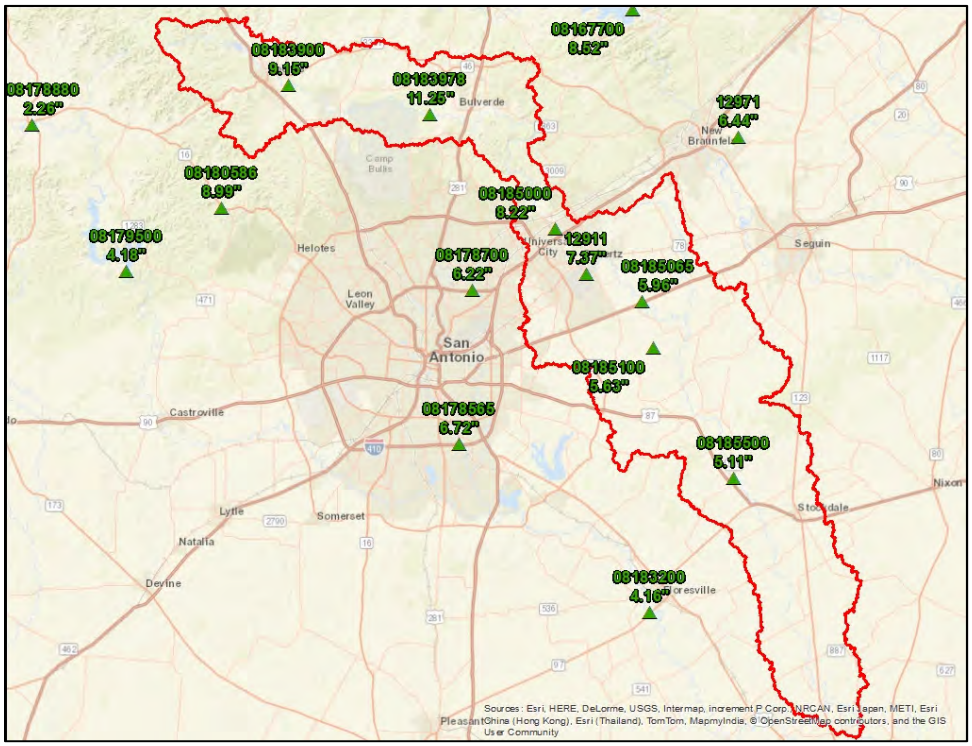


Figure 2-5 October 2015 Rainfall Depths

2.2.3. Control Specifications

This section provides the parameters of the theoretical and historic event control specifications required for the simulation of baseline conditions.

2.2.3.1. Theoretical Events

The control specifications for all the theoretical event simulations specify that that simulation begins on June 1, 2005 at 12:00 AM and ends on June 6, 2005 at 12:00 AM. The simulation time interval is 5 minutes.

2.2.3.2. Historical Events

The control specifications for the May 2013 historic storm event simulation specifies that that simulation begins on May 24, 2013 at 12:00 AM and ends on June 3, 2013 at 12:00 AM. The simulation time interval is 5 minutes.

The control specifications for the October 2015 historic storm event simulation specifies that that simulation begins on October 15, 2013 at 12:00 AM and ends on November 6, 2013 at 12:00 AM. The simulation time interval is 5 minutes.

2.2.4. Simulations

This section discusses the simulations included in the Cibolo Creek watershed hydrologic model, as well as the resulting peak flows. The hydrologic model simulations include the Baseline Existing and Baseline Future Theoretical Events (50%, 10%, 4%, 2%, 1%, and 0.2% AEP events), Baseline Existing May 2013 Event and the Baseline Existing October 2015 Event.

2.2.4.1. Baseline Existing Theoretical Events

The Baseline Existing Theoretical Event simulations required a total of 54 HEC-HMS simulations to produce Cibolo Creek watershed peak flows for the 50%, 10%, 4%, 2%, 1%, and 0.2% AEP events. Each simulation used the Baseline Existing basin model presented in Section 2.2.1.1, the theoretical event control

specifications presented in Section 2.2.3.1, and each of the 54 meteorological models presented in Section 2.2.2.1.

Table 2-8 compares the Baseline Existing contributing drainage area and 1% AEP event peak flows of Cibolo Creek against the effective values. The Kendall County FIS (Federal Emergency Management Agency, 2010a), the Bexar County FIS (Federal Emergency Management Agency, 2010), the Comal County FIS (Federal Emergency Management Agency, 2009), the Guadalupe County FIS (Federal Emergency Management Agency, 2007), the Wilson County FIS (Federal Emergency Management Agency, 2010), and the Karnes County FIS (Federal Emergency Management Agency, 2010) were the source of the effective hydrologic results. It should be noted that in many cases the documented county FIS hydrologic results overlap adjacent county boundaries and were derived from different effective models. Thus, the effective peak flow results are not necessarily consistent between counties. Despite the inconsistent model sources, Table 2-8 shows that, in general, the Baseline Existing contributing drainage areas are similar to effective values. However, the Baseline Existing 1% AEP event peak flows are much lower than effective values downstream of Balcones Creek. This large reduction in flow is primarily a result of the addition of channel losses applied to selected channel reaches of the upper Cibolo Creek watershed (see Section 2.2.1.1.5).

Atkins also compared the Existing Baseline hydrologic results against the results from the Upper Cibolo Creek HEC-HMS model (developed by the USACE), as seen in Table 2-9. This table shows that, similar to the effective hydrologic results, the Upper Cibolo Creek HEC-HMS model produces significantly higher peak flows than the Baseline Existing hydrologic model even though contributing drainage areas are comparable. The difference is likely that the Baseline Existing hydrologic model includes channel losses. Under the Baseline Existing model the most upstream channel losses are modelled on Frederick Creek, and may explain why Baseline Existing flows reduce on Cibolo Creek downstream of Frederick Creek in relation to the effective Upper Cibolo HEC-HMS model peak flows.

A complete list of Baseline Existing hydrologic model results, including the 50%, 10%, 4%, 2%, 1% and 0.2% AEP event peak flows may be found in Appendix A.

Table 2-8 Cibolo Creek Peak Flow Comparison to Effective

		Effective		*Baseline Existing*		*Comparison to Effective (% Difference)*	
HEC-HMS Node	**Location**	**Drainage Area (mi^2)**	**1% Peak Flow (ft^3/s)**	**Drainage Area (mi^2)**	**1% Peak Flow (ft^3/s)**	**Drainage Area**	**1% Peak Flow**
Kendall County							
C4010123	At Dam Site No. 1	19.74	152	19.83	3,098	0.5%	1938%
C4010139	D/S of IH-10	30.45	10,899	28.05	10,708	-7.9%	-1.7%
C4010146A	D/S of Frederick Creek	51.64	17,475	50.47	24,110	-2.3%	38.0%
C4010210	U/S of Menger Creek	57.37	17,995	56.39	28,202	-1.7%	56.7%
C4010231	U/S of Balcones Creek	76.92	47,550	76.89	39,638	0.0%	-16.6%
Comal County							
C4010231A	1004' U/S of County Boundary	100.80	70,638	100.89	57,929	0.1%	-18.0%
C4010306A	1994' D/S of Ralph Fair Road	115.20	74,909	115.27	62,310	0.1%	-16.8%
C4010402	U/S of Blanco Road	154.30	76,540	153.20	57,990	-0.7%	-24.2%
C4010415	2390' U/S of Meusebach Creek	179.20	89,412	165.43	55,547	-7.7%	-37.9%
C4020101A	7350' U/S of FM 1863	238.40	97,623	234.48	47,552	-1.6%	-51.3%
C4020123A	102' D/S of Bracken Trib.	271.20	99,570	272.28	40,120	0.4%	-59.7%
Bexar County							
C4010231A	D/S of Balcones Creek	101.02	53,270	100.89	57,929	-0.1%	8.7%
C4010301A	D/S of Post Oak Creek	109.78	59,480	110.91	61,723	1.0%	3.8%
C4010312	U/S of Pleasant Valley Creek	124.92	62,160	127.74	55,679	2.3%	-10.4%
C4010415A	D/S of Meusebach Creek	177.92	72,230	175.28	55,947	-1.5%	-22.5%
C4010438	U/S of Lewis Creek	207.85	78,600	206.56	49,043	-0.6%	-37.6%
C4020104A	D/S of Clear Springs Fork	249.22	95,790	249.50	43,296	0.1%	-54.8%
C4020116	Approx. 16,000' U/S of MPRR	258.82	94,800	260.10	40,152	0.5%	-57.6%
C4020201	At USGS Gage at Selma	274.00	93,940	272.74	40,027	-0.5%	-57.4%
Guadalupe County							
C4020201	731' U/S of County Line	271.61	99,469	272.74	40,027	0.4%	-59.8%
C4020235	IH-10	307.40	70,970	306.43	39,073	-0.3%	-44.9%
C4020244	U/S of Santa Clara Creek	317.00	58,020	315.19	38,285	-0.6%	-34.0%
C4020621	U/S of Martinez Creek	386.30	56,960	386.44	39,700	0.0%	-30.3%
C4020621A	D/S of Martinez Creek	473.70	67,490	474.42	47,681	0.2%	-29.4%
C4030201A	D/S Dry Hollow Creek	540.10	55,680	539.13	49,619	-0.2%	-10.9%
Wilson County							
C4030222	U/S of Elm Creek	544.60	54,910	546.43	49,161	0.3%	-10.5%
C4030408A	U/S of Gum Branch	640.05	69,990	633.66	48,231	-1.0%	-31.1%
C4040103	U/S of Clifton Branch	704.14	71,251	704.16	47,163	0.0%	-33.8%
C4040305	U/S of Dry Creek	773.07	70,296	773.17	46,094	0.0%	-34.4%
Karnes County							
C4040305	At County Line	773.07	70,296	773.17	46,094	0.0%	-34.4%
C4040503	USGS Gage 08186000	824.85	70,248	825.05	45,475	0.0%	-35.3%
C4040506	U/S of Mulifest Creek	834.38	69,896	834.25	45,093	0.0%	-35.5%
C4040508	Mouth	855.96	69,772	853.64	44,738	-0.3%	-35.9%

Table 2-9 Cibolo Creek Comparison to Upper Cibolo HEC-HMS

		Upper Cibolo HEC-HMS		*Baseline Existing*		*Comparison to Upper Cibolo HEC-HMS (% Difference)*	
HEC-HMS Node	**Location**	**Drainage Area (mi^2)**	**1% Peak Flow (ft^3/s)**	**Drainage Area (mi^2)**	**1% Peak Flow (ft^3/s)**	**Drainage Area**	**1% Peak Flow**
4010101	Headwaters of Cibolo Creek	1.39	2,166	1.40	3,689	0.9%	70.3%
C4010107		4.491	6,772	4.45	11,166	-0.8%	64.9%
C4010107A		9.33	13,130	7.72	18,766	-17.3%	42.9%
C4010120A	Upstream of Boerne Lake	17.51	23,068	17.62	31,386	0.6%	36.1%
S4010122	Downstream Boerne Lake	19.50	11,857	19.59	3,175	0.5%	-73.2%
C4010130A	D/S of Ranger Creek	27.70	13,958	27.82	10,589	0.4%	-24.1%
C4010146	U/S of Frederick Creek	33.20	15,731	33.43	17,256	0.7%	9.7%
C4010146A	D/S of Frederick Creek	49.76	23,513	50.47	24,110	1.4%	2.5%
C4010205	U/S of Curry Creek	52.22	25,528	52.92	25,653	1.3%	0.5%
C4010205A	D/S of Curry Creek	55.29	29,398	55.89	29,067	1.1%	-1.1%
C4010210	U/S of Menger Creek	55.77	28,863	56.39	28,202	1.1%	-2.3%
C4010210A	D/S of Menger Creek	62.52	36,762	63.13	34,879	1.0%	-5.1%
C4010231	U/S of Balcones Creek	76.32	44,856	76.89	39,638	0.8%	-11.6%
C4010231A	D/S of Balcones Creek	100.31	66,581	100.89	57,929	0.6%	-13.0%
C4010312	U/S of Pleasant Valley Creek	127.40	74,968	127.74	55,679	0.3%	-25.7%
C4010312A	D/S of Pleasant Valley Creek	149.68	82,659	150.01	58,945	0.2%	-28.7%
C4010403	U/S of Kelley Creek	153.84	82,839	154.24	56,274	0.3%	-32.1%
C4010403A	D/S of Kelley Creek	162.04	84,628	162.48	56,616	0.3%	-33.1%
C4010415	U/S of Meusbach Creek	165.00	85,101	165.43	55,547	0.3%	-34.7%
C4010415A	D/S of Meusbach Creek	174.76	87,577	175.28	55,947	0.3%	-36.1%
C4010423	U/S of Indian Creek	178.70	88,649	179.04	54,029	0.2%	-39.1%
C4010432A	D/S of Indian Creek	191.67	91,364	192.22	54,345	0.3%	-40.5%
C4010438	U/S of Lewis Creek	205.91	93,213	206.56	49,043	0.3%	-47.4%
C4010438A	D/S of Lewis Creek	228.38	96,716	228.92	48,975	0.2%	-49.4%
C4020123		265.09	99,049	266.59	40,076	0.6%	-59.5%
C4020123A		270.745	99,457	272.28	40,120	0.6%	-59.7%
C4020202		272.09	99,316	273.35	39,944	0.5%	-59.8%
C4020202A		280.20	99,823	280.67	40,017	0.2%	-59.9%
C4020214	U/S of Dietz Creek	284.88	99,413	285.46	39,645	0.2%	-60.1%
C4020214A		297.28	99,890	297.10	39,816	-0.1%	-60.1%
C4020244	U/S of Santa Clara Creek	311.85	98,769	315.19	38,285	1.1%	-61.2%

Baseline Existing peak flows were compared against effective values for SARA jurisdiction tributaries with at least one HEC-HMS node (see Table 2-10). These tributaries include: Balcones Creek, Rundale Creek, Unnamed Tributary to Rundale Creek, Meusebach Creek, Selma Creek, Tributary C to Selma Creek, Escondido Creek, Martinez Creek B, Tributary E to Martinez Creek B, Tributary F to Martinez Creek, and Woman Hollering Creek. The source of the effective contributing drainage areas and 1% AEP event peak flows is the Bexar County FIS (Federal Emergency Management Agency, 2010).

Table 2-10 Tributary Peak Flow Comparison

		Effective		*Baseline Existing*		*Comparison to Effective (% Difference)*	
HEC-HMS Node	**Location**	**Drainage Area (mi^2)**	**1% Peak Flow (ft^3/s)**	**Drainage Area (mi^2)**	**1% Peak Flow (ft^3/s)**	**Drainage Area**	**1% Peak Flow**
Balcones Creek							
C4010233	U/S of Rundale Creek	4.40	7,774	4.33	9,870	-1.6%	27%
C4010233A	D/S of Rundale Creek	8.44	14,259	8.36	18,682	-0.9%	31%
C4010237A	D/S of Toutant Beauregard Rd.	12.67	18,180	12.62	23,725	-0.4%	30%
C4010242	D/S of Old Fredricksburg Rd.	21.46	19,938	21.12	25,021	-1.6%	25%
C4010243	Mouth	24.14	18,995	24.00	23,009	-0.6%	21%
Rundale Creek							
C4010236	Mouth	4.05	6,568	4.04	8,836	-0.4%	35%
Unnamed Tributary to Rundale Creek							
4010235	Mouth	1.85	3,075	1.88	4,284	1.7%	39%
Meusebach Creek							
C4010417	At Blanco Road	6.37	9,267	6.63	10,357	4.0%	12%
C4010418A	900' U/S of Private Road	7.87	11,256	7.84	12,060	-0.4%	7%
C4010422	Mouth	9.84	13,493	9.85	14,892	0.1%	10%
Selma Creek							
4020203	U/S of Trib. E to Selma Creek	0.99	3,171	0.98	2,581	-1.1%	-19%
C4020205	D/S of Trib. E to Selma Creek	2.15	6,518	2.11	5,398	-1.7%	-17%
C4020205A	D/S of Arcadia Street	3.12	4,550	3.82	8,351	22.5%	84%
C4020208A	2000' D/S of IH35	4.80	6,700	5.47	9,794	13.9%	46%
Tributary C to Selma Creek							
4020204	Mouth	0.75	2,631	0.79	2,043	5.7%	-22%
Escondido Creek							
C4020535	IH-10 Main Lanes	0.00	0	1.95	3,407	0.0%	0%
C4020536	6,400' D/S of IH-10 East	3.65	6,448	3.58	6,002	-1.9%	-7%
Dam No. 3	Dam No. 3	3.65	1,644	3.58	2,093	-1.9%	27%
C4020537	Mouth	6.43	5,501	6.39	3,664	-0.6%	-33%

HEC-HMS Node	Location	*Effective*		*Baseline Existing*		*Comparison to Effective (% Difference)*	
		Drainage Area (mi^2)	**1% Peak Flow (ft^3/s)**	**Drainage Area (mi^2)**	**1% Peak Flow (ft^3/s)**	**Drainage Area**	**1% Peak Flow**
Martinez Creek							
C4020538	1,200' U/S of Walzem Road	1.80	5,428	1.81	5,794	0.8%	7%
C4020540	2,300' U/S of Dam No. 1	3.91	5,956	3.09	6,148	-21.1%	3%
Dam No. 1	Dam No. 1	6.11	1,767	6.14	1,964	0.4%	11%
C4020547	3,700' D/S of IH10 East	10.50	5,724	9.43	2,557	-10.2%	-55%
C4020551A	2,650' D/S of Schuwirth Road	16.00	9,316	15.07	9,324	-5.8%	0%
C4020556	500' D/S of FM 1518	28.04	10,247	28.81	11,842	2.8%	16%
C4020556A	2,300' D/S of FM 1518	59.07	16,964	58.55	20,711	-0.9%	22%
C4020601A	1,200' U/S of Miller Road	62.50	17,207	62.23	20,486	-0.4%	19%
C4020614A	5,200' U/S of Gable Road	80.35	25,903	80.03	30,413	-0.4%	17%
C4020620	Mouth	88.63	26,227	87.98	30,164	-0.7%	15%
Tributary E to Martinez Creek							
4020545	U/S of Dam No. 2	1.96	4,229	1.92	3,939	-1.8%	-7%
C4020546	Mouth	1.96	263	1.97	729	0.6%	177%
Tributary F to Martinez Creek							
4020542	FM 78	-	-	0.98	3,356	-	-
C4020543	Mouth	2.20	6,223	2.10	5,423	-4.6%	-13%

2.2.4.2. Baseline Future Theoretical Events

The Baseline Future Theoretical Event simulations required a total of 54 HEC-HMS simulations to produce Cibolo Creek watershed peak flows for the 50%, 10%, 4%, 2%, 1%, and 0.2% AEP events. Each simulation used the Baseline Future basin model presented in Section 2.2.1.2, the theoretical event control specifications presented in Section 2.2.3.1, and each of the 54 meteorological models presented in Section 2.2.2.1.

Compared to the Baseline Existing condition, the Baseline Future condition increased impervious values but did not modify any other components of the Baseline Existing model, including subbasin transformation parameters. The result is that, on a subbasin-level, the Baseline Future model generates subbasin hydrographs with more runoff volume than the Baseline Existing model with only minor increases to peak flow rates. The future condition of the watershed has an average impervious percentage of 20.6%, as opposed to 7.5% for the existing condition. The impervious percentage increases result in an average subbasin 1% annual chance event peak flow increase of 3.2% when comparing the future and existing condition.

Although on a subbasin-level the future condition develops only minor peak flow increases, on a watershed-level peak flow increases are more significant. The increased runoff volumes produced by the future condition has the effect of significantly increasing peak flows for more frequent storm events and for watersheds with large contributing drainage areas. Table 2-11 compares the 10% and 1% AEP event peak flows of Cibolo Creek for the existing and future condition. The table shows that future condition increases the 10% and 1% AEP event peak flows at the mouth of Cibolo Creek by 35.5% and 18.0%, respectively.

Table 2-11 Cibolo Creek Peak Flow Comparison (Existing-Future)

		Baseline Existing		*Baseline Future*		*Comparison to Upper Cibolo HEC-HMS (% Difference)*	
HEC-HMS Node	**Location**	**10% Peak Flow (ft^3/s)**	**1% Peak Flow (ft^3/s)**	**10% Peak Flow (ft^3/s)**	**1% Peak Flow (ft^3/s)**	**10% Peak Flow (ft^3/s)**	**1% Peak Flow**
4010101	Headwaters of Cibolo Creek	2,264	3,689	2,264	3,689	0.0%	0.0%
C4010107		6,738	11,166	6,738	11,166	0.0%	0.0%
C4010107A		11,014	18,766	11,014	18,766	0.0%	0.0%
C4010120A	Upstream of Boerne Lake	17,143	31,386	17,197	31,430	0.3%	0.1%
S4010122	Downstream Boerne Lake	459	3,175	460	3,433	0.2%	8.1%
C4010130A	D/S Ranger Creek	5,839	10,589	6,003	10,679	2.8%	0.9%
C4010146	U/S Frederick Creek	8,702	17,256	9,111	17,559	4.7%	1.8%
C4010146A	D/S Frederick Creek	11,365	24,110	11,787	24,451	3.7%	1.4%
C4010205A	D/S Curry Creek	13,764	29,067	14,343	29,484	4.2%	1.4%
C4010210	U/S Menger Creek	13,594	28,202	14,173	28,638	4.3%	1.5%
C4010210A	D/S Menger Creek	16,938	34,879	17,994	35,567	6.2%	2.0%
C4010231	U/S Balcones Creek	19,271	39,638	20,909	40,736	8.5%	2.8%
C4010231A	D/S Balcones Creek	27,479	57,929	30,189	59,952	9.9%	3.5%
C4010301A	D/S of Post Oak Creek	29,503	61,723	32,549	63,898	10.3%	3.5%
C4010312A	D/S Pleasant Valley Creek	28,639	58,945	32,317	61,598	12.8%	4.5%
C4010415A	D/S Meusebach Creek	26,468	55,947	30,421	58,496	14.9%	4.6%
C4010433	**US 281**	24,816	53,644	28,257	56,433	13.9%	5.2%
C4010438A	D/S Lewis Creek	22,213	48,975	25,687	52,086	15.6%	6.4%
C4020123A	D/S Bracken Tributary	17,336	40,120	20,410	43,189	17.7%	7.6%
C4020202	D/S Selma Creek	17,173	39,944	20,249	43,072	17.9%	7.8%
C4020213	**FM 78**	16,961	39,841	20,051	43,069	18.2%	8.1%
C4020214A	D/S Dietz Creek	16,695	39,816	19,818	43,058	18.7%	8.1%
C4020234	U/S of IH-10 Overflow	16,169	39,139	19,264	41,383	19.1%	5.7%
D4020234	Overlflow (Cibolo to IH-10 Trib.)	0	9,970	0	11,700	-	17.4%
C4020235	**IH-10**	16,148	39,073	19,246	41,349	19.2%	5.8%
C4020244	U/S Santa Clara Creek	15,478	38,285	18,507	41,491	19.6%	8.4%
C4020244A	D/S Santa Clara Creek	15,784	40,336	19,027	43,529	20.6%	7.9%
C4020621	U/S Martinez Creek	15,561	39,700	18,789	43,089	20.7%	8.5%
C4020621A	D/S Martinez Creek	21,969	47,681	25,845	50,744	17.6%	6.4%
C4030201	U/S Dry Hollow Creek	21,829	46,867	25,767	50,620	18.0%	8.0%
C4030201A	D/S Dry Hollow Creek	21,866	49,619	29,319	57,931	34.1%	16.8%
C4030222A	D/S Elm Creek	21,433	48,769	28,840	56,978	34.6%	16.8%
C4030408	U/S of FM 539 (Sutherland Springs)	21,159	48,262	28,483	56,187	34.6%	16.4%
C4030411	**U/S of US 87**	20,914	47,990	28,218	55,901	34.9%	16.5%
C4040103A	D/S Clifton Branch (Stockdale)	20,283	47,057	27,550	54,942	35.8%	16.8%
C4040503	**SH 123**	19,352	45,475	26,335	53,524	36.1%	17.7%
C4040508	Mouth Cibolo Creek	18,891	44,738	25,599	52,790	35.5%	18.0%

The future condition peak flow increases along the tributaries to Cibolo Creek are not as pronounced as the main stem. As seen in Table 2-12, Martinez Creek has a maximum peak flow increase of 16.8% and 8.7%

for the 10% and 1% AEP events, respectively. Escondido Creek has a maximum peak flow increase of 9.6% and 16.1% for the 10% and 1% AEP events, respectively. Balcones Creek has a maximum peak flow increase of 8.7% and 3.2% for the 10% and 1% AEP events, respectively. The remaining SARA tributaries have maximum peak flow increases for the 10% and 1% AEP event that are less than 3.4% and 8.1%, respectively. HEC-HMS node peak flow comparisons for all streams and frequencies may be found in Appendix A.

Table 2-12 SARA Tributaries Peak Flow Comparison (Exiting-Future)

		Baseline Existing		*Baseline Future*		*Comparison to Effective (% Difference)*	
HEC-HMS Node	**Location**	**10% Peak Flow (ft^3/s)**	**1% Peak Flow (ft^3/s)**	**10% Peak Flow (ft^3/s)**	**1% Peak Flow (ft^3/s)**	**10% Peak Flow**	**1% Peak Flow**
Balcones Creek							
C4010233	U/S of Rundale Creek	5,800	9,870	5,963	9,997	2.8%	1.3%
C4010233A	D/S of Rundale Creek	10,940	18,682	11,275	18,951	3.1%	1.4%
C4010237A	D/S of Toutant Beauregard Rd.	13,748	23,725	14,266	24,073	3.8%	1.5%
C4010242	D/S of Old Fredricksburg Rd.	13,409	25,021	14,340	25,663	6.9%	2.6%
C4010243	Mouth	11,628	23,009	12,634	23,751	8.7%	3.2%
Rundale Creek							
C4010236	Mouth	5,166	8,836	5,340	8,980	3.4%	1.6%
Unnamed Tributary to Rundale Creek							
4010235	Mouth	2,502	4,284	2,585	4,352	3.3%	1.6%
Meusebach Creek							
C4010417	At Blanco Road	5,552	10,357	5,651	10,534	1.8%	1.7%
C4010418A	900' U/S of Private Road	6,785	12,060	6,898	12,281	1.7%	1.8%
C4010422	Mouth	8,345	14,892	8,477	15,094	1.6%	1.4%
Selma Creek							
4020203	U/S of Trib. E to Selma Creek	1,597	2,581	1,620	2,600	1.4%	0.7%
C4020205	D/S of Trib. E to Selma Creek	3,337	5,398	3,400	5,450	1.9%	1.0%
C4020205A	D/S of Arcadia Street	5,095	8,351	5,221	8,454	2.5%	1.2%
C4020208A	2000' D/S of IH35	5,846	9,794	6,092	9,996	4.3%	2.1%
Tributary C to Selma Creek							
4020204	Mouth	1,263	2,043	1,295	2,069	2.6%	1.3%
Escondido Creek							
C4020535	IH-10 Main Lanes	2,081	3,407	2,122	3,441	0.0%	0.0%
C4020536	6,400' D/S of IH-10 East	3,566	6,002	3,647	6,068	2.5%	1.2%
Dam No. 3	Dam No. 3	233	2,093	251	2,397	9.6%	16.1%
C4020537	Mouth	2,180	3,664	2,221	3,713	3.8%	2.3%
Martinez Creek							
C4020538	1,200' U/S of Walzem Road	3,647	5,794	3,657	5,803	0.1%	0.0%

		Baseline Existing		*Baseline Future*		*Comparison to Effective (% Difference)*	
HEC-HMS Node	**Location**	**10% Peak Flow (ft^3/s)**	**1% Peak Flow (ft^3/s)**	**10% Peak Flow (ft^3/s)**	**1% Peak Flow (ft^3/s)**	**10% Peak Flow**	**1% Peak Flow**
C4020540	2,300' U/S of Dam No. 1	3,616	6,148	3,643	6,176	0.5%	0.3%
Dam No. 1	Dam No. 1	410	1,964	414	2,129	0.6%	6.1%
C4020547	3,700' D/S of IH10 East Access Road	1337	2557	1491	2747	9.6%	6.2%
C4020551A	2,650' D/S of Schuwirth Road	4966	9324	5337	9625	6.1%	2.6%
C4020556	500' D/S of FM 1518	5626	11842	6405	12753	16.6%	8.5%
C4020556A	2,300' D/S of FM 1518	10834	20711	12166	21986	13.8%	6.5%
C4020601A	1,200' U/S of Miller Road	10945	20486	12365	22186	14.4%	8.7%
C4020614A	5,200' U/S of Gable Road	16773	30413	18781	31746	13.7%	4.9%
C4020620	Mouth	15174	30164	17435	31886	16.8%	6.1%
Tributary E to Martinez Creek							
4020545	U/S of Dam No. 2	2,425	3,939	2,449	3,958	1.1%	0.5%
C4020546	Mouth	288	729	297	783	3.5%	8.1%
Tributary F to Martinez Creek							
4020542	FM 78	2,116	3,356	2,122	3,361	0.2%	0.1%
C4020543	Mouth	3,332	5,423	3,349	5,438	0.5%	0.3%

2.2.4.3. Baseline Existing Historical Events

The May 2013 and October 2015 storm events were simulated as part of the master plan. The simulations used the Baseline Existing basin model presented in Section 2.2.1.1, the theoretical event control specifications presented in Section 2.2.3.2, and the meteorological models presented in Section 2.2.2.2.

The results of the historical event simulations are discussed in Section 2.4.

2.3. Hydraulics

The hydraulic analysis for the Cibolo Watershed Master Plan, for the most part, utilized the HEC-RAS geometries of the effective studies and applied new steady flow files to these geometries based on results from the updated Cibolo Creek watershed HEC-HMS modelling. This was the situation for the streams within SARA's jurisdiction, where the models were developed for the 2007 Bexar County DFIRM update. The SARA jurisdiction models include:

- Balcones Creek
- Tributary G to Balcones Creek
- Meusebach Creek
- Rundale Creek
- Unnamed Tributary to Rundale Creek
- Escondido Creek
- Martinez Creek B
- Tributary F to Martinez Creek B
- Tributary E to Martinez Creek B
- Salitrillo Creek
- Tributary C to Selma Creek B
- Tributary D to Selma Creek B
- Woman Hollering Creek

On the main channel of Cibolo Creek there are multiple, many times overlapping, hydraulic models that were developed from differing topographic sources. As a result, Atkins consolidated the hydraulic simulations for the main channel of Cibolo Creek into two contiguous models, with the divide of these models located at the confluence with Martinez Creek. The Cibolo Creek hydraulic models had selected updates to channel geometry, channel n-values, and bridge and culvert configurations, in addition to steady flow updates.

This section discusses the development of the Lower Cibolo Creek hydraulic model, the Upper Cibolo Creek hydraulic model, and the hydraulic models within SARA's jurisdiction.

2.3.1. Lower Cibolo Creek

This section discusses the development of the HEC-RAS geometry data for Lower Cibolo Creek. It should be noted that the intent of the master plan was not to create new Cibolo Creek hydraulic models from scratch, but to leverage existing modeling and supplement the existing modeling with new topographic data where possible.

2.3.1.1. Geometry

The Lower Cibolo Creek hydraulic model is a conglomeration of three COE Study models (see Table 2-13) developed for Karnes County (LCiboloCr.prj), Wilson County (CiboloCreek.prj), and Guadalupe-Wilson County (Cibolo_Creek_DS.prj). Atkins started with Guadalupe-Wilson County model geometry and imported the other two model geometries into a single geometry file. There was an overlap in the Karnes and Wilson County models that resulted in seven repeated sections between sections 87,313 and 78,795. The overlapping sections appeared to be almost exact copies, with the one having less points (300 as compared to 450) in the cross section. The cross sections with 300 total points were kept to maintain consistency with upstream modeling. Reach lengths were updated for cross sections where model merging took place (XS 78,795 and 251,730).

Table 2-13 Available Lower Cibolo Creek Hydraulic Models

HEC-RAS Model	Jurisdiction(s)	Description	*Limits*	
			Upper	Lower
LCiboloCr.prj	Karnes County	COE Study by Halff Associates (2006)	Just U/S of FM 887	4,200 U/S of Mouth
CiboloCreek.prj	Wilson County	COE Study by Halff Associates	Elm Creek (La Vernia)	Just U/S of FM 887
Cibolo_Creek_DS.prj	Guadalupe-Wilson County	COE Study by Halff Associates (2008)	Martinez Creek	Elm Creek (La Vernia)

Atkins initially used the cross section locations of the combined Lower Cibolo HEC-RAS model and generated new cross section station-elevation data using the Master Plan DEM. However, within the limits of the Lower Cibolo HEC-RAS model, the Master Plan DEM produces cross sections that are coarser than the existing Cibolo Creek models. Consequently, the station-elevation data of the existing models were maintained.

Because the Lower Cibolo Creek hydraulic model was developed from three separate hydraulic models, Atkins decided to check and update various parameters, as necessary, to maintain consistency throughout the model. These parameters included:

- **Channel N-values**
- **Channel Bank Stations** – Banks stations were adjusted to maintain consistency in width and depth of the main channel within given reaches.

- **Expansion / Contraction Coefficients**
- **Ineffective Flow Areas** – Ineffective flow areas were checked in the vicinity of bridge and culvert crossings. Changes were made, as necessary, so the ineffective areas reflected a 1:1 contraction and 2:1 expansion of flow around flow restrictions. The elevation of ineffective areas were verified

2.3.1.1.1. Bridges / Culverts

No changes were made to the existing bridge configurations in the Lower Cibolo Creek hydraulic model.

2.3.1.2. Steady Flow Data

A total of four steady flow files were developed for the Lower Cibolo hydraulic model:

- Baseline Existing Flood Hazard - Contains profiles for the 50%, 10%, 4%, 2%, 1%, and 0.2% AEP events for the existing condition.
- Baseline Future Flood Hazard - Contains profiles for the 50%, 10%, 4%, 2%, 1%, and 0.2% AEP events for the future condition.
- Storage-Routing – Contains nine profiles that were used to develop Modified Puls routing relationships.
- Historical Event – Contains profiles for the May 2013 and October 2015 events

Each steady flow file is discussed below.

2.3.1.2.1. Baseline Existing Flood Hazard

A baseline condition flood hazard steady flow distribution for the main channel of Cibolo Creek was created from the baseline condition HEC-HMS results (see Section 2.2.4.1). The HEC-HMS node to HEC-RAS stream station relationship shown in Appendix A was used to develop the steady flow distribution. Peak flows were calculated for selected HEC-RAS cross-sections between nodes using a semi-log interpolation. It was attempted to achieve a maximum flow increase of 5% between interpolated 1% AEP event peak flows, although the distance between cross-sections caused the maximum flow increase to exceed 5% at several locations. These interpolated peak flows were adjusted to create the HEC-RAS steady flow distribution found in Appendix A.

The downstream reach boundary condition for the Baseline condition flood hazard model uses a normal depth slope of 0.002 ft/ft for all profiles.

2.3.1.2.2. Storage-Routing

The storage-routing steady flow file for Cibolo Creek includes nine (9) routing profiles. The peak flow for each profile is constant through each routing reach and is set as a percentage of the maximum 1% event peak flow expected in that reach. The profiles are 5%, 10%, 20%, 40%, 60%, 80%, 100%, 140%, and 300% of the maximum 1% AEP event peak flow.

The downstream reach boundary condition for the Baseline condition storage-routing steady flow file uses a normal depth slope of 0.002 ft/ft for all profiles.

2.3.1.2.3. Historical Events

A historical event steady flow file was created for the May 2013 and October 2015 events. The steady flow distribution was developed in the same manner and with the same flow change locations as the flood hazard steady flow distribution. The difference is that the historical steady flow file was developed from the historical event HEC-HMS simulation results (see Section 2.2.4.3).

2.3.1.3. Results

The section discusses the Lower Cibolo Creek hydraulic model results for the Baseline Existing and Baseline Future conditions.

2.3.1.3.1. Baseline Existing

This section compares the hydraulic results, specifically the 1% AEP event peak flood stages, of the Baseline Existing flood hazard model against effective values. Table 2-14 compares the Existing Baseline 1% AEP event peak flood stage against the values documented in the Wilson County and Guadalupe County FIS. Please note that the lower portion of Cibolo Creek in Wilson County and the entire reach of Cibolo Creek in Karnes County are mapped as "Approximate" by FEMA and do not document effective 1% AEP event peak flood stages. The table shows that the Baseline Existing 1% AEP event peak flood stages for Lower Cibolo Creek are significantly lower than effective values. These peak flood stage reductions are consistent with the fact that the Baseline Existing 1% AEP event peak flows are between 10.5% and 34.4% lower than effective values in Wilson County and between 10.9% and 29.4% lower than effective values in Guadalupe County.

Table 2-14 Lower Cibolo Peak Flood Stage Comparison (Effective vs. Baseline Existing)

HEC-RAS Station	Location	Effective 1% Peak Flood Stage (ft-NAVD88)	Baseline Existing 1% Peak Flood Stage (ft-NAVD88)	*Comparison (Difference-ft.)*
Wilson County				
307044	U/S Limit of County	524.7	519.4	-5.3
302406	U/S CR 440	518.3	513.1	-5.2
283703	D/S Scull Xing	500.2	497.8	-2.4
267287	U/S FM 775 (La Vernia)	477.8	474.8	-3.0
251730	D/S Limit of County	460.2	457.6	-2.6
Guadalupe County				
303216	XS "G"	522.4	515.4	-7.0
289541	XS "E"	507.2	500.6	-6.6
270237	XS "A"	482.9	479.5	-3.4

2.3.1.3.2. Baseline Future

Table 2-15 compares the Lower Cibolo Creek 10% and 1% AEP event peak flood stages for the Baseline Existing and Baseline Future conditions at selected locations. The comparison shows the future condition increases 10% and 1% AEP event peak flood stages at all locations. Within the Lower Cibolo Creek model, the future condition increases 10% AEP event peak flood stages by a minimum of 2.1 feet and a by a maximum of 3.9 feet. The future condition increases 1% AEP event peak flood stages by a minimum of 0.7 feet and a by a maximum of 1.4 feet. These peak flood stages are expected, as the future condition increases 10% AEP event peak flows between 18.1% and 34.8% within the model reach (see Table 2-11). Similarly, the future condition increases 1% AEP event peak flows between 7.3% and 18.9%.

Table 2-15 Lower Cibolo Peak Flood Stage Comparison (Baseline Existing vs. Baseline Future)

		Baseline Existing		*Baseline Future*		*Difference (ft)*	
HEC-RAS Station	**Location**	**10% Peak Flood Stage (ft-NAVD88)**	**1% Peak Flood Stage (ft-NAVD88)**	**10% Peak Flood Stage (ft-NAVD88)**	**1% Peak Flood Stage (ft-NAVD88)**	**10% Peak Flood Stage**	**1% Peak Flood Stage**
307044	D/S Martinez Creek	508.8	519.4	510.8	520.5	**2.1**	**1.1**
301832	CR 352/CR 440	502.3	513.0	504.4	513.9	**2.1**	**0.9**
284724	CR 347/CR 417	487.9	498.6	490.4	499.6	**2.5**	**1.0**
267058	Hwy 775	464.3	474.7	468.2	475.8	**3.9**	**1.1**
251087	C.R. 337	449.2	457.1	452.9	457.8	**3.8**	**0.7**
202165	FM 539	408.7	416.6	411.5	417.8	**2.7**	**1.2**
176421	US 87 (U/S)	388.2	396.0	390.9	397.4	**2.7**	**1.4**
176318	US 87 (D/S)	388.2	395.8	390.8	396.8	**2.7**	**1.0**
140167	FM 537	359.5	366.3	361.8	367.6	**2.2**	**1.3**
101033	FM 541	326.0	332.8	328.5	333.8	**2.5**	**1.0**
83035	Karnes-Wilson County Line	314.7	320.8	317.4	321.6	**2.7**	**0.8**
76686	FM 887	310.8	316.9	313.9	317.7	**3.1**	**0.8**
56645	SH 123	293.1	299.5	295.7	300.6	**2.6**	**1.1**
13657	SH 81	261.9	266.7	264.1	267.7	**2.2**	**1.0**
4756	Mouth	255.7	263.3	259.0	264.1	**3.3**	**0.8**

2.3.2. Upper Cibolo Creek

This section discusses the development of the HEC-RAS model for Upper Cibolo Creek. The development of the model's geometry, steady flow file, as well as the model results are presented.

2.3.2.1. Geometry Data

The Upper Cibolo Creek hydraulic model geometry was created by combining the geometries of three existing models (see Table 2-16). Atkins started with Bexar-Guadalupe County model geometry developed by the COE and imported the other two model geometries into a single geometry file. There was an overlap in the Bexar-Guadalupe and the Bexar-Comal models between cross section 471,196 and 471,492 (four cross sections and a bridge). The overlapping sections and bridge appeared to be exact copies, so the cross sections from the Bexar-Comal model were maintained.

Table 2-16 Available Upper Cibolo Creek Hydraulic Models

HEC-RAS Model	**Jurisdiction(s)**	**Description**	***Limits***	
			Upper	**Lower**
Lower_Cibolo_Creek.prj	Bexar - Guadalupe County	COE Study by Halff Associates (2006)	Just U/S of IH-10	Martinez Creek
Cibolo_Creek_Reach1.prj	Bexar - Guadalupe County		Lookout Road	Just U/S of IH-10
Cibolo_Creek_Reach2.prj	Bexar - Comal County		Fair Oaks Ranch	Lookout Road

The cross section stationing of the three Upper Cibolo Creek models (shown in Table 2-16) are compatible, meaning that, when merged, the single model has cross section stationing that matches the reach lengths of Cibolo Creek. However, the cross section stationing of the merged Upper Cibolo Creek hydraulic model and the merged Lower Cibolo Creek hydraulic model do not match where the two models meet (at Martinez Creek). To avoid the inconsistency in stationing, the Upper Cibolo Creek hydraulic model was re-stationed to begin at river station 0.

From Phase 1, it was known that the cross section geometry of the existing models of Upper Cibolo Creek do not match well with the project LiDAR. As a result, Atkins developed updated cross section station-elevation data for all the HEC-RAS cross sections using the project LiDAR dataset. All other parameters (n-values, ineffective areas, blockage obstructions, etc.) were maintained.

Comparisons also showed that the road profiles of bridge and culverts crossings didn't match well with the project LiDAR dataset. Atkins recut the bridge/culvert decks for eight existing crossings and added a new culvert crossing using the project LiDAR. Crossing configurations, such as low chord elevations, bridge spans, number and size of piers, and size and elevation of culverts were taken from the existing hydraulic models. Where aerial photography allowed, parameters such as culvert locations, deck width, and bridge span were corrected, as necessary.

Atkins reviewed and modified, as necessary, channel n-values, ineffective flow areas and expansion and contraction coefficients throughout the Upper Cibolo Creek hydraulic model.

The Upper Cibolo Creek hydraulic model contains four rivers reaches:

1. Cibolo Creek

2. Spill 1 – Models the overflow that occurs at an oxbow in Cibolo Creek just downstream of IH-10.

3. Spill 2 – Tributary of Cibolo Creek that receives extreme event overflows from Cibolo Creek just upstream of IH-10.

4. Spill 3 – Tributary of Spill 2 that receives overflow from Spill 2. The overflow occurs along the westbound frontage road of IH-10

2.3.2.2. Steady Flow Data

A total of four steady flow files were developed for the Upper Cibolo hydraulic model:

- Baseline Existing Flood Hazard - Contains profiles for the 50%, 10%, 4%, 2%, 1%, and 0.2% AEP events for the existing condition.
- Baseline Future Flood Hazard - Contains profiles for the 50%, 10%, 4%, 2%, 1%, and 0.2% AEP events for the future condition.
- Storage-Routing – Contains nine profiles that were used to develop Modified Puls routing relationships.
- Historical Event – Contains profiles for the May 2013 and October 2015 events

Each steady flow file is discussed below.

2.3.2.2.1. Baseline Existing Flood Hazard

A baseline existing condition flood hazard steady flow distribution for the Upper Cibolo Creek, which included Spill 1, Spill 2, and Spill 3, was created from the baseline existing condition HEC-HMS results (see Section 2.2.4.1). The HEC-HMS node to HEC-RAS stream station relationships shown in Appendix A was used to develop the steady flow distribution for the main channel of Upper Cibolo Creek, as well as Spill 2 and Spill 3. Peak flows were calculated for selected HEC-RAS cross-sections between nodes using a semi-log interpolation. It was attempted to achieve a maximum flow increase of 5% between interpolated 1% AEP event peak flows, although the distance between cross-sections caused the maximum flow increase to

exceed 5% at several locations. These interpolated peak flows were adjusted to create the HEC-RAS steady flow distributions found in Appendix A.

The steady flow relationship for Spill 1 was not developed directly from HEC-HMS results. Instead, the steady flows applied to Spill 1 were determined by balancing peak flood stages of Spill1 and Cibolo Creek. For a given profile, the flow split between Cibolo Creek (at Station 79594.1) and the most-upstream station of the Spill 1 (at Station 1362.3) was balanced to achieve peak flood stages that match within at least 0.5 feet.

The downstream reach boundary condition for the Baseline condition flood hazard model of Upper Cibolo Creek uses known water surface elevations that are specific to each profile. The known water surface elevation was calculated from the peak flood stage of the most-upstream cross section of the Lower Cibolo Creek hydraulic model (Station 307,044). Because there is approximately 652 feet between the most-downstream cross section of the Upper Cibolo model and the most-upstream of the Lower Cibolo model, the peak flood stage at Station 307,044 was increased by that cross section's Energy Grade Slope (ft/ft) multiplied by 652 feet.

2.3.2.2.2. Baseline Future Flood Hazard

The baseline future condition flood hazard steady flow distribution for the Upper Cibolo Creek, which included Spill 1, Spill 2, and Spill 3, was created from the baseline future condition HEC-HMS results (see Section 2.2.4.2). The baseline future steady flow distribution was developed with the same method as the baseline existing steady flow distribution, using the station versus HEC-HMS node relationships displayed in Appendix A.

2.3.2.2.3. Storage-Routing

The storage-routing steady flow file for Cibolo Creek includes nine (9) routing profiles. The peak flow for each profile is constant through each routing reach and is set as a percentage of the maximum 1% event peak flow expected in that reach. The profiles are 5%, 10%, 20%, 40%, 60%, 80%, 100%, 140%, and 300% of the maximum 1% event peak flow.

The downstream reach boundary condition for the Baseline condition storage-routing steady flow file uses a normal depth slope of 0.0014 ft/ft for all profiles.

2.3.2.2.4. Historical Events

A historical event steady flow file was created for the May 2013 and October 2015 events. The steady flow distribution was developed in the same manner and with the same flow change locations as the flood hazard steady flow distribution. The difference is that the historical steady flow file was developed from the historical event HEC-HMS simulation results.

2.3.2.3. Results

The section discusses the Upper Cibolo Creek hydraulic model results for the Baseline Existing and Baseline Future conditions.

2.3.2.3.1. Baseline Existing

This section compares the hydraulic results, specifically the 1% AEP event peak flood stages, of the Baseline Existing flood hazard model against effective values. Table 2-17 compares the Existing Baseline 1% AEP event peak flood stage against the values documented in the Guadalupe County, Bexar County and Comal County FIS. Although the peak flood stages from the various FIS documents are not the same, the comparison shows a consistent pattern. The table shows that the Baseline Existing 1% AEP event peak flood stages downstream of IH-10 are approximately 3 feet lower than effective values. Between IH-10 and IH-35 the Baseline Existing 1% AEP event peak flood stages are as much as 10 feet lower than effective values. Between IH-35 and FM 1863 the Baseline Existing 1% AEP event peak flood stages are as much as 11.6 feet lower than effective values. Between FM 1863 and US 281 the Baseline Existing 1% AEP event

peak flood stages are as much as 9.3 feet lower than effective values. Upstream of US 281 the Baseline Existing 1% AEP event peak flood stages are as much as 7.4 feet lower than effective values.

Table 2-17 Upper Cibolo Peak Flood Stage Comparison (Effective vs. Baseline Existing)

HEC-RAS Station	Location	Effective 1% Peak Flood Stage (ft-NAVD88)	Baseline Existing 1% Peak Flood Stage (ft-NAVD88)	*Comparison (Difference-ft.)*
Guadalupe County FIS				
171451.3	D/S of Lookout Road	763.0	752.6	**-10.4**
166843.8	U/S of IH-35 NBFR	755.7	745.7	**-10.1**
146980.9	U/S of Aviation Blvd	720.1	712.3	**-7.8**
133243	U/S of Pecan Grove	699.9	691.5	**-8.4**
118771.3	D/S of Schaefer Road	672.9	665.7	**-7.2**
101913.4	D/S of Lower Seguin Road	656.8	646.7	**-10.1**
80175.8	D/S of IH-10	618.8	615.9	**-2.9**
53346.94	U/S of Gin Road	586.2	583.7	**-2.5**
41640.67	U/S of Ulrich Road	570	566.8	**-3.2**
10055.85	D/S of FM 2538	537.4	534.7	**-2.7**
Bexar County FIS				
413602.5	U/S of Battle Intense Road	1,273.2	1,268.2	**-5.0**
406283.6	U/S of FM 3351	1258.3	1,254.0	**-4.3**
346681.4	U/S of Blanco Road	1134.8	1,127.4	**-7.4**
314294	U/S of US 281	1061.9	1,058.0	**-3.9**
289693.5	U/S of Smithson Valley Road	1018.8	1,011.8	**-7.0**
261524.4	U/S of FM 1863 (U/S)	964.3	955.0	**-9.3**
257579.7	U/S of FM 1863 (D/S)	958.8	947.2	**-11.6**
179366.2	Just D.S of FM 2252	775.9	766.4	**-9.5**
171560.2	U/S of Lookout Road	763.4	753.0	**-10.4**
166843.8	U/S of IH-35 NBFR	755.6	745.7	**-10.0**
146980.9	U/S of Aviation Blvd	720.2	712.3	**-7.9**
133243	U/S of Pecan Grove	700	691.5	**-8.5**
80893.35	U/S of IH-10 Mainlanes	621.6	617.9	**-3.7**
26412.8	Confluence-Santa Clara Creek	560.0	555.7	**-4.3**
Comal County FIS				
413602.5	U/S of Battle Intense Road	1273.1	1,268.2	**-4.9**
406283.6	U/S of FM 3351	1258.2	1,254.0	**-4.2**
346681.4	U/S of Blanco Road	1134.6	1,127.4	**-7.2**
314294	U/S of US 281	1062.2	1,058.0	**-4.2**
289693.5	U/S of Smithson Valley Road	1018.1	1,011.8	**-6.4**
261524.4	U/S of FM 1863 (U/S)	964.3	955.0	**-9.3**
257579.7	U/S of FM 1863 (D/S)	958.7	947.2	**-11.5**
179431	U/S of FM 2252	777.4	766.9	**-10.5**
171560.2	U/S of Lookout Road	763.3	753.0	**-10.3**

2.3.2.3.2. Baseline Future

Table 2-18 compares the Upper Cibolo Creek 10% and 1% AEP event peak flood stages for the Baseline Existing and Baseline Future conditions at selected locations. The comparison shows the future condition increases 10% and 1% AEP event peak flood stages at all locations, except just upstream of Ulrich Road. Within the Upper Cibolo Creek model, the future condition increases 10% AEP event peak flood stages by a maximum of 2.1 feet. The future condition increases 1% AEP event peak flood stages by a maximum of 1.0 feet. These peak flood stages are expected, as the future condition increases 10% and 1% AEP event peak flows at the downstream end of the Upper Cibolo hydraulic by 20.7% and 8.5%, respectively (see Table 2-11).

Table 2-18 Upper Cibolo Peak Flood Stage Comparison (Baseline Existing vs. Baseline Future)

		Baseline Existing		*Baseline Future*		*Difference (ft)*	
HEC-RAS Station	**Location**	**10% Peak Flood Stage (ft-NAVD88)**	**1% Peak Flood Stage (ft-NAVD88)**	**10% Peak Flood Stage (ft-NAVD88)**	**1% Peak Flood Stage (ft-NAVD88)**	**10% Peak Flood Stage**	**1% Peak Flood Stage**
413602.5	U/S of Battle Intense Road	1,262.7	1,268.2	1,263.4	1,268.4	**0.6**	**0.3**
406283.6	U/S of Ralph Fair Road	1,248.1	1,254.0	1,248.7	1,254.3	**0.6**	**0.3**
346681.4	U/S of Blanco Road	1,121.8	1,127.4	1,122.6	1,127.9	**0.8**	**0.4**
314294	U/S of US 281	1,051.7	1,058.0	1,052.7	1,058.5	**0.9**	**0.5**
289479.8	U/S of Smithson Valley Road	1,005.0	1,011.7	1,006.0	1,012.3	**1.0**	**0.6**
261462.9	U/S of FM 1863 (U/S)	949.0	954.9	950.0	955.5	**1.0**	**0.6**
257579.7	U/S of FM 1863 (D/S)	941.2	947.2	942.1	947.7	**1.0**	**0.5**
179431	U/S of FM 2252	761.0	766.9	762.0	767.5	**1.0**	**0.6**
171560.2	U/S of Lookout Road	746.7	753.0	747.6	753.8	**0.9**	**0.8**
166843.8	U/S of IH-35 SBFR	738.3	745.7	739.5	746.5	**1.2**	**0.8**
14960.53	U/S of Aviation Blvd.	530.8	540.2	532.8	541.2	**2.0**	**1.0**
133243	U/S of Pecan Grove Drive	684.2	691.5	685.4	692.3	**1.2**	**0.8**
118885.1	U/S of Schaefer Road	659.5	665.8	660.7	666.3	**1.2**	**0.6**
80964.75	U/S of IH-10 WBFR	611.6	618.1	613.4	618.7	**1.7**	**0.6**
53407.25	U/S of Gin Road	577.2	583.8	578.4	584.2	**1.2**	**0.4**
41614.69	U/S of Ulrich Road	562.2	567.2	563.6	566.8	**1.4**	-0.4
10255.19	U/S of FM 2538	525.4	535.8	527.5	536.2	**2.1**	**0.4**
73.82	U/S Martinez Creek	509.5	520.0	511.5	520.9	**2.0**	**0.9**

2.3.3. SARA Jurisdiction Models

The Cibolo Creek Holistic Watershed Master Plan developed Baseline Existing and Baseline Future condition hydraulic models for Cibolo Creek's tributaries within SARA Jurisdiction. These tributaries include:

- Balcones Creek
- Tributary G to Balcones Creek
- Rundale Creek
- Unnamed Tributary to Rundale Creek
- Meusebach Creek
- Tributary C to Selma Creek
- Tributary D to Selma Creek
- Escondido Creek (Upper)
- Escondido Creek (Lower)
- Martinez Creek B (Upper)
- Martinez Creek B (Lower)
- Salitrillo Creek
- Tributary E to Martinez Creek B
- Tributary F to Martinez Creek B
- Woman Hollering Creek

This section will discuss the development of these hydraulics models, as well as the resulting peak flood stages for Baseline Existing and Baseline Future condition.

It should be noted that a complete effective model for Selma Creek was not collected, therefore, hydraulic simulations were not performed for Selma Creek

2.3.3.1. Geometry Data

Atkins utilized the effective HEC-RAS geometries for the 15 SARA Jurisdiction models. No changes were made to the effective HEC-RAS geometries as part of this study, except for the Martinez Creek B (Upper) model. The railroad crossing just downstream of Gibbs Sprawl Road (HEC-RAS station 123596) within the effective model for Martinez Creek B (Upper) did not accurately reflect existing conditions. A field visit was conducted by Atkins on April 6, 2018 to confirm the railroads geometry.

To properly model the railroad crossing the bridge deck was expanded from 75 feet to 90 feet, and ineffective areas were added to provide a 1:1 contraction and 2:1 expansion of flows. The modelling approach was also changed to utilize a pressure method rather than an energy method.

2.3.3.2. Steady Flow Data

A maximum of four steady flow files were developed for the each of the SARA Jurisdiction models. Baseline Existing and Baseline Future Flood Hazard steady flow files were developed for each of the models. Modified Puls routing and historical event steady flow files were only developed for selected tributaries. Each steady flow file type is discussed below.

2.3.3.2.1. Baseline Existing Flood Hazard

A Baseline Existing condition flood hazard steady flow distribution for the 15 SARA Jurisdiction models was created from the baseline condition HEC-HMS results (see Section 2.2.4). The HEC-HMS node to HEC-RAS stream station relationships found in Appendix A were used to develop the steady flow distribution for the 15 SARA Jurisdiction models. Peak flows were calculated for selected HEC-RAS cross-sections between nodes using a semi-log interpolation. It was attempted to achieve a maximum flow increase of 5% between interpolated 1% AEP event peak flows, although the distance between cross-sections caused the maximum flow increase to exceed 5% at several locations. These interpolated peak flows were adjusted to create the HEC-RAS steady flow distributions found in Appendix A.

The majority of the SARA Jurisdiction models use a normal depth Downstream Reach Boundary Condition. Reach (see Table 2-19).

Table 2-19 SARA Jurisdiction Model Normal Depth Boundary Conditions (Baseline Existing)

Model	Downstream Boundary Condition	Normal Depth Slope
Balcones Creek	Normal Depth - All Profiles	0.002 ft/ft
Tributary G to Balcones Creek	Normal Depth - All Profiles	0.019 ft/ft
Rundale Creek	Normal Depth - All Profiles	0.012 ft/ft
Unnamed Tributary to Rundale Creek	Normal Depth - All Profiles	0.007 ft/ft
Meusebach Creek	Normal Depth - All Profiles	0.006 ft/ft
Tributary C to Selma Creek	Normal Depth - All Profiles	0.006 ft/ft
Tributary D to Selma Creek	Normal Depth - All Profiles	0.017 ft/ft
Escondido Creek (Lower)	Normal Depth - All Profiles	0.00256 ft/ft
Martinez Creek B (Lower)	Normal Depth - All Profiles	0.0013 ft/ft
Tributary E to Martinez Creek B	Normal Depth - All Profiles	0.00271 ft/ft
Salitrillo Creek	Normal Depth - All Profiles	0.0037182 ft/ft
Woman Hollering Creek	Normal Depth - All Profiles	0.005672 ft/ft

The downstream limit of three of the SARA Jurisdiction hydraulic models are located at reservoirs, making the normal depth downstream boundary condition not applicable for these tributaries. Instead, profile-specific downstream boundary conditions are set for these models based upon the peak stage in their receiving reservoir. The upper reach of Escondido Creek begins just upstream of SCS Dam #3. The Downstream Boundary Conditions for the upper reach of Escondido Creek may be see in Table 2-20. The upper reach of Martinez Creek B and the Tributary F to Martinez Creek B hydraulic models both begin just upstream of SCS Dam #1. The Downstream Boundary Conditions for upper reach of Martinez Creek B and the Tributary F to Martinez Creek B as the same and may be seen in Table 2-21.

Table 2-20 Upper Escondido Creek Starting Conditions (Baseline Existing)

Profile	Boundary Condition	Value
50% AEP	Known WSEL	636.09 feet
10% AEP	Known WSEL	636.11 feet
4% AEP	Known WSEL	636.34 feet
2% AEP	Known WSEL	636.87 feet
1% AEP	Known WSEL	637.36 feet
0.2% AEP	Known WSEL	638.46 feet

Table 2-21 Upper Martinez Creek B & Trib. F to Martinez Creek B Starting Conditions (Baseline Existing)

Profile	Boundary Condition	Value
50% AEP	Known WSEL	668.33 feet
10% AEP	Known WSEL	672.89 feet
4% AEP	Known WSEL	674.96 feet
2% AEP	Known WSEL	676.41 feet
1% AEP	Known WSEL	677.41 feet
0.2% AEP	Known WSEL	679.58 feet

2.3.3.2.2. Baseline Future Flood Hazard

Baseline Future condition flood hazard steady flow distributions for the 15 SARA Jurisdiction models were created from the Baseline Future condition HEC-HMS results (see Section 2.2.4.2). The HEC-HMS node to HEC-RAS stream station relationships presented in Section 2.3.3.2.1 also apply for the Baseline Future conditions. Peak flows were calculated for selected HEC-RAS cross-sections between nodes using a semi-log interpolation. It was attempted to achieve a maximum flow increase of 5% between interpolated 1% AEP event peak flows, although the distance between cross-sections caused the maximum flow increase to exceed 5% at several locations. These interpolated peak flows were adjusted to create the HEC-RAS steady flow distributions found in Appendix A.

The Baseline Existing normal depth starting conditions listed Table 2-19 are also applicable for the Baseline Future Condition. Table 2-22 presents the Baseline Future condition downstream starting condition for Upper Escondido Creek. Table 2-23 presents the downstream starting condition for Upper Martinez Creek B and Tributary F to Martinez Creek B.

Table 2-22 Upper Escondido Creek Starting Conditions (Baseline Future)

Profile	Boundary Condition	Value
50% AEP	Known WSEL	636.09 feet
10% AEP	Known WSEL	636.15 feet
4% AEP	Known WSEL	636.55 feet
2% AEP	Known WSEL	637.06 feet
1% AEP	Known WSEL	637.51 feet
0.2% AEP	Known WSEL	638.56 feet

Table 2-23 Upper Martinez Creek B & Trib. F to Martinez Creek B Starting Conditions (Baseline Future)

Profile	Boundary Condition	Value
50% AEP	Known WSEL	668.33 feet
10% AEP	Known WSEL	673.15 feet
4% AEP	Known WSEL	675.17 feet
2% AEP	Known WSEL	676.52 feet
1% AEP	Known WSEL	677.52 feet
0.2% AEP	Known WSEL	679.65 feet

2.3.3.2.3. Storage-Routing

The following SARA Jurisdiction streams have Modified Puls routing reaches in the Cibolo Creek watershed hydrologic model and, thus, required the development of a storage-routing simulation:

- Balcones Creek
- Rundale Creek
- Meusebach Creek
- Tributary C to Selma Creek
- Tributary D to Selma Creek
- Escondido Creek (Upper)
- Escondido Creek (Lower)
- Martinez Creek B (Upper)
- Martinez Creek B (Lower)
- Tributary E to Martinez Creek B
- Tributary F to Martinez Creek B
- Woman Hollering Creek

A storage-routing steady flow file was developed for these streams and includes nine (9) routing profiles. The peak flow for each profile is constant through each routing reach and is set as a percentage of the maximum 1% AEP event peak flow expected in that reach. The profiles are 5%, 10%, 20%, 40%, 60%, 80%, 100%, 140%, and 300% of the maximum 1% AEP event peak flow.

The downstream reach boundary condition for each stream is consistent with the boundary condition for the flood hazard simulation run presented in Section 2.3.3.2.1.

2.3.3.3. Results

The section presents the SARA Jurisdiction tributary hydraulic model results for the Baseline Existing and Baseline Future conditions.

2.3.3.3.1. Baseline Existing

As seen in Table 2-24, the Baseline Existing condition, in general, increases average 10% and 1% AEP event peak flood stages as compared to the compares the effective condition. Increases are expected as Table 2-10 shows that the Baseline Existing 1% AEP event peak flows are, in general, higher than the effective condition. However, it should be noted that the peak flow decreases on Tributary F to Martinez Creek and Lower Escondido Creek, as noted in Table 2-10, don't necessarily yield lower peak flood stages, as the methodology for applying hydrologic model peak flows to hydraulic models varied between the effective and Baseline Existing condition.

Table 2-24 SARA Tribs. Avg. Peak Flood Stage Change (Baseline Existing to Effective)

HEC-RAS Station	10% Peak Flood Stage Average Change* (ft)	1% Peak Flood Stage Average Change* (ft)
Balcones Creek	2.66	1.47
Tributary G to Balcones Creek	0.22	-0.01
Rundale Creek	1.14	0.86
Unnamed Tributary to Rundale Creek	1.46	1.03
Meusebach Creek	0.44	0.26
Tributary C to Selma Creek	1.48	1.83
Tributary D to Selma Creek	1.60	1.74
Escondido Creek (Lower)	-0.42	-0.44
Escondido Creek (Upper)	0.62	0.03
Martinez Creek B (Lower)	0.84	-0.03
Martinez Creek B (Upper)	0.42	0.45
Tributary E to Martinez Creek B	0.96	0.17
Tributary F to Martinez Creek B	0.60	0.43
Woman Hollering Creek	1.02	0.64

** - Positive values indicate that the Existing Baseline condition is higher than the effective condition.*

Detailed comparisons of Baseline Existing and Effective peak flood stages by modelled cross section may be found in Appendix A

2.3.3.3.2. Baseline Future

Baseline Future condition simulations were developed for each of the SARA Jurisdiction tributaries. Table 2-25 compares, for each tributary, the average 10% and 1% AEP event peak flood stage change between the Baseline Future and Baseline Existing condition. The table shows that, in general, the future condition causes only minor increases (less than 0.1 feet) to peak flood stages. The outliers are Balcones Creek and Lower Martinez Creek. Balcones Creek has an average 10% and 1% AEP event peak flood stage increase of 0.24 feet and 0.12 feet, respectively. Lower Martinez Creek has an average 10% and 1% AEP event peak flood stage increase of 0.45 feet and 0.33 feet, respectively.

Table 2-25 SARA Tribs. Avg. Peak Flood Stage Change (Baseline Existing to Baseline Future)

HEC-RAS Station	10% Peak Flood Stage Average Change* (ft)	1% Peak Flood Stage Average Change* (ft)
Balcones Creek	0.24	0.12
Tributary G to Balcones Creek	0.02	0.01
Rundale Creek	0.06	0.04
Unnamed Tributary to Rundale Creek	0.06	0.03
Meusebach Creek	0.03	0.03
Tributary C to Selma Creek	0.04	0.03
Tributary D to Selma Creek	-0.01	0.00
Escondido Creek (Lower)	0.05	0.09
Escondido Creek (Upper)	0.02	0.04
Martinez Creek B (Lower)	0.45	0.33
Martinez Creek B (Upper)	0.04	0.02
Tributary E to Martinez Creek B	0.01	0.01
Tributary F to Martinez Creek B	0.02	0.01
Woman Hollering Creek	0.09	0.04

* *- Positive values indicate that the Baseline Future condition is higher than the Baseline Existing condition.*

Appendix A contains tables for each SARA Jurisdiction Tributary that compare by cross section the peak flood stage differences for the Baseline Existing and Baseline Future conditions.

2.4. Model Calibration

This section presents the results of the May 2013 and October 2015 historical event simulations and the calibration of the hydrologic model against observed data for these historical events. Modeled results are compared against overserved peak flows, hydrographs and peak flood stages.

2.4.1. Peak Flows

There are seven USGS stream gages on the main channel of Cibolo Creek and one on Martinez Creek that provide observed flow measurements. The resulting peak flow results from the USGS flow observations were compared against simulated peak flows for the May 2013 in Table 2-26.

Table 2-26 Simulated vs. Observed Peak Flows (May 2013)

Location	USGS Gage	HEC-HMS Node	Stream Sta.	*May 25-27, 2013 Event*		
				Simulated Peak Flow (cfs)	*Obs. Peak Flow (cfs)*	*Difference (%)*
Cibolo Creek						
SH 123	08186000	C4040503	56391	20014	*2850*	602%
FM 539	08185500	C4030411	202165	20126	*2800*	619%
IH 10	08185065	C4020235	380709	18466	*6940*	166%
Lookout Road	08185000	C4020201	471196	19737	*12000*	64%
Smithson Valley Road	08184050	C4010437	589245		-	
D/S of Boerne	08183900	C4010210A		9304	*2980*	212%
Cibolo Nature Center	08183890	C4010210		7356	*888*	728%
Martinez Creek						
N. Gable Road	08185100	C4020616	16602	6772	1270	433%

The simulated peak flow results are significantly higher than the observed USGS values at all gage locations. It should be noted that the simulated peak flows are higher than observed values even though increased infiltration losses (see Section 2.2.1.1.2) and channel losses (see Section 2.2.1.1.5) were introduced to the hydrologic model.

Observed and simulated peak flows compare just as poorly for the October 2015 event, with exception of the USGS gages are Smithson Valley Road and Lookout Road. As seen in Table 2-27, simulated peak flow rates are within 14% and 23% of observed peak flow rates at these locations. Furthermore, the simulated peak flow rate at IH-10 yields resulting peak flood stages that match well with observed highwater marks obtained by Atkins (see Section 2.4.3). This fact puts into question the accuracy of the observed flows from the USGS gage at IH-10.

Table 2-27 Simulated vs. Observed Peak Flows (October 2015)

				Oct 2015 Events		
Location	**USGS Gage**	**HEC-HMS Node**	**Stream Sta.**	*Simulated Peak Flow (cfs)*	*Obs. Peak Flow (cfs)*	*Difference (%)*
Cibolo Creek						
SH 123	08186000	C4040503	56391	31431	*7870*	299%
FM 539	08185500	C4030411	202165	31030	*12100*	156%
IH-10	08185065	C4020235	380709	28855	*8470*	241%
Lookout Road	08185000	C4020201	471196	28923	*37600*	-23%
Smithson Valley Road	08184050	C4010437	589245	33902	*39230*	-14%
D/S of Boerne	08183900	C4010210A		11852	*2400*	394%
Cibolo Nature Center	08183890	C4010210		9516		
Martinez Creek						
N. Gable Road	08185100	C4020616	16602	10016	1930	419%

The Balcones Escarpment, which is the downstream limit where channel infiltration is expected along Cibolo Creek, is located between the USGS gages at Smithson Valley Road and Lookout Road. Atkins was unable to increase channel losses and infiltration rates within the Recharge Zone such that observed peak flow rates were matched at USGS gages 08186000 (SH 123) or 08185500 (FM 539). The only way to achieve simulated peak flows similar to observed USGS values would be to introduce channel infiltration downstream of the Balcones Escarpment and downstream of Lookout Road. Channel infiltration was not added downstream of Lookout Road, as this is inconsistent with current knowledge of channel infiltration in the area.

2.4.2. Hydrographs

As part of the calibration process Atkins compared the simulated HEC-HMS hydrographs against the observed USGS hydrographs at multiple locations. Figure 2-6 presents the simulated versus observed hydrographs on Cibolo Creek for the May 2013 event. The general shape of the observed and simulated hydrographs match at the upper limits of Cibolo Creek, even though the volume beneath the hydrographs do not match. Downstream of IH-10 the simulated hydrographs peaks earlier than the observed results.

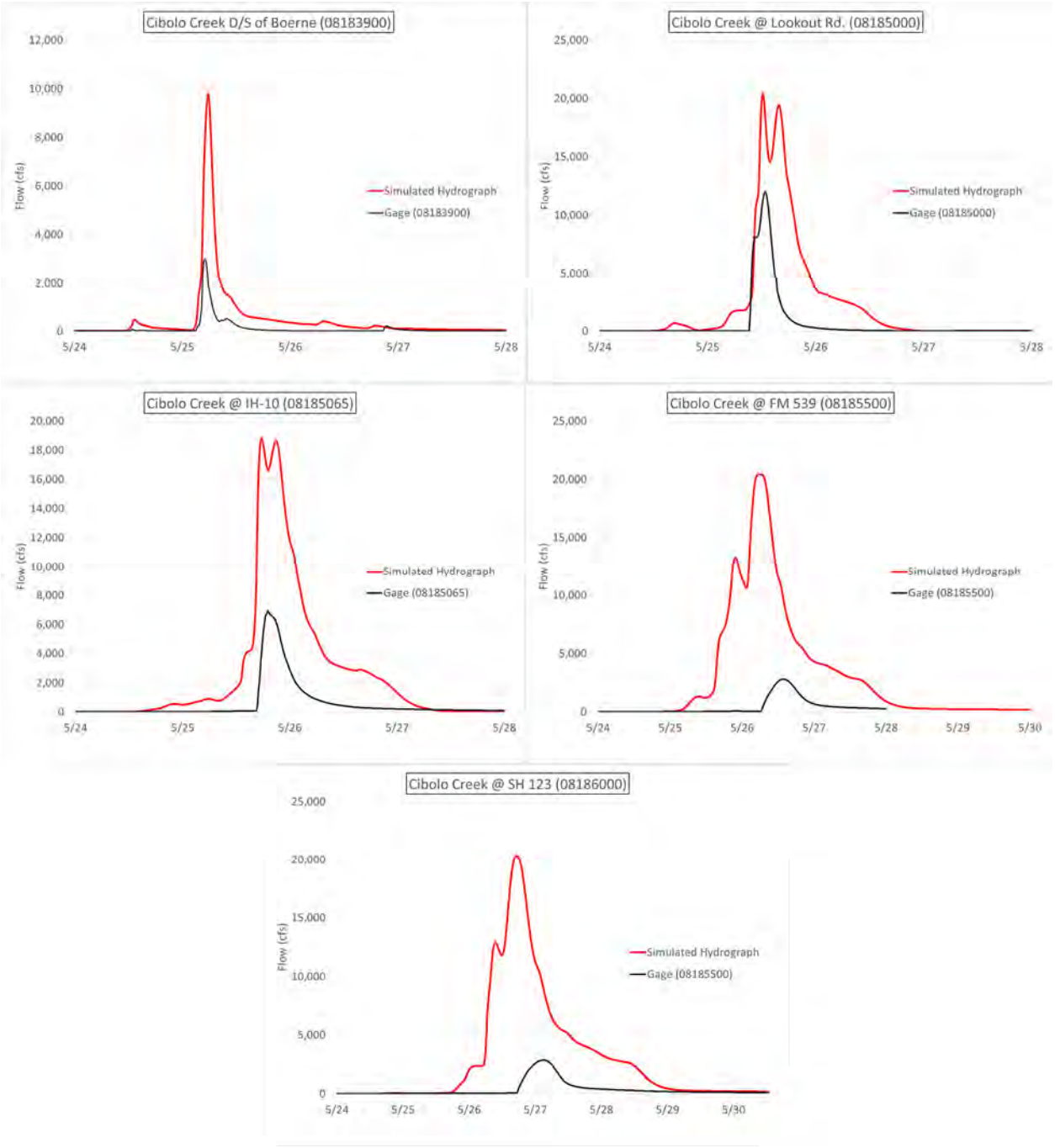


Figure 2-6 Cibolo Creek Simulated vs. Observed Flows (May 2013)

Table 2-28 shows the large discrepancy in the simulated and observed hydrograph volumes. The maximum difference is at the USGS gage at FM 539 and Cibolo Creek where the simulated hydrograph volume is 2,341% larger than the observed value.

Table 2-28 Simulated vs. Observed Hydrograph Volumes (May 2013)

				May 25-27, 2013 Event		
Location	**USGS Gage**	**HEC-HMS Node**	**Stream Sta.**	*Simulated Volume (ac-ft)*	*Obs. Volume (ac-ft)*	*Difference (%)*
Cibolo Creek						
SH 123	08186000	C4040503	56391	34,553	*1,707*	1924%
FM 539	08185500	C4030411	202165	36,468	*1,494*	2341%
IH 10	08185065	C4020235	380709	21,188	*1,665*	1173%
Lookout Road	08185000	C4020201	471196	18,101	*1,656*	993%
Smithson Valley Road	08184050	C4010437	589245		-	
D/S of Boerne	08183900	C4010210A		3,923	*167*	2244%
Cibolo Nature Center	08183890	C4010210				
Martinez Creek						
N. Gable Road	08185100	C4020616	16602			

As seen below in Figure 2-7, there are seven locations along Cibolo Creek and one location on Martinez Creek where observed USGS hydrographs were compared against simulated hydrograph for the October 2015 storms. Like the May 2013 event, the shape of the observed and simulated hydrographs match well in the upper reaches of the watershed. However, also like the May 2013 event, the volume of the simulated and observed hydrographs do not match. As seen in Figure 2-8, simulated and observed hydrographs don't compare well on Martinez Creek either. It should also be pointed out that, besides the gage at Boerne, the other USGS gages hardly register any flow resulting from the first major event in October (24th-25th). The simulated storm event shows significant runoff at all gage locations for the October 24th-25th event.

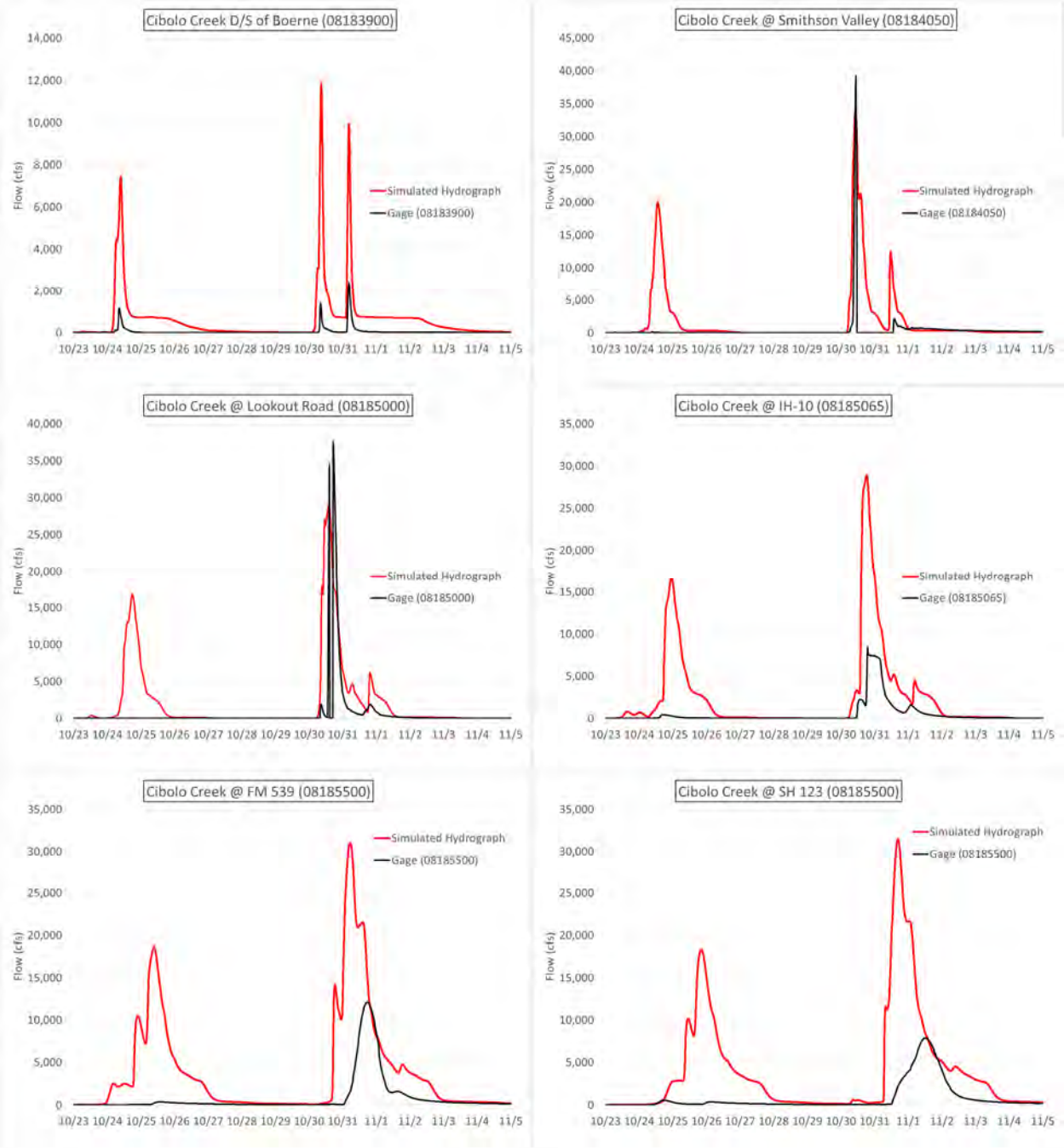


Figure 2-7 Cibolo Creek Simulated vs Observed Flows (October 2015)

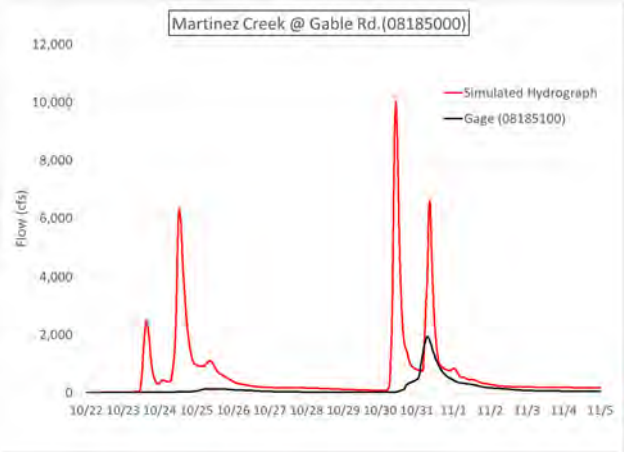


Figure 2-8 Martinez Creek Simulated vs Observed Flows (October 2015)

2.4.3. Peak Flood Stages

Atkins collected highwater marks along Cibolo Creek immediately after the October 2015 storm events. On November 3rd and 4th, 2015 Atkins noted debris lines at multiple locations along Cibolo Creek. The elevation of these highwater marks were estimated by measuring from nearby bridges or estimated using LiDAR data. It is understood that these highwater marks are approximate; however, at a minimum, the highwater marks provide another source to either support or disprove the USGS gage data.

As seen in Table 2-29, a total of nine highwater marks were collected. The table provides the approximate HEC-RAS stream station at the highwater mark location, the observed stage (highwater mark), the simulated peak stage from the October 2015 hydraulic simulation, as well as the difference between the simulated and observed stages. The table shows that, in general, the simulation produces stages that are too high in the upper reaches of the model (near Blanco Road), produces stages that are consistent with observations near US 281, and produces stages that are too low near Smithson Valley Road and FM 2252. At IH-10 the model produces stages that are consistent with observations. It should be noted that the observation at IH-10 was felt to be the most accurate of the collected highwater marks, as low chord of the IH-10 mainlane bridge provided defined elevation reference point to estimate the elevation of the highwater mark.

Table 2-29 Cibolo Creek Simulated vs. Observed Stages (October 2015)

HEC-RAS Station	Description	Observed Peak Stage (ft)	Simulated Peak Stage (ft)	Difference (ft)
346681.4	Blanco Road	1119.3	1120.9	1.6
336191.7	10,500' D/S of Blanco Road	1096.2	1097.7	1.5
324578.5	10,500' U/S of US 281	1077.75	1077.1	-0.7
323863.8	9,800' U/S of US 281	1075.5	1075.7	0.2
289444.8	Smithson Valley Road	1010.3	1008.1	-2.2
179351.2	FM 2252	766.1	763.9	-2.2
171560.2	Lookout Road	750.7	749.9	-0.8
166594.3	IH-35 Southeast Frontage Road	745.7	741.9	-3.8
80944.75	IH-10 Mainlanes	616.39	617.0	0.6

2.4.4. Calibration Results

After evaluating the observed data (USGS flow gage, USGS stage gage and Atkins collected high water marks) it was determined that an expansion of the channel infiltration limits and a reduction in the standard infiltration rate from the SARB Water Quality Modeling Standards was justified (Section 2.2.1.1.5). Prior to the expansion of the channel loss limits and reduction of the channel rates, simulated peak stages matched well with observed values near Blanco Road. However, simulated values were lower than observed values near US 281, and much lower than observed values from Smithson Valley Road to IH-35 (see Table 2-30).

Table 2-30 Cibolo Creek Simulated vs. Observed Stages Prior to Calibration (October 2015)

HEC-RAS Station	Description	Peak Stage (ft)	Simulated Stage (ft)	Difference (ft)
346681.4	Blanco Road	1119.3	1120.0	0.7
336191.7	10,500' D/S of Blanco Road	1096.2	1096.4	0.2
324578.5	10,500' U/S of US 281	1077.75	1075.7	-2.1
323863.8	9,800' U/S of US 281	1075.5	1074.2	-1.3
289444.8	Smithson Valley Road	1010.3	1005.7	-4.6
179351.2	FM 2252	766.1	760.5	-5.6
171560.2	Lookout Road	750.7	746.0	-4.7
166594.3	IH-35 Southeast Frontage Road	745.7	737.0	-8.7
80944.75	IH-10 Mainlanes	616.39	615.1	-1.3

The observed stages on Cibolo Creek help justify the observed USGS peak flows at Smithson Valley Road and Lookout Road. Conversely, the observed stages also point out that the USGS observed peak flow at IH-10 is likely much too low. For the October 2015 event, the USGS gages at Smithson Valley Road and Lookout Road appear to have failed to collect readings. It is assumed that the gage at IH-10 also failed during the October 2015 event and did not measure the true peak stage (or flow) of the event.

October 2015 observed stages were not collected on Martinez Creek, or on lower reaches of Cibolo Creek, where the gage results show significantly less flow than predicted by the simulations.

2.5. Damage Assessment

The goal of the Phase 2 flood risk analysis is to identify flood risk throughout the watershed for the Baseline (Existing and Future) condition. In Phase 3, potential solutions will target these flood risks, as well as areas with water quality concerns, or areas that have channel restoration or recreation potential. For the analysis, flood risk is identified in terms of flooded buildings, estimated annual damages, and dangerous crossings. This section discusses the location and intensity of flood risk in the Cibolo Watershed, as well as the methodology used to make the flood risk identification.

2.5.1. Flooded Buildings

The number of buildings that can potentially be flooded during a storm event was determined by comparing HEC-RAS peak flood stages against a structure database, which is unique to each stream, that contains points to represent individual buildings. Each building point has associated appraisal data, an assumed finished floor elevation, an associated stream, and the stream station of the building point in relation to the associated stream.

2.5.1.1. Methodology

Each structure database was created by first collecting the various appraisal district parcel shapefiles and associated databases. Next, each parcel was converted to a point, with each point representing a building. Each building point retained its appraisal data. Building points outside the effective 0.2% AEP event floodplain were removed and manual clean-up was performed by moving some points to align with buildings shown in aerial photography. Once the location of building points was finalized, the natural ground elevation below each point was determined from the project's LiDAR dataset. The finished floor of each building was assumed to be 0.5 feet above the natural ground elevation. Finally, each point was associated with a stream station.

Excel was used to associate the HEC-RAS results to each structure database. The structure database was imported into Excel and a peak flood stage was interpolated for each building for each profile in the HEC-RAS results. For each building and each profile the spreadsheet determined if the building's finished floor was overtopped by the event, and if so, the depth of flooding.

2.5.1.2. Results

The number of flooded structures were estimated for the Baseline Existing and Baseline Future condition for the main channel of Cibolo Creek and the SARA tributaries. Table 2-31 displays the results for the Baseline Existing condition and Table 2-32 displays the results for the Baseline Future condition. The tables document, by stream, the number of buildings flooded by each storm event, as well as the total number of buildings in the structure database.

As seen in Table 2-31, there are 4 structures flooded by the 50% AEP event, 18 flooded by the 10% AEP event and 142 flooded by the 1% AEP event. A significant number of 1% AEP event flooded structures are located along Upper Cibolo Creek (55), Lower Cibolo Creek (24) and Lower Martinez Creek (17).

Table 2-31 Flooded Structures (Baseline Existing)

Stream	Number of Flooded Buildings (by Annual Chance Event)					
	50%	10%	4%	2%	1%	0.2%
Cibolo Creek Upper	0	2	7	16	55	223
Cibolo Creek Lower	0	0	1	6	24	95
Balcones Creek	0	3	4	7	8	11
Meusebach Creek	0	0	0	0	0	1
Martinez Creek B Upper	1	4	11	18	28	97
Martinez Creek B Lower	1	5	11	13	17	20
Escondido Creek - Upper	1	2	2	2	4	8
Salitrillo Creek	0	0	1	1	1	3
Trib. F to Martinez Creek B	0	0	0	0	0	1
Woman Hollering Creek	1	2	2	4	5	8
Total	**4**	**18**	**39**	**67**	**142**	**467**

The number of flooded structures were also estimated for Baseline Future condition. As seen in Table 2-32, there are 6 structures flooded by the 50% AEP event, 21 flooded by the 10% AEP event and 165 flooded by the 1% AEP event. As with the Baseline Existing condition, a significant number of 1% AEP event flooded structures come from Upper Cibolo Creek (63). Lower Cibolo Creek (38) and Lower Martinez Creek (18).

Table 2-32 Flooded Structures (Baseline Future)

Stream	Number of Flooded Buildings (by Annual Chance Event)					
	50%	10%	4%	2%	1%	0.2%
Cibolo Creek Upper	0	3	13	31	63	283
Cibolo Creek Lower	0	0	9	24	38	116
Balcones Creek	0	4	4	7	8	11
Meusebach Creek	0	0	0	0	0	1
Martinez Creek B Upper	1	4	11	18	28	97
Martinez Creek B Lower	2	6	12	15	18	21
Escondido Creek - Upper	1	2	2	2	4	8
Salitrillo Creek	0	0	1	1	1	3
Trib. F to Martinez Creek B	0	0	0	0	0	1
Woman Hollering Creek	2	2	2	4	5	8
Total	**6**	**21**	**54**	**102**	**165**	**549**

2.5.2. Estimated Annual Damages

The number of flooded structures and their values were used to estimate the estimated annual damages in the watershed. This section presents the damage estimates, as well as the methodology for developing the estimated annual damages.

2.5.2.1. Methodology

The first step in the development of estimated annual damages was to calculate single event damages for the 50%, 10%, 4%, 2%, 1% and 0.2% AEP events. To do this the depth of flooding at individual buildings was determined for the six modelled storm events. The damage to each building, in terms of percentage of building value, was calculated using a depth-damage curve (Table 2-33) for short-duration flooding of on-slab single story structures from the U.S. Army Corps of Engineers (Gulf Engineers & Consultants, 2006). The percent damage value was multiplied by the structure's value to determine the damage to the structure for a given event.

Table 2-33 Depth-Damage Curve

Flood Level Relative to First Floor (ft)	% Damage of Structure
0	9.9%
0.5	27.1%
1	32.4%
1.5	34.0%
2	37.4%
3	42.0%
4	53.9%
5	58.5%
6	60.9%
7	61.3%
8	65.9%
9	71.3%
10	72.1%
11	72.2%
12	72.2%
13	72.6%
14	72.6%
15	72.6%

The single event damages for studied streams within the Cibolo Creek watershed were calculated for Baseline Existing and Baseline Future conditions, as seen in Table 2-34 and Table 2-35, respectively.

Table 2-34 Single Event Damages (Baseline Existing)

Stream	Single Event Damages (by Annual Chance Event)					
	50%	10%	4%	2%	1%	0.2%
Cibolo Creek Upper	$0	$22,832	$132,259	$279,541	$762,931	$6,447,022
Cibolo Creek Lower	$0	$0	$15,864	$34,530	$211,793	$1,755,980
Balcones Creek	$0	$28,497	$56,953	$88,546	$305,340	$604,314
Meusebach Creek	$0	$0	$0	$0	$0	$695
Martinez Creek B Upper	$1,420	$15,786	$62,036	$130,063	$208,263	$1,197,174
Martinez Creek B Lower	$3,651	$104,701	$186,165	$256,256	$346,483	$524,639
Escondido Creek - Upper	$37,094	$51,079	$61,482	$68,003	$112,531	$216,334
Salitrillo Creek	$0	$0	$5,829	$12,792	$13,339	$19,375
Trib. F to Martinez Creek B	$0	$0	$0	$0	$0	$14,179
Woman Hollering Creek	$3,879	$60,436	$67,198	$167,565	$219,120	$414,406
Total	**$46,043**	**$283,330**	**$587,786**	**$1,037,296**	**$2,179,799**	**$11,194,119**

Table 2-35 Single Event Damages (Baseline Future)

Stream	Single Event Damages (by Annual Chance Event)					
	50%	10%	4%	2%	1%	0.2%
Cibolo Creek Upper	$0	$46,224	$165,899	$417,410	$1,088,556	$9,242,414
Cibolo Creek Lower	$0	$0	$48,885	$203,780	$428,549	$2,364,563
Balcones Creek	$0	$42,350	$59,132	$94,554	$349,490	$611,635
Meusebach Crek	$0	$0	$0	$0	$0	$698
Martinez Creek B Upper	$1,420	$15,812	$62,330	$130,249	$208,898	$1,210,638
Martinez Creek B Lower	$9,463	$121,889	$213,364	$279,370	$391,392	$532,894
Escondido Creek - Upper	$37,130	$51,807	$61,905	$68,068	$113,745	$217,805
Salitrillo Creek	$0	$0	$7,291	$12,916	$13,512	$19,904
Trib. F to Martinez Creek B	$0	$0	$0	$0	$0	$14,449
Woman Hollering Creek	$28,195	$62,176	$67,586	$171,715	$220,581	$419,846
Total	**$76,208**	**$340,257**	**$686,393**	**$1,378,062**	**$2,814,722**	**$14,634,847**

Estimated annual damages (EAD) were calculated for each channel and for the entire Cibolo Creek watershed for the Baseline Existing and Baseline Future conditions using the equation below.

Equation 2-10

$$EAD = \left((1-50\%) * \frac{50\%\ Dmg}{2}\right) + \left((50\%-10\%) * \frac{50\%\ Dmg + 10\%\ Dmg}{2}\right) + \left((10\%-4\%) * \frac{10\%\ Dmg + 4\%\ Dmg}{2}\right) + \left((4\%-2\%) * \frac{4\%\ Dmg + 2\%\ Dmg}{2}\right) + \left((2\%-1\%) * \frac{2\%\ Dmg + 1\%\ Dmg}{2}\right) + \left((1\%-0.2\%) * \frac{1\%\ Dmg + 0.2\%\ Dmg}{2}\right)$$

Where:

EAD = Estimated Annual Damages
50% Dmg = Single Event Damage for 50% Annual Chance Event
10% Dmg = Single Event Damage for 10% Annual Chance Event
4% Dmg = Single Event Damage for 4% Annual Chance Event
2% Dmg = Single Event Damage for 2% Annual Chance Event
1% Dmg = Single Event Damage for 1% Annual Chance Event
0.2% Dmg = Single Event Damage for 0.2% Annual Chance Event

Table 2-36 presents the Baseline Existing EAD for each of the studied streams in the watershed. The Baseline Existing EAD for the entire watershed is $5,950,089, with approximately 65% of the damages coming from Upper Cibolo Creek, Lower Martinez Creek, and Upper Escondido Creek.

Table 2-36 Estimated Annual Damages (Baseline Existing)

Stream	Estimated Annual Damages (EAD) ($)	Present Value (PV) ($)
Cibolo Creek Upper	$47,389	($1,489,145)
Cibolo Creek Lower	$10,083	($316,831)
Balcones Creek	$15,326	($481,595)
Meusebach Creek	$3	($87)
Martinez Creek B Upper	$15,365	($482,820)
Martinez Creek B Lower	$42,232	($1,327,073)
Escondido Creek - Upper	$33,798	($1,062,047)
Salitrillo Creek	$623	($19,564)
Trib. F to Martinez Creek B	$57	($1,782)
Woman Hollering Creek	$24,477	($769,144)
Total	**$189,351**	**($5,950,089)**

Table 2-37 presents the Baseline Future EAD for each of the studied streams in the watershed. The Baseline Existing EAD for the entire watershed is $7,684,678 or 29% greater than the Baseline Existing EADs. Approximately 63% of the future EADs comes from Upper Cibolo Creek, Lower Martinez Creek, and Upper Escondido Creek.

Table 2-37 Estimated Annual Damages (Baseline Future)

Stream	Estimated Annual Damages (EAD) ($)	Present Value (PV) ($)
Cibolo Creek Upper	$70,295	($2,208,931)
Cibolo Creek Lower	$18,327	($575,910)
Balcones Creek	$19,116	($600,693)
Meusebach Creek	$3	($88)
Martinez Creek B Upper	$15,445	($485,339)
Martinez Creek B Lower	$50,672	($1,592,307)
Escondido Creek - Upper	$34,016	($1,068,912)
Salitrillo Creek	$687	($21,576)
Trib. F to Martinez Creek B	$58	($1,816)
Woman Hollering Creek	$35,932	($1,129,106)
Total	**$244,551**	**($7,684,678)**

2.5.3. Dangerous Crossings

Crossings along the main channel of Cibolo Creek and the SARA Jurisdiction streams were evaluated to determine if they were safe for the six simulated flood events. After the initial dangerous crossing counts were made the crossings were prioritized by calculating for each a dangerous crossing factor (DCF), Average Daily Traffic (ADT), and the distance to the nearest safe crossing. This section presents the analysis results and the methodology for identifying and prioritizing dangerous crossings.

2.5.3.1. Methodology

The City of San Antonio Unified Development Code (UDC) (City of San Antonio, Texas, 2016) identifies a threshold overtopping depth and velocity above which crossings may be considered dangerous (Figure 504-2 “Dangerous Conditions on Crossings During Floods”) (see Figure 2-9). Below the depth-velocity threshold the crossings are considered “safe”. For the master plan Atkins modified the UDC criteria by only considering crossings “safe” when they are not overtopped. Crossings that are overtopped but still below the “dangerous” threshold of Figure 2-9 were considered to be in the “caution” zone.

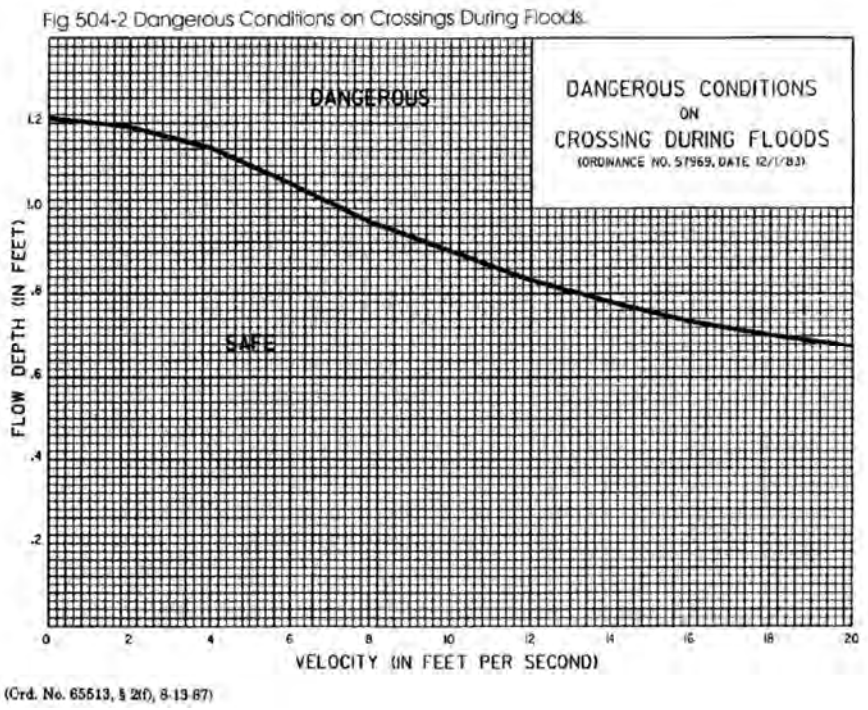


Figure 2-9 Dangerous Crossing Criteria

The 98 stream crossings of Cibolo Creek and the SARA jurisdictional streams were analysed for the Baseline Existing and Baseline Future conditions. The overflow depth and the overflow velocity were calculated for each of these crossings for the 50%, 10%, 4%, 2%, 1% and 0.2% AEP events. Based upon the calculated velocity a “safe” depth was determined from Figure 2-9. The calculated overflow depth was divided by the “safe” depth to determine a Safe Depth Ratio (SDR) value for each crossing and each storm event. The SDR value was used to assign a category of either safe, caution or dangerous for each crossing and each storm event based upon Table 2-38. A higher SDR value indicates a more dangerous crossing.

Table 2-38 Categories Based on Safe Depth Ratio

Safe Depth Ratio	Category
$X \leq 0$	Safe
$0 < X < 1$	Caution
$X \geq 1$	Dangerous

2.5.3.2. Results

This section discusses the results for how many crossings are deemed dangerous for each stream and the dangerous crossing factor (DCF) value calculated for each stream within the Cibolo Creek Watershed.

2.5.3.2.1. Dangerous Crossing Counts

As seen in Table 2-39, 42% of the 98 crossings are considered "dangerous" during the 50% AEP event. 45% of the crossings are dangerous during the 10% AEP event and 63% of the crossings are dangerous during the 1% AEP event. The Flood Risk (Damages) Workmap shows the location of each analysed crossing and identifies the least frequent storm event in which each crossing is considered safe.

Table 2-39 Dangerous Crossings (Baseline Existing)

Stream	Total Crossings	*# of Dangerous Crossings by Event*					
		50%	10%	4%	2%	1%	0.20%
Cibolo Creek (Upper)	23	12	12	12	12	12	13
Cibolo Creek (Lower)	15	5	6	10	10	11	13
Balcones Creek	10	8	8	8	8	8	8
Tributary G to Balcones Creek	0	0	0	0	0	0	0
Rundale Creek	0	0	0	0	0	0	0
Unnamed Tributary to Rundale Creek	0	0	0	0	0	0	0
Meusebach Creek	1	0	0	0	1	1	1
Selma Creek	-	-	-	-	-	-	-
Tributary C to Selma Creek	1	0	0	0	0	0	0
Tributary D to Selma Creek	1	0	0	0	0	0	0
Escondido Creek (Upper)	3	0	0	0	1	1	2
Escondido Creek (Lower)	5	3	3	3	4	5	5
Martinez Creek B (Upper)	7	1	1	2	3	4	5
Martinez Creek B (Lower)	11	4	4	4	4	5	8
Tributary E to Martinez Creek B	1	1	1	1	1	1	1
Tributary F to Martinez Creek B	3	0	0	1	1	2	3
Salitrillo Creek	4	0	0	0	0	0	4
Woman Hollering Creek	13	7	9	11	12	12	13
Total =	**98**	**41**	**44**	**52**	**57**	**62**	**76**
		42%	*45%*	*53%*	*58%*	*63%*	*78%*

Dangerous crossings were also analyzed for the Baseline Future condition. As seen in Table 2-40, 42% of the 98 crossings are considered "dangerous" during the 50% AEP event. 49% of the crossings are dangerous during the 10% AEP event and 65% of the crossings are dangerous during the 1% AEP event.

Table 2-40 Dangerous Crossings (Baseline Future)

Stream	Total Crossings	*# of Dangerous Crossings by Event*					
		50%	10%	4%	2%	1%	0.20%
Cibolo Creek (Upper)	23	12	12	12	12	12	13
Cibolo Creek (Lower)	15	5	9	10	11	12	14
Balcones Creek	10	8	8	8	8	8	8
Tributary G to Balcones Creek	0	0	0	0	0	0	0
Rundale Creek	0	0	0	0	0	0	0
Unnamed Tributary to Rundale Creek	0	0	0	0	0	0	0
Meusebach Creek	1	0	0	0	1	1	1
Selma Creek	-	-	-	-	-	-	-
Tributary C to Selma Creek	1	0	0	0	0	0	0
Tributary D to Selma Creek	1	0	0	0	0	0	0
Escondido Creek (Upper)	3	0	0	0	1	1	2
Escondido Creek (Lower)	5	3	3	4	4	5	5
Martinez Creek B (Upper)	7	1	1	2	3	4	5
Martinez Creek B (Lower)	11	4	4	4	4	5	8
Tributary E to Martinez Creek B	1	1	1	1	1	1	1
Tributary F to Martinez Creek B	3	0	0	1	1	2	3
Salitrillo Creek	4	0	0	0	0	1	4
Woman Hollering Creek	13	7	10	11	12	12	13
Total =	**98**	**41**	**48**	**53**	**58**	**64**	**77**
		42%	*49%*	*54%*	*59%*	*65%*	*79%*

2.5.3.2.2. Dangerous Crossing Factor (DCF)

Table 2-39 and Table 2-40 display the number of dangerous crossing problems on a stream and watershed level. However, to better distinct which crossings are more dangerous a dangerous crossing factor (DCF) was calculated. DCF is a value that represents the number of times in a given year the crossing will be subject to a "dangerous" event. DCF is calculated similarly to EAD (Equation 2-10):

$$DCF = \left((1-50\%)*\frac{SDR_{50\%}}{2}\right)+\left((50\%-10\%)*\frac{SDR_{50\%}+SDR_{10\%}}{2}\right)+\left((10\%-4\%)*\frac{SDR_{10\%}+SDR_{4\%}}{2}\right)$$
$$+\left((4\%-2\%)*\frac{SDR_{4\%}+SDR_{2\%}}{2}\right)+\left((2\%-1\%)*\frac{SDR_{2\%}+SDR_{1\%}}{2}\right)$$
$$+\left((1\%-0.2\%)*\frac{SDR_{1\%}+SDR_{0.2\%}}{2}\right)$$

Where:

DCF = *Dangerous Crossing Factor*
$SDR_{50\%}$ = *Safe Depth Ratio for 50% Annual Chance Event*
$SDR_{10\%}$ = *Safe Depth Ratio for 10% Annual Chance Event*
$SDR_{4\%}$ = *Safe Depth Ratio for 4% Annual Chance Event*
$SDR_{2\%}$ = *Safe Depth Ratio for 2% Annual Chance Event*
$SDR_{1\%}$ = *Safe Depth Ratio for 1% Annual Chance Event*
$SDR_{0.2\%}$ = *Safe Depth Ratio for 0.2% Annual Chance Event*

DCF was calculated for each crossing, and then the individual DCF values were summed together to calculate an overall DCF value for each stream for the Baseline Existing and Baseline Future condition. Table 2-41 below displays the calculated DCF for all stream models within the Cibolo Creek Watershed. The $DCF_{Baseline}$ value, which is the average between the $DCf_{Baseline\ Existing}$ and $DCF_{Baseline\ Future}$ values, was calculated to be 205.95 for the entire watershed.

Table 2-41 Dangerous Crossing Factor (Baseline Existing vs. Baseline Future)

Stream	Total Crossings	$DCF_{Baseline\ Existing}$	$DCF_{Baseline\ Future}$	$DCF_{Baseline}$
Cibolo Creek (Upper)	23	69.64	79.28	74.46
Cibolo Creek (Lower)	15	45.77	57.31	51.54
Balcones Creek	10	40.35	42.44	41.39
Tributary G to Balcones Creek	0	0.00	0.00	0.00
Rundale Creek	0	0.00	0.00	0.00
Unnamed Tributary to Rundale Creek	0	0.00	0.00	0.00
Meusebach Creek	1	0.22	0.23	0.23
Selma Creek	0	0.00	0.00	0.00
Tributary C to Selma Creek	1	0.00	0.00	0.00
Tributary D to Selma Creek	1	0.00	0.00	0.00
Escondido Creek (Upper)	3	0.29	0.30	0.29
Escondido Creek (Lower)	5	4.73	4.84	4.78
Martinez Creek B (Upper)	7	1.97	1.98	1.97
Martinez Creek B (Lower)	11	8.54	8.93	8.73
Tributary E to Martinez Creek B	1	1.25	1.26	1.26
Tributary F to Martinez Creek B	3	0.35	0.36	0.35
Salitrillo Creek	4	0.06	0.08	0.07
Woman Hollering Creek	13	20.62	21.11	20.87
Total	**98**	**193.80**	**218.10**	**205.95**

2.5.3.3. Dangerous Crossing Prioritization

A prioritized list of dangerous crossings is needed to develop specific crossing improvements under Phase 3 of the Master Plan. This section discusses 3 different factors used to help prioritize the 98 crossings within the Cibolo Creek Watershed.

2.5.3.3.1. Dangerous Crossing Factor (DCF)

A component of the prioritization is the calculation of the DCF value for each crossing. With each crossing having its own DCF value, the crossing with the highest DCF value was deemed the most dangerous while the crossing with the lowest DCF value was deemed the least dangerous.

2.5.3.3.2. Average Daily Traffic (ADT)

For a crossing to be dangerous it must be:

1. Overtopped at some frequency; and,
2. Subject to vehicular or pedestrian traffic during an overtopping event.

Although it is impossible to predict the frequency that the two above events will occur at a particular crossing, Average Daily Traffic (ADT) can indicate when these two events are more likely to occur. Atkins

made the assumption that, when two crossings are equal, the crossing with the higher ADT will also have the higher potential for danger.

As a result, Atkins estimated the Average Daily Traffic (ADT) at each of the evaluated crossings. ADT values were taken from the following sources:

- 2017 Bexar County Traffic Counts
- 2013-2017 City of San Antonio Traffic Counts
- 2013 TxDOT San Antonio District Traffic Maps

It should be noted that ADT values were not available for some crossings. In these cases ADT was assumed based upon the counts of nearby roadways. In addition, the following assumptions were made regarding ADT:

- A maximum ADT value of 50,000 was used to avoid major highways and interstates skewing the results.
- Private driveways were given an ADT value of 5.
- ADT remains constant between the existing and future condition.

2.5.3.3.3. Distance to Safe Crossing (DSC)

Another factor used to prioritize crossings is the distance to a safe crossing (DSC) on the same stream. As with ADT, the DSC may indicate the likelihood that traffic will attempt to utilize an overtopped stream crossing. Atkins made the assumption that, when two crossings are equal, the crossing that is further from a "safe" crossing on the same stream will have a higher likelihood of traffic attempting to cross during flooding events and, therefore, a higher potential for danger.

For this calculation a "safe" crossing is a stream crossing that is considered "safe" during the 10% AEP event. The distance (straight line) to the nearest safe crossing on the same stream was measured for each crossing. The following assumptions were also made regarding DSC:

- A maximum distance of 30,000 feet was used to avoid skewing the results.
- Crossings with no other "safe" crossing alternates were given a distance of 30,000 feet
- DSC remains constant between the existing and future condition.

2.5.3.3.4. Prioritization Results

The DCF, ADT and DSC values for each crossing were used to prioritize the crossings for the existing condition. All three factors were normalized (Equation 2-11) to achieve DCF, ADT and DSC values between 0 and 5. A value of 0 for all three factors indicates the least dangerous (least Dangerous Crossing Factor, least Average Daily Traffic, and the least Distance to Safe Crossing). A value of 5 for all three factors indicates the most dangerous (highest Dangerous Crossing Factor, highest Average Daily Traffic, and the largest Distance to Safe Crossing).

Equation 2-11

$$x_{norm} = (5 - 0) \times \left(\frac{x_i - \min(x)}{\max(x) - \min(x)}\right)$$

The normalized DCF, ADT and DSC values for each crossing were used to calculate a score for each crossing (Equation 2-12) for the existing condition. A higher score indicates a more dangerous crossing.

Equation 2-12

$$Dangerous\ Crossing\ Score = (0.45 \times DCF_{norm}) + (0.35 \times ADT_{norm}) + (0.2 \times DSC_{norm})$$

Using Equation 2-12, a list of the top 20 most dangerous crossings was generated. Table 2-42 below displays the top 20 most dangerous crossings within the Cibolo Creek Watershed.

Table 2-42 Prioritized Dangerous Crossings

Rank	Crossing	River	Station	DCF	ADT	DSC	$DCF_{Normal.}$	$ADT_{Normal.}$	$DSC_{Normal.}$	Dangerous Crossing Score
1	CR 352/CR 440	Cibolo Creek (Lower)	301,806	13.58	1,500	26,170	4.70	0.15	4.36	3.04
2	CR 347/CR 417	Cibolo Creek (Lower)	284,704	14.48	1,500	14,336	5.00	0.15	2.39	2.78
3	FM 537	Cibolo Creek (Lower)	140,088	8.00	680	29,029	2.65	0.07	4.84	2.18
4	FM 2538	Cibolo Creek (Upper)	10,227	7.29	752	26,279	2.42	0.08	4.38	1.99
5	FM 1863 (U/S)	Cibolo Creek (Upper)	261,494	5.75	2,922	28,066	1.98	0.29	4.68	1.93
6	Battle Intense Road	Cibolo Creek (Upper)	413,569	6.06	1,000	28,000	2.13	0.10	4.67	1.93
7	FM 3351	Cibolo Creek (Upper)	406,235	3.86	8,953	30,000	1.31	0.90	5.00	1.90
8	IH-10 East	Escondido Creek (Upper)	29,883	0.22	45,541	5,284	0.08	4.55	0.88	1.81
9	Blanco Road	Cibolo Creek (Upper)	346,639	5.63	2,560	23,983	1.96	0.26	4.00	1.77
10	Bexar Bowling	Cibolo Creek (Upper)	53,377	9.10	630	8,539	3.19	0.06	1.42	1.74
11	FM 1863 (D/S)	Cibolo Creek (Upper)	257,530	4.08	2,922	29,862	1.41	0.29	4.98	1.73
12	Lookout Road	Cibolo Creek (Upper)	171,532	8.98	1,600	3,870	3.15	0.16	0.65	1.60
13	Smithson Valley Road	Cibolo Creek (Upper)	289,587	6.59	1,355	15,451	2.26	0.14	2.58	1.58
14	Toutant Beuregard Road	Balcones Creek	49,753	5.39	493	16,791	1.97	0.05	2.80	1.46
15	FM 2724	Cibolo Creek (Lower)	23,022	8.12	500	7,161	2.54	0.05	1.19	1.40
16	Putter Road	Martinez Creek B (Upper)	115,687	0.15	27,000	8,723	0.05	2.70	1.45	1.26
17	Blanco Road	Meusebach Creek	14,500	0.23	1,951	30,000	0.08	0.20	5.00	1.11
18	Old Fredericksburg Road	Balcones Creek	19,798	5.87	869	3,835	2.09	0.09	0.64	1.10
19	N. Gable Road	Martinez Creek B (Lower)	16,632	4.87	92	7,872	1.79	0.01	1.31	1.07
20	Boerne Stage Road	Balcones Creek	31,924	4.84	1,687	5,590	1.73	0.17	0.93	1.02

3. Water Quality

3.1. Overview

3.1.1. Purpose and Scope

The purpose of this section of the report is to describe the development and results of the HSPF hydrologic and water quality model developed for Cibolo Creek. The model is built upon the hydraulic parameterization and basin delineation of the HEC-HMS and HEC-RAS modeling used in the Flood Risk (Chapter 2) portion of this analysis. Like the Flood Risk analysis, the Water Quality analysis identifies damage reaches and water quality damage centers. Using the HEC-HMS basins as the starting point for both hydraulic and water quality modeling efforts provides an additional synergy to the damage center analysis and a direct linkage to proposed best management practices to improve identified flooding and water quality conditions at the sub-catchment level.

3.1.2. Simulation Approach

The approach to the HSPF model was to start with the highly detailed basin delineation framework and hydraulic parameterization of the Flood Risk modeling performed for Cibolo Creek and integrate that level of detail into the HSPF model. Then using previous HSPF models generated in and around the Cibolo Creek watershed, segment the river into logical homogeneous hydrologic segments and parameterize the different watershed characterizations as a function of the watershed land uses. The generation of stormwater runoff, interflow and baseflow was then transferred to stream segments and routed down to Cibolo Creek's confluence with the San Antonio River.

The HSPF model, developed by EPA simulates both water quantity and water quality conditions. Utilizing watershed characteristics and physical configuration of river reaches, the HSPF model transforms applied rainfall into stream inputs while tracking losses to evaporation and the aquifer. In addition to water quantity, HSPF simulates the detachment and routing of sediments from the land surface into and down the stream. Sediment particles can contain nutrients components broken into individual forms of sand, silt, and clay. Other water quality parameters simulated include temperature, biological oxygen demand (BOD), dissolved oxygen (DO), total suspended solids (TSS), nutrients, chlorophyll-a, bacteria, lead and zinc.

The model was simulated for the continuous simulation period between 2000 and July 2016 to cover a range of data and river conditions, providing a longer-term perspective on water quality conditions in the river. As a future effort, the model results can be transformed into inputs of the ERPRIv1 model developed by the USACE. The ERPRiv1 model provides more detailed in-stream hydraulic control than HSPF often necessary to better simulate the river dynamics of varying cross sections.

The development of the HSPF model involved three distinct phases of development and calibration including, hydrologic/hydraulic model development, integration and simulation of sediment loads, and the simulation of other water quality parameters. These three phases of development served to first calibrate the quantity of water entering and flowing through Cibolo Creek. The water balance calibration was followed by a calibration of the sediment load. Sediments were separated as a distinct step, because portions of many of the remaining water quality parameters are linked to or directly impacted by the sediment load. Finally, input parameters are tweaked to calibrate the remaining water quality parameters. The sections that follow contain a discussion of the inputs and calibration of these three model development phases and results.

3.2. Hydrologic / Hydraulic Modeling

HSPF can track water movement from rainfall, through the soil column as well as losses to groundwater and evaporation. This section of the report describes the model inputs and calibration of water flows in Cibolo Creek.

3.2.1. Data Compilation

Building upon the Cibolo Creek Watershed Holistic Master Plan Phase I Report data collection efforts, the data compilation in this phase of the modeling involved transforming those inputs into inputs specific to the HSPF program.

3.2.1.1. Rainfall

Rainfall data provided by EPA's BASINS system provided the primary hydrologic input into the HSPF model. To extend the data to include more recent dates than are available through BASINS, daily data from NOAA at these stations were disaggregated to hourly using the closest nearby data from the North American Land Data Assimilation System (NLDAS) to provide the distribution pattern. Missing periods were filled using data from these NLDAS stations as well. For the Randolph station, recent NOAA data was not available, so data from the San Antonio Airport was used and then filled using NLDAS. Figure 3-1 displays the Rainfall stations along with polygons noting which portion of the watershed will be allocated to each station. Table 3-1 summarizes each rainfall station and available station statistics.

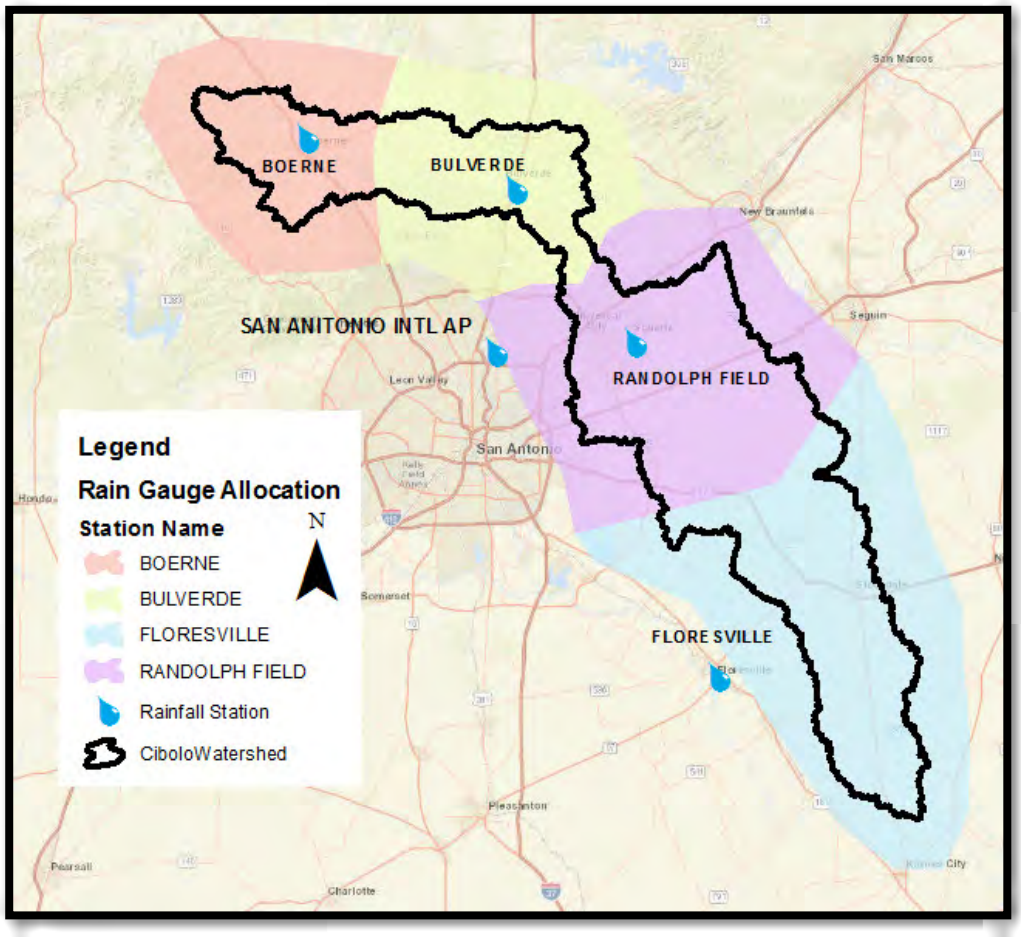


Figure 3-1 Rain Gauges Used in Cibolo Creek HSPF Model Simulations

Table 3-1 Cibolo Creek Rainfall Stations

ID	Name	Parameter Used	Begin Date
410902	Boerne	Rainfall	12/2/1931
411215	Bulverde	Rainfall	5/1/1988
417422	Randolph Field	Rainfall	11/1/1940
413201	Floresville	Rainfall	5/31/1916
417945	San Antonio Intl AP	Rainfall Radiation, Cloud Cover, Dewpoint, Temperature, Wind, Solar	8/31/1946

3.2.1.2. Evaporation

Input potential evapotranspiration data was provided by EPA's BASINS system, and then the period of record was extended using more recent data from NOAA. To extend the data, potential evapotranspiration at each rain gauge was estimated based upon the Hamon method in BASINS, using daily minimum and maximum air temperatures as input. For two of the stations, Bulverde and Randolph, air temperature at the San Antonio Airport was used as input due to lack of data at these stations from NOAA. The calculation results were compared to NOAA Technical Report NWS 33 (Farnsworth, Thompson, & Peck, NOAA Technical Report NWS 33 : Evaporation Atlas for the Contiguous 48 United States, 1982), NOAA Technical Report NWS 34 (Farnsworth & Thompson, 1982) and NOAA evaporation calculations for Texas. These comparisons indicated that historically, the calculated evaporation was between 1.4 and 1.2 times lower the NOAA measured data for the Cibolo Creek Watershed. To adjust the input potential evapotranspiration, a factor of 1.3 was applied to the calculated evaporation loss over each land use.

3.2.1.3. Air Temperature, Dew Point, solar radiation, cloud cover, and wind speed

Data for dew point temperature, solar radiation, cloud cover, and wind speed were obtained from the San Antonio Airport station. This station represented the longest continuous source of data for these parameters and is in acceptable proximity to all points within the watershed. Data was obtained from BASINS and then extended/disaggregated using NOAA data similar to the procedure used for rainfall parameter.

3.2.1.4. Flow Stations

Throughout the watershed, along the main stem of Cibolo Creek and in Martinez Creek, USGS gauging stations continuously measured flow conditions in the creek. Figure 3-2 shows the location of the USGS gauges used in the model calibration and Table 3-2 shows various statistics for each gauge. Note stations with end dates of 12/15/2016 reflect the extent of the data captured as part of this modeling analysis, however at the time of the writing of this report, each of these stations remains active.

Table 3-2 Cibolo Creek USGS Gauging Stations

Gage	Name	Contributing Watershed (sq miles)	Begin Date	End Date
08183850	Cibolo Ck nr Boerne, TX	30	5/23/1996	5/9/2007
08183890	Cibolo Ck at Cibolo Nature Cntr nr Boerne, TX	56	11/9/2005	12/5/2013
08183900	Cibolo Ck nr Boerne, TX	63	3/1/1962	12/15/2016
08184050	Cibolo Ck at Smithson Valley Rd nr Bulverde, TX	203	12/6/2010	12/15/2016
08185000	Cibolo Ck at Selma, TX	273	4/1/1946	12/15/2016
08185065	Cibolo Ck nr Saint Hedwig, TX	306	12/8/2005	12/15/2016
08185100	Martinez Ck nr Saint Hedwig, TX	83	11/16/2005	12/15/2016
08185500	Cibolo Ck at Sutherland Springs, TX	655	7/1/1924	12/15/2016
08186000	Cibolo Ck nr Falls City, TX	825	10/1/1930	12/15/2016

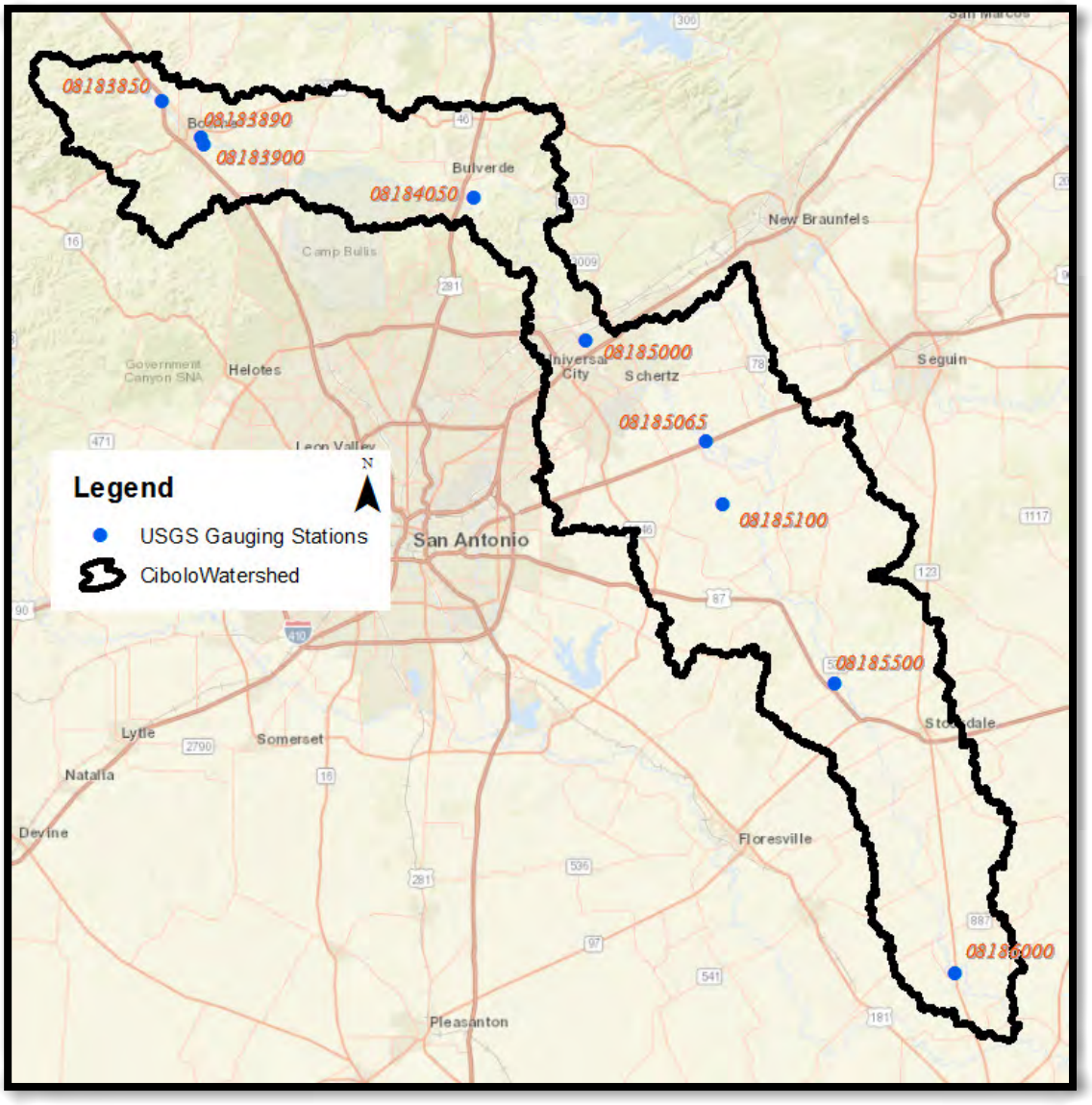


Figure 3-2 Cibolo Creek USGS Gauging Stations

3.2.1.5. Reservoirs

In Cibolo Creek and Martinez Creek, various reservoirs were built for flood flow attenuation. Figure 3-3 depicts the locations of these structures within the watershed. For consistency with the HEC-RAS modeling, the same storage discharge rating curves were used to simulate flows out of the reservoirs. These large volumes of open water are also used as water supply, as is the case with Boerne Lake, and will absorb many smaller events when storage is available. Each reservoir has a normal discharge to maintain the pool volume and a high level or emergency flood level. Both of these conditions are reflected in the reservoirs FTABLE volume-flow relationship. In addition, to reflect leakance from the reservoirs in the upper Cibolo Creek (above the recharge zone), a leakance rate was applied to each of the reservoirs. Leakance was applied during calibration to match available USGS gauge water level and flow observations.

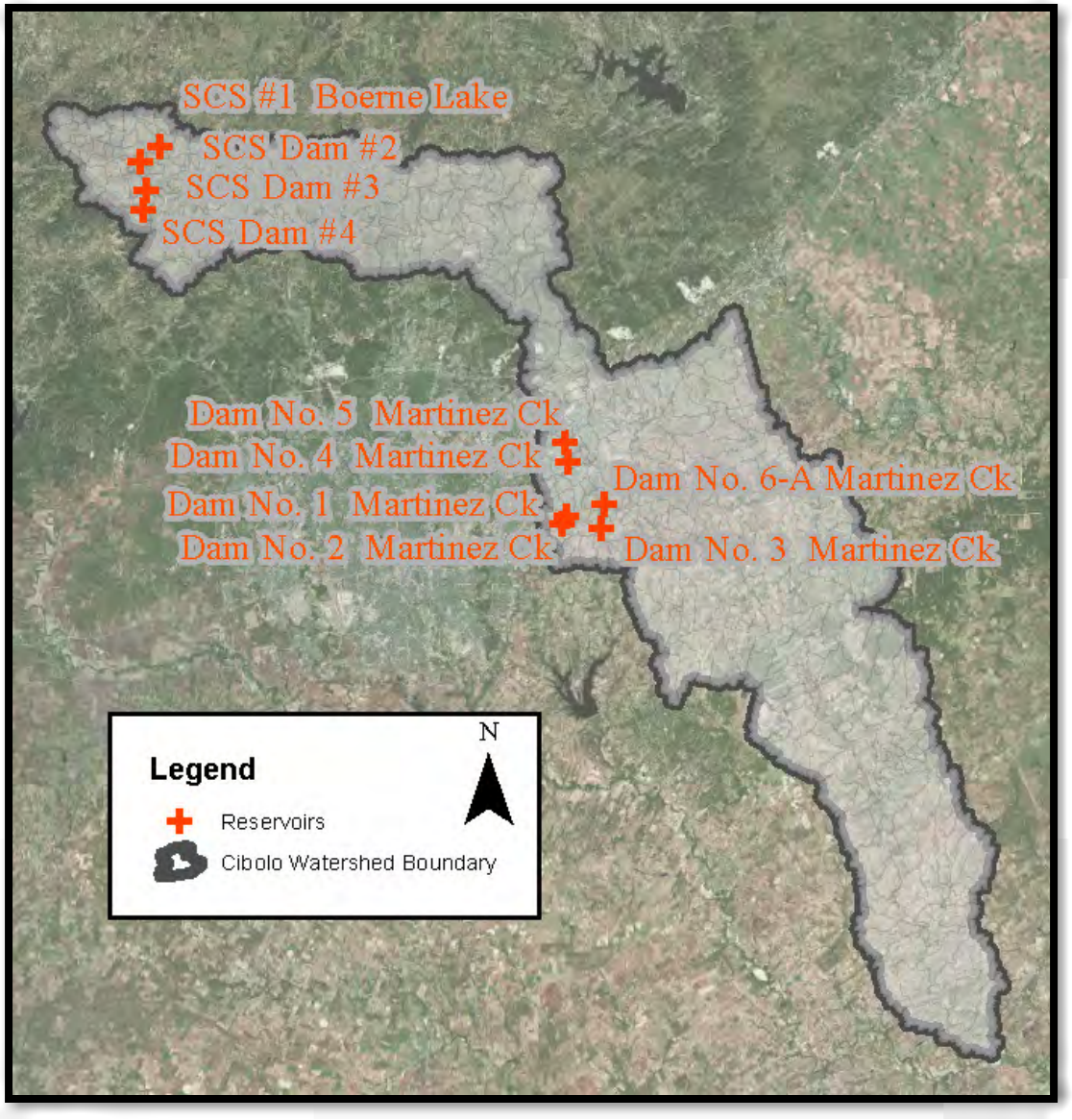


Figure 3-3 Cibolo Creek Reservoirs

3.2.1.6. Topography

The terrain of Cibolo Creek is a key feature that has shaped both the water flow and industry. The upper portion of the watershed has steeper slopes and is generally undeveloped, covered with brush capable of thriving in well drained soils that alternatively dry out completely and flood. The lower portion of the watershed is flatter and more accommodating of agriculture, which is the primary land use in in the lower portion of the watershed. The Cibolo Creek watershed has a maximum elevation of 2000 feet NAVD 88 near Boerne in the upper portion of the watershed and a minimum elevation of 200 feet NAVD 88 in the lower agricultural portion of the watershed. Slopes in the watershed were categorized as steep, moderate or minor as follows:

- Mild Slope: less than 3%
- Moderate Slope: between 3% and 4%
- Steep Slope: greater than 4%

Slopes in the upper portion of the watershed are generally moderate and funnel water into a valley with good connection to the Edwards Aquifer. This is followed by areas of steep sloping terrain, including the main channel of Cibolo Creek. In this section, Cibolo Creek bends to the south and runs dry downstream of the Edwards Aquifer Recharge Zone. As characterized by USGS Gauge 08185000 at Selma (downstream of the Recharge Zone), 90% of the time there is no flow in this river reach, however, the steep wide channel is capable of routinely passing over 20,000 cfs when it does flow. Water then spreads out into the agriculture lands in an area characterized by mild slopes. The Cibolo Creek Watershed Terrain is seen in Figure 3-4. The white and maroon coloring indicates higher elevations, while the green, cream, and blue colors represent lower elevations. Sharp changes in color, such as those seen in the upper watershed, where the white color sharply turns maroon and in the middle Cibolo Creek, where the maroon turns to yellow and green indicate highly sloped land features.

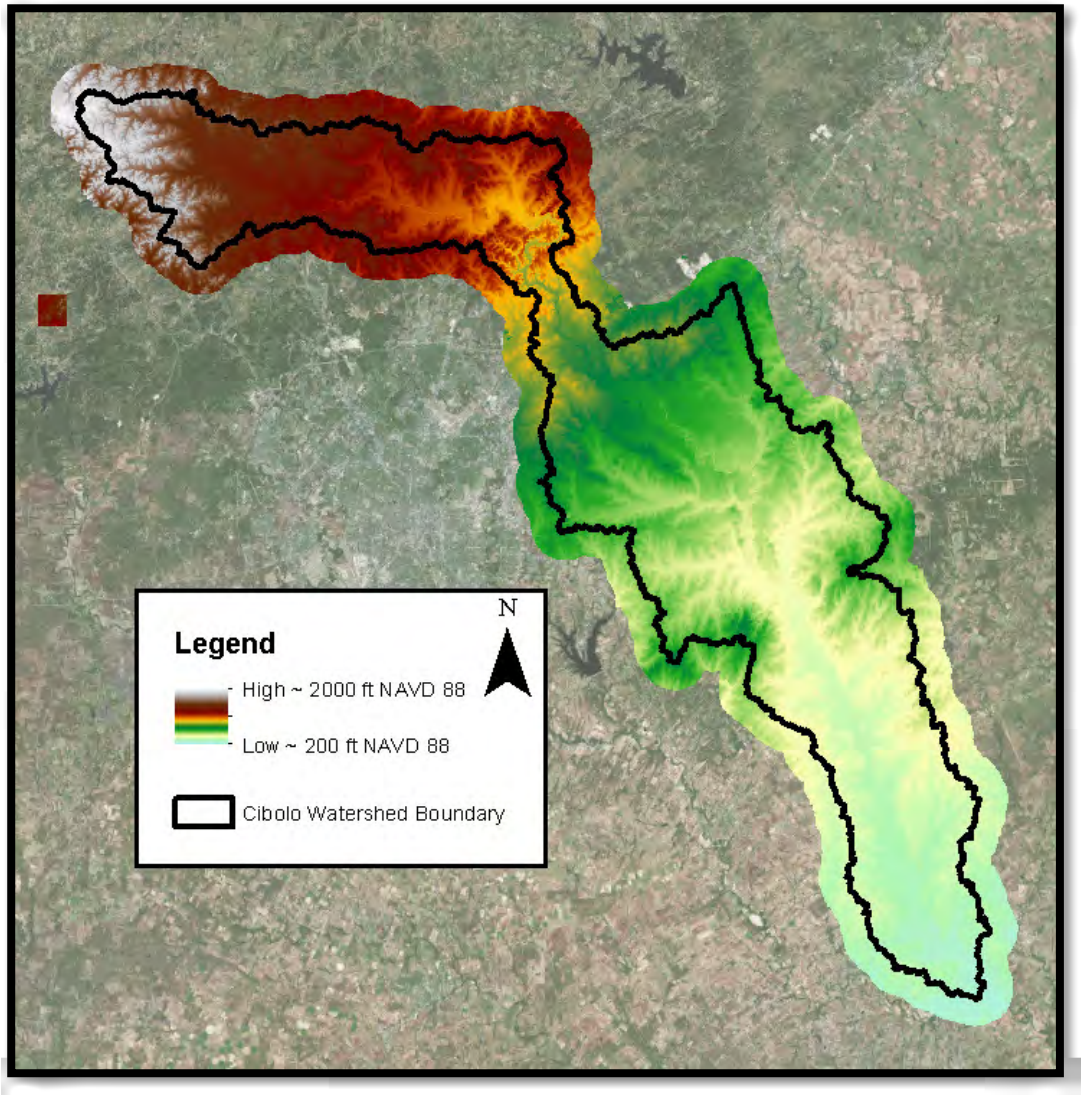


Figure 3-4 Cibolo Creek Topography

3.2.1.7. Existing Conditions Land Use

The Land Use Coverage for the Cibolo Creek watershed under existing conditions reflects 2015 land use. This land use is similar to that used in the previous Cibolo Creek models by USGS and it is the same land use used in the Flood Risk HEC-HMS model. The land use coverage seen in Figure 3-5 shows the extent of each land use as well as the addition of feed lot land use category. The feed lot land use was added based

upon feed lot point locations provided by SARA. Feed lot boundaries were delineated based upon review of aerial imagery. As seen in Figure 3-5, the upper portion of the watershed is primarily brush land, which transitions into a zone of urbanization, including medium density residential development, Randolph Air Force Base, and commercial development, near Selma. Downstream of Selma, the terrain flattens out and the land use is predominately agriculture with significant undeveloped areas of wetlands and forest. Table 3-3 summarizes the watershed by area and percentage of watershed falling in each HSPF land use category.

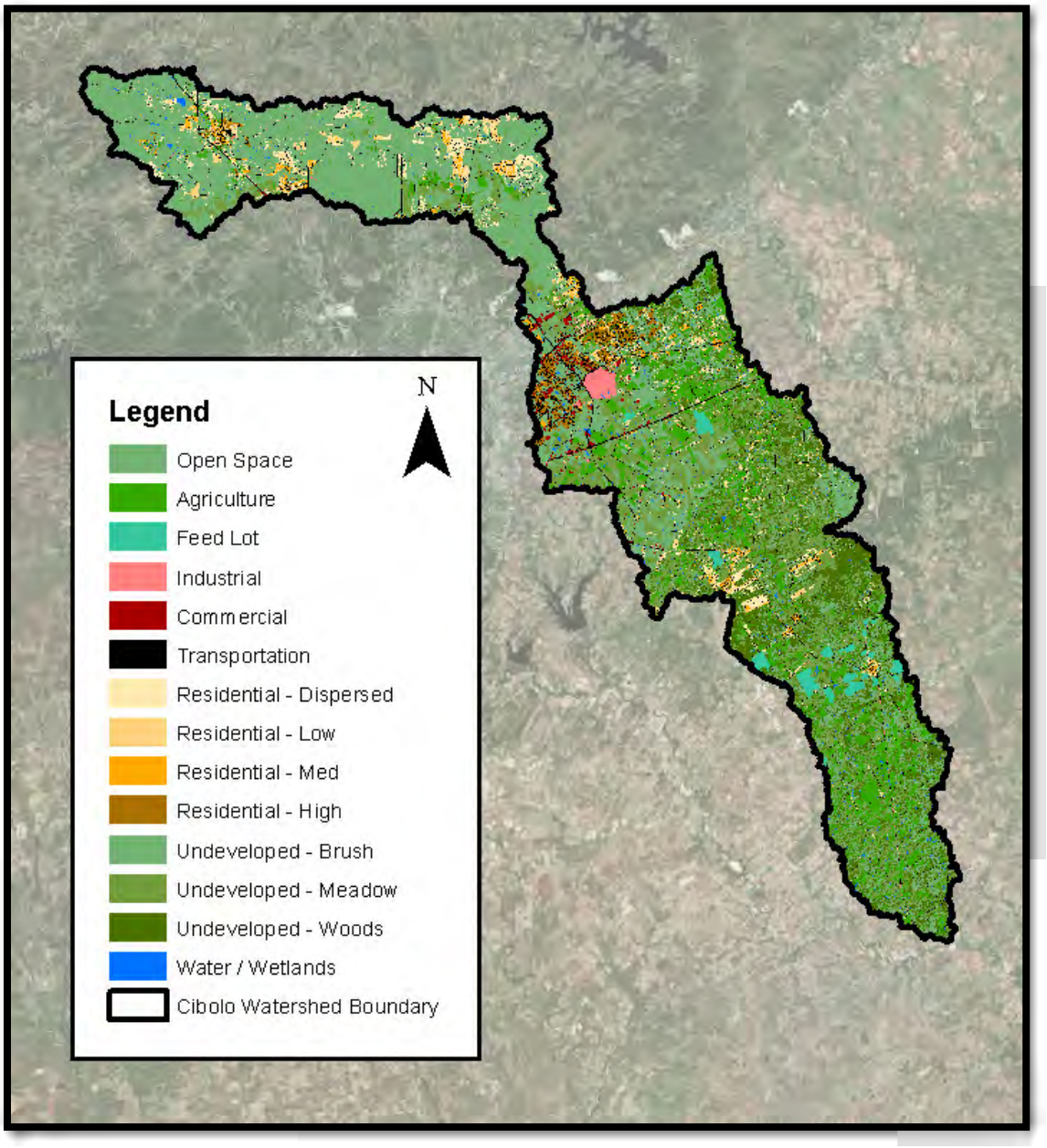


Figure 3-5 Cibolo Creek Existing Land Use (2015)

Table 3-3 Cibolo Creek Land Use Summary by Area

Segment	Ag	Brush	Commercial	Feed Lot	Industrial	Meadow	Open Space	Res Disp	Res High	Res Low	Res Med	Trans	Wetlands	Woods
Area sq miles	100	330	5	11	6	160	12	35	12	19	11	31	6	114
Percentage (%)	12%	39%	1%	1%	1%	19%	1%	4%	1%	2%	1%	4%	1%	13%

Another land use property used in the HSPF modeling process is percentage of imperviousness. This property delineates the runoff method between PERLND which simulates the pervious portion of the land use and IMPLND for the impervious portion of the land use. The percent impervious assumption began with standard values for land uses applied in the HEC-HMS model and were then confirmed or modified based upon aerial observations in which impervious areas were delineated for representative land uses. Although the resulting values calculated were less than standard values used in event based modeling, they are appropriate as HSPF modeling includes continuous simulations of both wet and dry conditions. Table 3-4 lists the imperviousness used for each land use and Figure 3-6 shows a sample of the impervious area delineation for an industrial land use in the watershed. It is of note that the only land use characterized as industrial is Randolph Air Force Base, which was determined to be more similar to medium density residential land use rather than a typical industrial area.

Table 3-4 Impervious percentage by Land Use

HSPF_no	Description	Impervious %
1	Open Space	0
2	Residential - Dispersed	20
3	Residential - Low	25
4	Residential - Med	38
5	Transportation	75
6	Undeveloped - Brush	0
7	Water / Wetlands	90
8	Industrial	35
9	Residential - High	50
10	Undeveloped - Meadow	0
11	Undeveloped - Woods	0
12	Agriculture	0
13	Commercial	85
14	Feed Lot	0



Figure 3-6 Industrial Land Use Imperviousness Delineation

3.2.1.8. Future Conditions Land Use

Like the future conditions land use generated for the Flood Risk analysis, the future conditions HSPF model was generated by updating the existing conditions land use coverage to incorporate future condition developments. It was assumed that areas of existing development would remain unchanged, while existing undeveloped, agriculture, or open spaces areas would potentially have a developed land use (residential, commercial, transportation, industrial or commercial) in the future condition. The resulting future conditions coverage is seen in Figure 3-7 and shows a significantly expanded residential corridor between I-10 and I-35, while retaining agriculture lands in the southern portion of the watershed. Expanded low density residential development is projected in the upper watershed. Table 3-5 summarizes the changes in land use from existing to future conditions. The increase in low density and medium density residential are up by 24 and 7 percent respectively, it is a dramatic increase over existing conditions, in which these developed land uses made up only 2 and 1 percent of the watershed respectively. On whole, the future land use condition represents a flip of the Cibolo Creek watershed from being 73% undeveloped under existing conditions to 56% developed in future conditions, which represents a 400% increase in the amount of developed area in the watershed. In simulating the future conditions it is assumed that, except for the land use change and WWTP flows (see Section 3.2.1.10), all other model elements remained the same, including soil characteristics, basin delineations, reservoir discharge relationships, and aquifer loss rates.

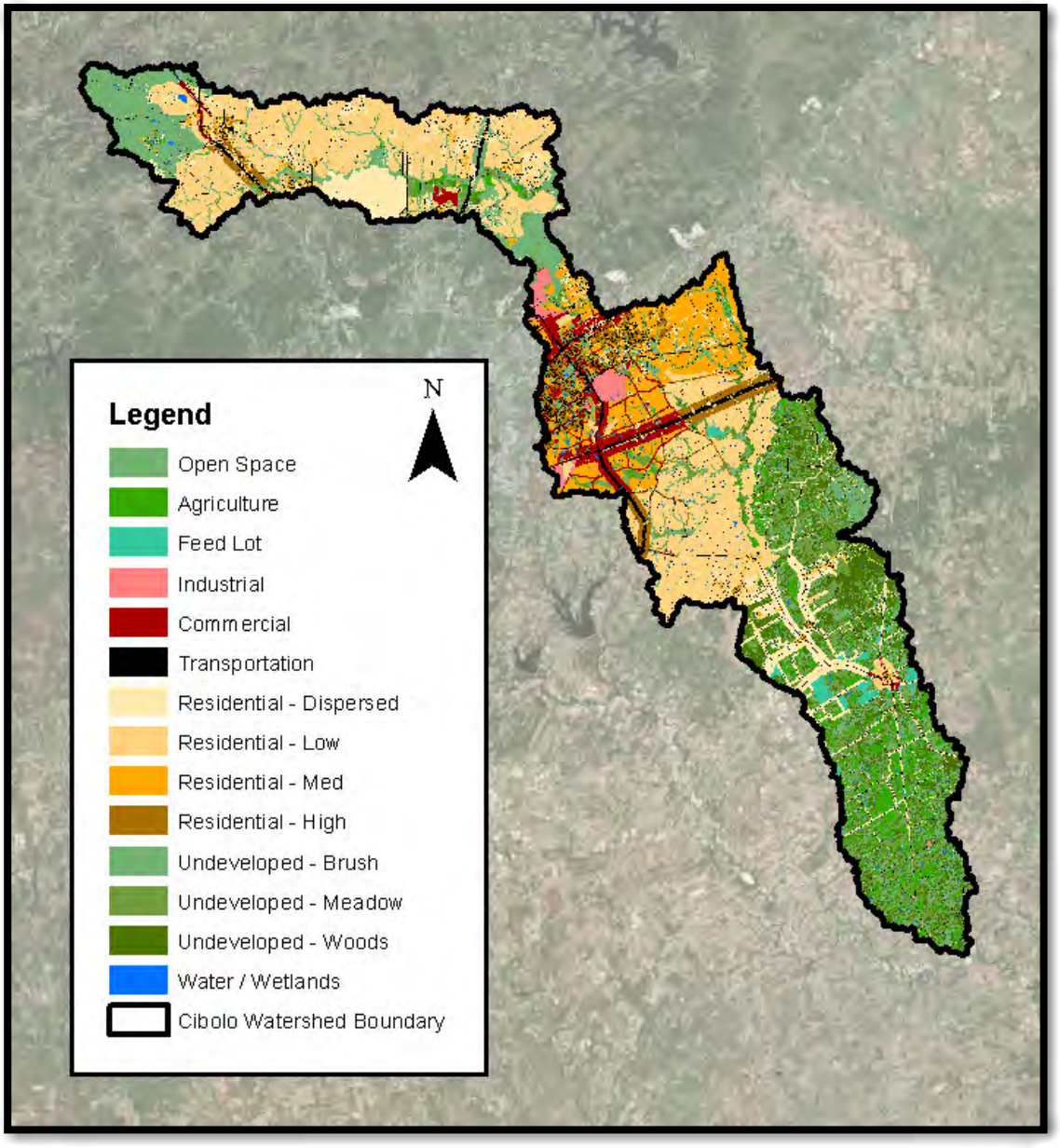


Figure 3-7 Future Land Use Coverage

Table 3-5 Land Use Summary – Existing vs Future Condition

HSPF ID	Land Use Description	Imp %	Existing Conditions		Future Conditions		Change
			Area sq mi	%	Area sq mi	%	
1	Open Space	0	12.3	1%	9.8	1%	0%
2	Residential - Dispersed	20	34.8	4%	81.8	10%	6%
3	Residential - Low	25	19.2	2%	220.3	26%	24%
4	Residential - Med	38	11.4	1%	73.5	9%	7%
5	Transportation	75	31.0	4%	37.9	4%	1%
6	Undeveloped - Brush	0	329.8	39%	135.5	16%	-23%
7	Water / Wetlands	90	6.5	1%	6.0	1%	0%
8	Industrial	35	6.4	1%	11.7	1%	1%
9	Residential - High	50	12.4	1%	26.4	3%	2%
10	Undeveloped - Meadow	0	160.3	19%	79.2	9%	-10%
11	Undeveloped - Woods	0	114.2	13%	82.6	10%	-4%
12	Agriculture	0	99.8	12%	54.5	6%	-5%
13	Commercial	85	4.7	1%	28.0	3%	3%
14	Feed Lot	0	11.3	1%	7.0	1%	-1%

Yellow highlighted rows indicate development
Change % (+ increase in land use; - decrease in land use)

3.2.1.9. Soils

Soil characteristics in the Cibolo Creek Watershed vary in permeability and sediment characteristics from the upper portion of the watershed down to the confluence with the San Antonio River. The upper portion of the watershed, much of which overlies the Edwards Aquifer, has a high connection to the aquifer along the river bed (Ockerman, 2007). This connection results in extended areas of dry riverbed conditions for the majority of the year. It is not until significant flows overwhelm the soils capacity to infiltrate that stream runoff begins to flow downstream. Figure 3-8 shows dry streambed conditions along Cibolo Creek at I-35 which are indicative of areas upstream of Selma for much of the year.



Figure 3-8 Cibolo Creek at I-35

Downstream of Selma and the Edwards Aquifer Outcrop there is unique soil regime that has many springs which leads to stream gains. In this area denoted as Zone 1 – Qle - Leona in Figure 3-9, the soil is largely sandy as opposed to the clay that persists in the majority of the watershed. Also, this area is characterized as rapid to very rapid infiltration rates as compared to lower permeability rates seen further downstream in the agriculture area. Figure 3-9 shows the major soil groupings used in the watershed segmentation process and provides a link to the previous USGS work, using the same soil and designations.

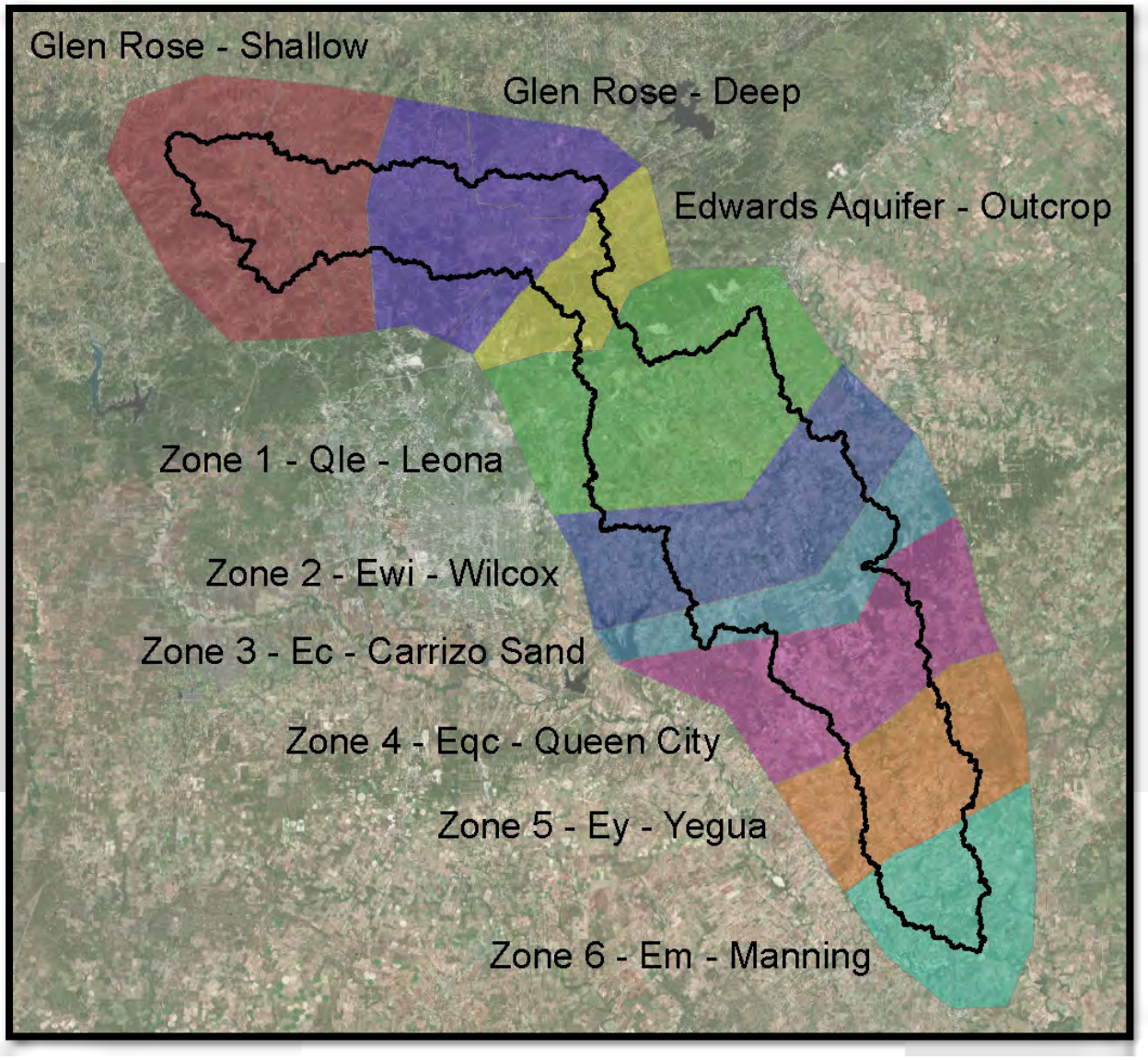


Figure 3-9 Cibolo Creek Soils

3.2.1.10. WWTP

Wastewater treatment plants in the Cibolo Creek watershed are significant sources of flow to Cibolo Creek, particularly during dry periods, and play a significant role in understanding the water quality conditions in the Cibolo Creek watershed. Figure 3-10 shows the location of each of the WWTPs simulated in the Cibolo Creek HSPF model. Table 3-6 lists the WWTPs included in the HSPF modeling, the average historical flow, and permitted conditions at each treatment plant. It is of note that during dry weather conditions, nearly all the flow in the lower river comes from these WWTPs. Data provided on the TCEQ website provides WWTP reported data to EPA Enforcement and Compliance History Online (ECHO) which was used to input flows and loads into the existing condition HSPF model. This information was imported into the model as point-source inflows of water quantity and water quality varying monthly. For the largest four WWTPs the water quality data was entered directly as reported, while the smaller plants applied average concentration at the plant to the reported flow rate.

The future condition HSPF model includes outflows from the WWTPs shown in Figure 3-10; however, the future WWTP flows were applied at permitted rates rather than actual reported rates.

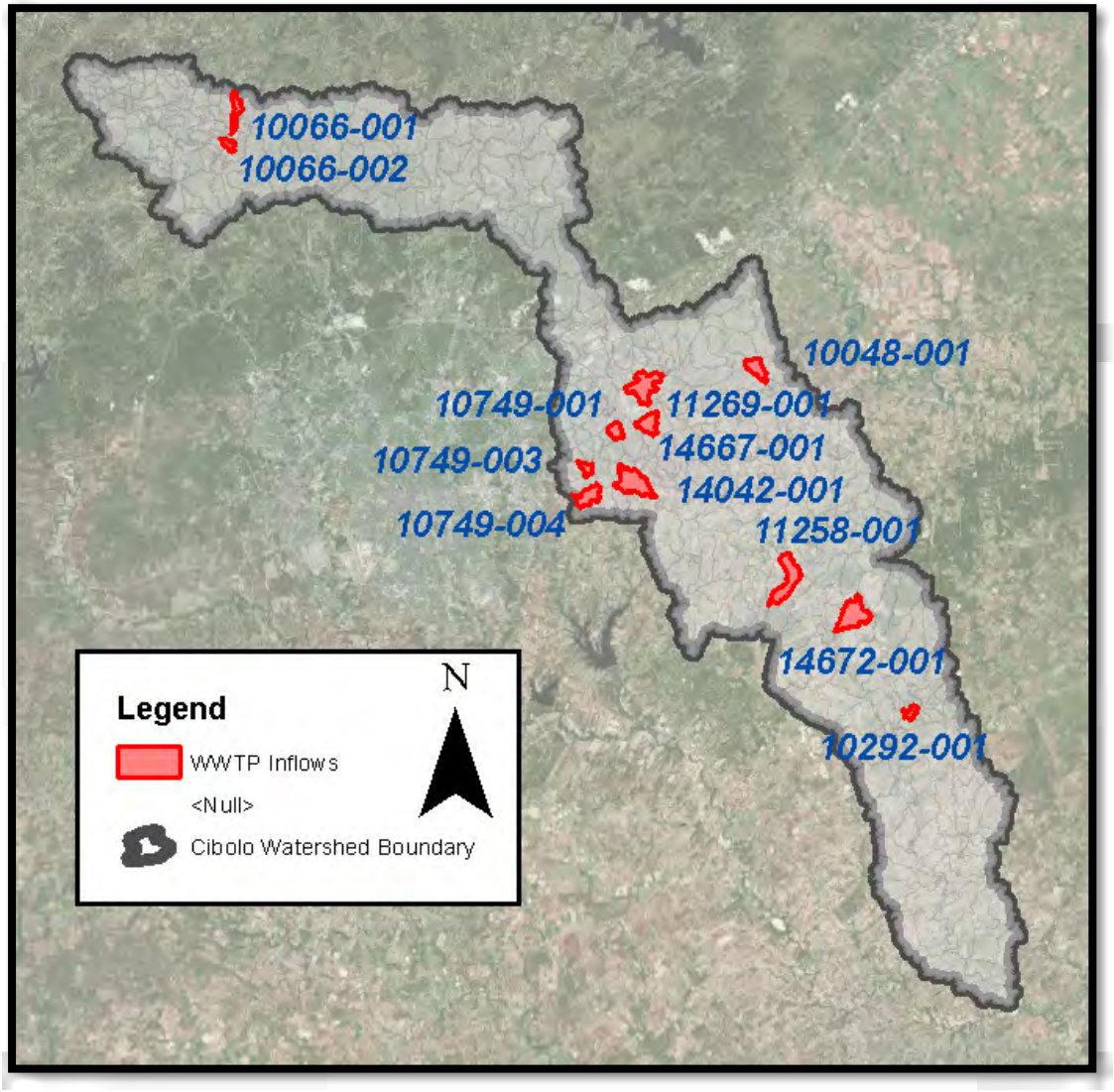


Figure 3-10 WWTPs in Cibolo Creek

Table 3-6 WWTPs in Cibolo Creek

WWTP ID	Waste Water Treatment Plant	HSPF Reach	Avg Flow cfs	Permitted						
				Flow cfs	CBOD mg/L	BOD mg/L	TSS mg/L	NH4 mg/L	E.coli CFU	DO mg/L
10048-001	CITY OF MARION WWTP	195	0.13	0.31		20	20		126	6
10066-001	CITY OF BOERNE WWTP	64	1.52	1.85	10		15	3	126	5
10066-002	BOERNE WWT AND RECYCLING	73	0.41	2.16	5		12	2	126	6
10292-001	CITY OF STOCKDALE WWTP	345	0.13	0.46		30	90		126	4
10749-001	SALATRILLO CREEK WWTP	218	6.08	8.98	7		15	2	126	6
10749-003	UPPER MARTINEZ CREEK WWTF	245	2.61	3.40		10	15	3	126	4
10749-004	MARTINEZ II WWTP	249	2.45	3.08	10		15	3	126	4
11258-001	CITY OF LA VERNIA WWTP	299	0.15	0.77		20	20		126	2
11269-001	ODO J. RIEDEL REGIONAL WWTP	165	5.64	9.55	10		15	3		6
14042-001	MARTINEZ III WWTF	239	0.02	0.23		20	20		126	3
14667-001	CITY OF SCHERTZ WWFT	259	0.02	1.46	10		15	2	126	6
14672-001	QUAIL RUN WWTP	319	0.03	0.39	10		15	3	126	4

3.2.1.11. Water Use and Water Right Losses

Water rights play a role in the total water balance of Cibolo Creek. Water rights loses, typically for agriculture irrigation purposes, are simulated in the HSPF model as a simulation outflow. The outflow data was extracted from the TCEQ's South Texas Watermaster Program website (Texas Commission on Environmental Quality, n.d.) and is based upon monthly reports submitted to TCEQ. Figure 3-11 shows the locations of the most significant water uses in Cibolo Creek, including water withdrawal from Lake Boerne to supplement water supply. Simulating the water usage as an outflow has the benefit of extracting water quality components (pollutants) along with water volume.

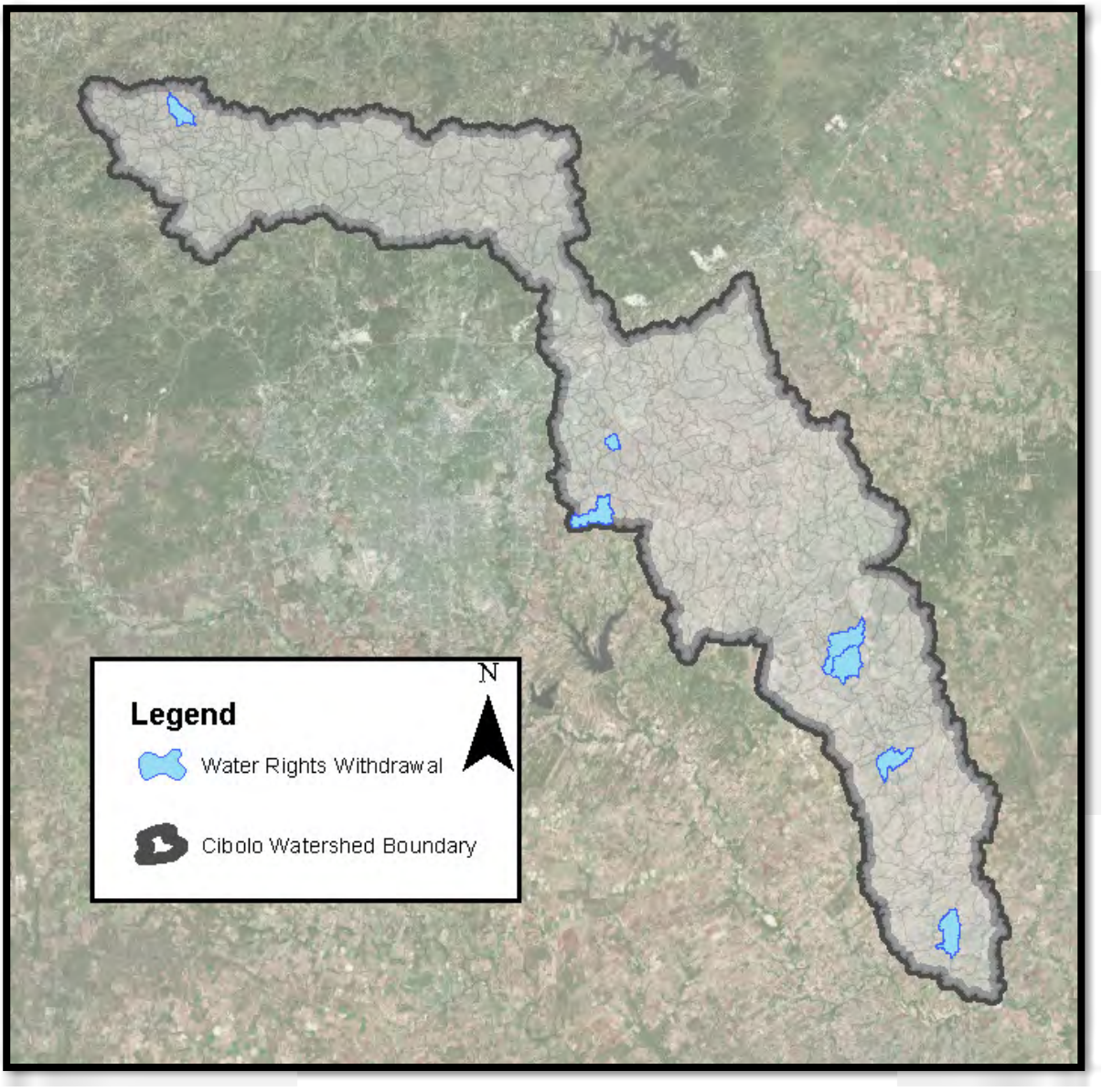


Figure 3-11 Water Use Rights in Cibolo Creek

3.2.1.12. Streamflow Loss

The Edwards Aquifer is an underground karst limestone formation between 300 and 700 feet thick. Rainfall reaching Cibolo Creek is a significant source of recharge to this aquifer system. The extent of the Edwards Aquifer is shown in Figure 3-12**.** The figure shows that Cibolo Creek covers the contributing zone, recharge zone, transitional zone, and artesian zones. The recharge zone extends up the length of the main channel of Cibolo Creek and extends to just east of the City of Bourne and extends along the creek to Selma. It has been estimated that the creek requires, approximately 2000 cfs of flow for any water to reach Selma. Otherwise all of the water will contribute to the Edwards Aquifer. The USGS Aquifer Recharge Investigation report 02-4241 (Ockerman, 2002) estimated the stream loss per stream mile as:

$$\text{Loss per mile} = (0.062) \times \text{streamflow} + 8.3$$

During the calibration process, it was ultimately a combination of the 2000 cfs observation and the loss per stream mile estimation that was used to update the streamflow. The river reach FTABLE for reaches in the Edwards Recharge Zone were then given a constant infiltration rate, whereby until the flow in the river exceeded a target value, streamflow would not pass beyond the recharge. Above the target value the streamflow rate also continues at a constant rate.

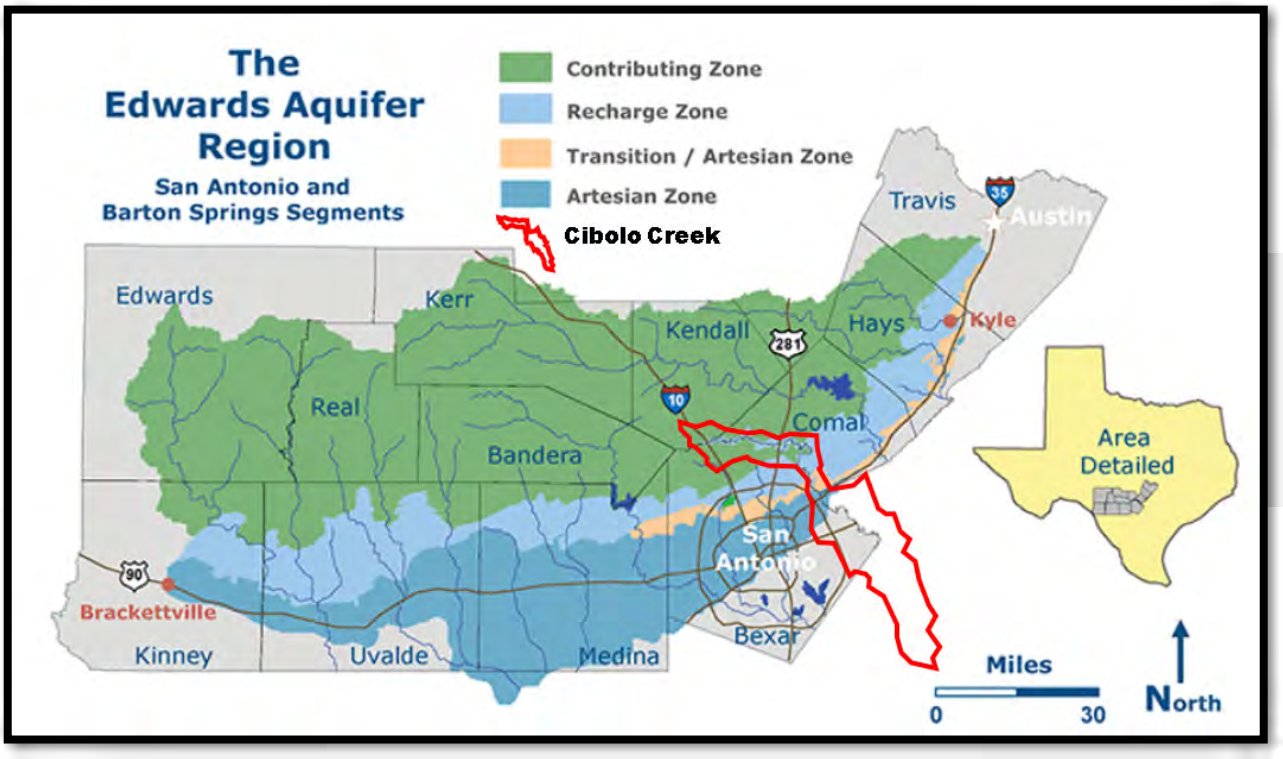


Figure 3-12 Edwards Aquifer Region (Source: *www.edwardsaquifer.net*)

3.2.1.13. Spring Flows

Downstream of Selma the watershed slope flattens out. As the slope changes the Edwards Aquifer enters its artesian zone. In the artesian zone a portion of the water that has percolated into the Edwards Aquifer reemerges into the Cibolo Creek through a series of springs or into the banks of the Creek. The most pronounced spring in the Cibolo Creek watershed is Sutherland Springs, however many other smaller springs are prevalent throughout the watershed. Observations of water coming out of the side banks of Cibolo have been observed south of Selma, contributing to a constant flow in the creek downstream of Selma to the confluence with the San Antonio River. While there is not a long term continuous measure of flow rates at Sutherland Springs, there is a correlation between the long-term J-17 well and flow rates in Sutherland Springs. Figure 3-13 depicts the profile of the confined Edwards formation relative to the J-17 well as depicted by www.edwardsaquifer.net. Figure 3-14 shows the resulting flow contributing to Cibolo Creek over the period of record. While the flow rate has dipped significantly in the past, even potentially becoming a sink in the mid 1950's, over the time period of this simulation, flows from Sutherland Springs ranges from 10 to 30 cfs.

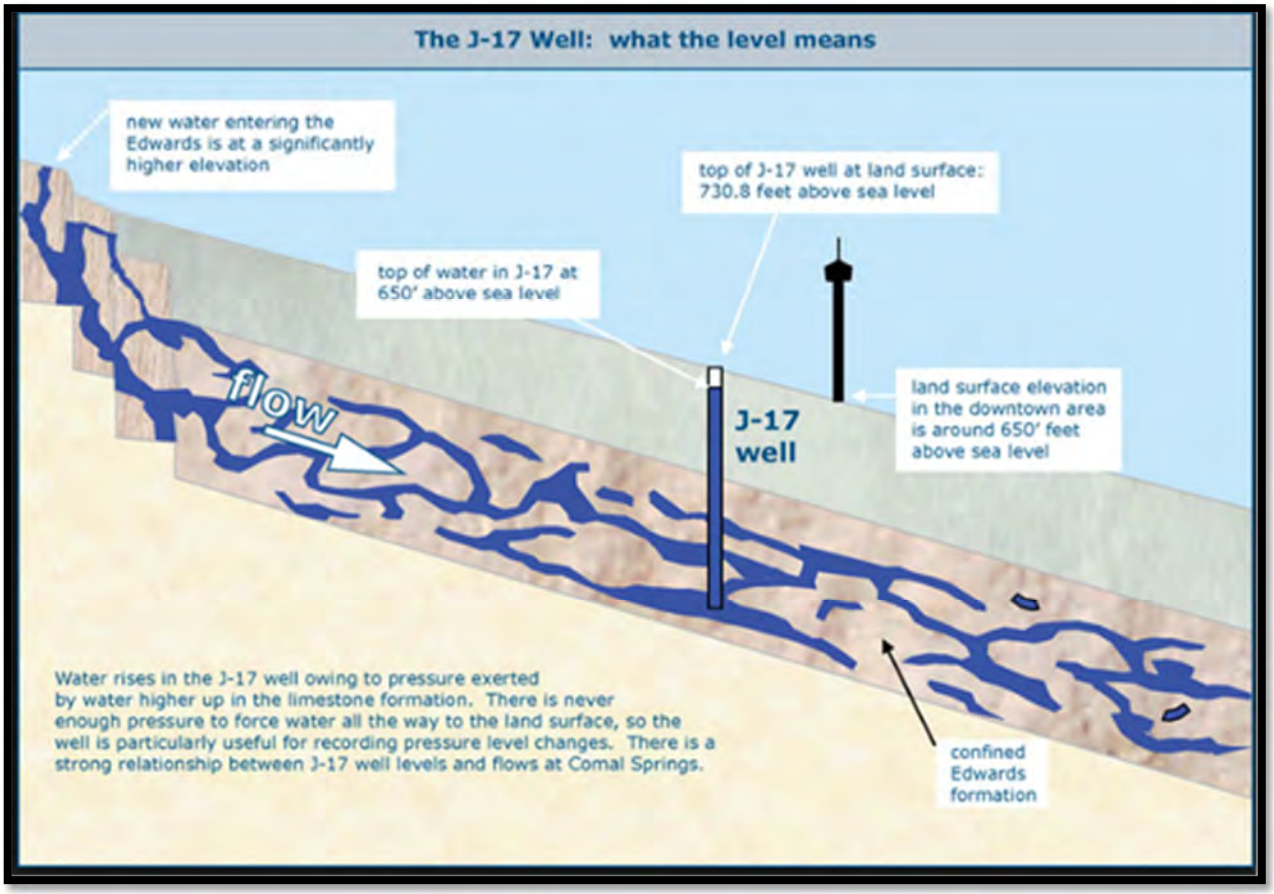


Figure 3-13 Edwards Aquifer Artesian Zone (Eckhardt, n.d.)

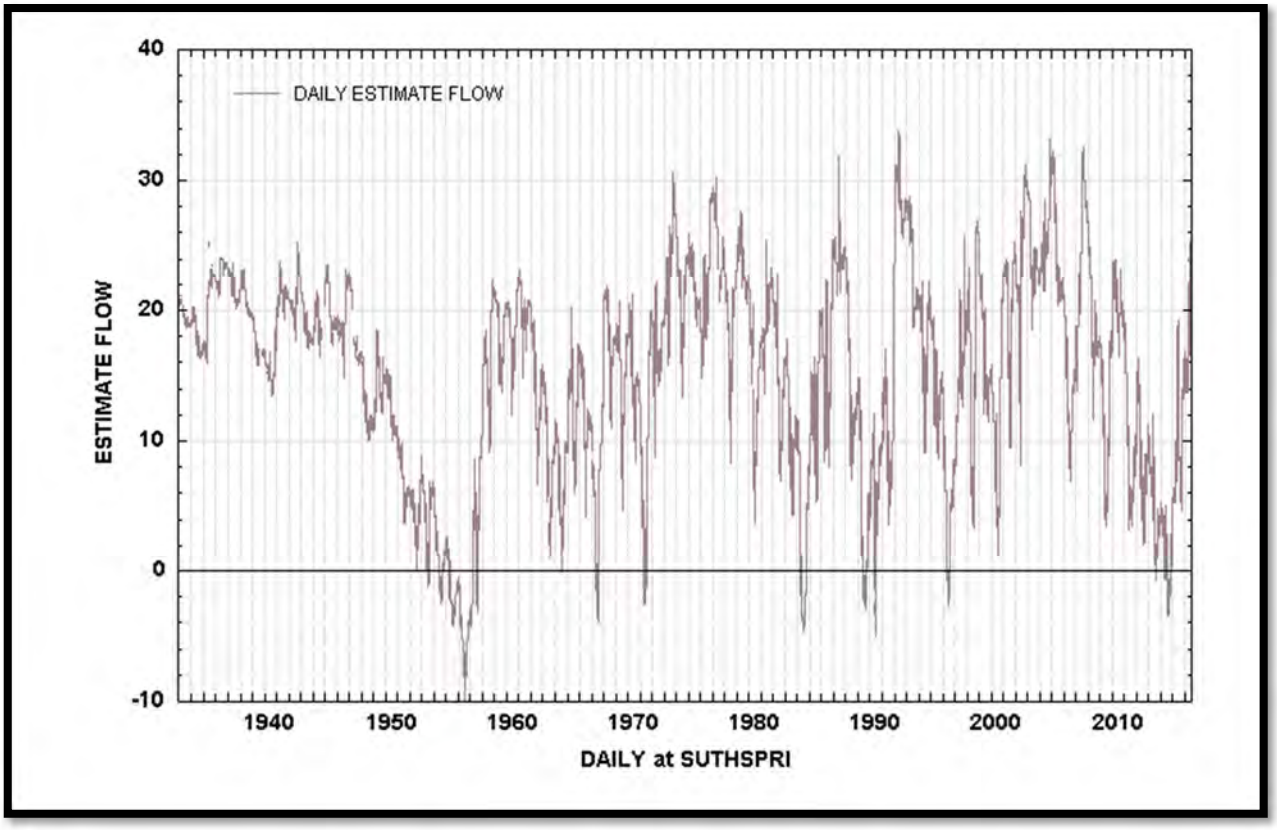


Figure 3-14 Flow estimated at Sutherland Springs

3.2.1.14. Surface Water Monitoring Data

Surface water quality monitoring data (SWQM) data, as detailed in the Phase I data collection report, was used to calibrate the water quality model. Figure 3-15 displays the locations of water quality monitoring stations used in the calibration and for reference, along with the locations of HSPF Reach IDs where the water quality sampling data has been aggregated. Data statistics aggregated at the identified HSPF Reach IDs area presented in Table 3-7. As seen in the table, the largest collection of observed data relates to the HSPF outlet reach 374 near the confluence with the San Antonio River.

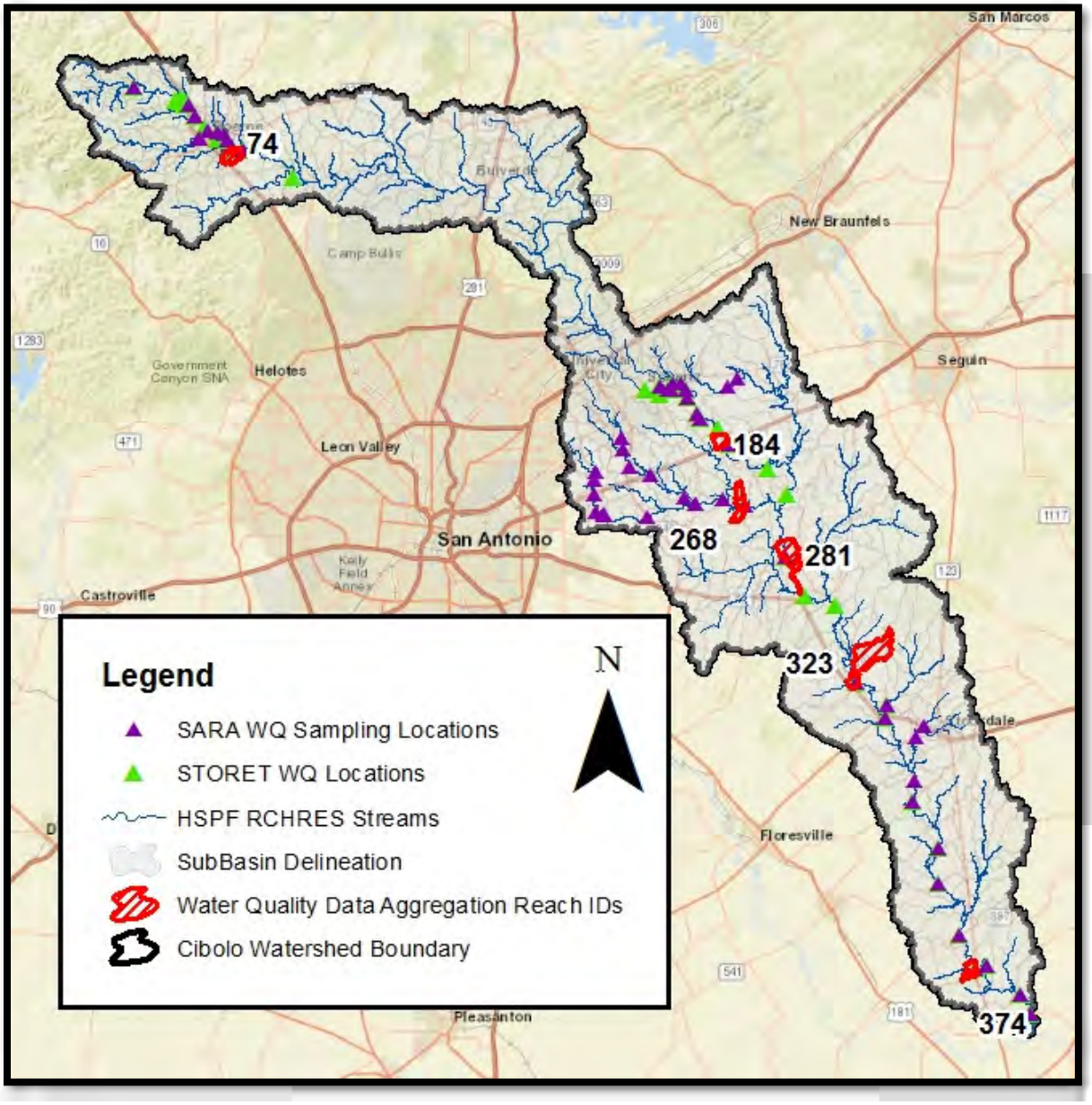


Figure 3-15 Cibolo Creek Water Quality Sampling Locations

Table 3-7 Surface Water Quality Monitoring Summary in Cibolo Creek

Reach ID	Parameter	Begin Date	End Date	Min Value	Max Value	Avg Value	# of Samples
74	BOD (mg/L)	18-Dec-07	18-Nov-08	2	2	2.00	15
74	DO (mg/L)	13-Oct-99	19-Nov-14	4	14.7	7.42	84
74	Ecoli (#col)	08-Feb-01	19-Nov-14	10	2419	197.14	53
74	NH3 (mg/L)	13-Oct-99	19-Nov-14	0.03	10.3	0.31	82
74	NO3 (mg/L)	20-May-03	18-Nov-08	0.08	3.46	0.73	21
74	OP (mg/L)	15-Aug-02	23-Aug-11	0.04	3.31	1.12	44
74	TKN (mg/L)	13-Oct-99	19-Nov-14	0.05	8.87	0.64	78
74	TN (mg/L)	20-May-03	18-Nov-08	0.52	4.14	1.20	21
74	TP (mg/L)	13-Oct-99	09-Oct-13	0.01	3.85	1.03	77
184	CBOD (mg/L)	18-Mar-16	12-Apr-16	2	2	2.00	2
184	DO (mg/L)	15-Dec-14	06-Nov-16	4.7	10.7	7.31	17
184	Ecoli (#col)	20-Oct-15	07-Dec-16	23	730	106.25	12
184	NH3 (mg/L)	07-Mar-16	07-Dec-16	0.1	0.1	0.10	3
184	NO2 (mg/L)	22-Oct-15	07-Dec-16	0.05	0.05	0.05	4
184	NO3 (mg/L)	22-Oct-15	07-Dec-16	3.14	11.9	9.51	4
184	Secchi	15-Dec-14	06-Nov-16	0.27	0.75	0.51	10
184	TKN (mg/L)	22-Oct-15	07-Dec-16	0.2	0.77	0.52	4
184	TN (mg/L)	22-Oct-15	07-Dec-16	3.96	12.47	9.46	3
184	TP (mg/L)	17-Oct-16	07-Dec-16	0.3	1.02	0.66	2
184	TSS (mg/L)	17-Oct-16	07-Dec-16	5	19.6	12.30	2
268	BOD (mg/L)	14-Oct-12	03-Apr-13	2	3	2.36	5
268	DO (mg/L)	05-Aug-05	15-Aug-16	5.6	11.1	7.84	54
268	Ecoli (#col)	27-Sep-06	15-Aug-16	93	7700	615.55	42
268	NH3 (mg/L)	27-Sep-06	15-Aug-16	0.02	0.17	0.09	42
268	NO3 (mg/L)	27-Sep-06	15-Aug-16	0.24	4.63	1.32	48
268	OP (mg/L)	27-Dec-06	23-Oct-12	1.03	1.54	1.29	2
268	Pb (ug/L)	27-Dec-06	27-Dec-06	0.1	0.1	0.10	1
268	TKN (mg/L)	27-Sep-06	15-Aug-16	0.6	1.55	0.84	46
268	TN (mg/L)	27-Sep-06	15-Aug-16	0.99	5.43	2.17	46
268	TP (mg/L)	27-Sep-06	15-Aug-16	0.42	2.04	1.27	47
268	Zn (ug/L)	27-Dec-06	27-Dec-06	7.2	7.2	7.20	1

Reach ID	Parameter	Begin Date	End Date	Min Value	Max Value	Avg Value	# of Samples
281	BOD (mg/L)	09-Jul-15	09-Jul-15	2	2	2.00	1
281	DO (mg/L)	04-Oct-99	10-Aug-16	5.3	13.87	8.44	107
281	Ecoli (#col)	07-Jun-05	10-Aug-16	17	7700	290.39	74
281	NH3 (mg/L)	04-Oct-99	10-Aug-16	0.02	0.19	0.08	106
281	NO3 (mg/L)	04-Oct-99	10-Aug-16	0.05	6.07	2.32	106
281	OP (mg/L)	03-Apr-08	15-Aug-11	0.2	1.09	0.70	22
281	Pb (ug/L)	21-Aug-00	20-Aug-01	2	2	2.00	2
281	TKN (mg/L)	04-Oct-99	10-Aug-16	0.2	1.55	0.61	94
281	TN (mg/L)	04-Oct-99	10-Aug-16	0.56	6.89	2.81	94
281	TP (mg/L)	04-Oct-99	10-Aug-16	0.1	2.1	0.74	105
281	Zn (ug/L)	21-Aug-00	20-Aug-01	5	5	5.00	2
323	DO (mg/L)	15-Jan-98	10-Aug-16	5.2	15.6	8.09	72
323	Ecoli (#col)	17-May-01	10-Aug-16	8.6	2200	131.99	55
323	NH3 (mg/L)	21-Jan-98	10-Aug-16	0.05	0.14	0.06	70
323	NO3 (mg/L)	16-Dec-02	10-Aug-16	1.25	5.37	2.71	16
323	OP (mg/L)	07-Aug-06	20-Jun-11	0.1	0.51	0.32	22
323	Pb (ug/L)	19-Dec-06	19-Dec-06	0.12	0.12	0.12	1
323	TKN (mg/L)	21-Jan-98	10-Aug-16	0.21	2.02	0.58	70
323	TN (mg/L)	16-Dec-02	10-Aug-16	2.15	5.75	3.35	16
323	TP (mg/L)	21-Jan-98	10-Aug-16	0.11	1.2	0.45	66
323	Zn (ug/L)	19-Dec-06	19-Dec-06	1.9	1.9	1.90	1
374	BOD (mg/L)	30-Apr-09	10-Aug-16	2	4	2.06	66
374	CBOD (mg/L)	12-Apr-16	12-Apr-16	2	2	2.00	1
374	DO (mg/L)	15-Jan-98	06-Nov-16	1.36	16.5	8.57	250
374	Ecoli (#col)	17-May-01	02-Dec-16	8	55000	561.11	466
374	NH3 (mg/L)	21-Jan-98	10-Oct-16	0.02	0.56	0.08	212
374	NO2 (mg/L)	04-Oct-10	10-Oct-16	0.05	0.05	0.05	39
374	NO3 (mg/L)	04-Oct-99	10-Oct-16	0.02	4.12	1.08	199
374	OP (mg/L)	03-Apr-08	08-Aug-11	0.02	0.3	0.18	38
374	Pb (ug/L)	21-Aug-00	10-Oct-16	0.1	2.76	0.80	13
374	TKN (mg/L)	21-Jan-98	10-Oct-16	0.2	6.28	0.62	200
374	TN (mg/L)	04-Oct-99	10-Oct-16	0.29	7.1	1.66	183
374	TP (mg/L)	21-Jan-98	10-Oct-16	0.02	1.4	0.26	211
374	TSS (mg/L)	04-Oct-10	10-Oct-16	3	244	20.54	37
374	Zn (ug/L)	21-Aug-00	10-Oct-16	1.2	23.9	5.78	12

3.2.2. Basin Delineation

The subbasin in HSPF is a primary building block for the transfer of water from land surface into a river reach. Subbasins should be sized appropriately such that in subsequent phases of the project, when BMPs are being evaluated, or areas are identified as damage centers, the results are specific enough to be able to identify a cause of the exceedance. The HSPF delineation was initially set at the level used for the HEC-HMS level, which included subbasins as small as 0.03 square miles. Evaluating the HEC-HMS basins larger than five square miles, each of these were redelineated as appropriate to adequately characterize the hydraulic flow throughout the Cibolo Creek Watershed. This resulted in a maximum basin size of 4.99 square miles and an average basin size for the 850 square mile of 2 square miles. The 428 subbasins simulated is seen in Figure 3-16.

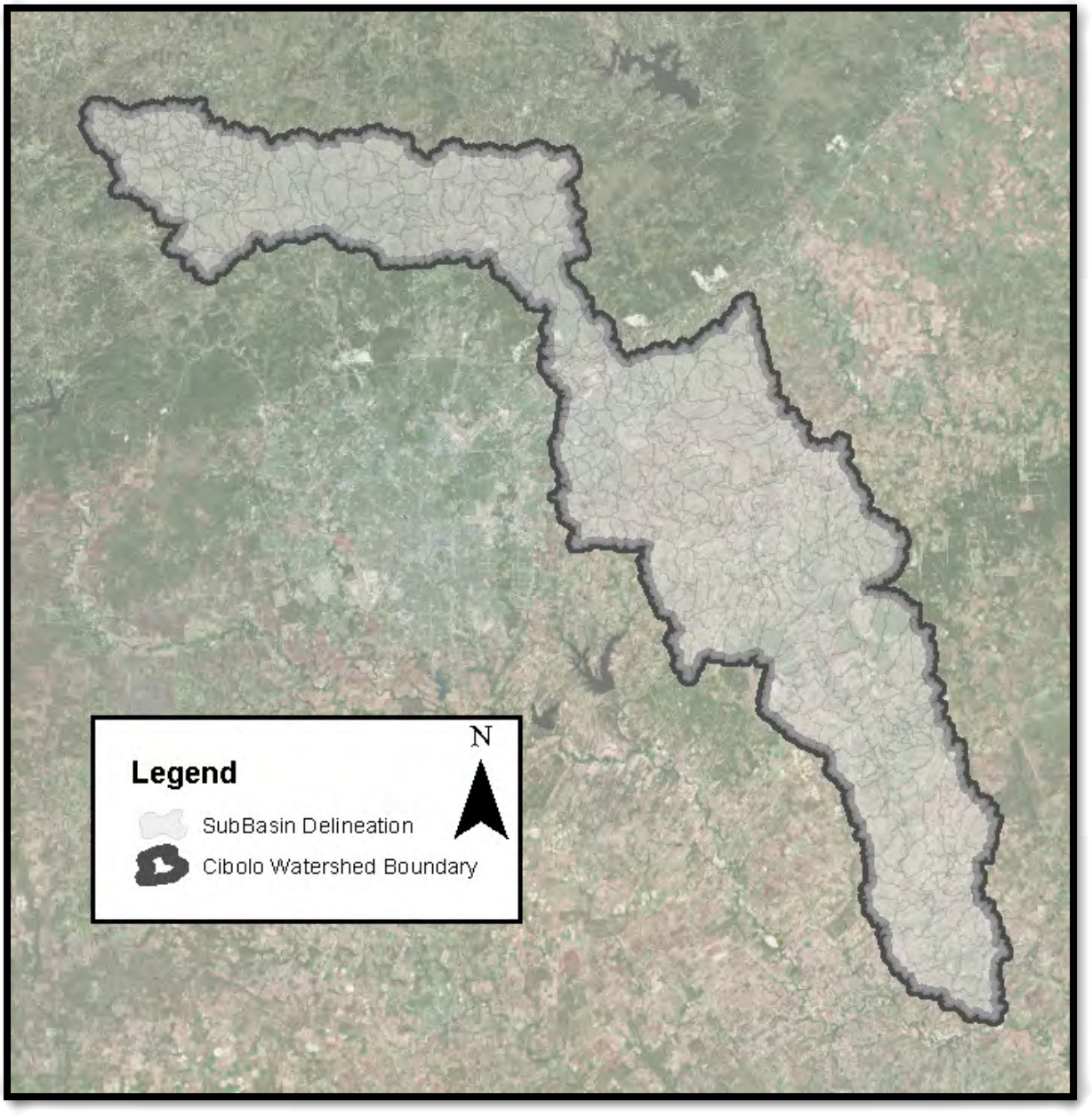


Figure 3-16 Cibolo Creek SubBasin Delineation

3.2.3. Model Segmentation

In HSPF model segmentation is the process of dividing the watershed into unique parts, to reflect varying characteristics throughout the watershed. For the Cibolo Creek watershed, segmentation was performed using watershed topography, soil conditions, and rainfall zones. This resulted in dividing the watershed into 11 unique segments, seen in Figure 3-17.

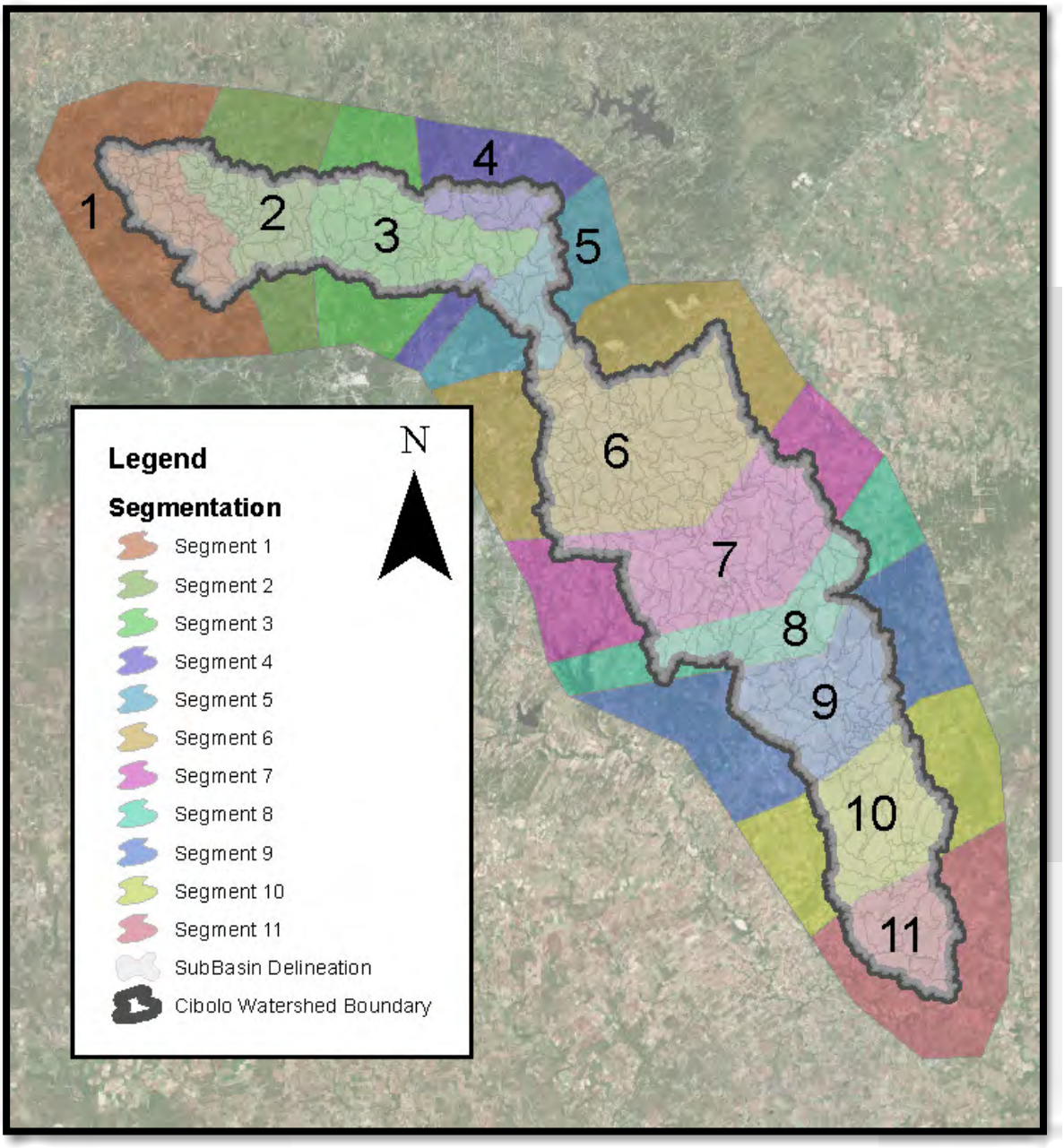


Figure 3-17 Cibolo Creek HSPF Model Segmentation

3.2.4. Hydrologic Parameterization

Over each subbasin, rainfall is converted into runoff through a combination of two mechanisms. These include runoff generated from pervious and impervious land use types. Basin runoff is simulated as the hydrological combination of contributions from HSPF runoff modules PERLND (for pervious) and IMPLND (for impervious).

3.2.4.1. PERLND

PERLND is the HSPF module that simulates the conversion of rainfall into runoff over pervious land surfaces. Rainfall is converted to runoff or stored on the land surface to either be evaporated or percolated into interflow, groundwater flow, or lost to the aquifer. The parameters governing these processes varying by land use and reflect the unique characteristics of each model segment. Key PERLND parameters used in each watershed segment are presented in **Appendix B**.

3.2.4.2. IMPLND

Simulating runoff from impervious land surfaces in the IMPLND module provides a similar model formulation as the PERLND's overland runoff portion, however unlike the PERLND, there is no soil interaction under impervious land surface. Water is stored on the land surface, then either evaporates or fills available storage and runs off. Key parameters by land use and segment are presented in **Appendix B.**

3.2.5. Hydraulic Parameterization

3.2.5.1. RCHRES

Each subbasin in the watershed has a corresponding river reach, that is simulated in HSPF's RCHRES module. Data defining the characteristics of the reach include physical properties, such as stream length, slope, shear stress potential and characteristics related to hydraulic performance such as the reach's storage discharge relationship (FTABLE) and connectivity to downstream elements. Reach connectivity is shown in Figure 3-18.

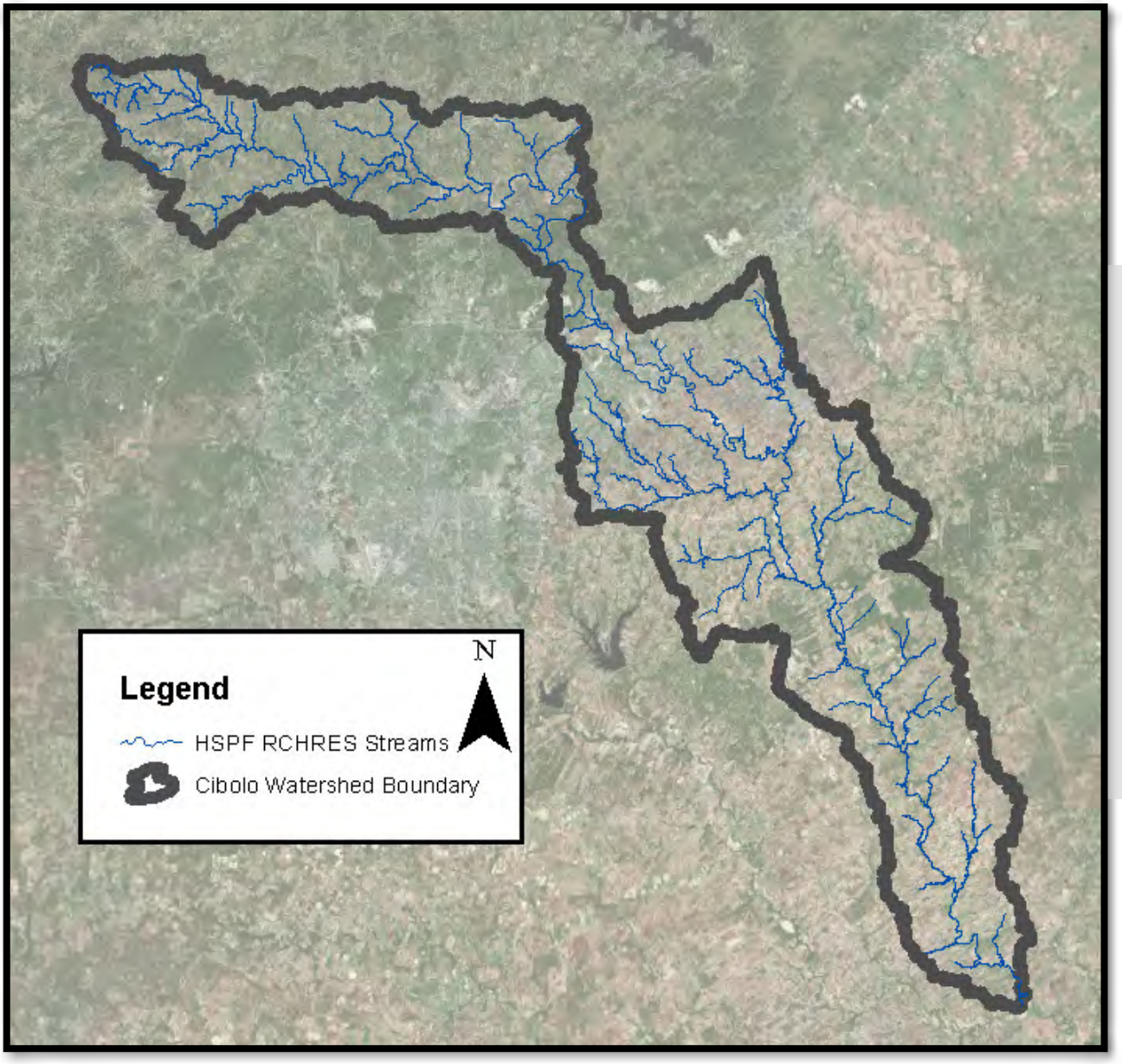


Figure 3-18 Cibolo Creek HSPF Model Reaches

3.2.5.2. FTABLE

In HSPF the FTABLE defines the flow rate as a function of storage volume for each river reach (RCHRES) in the model. While the flow portion of FTABLE does not consider dynamic backwater conditions, using a HEC-RAS approach to generating the tables incorporated normal depth approximations or depths at confluences for each river reach. The FTABLE consists of a depth, area, volume relationship as well as outflow rates. Outflow rates include both those that transfer water downstream and water lost to the Edwards Aquifer throughout the recharge zone.

3.2.5.2.1. Flow

Transferring flow downstream from one reach to another was based upon either an established discharge relationship at a flood control structure, or developed through a HEC-RAS model. The flood methodology involved cutting 12,000 cross sections throughout the watershed, covering every river reach, seen in Figure 3-19. Then to establish various flow regimes, a 100-year flow was applied, using data from the HMS model or regression equations as a starting point, then scaling this upwards by factors of 2 and 4 and downward by 7 power functions of 2. More refinement was made to the low end of the flow regime for two reasons. First, the majority of the flow in a typical year will be during stream events less than the mean annual event and second, through experience, the effective flow area, particularly during low flow conditions dramatically changes during minor flow and having stage discharge relationships in this flow regime provides for better storm and baseflow calibration.

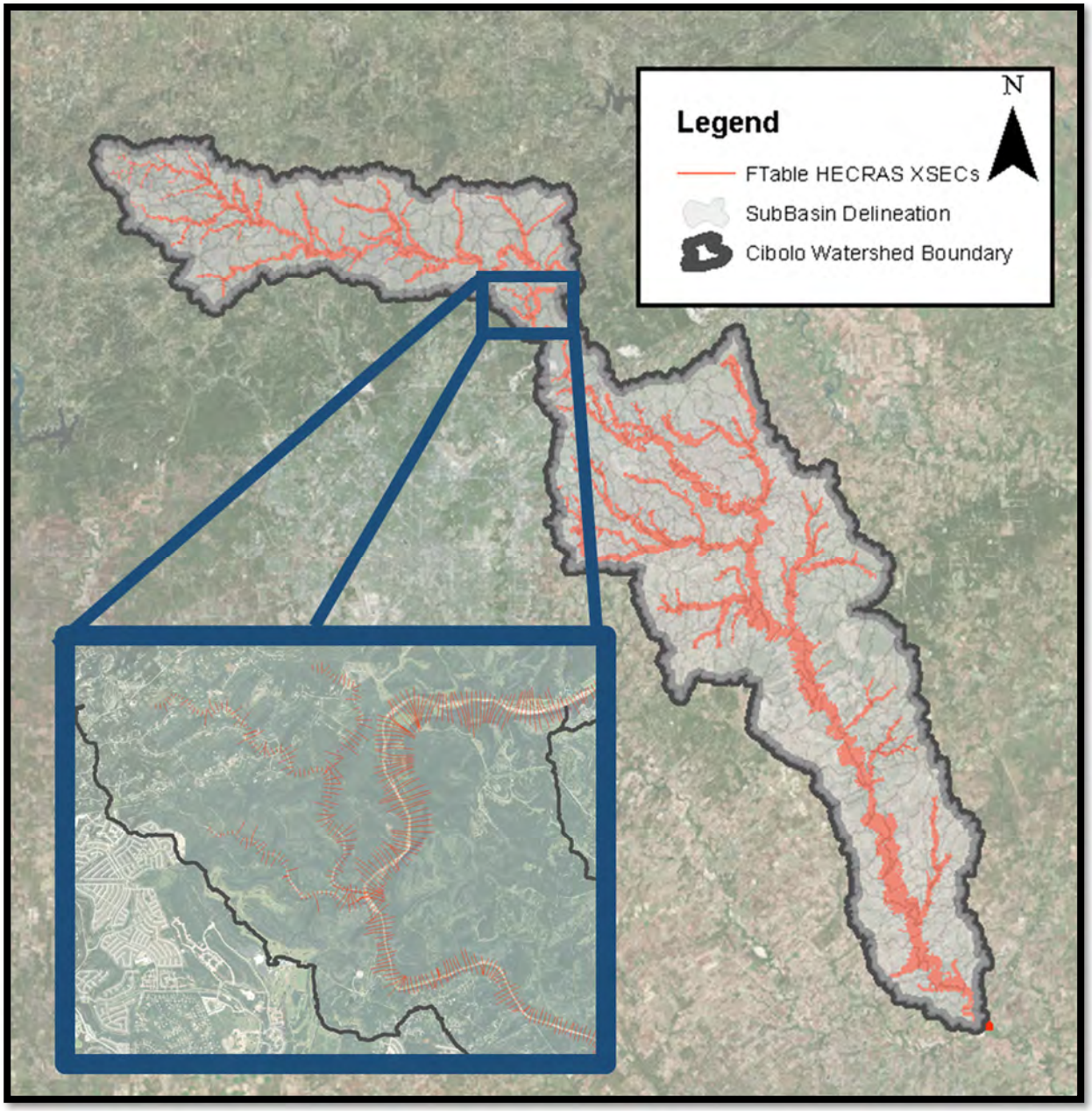


Figure 3-19 FTABLE HECRAS XSECs

3.2.5.2.2. Aquifer Loss

The aquifer loss portion of a reaches FTABLE was derived from USGS loss equation presented in Section 3.2.1.12 combined with field observations that unless Cibolo Creek is flowing more than 2000 cfs, no water will pass downstream of the recharge zone. This observation was put into numerical terms by calculating the loss per stream mile based upon the flow / loss equation and applying the resulting rate as a constant throughout the FTABLE rather than continuing to increase or decrease the loss amount as a function of depth or volume. It is presumed that the inflow into the Edwards Aquifer is minimally impacted by changing head in the stream and more driven by the capacity of the soils hydraulic conductivity. These assumptions are confirmed in looking at the UGSG Gauge 08185000 at Selma in which 90% of the historical flow is zero.

3.2.6. Calibration

Based upon a review of the data available at USGS streamflow stations throughout the watershed, calibration and verification time periods were established, these time periods include a series of dry and wet years, during which there were extreme events that caused watershed wide flooding and extended periods of drought. Water Quantity Calibration parameters adjusted included the following.

- LZSN – Lower zone nominal storage: used to calibrate total water volume
- INFILT – Index to infiltration capacity: used to calibrate the division of water between surface and interflow.
- AGWRC – Base Groundwater recession parameter: identifies the rate of groundwater flow based upon the previous day's flow. Lower values raise storm peaks yet lessen the total amount of water in the system.
- DEEPFR – Fraction of ground water flowing to deep recharge
- BaseTP – Fraction of remaining ET from baseflow
- AGWCTP – Fraction of remaining ET from active groundwater
- Monthly CEPSC – interception storage capacity
- UZSN – upper zone nominal soil moisture
- INTFW – interflow recession parameter
- Monthly LZETP – Lower zone ET parameter
- Impervious RETSC – retention storage capacity: the amount of impervious storage that is required to fill prior to runoff. In developed areas of Selma, this parameter was used to reflect the permitting requirement to retain the first inch of runoff over the pervious surface prior to discharge.
- Minimal basin flow – for model stability an external source of 0.001 cfs was added to each basin.

A model calibration period from 1/1/2001 to 1/1/2007 was chosen with a verification period from 1/1/2007 to 1/1/2012. Calibration began using the USGS gauges in the upper watershed, then moved downstream, cumulating at USGS gauge 08186000 at Fall City, which is just upstream of Cibolo Creek's confluence with the San Antonio River. Model calibration charts are seen in Figure 3-20 and Figure 3-21 with observed versus simulated statistics presented in Table 3-8. As seen in the figures the model has good agreement with the measured data over the calibration and verification periods and matches both the high and low flow regimes as presented in the flow duration plot and the calibration statistics. Discussions of some of the model statistics listed in Table 3-8 are presented below:

- Error in Total Volume – compares the total simulated runoff with observed runoff. Excessive errors in this parameter can be impacted from the runoff generation process, simulation of evaporation, or groundwater losses.

- Error in high flow / low flow distributions - highest 10% of flows, lowest 10%, etc – relates to storm peak and potential modifications to infiltration parameter, which shifts the watershed response between surface and groundwater.

- Error in Low Flow recession – compares the difference between the average value of daily recession and the base-flow period comparing simulated and observed flows. Changing AGWRC or DEEPFR impacts the shape of the recession limb.

- Error in storm volumes – specific identified storms, are capsulated and evaluated for volume, peak. This will drive the seasonal storm errors as well.

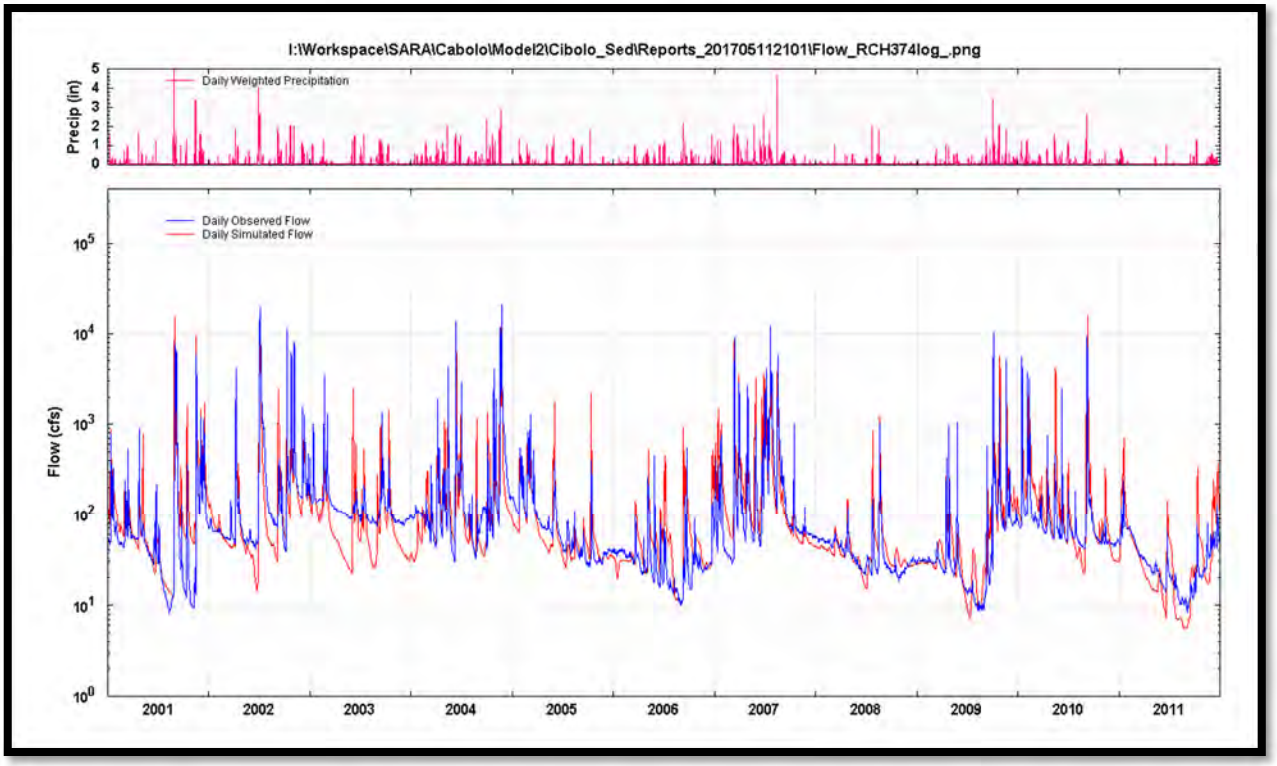


Figure 3-20 Cibolo Creek HSPF Model Calibration at USGS 08186000 – Time Series Plot

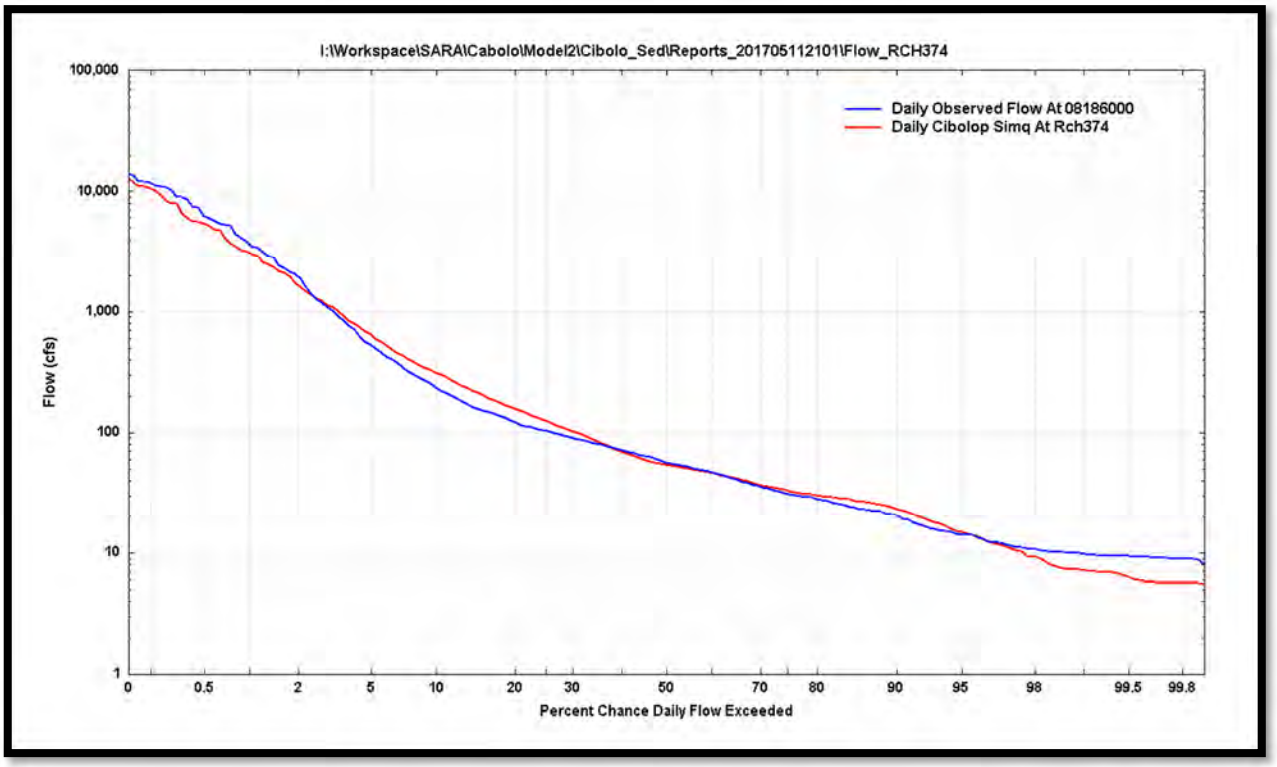


Figure 3-21 Cibolo Creek HSPF Model Calibration at USGS 08186000 – Flow Duration Plot

Table 3-8 USGS Gauge 08186000 Model Calibration Statistics

Simulation Period: 11 years from 2001/01/01 to 2011/12/31

	Observed Total Runoff	Simulated Total Runoff
Total (inches)	38.54	37.93
10% high (inches)	28.22	26.08
25% high (inches)	32.13	31.24
50% high (inches)	35.61	34.90
50% low (inches)	2.93	3.03
25% low (inches)	0.96	1.05
10% low (inches)	0.25	0.27
Storm volume (inches)	5.01	4.52
Average storm peak (cfs)	4083	3833
Baseflow recession rate	0.98	0.98
Coefficient of Determination		0.87
Mean Error		-0.06
Nash-Sutcliffe		0.85

	Current	Criteria	
Error in total volume (%)	-1.591	10	OK
Error in 10% highest flows (%)	-7.569	15	OK
Error in 25% highest flows (%)	-2.764	10	OK
Error in 50% highest flows (%)	-1.989	10	OK
Error in 50% lowest flows (%)	3.239	10	OK
Error in 25% lowest flows (%)	9.474	15	OK
Error in 10% lowest flows (%)	5.144	20	OK
Error in low-flow recession	0.004	0.03	OK
Error in storm volumes (%)	-9.695	15	OK
Seasonal volume error (%)	-6.754	20	OK
Error in average storm peak (%)	-6.101	15	OK
Summer volume error (%)	-7.203	20	OK
Winter volume error (%)	-0.449	15	OK

3.2.7. Sensitivity Analysis

Model sensitivity runs were performed in which flow and water quality parameters were adjusted (higher and lower) by 20%. The sensitivity runs illustrate how responsive the model results are to a single hydrologic or water quality parameter. Parameter modified include those used in the calibration process: LZSN, INFILT, DEEPFR, BaseTP, UZSN, INTFW, and impervious RETSC. Table 3-9 shows the results of the sensitivity analysis and presents the percentage change in total flow as compared to the calibrated model condition. Results indicate that no individual parameter had a dramatic impact on either the correlation coefficient or the Nash-Sutcliffe Efficiency coefficient. Also, while there were some differences within individual years, the model was not overly sensitive to any given parameter.

Table 3-9 Cibolo Creek Sensitivity Analysis Table

	Base	INFL		LZSN		BASETP		DEEPFR		INTFW		UZSN		RETSC	
	Inches	+20%	-20%	+20%	-20%	+20%	-20%	+20%	-20%	+20%	-20%	+20%	-20%	+20%	-20%
2001	2.67	-6%	8%	-9%	10%	-1%	0%	-9%	10%	-1%	1%	-4%	6%	-1%	1%
2002	5.03	-5%	7%	-4%	5%	0%	0%	-7%	8%	0%	0%	-5%	5%	-1%	1%
2003	7.06	-6%	8%	-3%	4%	0%	0%	-7%	9%	0%	0%	-4%	5%	-1%	1%
2004	2.78	-4%	5%	-2%	3%	-1%	0%	-8%	10%	0%	-1%	-5%	7%	-3%	3%
2005	4.86	-6%	7%	-4%	5%	0%	0%	-7%	9%	0%	0%	-5%	5%	-1%	1%
2006	0.9	-3%	4%	0%	2%	0%	0%	0%	2%	1%	0%	-6%	6%	-4%	6%
2007	4.43	-7%	9%	-4%	4%	0%	0%	-9%	10%	-1%	1%	-6%	7%	-2%	2%
2008	3.61	-5%	7%	0%	0%	0%	0%	-8%	11%	0%	0%	-5%	6%	-1%	1%
2009	0.91	-2%	4%	-2%	4%	0%	0%	-1%	2%	1%	0%	-2%	4%	-3%	4%
2010	4.63	-5%	7%	-5%	6%	0%	1%	-10%	13%	0%	1%	-5%	8%	-1%	2%
2011	2.5	-5%	7%	-2%	4%	0%	0%	-5%	7%	0%	0%	-4%	5%	-1%	2%
2012	2.59	-5%	6%	-5%	6%	0%	0%	-8%	10%	0%	0%	-5%	6%	-2%	2%
2013	1.58	-5%	6%	-2%	2%	-1%	0%	-4%	6%	-1%	0%	-6%	7%	-4%	3%
2014	1.48	-6%	7%	-5%	7%	0%	0%	-5%	6%	-1%	1%	-5%	6%	-3%	4%
Total	3.341	-5%	7%	-3%	-3%	0%	0%	-8%	10%	0%	0%	-5%	6%	-1%	2%
10% high	2.28	-8%	11%	-4%	-4%	0%	0%	-4%	5%	0%	1%	-6%	8%	-1%	1%
25% high	2.753	-7%	9%	-4%	-4%	0%	0%	-6%	8%	0%	0%	-6%	7%	-1%	2%
50% high	3.079	-6%	8%	-4%	-4%	0%	0%	-7%	10%	0%	0%	-5%	6%	-1%	2%
50% low	0.262	1%	-1%	-1%	-1%	0%	0%	-8%	10%	0%	0%	0%	0%	-2%	2%
25% low	0.086	0%	-1%	-1%	-1%	-1%	0%	-6%	7%	-1%	0%	-1%	0%	-2%	1%
10% low	0.02	0%	0%	0%	0%	0%	0%	0%	5%	0%	0%	0%	0%	0%	5%
Storm vol	0.515	-9%	11%	-2%	-2%	0%	0%	-4%	5%	-1%	1%	-7%	8%	-1%	1%
Peak (cfs)	6,273	-10%	13%	-3%	-3%	0%	0%	-2%	2%	-4%	5%	-6%	7%	-1%	1%
R^2	0.893	0%	0%	1%	-1%	0%	0%	1%	0%	0%	0%	0%	-1%	0%	0%
Nash-S Eff	0.749	-2%	-1%	1%	-2%	0%	0%	-2%	-2%	0%	0%	-1%	-1%	0%	-1%

3.3. Water Quality Modeling

The simulation of water quality constituents in the Cibolo Creek watershed builds upon the hydrologic and hydraulic calibration by incorporating the simulation of sediments followed by other water quality components. The simulation of sediments involves first detaching the sediments from the land surface, then the transmission of sediments to the creek. Once in the creek, based upon channel geometry and flow dynamics, additional sediments are either scoured out of the channel or deposited onto the channel bed. Following the sediment simulation, water quality components are incorporated including: nutrients, E.coli, and metals.

3.3.1. Sediment

Sediment parameterization in the HSPF model began with a range of values from the previously calibrated model encompassing Cibolo Creek from a 2014 USGS study (Banta & Ockerman, 2014) and also incorporated guidance from *EPA BASINS Technical Note 8* (United States Environmental Protection Agency, 2006). Sediments parameters were then adjusted at the washoff generation step in both PERLND and IMPLND modules. Once sediment concentrations from each land use was simulating appropriately compared to similar land use types, the sediment transport mechanism was calibrated. The reach calibration in the RCHRES module involved evaluating and modifying on a reach by reach basis, the shear stress thresholds for scour and degradation. Key parameters used in the HSPF model simulation are listed in **Appendix B**.

3.3.2. Nutrients, Metals, and E.coli

Pollutant loading of water quality parameters, such as nutrients, from pervious and impervious land surfaces in HSPF is generated using a build-up and wash off scheme, with the final loading being a combination of loads simulated from interflow, groundwater, and loads attached to sediments. As a function of land use and varying throughout the year, HSPF simulates the buildup rate of each pollutant on the land surface (ACQOP), limited by the maximum amount that parameter can be stored on the land surface (SQOLIM). When rainfall exceeds a target rate (WSQOP) then 90% of the stored pollutant will wash off with surface runoff. Pollutants from the pervious land surfaces also have concentrations associated with interflow (IOQC) and groundwater (AOQC). For parameters such as ortho-phosphorus, lead or zinc, the sediment simulated from wash off or scour also contain concentrations of pollutants and are accounted for in the potency factors. Breakdown of water quality parameters are included in **Appendix B.**

To accurately simulate the watershed is to recognize that water quality parameters do not only vary by land use and segment, but also by season. To account for this annual distribution, parameters of accumulation, total storage, interflow and groundwater rates were modeled as varying seasonally where appropriate. In general, the annual distribution follows the growth and dormant seasons of the year, whereby loading rates are highest in the summer and fall months and lowest in the winter months. While varying by parameter, Figure 3-22 shows the relative magnitudes of the loading rate by each land use. As seen in the figure, in general, the highest loading rates are associated with agriculture activities, followed by residential uses. Full breakdown of parameter usage can be found in **Appendix B**. This trend is followed by the interflow and groundwater parameters as well.

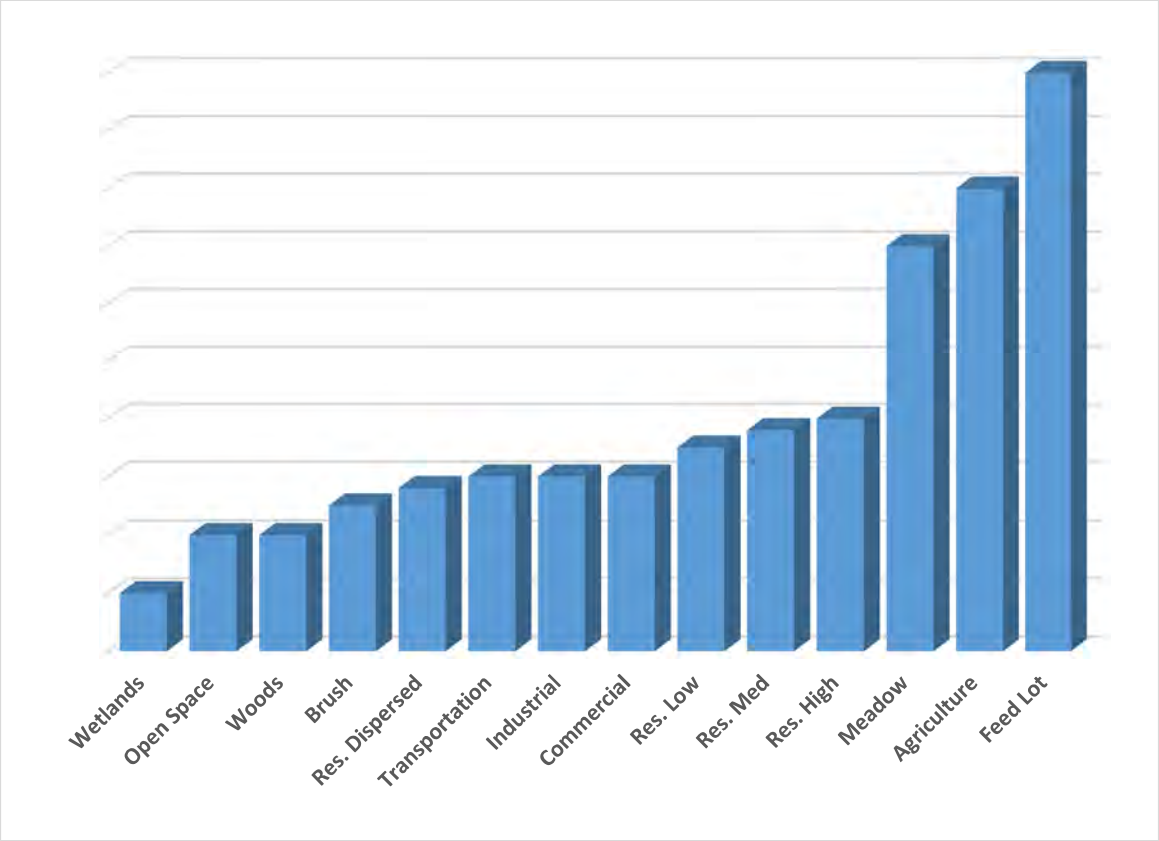


Figure 3-22 Cibolo Creek Nutrients Relative Loading Rate Distribution by Land Use

3.3.3. Water Quality Calibration

The water quality calibration process involved two steps. First, water quality loads were compared against similar loading throughout the country on a land use basis. Then resulting instream concentrations were visually compared to measured data for concurrence.

The results of the calibration process showed that water quality components coming from the land surface in Cibolo Creek were generally lower than those nationwide. While parameters were adjusted within generally acceptable limits, the loading was still below the land use targets. Closer examination of the calculation showed that the difference is more a function of water volume than of land use generated concentration. In the semi-arid climate of Cibolo Creek, where evaporation exceeds rainfall and without streamflow contributions from springs and WWTPs, the creek would run dry, this was not an unexpected conclusion. Considering the instream concentrations of pollutants showed a general agreement with the measured data, the calibrated concentrations were deemed appropriate.

3.3.4. Water Quality Results

The results of the water quality model simulation are shown at five locations throughout the watershed, where the highest density of observed water quality data were available. The five locations are shown in Figure 3-23, with labels indicating the HSPF modeled river reach, corresponding to the water quality graphs seen in Figure 3-24 through Figure 3-44. As seen in the figures, there is agreement between the water quality data samples taken and the measured data. It is of note that water quality samples are typically taken on a schedule rather than isolating individual events. As a result, samples often reflect baseflow conditions rather than peaks of hydrological events. Thereby, comparisons between measured and modeled data will primarily compare the lower flow conditions with isolated peaks occurring when a sampling event happens to align with a hydrologic event of significance. Notes relative to each parameter graphed are discussed below

- **Dissolved Oxygen** – concentrations vary seasonally throughout the watershed and track measured data at each of the calibration reaches

- **Total Nitrogen** – The largest concentration of data points for total nitrogen is located at Reach 374, which shows a general agreement with measured data, following the seasonal trends in increasing and decreasing water quality. Data at Reach 281 and 323 show an increasing trend in total nitrogen between 2015 and 2016. This trend is also seen in the modeled data at reach 184.

- **Total Phosphorus** – Near the confluence with the San Antonio River at Reach 374, total phosphorus samples were collected on nearly monthly intervals between 2010 and 2017. Results showed good correlation between 2011 and 2012 with the remainder of the simulation falling slightly below the measured results, yet within the range of modeled values. This trend holds true for the other sites as well, except for the upstream reach 74 at Boerne. The measured data at reach 74 falls between 0.5 and 3.0 mg/L, while the modeled results are less than 1.0 mg/L. It is not likely that land use contributions could see values naturally in this range, which suggests a contribution another point source, other than the WWTP, which is accounted for at concentrations as reported to EPA.

- **Total Suspended Solids** – available at reach 374. Comparisons to 6 samples takes in 2011 and 2012 show low concentrations in baseflow conditions in 2011 and storm concentrations in 2012 which generally agree with modeled results over these time periods

- **E.coli** – event driven peak concentrations range from 0 to nearly 300,000 CFUs. Measured data is significantly lower and likely reflects baseflow conditions. Comparing the model simulated data on the same day as the grab samples were taken shows comparable results within the same range of CFU values.

- **Lead** - only available at reach 374. Modeled values generally fall between 0.06 and 0.1 ug/L. The measured data is listed at 0.1 ug/L which is reported at the detection limit for the metal.

- **Zinc** – only available at reach 374. Modeled values generally fall between 1 and 2 ug/L. The measured data is listed at 5 ug/L which is reported at the detection limit for the metal.

While the Cibolo Creek watershed contains some unique features related to hydrology, evaporation, WWTP inflows, and aquifer recharge, based upon the data available to calibrate, the watershed model calibration is acceptable. Further, the use of this model for evaluating BMP conditions in the Cibolo Creek is appropriate.

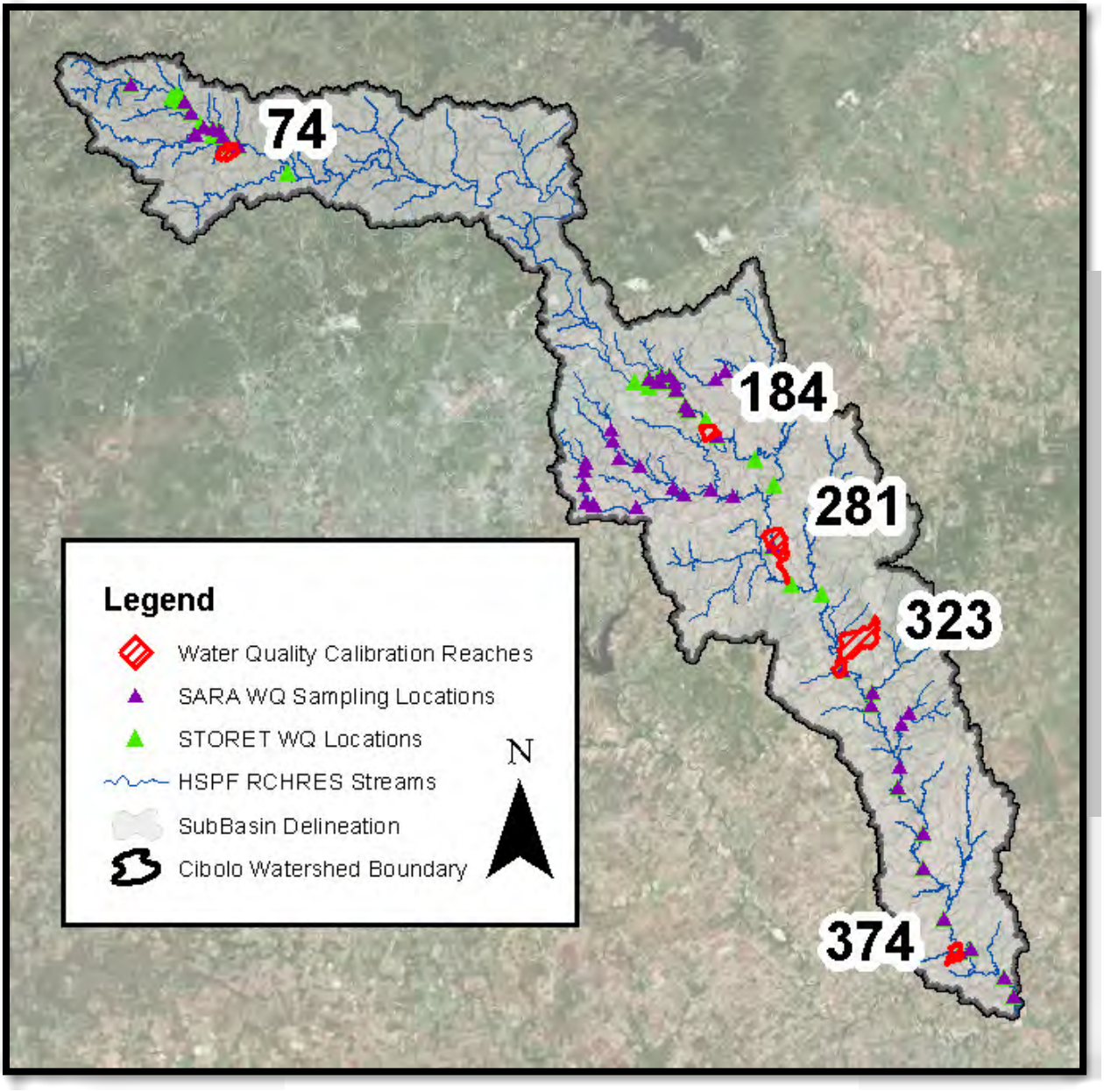


Figure 3-23 Cibolo Creek Water Quality Calibration Reaches

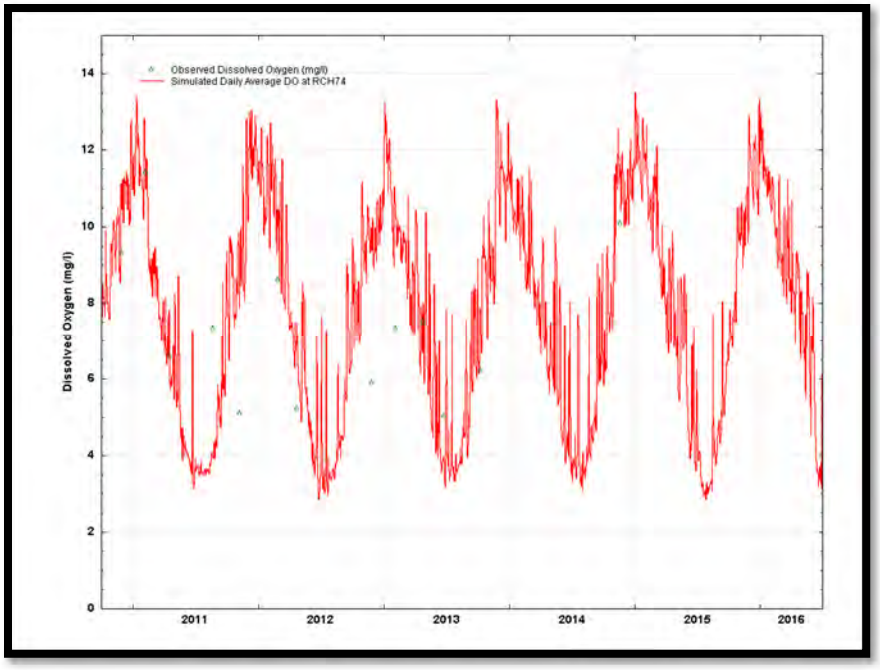


Figure 3-24 Dissolved Oxygen Measured vs Modeled Concentration at Reach 74

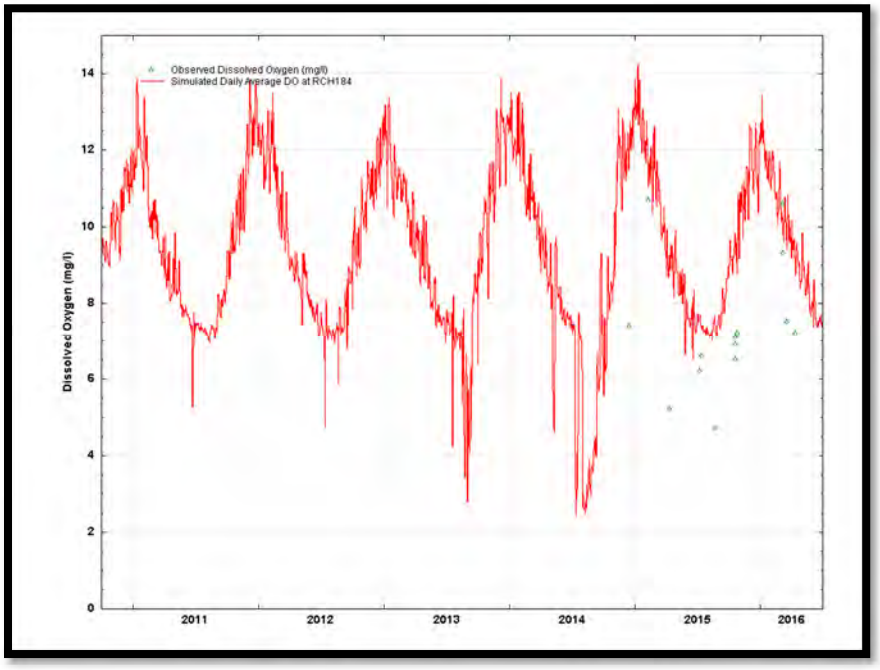


Figure 3-25 Dissolved Oxygen Measured vs Modeled Concentration at Reach 184

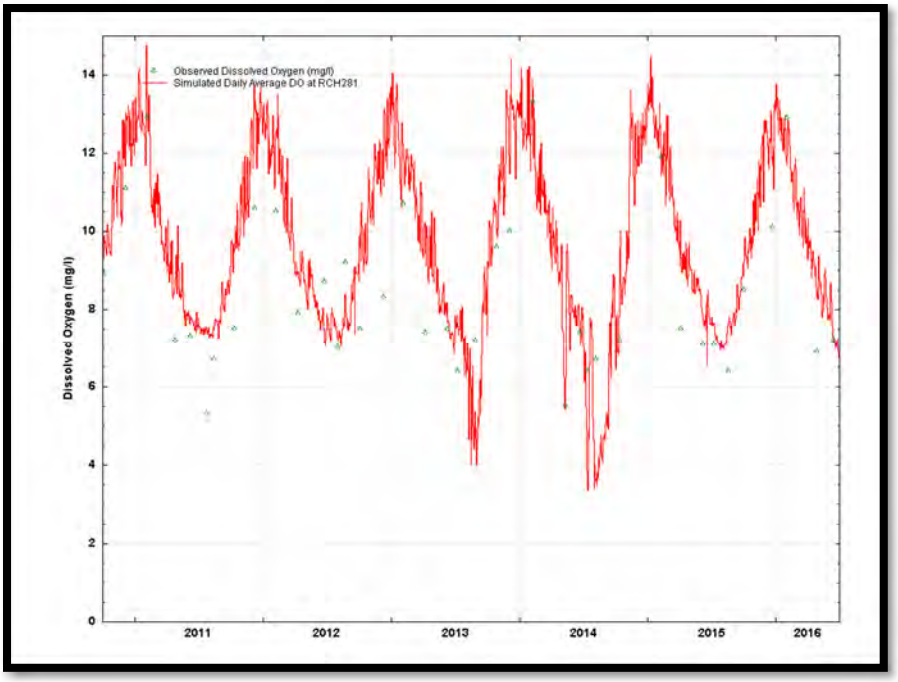


Figure 3-26 Dissolved Oxygen Measured vs Modeled Concentration at Reach 281

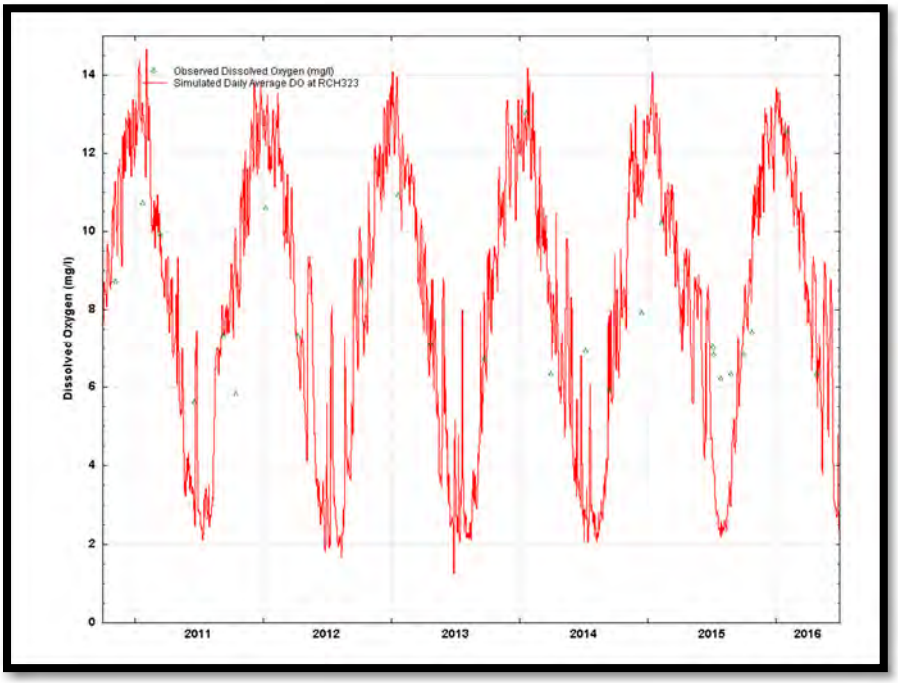


Figure 3-27 Dissolved Oxygen Measured vs Modeled Concentration at Reach 323

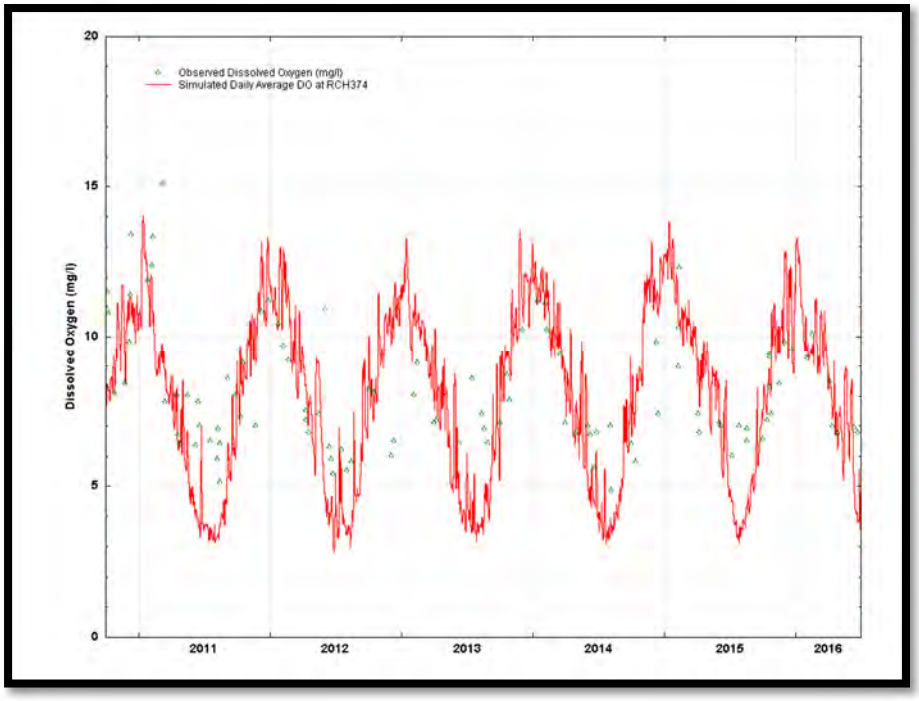


Figure 3-28 Dissolved Oxygen Measured vs Modeled Concentration at Reach 374

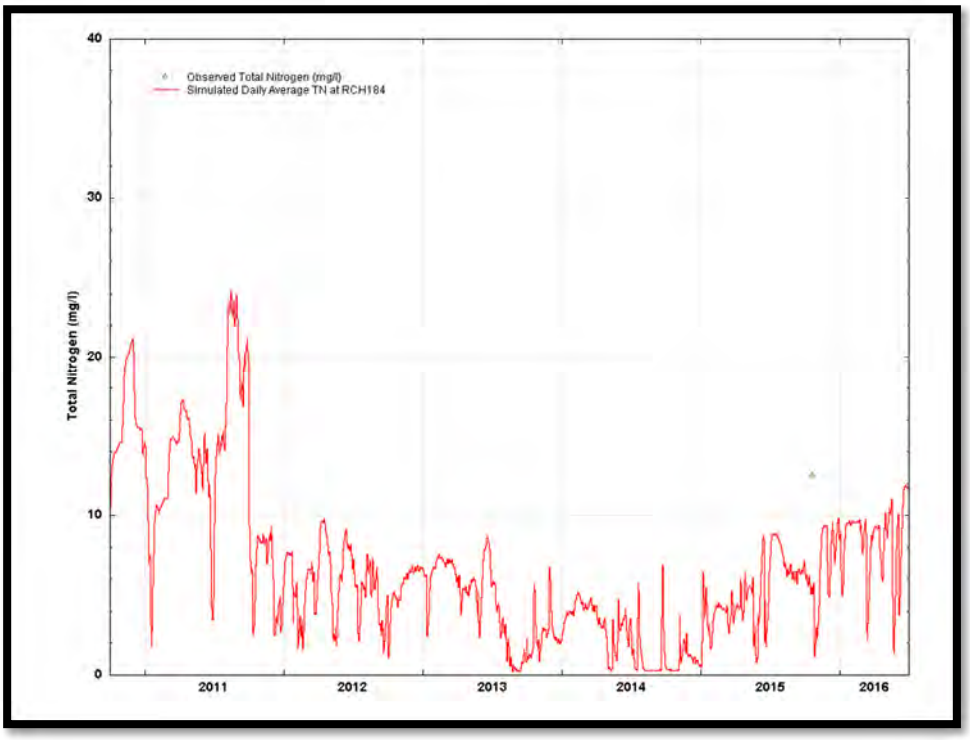


Figure 3-29 Total Nitrogen Measured vs Modeled Concentration at Reach 184

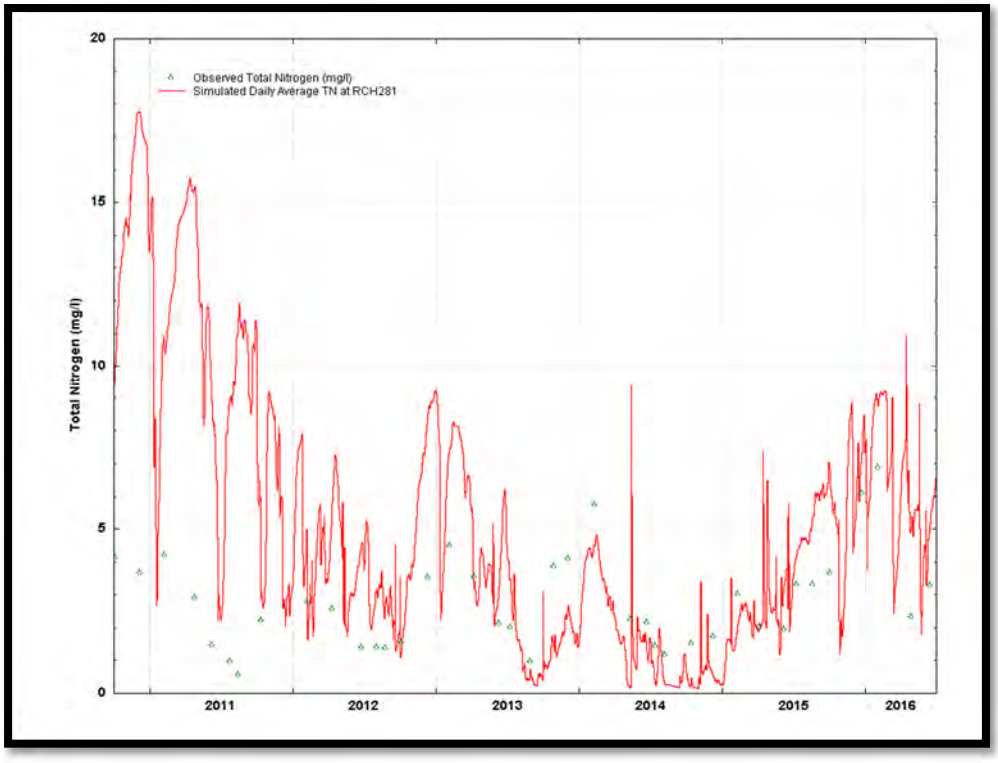


Figure 3-30 Total Nitrogen Measured vs Modeled Concentration at Reach 281

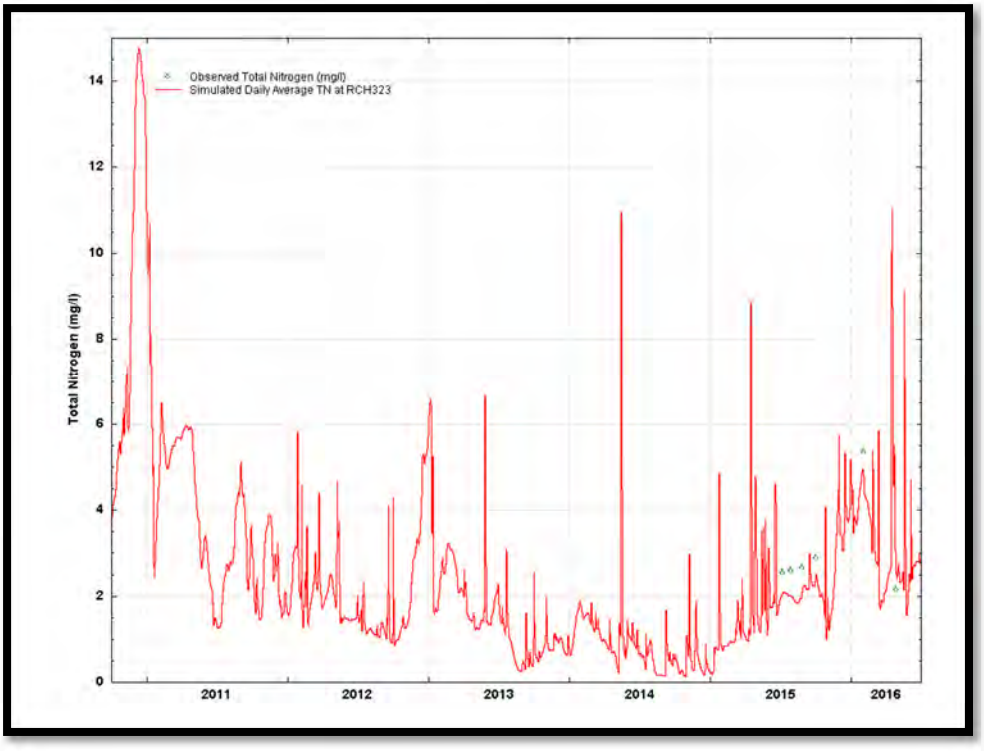


Figure 3-31 Total Nitrogen Measured vs Modeled Concentration at Reach 323

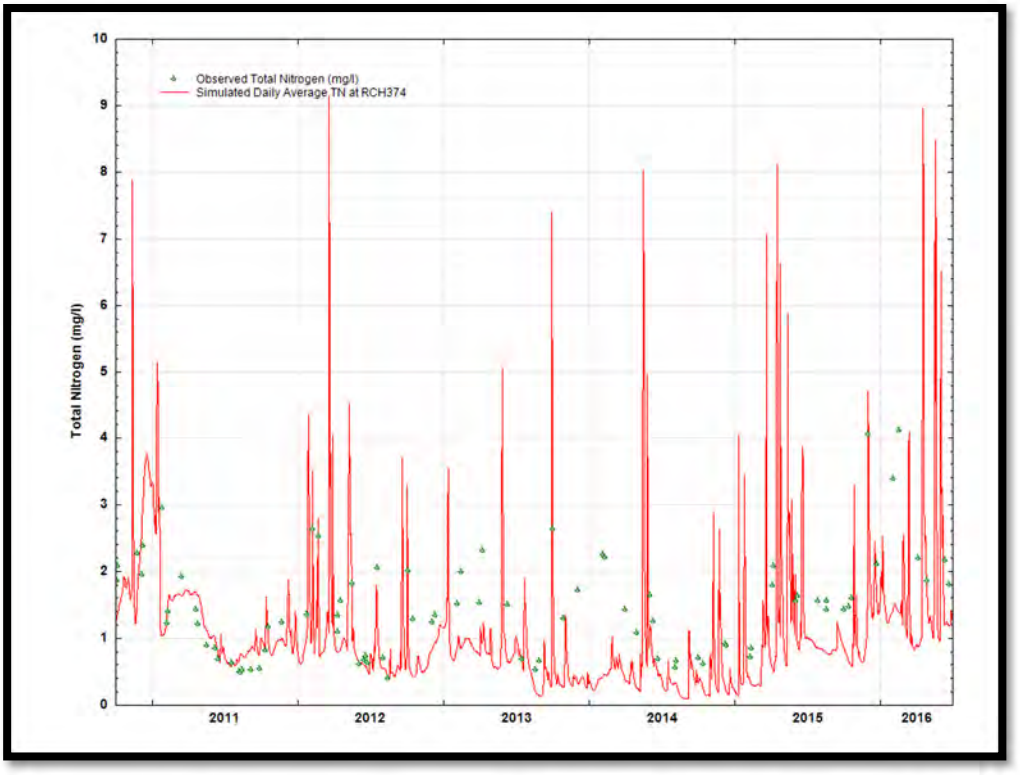


Figure 3-32 Total Nitrogen Measured vs Modeled Concentration at Reach 374

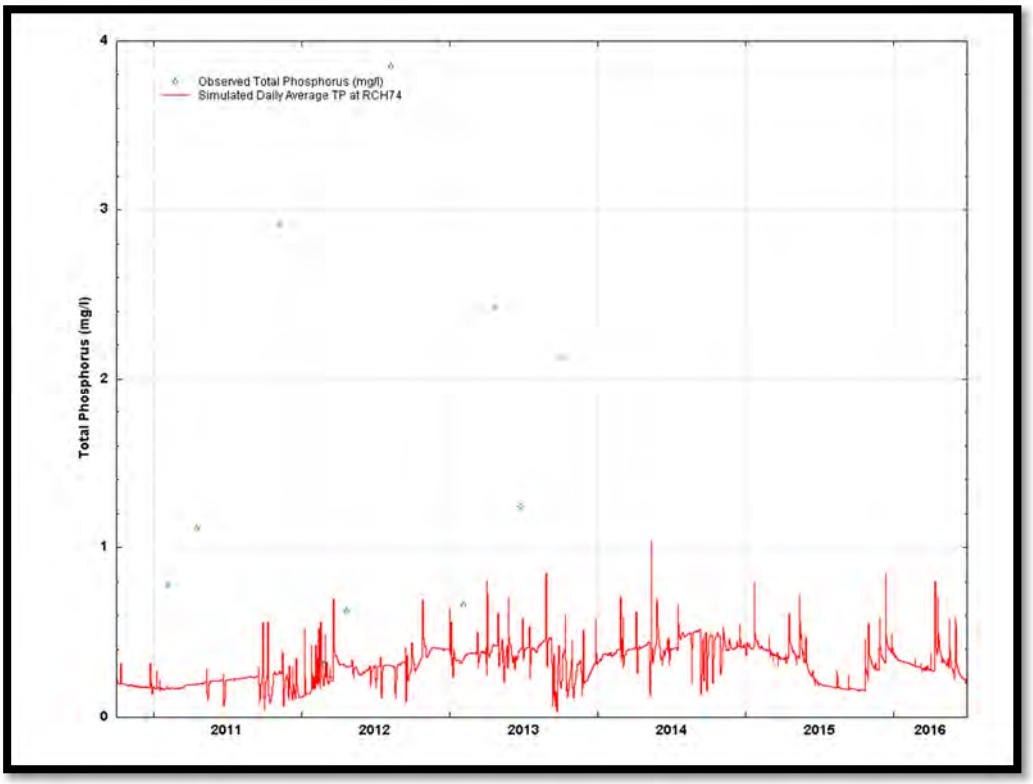


Figure 3-33 Total Phosphorus Measured vs Modeled Concentration at Reach 74

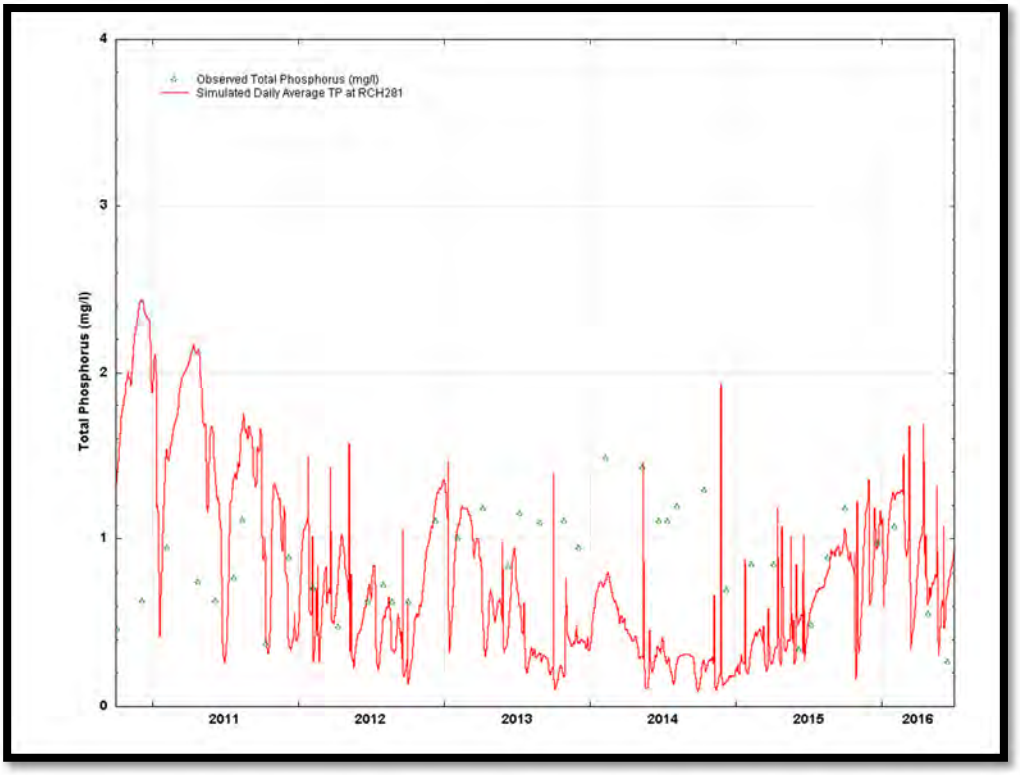


Figure 3-34 Total Phosphorus Measured vs Modeled Concentration at Reach 281

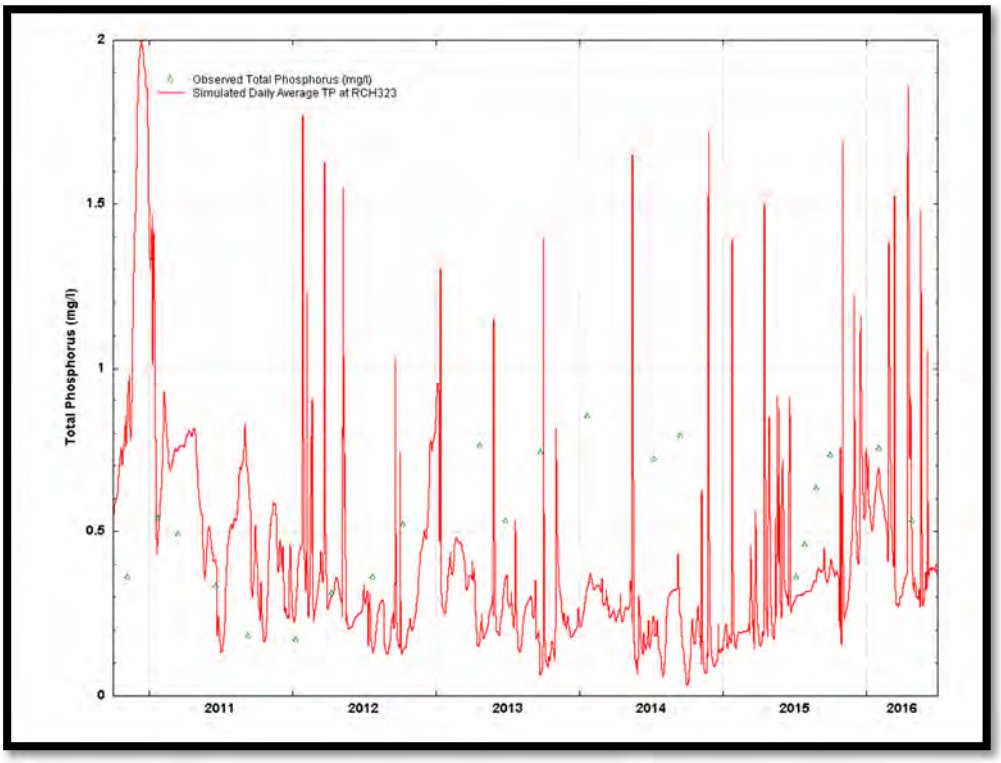


Figure 3-35 Total Phosphorus Measured vs Modeled Concentration at Reach 323

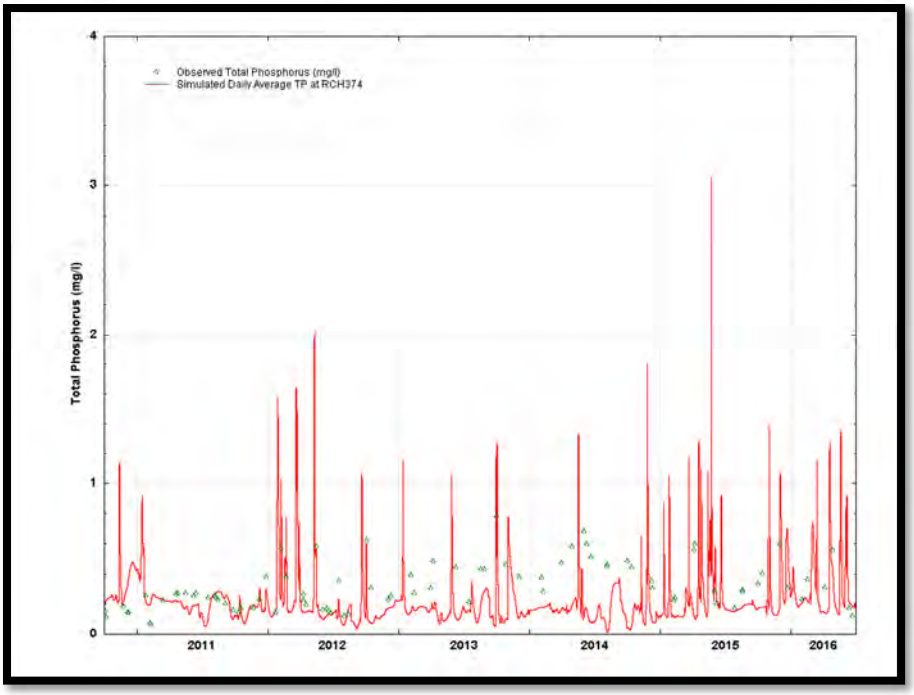


Figure 3-36 Total Phosphorus Measured vs Modeled Concentration at Reach 374

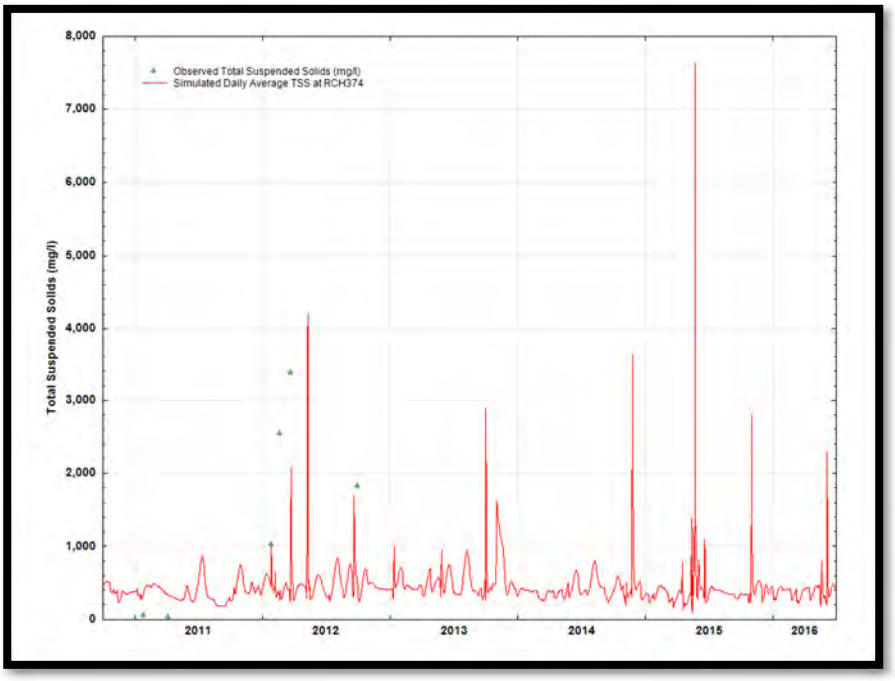


Figure 3-37 Total Suspended Solids Measured vs Modeled Concentration at Reach 374

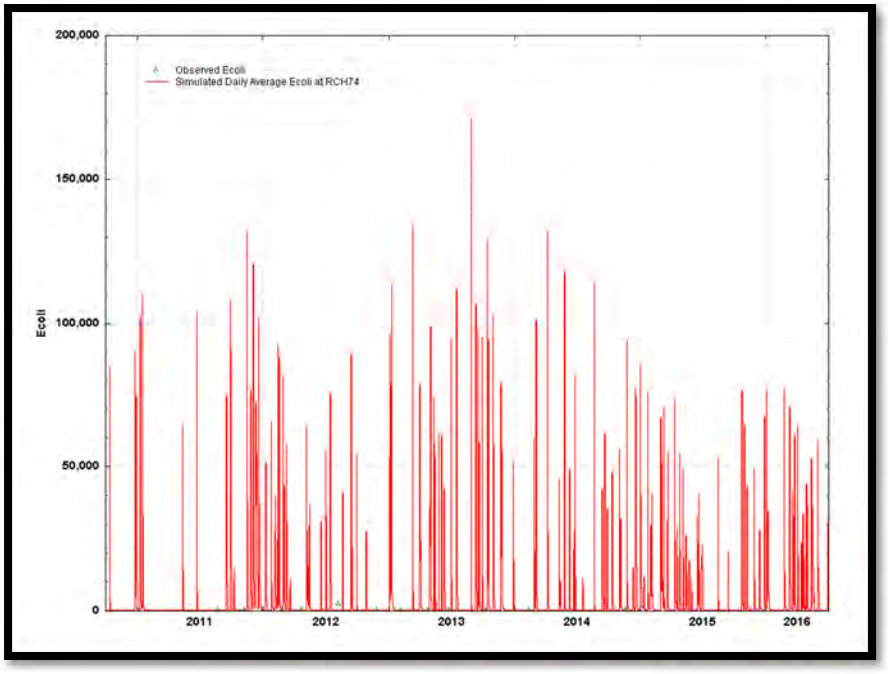


Figure 3-38 E.coli Measured vs Modeled Concentration at Reach 74

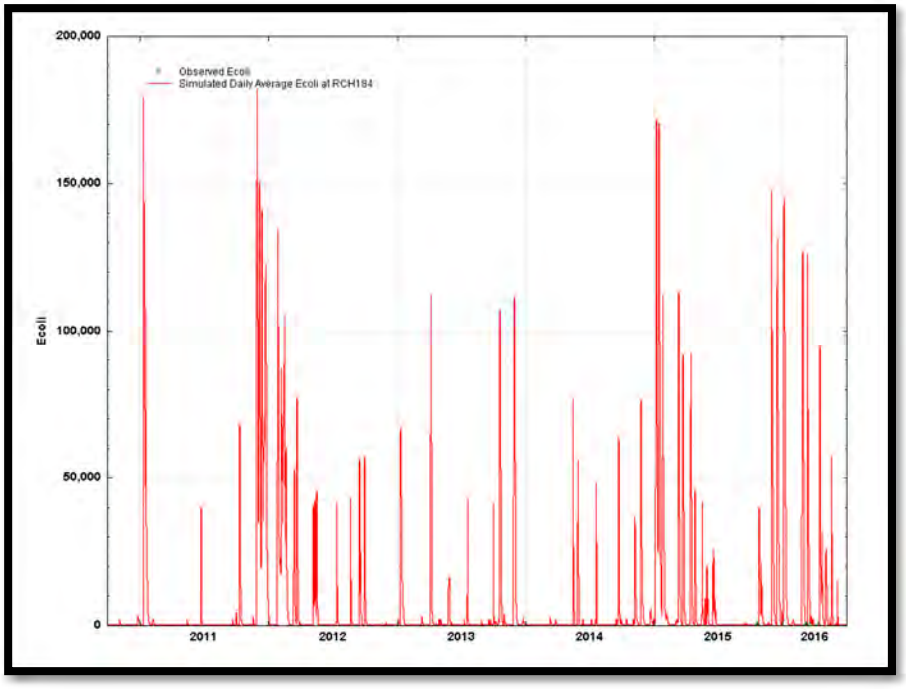


Figure 3-39 E.coli Measured vs Modeled Concentration at Reach 184

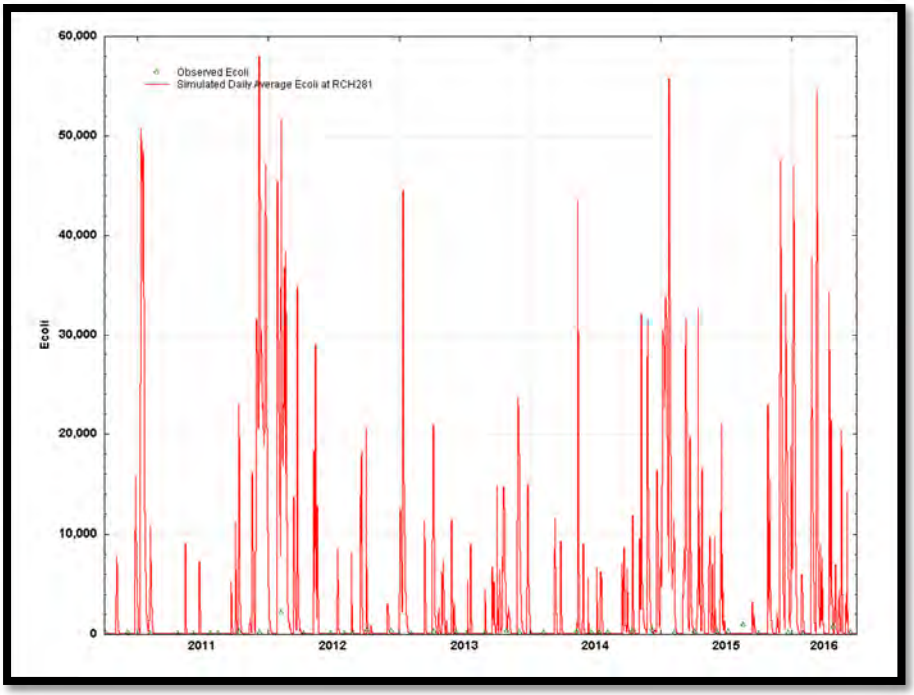


Figure 3-40 Ecoli Measured vs Modeled Concentration at Reach 281

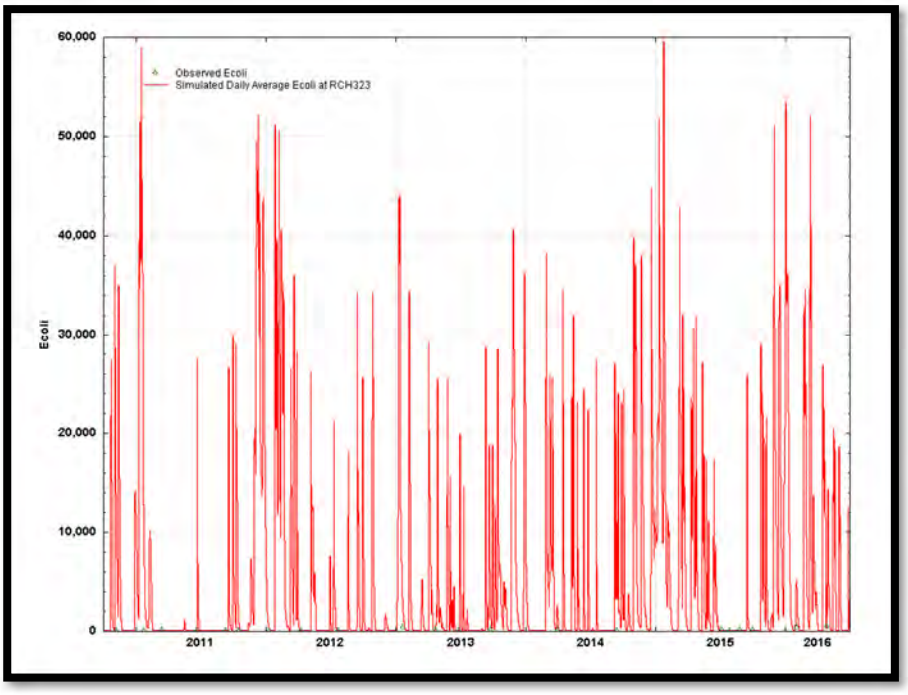


Figure 3-41 E.coli Measured vs Modeled Concentration at Reach 323

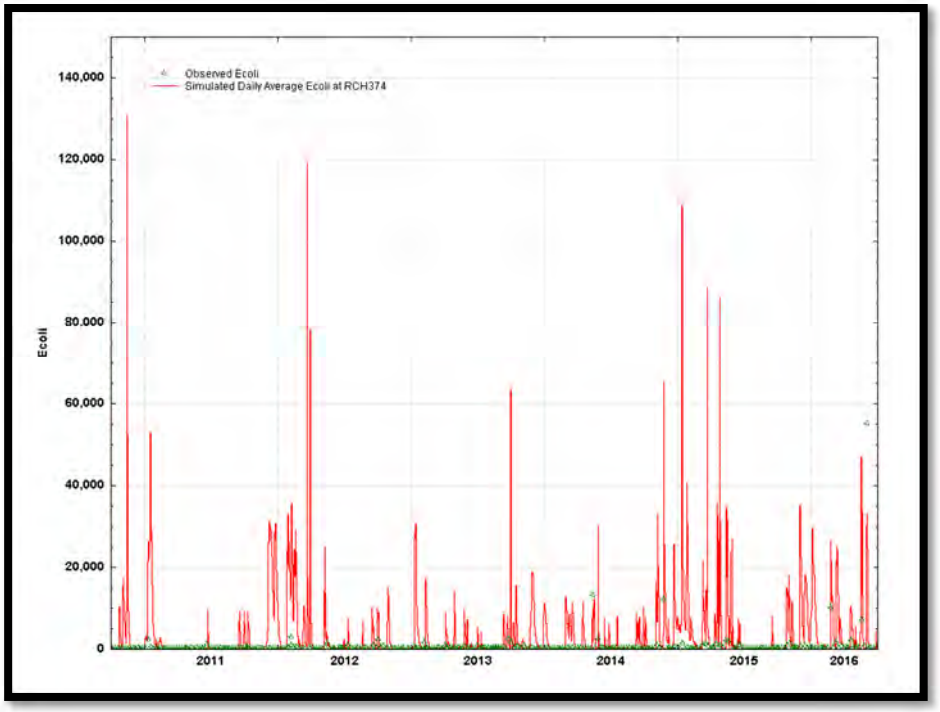


Figure 3-42 E.coli Measured vs Modeled Concentration at Reach 374

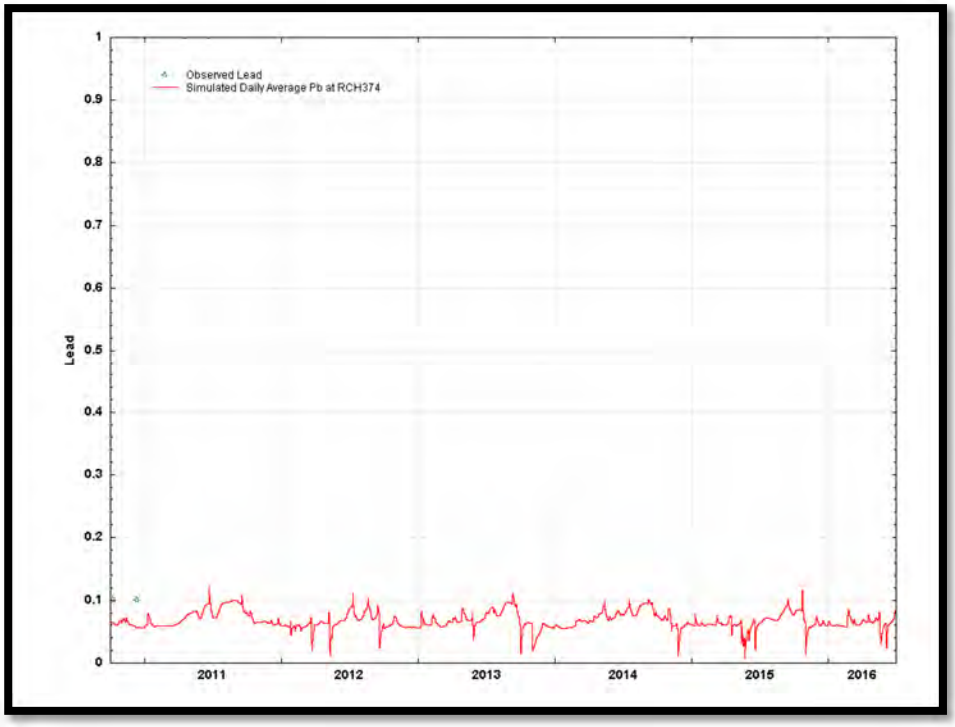


Figure 3-43 Lead Measured vs Modeled Concentration at Reach 374

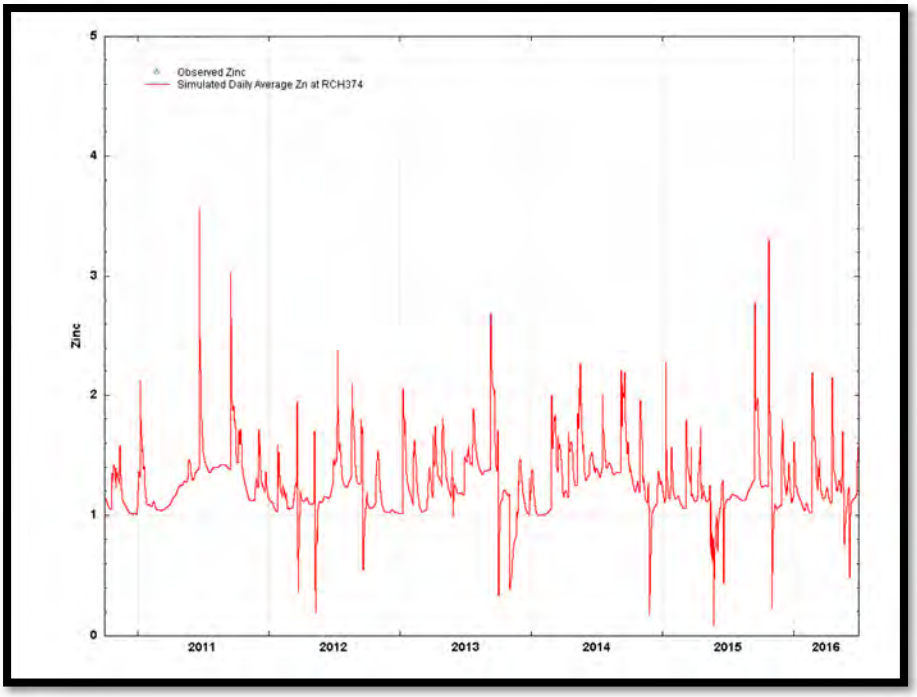


Figure 3-44 Zinc Measured vs Modeled Concentration at Reach 374

3.4. Water Quality Damage Reaches

This section discusses the Water Quality damage reaches throughout the watershed. For this report, Water Quality damage reaches are defined as river reaches that fail to meet a minimum screening level criteria for a water quality constituent over an extended period of time. Water Quality Damages are identified throughout the watershed by generating flow weighted average annual conditions for key water quality constituents and making an evaluation as to which reach falls below a targeted screening level.

3.4.1. Evaluation Criteria

Table 3-10 presents the screening levels for determining damage reaches. These levels are based upon the Texas Clean Rivers Program (CRP) and documented in Chapter 9 of SARA's Water Quality modeling standards (San Antonio River Authority, 2014). Reaches that fall above the screening level for nitrate nitrogen, ammonia nitrogen, organic phosphorus, ortho-phosphorus, chlorophyll a, or bacteria are identified as damage reaches. Reaches that fall below the screening level for dissolved oxygen are identified as damage reaches.

Table 3-10 Cibolo Creek Damage Reach Screening Levels

Water Quality Constituent	Screening Level	Unit
Dissolved Oxygen	3.0	mg/L
Nitrate Nitrogen	1.95	mg/L
Ammonia Nitrogen	0.33	mg/L
Organic Phosphorus	0.32	mg/L
Ortho-Phosphorus	0.37	mg/L
Chlorophyll a	14.1	ug/L
Bacteria (E.coli)	126	#/dL

3.4.2. Water Quality Damage Reach Evaluation

Flow weighted annual averages of water quality constituent concentrations were calculated based upon daily data outputted as part of the model simulation. Flow weighting the concentrations provides a larger importance towards times when reaches have their largest flow contribution, which prevents times of stagnant or low water conditions from skewing the result. Annual average constituent concentrations were calculated for each year between 2000 and 2016 and the resulting damage reaches by constituent are discussed below. The Water Quality Workmaps, in addition to the figures within the report, display the Water Quality damage reaches for the evaluated constituents.

In addition to the annual flow weighted averages, SARA's Load Reduction Tool (LRT) was applied to the watershed, focusing on Nitrate, Ammonia, Ortho-Phosphorus, and Chlorophyll-a. The LRT, automatically determines the amount of pollutant reduction needed to meet an instream water quality standard on a subbasin basis, progressing from upstream to downstream. The tool only considers surface loading in establishing load reductions and is a precursor step to running SARA's enhanced BMP tool, BMP Reporter Tool, or BMP Processor tools. These additional tools will be evaluated in the BMP assessment phase of this project as deemed beneficial to BMP selection and prioritization.

3.4.2.1. Dissolved Oxygen (DO)

There are no reaches in the watershed that exceed the screening threshold for dissolved oxygen. In all reaches, DO levels showed seasonal patterns, fluctuating with temperature, however in no instances did the dissolved oxygen levels drop below the screening level sufficiently to breach the screening level threshold

3.4.2.2. Nitrate Nitrogen (NO3)

Figure 3-45 shows the nitrate nitrogen damage reaches throughout the watershed. There are three groups of damage reaches:

- The most-upstream group includes damage reaches in tributaries to Cibolo Creek and located upstream of the Edwards Aquifer Outcrop. The basins for these tributaries are located over the Edwards Aquifer recharge zone. These reaches likely have high levels of nitrate nitrogen since they are dry much of the time. A lack of flow in these reaches could contribute to elevated concentrations of nitrate nitrogen when wash off does occur.

- Lower Cibolo Creek between IH-10 and Sutherland Springs is a damage reach. WWTPs and spring contributions account for the majority of the flow in these reaches during dry periods.

- A tributary to Elm Creek is a damage reach. This tributary is approximately 3.5 northwest of New Berlin and receives runoff primarily from pastures and woods.

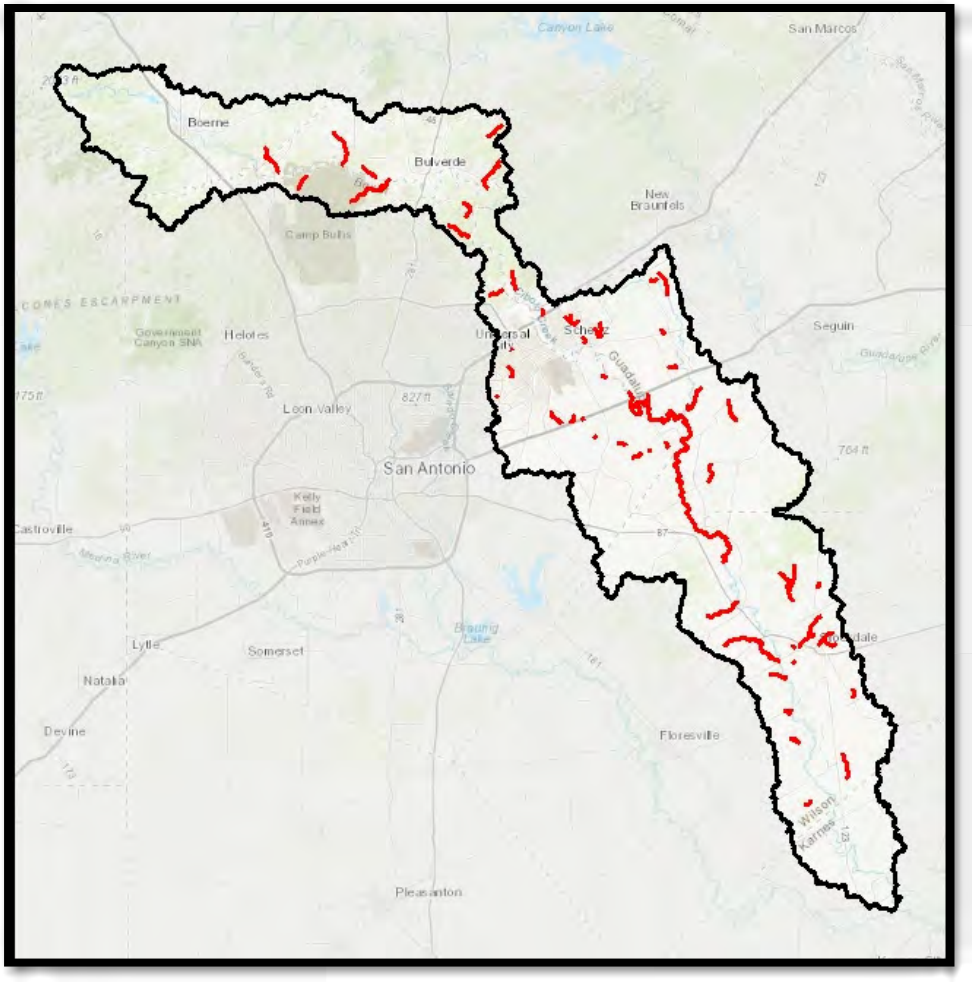


Figure 3-45 Nitrate Nitrogen Damage Reaches

3.4.2.3. Ammonia Nitrogen (NH4)

The isolated damage reaches for Ammonia Nitrogen area seen in in Figure 3-46. The areas are located in basins adjacent to the Edwards Outrrop or in basins adjacent to the main creek within the agriculture zone. Initially, the reach of Cibolo Creek just downstream of IH-10 was shown to have average annual concentrations higher than screening levels. This reach is located just downstream of a WWTP whose discharges caused the screening threshold to be exceeded. Inspection of the WWTP discharge data showed that plant discharges from 2005 and 2006 caused the exceedance. Plant discharge modifications since this time have resolved this issue and NH4 did not exceeded the screening threshold during the simulation period after 2006.



Figure 3-46 Ammonia Nitrogen Damage Reaches

3.4.2.4. Organic Phosphorus

There are no reaches in the watershed that exceed the screening threshold for organic phosphorus. The highest concentrations of organic phosphorus are in reaches of Cibolo Creek aligning with ortho-phosphorus damage reaches. These reaches are located within agricultural areas and low flows are developed from agricultural land uses and from spring flow.

3.4.2.5. Ortho-Phosphorus (PO4)

As seen in Figure 3-47, ortho-phosphorus is second to only Bacteria (see Section 3.4.2.7) in terms of the number of damage reaches. There are two primary areas that have exceeded the screening threshold for ortho-phosphorus. The first area is downstream of IH-10 where exceedances are driven by agriculture, feed lots, and springs inflows. The second area is in the upper portion of the watershed.

PO4 Damage Reaches:

- Downstream of Boerne and within the Edwards recharge zone, Cibolo Creek and several of its tributaries are considered damage reaches. Infrequent flow in these reaches is likely the cause of the exceedance.
- There are multiple reaches near the Martinez Creek watershed that are damage reaches. These reaches include Cibolo Creek between FM 78 and IH-10, Martinez Creek, Dry Santa Clara Creek, Dry Hollow Creek, as well as several other small tributaries. Cibolo Creek and Martinez Creek receive flow from nearby WWTPs and runoff from residential developments. Also, this area is not isolated to an inflow reach, but includes the entire tributary and Cibolo Creek itself.
- Cibolo Creek between its confluence with San Antonio River and Sutherland Springs. This area has measured total phosphorus concentrations between 0.40 mg/L and 0.60 mg/L, consistent with simulated PO4 values exceeding the screening threshold, confirming this damage center
- As seen in Figure 3-47, Cibolo Creek between IH-10 and Sutherland Springs is a damage reach. This reach includes at least three monitoring sites that have included ortho-phosphorus as a sampling parameter. The monitoring data supports the modeling results, as it also shows ortho-phosphorus in exceedance of its screening criteria.
- Dry Hollow Creek near La Vernia is a damage reach for ortho-phosphorus.
- Elm Creek was also flagged as a damage reach for ortho-phosphorus. The creek is fed by pasture lands, thus there is potential for agriculture-related BMPs to provide load reductions for both nitrogen and phosphorus.

The LRT was simulated to determine which ortho-phosphorus damage reaches can be removed through watershed reductions alone. The tool determined that the Cibolo Creek damage reach along the main channel and into the agriculture area, cannot have its concentrations brought below screening levels through watershed reductions alone. This damage reach will require a combination of approaches to achieve reduction to screening level. It is important for these reaches to integrate sediment load reduction or other sediment management, as phosphorus attaches to sediment particles. Limiting the extent to which sediment enters Cibolo Creek will have a corresponding reduction on phosphorus concentrations.

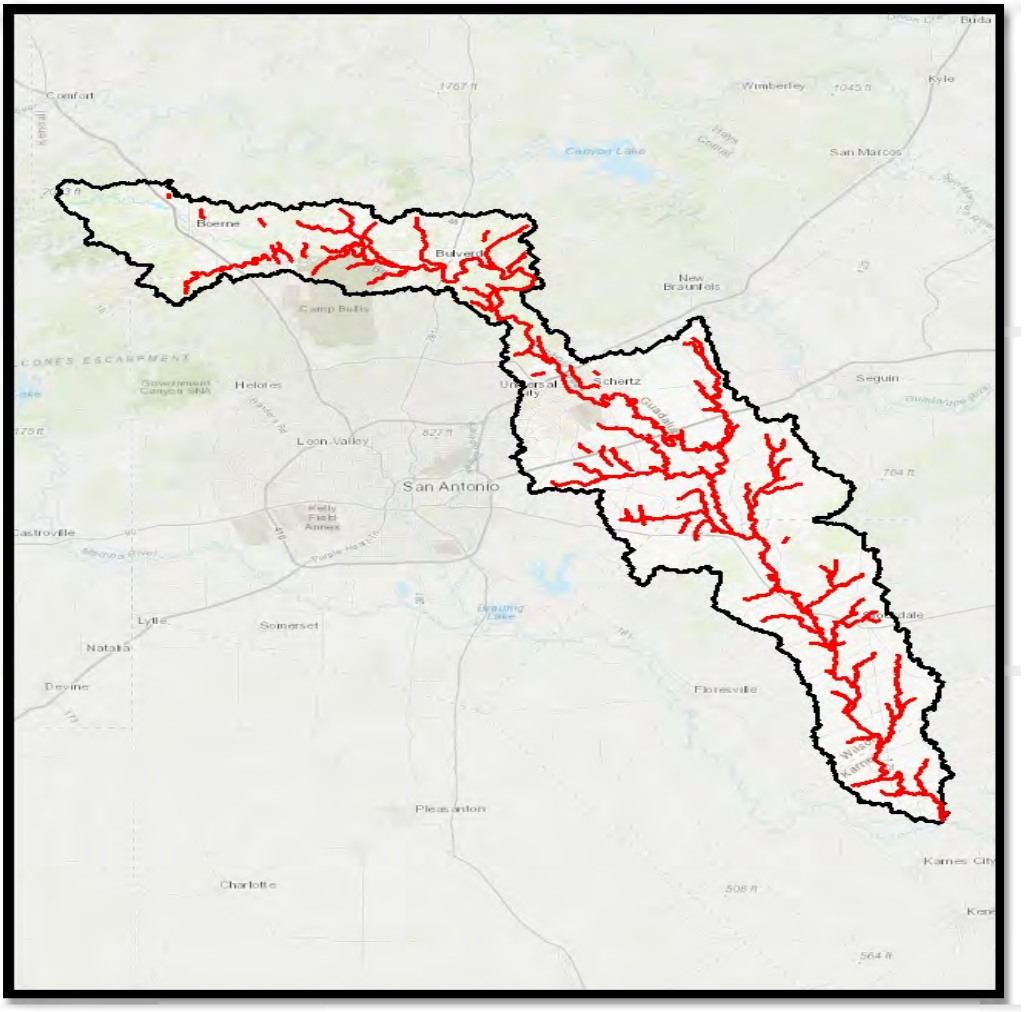


Figure 3-47 Ortho-Phosphorus Damage Reaches

3.4.2.6. Chlorophyll-a

There are no reaches in the watershed that exceed the screening threshold for chlorophyll-a. The highest concentration is located just upstream of Sutherland Springs and is also a damage reach for ortho-phosphorus and nitrate nitrogen.

3.4.2.7. Bacteria (E. Coli)

As seen in Figure 3-48, nearly every modeled reach in the watershed has an average annual exceedance of E.coli. This is likely due to the large spikes in concentration associated with the buildup of E.coli that get reintroduced into the stream during flow events. These large instantaneous concentrations are likely skewing the average annual concentrations.

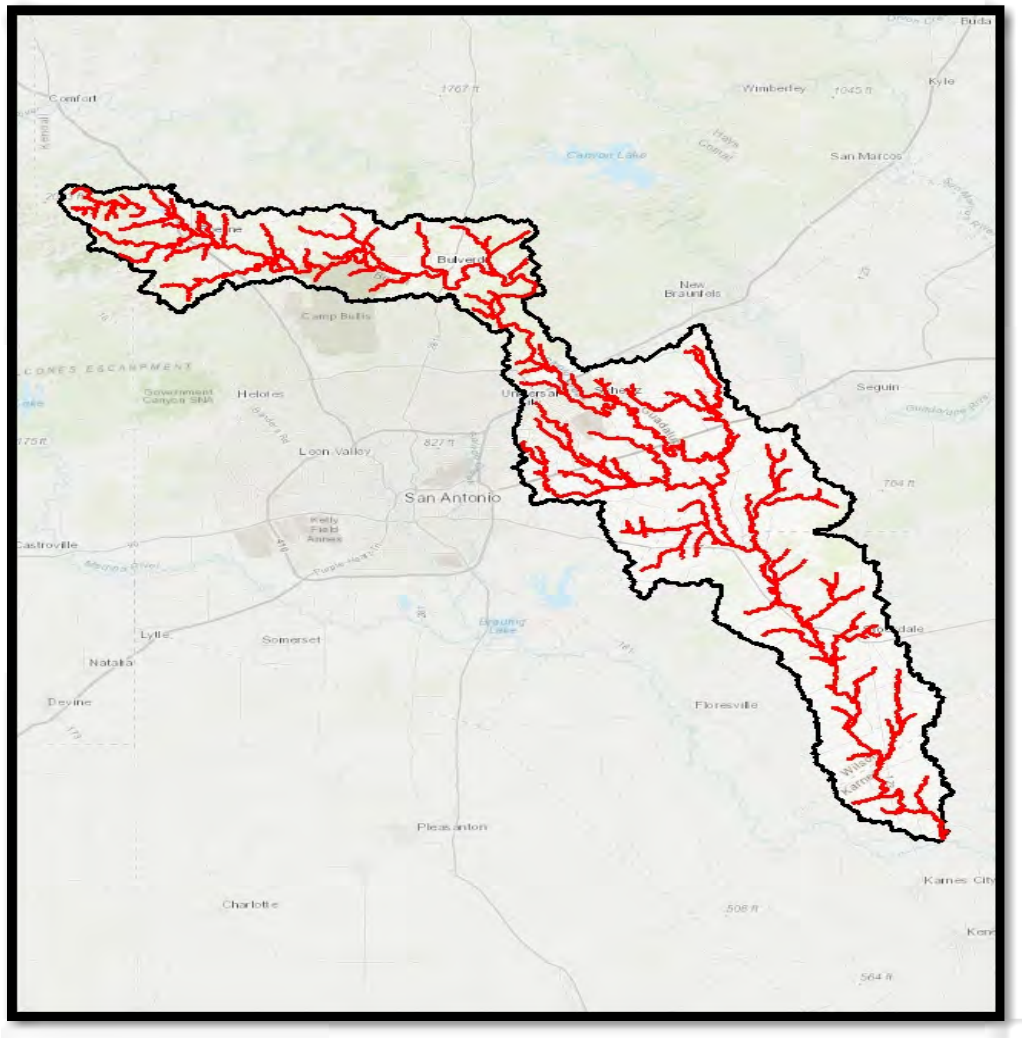


Figure 3-48 E.coli Damage Reaches

4. Nature-Based Recreation

The goal of the Phase 2 nature-based recreation effort is to identify potential opportunities for nature-based recreation areas and open space preservation areas along the 96-mile long Cibolo Creek corridor. These opportunities will be presented as a preliminary concept nature-based recreation plan. In Phase 3 of the C2MP the project team will look to incorporate these recreation opportunities into holistic solutions for flood risk, water quality and stream health concerns within the watershed.

4.1. Overview

The Cibolo Creek watershed includes portions of six counties, including Kendall, Bexar, Comal, Guadalupe, Wilson and Karnes counties (see Figure 4-1). Although only Bexar, Wilson, and Karnes counties are within SARA's jurisdiction, the entire watershed is included in the study. Being that the San Antonio River Authority is a regional organization, this plan is meant to build on and enhance existing and future planning efforts of numerous municipal entities within SARA's jurisdiction and based on the organizations' existing goals for nature-based recreation. Through this plan, SARA has an opportunity to work with communities to promote recreational infrastructure that will improve the quality of life both locally, and regionally. Key facets of this plan include the following:

- Review and analysis of population, land-use, cultural / historic locations, population centers.
- Study of physical and hydrological features (flood plain, vegetation, slopes, etc.).
- Study of existing and planned parks and recreation amenities in the region.
- Development of a *primary concept* for recreation concepts at key locations identified within the watershed. This concept has been developed into the Cibolo Greenway, a 15- mile paved trail system.
- Identification of *open space opportunity areas* that may be of interest for future recreation or conservation based on their location and site features.
- The theme of this plan is ***CONNECT TO THE CREEK*** – underscoring the idea that this plan is intended to provide opportunities to connect people to nature through Cibolo Creek, to connect communities to each other, and to connect environmental stewardship, community development, and physical health to open space.

Baseline research located in the Appendix C informs the conclusions and can be useful for developing recreational plans and concepts into the future. This planning document can also provide assistance in evaluating future project proposals in the Cibolo Watershed area.

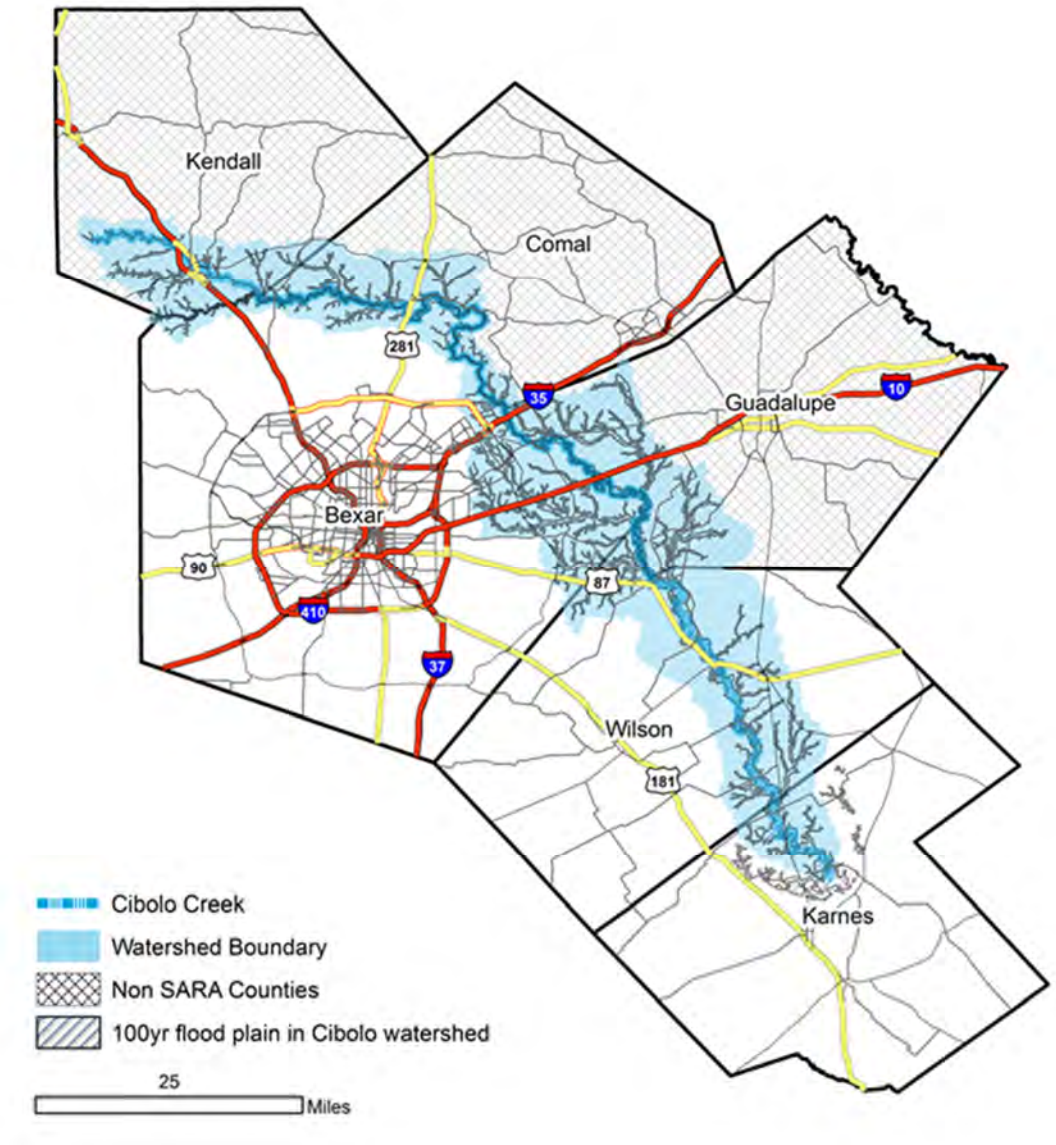


Figure 4-1 Study Area

4.1.1. Study Area

The Cibolo Creek traverses six counties, including Kendall, Bexar, Comal, Guadalupe, Wilson and Karnes. Figure 4-1 shows the Cibolo Creek centerline, watershed boundary, 100-year floodplain, counties boundaries, and major roads. The 100-year flood designation is important as it is indicative of areas that have higher flood risk and thus lend themselves to open space preservation.

4.1.2. Planning Steps

The primary steps taken to develop the Nature-based Recreation plan for the Cibolo Creek watershed include:

1. Watershed Evaluation – Conditions within the watershed that would affect a Nature-based Recreation plan were reviewed and documented. These include, but are not limited to population, land-uses, ecosystems, historic sites, schools, churches, bridges, etc. This evaluation was performed through collection of existing planning documents, site visits, and communication with government officials and planners in the watershed.

2. Plan Development – Findings from the Watershed Evaluation were used to develop a vision and a concept for the Nature-based Recreation plan. A conceptual plan was developed after first defining criteria for locating plan components.

The discussion of the nature-based recreation planning performed for the Cibolo Creek watershed is organized based upon the above steps.

4.2. Watershed Evaluation

This section discusses key factors in the watershed that influence the development of a nature-based recreation plan. At the end of this section a list of opportunities and constraints for the development of a nature-based recreation plan, which are influenced by the key factors, are presented.

4.2.1. Population

Table 4-1 (U.S. Census Bureau, n.d.) lists the seven counties that lie partially within the Cibolo Creek watershed and identifies their 2010 population and their projected 2014 populations. However, the population of each county within the Cibolo Creek watershed is a very small fraction these totals. For example, most of Bexar County's population (approximately 99%) is outside the watershed boundary. Therefore, this table demonstrates population and growth in the *larger* region in which the watershed is found. Total population of these counties was approximately 2.23 million in 2014. Of these counties, Bexar, which includes the City of San Antonio, is by far the largest with a 2014 estimated population of 1.86 million residents (83% percent of total). Bexar County is followed by Comal (123,700) and Guadalupe (147,250) counties which are both rapidly growing due to suburban and exurban population growth from San Antonio, as well as strong local economic growth. Kendall, Wilson, and Karnes are more sparsely populated, rural counties. The average growth in these seven counties between 2014 and 2010 is approximately 8.8%, making the region one of the fastest growing regions in Texas. Generally, most of the population within this table is within a 30 minute drove of Cibolo Creek, and its surrounding watershed.

Table 4-1 Local County Populations

County	2010 Pop. Census	Est. 2014 Pop	% Change
Bexar	1,714,800	1,855,900	8.2%
Comal	108,500	123,700	14.0%
Guadalupe	131,500	147,250	11.9%
Karnes	14,800	14,900	0.6%
Kendall	33,400	38,900	16.4%
Wilson	42,900	46,400	8.1%
Total	2,045,900	2,227,000	8.8%

Table 4-2 (U.S. Census Bureau, n.d.) shows the population of the municipalities whose boundaries fall, at least partially, within the watershed. San Antonio is by far the largest with over 1.44 million residents. The only other municipalities in the watershed with more than 10,000 residents are Schertz (36,900), Cibolo (25,280), Universal City (19,700), Timberwood Park (13,400) and Boerne (12,800). As with the county population data, much of these populations are not actually located within the watershed - rather they touch the boundary of the watershed. For example, the vast majority of San Antonio's population (99%) is not within the Cibolo Watershed. This table is provided as evidence of the regional growth and to understand the location of various population centers proximity to the watershed. Most of the overall population in this table is within a 10 mile drive of Cibolo Creek.

Table 4-2 Local Municipality Populations

City	2010 Pop. Census	2014 Est. Pop.	% Change
Boerne	10,592	12,835	21.18%
Bulverde	4,630	4,847	4.69%
Cibolo	20,093	25,280	25.81%
Fair Oaks Ranch	5,966	6,914	15.89%
La Vernia	1,034	1,208	16.83%
New Berlin	511	NA	NA
Selma	5,539	8,483	53.15%
Schertz	31,803	36,896	16.01%
San Antonio	1,327,558	1,436,697	8.22%
Saint Hedwig	2,094	2,289	9.31%
Timberwood Park	13,447	NA	NA
Universal City	18,530	19,721	6.43%
Zuehl	376	NA	NA

As seen in Figure 4-2, Interstate 10 geographically bisects the Cibolo watershed, almost evenly dividing north and south. Approximately 99% of the population living within the watershed is found north of Interstate 10. This region is expected to continue its steady growth through birth-rate, migration, and as annexation by San Antonio brings more infrastructure to undeveloped areas.

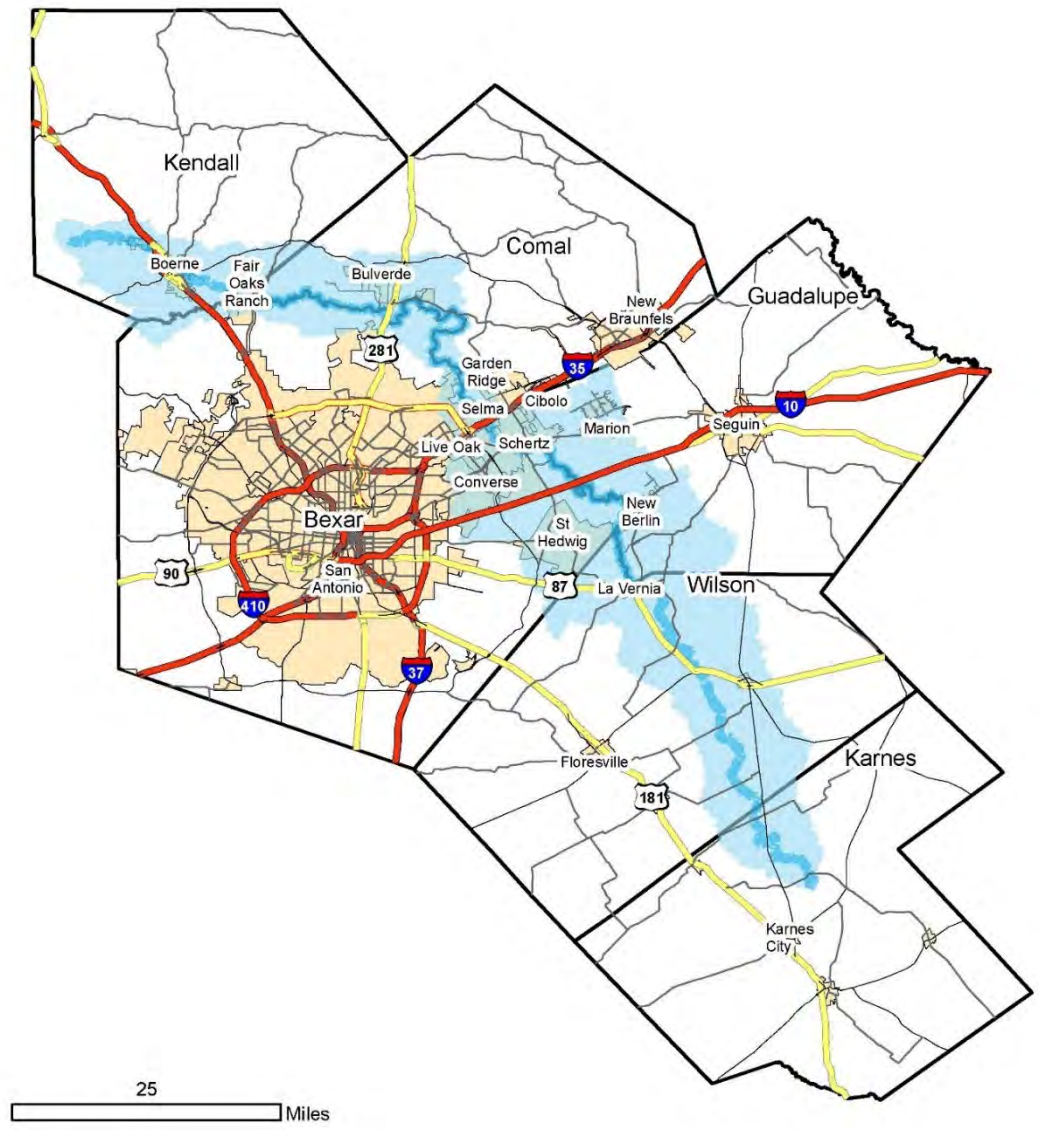


Figure 4-2 Municipalities within the Cibolo Creek Watershed

The area along the western boundary of the watershed is most heavily populated from about five miles north of Interstate 10 to FM 2252 (Selma, Schertz, Universal City, Cibolo area). East of this area the watershed is mostly rural. It is anticipated that this area to the east will see rapid suburban expansion in the next 20 years as it is situated along the high-growth San Antonio to New Braunfels corridor. For this reason, there have been efforts to obtain land for conservation on environmentally sensitive areas by private organizations such as Bat Conservation International (BCI), Nature Conservancy, and SAWS.

The rural character north of FM 2252 generally persists until the Cibolo Creek reaches FM 3351 to the east of Boerne where subdivision developments have been constructed. There are pockets where the Creek is flanked by low density suburban housing, but for the most part, there is sparse development between FM 2252 and Boerne along the Cibolo. In this area however, most growth is occurring on the east side of Boerne and south of Cibolo Creek around Bulverde Road.

South of Interstate 10, the entire watershed region is very sparsely populated and predominately agricultural.

While much of the area within the Cibolo watershed is still undeveloped, the area west of the watershed is heavily developed and considered to be part of the San Antonio metro area.

For recreation planning purposes, it is important to remember that people are not usually aware of the 'imaginary lines' (political boundaries) of counties, municipalities, and watersheds. Recreation demand is usually influenced by the proximity of people to the resource, as well as the quality of the resource. An attractive park, bike trail, or nature center can easily draw visitors from outside of the watershed boundary.

Data has been compiled to measure total population, population density, and population growth along the watershed's length. Figure 4-3 (Missouri Census Data Center, n.d.) identifies the population living within a 5-mile radius of selected bridges (crossings) of Cibolo Creek. The data in Figure 4-3 confirms that the majority of the population within the watershed is located from between IH-10 and Nacogdoches Road. Areas south of I-10 are the least populated.

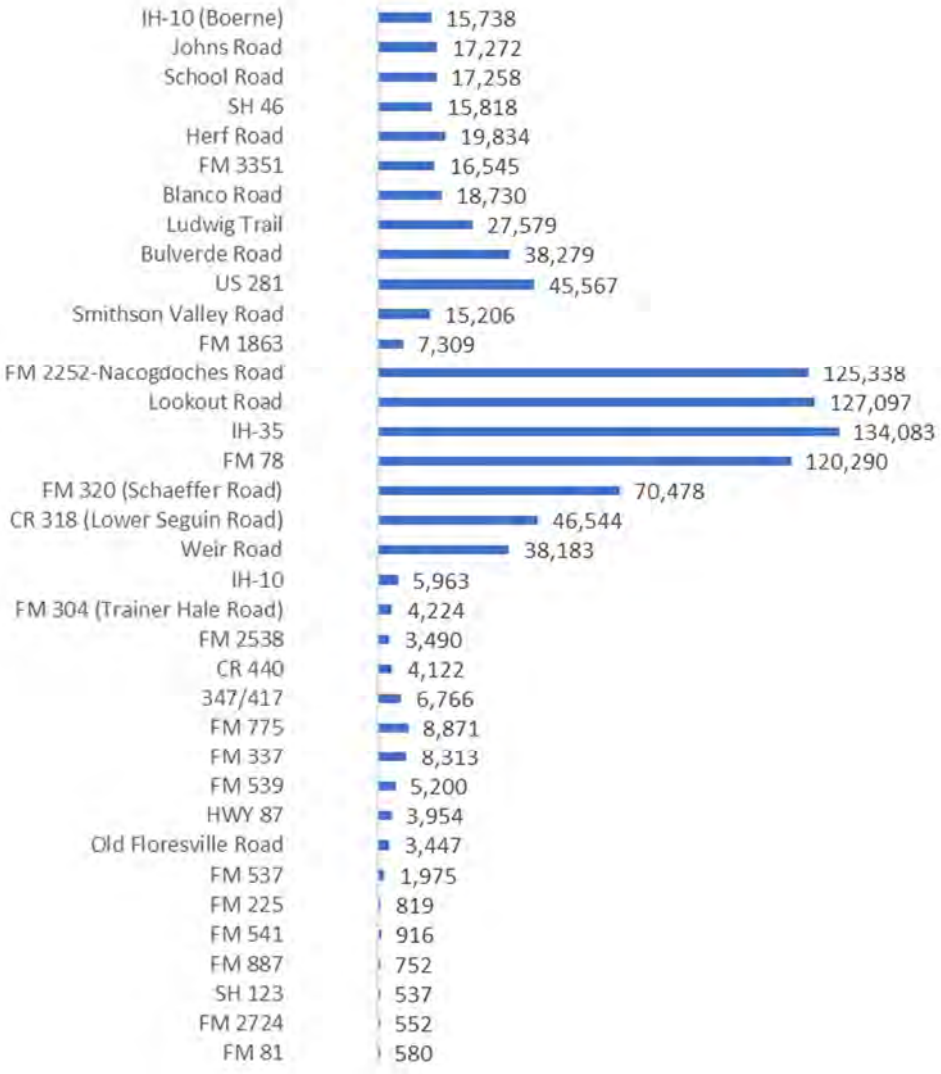


Figure 4-3 Total population (2010 Census) within 5 mile radius of selected crossings

Figure 4-4 shows the percent change in population within a 5-mile radius of selected crossings along Cibolo Creek. The largest growth has occurred between US 281 and Blanco Road in the areas north of San Antonio. These areas include suburban growth around US 281 (264%), Bulverde Road (200%), and Ludwig Trail (160%). Highest growth in terms of population was at Interstate 10 (45,600), FM 78 (43,770), and Lookout Road (43,500). Only three areas in the watershed had negative growth between 2000 and 2010.

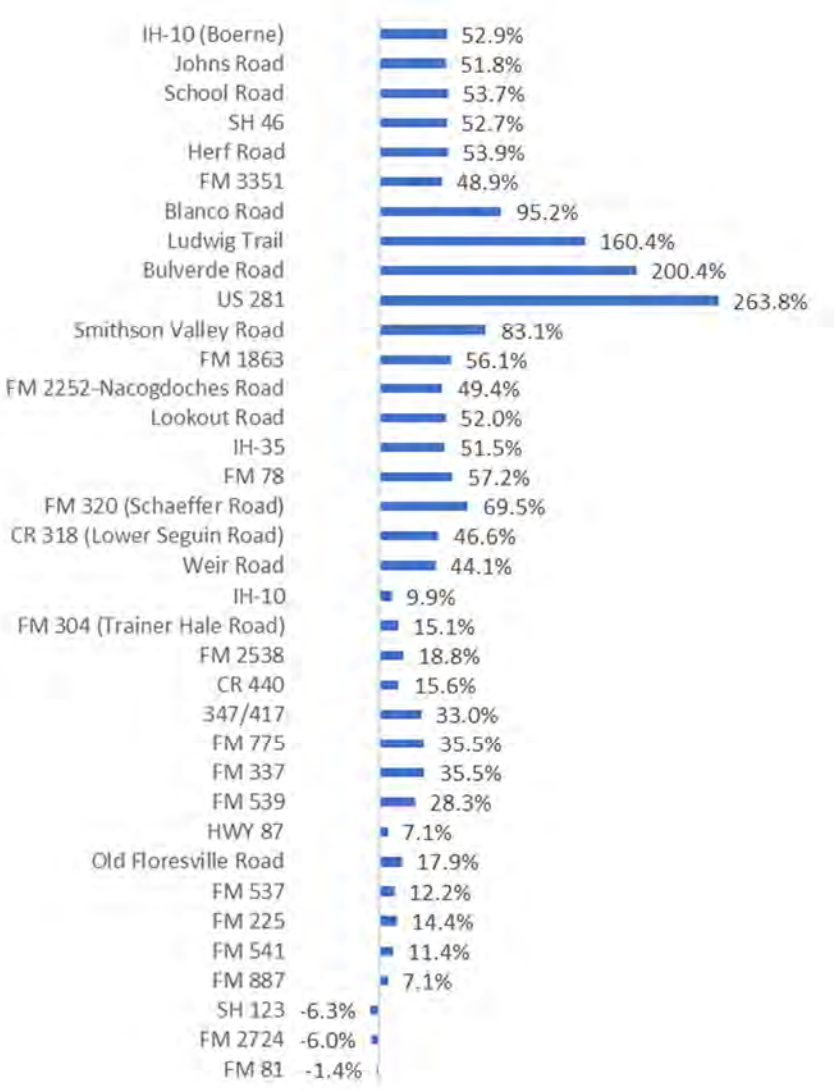


Figure 4-4 Population Change (2000 – 2010) within 5-mile radius of selected crossings

4.2.2. Land-use

Land-use in this region is steadily changing as growth pushes east from San Antonio and west from New Braunfels. The land-use map provided shown is only a snap shot. As time progresses many areas will become developed, and new roads will be constructed. Typically, the local development pattern is marked by the conversion of agricultural space into residential subdivisions. As the population grows, schools are built, commercial (shopping, storage, restaurants, etc.) and office spaces follow. Often parks and recreational spaces are developed relatively late in the process as new residents begin to demand places to play and relax.

The land-use map shown in Figure 4-5 shows the residential and non-residential land-uses throughout the watershed. The purpose of this map is a general overview of where people are living within the watershed. The brighter yellow shade represents areas with typical suburban residential densities or higher. The lighter yellow represents lower residential densities (rural). The majority of homes in the region are single family, with subdivisions around Schertz, Universal City, Selma, and Cibolo having lots that are less than 1/4 acre. Generally, homes in this area are occupied by families with school-age children.

In the hilly, rural areas of Timberwood Park, Bulverde, and Boerne, there are large tracts of land that have been subdivided for residential development. The densities in these areas are often substantially lower than those found in Schertz and Universal City, with lots ranging in size from 1/2 acre to several acres. Residential parcels that are more than a few acres are not highlighted because these tend to be small farms, ranches, second homes, or estates with very low population density. The population in these areas tends to be a bit older, due to the number of retirees.

The location of residential developments indicates that growth is happening in the suburban cities north of I-10. Much of the open land around Schertz, Universal City, Selma, and Cibolo has already been platted and will likely be developed into single family homes as demand increases in the next decade.

In Figure 4-5, areas shaded in pink are non-agricultural / non-residential land-uses (ex. schools, churches, shopping malls, office buildings, factories, quarries, drilling sites, etc.). These areas are designated on the map to show places that are *not* likely to be converted into any public open space - and to show that they are not residential.

The brown shade on the map indicates major military installations - Camp Bullis and Randolph Air Force Base.

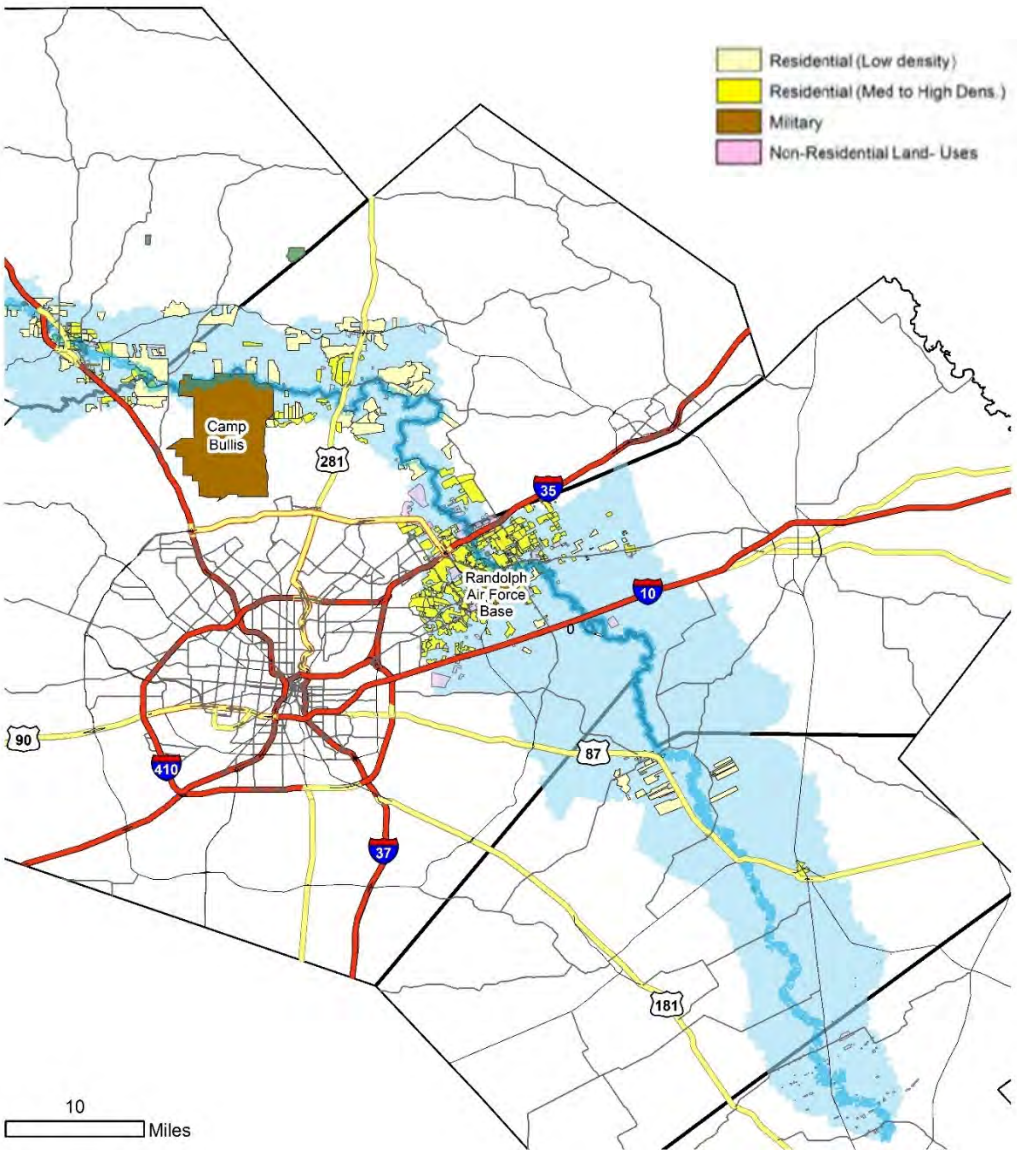


Figure 4-5 Residential / non-residential land use in the study area

4.2.3. Parks and Recreation

As part of the research process for the Cibolo Creek Watershed Holistic Plan for Nature Based Recreation, the existing and planned parks, open spaces, and conservation areas have been visited, inventoried, and studied to inform the plan regarding parks and open space planning in the region.

Generally, municipal parks and conservation areas are found predominantly in population centers within the Cibolo Creek watershed. State parks and regional parks tend to be more remote. A significant amount of public park space is located near or adjacent to Cibolo Creek, specifically in Boerne, Selma, Schertz, Universal City, and Cibolo where there is a growing population. It can also be surmised that overall land development is generally increasing at a rate that is faster than the provision of public open space. Within the region, there are a number of planned projects underway including trails projects in Boerne, the Herff Farm project (Boerne), a proposed disc golf course in Selma, and opening of the new Harrison House historic park in Selma.

Areas in the watershed south of I-10 have few parks, primarily due to low population density. Topography in this area tends to be flatter, and farming is the dominant land use. There are also fracking/drilling sites found in the southern portions of the watershed. As the population increases in Wilson and Karnes Counties, demand for public space will increase, but currently the base population and public funding is not enough to support many parks.

As the growth areas develop and local tax bases increase in the region, there will likely be an increase in investment in parks. Boerne, Bulverde, and Schertz are examples of cities that have written master plans which outline their park needs. It is apparent from surveys, that among most communities, the most requested recreational amenity are hike and bike trails.

Within the Cibolo Watershed there have also been places where large parcels of land have been placed into conservation easements or land-trusts. For example, the UTSA Cibolo Preserve (Kendall County) or Bracken Cave (Comal County) are places that are intended to preserve natural environments, but have strictly limited access for the general public.

There is one SARA-managed park in the watershed; the 50-acre Jackson Nature Park in Wilson County. SARA is also working on plans for other parks within its jurisdiction, that are outside the watershed.

Outside the Cibolo Creek watershed, the City of San Antonio has partnered with other organizations to develop several hike and bike trails in the last 10 years. These include 13.5 miles on the Leon Creek Greenway, about 11 miles on Salado Creek, about seven miles on the Medina River, and eight miles on SARA's Mission Trail. Further descriptions, photos, and mapping of existing parks can be found in Appendix C.

4.2.4. Regional Recreational Activities on Public Land

Following are brief descriptions of existing outdoor recreational activities that occur in the area:

Hiking / Trail Walking - For several decades, shared-use trails (separate from vehicular traffic) have been developed around the country as a way to encourage connectivity, physical activity, and safe recreation. San Antonio, Bexar County, and SARA have been very successful with their recent trail developments along Leon Creek, Salado Creek, the Medina River, and the San Antonio River. These projects have contributed to the quality of life in the region, as well as improve the community's image. Attractive and well-designed trails have the ability to attract visitors from outside the local area, as well as local residents routinely walk, jog, or ride along the paths.

Intensively used trails need to be paved, especially for ADA accessibility and ongoing maintenance. Nature trails or mountain bike trails can be unpaved, but have maintenance issues such as erosion, mud, and overgrowth. Challenges to trail development include the cost of land acquisition and easements, ongoing maintenance and provision of safety over a large region, and planning between various governmental jurisdictions. Parking areas and public access points are part of any successful trail plan.

Municipal master plans throughout the Cibolo watershed have identified trails as one of the most desired recreational amenities. The City of Boerne has built trails along the Cibolo, as well as along abandoned trail corridors. Bulverde is planning for trails in the long term. The cities of Cibolo and Schertz are also actively developing paved trails and planning connections. Due to the intrinsic linear quality of Cibolo Creek and the perceived demand for trails, trail development is *highly* recommended as a cornerstone of the holistic watershed plan.

Cycling / Mountain Biking - Cycling is also part of the trails component. Central Texas region has a very active cycling community; both for road cyclists as well as mountain bikers. Many road cyclists enjoy the areas around Bulverde for its rolling topography. The flat, relatively empty roads around La Vernia and Floresville are popular with road cyclists. Creating conditions to promote safety for riders would be a part of the overall vision for the Cibolo Greenway. The provision of areas for mountain biking is also a worthy goal. However, there are issues with mountain biking related to disturbance to soil, vegetation, and hydrology.

Mountain biking activity would need careful planning to avoid conflict with natural areas near Cibolo Creek. With the paved trails, it is important to design in such a way to minimize conflicts between cyclists and pedestrians. Striping, safety signage, and bike lock areas are necessary to accommodate cyclists.

Canoeing / Kayak - Canoeing, kayaking, and paddle boarding have become very popular at Central Texas in rivers and lakes. Boerne Lake City Park is popular site for these activities, as is the Live Oak Lake. During periods of heavy rains, the Cibolo is somewhat 'navigable' and has pockets of deeper water. However, these periods are relatively short lived and typically there is not enough water flow to warrant considerable investment in aquatic based amenities. This plan does not include specific plans for kayak, canoe, or paddle board access due to limited potential.

Active Recreation / Team Sports - Ball fields and amenities for active (or team) sports such as soccer, baseball, tennis are typically provided in suburban / urban areas. This is the case in Boerne, Selma, Schertz etc. Within the Cibolo watershed, there are a number of parks being developed to provide places for organized sports. Most of the developments are organized by local municipalities, and demand for these needs to be established locally. This plan does not specifically recommend ball-fields and sport courts, since this is considered a local need, rather than regional, and it does not really 'nature-based.'

Bird Watching / Wildlife Viewing - Nationally, bird watching is a growing hobby. There is an active demographic of birdwatchers and wildlife watching groups, such as the Audubon Society in Central Texas. Amenities to promote visitation by birdwatchers include viewing blinds, trails, parking areas, and interpretive signage. Generally, the quality (abundance and diversity) of bird watching areas depends of on the degree to which that ecosystem is intact. Areas with water are attractive to waterfowl. Cibolo Creek has many locations that would be attractive for bird watching locations. These do not have to be sole purpose recreation areas, they can be tied into hike/bike trails, disc golf, or other passive recreation areas which leave natural vegetation relatively undisturbed. In doing site-specific planning and design, it is important to consult with bird watchers and ornithologists to identify locations for overlooks, bird-blinds, boardwalks, and other amenities to help enthusiasts see birds in their natural habitat.

Disc Golf - While traditional golf course development has stagnated in recent years, the sport of disc golf has grown considerably. In the Cibolo watershed, there are several existing disc golf courses, as well as one planned in Selma. The City of Schertz lists 'Construct a Disc Golf Course in the city ' as one of the top ten priority capital improvement actions. Universal City also has an 18-hole disc golf course, as does Boerne. It remains to be seen how popular the sport will grow, and if there is sufficient demand to build more courses. The benefits of disc golf courses to the public are part of the reasons for the growth of the sport. The sport is usually free to play, it can be played alone or in groups, and the maintenance costs are very low. Like regular golf, disc golf can make use of flood prone areas that would be unsuitable for other types of development. There are some issues with disc golf - public safety is a concern, as an errantly thrown disc can injure person in the vicinity. It is important to plan the course layout to minimize potential of injuries.

Golf - There are a number of golf courses in the watershed, some of which are privately owned, and some publicly. Golf courses are often located in flood prone areas due to land being unsuitable for residential or commercial development. The provision of golf courses is very much demand driven, given that it is typically a revenue generating activity. After a period of dramatic growth in the golf course industry, the last decade has seen a decline in demand for new golf courses. If new golf courses are developed in the watershed it will be advisable to make provisions for public access (such as walking trails) on the periphery. Additionally, treatment of the golf course with chemicals needs to be addressed to prevent runoff into the Cibolo Creek. Existing courses are located in Universal City and Timberwood Park.

Fishing - Fishing is a popular activity in several locations along Cibolo Creek. There are a number of deeper pools where locals fish for fresh-water species. There have also been some plans to provide more fishing amenities (such as piers) locally. The City of Schertz has placed improving fishing access at Cibolo Creek at Crescent Bend Nature Park on their list of capital improvement priorities. The ability to promote fishing along the Creek is limited somewhat by the amount of fish the Creek can support. Additionally, the

long dry periods mean that, for much of the year, the water flow is not sufficient to support many fishing activities.

SUMMARY - There are many recreational activities that have been developed by communities within the Cibolo Watershed. For the purposes of this plan, the emphasis will remain on nature-based activities – primarily trails that allow non-motorized access to natural areas, as well as amenities for trail users. Active sports infrastructure (ball fields, basketball courts, golf courses, etc.) are considered within the realm of local planning and not 'nature-based', and thus are not specified in this plan.

4.2.5. Opportunities and Constraints

The development of new recreational activities within the Cibolo Watershed provides great opportunities to enhance the environment and quality of life for citizens in the region. As with any large-scale planning process, there are constraints and challenges in the achievement of goals. Following is a general summary of the significant *opportunities* and *constraints* facing SARA and/or other municipalities and organizations involved in the development of nature-based recreation projects proposed within this plan.

4.2.5.1. OPPORTUNITIES

Growing population, growing tax base - The San Antonio metropolitan area is one of the fastest growing regions in Texas and in the United States. This growth provides an influx of workers and families to the region increasing demand for everything - including land, housing, water, transportation, and open space. While this growth places a strain on existing public resources it also provides increased revenue for local municipalities through sales and property taxes. These funds (if appropriated) can be used to carry out the objectives of the watershed plan.

Large geographic area - The Cibolo Creek watershed stretches 96 miles, through six counties. There are thousands of acres of undeveloped land adjacent to the creek providing substantial opportunities to conserve open spaces and provide nature-based recreation. While land development is occurring, there are still opportunities to preserve public land for conservation. As the region develops, conservation will become more difficult as land value rises.

Prior success of trails / greenways / linear parks in the region - Shared use trails (for bikes, pedestrians, etc.) have been developed in the region for over a decade. San Antonio, Boerne, and surrounding municipalities have been successful in developing trail projects, adding to the quality of life. In San Antonio, one only has to walk the trails of Salado Creek, Medina Greenway, the Mission Trail, and Leon Creek to encounter satisfied citizens exercising and enjoying the outdoors. Trails, unlike tennis courts or baseball fields, are used for the experience with nature they provide, thus people often to travel to try new trails periodically, as well as using their local trails on a regular basis.

Community Appreciation - One of the keys to the success of any long-term plan is the appreciation and devotion of the local community to a resource. Cibolo Creek already provides recreational enjoyment and physical beauty to many residents of the region. It is used informally by people from Boerne, south to the Schertz area as a corridor for fishing, walking, exploring nature, and passive recreation. For example, the Boerne community has a great appreciation for Cibolo Creek, with its Nature Center dedicated to educating people about the natural resources. Other communities in the watershed have this potential to develop parks on the Cibolo if their communities are organized and motivated.

4.2.5.2. CONSTRAINTS

Private property ownership - Much of the land along the banks of Cibolo Creek is privately owned. This is a major constraint as public land is the most critical resource required for recreation planning. Given that land acquisition is needed to create any "critical mass" of recreational space in the region, the cost associated with land acquisition can be a challenge for local governments. Individual owners may object to trail development through their property or may be unwilling to sell land for a number of reasons. As with many trail projects, it can be a major challenge to acquire private property or establish public easement

through private property. As this area grows, it is advisable to acquire potential trail routes before the costs inhibit project feasibility.

Lack of Navigable Water - During the summer months much of Cibolo Creek runs completely dry. Even in periods of normal precipitation, Cibolo Creek does not typically provide water to a depth that can accommodate activities such as swimming, boating, or fishing in the Greenway (except for a few deep pockets of water). Therefore, recreational developments proposed will not be aquatic based.

Topography - Embankments along Cibolo Creek in the Cibolo Creek Greenway area are steep in many locations, which could require a significant amount of engineering to build trails at the required slopes for safety and ADA accessibility. There are several areas where the grade might be too steep on one side of Creek, in which case, the design would need to consider crossing to the other side of the Creek (requiring bridges) as an alternative.

Potential for Degradation - Recreational use of any environmental resource can cause degradation when it is 'loved to death'. This is a potential issue along the Cibolo. Dog walking and equestrian activity leads to increased fecal matter in the stream. Horse trails and mountain bike trails can cause erosion and deterioration of natural vegetation. Paved trails increase the pervious surface and can cause further erosion and requires earthwork to grade the banks to suitable slopes, altering the natural riparian zone. The risk must be acknowledged and mitigated through proper management and design.

Population Location - The population within the Cibolo watershed is growing, however, most of it is happening north of Interstate 10. Areas north of Interstate 10 are the fastest growing parts of the watershed region, more than 90% of its population. Areas south of the Interstate are sparsely populated. It is advised to direct resources to areas that are most densely populated, or where the potential for providing nature based recreation is exceptional. The areas south and east of Bulverde and Timberwood Park are sparsely populated, which increases the potential for conservation areas and nature reserves in these areas. The same could be said for the entire northern flank of the watershed - outside of the populated parts of Boerne, Timberwood Park, and Bulverde. These areas are lightly populated and thus demand for recreational activities in these areas would be less than the densely populated areas.

Military Bases - Within the Cibolo Creek watershed the two major military land uses are Randolph Air Force Base and Camp Bullis. Given the thousands of people who are employed at the Air Force base it is reasonable to believe that recreation amenities close by along Cibolo Creek would be used by this local workforce and their families.

Randolph Air Force Base encompasses more than 2,400 acres entirely within the watershed, and is located just south of Universal City and Schertz. Camp Bullis is almost 28,000 acres in size. The northern part of the Camp Bullis is contiguous with Cibolo Creek following the creek bed for over 10 miles from Ralph Fair Road to Blanco Road, and about 1/3 of Camp Bullis is in the watershed. This is a very large area that is off limits to the public. If Camp Bullis were to ever vacate, it could be a desirable location for a regional park with large areas set aside for conservation and rehabilitation.

Road Crossings and Parking - Providing recreational opportunities on or near Cibolo Creek will require convenient public access for users as well as emergency personnel. Because most of the land along the creek and in the watershed is privately held, the easiest areas to develop for public recreation will be areas that already have access by an existing public road. Within the watershed, roads typically intersect Cibolo Creek at intervals of three to five miles. These bridges are places where pull-offs can be potentially developed, with parking to allow access to trails and open space. Areas within close proximity to the Creek are also among the most environmentally sensitive and flood-prone, which presents certain planning challenges. Additionally, road crossings and rail crossings will require special design and adaptation if they are to accommodate trails.

Municipal Boundaries – The Cibolo Creek watershed includes portions of six counties and more than 10 municipalities. Each of these political jurisdictions potentially has differing regulations and attitudes toward

recreation development. Regional plans can be successful, but there is always potential for conflict due to variability in regulations and alternative visions about the needs of the local/regional community.

Conservation Properties - The desire to protect wildlife, the unique ecosystems the Texas hill country and an effort to preserve the rural character of the region has resulted in thousands of acres being set aside for conservation. Organizations involved in this effort include the Nature Conservancy, the Cibolo Preserve/UTSA, the Edwards Aquifer Authority, San Antonio Water System, Bat Conservation International, and private land-holders who enter into conservation easements and transfer of development rights. These properties, while preserving the natural environment, are not conducive to recreational activities, due to the limited access allowed onto the properties by the general public and limitations on the type of activities permitted. It will be necessary to plan around these properties to minimize conflict.

Maintenance – There is often considerable support for building parks. However, if there is not proper planning and funding for their ongoing maintenance, these projects can eventually fail. Recreational open spaces have their own unique maintenance challenges. These include solid waste management, graffiti, vandalism, degradation by ATV's and mountain bikes, and biological wastes. Built amenities such as playgrounds, trails, interpretive signage, restrooms, and sports facilities will need periodic maintenance. It will be important to designate which entities are responsible for ongoing maintenance, as well as liability for safety issues at the particular location before development happens. If public organizations are not willing (or don't have capacity) to effectively maintain the area to a satisfactory degree of cleanliness and safety, it is better if the land remain in private ownership.

Access - Efficient access is required for recreational amenities, such as Greenways, to be successfully used by the public. In areas where existing developments abut the Creek, there may have to be some retrofitting, redesigning, or provision of easements required to provide public access. In older developments, subdivisions and other developments have previously limited access to and from waterways. Trail heads, and public parking at strategically planned are encouraged to provide convenient access for the public.

Funding - The opportunities outlined in this plan would be a significant undertaking, on par with other linear greenways in central Texas (Leon Creek, Mission Trail, Salado Creek). While there might be sufficient public support, funding is always a challenge to expedient project development. There are a number of different funding sources for projects such as these - each with pros and cons. They can include grants and private donations, municipal bonds, federal or state grants, etc. Ideally, there will be opportunities to share costs among the municipalities, counties, and various organizations involved

4.3. Conceptual Plan

This section discusses the formulation process for the Conceptual Nature-based Recreation plan for the Cibolo Creek watershed. The section includes a discussion of the vision for the plan, the general concept of the plan, criteria for locating plan components, and presents the conceptual plan.

4.3.1. Vision

The main concept of the Cibolo Creek watershed recreation master plan is simply **'Connect to the Creek**.' Cibolo Creek itself is the spine of the watershed, the greenest and most natural, but also one of the least-used areas because accessibility to the Creek bed is limited. The main objective of this plan is to explore viable options to bring people closer to the Creek to provide spaces where people can enjoy its natural beauty. The dearth of national, state, and regional parks in this area suggest there is a need in this growing area for open spaces. The Creek itself is the resource. Playgrounds, ball fields, and golf (and disc golf) courses are on the periphery of the Creek, but are not currently connected or integrated in any meaningful way. The aim should be to protect the Creek from degradation, and allow people to enjoy this resource.

Connections to the creek can be physical; i.e. bridges, trails, piers, and overlooks. Connections can also be emotional, such as feelings of peace, adventure, or freedom. The connection to nature that is increasingly difficult to find; connecting the environment to people's actions, connecting to different cultures, connecting to history, connecting to family. A clean, safe, and accessible Cibolo Creek can create physical and

emotional connections that will benefit communities and individuals, who will in-turn become environmental steward's for the Creek.

While the watershed encompasses hundreds of square miles, the most ecologically and recreationally valuable are typically within the stream bed and on the stable banks of the creek. These areas also tend to be flood prone so these lands are often devalued for commercial and residential purposes. This makes them ideal for recreational development and conservation.

A unified and interconnected green space along Cibolo Creek can serve as a haven for residents; an oasis of nature. It can be a place where people can get out of their cars and enjoy the simple natural pleasures of walking, wandering or listening to the trickling of water through a narrow rivulet, observing the sway of natural grasses in the wind, or hearing the hoot of an owl. Access to nature itself is the recreation.

The Cibolo watershed region is large. This Holistic Watershed Plan for Nature Based Recreation looks at potential recreational proposals and alternatives on a regional level. Each project will have unique challenges including land ownership issues, funding, and design issues. The concepts proposed in this plan can be seen a starting point.

From communications with local leaders and planners, as well as review of city plans, and park master plans, it appears there are several key desires and objectives that should be the focus of the nature-based recreation master plan. These include the following:

1) **TRAILS** - Communities in the watershed generally support trail development. Trails generally serve walkers, runners, and bicyclists. Some communities within the watershed already have trails within existing parks, but seek to expand into a system of trails that connects green spaces; allowing people to venture farther than their usual routines allow without the necessity of a car. *Connectivity* is key - allowing people to use the trails not just inside one green space, but to connect to other parks, road networks, schools, and workplaces. There is already strong appreciation for trails within the San Antonio area, (Medina, Mission Trail, Salado, Leon Creek, etc.). Most of the areas in the Cibolo Watershed are comparatively underserved by trails.

2) **CONSERVATION -** The need in Cibolo Creek watershed region for conservation of natural habitats and open spaces is evident. The ecosystems in this region include Balcones Escarpment, Blackland Prairies, and Post Oak Savannah (see Appendix 4 for a map and descriptions of the ecological regions). These landscapes are a limited and threatened natural resource due to rapid economic development. This region, despite its population, has a limited number of large scale parks where people can enjoy these ecosystems in a natural state. There are not any state parks (and only one park larger than 100+ acres) in the watershed boundaries, and no public camping areas. As this region rapidly develops, the window of opportunity to acquire land at reasonable prices will diminish.

   Passive recreation such as hiking, bird watching, and picnicking co-exist well within conservation areas. Much literature is available on the 'nature deficit disorder' and the negative impacts (intellectual, emotional, social etc.) that are attributed to children who don't have access to natural areas. There are a number of conservation areas within the watershed that have been preserved in a natural state with the help of the Nature Conservancy and Edwards Aquifer Authority and land trusts. Properties that are strictly for conservation don't hold much value for recreation because often public access is forbidden. However, there remain opportunities to combine recreation and conservation on public lands, such as one would see at a state park or regional nature park.

3) **INTERPRETATION / PUBLIC AWARENESS / MANAGEMENT** - The interpretation/public knowledge component of nature-based master plan is an element that can help create a long-term sustainable strategy for the benefit of a watershed. This can be seen as 'soft-infrastructure' to complement the land, trails, parking lots, the recreational amenities, and other planned hard infrastructure. "Interpretation" can be defined as the action of explaining the meaning of something; i.e. providing enhanced meaning about the resource so that people might understand its value more

deeply. Cibolo Creek has historical uses and a variety of natural ecosystems which provide great opportunities for learning. There is an opportunity to present Cibolo Creek as not just 'a place', but as repository of unique geomorphology, wildlife haven, and cultural artifact. The City of Boerne has done an admirable job providing interpretive kiosks along Cibolo Creek and the Old Number 9 trail which introduces historical understanding of the region. Interpretation can be provided in many ways: signs, plaques, visitor centers, videos, etc. Interpretation can also be provided though programs, such as (day camps, special events, classes, symposiums, etc.).

The 'public awareness' component refers to interpretation of the natural and historic resources, but also to promoting a message to the public who may not be using the resource directly. Public appreciation of the watershed and its recreational places, will help accomplish SARA's goals of health, safety, quality of life, etc. These objectives might be carried out by any county, municipality, or organization in the Cibolo Creek watershed. Examples of the public awareness efforts might include the following:

- Street signage announcing when entering / exiting the watershed.
- Informing the public about the importance of watersheds (kiosks, signs, programs, etc.)
- Watershed photography and art competitions
- Public campaigns to 'get outside' and experience parks and trails in the area.
- Development and dissemination of maps or other materials to promote awareness of the watershed and open spaces
- Public events such as festivals, cleanups, fun-runs, scavenger hunts, etc to promote awareness
- Public health initiatives

The 'management' component of the watershed recreation plan needs further research and communication between and among the SARA, the municipalities in the watershed, the county governments, potential funding organizations, TxDOT, and the constituents and neighborhood organizations that will be impacted by the outcome of the plan. Management refers to provision of safety, maintenance, security, daily operations, etc.

4.3.2. Plan Components

A plan concept was developed following the vision presented in Section 4.3.1. This concept includes a primary concept, the Cibolo Greenway, which is a 15-mile linear Greenway. The second component of this plan are open space opportunity areas that have been identified as potential locations for nature-based recreation. These areas do not have any suggested program or planned infrastructure (unless they are in the Greenway), except that they can be potential areas for future acquisition as open space and nature-based recreation. Some of these locations are within the proposed Cibolo Greenway area, while others are located in other parts.

4.3.3. Component Site Selection Criteria

In the interest of promoting goals and objectives that could be *realistically* developed, the components of the concept plan are limited to areas considered to have the greatest financial and environmental feasibility. The locations of the Cibolo Greenway and the open space opportunity areas were determined based on key site selection criteria, as outlined below:

BOTH PRIMARY CONCEPT PLAN & OPEN SPACE OPPORTUNITY AREAS

- Located in areas where Cibolo Creek or its tributaries have tree cover, attractive scenery, special environmental features, or attributes conducive to nature-based recreation.
- Located in areas where there is reasonable public access by road ensuring both ease of visitation and visibility by the general public, as well as ease of access by emergency and maintenance vehicles.

PRIMARY CONCEPT PLAN

- The Cibolo Greenway is located in - or within proximity to - existing municipalities (Selma, Universal City, Shertz, Cibolo). Being close to population centers ensures that the project site will have access to park infrastructure connections for electricity, water, waste-water, and emergency

personnel. This also makes it more likely that the project will have local partners that will help gain political and financial support for the project to help ensure long-term sustainability.

- Located in areas where there is a significant population growth trend; whereby the demand for recreational areas will continue to grow.
- Located in areas where a city parks master plan or a general master plan have acknowledged surveys or general sentiment supporting park development, trail development, and land conservation.
- Located relatively close to existing residential land-uses. Also, locations where residents can conceivably walk or ride a bike to arrive at the Greenway.
- Located in areas where there are existing parks and public lands to which they can connect, thereby adding value to existing public spaces.
- Not located where it could disrupt conservation easements or private nature preserves that are not intended for public access.
- Not located south of I-10 due to very low density population and slow growth.
- Not located north of Classen Ranch Road due to lower population density and difficult access.

OPEN SPACE OPPORTUNITY AREAS

Open space opportunity areas are the specific areas that might be desirable as open space. Some of these sites are located within the corridor of the proposed Cibolo Greenway. Some of these sites are located well outside the Greenway. Many open space opportunity areas share the following traits:

- More geographically distant from population centers.
- Large size (most are 50+ acres)
- Environmentally rich land (tree cover, some wildlife, natural vegetation and tree cover, topography)
- High percentage of land in flood plain (lower potential for commercial or residential land development). Lower land value makes acquisition easier.

Public recreational amenities built in the watershed are an investment, underscoring the need by any organization involved to economize their expenditures. Advantages lie in recreational proposals that are targeted towards places that already have park and recreation infrastructure to build on, have significant population of potential recreational space users, and have a general level of socio-political support for the type of projects proposed. This philosophy has informed the recommendations in this plan. Additionally, a 'matrix' has been developed as a tool to help rank the selected areas using values assigned for the sites' qualities such as size, tree cover, local population, or other factors.

4.3.4. Plan Details

4.3.4.1. Cibolo Greenway

Following is a concept outline for a shared-use trail and 'Greenway' along Cibolo Creek. This is envisioned as a regional project spanning approximately 15 miles, divided into three separate project areas. For the purpose of this document the following are defined:

> *Greenway* - a strip of undeveloped land near an urban area, set aside for recreational use or environmental protection.
>
> *Shared-Use Trail* **-** a multi-use trail or other path, physically separated from motorized vehicular traffic by an open space or barrier, either within a highway right-of-way or within an independent right-of-way, and usable by pedestrians, bicyclists, skaters, equestrians, and other non-motorized users.

In this plan, the proposed trail map is simply a concept. Actual trail alignment may vary from these maps depending on factors such as slopes, access to infrastructure, points of ingress/egress, property boundaries, the side of the creek chosen for the path, etc. Further analysis will be needed to plan trail alignment.

Figure 4-6 provides an overview of the proposed 15-mile Cibolo Greenway divided into “North” (4 miles), “Central” (4 miles), and “South” (4 miles) sections.

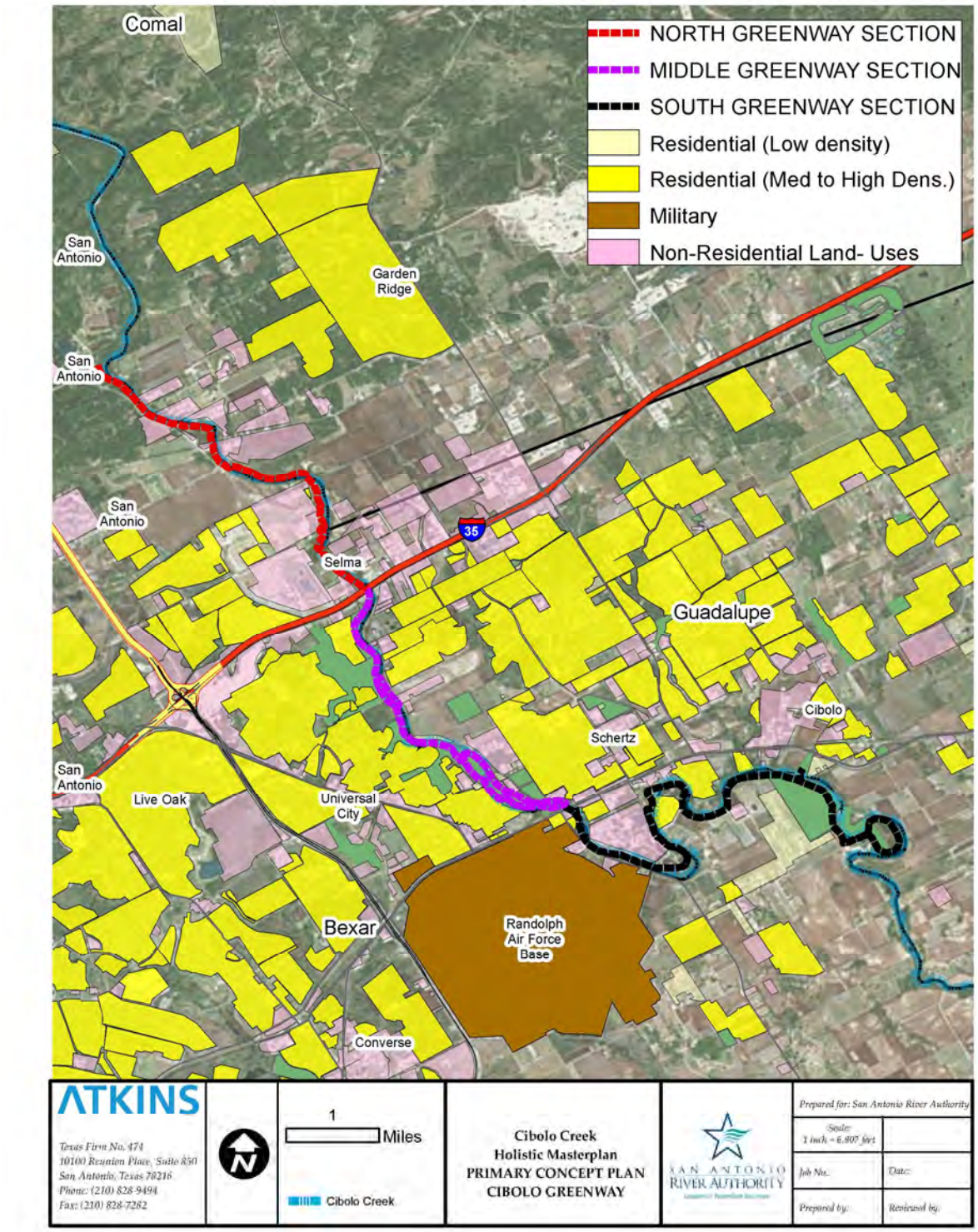


Figure 4-6 Cibolo Creek Greenway Concept Plan

As Cibolo Creek flows in a northwest to southeast arch outside of San Antonio, the water, trees, and wildlife are a sliver of 'wild' within a region that is experiencing rapid suburban growth. Several ecosystems are found in this area (see Appendix C for descriptions) where undeveloped land serve as a sanctuary for wildlife, including coyotes, deer, egrets, frogs, herons, owls, possums, rabbits raccoons skunks, snakes, turtles. The creek is wide and deeper in some areas, and in other areas its flow is a mere trickle, or non-existent. When heavy rains occur, a torrent of white-water rips through the creek bed, carrying debris along the way, scouring rocky outcrops and depositing gravely shoals.

The terrain is varied, with some areas being waterlogged, or dry mud beds, and others rocky and steep slopes. One can find wetland grasses, cedar elm, pecan, hackberry and other native trees, as well as a host of invasive plant species that could benefit from wildlife management. Between I-35 and Crescent Bend Nature Park, the major road crossing is at FM 78, leading to a sense of peace, isolation, and wild.

The proposed Cibolo Creek Greenway is envisioned as the following:

- A shared-use trail and Greenway, completely separated from auto-traffic along the banks of Cibolo Creek for approximately 15 miles. A place to safely connect people to the Creek, and to nature.
- A safe and clean natural area that would be conducive to walking, cycling, skating, and other physical activity by residents and visitors to the area.
- A greenway trail that is accessible from multiple points of entry including city parks along Cibolo Creek, as well as access points along FM 1518, Evans Road and local neighborhood streets.
- A place that will raise the environmental consciousness of local residents to understand watersheds and the environmental impacts of human actions within the watershed.
- Another beautiful linear greenway for the San Antonio region that will serve residents for decades in this growing region that will add to the region's reputation for open space and trails.
- A place that brings a sense of cohesion and connectivity to the patchwork of existing open spaces in the local area.
- A public space that will increase the sense of community pride, physical health, and appreciation of nature.
- A retreat from the urban/suburban/auto-oriented environment, offering a sense of 'wild.'
- A series of open spaces, not just in the Greenway, but in other areas of the watershed that have been designated for park space.

The three sections of Greenway proposed are described as North / Central / South sections.

- Total 15 mile shared-use concrete trail (Classen Ranch Road to south of Crescent Bend Nature Park)
  - **North Section** - approximately 4 miles
  - **Central Section** - approximately 4 miles
  - **South Section** - approximately 7 miles

Following are items that are often included in greenways and trail development, which would likely be program elements for the Cibolo Greenway.

- public access points with parking
- neighborhood access points
- seating areas
- scenic overlooks
- bike and pedestrians bridges (where necessary)
- exercise stations
- fences / walls (where necessary to buffer private property)
- maps and interpretive signage
- tree plantings; vegetation and stream restoration
- 911 call-boxes



Figure 4-7 Renderings of Proposed Cibolo Greenway

4.3.4.1.1. North Section

The north section of the proposed Greenway, as seen in Figure 4-8, would extend from Classen Ranch Road south to where Cibolo Creek passes under I-35, a distance of approximately four miles. Within this corridor there are major road crossings at Lookout Road and FM 2252. There are also two railroad crossings. The road and railway corridor will require effective strategic planning and engineering to maximize safety for the trail users. Evans Road runs parallel to Cibolo Creek the entire distance to the west of the Creek until Classen Ranch Road. Most of this area is within the Selma city limits. There are no existing parks in this general area.

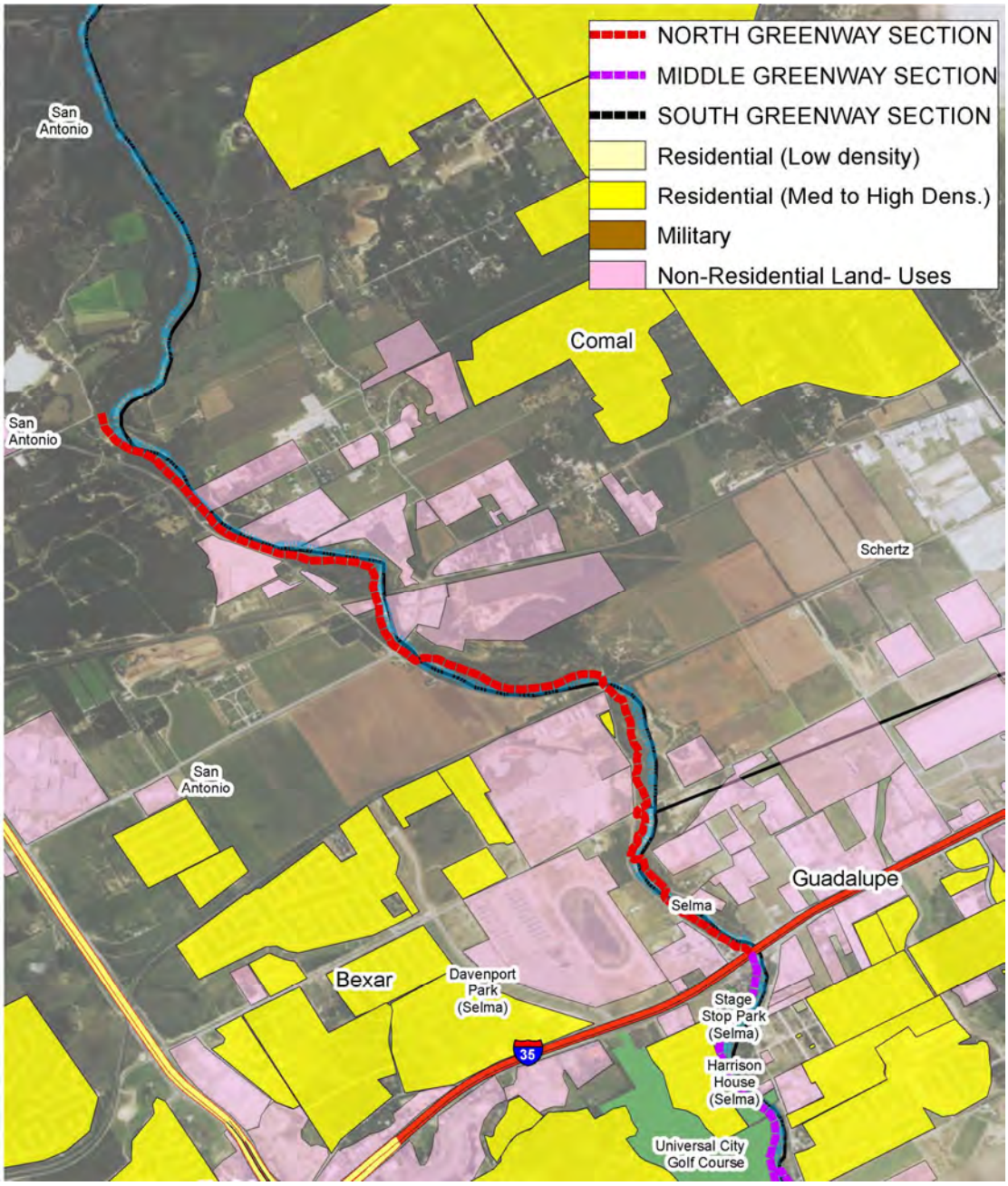


Figure 4-8 Cibolo Greenway-North Section

This area still retains a rural character, but significant industrial and commercial growth has proliferated. For example, Retama Park (race track) is part of a large developed area that straddles Lookout Road, just west of Evans Road. There are also extensive industrial land uses along FM 2252, east of the Cibolo. This area has less residential land-uses then the Central Section; but there are suburban developments and apartments about a mile to the west of the Creek. There are also individual single family lots along Evans Road and to the north of Wagon Road, there are industrial properties on both sides of the Cibolo. Additionally, there are substantial undeveloped or agricultural tracts in the North Section of the proposed Greenway. It is anticipated that this area will continue to develop following the San Antonio and New Braunfels growth trend along the I-35 corridor. As population grows here, it will provide a larger population base for users.

The North section, despite lower residential density than the central section, holds strong potential as Greenway for several reasons. There is a wide enough section along the Creek in most places to accommodate a trail. Also, the natural topography includes a number of interesting rocky features. The area has tree cover and much of it is in the 100-year flood plain. There are larger open spaces which, if acquired, could be incorporated as regional park space that could lead off the main trail.



Figure 4-9 Cibolo Creek-Looking North from Lookout Road

4.3.4.1.2. Central Section

Moving south along Cibolo Creek, the proposed Central Section is defined as the corridor between I-35 and FM 78; just to the west and - parallel to FM 1518. In the Central Section, Cibolo Creek links a substantial number of public parks, municipally owned properties, and open spaces within the city limits of Selma, Universal City, Schertz, and Cibolo. This area the most densely populated part of the watershed entire. Land in this area is not yet fully developed; some pockets of undeveloped land remain. This has many existing public parks and municipally-owned land that could be integrated to create a contiguous greenway segment of substantial size.

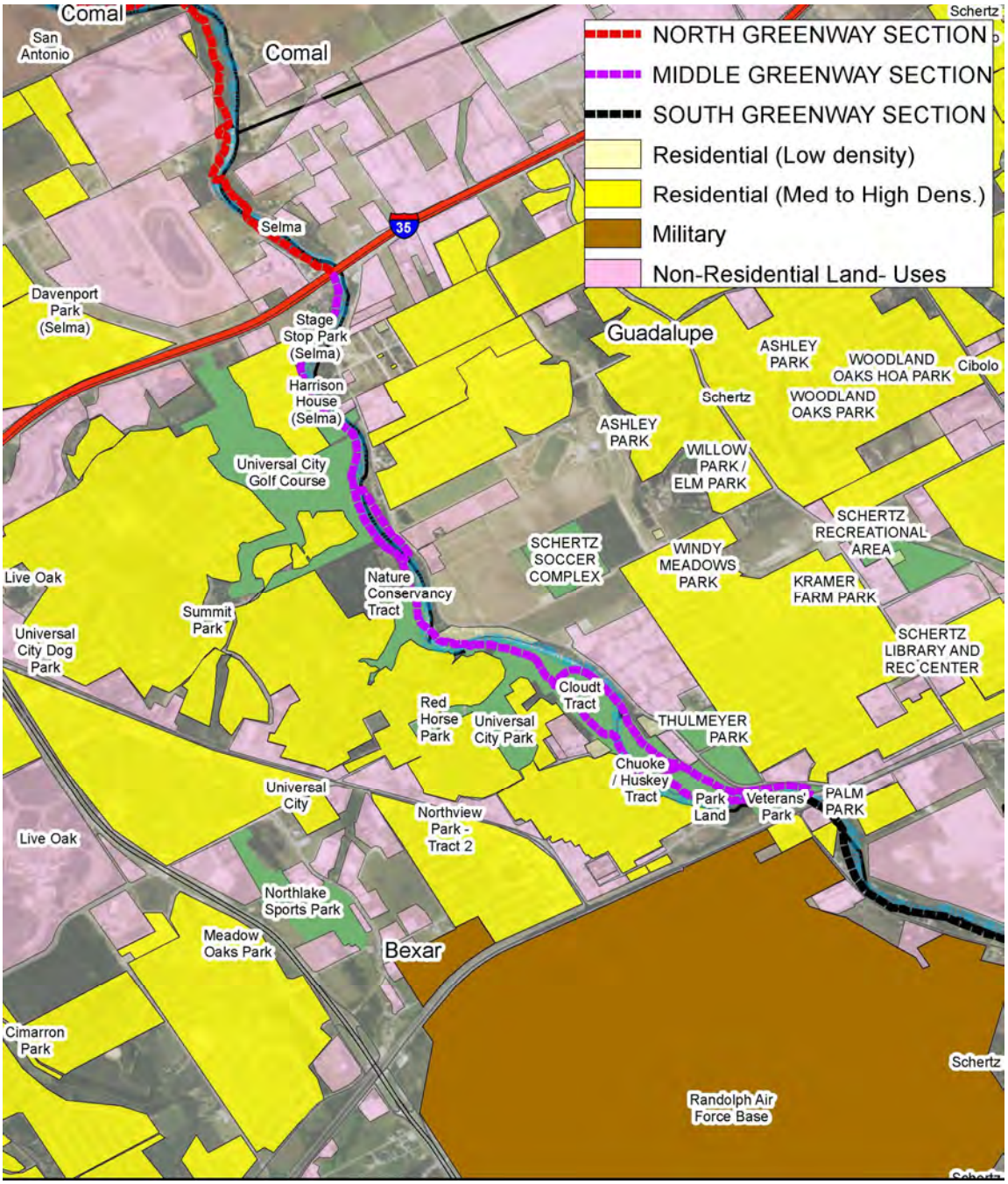


Figure 4-10 Cibolo Greenway – Central Section

Following is a list of the open spaces that could be linked along the central section of the proposed Cibolo Creek Greenway:

West Side of Cibolo Creek (from north to south):

- Stage Stop Park (City of Selma) (15 acres)
- Harrison House Park (City of Selma) (11 acres)
- Universal City Golf Course / Olympia Hills (178 acres)
- Universal City Park (22 acres)
- Red Horse Park (Universal City) (12 acres)
- Nature Conservancy Tract (Universal City) (9 acres)
- Cloudt Tract (Universal City Public Works) (41 acres)
- Rose Garden Drain Easement (UC Public Works) (11 acres)
- Universal City Park land (Public works) (8 acres)
- Veteran's Park: (Universal City) (7 acres)

East Side Of Cibolo Creek (from north to south):

- FM 1518 Park (City of Selma) (1.6 acres)
- Cut-off-Park (City of Schertz) (57 acres)
- Future Selma Disc Golf Course (boundaries not determined)
- Selma City owned floodplain land (boundaries not determine)
- *Pickrell Park (City of Schertz) (17 acres)
- *Thulemeyer Park (City of Schertz) (16 acres)

* = Separated from Cibolo Creek by FM1518.

The area between I-35 and FM 78 has been used informally for years as an open space for walkers, mountain bikers, and recreational fisherman. A sign indicating a primitive trail has been installed near Cut-off-Park that shows a contiguous path on both sides of the Cibolo between I-35 and FM 78. It is unclear who installed the sign or cleared the trail.

The various parks along its edges are already well used by the public. Cibolo Creek in this section offers some interesting rocky outcrops (see Figure 4-11), pockets of deep water, and a variety of vegetation. Much of the land is in the 100-year floodplain, and thus has limited potential for commercial development.



Figure 4-11 Rock Formations Along Central Section



Figure 4-12 Cut-Off Park in Schertz

Of the three sections proposed for this Greenway, the Central Section holds the most potential for immediate need as it would provide the access for the most proximate population, and would require acquisition of the least amount of private property since much of it is already owned by local municipalities. There are already various pathways developed by informal use as well as established automobile tracks and areas that have been cleared and paved with gravel or rock. In some places there are informal low water crossings, allowing movement back and forth from either side of Cibolo Creek and improving the visitor experience through paved trails, safety measures, signage, and sanitation.

A number of park projects are planned in this area. The City of Selma is building a disc-golf course in flood plain land between Cibolo Creek and FM 1518. It is also rehabilitating the historic 'Harrison House' on the west side of the Creek and will connect it to Stage Stop Park with a trail. The Cibolo Creek Greenway could connect existing parks such as Cut-Off Park (Figure 4-12) in the Central Section with points south of the FM 78 bridge.

4.3.4.1.3. South Section

South of the FM 78 overpass, there is an opportunity to extend the Greenway under the bridge and continue the trail system several miles further along Cibolo Creek, where there are some wide arcs in the Creek's path. This route would follow the Cibolo mainly though undeveloped private land, much of which is within the 100-year floodplain. The main benefit of the South Section would be to connect the Central Section to Crescent Bend Nature Park - one of the largest parks (175-acres) in the entire Cibolo watershed. There is also the undeveloped 'Palm Park' near FM 78 that could be incorporated into the proposed Greenway. Directly across the Creek from Crescent Bend Nature Park, in Guadalupe County, is Niemietz Park (City of Cibolo), an 11-acre community park with ball fields, playgrounds, and basketball courts. There is currently no formal trail connection between these Niemietz and Crescent Bend parks. An extension of the Cibolo Greenway to Crescent Bend Nature Park would provide opportunities to link to Niemietz Park for pedestrians and cyclists, giving them access to the rest of the trail system. Figure 4-13 displays the proposed Cibolo Greenway-South Section in relations to existing parks and development.

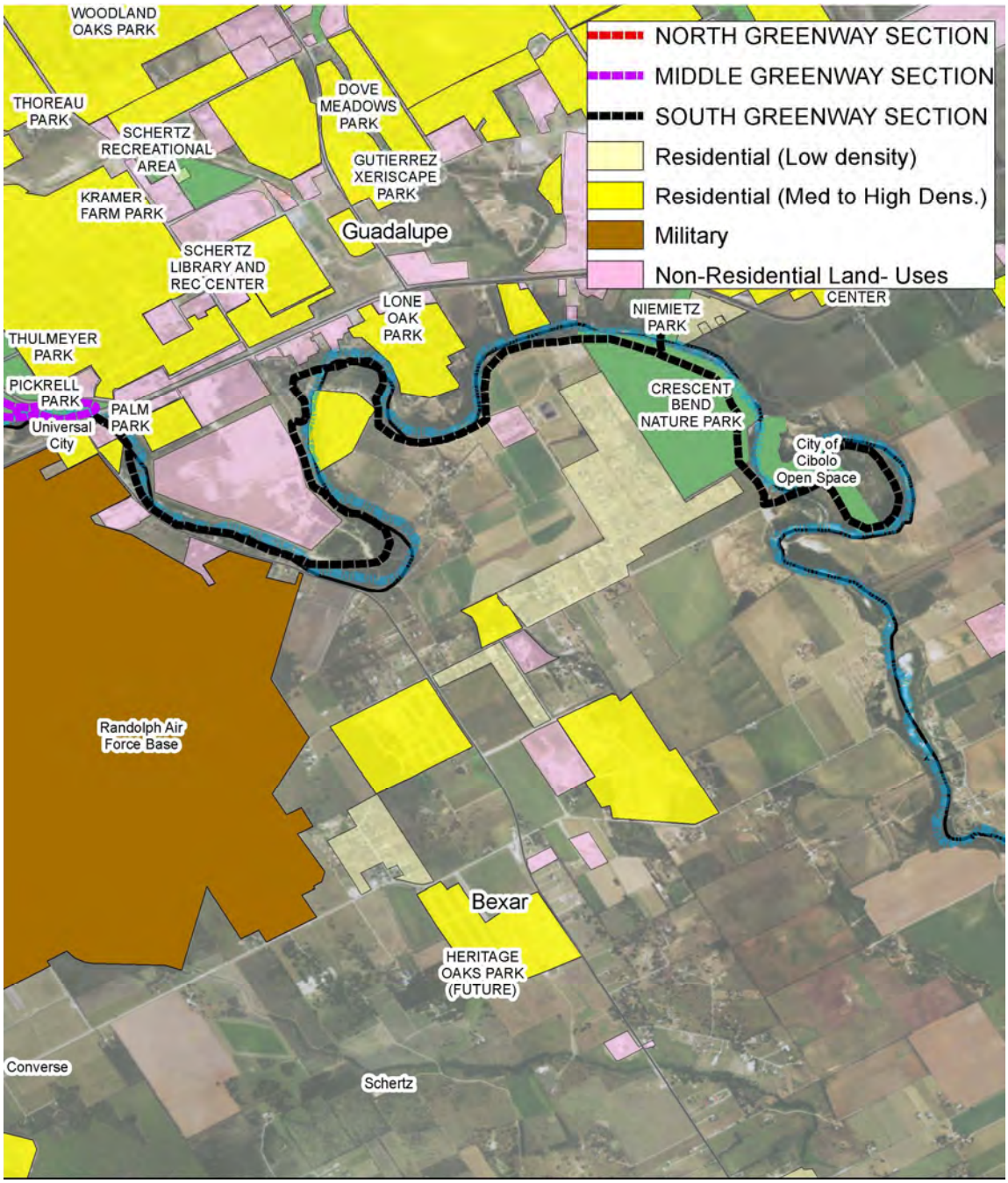


Figure 4-13 Cibolo Greenway – South Section

Since as much of the south section is still undeveloped (or abandoned), there is opportunity to acquire new properties that could be incorporated to expand the offering of open space in the area to the immediate east of Randolph Air Force Base. While currently mostly undeveloped, it is speculated that suburban growth could fill in the areas to the north of Interstate 10 over the next 10 to 20 years. The proposed South Section, especially if augmented with larger land acquisitions, could help create a greenbelt that would provide a respite of permanent green space within the Cibolo Creek corridor between I-10 and I-35. This would create a significant incentive for local investment and improve the area's quality of life.



Figure 4-14 View into Crescent Bend Nature Park from Schaefer Road (looking North)

4.3.4.2. Open Space Opportunity Areas

As mentioned in the plan development strategy, the sites identified as *open space opportunity areas* represent locations that hold potential for nature based recreation or conservation potential based on key site characteristics. Some of the designated open space opportunities areas are located in the area within the Cibolo Creek Greenway, and would be essential to the Greenway plan. Many of the sites are well-outside of this area. This plan sought to identify areas for nature based recreations that are found throughout the watershed – even outside of the proposed Greenway.

The following criteria were used to select the open space opportunity areas:

- Proximity to population
- Proportion of site in floodplain
- Tree cover and natural vegetation
- Convenient road access
- Topography
- Proximity to or adjacent to Cibolo Creek; length of frontage
- Size
- Adjacency to public land
- Located within proposed Cibolo Creek Greenway

The rational for this criteria and ranking are outlined in further detail in Appendix C.

Note that most of the open space opportunity areas are located on privately owned land, so that research and analysis was limited to aerial photos/Google Earth. The list of open space opportunity areas does not imply that every single site will be desirable for a park or must be considered for acquisition, it is just a location to be aware of in terms of future planning which may impact the particular location.

The open space opportunity areas within private property on the proposed Cibolo Creek Greenway would need easements or acquisition to allow trail access. The opportunity areas outside the greenway would most likely be a 'stand-alone' park or conservation areas.

Compared to the location of the proposed Cibolo Greenway, many of the Open Space Opportunity Areas are in areas that are less populated and less developed. For example there are a number of sites in the low density rural areas south of I-10, as well as in the less developed areas northeast of San Antonio. Because these areas are less developed at the moment, the urgency in preserving them or acquiring them is perhaps less compared to densely populated areas that are within the Cibolo Creek Greenway. However, they do represent areas that could be worth further examination for future recreational opportunities or planning.

Note that the evaluation of each Open Space Opportunity Area is estimated based upon desktop assessments of flood plain coverage, tree cover, site acreage, and the amount of intact creek frontage. Parcel boundaries change often, so for detailed analysis of any particular location (for example during due diligence before an acquisition), a new survey would be required for each particular site. The Open Space Opportunity Areas are displayed in the Recreation Workmaps.

Table 4-3 below shows data as well as estimations of physical characteristics and simple rankings (low, medium, high) to help understand the advantages and disadvantages of each particular open space opportunity area. In the following Table 4-4, all of the data is converted into low, medium, high, or very high rankings. Values for each score are low (1), medium (2), high (3), and very high (3.5). These points are tallied in Table 4-5 to provide a ranking system for the sites. It should be noted that the numeric values (including flood plain area, tree cover, etc) and many of the other values (such as 'variable topography) are estimates or loosely interpreted through visual observation. There are factors not present in this table, such as acquisition cost or environmental hazards (that would be exposed through environmental studies) that would also weigh heavily in decision making. So, these tables should be seen only as a 'starting point' from which more extensive research would be beneficial.

Table 4-3 Open space opportunity area site data and assessments

MAP #	SITE NAME	COUNTY	PROXIMITY TO POPULATION	PROPERTY IN FLOODPLAIN	TREE COVER (est.)	VARIABLE TOPOGRAPHY	DIRECT ROAD ACCESS	CIBOLO CREEK FRONTAGE	SIZE (ACRES)	NO. OF PARCELS	ADJACENT TO PUBLIC LAND	WITHIN PROPOSED GREENWAY
1	Bend at HWY 87	Wilson	low	100%	90%	med	high	0.33	22	1	no	no
2	Boerne Area Tracts	Bexar/Comal	med	10%	80%	high	low	2.00	665	2	yes	no
3	Bulverde Agglomeration	Bexar/Comal	med	75%	15%	med	med	1.00	253	3+	no	no
4	FM 1863 North Side of Creek	Comal	low	50%	20%	high	low	1.37	197	1	no	no
5	FM 2828	Guadelupe	low	60%	55%	low	high	1.15	142	1	no	no
6	FM337 at FM539	Wilson	low	50%	85%	high	high	0.90	246	1	no	no
7	I35 to Lookout Rd	Bexar/Comal	high	100%	50%	high	high	0.86	72	2	no	yes
8	Kitty Hawk Rd	Bexar	v.high	30%	70%	high	med	0.27	52	2	yes	yes
9	Land off 228	Wilson	low	65%	85%	high	med	0.32	97	3+	no	no
10	Land off 2724	Karnes	low	65%	80%	high	high	0.90	182	2	no	no
11	Land off 537	Bexar/Wilson	low	90%	66%	med	high	0.63	153	2	no	no
12	Lookout Rd to Railway	Bexar/Comal	high	85%	35%	high	high	0.60	66	3+	no	yes
13	Near Crescent Bend	Bexar/Guadelupe	high	90%	50%	med	high	2.25	185	3+	no	yes
14	Near JW Marriott	Bexar	high	2%	75%	v.high	med	0.00	334	2	yes	no
15	North of Classen Ranch Rd	Bexar	high	50%	50%	high	high	1.26	180	2	no	no
16	Oxbow Near Confluence	Karnes	low	100%	95%	high	low	1.10	42	1	no	no
17	Oxbow of 1518	Guadelupe	med	100%	75%	low	low	0.85	56	1	no	yes
18	Oxbow South of Crescent Bend	Bexar/Guadelupe	med	95%	25%	med	med	2.26	180	3+	yes	yes
19	Railway - 2252 - Railway	Bexar/Guadelupe	high	90%	40%	high	high	1.15	118	3+	no	yes
20	Shay Pass	Bexar	med	75%	20%	high	low	2.61	270	1	no	no
21	Smithson Valley	Bexar	med	35%	35%	high	high	0.60	300	1	no	no
22	Sutherland Springs	Wilson	med	50%	65%	med	high	1.77	525	3+	no	no
23	Vogel Valley	Bexar	med	75%	45%	med	low	1.15	240	1	no	no
24	Wagon Road to Classen Ranch	Bexar/Guadelupe/Comal	high	95%	50%	high	high	1.45	77	3+	no	yes

The following table converts data from the into high/medium/low attributes.

Table 4-4 Open space opportunity area criteria assessment

MAP #	SITE NAME	COUNTY	PROXIMITY TO POPULATION	PROPERTY IN FLOODPLAIN	TREE COVER (est.)	VARIABLE TOPOGRAPHY	DIRECT ROAD ACCESS	CIBOLO CREEK FRONTAGE	SIZE	NO. OF PARCELS	ADJACENT TO PUBLIC LAND	WITHIN PROPOSED GREENWAY
1	**Bend at HWY 87**	Wilson	low	v.high	v.high	med	high	low	low	high	no	no
2	**Boerne Area Tracts**	Bexar/Comal	med	low	high	high	low	high	v.high	med	yes	no
3	**Bulverde Agglomeration**	Bexar/Comal	med	high	low	med	med	high	high	low	no	no
4	**FM 1863 North Side of Creek**	Comal	low	med	low	high	low	high	high	high	no	no
5	**FM 2528**	Guadelupe	low	med	med	low	high	high	low	high	no	no
6	**FM337 at FM 539**	Wilson	low	med	high	high	high	high	high	high	no	no
7	**I35 to Lookout Road**	Bexar/Comal	v.high	high	med	high	high	med	med	med	no	yes
8	**Kitty Hawk Road**	Bexar	v.high	low	high	high	med	med	med	low	yes	yes
9	**Land off 228**	Wilson	low	high	high	high	med	med	med	med	no	no
10	**Land off 2724**	Karnes	low	high	high	high	high	low	high	med	no	no
11	**Land off 537**	Bexar/Wilson	low	v.high	high	med	high	low	high	med	no	no
12	**Lookout Road to Railway**	Bexar/Comal	high	high	high	high	high	med	med	low	no	yes
13	**Near Crescent Bend**	Bexar/Guadelupe	high	v.high	med	med	high	high	high	low	yes	yes
14	**Near JW Marriott**	Bexar	high	low	high	v. high	med	med	v. high	high	no	no
15	**North of Classen Ranch Rd**	Bexar	high	med	med	high	high	none	high	med	no	no
16	**Oxbow Near Confluence**	Karnes	low	v.high	v.high	high	low	high	low	high	no	no
17	**Oxbow off 1518**	Guadelupe	med	v.high	high	low	low	med	med	high	no	yes
18	**Oxbow South of Crescent Bend**	Bexar/Guadelupe	med	v.high	low	med	med	high	high	low	yes	yes
19	**Railway - 2252 - Railway**	Bexar/Guadelupe	high	v.high	med	high	high	high	high	low	no	yes
20	**Shay Pass**	Bexar	med	high	low	high	low	high	high	high	no	no
21	**Smithson Valley**	Bexar	med	low	low	high	yes	med	high	high	no	no
22	**Sutherland Springs**	Wilson	med	med	high	med	high	high	high	low	no	no
23	**Vogel Valley**	Bexar	med	high	med	med	low	high	v.high	high	no	no
24	**Wagon Road to Classen Ranch**	Bexar/Guadelupe/Coma	high	v.high	med	high	high	high	med	low	no	yes

Table 4-5 Open space opportunity area comparison by points assessed

MAP #	SITE NAME	COUNTY	PROXIMITY TO POPULATION	PROPERTY IN FLOODPLAIN	TREE COVER (est.)	VARIABLE TOPOGRAPHY	DIRECT ROAD ACCESS	CIBOLO CREEK FRONTAGE	SIZE	NO. OF PARCELS	ADJACENT TO PUBLIC LAND	WITHIN PROPOSED GREENWAY	TOTAL POINTS
1	**Bend at HWY 87**	Wilson	1	3.5	3.5	2	3	1	1	3	0	0	18.0
2	**Boerne Area Tracts**	Bexar/Comal	2	1	3	3	1	3	3.5	2	1	0	19.5
3	**Bulverde Agglomeration**	Bexar/Comal	2	3	1	2	2	3	3.5	1	0	0	17.5
4	**FM 1863 North Side of Creek**	Comal	1	2	1	3	1	3	3	3	0	0	17.0
5	**FM 2528**	Guadelupe	1	2	2	1	3	3	3	3	0	0	18.0
6	**FM337 at FM 539**	Wilson	1	2	3	3	3	3	3.5	3	0	0	21.5
7	**I35 to Lookout Road**	Bexar/Comal	3.5	3.5	2	3	3	2	2	2	0	1	22.0
8	**Kitty Hawk Road**	Bexar	3.5	1	3	3	2	1	2	2	1	1	19.5
9	**Land of 228**	Wilson	1	3	3	3	2	2	2	2	0	0	18.0
10	**Land of 2724**	Karnes	1	3	3	3	3	1	3	2	0	0	19.0
11	**Land off 537**	Bexar/Wilson	1	3.5	3	2	3	1	3	2	0	0	18.5
12	**Lookout Road to Railway**	Bexar/Comal	3	3	3	3	3	2	2	1	0	1	21.0
13	**Near Crescent Bend**	Bexar/Guadelupe	3	3.5	2	2	3	3.5	3	1	1	1	23.0
14	**Near JW Marriott**	Bexar	3	1	3	3.5	2	2	3.5	3	0	0	21.0
15	**North of Classen Ranch Rd**	Bexar	3	2	2	3	3	0	3	2	0	0	18.0
16	**Oxbow Near Confluence**	Karnes	1	3.5	3.5	3	1	3	1	3	0	0	19.0
17	**Oxbow off 1518**	Guadelupe	2	3.5	3	1	1	2	2	3	0	1	18.5
18	**Oxbow South of Crescent Bend**	Bexar/Guadelupe	2	3.5	1	2	2	3.5	3	1	1	1	20.0
19	**Railway - 2252 - Railway**	Bexar/Guadelupe	3	3.5	2	3	3	3	3	1	0	1	22.5
20	**Shay Pass**	Bexar	2	3	1	3	1	3	3.5	3	0	0	19.5
21	**Smithson Valley**	Bexar	2	1	1	3	3	2	3.5	3	0	0	18.5
22	**Sutherland Springs**	Wilson	2	2	3	2	3	3	3.5	1	0	0	19.5
23	**Vogel Valley**	Bexar	2	3	2	2	1	3	3.5	3	0	0	19.5
24	**Wagon Road to Classen Ranch**	Bexar/Guadelupe/Comal	3	3.5	2	3	3	3	2	1	0	1	21.5

From the Table 4-5 above, assumptions can be made about the 'best' open space opportunity areas. The highest ranking are #13, #19, and #7. All three sites happen to be adjacent to the Cibolo Creek Greenway, which awards each area a point. This matrix can be altered in terms of the point system, and there is more research needed for each site, but it is a starting point for comparison of sites.

4.3.5. Implementation

This section presents some general strategies and specific steps to facilitate the successful development and execution of a nature-based recreation plan.

4.3.5.1. General Strategies

Following are general strategies related to acquisition and development of recreational opportunity areas that apply to SARA - or any of the municipalities in the Cibolo watershed region that are participating in development of projects related to the Cibolo Creek Holistic Watershed Plan.

- Municipalities and local organizations should consider partnering with a regional agency (such as SARA) to coordinate land acquisition, trail planning and development for situations where projects overlap multiple municipal boundaries. Alternatively, a non-profit organization dedicated solely to Cibolo Creek could be developed to help promote and organized the development plan.
- Focus recreational projects in areas with high established need, and high population growth potential.
- Develop local community 'buy-in' for project planning and development. Build partnerships with local planners, government, businesses, and organizations.
- Acquire properties and easements in locations that are adjacent to existing parks, to link these spaces for greater regional connectivity.
- Pursue conservation easements with local landowners to acquire space for trails along the Cibolo while allowing landowners to retain their property. This can help build linkages without requiring purchases of entire parcels.
- Partner with private donors and organizations (for example the Nature Conservancy) to identify key opportunities for conservation properties, and determine the appropriate level of public access.
- Create a 'brand' for the Cibolo Creek Watershed - using signage, special events, brochures and other media. Increased awareness will help build support for efforts to protect Cibolo Creek natural environments (from litter, dumping, etc) and to help develop recreational spaces.
- Incentivize preservation of land in the most environmentally sensitive areas. This can be accomplished through grants, or tax subsidies, with assistance of conservation organizations.
- Locate creek access and public recreational amenities convenient to public roads, making it more efficient for visitation and management.

4.3.5.2. Implementation

Following is a general overview of the steps required to see such a project to completion. These are not necessarily linear project phases and some steps will overlap. This outline also does not assign specific roles for SARA, local governments, or community groups. Roles may overlap in some cases depending on the particular project and outcome.

Prepare in-depth financial feasibility analysis for land acquisition, purchase of easements, trail construction, and ongoing maintenance. Also, examine funding sources for the project and ongoing expenses. This will require analysis and discussion with stakeholders, but eventually should lead to decisions regarding the financial and institutional capacity to move forward with the proposed plans. Cost-benefit analysis of these projects as well study of opportunities and constraints will help to inform local communities where the projects will be developed and will help forecast potential obstacles.

Prioritize plans. Come to conclusions on which projects will be undertaken and the chronological order in which they will be developed. Determine when projects will begin, and anticipated completion dates. Further flesh out the order of tasks to be complete and organize short-term and long-term goals.

Define roles for SARA, and participating municipalities - The cities of Selma, Universal City, Schertz, and Cibolo all maintain park land and municipal property directly within the proposed Cibolo Greenway corridor. Each city potentially has an interest to see a Greenway constructed, however, they might not have the political or financial ability to lead such a project. SARA 's role could be to offer support to work with these entities to help guide the project through technical expertise, political leadership, financial help, legal help, or other assistance. To begin the project, there must be some negotiation towards the role of each organization with regards to the effort and the outcome of the project. Particularly relevant issues include project funding and long-term maintenance. These roles are best explored and resolved relatively early in the planning process.

Build public support from the community - If built, the Cibolo Creek Greenway project could be developed on both private and public land, and will likely be funded in-part by public money for construction and maintenance. It is important that public input be sought and that the project outcomes reflect the community's desire. The general public has already used this land for recreational purposes such as fishing and hiking. Their ideas for the Cibolo Greenway will be considered through public meetings, design charettes, surveys, or other efforts to solicit community buy-in for the project.

Build support and formal approval from local municipalities - Support must also be gained from the local city leadership. The project has the potential to be a great benefit for all parties involved, but careful effort must be made to deal with the issues and concerns of all entities to make sure the project stays on track and remains sustainable in the long-term. At a fairly early juncture in the planning process, it will be necessary to develop a long-term operating agreement to delineate clearly which organizations will be responsible for maintenance, security, and liability along all portions of the proposed Cibolo Greenway.

Acquire necessary private property easements - As mentioned, a major challenge is to gain access to build trails on the portions of the proposed Cibolo Greenway that are privately owned. It is advisable to acquire properties (or easements through them) early in the development process to avoid exorbitant costs in the future.

Finalize conceptual plans - The concept plan provided in this document is preliminary in scope; meant to illustrate the general potential of Cibolo Creek Greenway. With the added input of citizens, partners, and key constituents, the final concept plan will be refined. A concept plan would include a more detailed trail alignment plan, location of access points, and locations for seating and other developed areas, parking areas, and an inventory of key program elements like signage, lighting, and bridges.

Construction plans - Following acceptance of a concept plan for the Cibolo Greenway, the construction documents and building schedules can be developed. This might require some changes to the concept plan as well, given discoveries about engineering issues or property boundaries. Construction plans would be divided and phased into different categories such as grading, trail design, lighting, amenities, and plantings.

Secure funding - Funding is a significant challenge for public projects such as parks or greenways, especially as this project overlaps multiple cities and counties. Funding can be obtained from capital improvements plans, municipal bonds, private grants and foundations, and Federal or State grants. Funding provision should be thought of in terms of one time design/construction costs, as well as long-term maintenance costs. Due to the long time-table for funding such projects, it is advisable to start early in the process to establish anticipated costs and identify sources of funding.

Project construction - When construction documents are complete, funding is secured, and approval is granted, construction can move forward. It is likely a project such as a 15-mile Greenway could take several years to build depending on the complexity of the trail alignment, and if there are other project elements (such as habitat restoration, bridge underpasses, etc.). It is important to remember some of the construction might not just be on the 'new' portions of the trail, but at existing parks along the Creek to retro-fit them to extend access to the Greenway.

Maintenance - A reliable foundation of maintenance is a key ingredient for success of virtually any public project. Linear parks have an often endless supply of maintenance issues ranging from fallen trees, flood debris, litter, graffiti, and trail repair. Routine costs include mowing, weeding, and removal of vegetation to keep land from becoming overgrown. In addition to the physical maintenance issues, there are ongoing costs that the project will incur relating to provision of security, waste management, electricity costs, and other expenses relating to maintenance of public land. Decision making regarding long-term maintenance obligations should be organized early in the planning process.

4.4. Conclusions

Passing through six counties, Cibolo Creek is a haven for wildlife, and for people seeking to enjoy nature. While there are already a number of nature reserves and public parks along the Creek, there is strong

potential to develop additional parks, trails, and greenways along this linear corridor. The rapid commercial and suburban growth experienced in municipalities to the north and east of San Antonio has created a need for conservation of open space and nature-base recreation opportunities.

This plan, through research on population, land-use, existing conditions, and environmental factors, has identified areas where there is strong potential for public park and recreation development. Surveys among local communities and discussions with local leaders have indicated that trails and additional park space are the amenities that are most desired by local residents.

This plan proposes two a two-part strategy for providing nature based recreation in the watershed. The first part is a *primary concept plan* for a Greenway on Cibolo Creek; the second part is the identification of *open space opportunity areas*. The proposed Cibolo Creek Greenway would stretch approximately 15 miles from Classen Ranch Road south past Crescent Bend Nature Park. The greenway plan has been divided into three basic geographies: North, Central, and South. The proposed greenway would pass through the cities Selma, Universal City, Schertz, and Cibolo and link a number of existing parks with a ribbon of shared-use trail. If fully built, it would be one of the longest paved trail systems in Texas.

While this general area is not yet fully developed, rapid suburban growth of the region suggests it would be conducive to the development of a greenway. There are a number of challenges that could face the development of the proposed project. However, with strong leadership and effective planning, the area could be transformed into a beautiful linear green space that will make the region and local communities more attractive and liveable.

The Central section holds the greatest potential for the near term development as it connects more than a dozen existing public parks and open space and is already traversed by people in a manner similar to a linear Greenway. If the entire proposed Greenway is developed, it would be feasible a person could safely- and easily-ride a bicycle from Classen Ranch Road to all the way to Crescent Bend Nature Park - and back - in an afternoon.

The open space opportunity areas identified represent areas to that have been selected for having characteristics that might be favorable for nature-based recreation based on the natural features, location, and other criteria. Most of these sites are on private land and would need further investigation before determine if they would actually be viable as public park sites. Some of the open space opportunity areas in this plan are within the proposed Cibolo Creek Greenway, but many are located well outside the Greenway. Those outside the Greenway may not have the more immediate viability for park land or trail development as found in the proposed Greenway. However, they have been identified to be aware of them should opportunities arise for conservation designation or park development. There are no *immediate* plans (acquisition, or otherwise) for any of these locations, but the awareness of these locations within the watershed will hopefully help to preserve some of them from development and could provide much needed natural open space for future generations.

5. Stream Health

An assessment of stream restoration potential for the Cibolo Creek watershed was performed through two independent efforts. Michael Baker, Inc. was contracted by SARA to evaluate stream restoration potential for portions of the Cibolo Creek and its major tributaries within Bexar County, and in May 2015 URS completed an assessment of stream restoration potential for selected streams within Wilson, Karnes and Goliad Counties. These studies assess the condition of natural stream segments and engineered channels within the watershed and the need and potential for preservation, protection, and implementation of stream restoration projects in the watershed.

Natural streams were grouped into three assessment categories:

- **Stream Restoration** – reaches in this category are typically unstable both vertically and horizontally, exhibit erosion of both the streambed and banks, and have site constraints that allow for a higher level of restoration of stream functions.
- **Stream Rehabilitation** – reaches in this category are relatively stable, but exhibit localized areas of instability, such as bank erosion. The instabilities are usually visible on an aerial photo and/or contours where there are steep banks, tight meander bends, or absence of sufficient riparian buffer and vegetation. These reaches typically require localized bank stability treatments, such as re-vegetation and/or bioengineering, or changes in land management practices.
- **Stream Preservation** – reaches in this category are stable, and appear to be in pristine condition. These sites are candidates for preservation

Engineered channels were classified into one of two categories based on the potential for stream restoration through natural channel design (NCD) or other methods:

- **NCD1** – reaches in this category have the potential to be restored or rehabilitated using NCD techniques (in this case meander or step-pool designs were evaluated) to restore some stream functions and provide improved geomorphic stability based on existing constraints.
- **NCD2** – reaches in this category do not provide an opportunity for restoration or rehabilitation using NCD techniques due to existing constraints, such as limited right of way (ROW). Future widening of the flood corridor through buyouts can introduce opportunities for these reaches to be reclassified as NCD1 reaches. Alternative methods may also be required, such as hard armoring for stabilization.\

The Michael Baker and URS stream restoration potential reports may be found in Appendix D. The Stream Health Workmap displays the stream restoration assessment categories for portions of Cibolo Creek and its major tributaries within Bexar County.

6. Damage and Opportunity Centers

Phase 2 of the master plan analyzed flood risk, water quality and stream health within the Cibolo Creek watershed and identified potential concerns relating to each of those categories. This section summarizes those concerns and presents them together as Damage Centers. This comprehensive look at watershed concerns will facilitate the development of holistic solutions in Phase 3. This section will also summarize Opportunity Centers within the watershed, which are areas with positive features that can potentially be preserved or enhanced. The Opportunity Centers are primarily related to recreation and stream preservation opportunities.

6.1. Damage Centers

For the intent of this master plan damage centers are defined as areas with significant flood risk, water quality, and/or stream health concerns that are of an intensity and contiguity to potentially warrant an improvement project under Phase 3.

6.1.1. Flood Risk

The flood risk concerns discussed in Section 2.5, including flooded buildings and estimated annual damages, were reviewed and it was found that five areas may be considered damage centers (see Damage Center Workmap). These areas include:

- Upper Cibolo Creek – Approximately 10,000 feet upstream of US 281
- Upper Cibolo Creek – Near Gibbs-Sprawl Road (FM 78)
- Upper Martinez Creek B – Gibbs-Sprawl Road to Montgomery Drive
- Lower Martinez Creek B – FM 1518 to Loop 1604
- Upper Escondido Creek – FM 1516 to Binz-Engleman Road

Table 6-1 shows the number of flooded buildings for each damage center by storm event. The table also compares the number of flooded buildings for the damage centers against the total number of flooded buildings in the watershed. There are a total of 3, 10, 22, 35 and 80 flooded structures within these damage centers for the 50%, 10%, 4%, 2% and 1% exceedance events, respectively. The damage center flooded buildings equate to 75%, 56%, 56%, 52%, and 56% of the total number of flooded buildings in the Cibolo Creek watershed for the 50%, 10%, 4%, 2% and 1% exceedance events, respectively.

Table 6-1 Damage Center - Number of Flooded Structures (Baseline Existing)

Damage Center	Number of Flooded Buildings (by Annual Chance Event)					
	50%	10%	4%	2%	1%	0.2%
Cibolo Creek - U/S of US 281	0	0	1	4	20	45
Cibolo Creek - near FM 78	0	1	1	2	15	109
Upper Martinez Creek - Gibbs-Sprawl Rd to Montgomery Ave.	1	3	10	17	27	92
Lower Martinez Creek - FM 1518 to Loop 1604	1	4	8	10	14	16
Upper Escondido Creek - FM 1516 to Binz-Engleman Road	1	2	2	2	4	5
Total	**3**	**10**	**22**	**35**	**80**	**267**
Total in Watershed (All Streams)	**4**	**18**	**39**	**67**	**142**	**467**

Table 6-2 displays the estimated annual damages for each of the damage centers, as well as the present value of those damages assuming a 50 year project life with a 2% interest rate. The five damage centers have a total estimated annual damage of $83,185, which is 44% of the total estimated annual damage for the Cibolo Creek watershed under Baseline Existing conditions.

Table 6-2 Damage Center - Estimated Annual Damages (Baseline Existing)

Damage Center	Estimated Annual Damages (EAD) ($)	Present Value (PV) ($)
Cibolo Creek - U/S of US 281	$5,264	($165,416)
Cibolo Creek - near FM 78	$9,459	($297,227)
Upper Martinez Creek - Gibbs-Sprawl Rd to Montgomery Ave.	$12,843	($403,567)
Lower Martinez Creek - FM 1518 to Loop 1604	$21,997	($691,215)
Upper Escondido Creek - FM 1516 to Binz-Engleman Road	$33,623	($1,056,557)
Total	**$83,185**	**($2,613,981)**
Total in Watershed (All Streams)	**$189,351**	**($5,950,089)**

Dangerous crossings are located throughout the watershed and on most studied streams. These crossings are generally not located close enough to be considered part of the five identified damage centers or in a close enough proximity to one another to comprise additional stand-alone damage centers. However, the dangerous crossings pose a significant threat to safety and should be considered for Phase 3 improvements. Atkins prioritized the dangerous crossings in the watershed based upon the number of times in a year each crossing is anticipated to experience a “dangerous” event, the estimated annual daily traffic at the crossing, and the distance to the nearest safe crossing. The top 50 most dangerous crossings in the watershed are shown in Table 6-3.

Table 6-3 Prioritized Dangerous Crossings

Rank	Crossing	River
1	CR 352/CR 440	Cibolo Creek (Lower)
2	CR 347/CR 417	Cibolo Creek (Lower)
3	FM 537	Cibolo Creek (Lower)
4	FM 2538	Cibolo Creek (Upper)
5	FM 1863 (U/S)	Cibolo Creek (Upper)
6	Battle Intense Road	Cibolo Creek (Upper)
7	FM 3351	Cibolo Creek (Upper)
8	IH-10 East	Escondido Creek (Upper)
9	Blanco Road	Cibolo Creek (Upper)
10	Bexar Bowling	Cibolo Creek (Upper)
11	FM 1863 (D/S)	Cibolo Creek (Upper)
12	Lookout Road	Cibolo Creek (Upper)
13	Smithson Valley Road	Cibolo Creek (Upper)
14	Toutant Beuregard Road	Balcones Creek
15	FM 2724	Cibolo Creek (Lower)
16	Putter Road	Martinez Creek B (Upper)
17	Blanco Road	Meusebach Creek
18	Old Fredericksburg Road	Balcones Creek
19	N. Gable Road	Martinez Creek B (Lower)
20	Boerne Stage Road	Balcones Creek

6.1.2. Water Quality

The water quality damage reaches discussed in Section 3.4.2 were evaluated and used to define water quality damage centers. Damage centers are areas with intense water quality damages or damages reaches within a close proximity of one another. As seen in the Damage Center Workmap, there are nine water quality damage centers that are discussed below. It should be noted, that elevated bacteria concentrations are found throughout the watershed and, as a result, specific bacteria damage centers were not defined. However, measures to reduce bacteria loads throughout the watershed will be considered during Phase 3 of the master plan.

Area 1 – This area is upstream of Boerne and includes the upper limits of Cibolo Creek and several unnamed tributaries. The main channel of Cibolo Creek is damaged primarily in terms of ortho-phosphorus and the tributaries are damaged primarily in terms of nitrate nitrogen. The damages are likely caused by the predominately dry (low flow) condition of these reaches. The initial wash-off of pollutants from the land surface tends to skew the flow-weighted constituent concentration results.

Area 2 – This area is upstream of Boerne and includes the upper limits of Frederick Creek. Frederick Creek is damaged in terms of ortho-phosphorus and nitrate nitrogen. The damages are likely caused by the predominately dry (low flow) condition of these reaches. The initial wash-off of pollutants from the land surface tends to skew the flow-weighted constituent concentration results.

Area 3 – This area is upstream of Boerne and includes the upper limits of Balcones Creek and an Unnamed Tributary of Rundale Creek. Balcones Creek is damaged in terms of ortho-phosphorus and the Unnamed Tributary of Rundale Creek is damaged in terms of nitrate nitrogen. The damages are likely caused by the predominately dry (low flow) condition of these reaches. The initial wash-off of pollutants from the land surface tends to skew the flow-weighted constituent concentration results.

Area 4 – This damage center includes areas along Cibolo Creek upstream of the Edwards Aquifer Outcrop. The main channel of Cibolo Creek is damaged in terms of ortho-phosphorus and several minor tributaries in this area are damaged in terms of dissolved oxygen. The damages are likely caused by the predominately dry (low flow) condition of these reaches. The initial wash-off of pollutants from the land surface tends to skew the flow-weighted constituent concentration results.

Area 5 – Martinez Creek has elevated ortho-phosphorus concentrations downstream of FM 1516. Upper portions of the Martinez Creek watershed are heavily developed. Storm runoff from residential development and WWTP discharges likely contribute to the elevated phosphorus concentrations.

Area 6 - Dry Hollow Creek and several of its tributaries have both major and minor damages in terms of ortho-phosphorus. Agricultural runoff is the likely cause for the damages, which means that agricultural BMPs may be an effective solution to evaluate during Phase 3.

Area 7 – Elm Creek and several of its tributaries have both major and minor damages in terms of ortho-phosphorus. One unnamed tributary to Elm Creek has elevated levels of nitrate nitrogen. Agricultural runoff is the likely cause for the damages, which means that agricultural BMPs may be an effective solution to evaluate during Phase 3.

Area 8 – This damage center includes the main channel of Cibolo Creek between I-10 and Southerland Springs. The damages are attributed to elevated concentrations of ortho-phosphorus, with a limited reach of elevated concentrations of chlorophyll-a.

Area 9 – The main channel of Cibolo Creek downstream of Southerland Springs has elevated concentrations of ortho-phosphorus that was confirmed HSPF modeling, as well as by measured water quality samples.

6.1.3. Stream Health

As seen in the Damage Center Workmap stream health damage centers were defined throughout the Cibolo Creek watershed using the stream health assessment documented in Chapter 5. Stream reaches that are identified as having “restoration potential” are considered damage centers.

6.2. Opportunity Centers

Opportunity Centers within the watershed, which are areas with positive features that can potentially be preserved or enhanced. The Opportunity Centers are primarily related to recreation and stream preservation opportunities. The Opportunity Center Workmap displays existing parks, stream preservation opportunities (see Section 5), open space preservation opportunities (see Section 4.3.4.2) and the proposed Cibolo Greenway (see 4.3.4.1).

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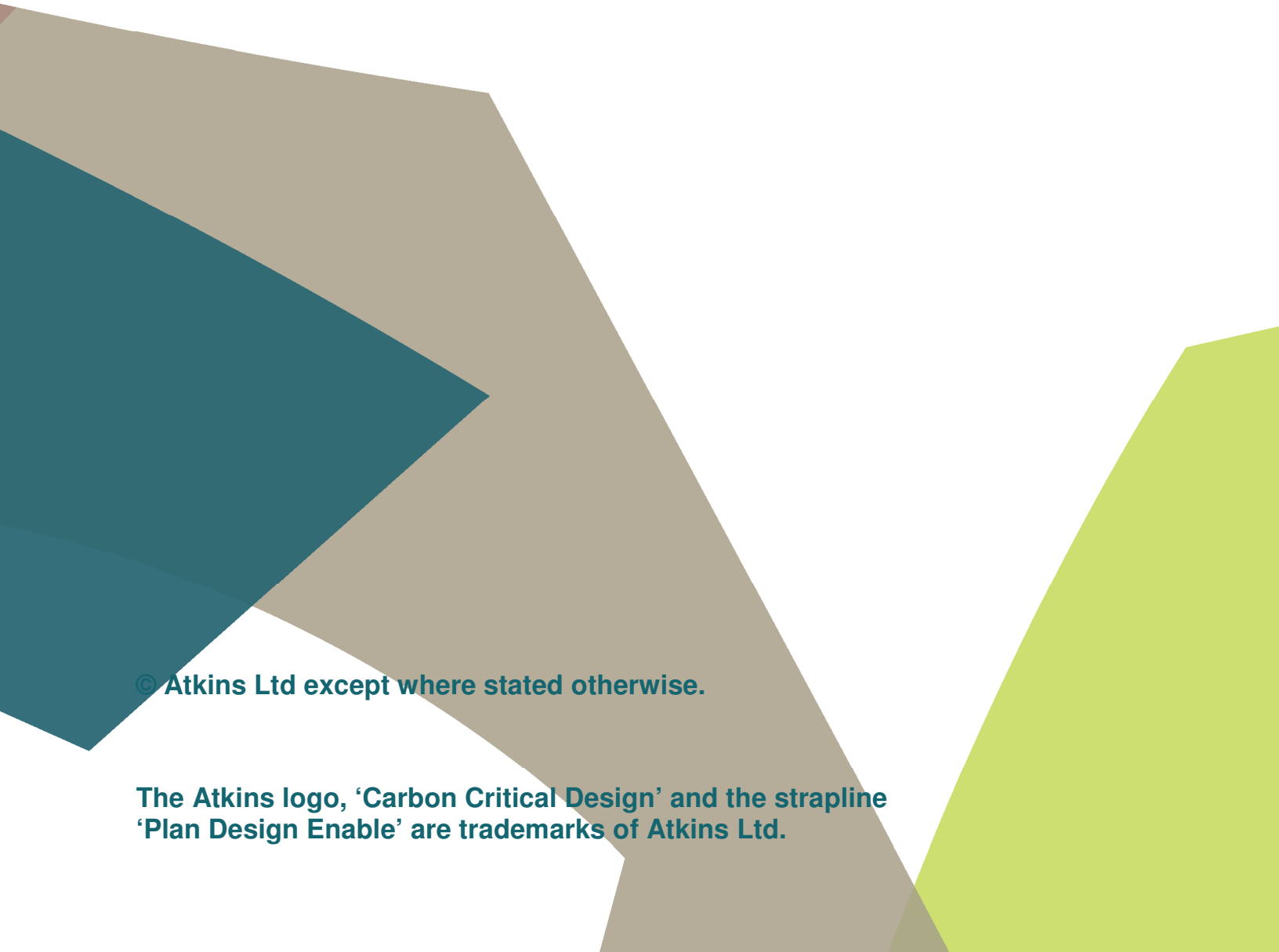
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Cibolo Creek Watershed Holistic Master Plan

Phase III Report

San Antonio River Authority

July 2018

SAN ANTONIO RIVER AUTHORITY
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Atkins North America, Inc.
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Table of acronyms

AAD	Avoided Annual Damages
ADT	Average Daily Traffic
AEP	Annual Exceedance Probability
BMP	Best Management Practice
BMPRAC	Best Management Practice Evaluation
C2MP	Cibolo Creek Holistic Watershed Master Plan
CMP	Corrugated Metal Pipe
DCF	Dangerous Crossing Factor
DSC	Distance to Safe Crossing
D/S	Downstream
EAD	Estimate Annual Damage
EPA	Environmental Protection Agency
FTABLES	Hydraulic Function Tables
FL	Flowline
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HSPF	Hydrological Simulation Program – Fortran
LID	Low Impact Development
NAVD88	North American Vertical Datum of 1988
NCD	Natural Channel Design
NOAA	National Oceanic and Atmospheric Administration
PV	Present Value
RCB	Reinforced Concrete Box
RCP	Reinforced Concrete Pipe
SARA	San Antonio River Authority
SDR	Safe Depth Ratio
SUSTAIN	System for Urban Stormwater Treatment and Analysis Integration
SWPPP	Stormwater Pollution Prevention Plan
TxDOT	Texas Department of Transportation
USGS	United States Geological Survey
U/S	Upstream

Executive Summary

The San Antonio River Authority contracted Atkins to develop the Cibolo Creek Holistic Watershed Master Plan (C2MP) with the objective of providing communities in the watershed with sustainable solution concepts that address a variety of concerns including flooding, water quality, stream health and recreation. The primary objectives of the C2MP were:

- Reduce flood risk using structural and non-structural measures,
- Reduce or remove pollutant loadings in waterways through natural processes and/or improved management practices,
- Protect or restore riparian corridors, and
- Incorporate recreational features, as feasible.

Phase 1

Phase 1 of the master plan collected data for the Cibolo Creek watershed related to flood risk, water quality, stream health and recreation. The majority of the data collected for the Phase 1 effort was obtained through research of readily available sources, including accessing websites (ex. SARA's D2MR, the National Climatic Data Center, TCEQ, etc.), contacting agencies directly, and collecting data directly from SARA. The data was organized and evaluated for its potential use in the master plan. The Phase 1 effort was concluded by documenting any identified data gaps. The identified data gaps included:

- Inaccurate land use coverages outside of Bexar County
- Inaccurate LiDAR grid accuracy in steep areas
- Limited rainfall gages in the lower watershed
- No appraisal values for parcels in Comal, Karnes, Kendall and Wilson Counties
- Limited detailed hydraulic models outside of Bexar County
- Limited historic highwater mark information
- No existing study data for overland infiltration rates into the Edwards Aquifer

Stakeholder engagement was an important part of the Phase 1 effort. The objective was to identify key stakeholders, collect available data and conduct stakeholder meetings to discuss potential areas of interest. The identified stakeholders in the watershed were engaged through specific individual meetings, as these individual meetings provided a better platform to encourage data and information sharing than meeting in a group format. SARA staff along with the Atkins' team developed a stakeholder engagement plan that included an initial list of key stakeholders. The engagement plan established a standard approach to stakeholder coordination. This approach provided a thorough overview of the project and encouraged feedback from the stakeholders.

A total of 22 stakeholder meetings were held between April 2014 and September 2014. Stakeholders were primarily interested in the data availability after the project was complete, as well as if there was going to be project funding associated with the final recommendations. The stakeholders were informed that the final report would be made available for their review and use but project funding would have to be identified by the stakeholders.

Phase 2

Phase 2 of the master plan focused on identifying Baseline conditions in the watershed in terms of hydrology, stream hydraulics, water quality, stream health, and recreational features. "Damage centers", which are areas where potential problems exist, were identified based on models of existing and future conditions. A preliminary list of watershed improvement concepts was developed and areas with positive features that can be potentially preserved or enhanced ("Opportunity centers") were identified.

The Baseline flood risk analysis results showed that estimated annual damage from building flooding in the watershed is relatively small at $189,351. Although these damages were identified throughout the watershed, there are five areas of primary flooding concern (Damage Centers). These areas include:

- Upper Cibolo Creek – Approximately 10,000 feet upstream of US 281
- Upper Cibolo Creek – Near Gibbs-Sprawl Road (FM 78)
- Upper Martinez Creek B – Gibbs-Sprawl Road to Montgomery Drive
- Lower Martinez Creek B – FM 1518 to Loop 1604
- Upper Escondido Creek – FM 1516 to Binz-Engleman Road

Dangerous crossings were also evaluated as potential Damage Centers within the watershed. Atkins evaluated each crossing to determine its Dangerous Crossing Factor (DCF), which represents how much the "safe depth" of a crossing can expect to be exceeded on an annual basis. A prioritized list of the most dangerous crossings was developed by considering each crossing's DCF, estimated average daily traffic and the distance to the nearest safe crossing. The five most dangerous crossings in the Cibolo Creek watershed were identified as:

1. CR 352/CR 440 (Zuehl Crossing) at Cibolo Creek
2. CR 347/CR 417 (Scull Crossing) at Cibolo Creek
3. FM 537 at Cibolo Creek
4. FM 2538 at Cibolo Creek
5. FM 1863 (upstream crossing) at Cibolo Creek

Baseline water quality modeling was developed for the Cibolo Creek watershed during Phase 2. The modeling simulated seven constituents, including dissolved oxygen, nitrate nitrogen, ammonia nitrogen, organic phosphorus, ortho-phosphorus, chlorophyll-a and bacteria. The constituent concentrations throughout the watershed were compared against SARA's screening levels to identify stream reaches that are damaged in terms of water quality. This yielded nine water quality Damage Centers:

- **Area 1** – This area is upstream of Boerne and includes the upper limits of Cibolo Creek and several unnamed tributaries. The main channel of Cibolo Creek is damaged primarily in terms of ortho-phosphorus and the tributaries are damaged primarily in terms of nitrate nitrogen. The damages are likely caused by the predominately dry (low flow) condition of these reaches. The initial wash-off of pollutants from the land surface tends to skew the flow-weighted constituent concentration results.

- **Area 2** – This area is upstream of Boerne and includes the upper limits of Frederick Creek. Frederick Creek is damaged in terms of ortho-phosphorus and nitrate nitrogen. The damages are likely caused by the predominately dry (low flow) condition of these reaches. The initial wash-off of pollutants from the land surface tends to skew the flow-weighted constituent concentration results.

- **Area 3** – This area is upstream of Boerne and includes the upper limits of Balcones Creek and an Unnamed Tributary of Rundale Creek. Balcones Creek is damaged in terms of ortho-phosphorus and the Unnamed Tributary of Rundale Creek is damaged in terms of nitrate nitrogen. The damages are likely caused by the predominately dry (low flow) condition of these reaches. The initial wash-off of pollutants from the land surface tends to skew the flow-weighted constituent concentration results.

- **Area 4** – This damage center includes areas along Cibolo Creek upstream of the Edwards Aquifer Outcrop. The main channel of Cibolo Creek is damaged in terms of ortho-phosphorus and several minor tributaries in this area are damaged in terms of dissolved oxygen. The damages are likely caused by the predominately dry (low flow) condition of these reaches. The initial wash-off of pollutants from the land surface tends to skew the flow-weighted constituent concentration results.

- **Area 5** – Martinez Creek has elevated ortho-phosphorus concentrations downstream of FM 1516. Upper portions of the Martinez Creek watershed are heavily developed. Storm runoff from residential development and WWTP discharges likely contribute to the elevated phosphorus concentrations.

- **Area 6** - Dry Hollow Creek and several of its tributaries have both major and minor damages in terms of ortho-phosphorus. Agricultural runoff is the likely cause for the damages, which means that agricultural BMPs may be an effective solution to evaluate during Phase 3.

- **Area 7** – Elm Creek and several of its tributaries have both major and minor damages in terms of ortho-phosphorus. One unnamed tributary to Elm Creek has elevated levels of nitrate nitrogen. Agricultural runoff is the likely cause for the damages, which means that agricultural BMPs may be an effective solution to evaluate during Phase 3.

- **Area 8** – This damage center includes the main channel of Cibolo Creek between I-10 and Southerland Springs. The damages are attributed to elevated concentrations of ortho-phosphorus, with a limited reach of elevated concentrations of chlorophyll-a.

- **Area 9** – The main channel of Cibolo Creek downstream of Southerland Springs has elevated concentrations of ortho-phosphorus that was confirmed HSPF modeling, as well as by measured water quality samples.

Baseline stream restoration potential for the Cibolo Creek watershed was performed through two independent efforts. Michael Baker, Inc. was contracted by SARA to evaluate stream restoration potential for portions of the Cibolo Creek and its major tributaries within Bexar County, and in May 2015 URS completed an assessment of stream restoration potential for selected streams within Wilson, Karnes and Goliad Counties. These studies assessed the condition of natural stream segments and engineered channels within the watershed and the need and potential for preservation, protection, and implementation of stream restoration projects in the watershed.

The final component of the Phase 2 assessment was related to recreation - specifically nature-based recreation. The goal of the Phase 2 nature-based recreation effort was to identify potential opportunities for nature-based recreation areas and open space preservation areas along the 96-mile long Cibolo Creek corridor. These identified opportunities were considered Opportunity Centers. The team first evaluated the watershed in terms of population, land-uses, ecosystems, historic sites, schools, churches, bridges, etc. This evaluation was performed through collection of existing planning documents, site visits, and communication with government officials and planners in the watershed. Next, the team used the findings of the watershed evaluation to develop a vision and a concept for the Nature-based Recreation plan.

The conceptual plan included the Cibolo Greenway, which is envisioned as:

- A shared-use trail and Greenway, completely separated from auto-traffic along the banks of Cibolo Creek for approximately 15 miles. A place to safely connect people to the Creek, and to nature.
- A safe and clean natural area that would be conducive to walking, cycling, skating, and other physical activity by residents and visitors to the area.
- A greenway trail that is accessible from multiple points of entry including city parks along Cibolo Creek, as well as access points along FM 1518, Evans Road and local neighborhood streets.
- A place that will raise the environmental consciousness of local residents to understand watersheds and the environmental impacts of human actions within the watershed.
- Another beautiful linear greenway for the San Antonio region that will serve residents for decades in this growing region, and that will add to the region's reputation for open space and trails.
- A place that brings a sense of cohesion and connectivity to the patchwork of existing open spaces in the local area.

- A public space that will increase the sense of community pride, physical health, and appreciation of nature.
- A retreat from the urban/suburban/auto-oriented environment, offering a sense of 'wild.'
- A series of open spaces, not just in the Greenway, but in other areas of the watershed that have been designated for park space.

The Cibolo Greenway is proposed to have three sections:

- North Section (4 miles) – from Classen Ranch Road to IH-35
- Central Section (4 miles) – from IH-35 to FM 78
- South Section (7 miles) – from FM 78 to Crescent Bend Nature Park

Phase 3

The initial vision for Phase 3 was to develop a list of holistic improvement concepts to address flooding, water quality and stream health concerns in Damage Centers identified in Phase 2 and to enhance stream health and recreation opportunities of the Opportunity Centers identified in Phase 2. These improvement concepts would be ranked based upon the benefits they provide in addressing the watershed's concerns and preserving the watershed's positive features. It was also understood that flood risk benefits would be the primary driver of the rankings but water quality, stream health and recreation benefits would also be considered. However, as the team progressed into Phase 3 it became apparent that the watershed's Damage Centers did not have the intensity or contiguity of damages to justify the holistic solutions that were originally envisioned.

The team concluded that the C2MP would not develop a list of economically viable, flood risk-driven solutions as found in most traditional master plans. Instead, the C2MP developed and evaluated various holistic concepts such as restrictors, localized channel improvements, LID requirements for future development, BMP retrofit for existing development, regional water quality ponds, and fertilizer management. Although these concepts were modeled with a specific set of assumptions (location, size, cost, etc.), the concepts were developed with the intent that their results can be extrapolated to other parts of the watershed and used to direct future planning efforts.

Atkins developed scores for both quantitative and qualitative benefits of each concept based upon the benefits provided over a 50-year timeframe. The quantitative benefits of each concept, which were calculated using modeling results, were normalized against the results of all concepts to produce a score between 0 and 5. The project team scored each concepts' qualitative benefit criterion between 0 to 5.

The criteria used in the analysis is listed below:

Quantitative Criteria

- Avoided Annual Damages (AAD)
- Reduced Dangerous Crossing Factor
- Increased Average Dissolved Oxygen Load
- Reduced Average Nitrate Nitrogen Load
- Reduced Average Ammonia Nitrogen Load
- Reduced Average Organic Phosphorus Load
- Reduced Average Ortho-Phosphorus Load
- Reduced Average Chlorophyll-a Load
- Reduced Average Bacteria Load

Qualitative Criteria

- Compatibility with Park Plan
- Environmental Enhancements
- Ease of Permitting
- Stream Stabilization
- Public Support

Each benefit criterion was given a weight between 0% and 100% to reflect its perceived importance by stakeholders. The sum of the criterion weights is 100%. An overall score was generated for each concept by calculating the sum-product of the benefit criterion scores and weights. Finally, a benefit-to-cost ratio was calculated for each concept by dividing each concept's benefit score by the present value of the cost to implement the concept. Table E-1 displays the ranking of the various improvement concepts analyzed in Phase 3.

Table E-1 Concept Rankings

Rank	Concept	Description	Concept Score / $100,000 Cost
1	Concept 3B	LWC Replacement (CR 352/CR 440)	12.9
2	Concept 3C	LWC Replacement (CR 347/CR 417)	7.4
3	Concept 4	LID Requirements	5.1
4	Concept 2	Upper Martinez Creek Improvements	5.1
5	Concept 6	Regional Water Quality Pond	3.6
6	Concept 3D	LWC Replacement (FM 537)	3.5
7	Concept 3A	LWC Replacement (FM 1863)	2.0
8	Concept 5	BMP Retrofit	1.2
9	Concept 1	Restrictor (S-191)	1.1
10	Concept 7	Fertilizer Management & Education	1.0

Although the concepts above were modeled with a specific set of assumptions (location, size, cost, etc.), the rankings and concept results can, in many cases, be extrapolated to other parts of the watershed and used to direct future planning efforts. In addition, Atkins recommends that the following be considered for any future planning efforts:

- Dangerous low water crossings are a significant concern in the watershed. Approximately 42% of the modeled creek crossings in the watershed are dangerous during the 50% AEP event. Additional dangerous low water crossing replacements should be evaluated using methodologies outlined in the C2MP.

- The Upper Martinez Creek Improvements (Concept 2) concept can likely be optimized. The current concept includes a replacement of the Gibbs Sprawl Road low water crossing, which provides only minimal flood damage reduction and safety benefits. Stand-alone channel improvements to Upper Martinez Creek may score better without the added expense of the Gibbs Sprawl Road replacement.

- The Upper Martinez Creek Improvements (Concept 2) concept includes a reach of Upper Martinez Creek that was assigned a category of NCD1 in the Phase 2 stream restoration potential assessment since it has the potential to be restored or rehabilitated using NCD techniques based on existing constraints. Any channel improvements in this reach should consider using NCD techniques such as meandering or step-pool designs to restore stream function and provide improved geomorphic stability.

- Restrictor S-191 may perform better if it is simulated as a reservoir instead of a restrictor. Although a reservoir might have impacts to pulse flows, it would likely have some water quality benefits and aquifer recharge benefits in addition to flood risk reduction and safety improvement benefits.

- The pending update to NOAA Atlas 14 will likely increase rainfall depths across the upper portion of the Cibolo Creek watershed, which may affect flood damage and dangerous crossings in the watershed. The concepts that have at least some flood risk benefits (Concept 1, 2, 3 and 4) may score better with larger baseline flood damages and more dangerous crossings.

- The implementation of LID across the watershed as applied to future development is shown to provide significant improvements in water quality conditions. Encouraging communities to incorporate these practices in their development codes, should result in significant improvements in watershed water quality. While the current standard addresses treatment of 80% of the increase in new loading, considering more stringent criteria or applying the criteria to redevelopment will have benefits. Alternatively, providing incentives to implement these practices as retrofit alternatives is a cost-effective way to increase water quality conditions and enhance landscapes.

- The BMPs proposed for Concept 5 (BMP Retrofit) are applicable to the entire watershed, particularly where urban development exists. Depending on the right-of-way availability, enhancement of existing swales areas may be a low-cost alternative to provide water quality treatment. Encouraging retrofits at the local or homeowner level through grants or regulation would have a beneficial impact on the watershed.

- Effective fertilizer and land tilling practices, achieved through education and community ordinances, provide both a beneficial impact to water quality and reduces overall fertilizer application rates. The low cost to implement these practices makes it a valuable element of the holistic watershed improvement plan.

- Water quality reservoirs, both small and large, provide opportunities for ecological restoration and aquifer recharge without claiming significant amounts of land that is otherwise barren or allocated to agriculture use or ranching applications. These reservoirs can be constructed in minor creeks and dry riverbeds through check dams. Water quality reservoirs can both enhances the existing land and provides for water quality treatment.

1. Introduction

The Cibolo Creek Holistic Watershed Master Plan (C2MP) seeks to provide communities with sustainable solution concepts that address a variety of concerns including flooding, water quality, stream health and recreation. The C2MP will provide a prioritized list of proposed concepts that consider the following objectives:

- Reduce flood risk using structural and non-structural measures,
- Reduce or remove pollutant loadings in waterways through natural processes and/or improved management practices,
- Protect or restore riparian corridors, and
- Incorporate recreational features, as feasible.

The C2MP consists of three phases:

Phase 1 – This phase evaluated available data and identified additional data needs to be collected for the C2MP. Meetings were held with local stakeholders. The purpose of those meetings was to collect available data, review it based on stakeholder input, and determine areas of interest throughout the watershed. The limits and focus of the individual study elements (Water Resources, Water Quality, Stream Health, and Human Interface/Recreation) were determined. A Phase 1 report was completed in June 2015 to document the effort. The Phase 1 report was updated and resubmitted to SARA in July 2018.

Phase 2 – This phase included an analysis of the existing hydrology, stream hydraulics, water quality, stream health, and recreational features. “Damage centers”, which are areas where potential problems exist, were identified based on models of existing and future conditions. A preliminary list of watershed improvement concepts was developed. “Opportunity centers”, were identified as areas with positive features that can be potentially preserved or enhanced. The Phase 2 analysis was documented in a report that was submitted to the San Antonio River Authority (SARA) in October 2017. The Phase 2 report was updated and resubmitted to SARA in July 2018.

Phase 3 – This phase includes an evaluation of improvement concepts that targeted “damage centers”. Scoring criteria, including factors such as flood damage reduction, crossing safety improvements, water quality benefits, recreational enhancements, and stream function improvements were used to evaluate each concept. A prioritized list of project concepts was developed.

The initial vision for Phase 3 was to develop a list of holistic improvement concepts to address flooding, water quality and stream health concerns in Damage Centers and to enhance stream health and recreation opportunities of the Opportunity Centers. These improvement concepts would be ranked based upon the benefits they provide in addressing the watershed’s concerns and preserving the watershed’s positive features. It was also understood that flood risk benefits would be the primary driver of the rankings but water quality, stream health and recreation benefits would also be considered.

As the C2MP progressed into Phase 3 it became apparent that the watershed’s Damage Centers did not have the intensity or contiguity of damages to justify the holistic solutions that we originally envisioned:

- Under the existing development condition there are only $189,351 in Estimated Annual Damages for the watershed. These flood damages are located on eight of the SARA jurisdiction streams. Justifying a project based upon flood damage reduction is not likely given the limited anticipated flood damage.

- There are 41 low water crossings, located on six SARA jurisdiction streams, that are considered dangerous during the 50% AEP event. The most effective method of improving the safety of these crossings is to elevate the crossings and replace them with bridge structures. Typically, the low water crossing replacements can be implemented as stand-alone solutions. There is minimal benefit to combining the low water crossing replacements with other solutions.

- Nitrate nitrogen, ortho-phosphorus, and bacteria are the water quality constituents that exceed threshold levels through the greatest number of reaches in the watershed. Although bacteria concerns are wide-spread, nitrate nitrogen and ortho-phosphorus levels are generally highest along Cibolo Creek downstream of IH-10. There is little overlap between the water quality and flood risk Damage Centers.

- The greatest stream health concerns do not have a significant overlap with the flood risk Damage Centers. There is, however, a potential to incorporate stream restoration/rehabilitation components with the proposed Cibolo Greenway.

It was concluded that the C2MP would not develop a list of economically viable, flood risk-driven solutions as found in most traditional master plans. The watershed's flood damages, and the C2MP's schedule and scope limitations did not allow this. Instead, the C2MP developed and evaluated various holistic concepts such as restrictors, localized channel improvements, LID requirements for future development, BMP retrofit for existing development, regional water quality ponds, and fertilizer management. Although these concepts were modeled with a specific set of assumptions (location, size, cost, etc.), the concepts were developed with the intent that their results of can be extrapolated to other parts of the watershed and used to direct future planning efforts.

This report documents the Phase 3 efforts for the C2MP and, like the Phase 1 and Phase 2 reports, is intended to serve as a stand-alone document.

2. Ranking System

The concepts developed in Phase 3 of the Master Plan provide benefits to the Cibolo Creek watershed in terms of flood damage reduction, water quality improvements, public safety improvements, increased recreational opportunities, and increased stream stability. Traditional master plans typically measure benefits only in terms of economics; however, a dollar value cannot be easily applied to many of the benefits created by the concepts proposed for Phase 3. Therefore, Atkins developed scores for both quantitative and qualitative benefits for each concept based upon the benefits provided over a 50-year timeframe. The effectiveness of each concept was calculated by dividing its total benefit score by its cost. Effectiveness, or a benefit-to-cost ratio, was used to rank the various improvement concepts. This section explains this process.

2.1. Benefit Criteria

Atkins worked with SARA to develop a list of benefit criteria to evaluate each concept. The criteria include quantitative benefit criteria, such as flood damage reduction and water quality pollutant reduction, as well as qualitative benefit criteria, such as public support. The benefit criteria used in the Master Plan is listed below:

Quantitative Criteria

- Avoided Annual Damages (AAD)
- Reduced Dangerous Crossing Factor
- Increased Average Dissolved Oxygen Load
- Reduced Average Nitrate Nitrogen Load
- Reduced Average Ammonia Nitrogen Load
- Reduced Average Organic Phosphorus Load
- Reduced Average Ortho-Phosphorus Load
- Reduced Average Chlorophyll-a Load
- Reduced Average Bacteria Load

Qualitative Criteria

- Compatibility with Park Plan
- Environmental Enhancements
- Ease of Permitting
- Stream Stabilization
- Public Support

2.2. Benefit Criteria Scores

The project team used flood risk and water quality analysis results from the modeling effort to calculate quantitative benefits for each concept. The quantitative benefits of each concept were normalized against the results of all concepts to produce a score between 0 and 5. For example, when scoring concepts based on avoided annual damages (AAD), the concept with the most AAD will have a score of 5 and the concept with the lowest AAD will have a score of 0. The project team scored each concepts' qualitative benefit criterion between 0 to 5. A score of 0 represents the least benefit, while a score of 5 represents the most benefit.

The following sections provide details of how each benefit criterion is scored.

2.2.1. Quantitative Benefit Criteria

The Master Plan calculates quantitative criteria benefits in terms of reduced damages based upon the following equation:

$$\boldsymbol{Benefits = Damage_{Post-Project} - Damage_{Baseline}} \quad \textbf{(2-1)}$$

However, the Master Plan is evaluating improvement concepts over a 50-year period. The Master Plan assumes that the Existing condition represents the year 2018 condition of the watershed and the Future condition represents the year 2068 (50 years in the future) condition of the watershed. Baseline Existing damages represent damages that can be expected in the watershed under year 2018 conditions without any improvement concepts in place. Baseline Future damages represent damages that can be expected in the watershed under year 2068 conditions without any improvement concepts in place. As seen in Equation 2-2, Baseline damages are assumed to be the average of the year 2018 (Existing) and year 2068 (Future) Baseline damages.

$$\boldsymbol{Damage_{Baseline} = \frac{(Damage_{Baseline\ Existing} + Damage_{Baseline\ Future})}{2}} \quad \textbf{(2-2)}$$

Post-Project Existing damages represent damages that can be expected in the watershed under year 2018 conditions with an improvement concept in place. Post-Project Future damages represent damages that can be expected in the watershed under year 2068 conditions with an improvement concept in place. As seen in Equation 2-3, Post-Project damages are assumed to be the average of the year 2018 (Existing) and year 2068 (Future) Post-Project damages.

$$\boldsymbol{Damage_{Post-Project} = \frac{(Damage_{Post-Project\ Existing} + Damage_{Post-Project\ Future})}{2}} \quad \textbf{(2-3)}$$

The following sections discuss in more detail how benefits in terms of AAD, reduced dangerous crossings and pollutant reductions were calculated.

2.2.1.1. Avoided Annual Damages

One potential benefit of an improvement concept is AAD. To calculate AAD the estimated annual damages (EAD) for both the Baseline Existing and Baseline Future conditions must first be calculated. Equation 2-4 can be used to calculate the EAD for Baseline conditions.

$$\boldsymbol{EAD_{Baseline} = \frac{(EAD_{Baseline\ Existing} + EAD_{Baseline\ Future})}{2}} \quad \textbf{(2-4)}$$

Equation 2-5 can be used to calculate EAD for Post-Project conditions using the EAD values for Post-Project Existing and Post-Project Future conditions.

$$\boldsymbol{EAD_{Post-Project} = \frac{(EAD_{Post-Project\ Existing} + EAD_{Post-Project\ Future})}{2}} \quad \textbf{(2-5)}$$

The avoided annual damages (AAD), or benefits of each concept, was calculated using Equation 2-6 below:

$$\boldsymbol{AAD = EAD_{Post-Project} - EAD_{Baseline}} \quad \textbf{(2-6)}$$

2.2.1.2. Reduced Dangerous Crossing Factor

During Phase 2 of the Master Plan Atkins evaluated each of the 98 modeled crossings in the watershed to determine if they could be rated as being “safe” during the 50%, 10%, 4%, 2%, 1% and 0.2% AEP events. As discussed in the Phase 2 report, for each event a crossing has a maximum overtopping depth and velocity which defines the threshold to be rated as a “safe” crossing. This threshold is defined using Figure 504-2 of the City of San Antonio Unified Development Code (City of San Antonio, Texas, 2016). The calculated overflow depth was divided by the “safe” depth for each storm event. This calculation yielded a Safe Depth Ratio (SDR) for each storm event. The SDR was used to assign a category of either safe, caution or dangerous for each crossing and each storm event using Table 2-1. It should be noted that

although Figure 504-2 of the UDC defines a “safe” overtopping depth, Atkins assumed that any crossing that is overtopped to a depth less than the “safe” depth is given a category of “caution”. Atkins assumed that only crossings that are not overtopped may be considered safe.

Table 2-1 Crossing Categories

Safe Depth Ratio	Category
X ≤ 0	Safe
0 < X < 1	Caution
X ≥ 1	Dangerous

The SDR values for each storm event were used to calculate a Dangerous Crossing Factor (DCF) for each crossing using Equation 2-7. DCF represents how much the safe depth of a given crossing can expect to be exceeded on an annual basis. A higher DCF value indicates that a crossing is more likely to experience a dangerous overtopping event. For example, a crossing with a DCF of 2.0 could expect to be overtopped on an annual basis to a level that is twice the “safe” depth.

$$\boldsymbol{DCF} = \left((\mathbf{1} - \mathbf{50}\%) * \frac{\boldsymbol{SDR}_{\mathbf{50}\%}}{\mathbf{2}}\right) + \left((\mathbf{50}\% - \mathbf{10}\%) * \frac{\boldsymbol{SDR}_{\mathbf{50}\%} + \boldsymbol{SDR}_{\mathbf{10}\%}}{\mathbf{2}}\right) + \left((\mathbf{10}\% - \mathbf{4}\%) * \frac{\boldsymbol{SDR}_{\mathbf{10}\%} + \boldsymbol{SDR}_{\mathbf{4}\%}}{\mathbf{2}}\right) \quad \textbf{(2-7)}$$

$$+ \left((\mathbf{4}\% - \mathbf{2}\%) * \frac{\boldsymbol{SDR}_{\mathbf{4}\%} + \boldsymbol{SDR}_{\mathbf{2}\%}}{\mathbf{2}}\right) + \left((\mathbf{2}\% - \mathbf{1}\%) * \frac{\boldsymbol{SDR}_{\mathbf{2}\%} + \boldsymbol{SDR}_{\mathbf{1}\%}}{\mathbf{2}}\right) + \left((\mathbf{1}\% - \mathbf{0.2}\%) * \frac{\boldsymbol{SDR}_{\mathbf{1}\%} + \boldsymbol{SDR}_{\mathbf{0.2}\%}}{\mathbf{2}}\right)$$

Where:

DCF = *Dangerous Crossing Factor*
$SDR_{50\%}$ = *Safe Depth Ratio for 50% AEP Event*
$SDR_{10\%}$ = *Safe Depth Ratio for 10% AEP Event*
$SDR_{4\%}$ = *Safe Depth Ratio for 4% AEP Event*
$SDR_{2\%}$ = *Safe Depth Ratio for 2% AEP Event*
$SDR_{1\%}$ = *Safe Depth Ratio for 1% AEP Event*
$SDR_{0.2\%}$ = *Safe Depth Ratio for 0.2% AEP Event*

DCF reflects damages in terms of dangerous stream crossings. The individual crossing DCF values were summed to identify the baseline damages (Equation 2-2) and post-project damages (Equation 2-3) throughout the watershed. The benefit of each concept was measured based upon its reduced DCF using Equation 2-1.

2.2.1.3. Reduced / Increased Water Quality Constituent Loads

During Phase 2 of the Master Plan, Atkins simulated Baseline Existing and Baseline Future water quality in the Cibolo Creek watershed using HSPF. Among other things, the HSPF simulations calculated constituent loads and concentrations for each modeled stream reach in the watershed. For the purpose of this analysis, water quality damage for a given constituent is the average reach constituent load for all reaches in the watershed. Water quality damages were calculated for the following constituents for the Baseline condition using Equation 2-2 and the Post-Project condition using Equation 2-3:

- Dissolved Oxygen
- Nitrate Nitrogen
- Ammonia Nitrogen
- Organic Phosphorus
- Ortho-Phosphorus
- Chlorophyll-a
- Bacteria

A benefit for the seven constituents was calculated for each concept using Equation 2-1. This benefit was measured in terms of reduced average reach constituent load for all constituents except dissolved oxygen. The benefit for dissolved oxygen was measured in terms of increased average reach dissolved oxygen load.

2.2.2. Qualitative Benefit Criteria

In addition to the quantitative benefit criteria that is scored using modeling results, the concepts were also scored based upon qualitative criteria. Because the qualitative criteria are subjective, a ranking system was created for each category as explained below.

2.2.2.1. Compatibility with Park Plan

Each concept was scored on its potential compatibility with the park plan presented in the Phase 2 report. The score ranged from 0 to 5, with a value of 0 given to a concept that has no foreseeable potential to connect with the proposed park plan or no potential to incorporate recreation elements. A score of 5 was assigned to a concept with the potential to connect with the proposed park plan or to incorporate recreation elements.

2.2.2.2. Environmental Enhancements

Each concept was scored on its potential for environmental enhancement. The score ranged from 0 to 5, with a value of 0 given to a concept that produces harmful impacts to pulse flows and significant negative impacts to the environment, and 5 assigned to a concept with no impacts to pulse flows and beneficial impacts to the environment.

2.2.2.3. Ease of Permitting

Each concept was scored on its likely ease of permitting and implementation. The score ranged from 0 to 5, with a value of 0 given to a concept for which permitting would be likely denied due to permitting challenges, and a value of 5 to a concept with no permit requirements or minimum permit requirements.

2.2.2.4. Stream Stabilization

Each concept was scored on its ability to provide stream stabilization. The score ranged from 0 to 5, with a value of 0 given to a concept that produces harmful impacts to stream stability, and 5 assigned to a concept with major improvements to stream stability.

2.2.2.5. Public Support

Each concept was scored on its potential for public support. The score ranged from 0 to 5, with a value of 0 given to a concept with high public and stakeholder opposition, and 5 assigned to a concept with high public and stakeholder support.

2.3. Concept Scores

With consultation with SARA, each benefit criterion was given a weight between 0% and 100% to reflect its perceived importance by stakeholders. The sum of the criterion weights is 100%. An overall score was generated for each concept by calculating the sum-product of the benefit criterion scores and weights. Finally, a benefit-to-cost ratio was calculated for each concept by dividing each concept's benefit score by the present value of the cost to implement the concept.

3. Improvement Concepts

Atkins worked with SARA staff to develop a list of improvement concepts that includes:

- Restrictor S-191
- Upper Martinez Creek Improvements
- Low Water Crossing Replacements (5 crossings)
- LID Requirements for Future Development
- Infiltration BMP Retrofit
- Regional Water Quality Pond
- Fertilizer Management & Education

This section will provide a detailed discussion of each concept.

3.1. Restrictor S-191 (Concept 1)

This concept is a modification of Reservoir S-191 that was formulated in a 2007 USGS Report (Ockerman, 2007). The USGS report recommended a reservoir on the main channel of Cibolo Creek, near the confluence with Clear Fork, with a total dam height of 80 feet and emergency spillway height of 60 feet. The USGS report does not provide a specific outfall configuration for the reservoir. However, it can be presumed that the outfall was configured to attenuate frequent storm event flows, as the report showed that the reservoir increased channel infiltration.

During a January 18, 2018 meeting, SARA staff requested that any reservoir concepts consider stream pulse and temperature impacts. Consequently, Atkins decided to develop this concept to limit downstream stream pulse or temperature impacts by configuring it without a permanent pool. The concept, named Restrictor S-191, is located on the main channel of Cibolo Creek, just downstream of Clear Fork (see Figure 3-1). The location of the Natural Bridge Caverns, which is upstream of the restrictor, was taken into consideration ensuring no increase in the 1% AEP event floodplain or flood stages within the park property. Restrictor S-191 is configured to have minimal impacts upon normal stream flows and limited attenuation for frequent storm events. The restrictor reserves most of its attenuation capacity for less frequent storm events.

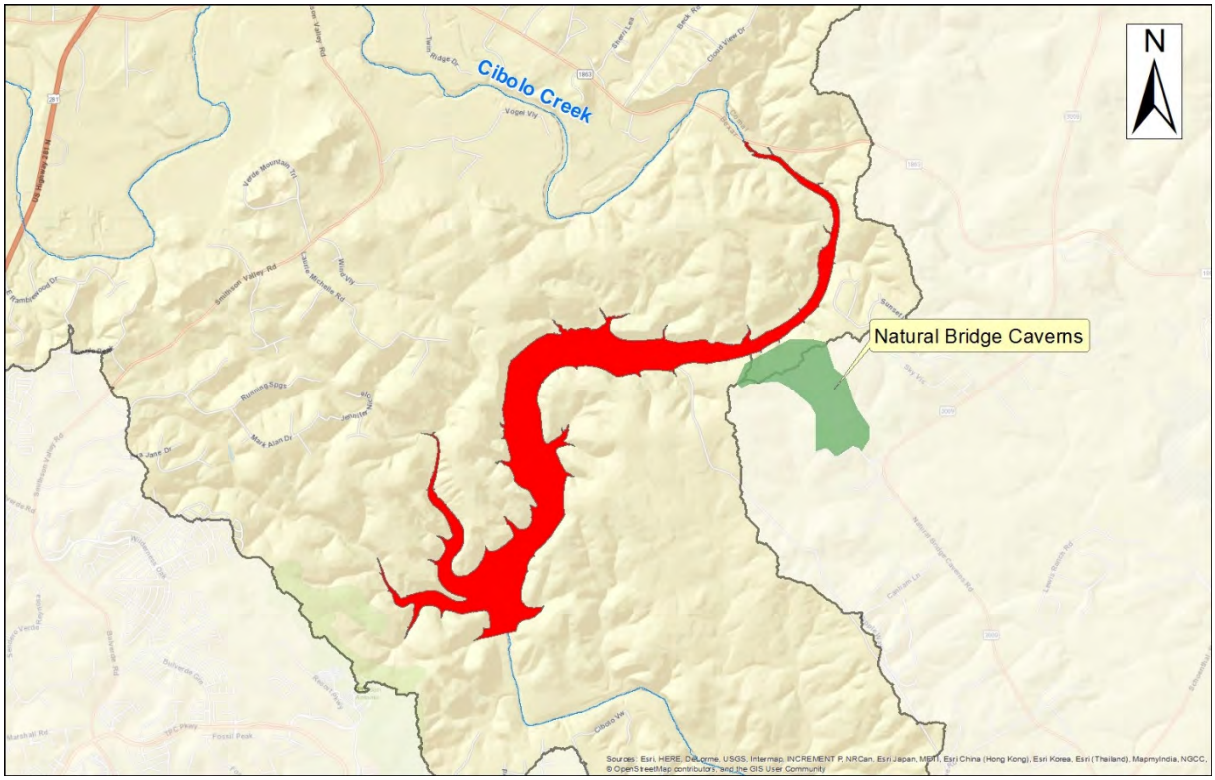


Figure 3-1 Restrictor S-191 Location

As seen in Figure 3-2 , the S-191 Restrictor has a total height of approximately 55 feet (top of restrictor at 905 feet) and a 160 foot bottom width emergency spillway with a depth of 10 feet. The outfall for the structure is comprised of 4-12'x12' RCBs at the flowline of Cibolo Creek and an additional 7-12'x12' RCBs with flowline elevations that are 2.8 feet above the flowline of Cibolo Creek.

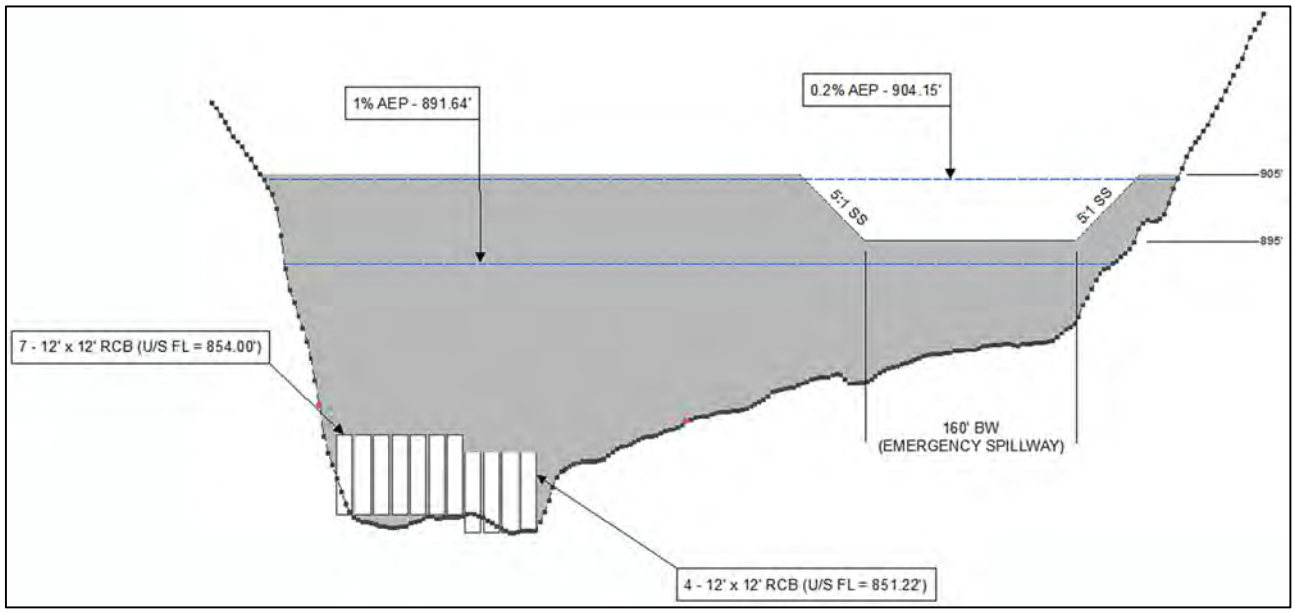


Figure 3-2 Restrictor S-191 Cross Section

3.1.1. Flood Risk

This section discusses the development and results of the hydrologic and hydraulic models used to simulate the Restrictor S-191 concept. The flood risk benefits, in terms of reduced damages, is also discussed.

3.1.1.1. Hydrology

The hydrologic simulation of this concept was created from the Baseline Existing and Baseline Future conditions HEC-HMS models developed under Phase 2. This section discusses the hydrologic model development and results.

3.1.1.1.1. Model Development

The baseline HEC-HMS basin model was modified to create the Restrictor S-191 simulation. Figure 3-3 compares the baseline HEC-HMS basin model (left) against the Restrictor S-191 HEC-HMS basin model (right). As seen in Figure 3-3, the Restrictor S-191 basin model includes an additional junction, C4020104B, which is just downstream of the restrictor. In addition, the baseline routing reach R4020114 was split into two new routing reaches: R4020114A and R4020114B.

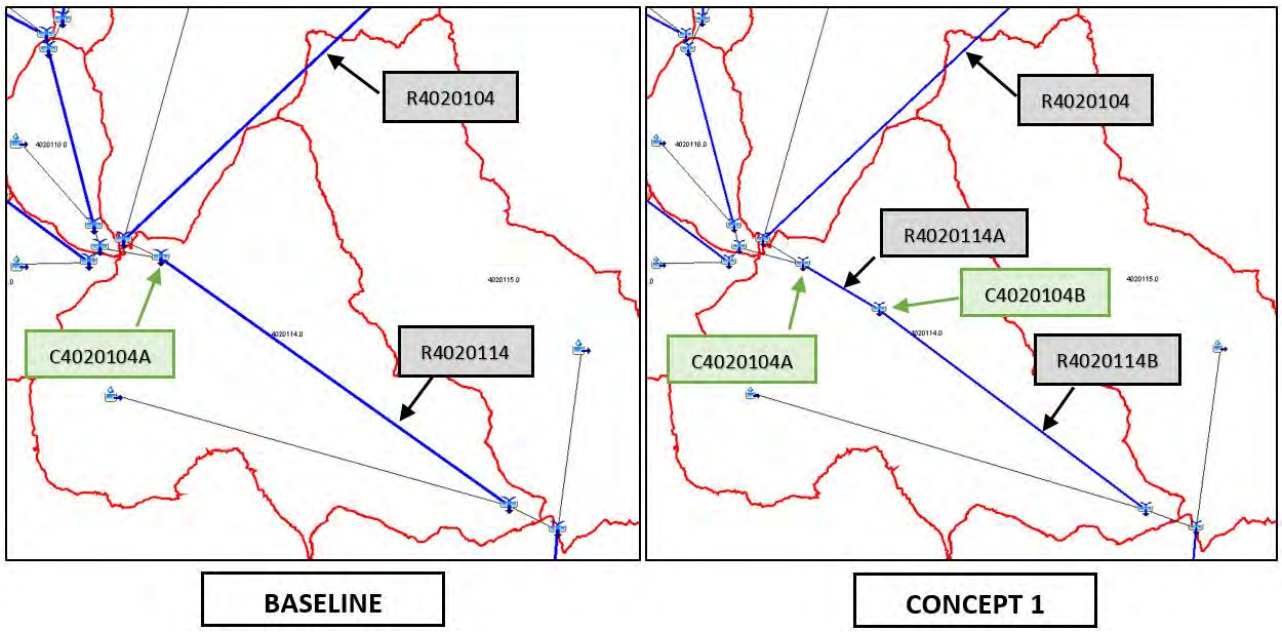


Figure 3-3 HEC-HMS Node Configuration (Baseline vs. Concept 1)

The Modified Puls storage routing relationships in the Restrictor S-191 basin model were recalculated to reflect the proposed improvement. A HEC-RAS geometry for Upper Cibolo Creek was developed (see Section 3.1.1.2) to include the restrictor and was used to create a storage-routing simulation. The results of the simulation were used to update the Modified Puls inflow versus volume relationships and number of sub-reaches for HEC-HMS routing reaches R4020114B, R4020114A and R4020104. Routing reach R4020114B is downstream of the restrictor and, as a result, reflects no increased storage over the Baseline condition. Routing reaches R4020114A and R4020104 are upstream of the restrictor and reflect additional storage and slower routing velocities. No other routing reaches were changed from the Baseline condition.

Table 3-1 compares HEC-RAS routing results for the Baseline and Restrictor concept within the backwater limits of the restrictor. As seen in Table 3-1, the restrictor concept more than doubles the Baseline 1% AEP event storage volume and more than doubles travel time through the reach. Modified Puls storage routing relationships and sub-reaches for Concept 1 may be found in Appendix C.

Table 3-1 Storage-Routing Comparison (Existing Conditions)

HEC-RAS Stations: 219950.2 - 233743.3		
Parameter	**Baseline Existing**	**Concept 1 Existing**
1% AEP Volume (ac-ft)	3048	6958
Time Steps (5-MIN)	5	11

3.1.1.1.2. Results

This section presents the peak flow results of the Concept 1 HEC-HMS simulations for the existing and future conditions. Simulations were created for the 50%, 10%, 4%, 2%, 1%, and 0.2% AEP events.

Table 3-2 compares the 10% and 1% AEP event peak flows along Cibolo Creek for the Baseline Existing and Concept 1 Existing condition. As seen in Table 3-2, Restrictor S-191 is located between HEC-HMS junction C4010438A and C4020123A. Upstream of junction C4010438A there is no change to the calculated peak flows of the Baseline and Concept 1 condition. Concept 1 peak flows at and downstream of junction C4020123A are lower than the Baseline condition due to the increased storage and reduced routing times produced by the restrictor. As seen in Table 3-2, Concept 1 reduces the 10% and 1% AEP event existing condition peak flows by a maximum of 0.12% and 3.65%, respectively. The peak flow reductions are present along Cibolo Creek from the Restrictor S-191 location to Cibolo Creek's confluence with Martinez Creek.

Table 3-3 compares the 10% and 1% AEP event peak flows along Cibolo Creek for the Baseline Future and Concept 1 Future condition. Upstream of junction C4010438A (the restrictor), there is no change to the calculated peak flows of the Baseline and Concept 1 Future conditions. HEC-HMS peak flows at and downstream of junction C4020123A for Concept 1 are lower than the peak flows observed for the Baseline condition. The lower peak flows are due to the increased storage and reduced routing times produced by the restrictor. As seen in Table 3-3, Concept 1 reduces the 10% and 1% AEP event future condition peak flows by a maximum of 0.23% and 4.95%, respectively. The peak flow reductions are present along Cibolo Creek from the Restrictor S-191 location to Cibolo Creek's confluence with Martinez Creek.

Table 3-2 Concept 1 - Cibolo Creek Peak Flow Comparison (Existing Condition)

		Baseline Existing		*Concept 1 Existing*		*Comparison to Upper Cibolo HEC-HMS (% Difference)*	
HEC-HMS Node	**Location**	**10% Peak Flow (ft^3/s)**	**1% Peak Flow (ft^3/s)**	**10% Peak Flow (ft^3/s)**	**1% Peak Flow (ft^3/s)**	**10% Peak Flow (ft^3/s)**	**1% Peak Flow**
4010101	Headwaters of Cibolo Creek	2,264	3,689	2,264	3,689	0.00%	0.00%
C4010107		6,738	11,166	6,738	11,166	0.00%	0.00%
C4010107A		11,014	18,766	11,014	18,766	0.00%	0.00%
C4010120A	Upstream of Boerne Lake	17,143	31,386	17,143	31,386	0.00%	0.00%
S4010122	Downstream Boerne Lake	459	3,175	459	3,175	0.00%	0.00%
C4010130A	D/S Ranger Creek	5,839	10,589	5,839	10,589	0.00%	0.00%
C4010146	U/S Frederick Creek	8,702	17,256	8,702	17,256	0.00%	0.00%
C4010146A	D/S Frederick Creek	11,365	24,110	11,365	24,110	0.00%	0.00%
C4010205A	D/S Curry Creek	13,764	29,067	13,764	29,067	0.00%	0.00%
C4010210	U/S Menger Creek	13,594	28,202	13,594	28,202	0.00%	0.00%
C4010210A	D/S Menger Creek	16,938	34,879	16,938	34,879	0.00%	0.00%
C4010231	U/S Balcones Creek	19,271	39,638	19,271	39,638	0.00%	0.00%
C4010231A	D/S Balcones Creek	27,479	57,929	27,479	57,929	0.00%	0.00%
C4010301A	D/S of Post Oak Creek	29,503	61,723	29,503	61,723	0.00%	0.00%
C4010312A	D/S Pleasant Valley Creek	28,639	58,945	28,639	58,945	0.00%	0.00%
C4010415A	D/S Meusebach Creek	26,468	55,947	26,468	55,947	0.00%	0.00%
C4010433	**US 281**	24,816	53,644	24,816	53,644	0.00%	0.00%
C4010438A	D/S Lewis Creek	22,213	48,975	22,213	48,975	0.00%	0.00%
Approximate Location of Restrictor S-191							
C4020123A	D/S Bracken Tributary	17,336	40,120	17,320	38,825	-0.09%	-3.23%
C4020202	D/S Selma Creek	17,173	39,944	17,158	38,600	-0.09%	-3.36%
C4020213	**FM 78**	16,961	39,841	16,946	38,445	-0.09%	-3.51%
C4020214A	D/S Dietz Creek	16,695	39,816	16,677	38,364	-0.11%	-3.65%
C4020234	U/S of IH-10 Overflow	16,169	39,139	16,157	37,726	-0.07%	-3.61%
C4020235	**IH-10**	16,148	39,073	16,136	37,666	-0.07%	-3.60%
C4020244	U/S Santa Clara Creek	15,478	38,285	15,471	36,952	-0.04%	-3.48%
C4020244A	D/S Santa Clara Creek	15,784	40,336	15,765	38,889	-0.12%	-3.59%
C4020621	U/S Martinez Creek	15,561	39,700	15,546	38,320	-0.09%	-3.48%
C4020621A	D/S Martinez Creek	21,969	47,681	21,969	47,681	0.00%	0.00%
C4030201	U/S Dry Hollow Creek	21,829	46,867	21,829	46,867	0.00%	0.00%
C4030201A	D/S Dry Hollow Creek	21,866	49,619	21,866	49,619	0.00%	0.00%
C4030222A	D/S Elm Creek	21,433	48,769	21,433	48,769	0.00%	0.00%
C4030408	U/S of FM 539 (Sutherland Springs)	21,159	48,262	21,159	48,262	0.00%	0.00%
C4030411	**U/S of US 87**	20,914	47,990	20,914	47,990	0.00%	0.00%
C4040103A	D/S Clifton Branch (Stockdale)	20,283	47,057	20,283	47,057	0.00%	0.00%
C4040503	**SH 123**	19,352	45,475	19,352	45,475	0.00%	0.00%
C4040508	Mouth Cibolo Creek	18,891	44,738	18,891	44,737	0.00%	0.00%

Table 3-3 Concept 1 - Cibolo Creek Peak Flow Comparison (Future Condition)

		Baseline Future		*Concept 1 Future*		*Comparison to Upper Cibolo HEC-HMS (% Difference)*	
HEC-HMS Node	**Location**	**10% Peak Flow (ft^3/s)**	**1% Peak Flow (ft^3/s)**	**10% Peak Flow (ft^3/s)**	**1% Peak Flow (ft^3/s)**	**10% Peak Flow (ft^3/s)**	**1% Peak Flow**
4010101	Headwaters of Cibolo Creek	2,264	3,689	2,264	3,689	0.00%	0.00%
C4010107		6,738	11,166	6,738	11,166	0.00%	0.00%
C4010107A		11,014	18,766	11,014	18,766	0.00%	0.00%
C4010120A	Upstream of Boerne Lake	17,197	31,430	17,197	31,430	0.00%	0.00%
S4010122	Downstream Boerne Lake	460	3,433	460	3,433	0.00%	0.00%
C4010130A	D/S Ranger Creek	6,003	10,679	6,003	10,679	0.00%	0.00%
C4010146	U/S Frederick Creek	9,111	17,559	9,111	17,559	0.00%	0.00%
C4010146A	D/S Frederick Creek	11,787	24,451	11,787	24,451	0.00%	0.00%
C4010205A	D/S Curry Creek	14,343	29,484	14,343	29,484	0.00%	0.00%
C4010210	U/S Menger Creek	14,173	28,638	14,173	28,638	0.00%	0.00%
C4010210A	D/S Menger Creek	17,994	35,567	17,994	35,567	0.00%	0.00%
C4010231	U/S Balcones Creek	20,909	40,736	20,909	40,736	0.00%	0.00%
C4010231A	D/S Balcones Creek	30,189	59,952	30,189	59,952	0.00%	0.00%
C4010301A	D/S of Post Oak Creek	32,549	63,898	32,549	63,898	0.00%	0.00%
C4010312A	D/S Pleasant Valley Creek	32,317	61,598	32,317	61,598	0.00%	0.00%
C4010415A	D/S Meusebach Creek	30,421	58,496	30,421	58,496	0.00%	0.00%
C4010433	**US 281**	28,257	56,433	28,257	56,433	0.00%	0.00%
C4010438A	D/S Lewis Creek	25,687	52,086	25,687	52,086	0.00%	0.00%
Approximate Location of Restrictor S-191							
C4020123A	D/S Bracken Tributary	20,410	43,189	20,394	42,104	-0.08%	-2.51%
C4020202	D/S Selma Creek	20,249	43,072	20,233	41,920	-0.08%	-2.68%
C4020213	**FM 78**	20,051	43,069	20,035	41,752	-0.08%	-3.06%
C4020214A	D/S Dietz Creek	19,818	43,058	19,801	41,571	-0.09%	-3.45%
C4020234	U/S of IH-10 Overflow	19,264	41,383	19,245	40,541	-0.10%	-2.03%
C4020235	**IH-10**	19,246	41,349	19,230	40,499	-0.08%	-2.06%
C4020244	U/S Santa Clara Creek	18,507	41,491	18,491	39,970	-0.09%	-3.67%
C4020244A	D/S Santa Clara Creek	19,027	43,529	18,984	41,376	-0.23%	-4.95%
C4020621	U/S Martinez Creek	18,789	43,089	18,747	40,979	-0.22%	-4.90%
C4020621A	D/S Martinez Creek	25,845	50,744	25,845	50,744	0.00%	0.00%
C4030201	U/S Dry Hollow Creek	25,767	50,620	25,767	50,620	0.00%	0.00%
C4030201A	D/S Dry Hollow Creek	29,319	57,931	29,319	57,931	0.00%	0.00%
C4030222A	D/S Elm Creek	28,840	56,978	28,840	56,978	0.00%	0.00%
C4030408	U/S of FM 539 (Sutherland Springs)	28,483	56,187	28,483	56,187	0.00%	0.00%
C4030411	**U/S of US 87**	28,218	55,901	28,218	55,901	0.00%	0.00%
C4040103A	D/S Clifton Branch (Stockdale)	27,550	54,942	27,550	54,942	0.00%	0.00%
C4040503	**SH 123**	26,335	53,524	26,335	53,524	0.00%	0.00%
C4040508	Mouth Cibolo Creek	25,599	52,790	25,599	52,789	0.00%	0.00%

3.1.1.2. Hydraulics

A hydraulic simulation was created for the Restrictor S-191 concept for both the existing and future conditions. The Concept 1 hydraulic model was created by modifying the Baseline condition hydraulic model for upper Cibolo Creek. This section discusses the hydraulic model development and results.

3.1.1.2.1. Model Development

The Baseline condition hydraulic geometry for upper Cibolo Creek was updated to create a hydraulic model geometry for Concept 1. The only difference between the Baseline and Concept 1 geometries is that the Concept 1 geometry includes a culvert crossing at station 219843.8 to reflect Restrictor S-191 (see Figure 3-4 below). As seen in Figure 3-2, the HEC-RAS deck for the crossing has a level high chord elevation of 905 feet and a 160 foot bottom width trapezoidal emergency spillway. The spillway has a minimum elevation of 895 feet and 5:1 side slopes. Ineffective areas for the restrictor's bounding cross sections were modified to reflect a 1:1 contraction and 2:1 expansion of flow through the restrictor. A more detailed layout of the restrictor, as well as its location, may be found in Appendix A.

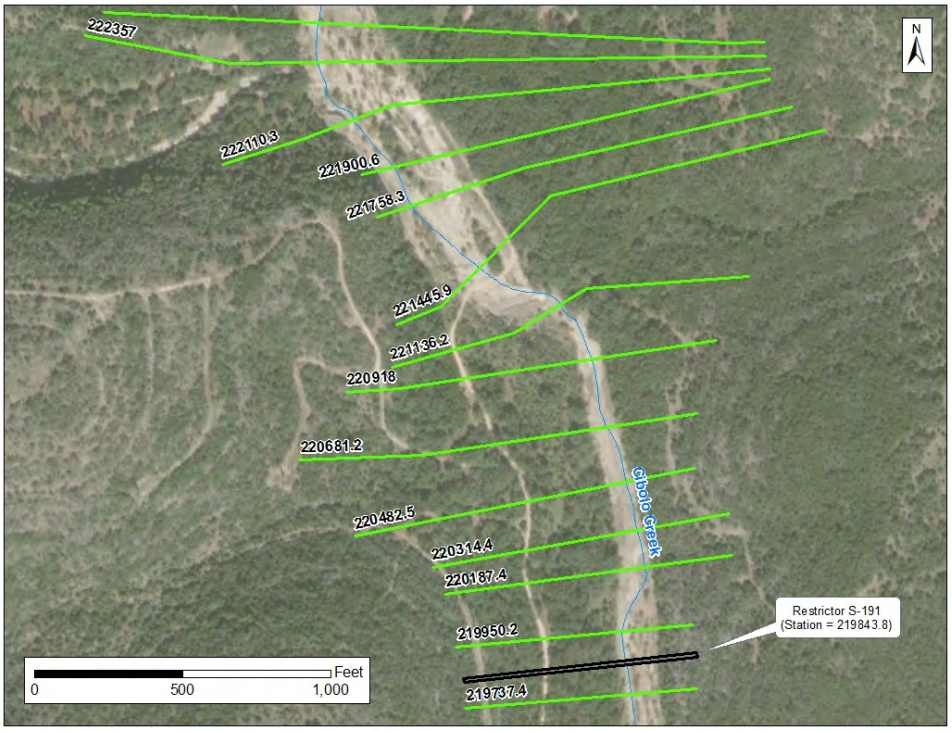


Figure 3-4 HEC-RAS Cross Section Layout for Restrictor S-191

The steady flow distribution for the hydraulic simulations were updated to reflect the hydrologic results presented in Section 3.1.1.1.2. Simulations were created for the 50%, 10%, 4%, 2%, 1%, and 0.2% AEP events.

3.1.1.2.2. Results

Table 3-4 compares the 10% and 1% AEP event peak flood stages at selected locations along Cibolo Creek for the Baseline Existing and Concept 1 Existing conditions. The comparison shows that Restrictor S-191 reduces the 1% AEP event peak flood stages by a maximum of 0.36 feet at Pecan Grove Drive and the Southbound Frontage Road of IH-35. Reductions to the 10% AEP event peak flood stages are minimal. Appendix C contains a cross section by cross section comparisons of peak flood stages for all modeled cross section of upper Cibolo Creek. Appendix C shows that along upper Cibolo Creek (upstream of Martinez Creek), Concept 1 reduces the 10% AEP and 1% AEP peak flood stages by a maximum of 0.18

feet and 0.85 feet, respectively. The concept reduces the 1% AEP event peak flood stages between the restrictor and Martinez Creek by an average of 0.25 feet.

Table 3-5 compares the 10% and 1% AEP event peak flood stages at selected locations along Cibolo Creek for the Baseline Future and Concept 1 Future conditions. The comparison shows that Restrictor S-191 reduces the 1% AEP event peak flood stages by 0.33 feet at Pecan Grove Drive and 0.31 feet at the Southbound Frontage Road of IH-35. Reductions to the 10% AEP event peak flood stages are minimal. Appendix C includes a cross section by cross section comparison of peak flood stage for all modeled cross sections of upper Cibolo Creek. Appendix C shows that along upper Cibolo Creek (upstream of Martinez Creek), Concept 1 reduces the 10% AEP and 1% AEP peak flood stages by a maximum of 0.24 feet and 1.09 feet, respectively. The concept reduces the 10% AEP and 1% AEP event peak flood stages between the restrictor and Martinez Creek by an average of 0.01 feet and 0.27 feet, respectively.

Table 3-4 Concept 1 - Upper Cibolo Creek Peak Flood Stage Comparison (Existing Condition)

		Baseline Existing		*Concept 1 Existing*		*Difference (ft)*	
HEC-RAS Station	**Location**	**10% Peak Flood Stage (ft-NAVD88)**	**1% Peak Flood Stage (ft-NAVD88)**	**10% Peak Flood Stage (ft-NAVD88)**	**1% Peak Flood Stage (ft-NAVD88)**	**10% Peak Flood Stage**	**1% Peak Flood Stage**
413602.5	U/S of Battle Intense Road	1,262.7	1,268.2	1,262.7	1,268.2	0.00	0.00
406283.6	U/S of Ralph Fair Road	1,248.1	1,254.0	1,248.1	1,254.0	0.00	0.00
346681.4	U/S of Blanco Road	1,121.8	1,127.4	1,121.8	1,127.4	0.00	0.00
314294	U/S of US 281	1,051.7	1,058.0	1,051.7	1,058.0	0.00	0.00
289479.8	U/S of Smithson Valley Road	1,005.0	1,011.7	1,005.0	1,011.7	0.00	0.00
261462.9	U/S of FM 1863 (U/S)	949.0	954.9	949.0	954.9	0.00	0.00
257579.7	U/S of FM 1863 (D/S)	941.2	947.2	941.2	947.2	0.00	0.00
Approximate Location of Restrictor S-191							
179431	U/S of FM 2252	761.0	766.9	761.0	766.6	-0.01	-0.28
171560.2	U/S of Lookout Road	746.7	753.0	746.7	752.7	**0.01**	-0.33
166843.8	U/S of IH-35 SBFR	738.3	745.7	738.3	745.3	-0.01	-0.36
14960.53	U/S of Aviation Blvd.	530.8	540.2	530.8	540.0	-0.01	-0.14
133243	U/S of Pecan Grove Drive	684.2	691.5	684.2	691.2	0.00	-0.36
118885.1	U/S of Schaefer Road	659.5	665.8	659.5	665.5	-0.01	-0.27
80964.75	U/S of IH-10 WBFR	611.6	618.1	611.6	617.7	-0.01	-0.33
53407.25	U/S of Gin Road	577.2	583.8	577.2	583.5	0.00	-0.28
41614.69	U/S of Ulrich Road	562.2	567.2	562.2	567.0	-0.01	-0.24
10255.19	U/S of FM 2538	525.4	535.8	525.4	535.6	-0.01	-0.20
73.82	U/S Martinez Creek	509.5	520.0	509.5	520.0	0.00	0.00

Table 3-5 Concept 1 - Upper Cibolo Creek Peak Flood Stage Comparison (Future Condition)

		Baseline Future		*Concept 1 Future*		*Difference (ft)*	
HEC-RAS Station	**Location**	**10% Peak Flood Stage (ft-NAVD88)**	**1% Peak Flood Stage (ft-NAVD88)**	**10% Peak Flood Stage (ft-NAVD88)**	**1% Peak Flood Stage (ft-NAVD88)**	**10% Peak Flood Stage**	**1% Peak Flood Stage**
413602.5	U/S of Battle Intense Road	1,263.4	1,268.4	1,263.4	1,268.4	0.00	0.00
406283.6	U/S of Ralph Fair Road	1,248.7	1,254.3	1,248.7	1,254.3	0.00	0.00
346681.4	U/S of Blanco Road	1,122.6	1,127.9	1,122.6	1,127.9	0.00	0.00
314294	U/S of US 281	1,052.7	1,058.5	1,052.7	1,058.5	0.00	0.00
289479.8	U/S of Smithson Valley Road	1,006.0	1,012.3	1,006.0	1,012.3	0.00	0.00
261462.9	U/S of FM 1863 (U/S)	950.0	955.5	950.0	955.5	0.00	0.00
257579.7	U/S of FM 1863 (D/S)	942.1	947.7	942.1	947.7	0.00	0.00
Approximate Location of Restrictor S-191							
179431	U/S of FM 2252	762.0	767.5	762.0	767.3	-0.01	-0.22
171560.2	U/S of Lookout Road	747.6	753.8	747.6	753.5	**0.02**	-0.27
166843.8	U/S of IH-35 SBFR	739.5	746.5	739.5	746.2	-0.01	-0.31
14960.53	U/S of Aviation Blvd.	532.8	541.2	532.8	540.9	-0.03	-0.29
133243	U/S of Pecan Grove Drive	685.4	692.3	685.4	692.0	-0.01	-0.33
118885.1	U/S of Schaefer Road	660.7	666.3	660.7	666.1	-0.01	-0.26
80964.75	U/S of IH-10 WBFR	613.4	618.7	613.4	618.5	0.00	-0.22
53407.25	U/S of Gin Road	578.4	584.2	578.4	583.9	-0.02	-0.34
41614.69	U/S of Ulrich Road	563.6	566.8	563.6	566.9	-0.01	**0.09**
10255.19	U/S of FM 2538	527.5	536.2	527.5	535.9	-0.03	-0.27
73.82	U/S Martinez Creek	511.5	520.9	511.5	520.9	0.00	0.00

3.1.1.3. Damage Assessment

This section discusses the change to flood risk damages in terms of flooded buildings, estimated annual damages to buildings, and dangerous crossings.

3.1.1.3.1. Flooded Buildings

Peak flood stages on Lower Cibolo Creek and tributaries of Cibolo Creek were not affected by this concept. As a result, peak flood stages and the number of flooded buildings were reduced only on Upper Cibolo Creek. As seen in Table 3-6, Concept 1 removes 5 buildings from the 1% AEP event floodplain and 1 building from the 0.2% AEP event floodplain under the existing condition. Under the future condition 1, 2, and 1 building are removed from the future condition for the 2%, 1% and 0.2% AEP event floodplains, respectively.

Table 3-6 Concept 1 - Upper Cibolo Creek Flooded Structures

Condition	Number of Flooded Buildings (by Event)					
	50% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.2% AEP
Baseline Existing	0	2	7	16	55	223
Concept 1 Existing	0	2	7	16	50	222
Baseline Future	0	3	13	31	63	283
Concept 1 Future	0	3	13	30	61	282
Concept 1 Change (Existing) =	***0***	***0***	***0***	***0***	***-5***	***-1***
Concept 1 Change (Future) =	***0***	***0***	***0***	***-1***	***-2***	***-1***

3.1.1.3.2. Estimated Annual Damages

The depth of flooding at each building was determined for the six modeled storm events to calculate Estimated Annual Damages (EAD). The damage to each building, in terms of percentage of building value, was calculated using a depth-damage curve from the U.S. Army Corps of Engineers (Gulf Engineers & Consultants, 2006). The percent damage value was multiplied by the structure's value to determine the damage to the structure for a given event. Existing condition EAD values were calculated using the existing (2018) values of each structure. Future condition EAD values were calculated using an expected future value of each structure in 2068 assuming a 2% yearly rate of inflation.

Concept 1 reduced the number of flooded buildings and the depth of building flooding along selected reaches of Cibolo Creek. These reductions resulted in lower EAD on Upper Cibolo Creek under Concept 1. As seen in Table 3-7, Concept 1 reduces the existing condition EAD on Upper Cibolo Creek by $1,452 and reduces the future condition EAD by $5,547.

The EAD values for Upper Cibolo Creek (Table 3-7) were used to calculate watershed-wide EAD values that were applied to the Concept 1 scoring discussed in Section 4.1.1.

Table 3-7 Concept 1 - Upper Cibolo Creek EAD

Condition	Estimated Annual Damages (EAD) ($)
Baseline Existing	$47,389
Concept 1 Existing	$45,937
Baseline Future	$189,206
Concept 1 Future	$183,659
Concept 1 Change (Existing) =	**($1,452)**
Concept 1 Change (Future) =	**($5,547)**

3.1.1.3.3. Dangerous Crossings

The crossings along Upper Cibolo Creek were simulated under the Baseline Existing and Concept 1 Existing condition. As seen in Table 3-8, Concept 1 reduces crossing SDR values slightly for the 4%, 2%, 1% and 0.2% AEP events. These SDR reductions yield minimal DCF reductions for crossings in the Upper Cibolo Creek reach. The total of DCF values in Upper Cibolo Creek was reduced by 0.01 under the existing condition.

Table 3-8 Concept 1 - Dangerous Crossing Summary (Existing Condition)

Crossing	Baseline Existing SDR						Concept 1 Existing SDR						DCF	
	50%	10%	4%	2%	1%	0.20%	50%	10%	4%	2%	1%	0.20%	Baseline Exist	Concept 1 Exist
Battle Intense Road	5.6	10.1	12.9	14.2	15.5	18.6	5.6	10.1	12.9	14.2	15.5	18.6	5.79	5.79
FM 3351	2.7	7.0	9.5	11.0	12.4	15.9	2.7	7.0	9.5	11.0	12.4	15.9	3.57	3.57
Blanco Road	5.2	9.2	12.0	13.6	15.1	19.5	5.2	9.2	12.0	13.6	15.1	19.5	5.33	5.33
US 281	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
Smithson Valley Road	5.5	11.4	14.7	16.0	17.2	19.8	5.5	11.4	14.7	16.0	17.2	19.8	6.15	6.15
FM 1863 (U/S)	5.3	9.2	11.8	13.1	14.6	18.2	5.3	9.2	11.8	13.1	14.6	18.2	5.38	5.38
FM 1863 (D/S)	3.5	6.8	9.4	10.8	12.4	15.9	3.5	6.8	9.4	10.8	12.4	15.9	3.84	3.84
Railroad	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
FM 2252	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
Railroad	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
Lookout Road	9.2	14.0	16.2	17.7	19.3	23.1	9.3	14.0	16.1	17.6	19.0	23.0	8.54	8.56
Unnamed Crossings	6.9	12.0	15.1	16.8	18.8	23.4	6.9	12.0	15.0	16.6	18.4	23.3	7.00	6.99
IH-35 SBFR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
IH-35 Mainlanes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
IH-35 NBFR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
Aviation Blvd.	2.8	8.6	12.1	14.0	16.2	21.3	2.8	8.6	12.0	13.8	15.9	21.2	4.14	4.13
Railroad	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
FM 78	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	1.5	0.01	0.01
Pecan Grove Road	4.0	8.5	11.9	13.6	15.5	19.3	4.0	8.5	11.7	13.4	15.1	19.2	4.67	4.66
IH-10 WBFR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
IH-10 Mainlanes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
Bexar Bowling	9.2	14.2	17.2	18.7	20.2	20.8	9.2	14.3	17.1	18.6	20.0	20.9	8.65	8.66
FM 2538	5.0	13.0	18.1	20.8	23.1	27.2	5.0	13.0	18.0	20.5	22.8	27.0	6.57	6.56
												Total =	**69.64**	**69.63**

Concept 1 also reduces crossing SDR values slightly under the future condition for the 4%, 2%, 1% and 0.2% AEP events. As seen in Table 3-9, future condition DCF values are reduced by 0.12 for the crossings along Upper Cibolo Creek.

The Upper Cibolo Creek DCF values (Table 3-8 and Table 3-9) were used to calculate watershed-wide DCF values that were applied to the Concept 1 scoring discussed in Section 4.1.2.

Table 3-9 Concept 1 - Dangerous Crossing Summary (Future Condition)

Crossing	Baseline Future SDR						Concept 1 Future SDR						DCF	
	50%	10%	4%	2%	1%	0.20%	50%	10%	4%	2%	1%	0.20%	Baseline Future	Concept 1 Future
Battle Intense Road	6.4	10.7	13.2	14.5	15.8	18.8	6.4	10.7	13.2	14.5	15.8	18.8	6.33	6.32
FM 3351	3.7	7.6	9.9	11.3	12.7	16.1	3.7	7.6	9.9	11.3	12.7	16.1	4.15	4.15
Blanco Road	6.0	10.0	12.6	14.1	15.5	19.9	6.0	10.0	12.6	14.1	15.5	19.9	5.92	5.92
US 281	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
Smithson Valley Road	6.8	12.5	15.4	16.5	17.5	20.1	6.8	12.5	15.4	16.5	17.5	20.1	7.03	7.03
FM 1863 (U/S)	6.4	10.1	12.5	13.7	15.2	18.7	6.4	10.1	12.5	13.7	15.2	18.7	6.11	6.12
FM 1863 (D/S)	4.0	7.7	10.2	11.5	12.8	16.4	4.0	7.7	10.2	11.5	12.8	16.4	4.33	4.33
Railroad	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
FM 2252	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
Railroad	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
Lookout Road	10.7	14.7	16.9	18.4	19.9	23.6	10.7	14.7	16.9	18.3	19.7	23.6	9.43	9.43
Unnamed Crossings	8.2	13.1	16.1	17.6	19.6	24.1	8.1	13.1	15.9	17.4	19.3	24.0	7.86	7.84
IH-35 SBFR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
IH-35 Mainlanes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
IH-35 NBFR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
Aviation Blvd.	4.1	9.8	13.3	15.0	17.2	21.9	4.1	9.8	13.1	14.8	16.8	21.9	5.11	5.10
Railroad	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
FM 78	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	2.2	0.01	0.01
Pecan Grove Road	5.1	9.7	12.9	14.4	16.2	19.9	5.1	9.7	12.8	14.2	15.9	19.9	5.46	5.45
IH-10 WBFR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
IH-10 Mainlanes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
Bexar Bowling	10.4	15.5	18.2	19.6	20.2	21.5	10.5	15.3	18.1	19.3	20.2	21.3	9.55	9.50
FM 2538	6.9	14.9	20.1	22.1	23.8	28.3	6.9	14.9	19.7	21.8	23.3	27.9	8.00	7.97
												Total =	**79.28**	**79.16**

3.1.2. Water Quality

Since the S-191 Restrictor was designed with no permanent pool volume, this concept is not expected to produce quantifiable water quality benefits. Consequently, a water quality simulation was not performed for this concept.

3.1.3. Cost Estimate

A construction cost estimate was developed for Concept 1 using unit prices from TxDOT and the City of San Antonio. On February 27, 2018, Atkins received an email from SARA stating that their real estate department assumes land acquisition costs are 5 times the appraisal district value. This assumption was used for Atkins' acquisition estimates. SARA's real estate department also said that an inundation easement is the minimum land right that should be employed. SARA did not have any general rules for how much these easements might cost per acre, as they are dependent upon negotiations with property owners. Atkins assumed a per acre inundation easement cost of 0.25 times the appraised value. As seen in Table 3-10, the grand project total for construction of Restrictor S-191 was estimated to be $10,550,440. Details of the cost estimate may be found in Appendix B.

The restrictor will likely require normal maintenance activities such as routine inspections, mowing, repairs (minor or major), etc. Mowing was assumed to be done twice a year at $120/acre. Inspections were assumed to be done quarterly at a fixed cost for a day's rate of $400. Restrictor S-191 is about 11 acres in size, and so at $120/acre it will cost about $2,640 to mow the restrictor twice a year. It will cost about $1,600 a year for inspections to be performed. With the cost of repairs depending on the probability and severity of an issue happening, a lump sum of $20,000 was assumed. These factors bring a total of about $24,240 in annual maintenance fees. Assuming a project life of 50 years, an interest rate of 2%, and a growth rate of 2%, the present value of annual maintenance was calculated to be $1,188,235.

Not knowing when this concept, or any of the remaining concepts, will be bid upon or designed, a 2-4% escalation factor can be applied to the cost. According to the Turner Building Cost Index, provided by Turner Construction Company, a 4% factor is suggested as the past 5 years show an average of 4% increases.

Table 3-10 Concept 1 - (Restrictor S-191) Construction and Maintenance Estimate

Construction Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
TREE REMOVAL & CLEARING/GRUBBING		LS	-	$41,350
EXCAVATION	53636	CY	$20	$1,072,720
EMBANKMENT (DENS CONT TYP C)	131153	CY	$12	$1,573,836
CONCRETE CULVERT BOX (12' X 12')	2548	LF	$780	$1,987,440
CONCRETE WINGWALLS	183	CY	$1,700	$311,100
CONCRETE LINED CHANNEL	286	CY	$400	$114,400
STONE RIPRAP (1.5" THICK)	1246	CY	$115	$143,290
MTL W-BEAM GD FENCE (TIM POST)	340	LF	$20	$6,800
FERTILIZER	11	AC	$800	$8,800
BROADCREST SEED (PERM)	11	AC	$500	$5,500
WATERING	960	MG	$11	$10,560
TRAFFIC CONTROL		LS	-	$18,300
			Construction Total	$5,294,096
Fringe Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
INUNDATION EASEMENT ACQUISTION	95	AC	$1,728	$164,113
RIGHT-OF-WAY ACQUISITION	26	AC	$34,550	$898,300
ENVIRONMENTAL PERMITTING		LS	-	$162,000
MOBILIZATION		LS	10%	$529,410
ENGINEERING		LS	10%	$529,410
SURVEYING (5% OF ENGINEERING)		LS	5%	$26,470
			Fringe Total	$2,309,702
Continuation Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ANNUAL MAINTENANCE COST		LS	-	$24,240
			Continuation Total, 50-Year Project Life (Present Value)	$1,188,235
			Project Total (Construction + Fringe + Continuation)	$8,792,033
			20% Contingency on Conceptual Estimates	$1,758,407
			PROJECT GRAND TOTAL	**$10,550,440**

3.2. Upper Martinez Creek Improvements (Concept 2)

This concept provides conveyance improvements on Upper Martinez Creek to reduce flood risk in the area. The concept includes a channel improvement on Martinez Creek between Montgomery Drive and Walzem Road, as well as the replacement of the Gibbs Sprawl Road low water crossing with a bridge structure. The existing Gibbs Sprawl Road crossing of Martinez Creek develops a large headloss and is frequently overtopped. A layout of the proposed improvements are presented in Figure 3-5 and Appendix A.

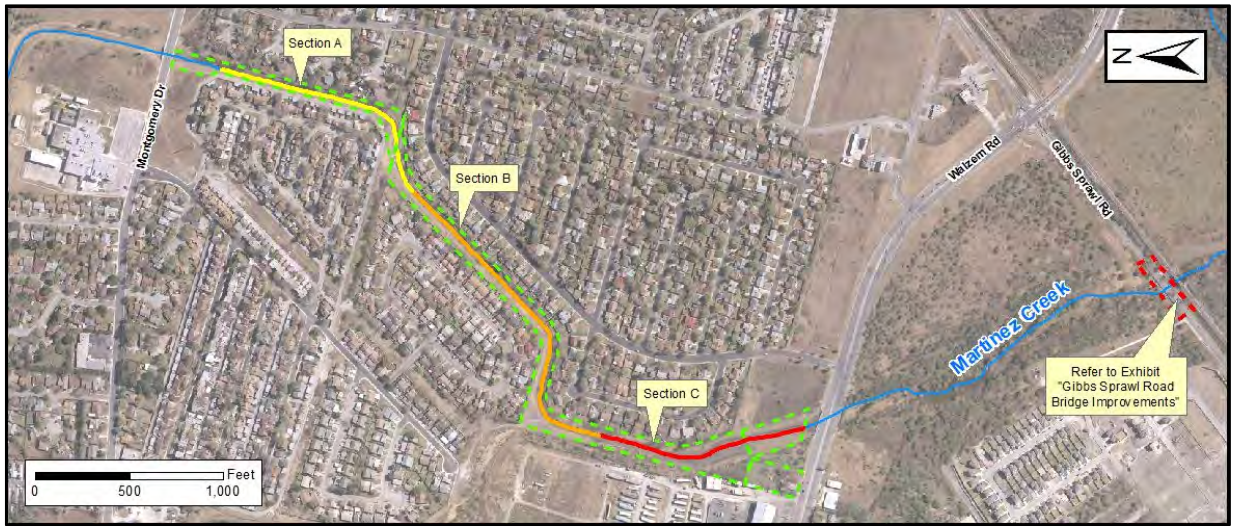


Figure 3-5 Upper Martinez Creek Improvements

Initially, a concrete-lined pilot channel was considered to increase conveyance capacity through this reach. However, it was decided that a concrete-lined pilot channel would potentially have negative environmental impacts such as increased water temperature and reduced infiltration. Furthermore, although this stream reach is man-made, the Phase 2 assessment of stream restoration potential categorized this reach as NCD1, which mean that is has potential to be restored or rehabilitated. A concrete-lined pilot channel is not compatible with a future channel restoration or rehabilitation of this reach. Future refinement of this concept should consider the inclusion of meander or step-pool designs to restore or rehabilitate stream function.

3.2.1. Flood Risk

This section discusses the development and results of the hydrologic and hydraulic models used to simulate the Upper Martinez Creek Improvement concept. The flood risk benefits, in terms of reduced damages, are also presented.

3.2.1.1. Hydrology

The Baseline hydrology model was not updated for this concept, as it is not located within a hydrologic model routing reach. As a result, downstream peak flow impacts from the conveyance improvements cannot be estimated by modifying a Modified Puls routing relationship. Furthermore, any downstream peak flow increases induced by the concept will likely be mitigated by the reservoir that is located just downstream of Gibbs Sprawl Road.

3.2.1.2. Hydraulics

The Concept 2 hydraulic simulation of Upper Martinez Creek was created by updating the Baseline hydraulic models with the proposed channel and bridge improvements. These updates and the results of the Concept 2 simulation are described below.

3.2.1.2.1. Model Development

The proposed channel improvements for Concept 2 have three typical sections:

Section A – from 300 feet downstream of Montgomery Drive to approximately 1,340 feet downstream of Montgomery Drive.

Section B - from 1,340 feet downstream of Montgomery Drive to approximately 1,250 feet upstream of Walzem Road.

Section C – from 1,250 feet upstream of Walzem Road to just upstream of Walzem Road.

The configuration of Section A, B and C are shown in Figure 3-6, Figure 3-7 and Figure 3-8, respectively.

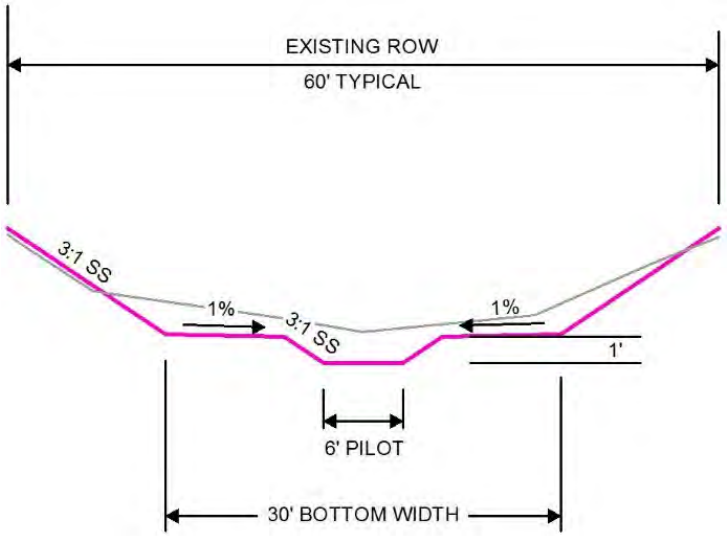


Figure 3-6 Channel Section A

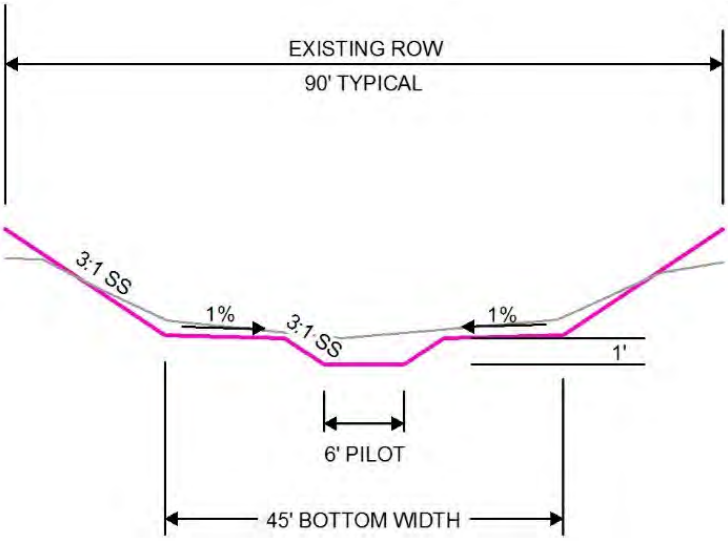


Figure 3-7 Channel Section B

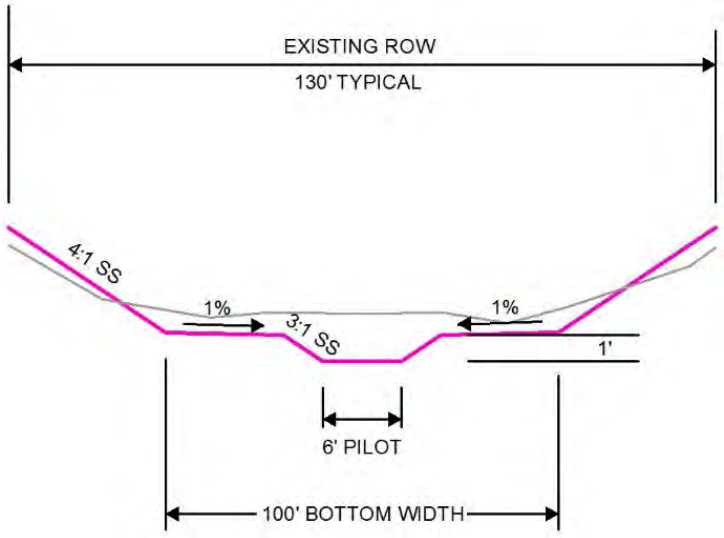


Figure 3-8 Channel Section C

The proposed channel improvements do not exceed the limits of the existing channel right-of-way. The additional channel conveyance capacity is gained through a deepening of the channel, primarily within the 6 foot wide pilot channel. As seen in Figure 3-9, the proposed channel flowline is on average about 1.5 feet deeper than the existing channel flowline within the improvement reach. This depth is gained by modifying the channel slope. The proposed channel slope is approximately 0.22% from Walzem Road to approximately 1,200 feet upstream. The proposed channel slope is approximately 0.93% from 1,200 feet upstream of Walzem Road to approximately 250 feet downstream of Montgomery Drive. A more detailed channel improvement layout is provided in Appendix A.

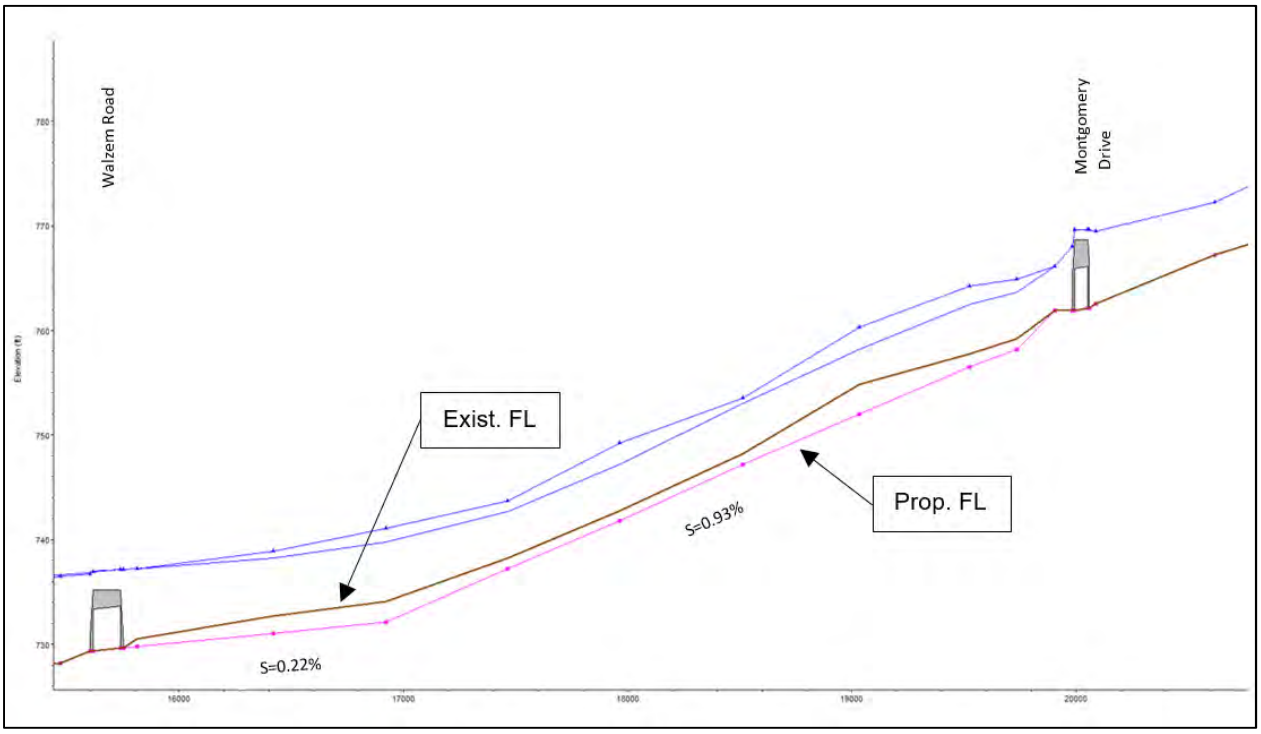


Figure 3-9 Upper Martinez Channel Improvement Profile

The hydraulic model's geometry was also updated to reflect bridge improvements for Gibbs Sprawl Road. The existing Gibbs Sprawl Road crossing of Martinez Creek (see Figure 3-10) is a culvert crossing (10-72" CMPs) with a minimum road elevation of approximately 730.6 feet. The existing condition 50% AEP event overtops the existing crossing by 1.4 feet. To reduce headloss at the crossing and improve safety, the crossing is proposed to be replaced by a bridge structure (see Figure 3-11). The proposed bridge structure has a total bridge span of 150 feet, a minimum low chord elevation of 734.1 feet, and a top deck elevation of 737.1 feet (6.5 feet higher than the existing crossing). The 1% AEP event does not overtop the proposed bridge structure. A more detailed layout of the proposed bridge may be found in Appendix A.

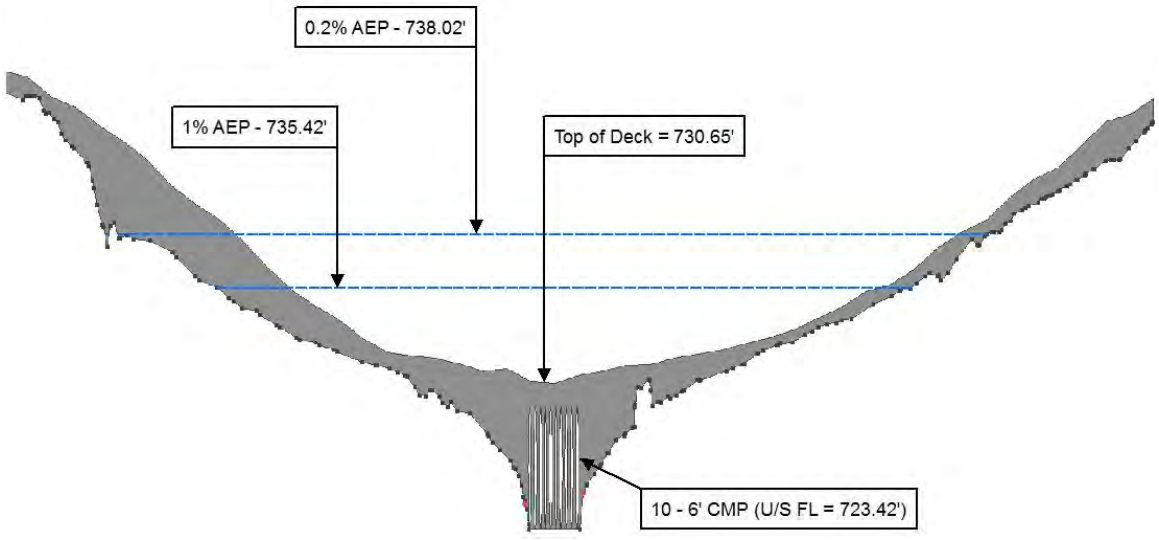


Figure 3-10 Existing Gibbs Sprawl Road Low Water Crossing

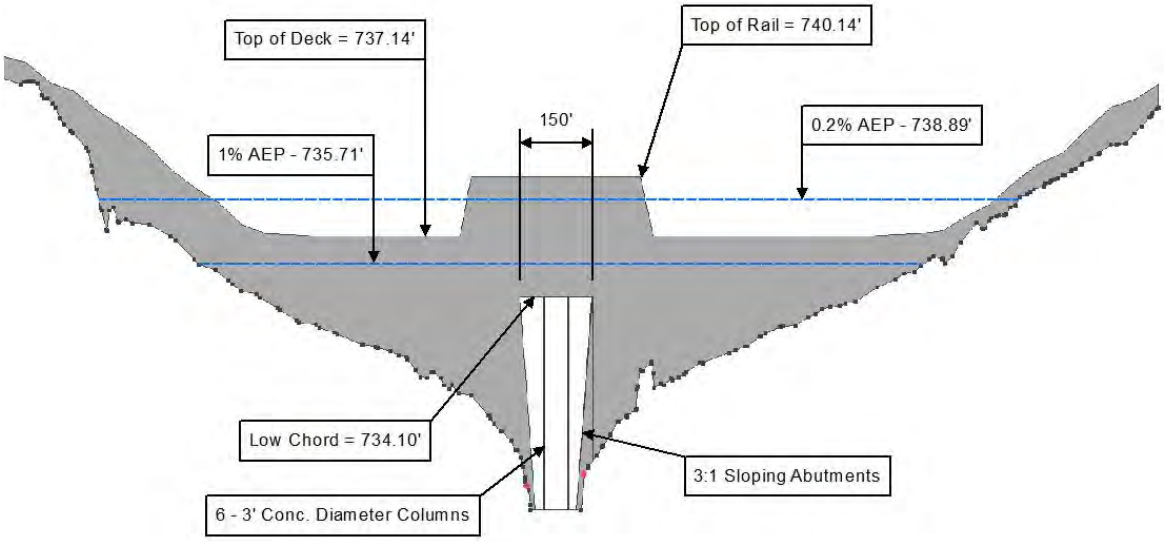


Figure 3-11 Proposed Gibbs Sprawl Bridge

3.2.1.2.2. Results

This section presents the peak flood stage, building damages and dangerous crossing results for Concept 2. Hydraulic simulations for the 50%, 10%, 4%, 2%, 1%, and 0.2% AEP events were used to generate the results.

Table 3-11 compares 10% and 1% AEP event existing peak flood stages along Upper Martinez Creek from 4,000 feet downstream of the railroad crossing to 1,800 feet upstream of Montgomery Drive. As seen in the table, peak flood stages for the 10% AEP event are reduced by a maximum of 2.35 feet about 460 feet downstream of Montgomery Drive. Existing condition 1% AEP event peak flood stages are reduced by a maximum of 2.15 feet about 1,000 feet downstream of Montgomery Drive. Although the Gibbs Sprawl Road improvements lower the 10% AEP event peak flood stages by 0.7 feet just upstream of the proposed bridge, the 1% AEP event peak flood stages are raised by 0.29 feet.

Table 3-11 Concept 2 - Upper Martinez Creek Peak Flood Stages (Existing Condition)

		Baseline Existing		*Concept 2 Existing*		*Difference (ft)*	
HEC-RAS Station	**Location**	**10% Peak Flood Stage (ft-NAVD88)**	**1% Peak Flood Stage (ft-NAVD88)**	**10% Peak Flood Stage (ft-NAVD88)**	**1% Peak Flood Stage (ft-NAVD88)**	**10% Peak Flood Stage**	**1% Peak Flood Stage**
132264		779.6	780.5	779.6	780.5	0.00	0.00
131691		775.8	777.2	775.8	777.2	0.00	0.00
131068		771.5	772.2	771.5	772.2	0.00	0.00
130477		768.3	769.5	768.3	769.5	0.00	0.00
130447	Montgomery Drive	768.5	769.6	768.5	769.6	0.00	0.00
130371	Montgomery Drive	766.8	768.0	766.8	768.0	0.00	0.00
130296		765.4	766.1	765.4	766.1	0.00	0.00
130121	*- Channel Improvement -*	764.0	764.9	762.6	763.6	-1.38	-1.27
129914	*- Channel Improvement -*	763.4	764.3	761.0	762.4	-2.35	-1.81
129390	*- Channel Improvement -*	759.0	760.3	757.1	758.2	-1.89	-2.15
128778	*- Channel Improvement -*	752.6	753.5	751.7	753.0	-0.86	-0.53
128232	*- Channel Improvement -*	748.4	749.2	746.1	747.2	-2.33	-2.02
127737	*- Channel Improvement -*	742.3	743.7	741.5	742.7	-0.78	-1.01
126964	*- Channel Improvement -*	739.7	741.1	738.4	739.8	-1.37	-1.28
126412	*- Channel Improvement -*	737.8	738.9	737.1	738.3	-0.66	-0.65
125834	*- Channel Improvement -*	736.2	737.2	736.1	737.2	-0.09	0.00
125770	Walzem Road	736.1	737.1	736.1	737.2	-0.05	**0.05**
125595	Walzem Road	735.0	736.7	734.9	736.8	-0.11	**0.14**
125462		734.6	736.4	734.4	736.6	-0.16	**0.17**
124801		733.9	735.9	733.5	736.2	-0.40	**0.23**
124284		733.6	735.7	733.0	736.0	-0.56	**0.25**
123741		733.3	735.4	732.6	735.7	-0.70	**0.28**
123707	Gibbs Sprawl Rd (U/S) - Improved	733.3	735.4	732.6	735.7	-0.70	**0.29**
123639	Gibbs Sprawl Rd (D/S) - Improved	732.3	735.2	732.3	735.2	0.00	0.00
123554	Railroad (U/S)	728.3	729.7	728.3	729.7	0.00	0.00
123378	Railroad (D/S)	727.4	728.4	727.4	728.4	0.00	0.00
122605		724.7	725.6	724.7	725.6	0.00	0.00
121646		721.9	722.9	721.9	722.9	0.00	0.00
120315		717.6	718.0	717.6	718.0	0.00	0.00
119353		712.7	713.7	712.7	713.7	0.00	0.00

As seen in Table 3-12, Concept 2 reduces future condition 10% AEP event peak flood stages by a maximum of 2.35 feet about 500 feet downstream of Montgomery Drive. Future condition 1% AEP event peak flood stages are reduced by a maximum of 2.15 feet about 1,000 feet downstream of Montgomery Drive. Although the Gibbs Sprawl Road improvements lower 10% AEP event peak flood stages by 0.69 feet just upstream of the proposed bridge, 1% AEP event peak flood stages are raised by 0.27 feet at the same location.

Please refer to Appendix C for a cross section by cross section comparison of peak flood stages for all modeled cross sections of Upper Martinez Creek.

Table 3-12 Concept 2 - Upper Martinez Creek Peak Flood Stages (Future Condition)

		Baseline Future		*Concept 2 Future*		*Difference (ft)*	
HEC-RAS Station	**Location**	**10% Peak Flood Stage (ft-NAVD88)**	**1% Peak Flood Stage (ft-NAVD88)**	**10% Peak Flood Stage (ft-NAVD88)**	**1% Peak Flood Stage (ft-NAVD88)**	**10% Peak Flood Stage**	**1% Peak Flood Stage**
132264		779.6	780.5	779.6	780.5	0.00	0.00
131691		775.8	777.2	775.8	777.2	0.00	0.00
131068		771.5	772.2	771.5	772.2	0.00	0.00
130477		768.3	769.5	768.3	769.5	0.00	0.00
130447	Montgomery Drive	768.5	769.6	768.5	769.6	0.00	0.00
130371	Montgomery Drive	766.8	768.0	766.8	768.0	0.00	0.00
130296		765.4	766.1	765.4	766.1	0.00	0.00
130121	*- Channel Improvement -*	764.0	764.9	762.6	763.6	-1.38	-1.27
129914	*- Channel Improvement -*	763.4	764.3	761.0	762.4	-2.35	-1.81
129390	*- Channel Improvement -*	759.0	760.3	757.1	758.2	-1.89	-2.15
128778	*- Channel Improvement -*	752.6	753.5	751.7	753.0	-0.86	-0.53
128232	*- Channel Improvement -*	748.4	749.2	746.1	747.2	-2.33	-2.02
127737	*- Channel Improvement -*	742.3	743.7	741.5	742.7	-0.79	-1.01
126964	*- Channel Improvement -*	739.7	741.1	738.4	739.8	-1.37	-1.29
126412	*- Channel Improvement -*	737.8	738.9	737.1	738.3	-0.66	-0.65
125834	*- Channel Improvement -*	736.2	737.2	736.2	737.2	-0.08	0.00
125770	Walzem Road	736.1	737.1	736.1	737.2	-0.04	**0.05**
125595	Walzem Road	735.0	736.7	734.9	736.9	-0.11	**0.13**
125462		734.6	736.5	734.4	736.6	-0.17	**0.16**
124801		733.9	736.0	733.5	736.2	-0.39	**0.22**
124284		733.6	735.7	733.0	736.0	-0.55	**0.25**
123741		733.3	735.5	732.6	735.7	-0.69	**0.28**
123707	Gibbs Sprawl Rd (U/S) - Improved	733.3	735.5	732.6	735.7	-0.69	**0.27**
123639	Gibbs Sprawl Rd (D/S) - Improved	732.3	735.2	732.3	735.2	0.00	0.00
123554	Railroad (U/S)	728.3	729.7	728.3	729.7	0.00	0.00
123378	Railroad (D/S)	727.4	728.4	727.4	728.4	0.00	0.00
122605		724.7	725.6	724.7	725.6	0.00	0.00
121646		721.9	722.9	721.9	722.9	0.00	0.00
120315		717.6	718.0	717.6	718.0	0.00	0.00
119353		712.7	713.8	712.7	713.8	0.00	0.00

3.2.1.3. Damage Assessment

This section discusses the change to flood risk damages in terms of flooded buildings, estimated annual damages to buildings, and dangerous crossings.

3.2.1.3.1. Flooded Buildings

This concept reduced peak flood stages along Martinez Creek from Montgomery Drive to Gibbs Sprawl Road. As seen in Table 3-13, under both the existing and future condition, Concept 2 removes 1, 3, 10, 17, 26 and 36 buildings from flooding during the 50%, 10%, 4%, 2%, 1% and 0.2% AEP events, respectively.

Table 3-13 Concept 2 - Upper Martinez Creek Flooded Structures

Condition	Number of Flooded Buildings (by Event)					
	50% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.2% AEP
Baseline Existing	1	4	11	18	28	97
Concept 2 Existing	0	1	1	1	2	61
Baseline Future	1	4	11	18	28	97
Concept 2 Future	0	1	1	1	2	61
Concept 2 Change (Existing) =	***-1***	***-3***	***-10***	***-17***	***-26***	***-36***
Concept 2 Change (Future) =	***-1***	***-3***	***-10***	***-17***	***-26***	***-36***

3.2.1.3.2. Estimated Annual Damages

EAD values for Concept 2 were calculated according to the procedure described in Section 3.1.1.3.2. The concept reduced the number of flooded buildings, which resulted in lower EAD values. As seen in Table 3-14, Concept 2 reduces the existing condition EAD on Upper Martinez Creek by $10,098 and the future condition EAD was reduced by $27,366. The EAD values for Upper Martinez Creek (Table 3-14) were used to calculate watershed-wide EAD values that were applied to the Concept 2 scoring discussed in Section 4.1.1.

Table 3-14 Concept 2 - Upper Martinez Creek EAD

Condition	Estimated Annual Damages (EAD) ($)
Baseline Existing	$15,365
Concept 2 Existing	$5,267
Baseline Future	$41,572
Concept 2 Future	$14,206
Concept 2 Change (Existing) =	**($10,098)**
Concept 2 Change (Future) =	**($27,366)**

3.2.1.3.3. Dangerous Crossings

The crossings along Upper Martinez Creek were simulated under the Baseline Existing and Concept 2 Existing condition. As seen in Table 3-15, SDR reductions for Concept 2 occur primarily at Gibbs Sprawl Road for all AEP events. Walzem Road shows a slight decrease in SDR for the 10% AEP, but an increase for the 0.20% AEP event. Total DCF values along Upper Martinez Creek decrease by 1.20.

Table 3-15 Concept 2 - Dangerous Crossing Summary (Existing Condition)

Crossing	Baseline Existing SDR						Concept 2 Existing SDR						DCF	
	50%	10%	4%	2%	1%	0.20%	50%	10%	4%	2%	1%	0.20%	Baseline Exist	Concept 2 Exist
Crestway Drive	0.0	0.3	0.5	0.6	0.7	0.9	0.0	0.3	0.5	0.6	0.7	0.9	0.11	0.11
Glen Fair	0.0	0.5	1.0	1.4	1.8	2.5	0.0	0.5	1.0	1.4	1.8	2.5	0.21	0.21
Montgomery Drive	0.0	0.0	0.3	0.6	0.8	1.1	0.0	0.0	0.3	0.6	0.8	1.1	0.03	0.03
Walzem Road	0.0	0.8	1.1	1.4	1.7	3.2	0.0	0.7	1.1	1.4	1.7	3.7	0.27	0.27
Gibbs Sprawl Road	1.0	2.2	2.7	3.3	4.2	6.4	0.0	0.0	0.0	0.0	0.0	0.0	1.19	0.00
Railroad	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
Putter Road	0.0	0.4	0.7	0.9	1.2	1.7	0.0	0.4	0.7	0.9	1.2	1.7	0.15	0.15
												Total =	**1.97**	**0.77**

Concept 2 also reduces crossing SDR for the future conditions in a similar manner to existing conditions. As seen on Table 3-16, SDR reductions under future conditions for Concept 2 only occur at Gibbs Sprawl Road for all AEP events. Walzem Road shows an increase in SDR for the 0.20% AEP event. Total Future condition DCF values along Upper Martinez Creek decrease by 1.21.

The Upper Martinez Creek DCF values (Table 3-15 and Table 3-16) were used to calculate watershed-wide DCF values that were applied to the Concept 2 scoring discussed in Section 4.1.2.

Table 3-16 Concept 2 - Dangerous Crossing Summary (Future Condition)

Crossing	Baseline Future SDR						Concept 2 Future SDR						DCF	
	50%	10%	4%	2%	1%	0.20%	50%	10%	4%	2%	1%	0.20%	Baseline Future	Concept 2 Future
Crestway Drive	0.0	0.3	0.5	0.6	0.7	0.9	0.0	0.3	0.5	0.6	0.7	0.9	0.11	0.11
Glen Fair	0.0	0.5	1.0	1.4	1.8	2.5	0.0	0.5	1.0	1.4	1.8	2.5	0.21	0.21
Montgomery Drive	0.0	0.0	0.3	0.6	0.8	1.1	0.0	0.0	0.3	0.6	0.8	1.1	0.03	0.03
Walzem Road	0.0	0.8	1.1	1.4	1.7	3.2	0.0	0.8	1.1	1.4	1.7	3.7	0.28	0.27
Gibbs-Sprawl Road	1.1	2.2	2.7	3.4	4.2	6.4	0.0	0.0	0.0	0.0	0.0	0.0	1.20	0.00
Railroad	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
Putter Road	0.0	0.4	0.7	0.9	1.2	1.7	0.0	0.4	0.7	0.9	1.2	1.7	0.15	0.15
												Total =	**1.98**	**0.77**

3.2.2. Water Quality

The Upper Martinez Creek improvements in their current configuration are not expected to produce quantifiable water quality benefits. Water quality benefits could be generated if features such as step-pools were added to the channel design. However, the benefits of any water quality features would likely be minimal as, outside of bacteria concentrations, water quality concerns were not identified for this reach. Furthermore, the reservoir just downstream of Concept 2 produces water quality benefits under the Baseline condition and would likely reduce the benefits of any water quality features added to Concept 2. For these reasons a water quality simulation was not performed for this concept.

3.2.3. Cost Estimate

The construction and maintenance costs for this concept were separated into two different cost estimates: one for the channel improvements and another for the bridge improvements. As seen in Table 3-17, construction of the channel improvements along upper Martinez Creek is estimated to cost $482,571. The proposed channel improvement was assumed to have no additional maintenance cost beyond that of the existing channel. Therefore, no additional maintenance cost was estimated for the channel improvement of this concept.

Table 3-17 Concept 2 - (Channel Improvement Only) Construction and Maintenance Estimate

Construction Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
CHANNEL EXCAVATION(5,000 CY < X < 70,000 CY)	11880	CY	$15	$178,200
FERTILIZER	10	AC	$800	$8,000
BROADCREST SEED (PERM)	10	AC	$500	$5,000
WATERING	835	MG	$11	$9,185
TRAFFIC CONTROL		LS	-	$10,900
			Construction Total	$211,285
Fringe Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ENVIRONMENTAL PERMITTING		LS	-	$128,000
MOBILIZATION		LS	10%	$21,129
PREPARING RIGHT-OF-WAY		LS	4%	$8,451
ENGINEERING		LS	15%	$31,693
SURVEYING (5% OF ENGINEERING)		LS	5%	$1,585
			Fringe Total	$190,857
Continuation Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ANNUAL MAINTENANCE COST		LS	-	-
			Continuation Total, 50-Year Project Life (Present Value)	-
			Project Total (Construction + Fringe + Continuation)	$402,142
			20% Contingency on Conceptual Estimates	$80,428
			PROJECT GRAND TOTAL	**$482,571**

The construction estimate for the Concept 2 bridge improvement may be found in Table 3-18. Construction of the bridge improvement is estimated to cost $3,366,181. The proposed bridge improvement was assumed to have no additional maintenance cost beyond that of the existing crossing. Therefore, no additional maintenance cost was estimated for the bridge improvement of this concept.

Table 3-18 Concept 2 - (Bridge Only) Construction and Maintenance Estimate

Construction Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
REMOVAL/RECLAIM (3" ASPHALT PAVEMENT)	4980	SY	$3	$14,940
CULVERT REMOVAL	107	LF	$80	$8,560
MTL BEAM GD FENS (REMOVAL)	500	LF	$5	$2,500
REMOVE TERMINAL ANCHOR SECTION	4	EA	$250	$1,000
EMBANKMENT (DENS CONT TYP C)	4250	CY	$12	$51,000
FLEXIBLE BASE (14" COMP. DEPTH)	3290	TON	$60	$197,400
HOT MIX ASPHALTIC PAVEMENT, TYPE B (2" - 6" COMPACTED DEPTH)	704	TON	$100	$70,400
RETAINING WALL (SPREAD FOOTING)	8015	SF	$50	$400,750
RETAINING WALL (CAST-IN-PLACE)	11900	SF	$65	$773,500
CONCRETE STRUCTURE (APPROACH SLABS)	55	CY	$500	$27,500
CONCRETE STRUCTURE (ABUTMENTS & WINGWALLS)	43	CY	$950	$40,850
CONCRETE STRUCTURE (BRIDGE DECKS)	134	CY	$1,400	$187,600
PRESTRESSED CONCRETE I-GIRDER (Tx28)	600	LF	$125	$75,000
CONCRETE STRUCTURE (BRIDGE CAPS)	30	CY	$1,100	$33,000
CONCRETE STRUCTURE (BRIDGE COLUMNS & PIERS)	19	CY	$1,000	$19,000
CL C CONC (FOOTING)	22	CY	$850	$18,700
PRESTR CONC PIL (18 IN SQ)	1160	LF	$95	$110,200
RIP-RAP (CONC) (CL B) (RR8 & RR9)	91	CY	$400	$36,400
RAIL (TY SSTR)	380	LF	$50	$19,000
MTL BEAM GD FEN TRANS (THRIE-BEAM)	4	EA	$1,700	$6,800
MTL W-BEAM GD FENCE (TIM POST)	100	LF	$20	$2,000
GUARDRAIL END TREATMENT (INSTALL)	4	EA	$2,400	$9,600
SMALL ROADSIDE SIGN ASSEMBLY	4	EA	$750	$3,000
FERTILIZER	0.23	AC	$800	$184
BROADCREST SEED (PERM)	0.23	AC	$500	$115
WATERING	21	MG	$11	$231
TRAFFIC CONTROL		LS	-	$14,200
			Construction Total	$2,123,430
Fringe Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ENVIRONMENTAL PERMITTING		LS	-	$50,000
MOBILIZATION		LS	10%	$212,343
PREPARING RIGHT-OF-WAY		LS	4%	$84,937
ENGINEERING		LS	15%	$318,515
SURVEYING (5% OF ENGINEERING)		LS	5%	$15,926
			Fringe Total	$681,720
Continuation Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ANNUAL MAINTENANCE COST		LS	-	-
			Continuation Total, 50-Year Project Life (Present Value)	-
			Project Total (Construction + Fringe + Continuation)	$2,805,150
			20% Contingency on Conceptual Estimates	$561,030
			PROJECT GRAND TOTAL	**$3,366,181**

3.3. Low Water Crossing Replacements

This concept provides the option of replacing 5 low water crossings (LWC) within the Cibolo Creek watershed. As previously mentioned in the Phase 2 Report, the 98 crossings within the watershed were ranked on three different criteria (DCF, ADT, and DSC). Each criterion was normalized between the values of 0 (least dangerous) to 5 (most dangerous), and then a Dangerous Crossing Score was calculated by assigning a weight to each of the three criteria (Equation 3-1). Table 3-19 below shows the top 20 most dangerous crossings within the watershed. The top 5 most dangerous crossings in the watershed are located on Cibolo Creek, and include: CR 352/CR 440, CR 347/CR 417, FM 537, FM 2538, and FM 1863 Upstream (U/S).

$$\boldsymbol{Dangerous\ Crossing\ Score} = (\mathbf{0.45} \times \boldsymbol{DCF_{norm}}) + (\mathbf{0.35} \times \boldsymbol{ADT_{norm}}) + (\mathbf{0.2} \times \boldsymbol{DSC_{norm}}) \quad \textbf{(3-1)}$$

Table 3-19 Prioritized Dangerous Crossings

Rank	Crossing	River	Station	DCF	ADT	DSC	$DCF_{Normal.}$	$ADT_{Normal.}$	$DSC_{Normal.}$	Dangerous Crossing Score
1	CR 352/CR 440	Cibolo Creek (Lower)	301,806	13.58	1,500	26,170	4.70	0.15	4.36	3.04
2	CR 347/CR 417	Cibolo Creek (Lower)	284,704	14.48	1,500	14,336	5.00	0.15	2.39	2.78
3	FM 537	Cibolo Creek (Lower)	140,088	8.00	680	29,029	2.65	0.07	4.84	2.18
4	FM 2538	Cibolo Creek (Upper)	10,227	7.29	752	26,279	2.42	0.08	4.38	1.99
5	FM 1863 (U/S)	Cibolo Creek (Upper)	261,494	5.75	2,922	28,066	1.98	0.29	4.68	1.93
6	Battle Intense Road	Cibolo Creek (Upper)	413,569	6.06	1,000	28,000	2.13	0.10	4.67	1.93
7	FM 3351	Cibolo Creek (Upper)	406,235	3.86	8,953	30,000	1.31	0.90	5.00	1.90
8	IH-10 East	Escondido Creek (Upper)	29,883	0.22	45,541	5,284	0.08	4.55	0.88	1.81
9	Blanco Road	Cibolo Creek (Upper)	346,639	5.63	2,560	23,983	1.96	0.26	4.00	1.77
10	Bexar Bowling	Cibolo Creek (Upper)	53,377	9.10	630	8,539	3.19	0.06	1.42	1.74
11	FM 1863 (D/S)	Cibolo Creek (Upper)	257,530	4.08	2,922	29,862	1.41	0.29	4.98	1.73
12	Lookout Road	Cibolo Creek (Upper)	171,532	8.98	1,600	3,870	3.15	0.16	0.65	1.60
13	Smithson Valley Road	Cibolo Creek (Upper)	289,587	6.59	1,355	15,451	2.26	0.14	2.58	1.58
14	Toutant Beuregard Road	Balcones Creek	49,753	5.39	493	16,791	1.97	0.05	2.80	1.46
15	FM 2724	Cibolo Creek (Lower)	23,022	8.12	500	7,161	2.54	0.05	1.19	1.40
16	Putter Road	Martinez Creek B (Upper)	115,687	0.15	27,000	8,723	0.05	2.70	1.45	1.26
17	Blanco Road	Meusebach Creek	14,500	0.23	1,951	30,000	0.08	0.20	5.00	1.11
18	Old Fredericksburg Road	Balcones Creek	19,798	5.87	869	3,835	2.09	0.09	0.64	1.10
19	N. Gable Road	Martinez Creek B (Lower)	16,632	4.87	92	7,872	1.79	0.01	1.31	1.07
20	Boerne Stage Road	Balcones Creek	31,924	4.84	1,687	5,590	1.73	0.17	0.93	1.02

Upon review of the top 20 most dangerous crossings, Atkins decided to pair the replacement of FM 1863 (U/S) (#5 on list) with FM 1863 (D/S) (#11 on list). This decision was made because the two crossings are within 0.75 miles of each other and it would be pointless to replace only one of the FM 1863 crossings. Therefore, the 5 crossings considered for improvement are CR 352/CR 440 (Zuehl Crossing Road/Lupon Road), CR 347/CR 417 (Scull Crossing), FM 537, FM 1863 (U/S) and FM 1863 (D/S). Figure 3-12 and Figure 3-13 below shows the location of these 5 crossings within the watershed.

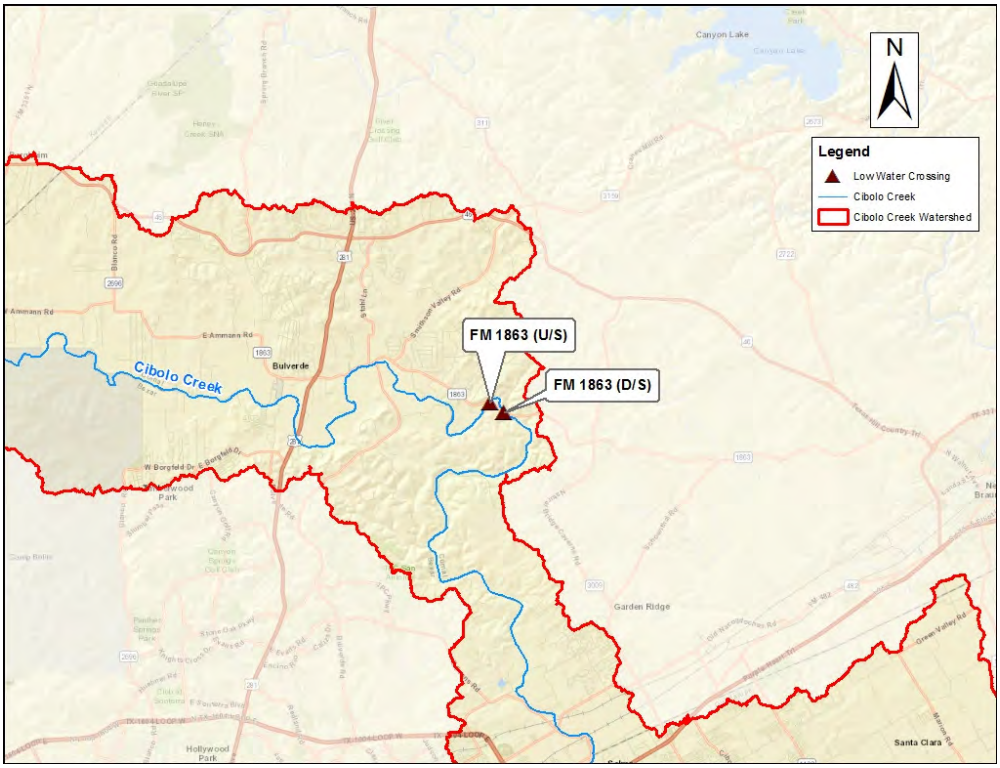


Figure 3-12 Proposed Low Water Crossing Improvements (Upper Cibolo)

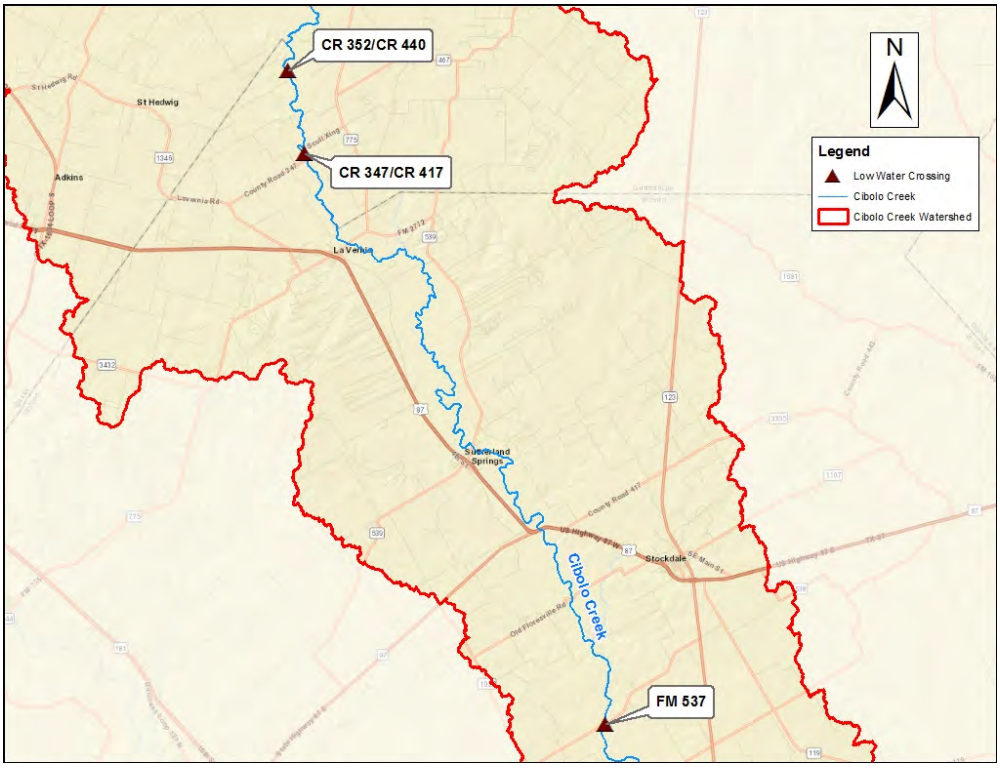


Figure 3-13 Proposed Low Water Crossing Improvements (Lower Cibolo)

3.3.1. FM 1863 (Concept 3A)

The two FM 1863 crossings of Cibolo Creek were evaluated together as Concept 3A. Their locations, as seen in Figure 3-12, are about 10 miles downstream of US Highway 281. The upstream FM 1863 crossing of Cibolo Creek currently consists of 8-corrugated arch pipes (4.8' span X 2.9' rise X 40' length) as seen in Figure 3-14. The crossing is proposed to be replaced by a 600 foot long bridge that has 10-60 foot spans. The downstream crossing of FM 1863 consists of 9-corrugated arch pipes (4.5' span X 3.0' rise X 40' length), as seen in Figure 3-15. This concept proposes to replace this crossing with a 650 foot long bridge that has 13-50 foot spans.

3.3.1.1. Flood Risk

This section discusses the Baseline and Post-Project flood risks associated with the FM 1863 crossings of Cibolo Creek.

3.3.1.1.1. Baseline Conditions

Under existing and future conditions the upstream FM 1863 crossing is overtopped by all modeled storm events. As seen in Table 3-20, the crossing is considered dangerous for all modeled storm events (50%, 10%, 4%, 2%, 1% and 0.2% AEP) for both the existing and future condition. The existing condition 50% AEP event SDR value for the crossing is 5.3, which means that for the 50% AEP event the crossing can expect to have an overtopping depth that is 5.3 times the safe value. For the future condition the 50% AEP event SDR value is 6.4. The existing and future condition SDR values were used to calculate an existing and future condition DCF value of 5.38 and 6.11, respectively.

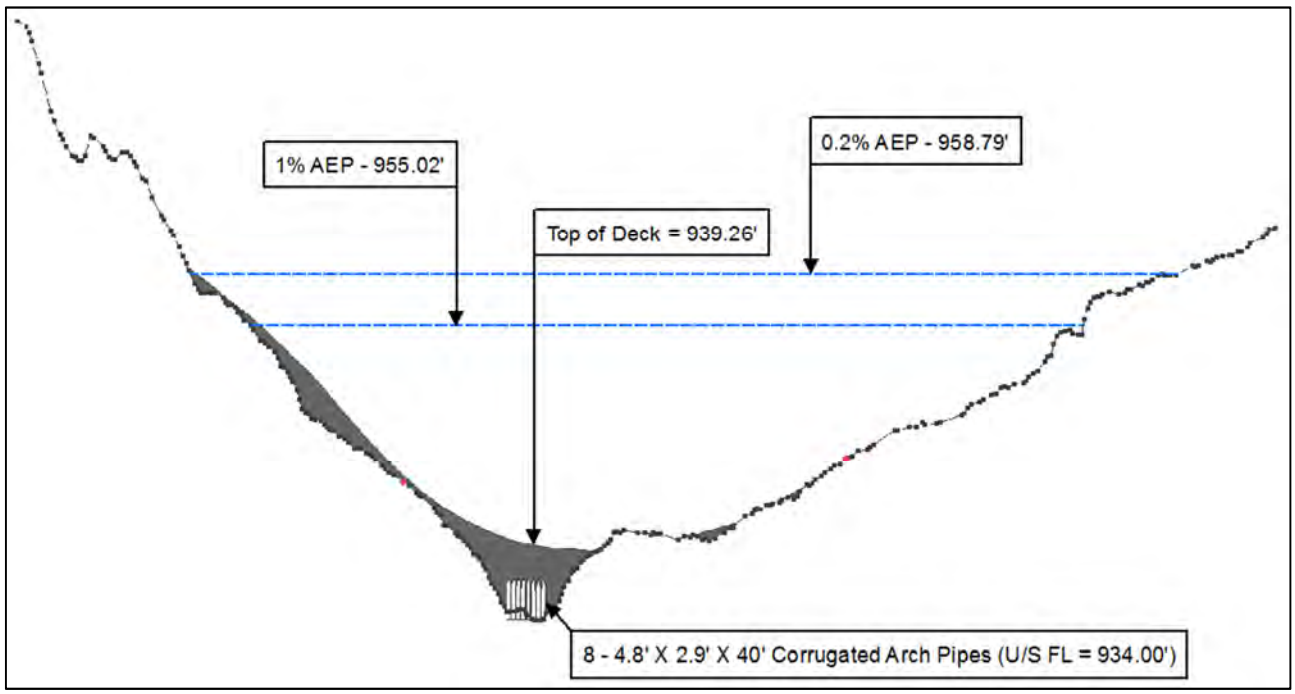


Figure 3-14 Existing Cross Section of FM 1863 (Upstream)

Table 3-20 Concept 3A - FM 1863 (U/S) Baseline Flood Risk Summary

	Baseline Existing						Baseline Future					
Parameter	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**
Overflow Velocity (ft/s)	4.0	4.5	4.7	4.8	4.9	5.2	3.8	4.6	4.7	4.8	5.0	5.2
Overflow Depth (ft)	6.1	10.3	13.1	14.6	16.1	19.9	7.3	11.3	13.9	15.2	16.7	20.4
Status	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger
SDR	5.3	9.2	11.8	13.1	14.6	18.2	6.4	10.1	12.5	13.7	15.2	18.7

As with the upstream FM 1863 crossing, the downstream crossing is overtopped by and considered dangerous for all modeled storm events for both the existing and future condition (see Table 3-21). The 50% AEP event SDR value for the crossing is 3.5 and 4.0 for the existing and future conditions, respectively. The existing and future condition SDR values were used to calculate an existing and future condition DCF value of 3.84 and 4.33, respectively. DCF calculations may be found in Appendix C.

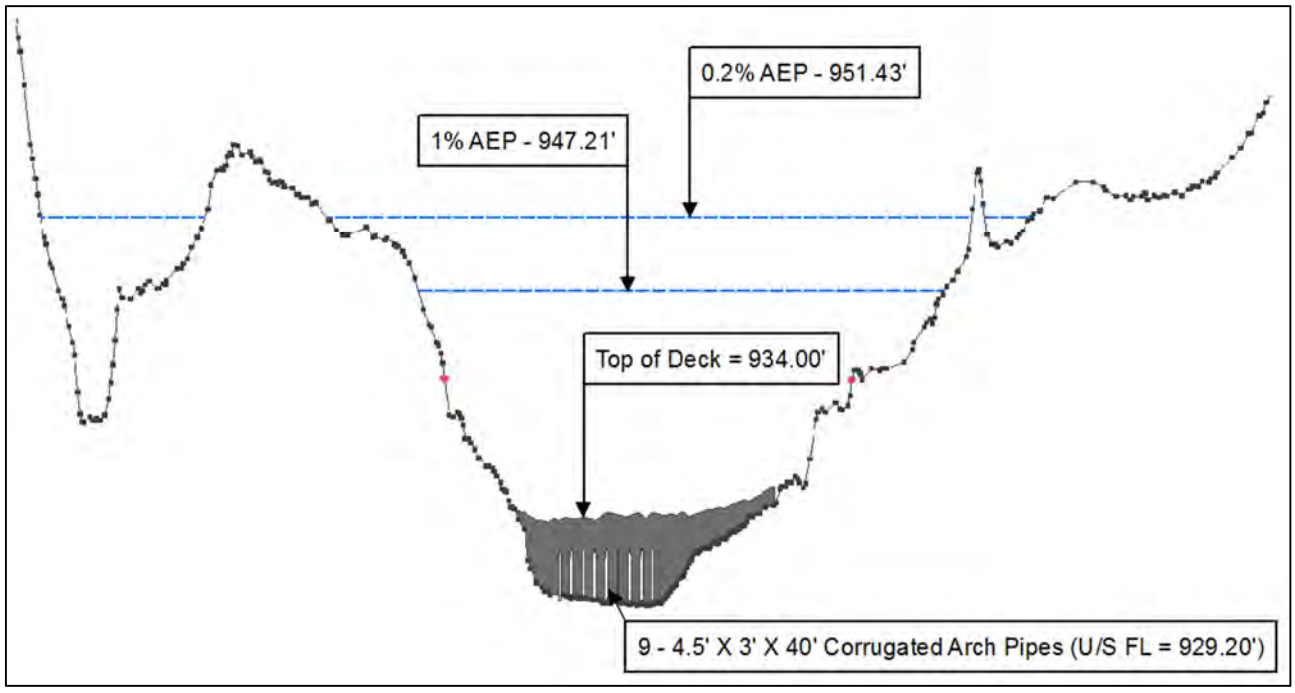


Figure 3-15 Existing Cross Section of FM 1863 (Downstream)

Table 3-21 Concept 3A - FM 1863 (D/S) Baseline Flood Risk Summary

	Baseline Existing						Baseline Future					
Parameter	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**
Overflow Velocity (ft/s)	4.6	5.2	5.1	5.1	5.2	4.7	4.9	5.2	5.1	5.1	5.3	4.6
Overflow Depth (ft)	3.8	7.5	10.3	11.9	13.5	17.7	4.4	8.4	11.2	12.6	14.0	18.3
Status	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger
SDR	3.5	6.8	9.4	10.8	12.4	15.9	4.0	7.7	10.2	11.5	12.8	16.4

3.3.1.1.2. Proposed Conditions

For the upstream FM 1863 crossing of Cibolo Creek a bridge was proposed to replace the existing low water crossing. The proposed bridge has a total length of 600 feet and is comprised of 10-60 foot spans, with the spans supported by 36-inch circular piers. The proposed bridge has a top deck elevation of 957.8 feet, which is 18.5 feet higher than the existing crossing. The bridge has an assumed low chord elevation of 955.25 feet that gives it a 0.23 foot freeboard above the Baseline Existing 1% AEP peak flood stage (955.02 feet). The proposed bridge for the downstream FM 1863 crossing has a total length of 650 feet and is comprised of 12-50 foot spans, with the spans supported by 36-inch circular piers. The proposed bridge has a top deck elevation of 949.8 feet, which is 15.8 feet higher than the existing crossing. The bridge low chord elevation of 947.25 feet is just above the existing condition 1% AEP event peak flood stage of 947.21 feet. A detailed layout of the FM 1863 bridge crossings may be found in Appendix A.

Table 3-22 and Table 3-23 display the flood risk for both proposed FM 1863 crossings. The proposed crossing improvements make both crossings safe for the existing and future 1% AEP event. Both proposed crossings will still be dangerous for the 0.2% AEP event for the existing and future condition. The existing and future condition DCF values for both crossings is 0.01 (see Appendix C). The decrease in DCF values for this concept was used to calculate watershed-wide DCF values that were applied to the Concept 3A scoring discussed in Section 4.1.2.

Table 3-22 Concept 3A - FM 1863 (U/S) Post-Project Flood Risk Summary

	Concept 3A Existing						Concept 3A Future					
Parameter	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**
Overflow Velocity (ft/s)	0.0	0.0	0.0	0.0	0.0	6.5	0.0	0.0	0.0	0.0	0.0	6.6
Overflow Depth (ft)	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	2.7
Status	Safe	Safe	Safe	Safe	Safe	Danger	Safe	Safe	Safe	Safe	Safe	Danger
SDR	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	2.6

Table 3-23 Concept 3A - FM 1863 (D/S) Post-Project Flood Risk Summary

	Concept 3A Existing						Concept 3A Future					
Parameter	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**
Overflow Velocity (ft/s)	0.0	0.0	0.0	0.0	0.0	5.1	0.0	0.0	0.0	0.0	0.0	5.1
Overflow Depth (ft)	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	3.2
Status	Safe	Safe	Safe	Safe	Safe	Danger	Safe	Safe	Safe	Safe	Safe	Danger
SDR	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	2.9

3.3.1.2. Water Quality

There are no foreseeable water quality benefits associated with this concept. A water quality analysis was not performed for this concept.

3.3.1.3. Cost Estimate

As seen in Table 3-24, construction of the upstream FM 1863 bridge over Cibolo Creek is estimated to cost $3,137,835. The proposed bridge was assumed to have no additional maintenance cost beyond that of the existing crossing. Construction of the downstream FM 1863 bridge over Cibolo Creek is estimated to cost $4,884,249. It should be noted that this construction cost is significantly higher than the upstream FM 1863 crossing due to a small tributary crossing (10x10 RCB) just east of Cibolo Creek that was included with the downstream crossing. The proposed bridge was assumed to have no additional maintenance cost beyond that of the existing crossing.

Table 3-24 Concept 3A - (Upstream FM 1863 Bridge) Construction and Maintenance Estimate

Construction Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
REMOVAL/RECLAIM (3" ASPHALT PAVEMENT)	4200	SY	$3	$12,600
CULVERT REMOVAL	55	LF	$80	$4,400
EXCAVATION	113	CY	$20	$2,260
EMBANKMENT (DENS CONT TYP C)	2612	CY	$12	$31,344
FLEXIBLE BASE (14" COMP. DEPTH)	1558	TON	$60	$93,480
HOT MIX ASPHALTIC PAVEMENT, TYPE B (2" - 6" COMPACTED DEPTH)	334	TON	$100	$33,400
RETAINING WALL (SPREAD FOOTING)	294	SF	$50	$14,700
RETAINING WALL (CAST-IN-PLACE)	450	SF	$65	$29,250
CONCRETE STRUCTURE (APPROACH SLABS)	49	CY	$500	$24,500
CONCRETE STRUCTURE (ABUTMENTS & WINGWALLS)	39	CY	$950	$37,050
CONCRETE STRUCTURE (BRIDGE DECKS)	473	CY	$1,400	$662,200
PRESTRESSED CONCRETE I-GIRDER (Tx28)	2400	LF	$125	$300,000
CONCRETE STRUCTURE (BRIDGE CAPS)	115	CY	$1,100	$126,500
CONCRETE STRUCTURE (BRIDGE COLUMNS & PIERS)	103	CY	$1,000	$103,000
CL C CONC (FOOTING)	96	CY	$850	$81,600
PRESTR CONC PIL (18 IN SQ)	2700	LF	$95	$256,500
RIP-RAP (CONC) (CL B) (RR8 & RR9)	85	CY	$400	$34,000
RAIL (TY SSTR)	1280	LF	$50	$64,000
MTL BEAM GD FEN TRANS (THRIE-BEAM)	4	EA	$1,700	$6,800
MTL W-BEAM GD FENCE (TIM POST)	100	LF	$20	$2,000
GUARDRAIL END TREATMENT (INSTALL)	4	EA	$2,400	$9,600
SMALL ROADSIDE SIGN ASSEMBLY & BARRICADES	1	LS	$20,000	$20,000
FERTILIZER	0.55	AC	$800	$440
BROADCREST SEED (PERM)	0.55	AC	$500	$275
WATERING	46	MG	$11	$506
TRAFFIC CONTROL		LS	-	$7,100
			Construction Total	$1,957,505
Fringe Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ENVIRONMENTAL PERMITTING		LS	-	$75,000
MOBILIZATION		LS	10%	$195,751
PREPARING RIGHT-OF-WAY		LS	4%	$78,300
ENGINEERING		LS	15%	$293,626
SURVEYING (5% OF ENGINEERING)		LS	5%	$14,681
			Fringe Total	$657,358
Continuation Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ANNUAL MAINTENANCE COST		LS	-	-
			Continuation Total, 50-Year Project Life (Present Value)	-
			Project Total (Construction + Fringe + Continuation)	$2,614,863
			20% Contingency on Conceptual Estimates	$522,973
			PROJECT GRAND TOTAL	**$3,137,835**

Table 3-25 Concept 3A - (Downstream FM 1863 Bridge) Construction and Maintenance Estimate

Construction Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
REMOVAL/RECLAIM (3" ASPHALT PAVEMENT)	7000	SY	$3	$21,000
CULVERT REMOVAL	185	LF	$80	$14,800
MTL BEAM GD FENS (REMOVAL)	2150	LF	$5	$10,750
EXCAVATION	1077	CY	$20	$21,540
EMBANKMENT (DENS CONT TYP C)	10236	CY	$12	$122,832
FLEXIBLE BASE (14" COMP. DEPTH)	3594	TON	$60	$215,640
HOT MIX ASPHALTIC PAVEMENT, TYPE B (2" - 6" COMPACTED DEPTH)	770	TON	$100	$77,000
CONCRETE CULVERT BOX (10' X 10')	28	LF	$815	$22,820
RETAINING WALL (SPREAD FOOTING)	4638	SF	$50	$231,900
RETAINING WALL (CAST-IN-PLACE)	6800	SF	$65	$442,000
CONCRETE STRUCTURE (APPROACH SLABS)	49	CY	$500	$24,500
CONCRETE STRUCTURE (ABUTMENTS & WINGWALLS)	39	CY	$950	$37,050
CONCRETE STRUCTURE (BRIDGE DECKS)	512	CY	$1,400	$716,800
PRESTRESSED CONCRETE I-GIRDER (Tx28)	2600	LF	$125	$325,000
CONCRETE STRUCTURE (BRIDGE CAPS)	153	CY	$1,100	$168,300
CONCRETE STRUCTURE (BRIDGE COLUMNS & PIERS)	143	CY	$1,000	$143,000
CL C CONC (FOOTING)	128	CY	$850	$108,800
PRESTR CONC PIL (18 IN SQ)	3420	LF	$95	$324,900
RIP-RAP (CONC) (CL B) (RR8 & RR9)	52	CY	$400	$20,800
RAIL (TY SSTR)	1380	LF	$50	$69,000
MTL BEAM GD FEN TRANS (THRIE-BEAM)	4	EA	$1,700	$6,800
MTL W-BEAM GD FENCE (TIM POST)	2250	LF	$20	$45,000
GUARDRAIL END TREATMENT (INSTALL)	4	EA	$2,400	$9,600
SMALL ROADSIDE SIGN ASSEMBLY & BARRICADES	1	LS	$20,000	$20,000
FERTILIZER	1	AC	$800	$800
BROADCREST SEED (PERM)	1	AC	$500	$500
WATERING	70	MG	$11	$770
TRAFFIC CONTROL		LS	-	$7,100
			Construction Total	$3,209,002
Fringe Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ENVIRONMENTAL PERMITTING		LS	-	$75,000
MOBILIZATION		LS	10%	$320,900
PREPARING RIGHT-OF-WAY		LS	4%	$128,360
ENGINEERING		LS	10%	$320,900
SURVEYING (5% OF ENGINEERING)		LS	5%	$16,045
			Fringe Total	$861,205
Continuation Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ANNUAL MAINTENANCE COST		LS	-	-
			Continuation Total, 50-Year Project Life (Present Value)	-
			Project Total (Construction + Fringe + Continuation)	$4,070,207
			20% Contingency on Conceptual Estimates	$814,041
			PROJECT GRAND TOTAL	**$4,884,249**

3.3.2. CR 352/CR 440 (Concept 3B)

The CR 352/CR 440 crossing of Cibolo Creek (Zuehl Crossing) is ranked as the most dangerous crossing in the Cibolo Creek watershed (see Table 3-19) when considering a combination of its DCF, average daily traffic and the distance to the nearest safe crossing. The CR 352/CR 440 crossing is located about 1.1 miles downstream of the confluence of Martinez Creek and Cibolo Creek and lies within both Wilson and Guadalupe County (see Figure 3-13). The low water crossing conveys Cibolo Creek's flow through 2-30-inch RCPs. The low water crossing is overtopped by more than 15 feet during the 50% AEP event, which is more than 13 times the crossing's safe overtopping depth. The low water crossing is proposed to be replaced by a 300-foot long bridge that includes 4-75 foot spans. The spans will be supported by 36-inch circular piers. The proposed bridge's low chord elevation is 514.00 feet, which is 1.04 feet above the 1% AEP event peak flood stage (512.96 feet).

3.3.2.1. Flood Risk

This section discusses the Baseline and Post-Project flood risks associated with CR 352/CR440.

3.3.2.1.1. Baseline Conditions

As seen in Figure 3-16, the existing CR 352/CR 440 crossing of Cibolo Creek does not cross perpendicular to Cibolo Creek. Under existing and future conditions, the crossing is overtopped and considered dangerous for the 50% AEP event and less frequent storm events (see Table 3-26). The 50% AEP event SDR value for the crossing is 13.2 and 15.5 for the existing and future conditions, respectively. The existing and future condition SDR values were used to calculate an existing and future condition DCF value of 12.77 and 14.39, respectively (See Appendix C).



Figure 3-16 CR 352/CR 440 Location

Table 3-26 Concept 3B - CR 352/CR 440 Baseline Flood Risk Summary

	Baseline Existing						Baseline Future					
Parameter	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**
Overflow Velocity (ft/s)	3.7	4.2	4.6	4.8	5.2	4.1	3.8	4.4	4.8	5.0	5.2	3.9
Overflow Depth (ft)	15.1	24.3	29.6	32.4	34.9	38.0	17.8	26.4	31.7	33.9	35.8	38.8
Status	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger
SDR	13.2	21.4	26.5	29.2	32.0	33.4	15.5	23.4	28.5	30.8	32.7	33.8

3.3.2.1.2. Proposed Conditions

The skewed angle of the existing CR 352/CR 440 crossing of Cibolo Creek would require an excessively long bridge if the existing low water crossing alignment was maintained. Instead Atkins proposed to re-route CR 352/CR 440 to cross perpendicular to Cibolo Creek. This reroute requires a right-of-way purchase, but will shorten the required length of the proposed bridge. The proposed bridge has a total span of 300 feet and a low chord elevation of 514 feet. The proposed bridge has a top deck elevation of 517.0 feet, which is 39.0 feet higher than the existing crossing. The bridge has a 1.04 feet freeboard over the Baseline Existing 1% AEP peak flood stage of 512.96 feet. A more detailed layout showing the bridge schematic and rerouting of CR 352/CR 440 can be found within Appendix A.

Table 3-27 displays the flood risk for the proposed CR 352/CR 440 crossing. The proposed crossing improvement makes the crossing safe for the existing and future 1% AEP event. The proposed crossing will still be dangerous for the 0.2% AEP event for the existing and future condition. The existing and future condition DCF value of the crossing is 0.01 (see Appendix C). The decrease in DCF values for this concept was used to calculate watershed-wide DCF values that were applied to the Concept 3B scoring discussed in Section 4.1.2.

Table 3-27 Concept 3B - CR 352/CR 440 Post-Project Flood Risk Summary

	Concept 3B Existing						Concept 3B Future					
Parameter	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**
Overflow Velocity (ft/s)	0.0	0.0	0.0	0.0	0.0	4.1	0.0	0.0	0.0	0.0	0.0	3.9
Overflow Depth (ft)	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	2.8
Status	Safe	Safe	Safe	Safe	Safe	Danger	Safe	Safe	Safe	Safe	Safe	Danger
SDR	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	2.5

3.3.2.2. Water Quality

There are no foreseeable water quality benefits associated with this concept.

3.3.2.3. Cost Estimate

As seen in Table 3-28, construction of the CR 352 bridge over Cibolo Creek is estimated to cost $1,393,824. The proposed bridge was assumed to have no additional maintenance cost beyond that of the existing crossing.

Table 3-28 Concept 3B - (CR 352/CR 440 Bridge) Construction and Maintenance Estimate

Construction Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
TREE REMOVAL & CLEARING/GRUBBING		LS	-	$8,550
REMOVAL/RECLAIM (3" ASPHALT PAVEMENT)	368	SY	$3	$1,104
EMBANKMENT (DENS CONT TYP C)	123	CY	$12	$1,476
FLEXIBLE BASE (14" COMP. DEPTH)	154	TON	$60	$9,240
HOT MIX ASPHALTIC PAVEMENT, TYPE B (2" - 6" COMPACTED DEPTH)	33	TON	$100	$3,300
CONCRETE STRUCTURE (APPROACH SLABS)	42	CY	$500	$21,000
CONCRETE STRUCTURE (ABUTMENTS & WINGWALLS)	36	CY	$950	$34,200
CONCRETE STRUCTURE (BRIDGE DECKS)	205	CY	$1,400	$287,000
PRESTRESSED CONCRETE I-GIRDER (Tx28)	1200	LF	$125	$150,000
CONCRETE STRUCTURE (BRIDGE CAPS)	33	CY	$1,100	$36,300
CONCRETE STRUCTURE (BRIDGE COLUMNS & PIERS)	59	CY	$1,000	$59,000
CL C CONC (FOOTING)	32	CY	$850	$27,200
PRESTR CONC PIL (18 IN SQ)	1260	LF	$95	$119,700
RIP-RAP (CONC) (CL B) (RR8 & RR9)	28	CY	$400	$11,200
RAIL (TY SSTR)	680	LF	$50	$34,000
MTL BEAM GD FEN TRANS (THRIE-BEAM)	4	EA	$1,700	$6,800
MTL W-BEAM GD FENCE (TIM POST)	100	LF	$20	$2,000
GUARDRAIL END TREATMENT (INSTALL)	4	EA	$2,400	$9,600
SMALL ROADSIDE SIGN ASSEMBLY & BARRICADES	1	LS	$20,000	$20,000
FERTILIZER	1.50	AC	$800	$1,200
BROADCREST SEED (PERM)	1.50	AC	$500	$750
WATERING	131	MG	$11	$1,441
TRAFFIC CONTROL		LS	-	$5,750
			Construction Total	$850,811
Fringe Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
RIGHT-OF-WAY ACQUISITION	2.25	AC	$18,500	$41,625
ENVIRONMENTAL PERMITTING		LS	-	$50,000
MOBILIZATION		LS	10%	$85,081
ENGINEERING		LS	15%	$127,622
SURVEYING (5% OF ENGINEERING)		LS	5%	$6,381
			Fringe Total	$310,709
Continuation Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ANNUAL MAINTENANCE COST		LS	-	-
			Continuation Total, 50-Year Project Life (Present Value)	-
			Project Total (Construction + Fringe + Continuation)	$1,161,520
			20% Contingency on Conceptual Estimates	$232,304
			PROJECT GRAND TOTAL	**$1,393,824**

3.3.3. CR 347/CR 417 (Concept 3C)

The CR 347/CR 417 crossing of Cibolo Creek (Scull Crossing) is ranked as the second-most dangerous crossing in the Cibolo Creek watershed (see Table 3-19) when considering a combination of its DCF, average daily traffic and the distance to the nearest safe crossing. The crossing, as seen in Figure 3-13Figure 3-12, is located about 4.3 miles downstream of the confluence of Martinez Creek and Cibolo Creek. Cibolo Creek forms the boundary between Wilson County and Guadalupe County at this location. As seen in Figure 3-17, the existing CR 347/CR 417 bridge does not cross perpendicular to Cibolo Creek. The existing crossing is a 28.5 feet span bridge with a low chord elevation of 459.8 feet (see Figure 3-18). The existing condition 50% AEP event will overtop the bridge by more than 16 feet, which is more than 14 times the safe overtopping depth of the crossing. To improve safety a bridge is proposed for this crossing that will have a total length of 500 feet with 10-50 feet spans. The proposed bridge will have a low chord elevation of 500.0 feet which is approximately 1.45 feet above the 1% AEP event peak flood stage (498.55 feet).

3.3.3.1. Flood Risk

This section discusses the Baseline and Post-Project flood risks associated with CR 347/CR 417.

3.3.3.1.1. Baseline Conditions

Under existing and future conditions, the CR 347/CR 417 crossing is overtopped and considered dangerous for all modeled storm events (50%, 10%, 4%, 2%, 1% and 0.2% AEP). As seen in Table 3-29, the 50% AEP event SDR value for the crossing is 14.0 and 16.6 for the existing and future conditions, respectively. The existing and future condition SDR values were used to calculate an existing and future condition DCF value of 13.57 and 15.39, respectively.



Figure 3-17 CR 347/CR 417 Location

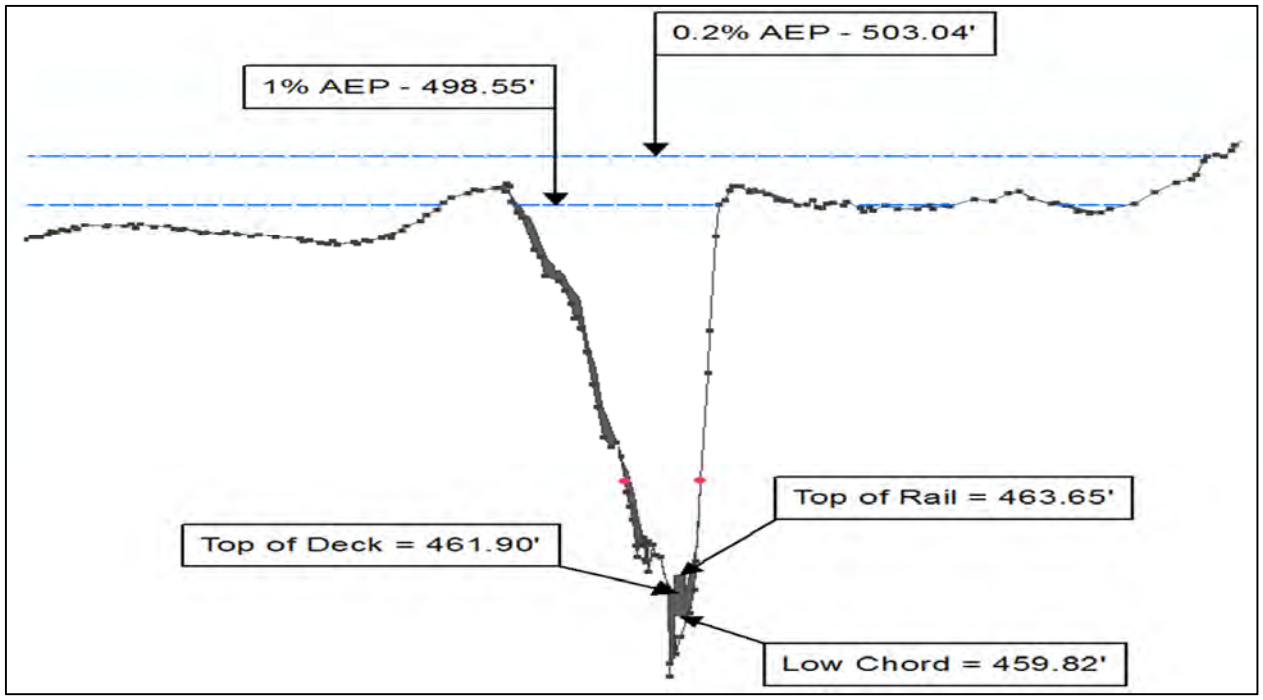


Figure 3-18 Existing Cross Section of CR 347/CR 417

Table 3-29 Concept 3C - CR 347/CR 417 Baseline Flood Risk Summary

	Baseline Existing						Baseline Future					
Parameter	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**
Overflow Velocity (ft/s)	2.9	3.9	4.5	4.7	4.5	3.5	3.2	4.1	4.7	4.6	4.3	3.4
Overflow Depth (ft)	16.4	26.0	31.7	34.5	36.7	41.1	19.3	28.5	34.0	35.9	37.7	42.2
Status	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger
SDR	14.0	22.7	28.3	31.0	32.6	35.6	16.6	25.1	30.5	32.1	33.3	36.5

3.3.3.1.2. Proposed Conditions

To reduce the length of the proposed CR 347/CR 417 bridge, the alignment of crossing was revised to minimize the proposed bridge length. The proposed bridge has a total span of 500 feet and a low chord elevation of 500 feet, which is approximately 1.45 feet above the Baseline Existing 1% AEP peak flood stage of 498.55 feet. The proposed bridge has a top deck elevation of 503.0 feet, which is 41.1 feet higher than the existing crossing. A more detailed layout showing the bridge schematic and rerouting of CR 347 can be found within Appendix A.

As shown in Table 3-30, the proposed bridge significantly increases safety of the crossing compared to the existing condition. The proposed CR 347/CR 417 bridge is safe for the 50%, 10%, 4%, 2% and 1% AEP events for the existing and future condition. The proposed bridge is, however, considered dangerous for the 0.2% AEP event under the existing and future condition. The existing and future condition DCF value for the crossing is 0.02. The decrease in DCF values for this concept was used to calculate watershed-wide DCF values that were applied to the Concept 3C scoring discussed in Section 4.1.2.

Table 3-30 Concept 3C - CR 347/CR 417 Post-Project Flood Risk Summary

	Concept 3C Existing						Concept 3C Future					
Parameter	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**
Overflow Velocity (ft/s)	0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	3.4
Overflow Depth (ft)	0.0	0.0	0.0	0.0	0.0	6.1	0.0	0.0	0.0	0.0	0.0	7.2
Status	Safe	Safe	Safe	Safe	Safe	Danger	Safe	Safe	Safe	Safe	Safe	Danger
SDR	0.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	6.2

3.3.3.2. Water Quality

There are no foreseeable water quality benefits associated with this concept.

3.3.3.3. Cost Estimate

As seen in Table 3-31, construction of the CR 347/CR 417 bridge over Cibolo Creek is estimated to cost $2,498,909. The proposed bridge was assumed to have no additional maintenance cost beyond that of the existing crossing.

Table 3-31 Concept 3C - (CR 347/CR 417 Bridge) Construction and Maintenance Estimate

Construction Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
TREE REMOVAL & CLEARING/GRUBBING		LS	-	$10,300
REMOVAL/RECLAIM (3" ASPHALT PAVEMENT)	448	SY	$3	$1,344
EMBANKMENT (DENS CONT TYP C)	70	CY	$12	$840
FLEXIBLE BASE (14" COMP. DEPTH)	52	TON	$60	$3,120
HOT MIX ASPHALTIC PAVEMENT, TYPE B (2" - 6" COMPACTED DEPTH)	11	TON	$100	$1,100
RETAINING WALL (SPREAD FOOTING)	475	SF	$50	$23,750
RETAINING WALL (CAST-IN-PLACE)	700	SF	$65	$45,500
CONCRETE STRUCTURE (APPROACH SLABS)	42	CY	$500	$21,000
CONCRETE STRUCTURE (ABUTMENTS & WINGWALLS)	36	CY	$950	$34,200
CONCRETE STRUCTURE (BRIDGE DECKS)	342	CY	$1,400	$478,800
PRESTRESSED CONCRETE I-GIRDER (Tx28)	2000	LF	$125	$250,000
CONCRETE STRUCTURE (BRIDGE CAPS)	98	CY	$1,100	$107,800
CONCRETE STRUCTURE (BRIDGE COLUMNS & PIERS)	174	CY	$1,000	$174,000
CL C CONC (FOOTING)	96	CY	$850	$81,600
PRESTR CONC PIL (18 IN SQ)	2700	LF	$95	$256,500
RIP-RAP (CONC) (CL B) (RR8 & RR9)	15	CY	$400	$6,000
RAIL (TY SSTR)	1080	LF	$50	$54,000
MTL BEAM GD FEN TRANS (THRIE-BEAM)	4	EA	$1,700	$6,800
MTL W-BEAM GD FENCE (TIM POST)	100	LF	$20	$2,000
GUARDRAIL END TREATMENT (INSTALL)	4	EA	$2,400	$9,600
SMALL ROADSIDE SIGN ASSEMBLY & BARRICADES	1	LS	$20,000	$20,000
FERTILIZER	0.60	AC	$800	$480
BROADCREST SEED (PERM)	0.60	AC	$500	$300
WATERING	53	MG	$11	$583
TRAFFIC CONTROL		LS	-	$5,750
			Construction Total	$1,595,367
Fringe Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
RIGHT-OF-WAY ACQUISITION	1.5	AC	$17,500	$26,250
ENVIRONMENTAL PERMITTING		LS	-	$50,000
MOBILIZATION		LS	10%	$159,537
ENGINEERING		LS	15%	$239,305
SURVEYING (5% OF ENGINEERING)		LS	5%	$11,965
			Fringe Total	$487,057
Continuation Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ANNUAL MAINTENANCE COST		LS	-	-
			Continuation Total, 50-Year Project Life (Present Value)	-
			Project Total (Construction + Fringe + Continuation)	$2,082,424
			20% Contingency on Conceptual Estimates	$416,485
			PROJECT GRAND TOTAL	**$2,498,909**

3.3.4. FM 537 (Concept 3D)

The FM 537 crossing of Cibolo Creek is ranked as the third-most dangerous crossing in the Cibolo Creek watershed (see Table 3-19). As seen in Figure 3-13, the FM 537 crossing is in Wilson County, about 5 miles southwest of Stockdale. As seen in Figure 3-19, the roadway crosses Cibolo Creek almost perpendicular to the direction of flow. The existing crossing is comprised of a 100-feet long bridge with 4 spans and is supported by 3-12-inch diameter piers (see Figure 3-20). The bridge has a minimum low chord elevation of 334.4 feet. Under the existing condition the 50% AEP event will produce peak flood stages that overtop the existing crossing by more than 7 times the safe overtopping depth. To increase safety the bridge is proposed to be replaced by a 750-feet long bridge with 15-50 feet spans. The proposed bridge will have a low chord elevation of 367.0 feet which is 0.53 feet above the 1% AEP event peak flood stage (366.47 feet).

3.3.4.1. Flood Risk

This section discusses the Baseline and Post-Project flood risks associated with FM 537.

3.3.4.1.1. Baseline Conditions

Under existing and future conditions, the crossing is overtopped and considered dangerous for all modeled storm events (50%, 10%, 4%, 2%, 1% and 0.2% AEP). The 50% AEP event SDR value for the crossing is 7.1 and 9.3 for the existing and future conditions, respectively (see Table 3-32). The existing and future condition SDR values were used to calculate an existing and future condition DCF value of 7.19 and 8.80, respectively.



Figure 3-19 FM 537 Existing Crossing

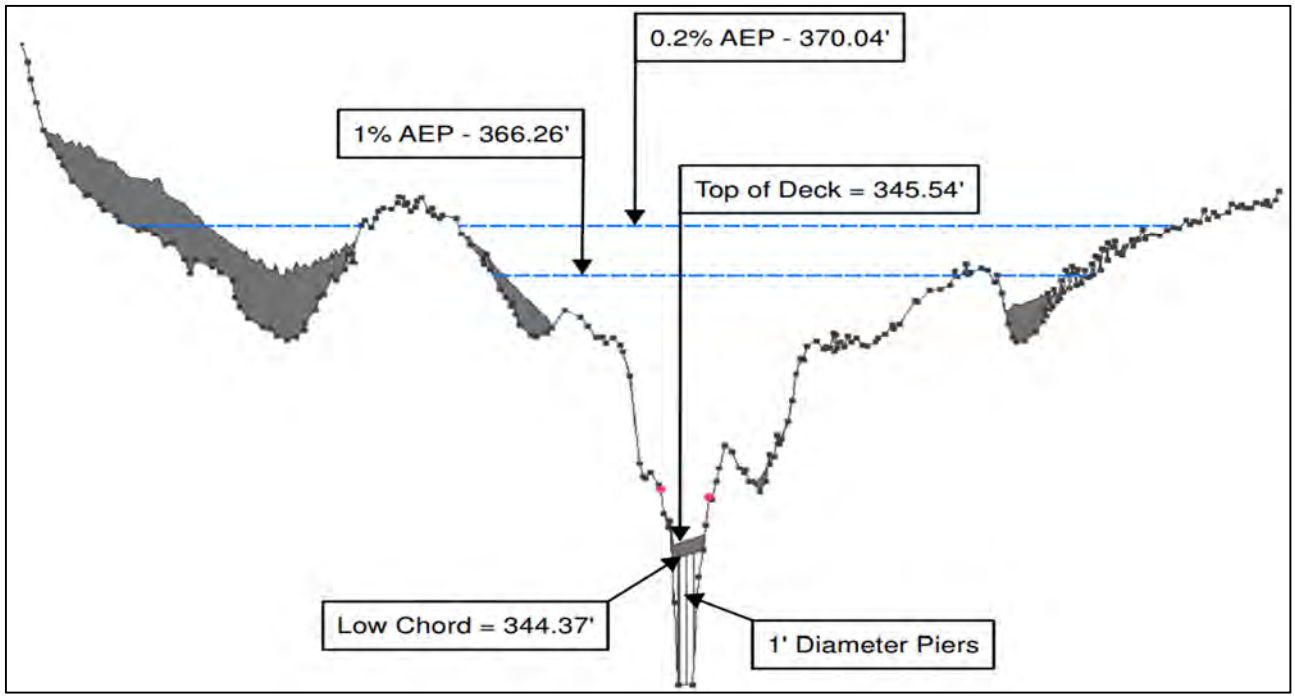


Figure 3-20 Existing Cross Section of FM 537

Table 3-32 Concept 3D - CR 537 Baseline Flood Risk Summary

	Baseline Existing						Baseline Future					
Parameter	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**
Overflow Velocity (ft/s)	3.5	4.5	5.0	4.9	4.8	4.4	3.9	5.0	4.9	4.8	4.5	4.5
Overflow Depth (ft)	8.2	14.0	17.2	19.0	20.8	24.6	10.6	16.2	19.2	20.8	22.1	25.4
Status	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger	Danger
SDR	7.1	12.5	15.6	17.2	18.7	21.8	9.3	14.7	17.4	18.7	19.7	22.7

3.3.4.1.2. Proposed Conditions

The proposed bridge has a total span of 750 feet and a low chord elevation of 367 feet, which is approximately 0.74 feet above the Baseline Existing 1% AEP peak flood stage of 498.55 feet. The proposed bridge has a top deck elevation of 370.0 feet, which is 24.5 feet higher than the existing crossing. A more detailed layout showing the bridge schematic of FM 537 can be found within Appendix A.

As shown in Table 3-33, the proposed bridge significantly increases safety of the crossing compared to the existing condition. The proposed FM 537 bridge is safe for the 50%, 10%, 4%, 2% and 1% AEP events for

the existing condition. For the future condition the proposed bridge is safe for the 50%, 10%, 4% and 2% AEP events. For the future condition 1% AEP event the proposed bridge is overtopped by 0.6 feet, but is not considered dangerous. The proposed bridge is, however, considered dangerous for the 0.2% AEP event under the existing and future condition. The existing and future condition DCF values for the crossing is 0.02. The decrease in DCF values for this concept was used to calculate watershed-wide DCF values that were applied to the Concept 3D scoring discussed in Section 4.1.2.

Table 3-33 Concept 3D - CR 537 Post-Project Flood Risk Summary

	Concept 3D Existing						Concept 3D Future					
Parameter	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**	**50% AEP**	**10% AEP**	**4% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**
Overflow Velocity (ft/s)	0.0	0.0	0.0	0.0	0.0	4.1	0.0	0.0	0.0	0.0	5.5	4.2
Overflow Depth (ft)	0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.6	4.4
Status	Safe	Safe	Safe	Safe	Safe	Danger	Safe	Safe	Safe	Safe	Caution	Danger
SDR	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.6	3.9

3.3.4.2. Water Quality

There are no foreseeable water quality benefits associated with this concept.

3.3.4.3. Cost Estimate

As seen in Table 3-34, construction of the FM 537 bridge over Cibolo Creek is estimated to cost $3,970,548. The proposed bridge was assumed to have no additional maintenance cost beyond that of the existing crossing.

Table 3-34 Concept 3D - (FM 537 Bridge) Construction and Maintenance Estimate

Construction Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
REMOVAL/RECLAIM (3" ASPHALT PAVEMENT)	6534	SY	$3	$19,602
EXCAVATION	17	CY	$20	$340
EMBANKMENT (DENS CONT TYP C)	13840	CY	$12	$166,080
FLEXIBLE BASE (14" COMP. DEPTH)	3388	TON	$60	$203,280
HOT MIX ASPHALTIC PAVEMENT, TYPE B (2" - 6" COMPACTED DEPTH)	726	TON	$100	$72,600
CONCRETE STRUCTURE (APPROACH SLABS)	42	CY	$500	$21,000
CONCRETE STRUCTURE (ABUTMENTS & WINGWALLS)	36	CY	$950	$34,200
CONCRETE STRUCTURE (BRIDGE DECKS)	512	CY	$1,400	$716,800
PRESTRESSED CONCRETE I-GIRDER (Tx28)	3000	LF	$125	$375,000
CONCRETE STRUCTURE (BRIDGE CAPS)	153	CY	$1,100	$168,300
CONCRETE STRUCTURE (BRIDGE COLUMNS & PIERS)	179	CY	$1,000	$179,000
CL C CONC (FOOTING)	150	CY	$850	$127,500
PRESTR CONC PIL (18 IN SQ)	3900	LF	$95	$370,500
RIP-RAP (CONC) (CL B) (RR8 & RR9)	40	CY	$400	$16,000
RAIL (TY SSTR)	1580	LF	$50	$79,000
MTL BEAM GD FEN TRANS (THRIE-BEAM)	4	EA	$1,700	$6,800
MTL W-BEAM GD FENCE (TIM POST)	100	LF	$20	$2,000
GUARDRAIL END TREATMENT (INSTALL)	4	EA	$2,400	$9,600
SMALL ROADSIDE SIGN ASSEMBLY & BARRICADES	1	LS	$20,000	$20,000
FERTILIZER	3	AC	$800	$2,400
BROADCREST SEED (PERM)	3	AC	$500	$1,500
WATERING	250	MG	$11	$2,750
TRAFFIC CONTROL		LS	-	$23,250
			Construction Total	$2,617,502
Fringe Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ENVIRONMENTAL PERMITTING		LS	-	$50,000
MOBILIZATION		LS	10%	$261,750
PREPARING RIGHT-OF-WAY		LS	4%	$104,700
ENGINEERING		LS	10%	$261,750
SURVEYING (5% OF ENGINEERING)		LS	5%	$13,088
			Fringe Total	$691,288
Continuation Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ANNUAL MAINTENANCE COST		LS	-	-
			Continuation Total, 50-Year Project Life (Present Value)	-
			Project Total (Construction + Fringe + Continuation)	$3,308,790
			20% Contingency on Conceptual Estimates	$661,758
			PROJECT GRAND TOTAL	**$3,970,548**

3.4. LID Requirements for Future Development (Concept 4)

This concept evaluates the implementation of Low Impact Development (LID) requirements for all future development within the Cibolo Creek watershed. Under the existing condition the 853.6 square mile watershed is approximately 26.5% developed and under the future condition the watershed is assumed to be 72.8% developed. This increase in development equates to approximately 395 square miles (252,799 acres) of additional development over the next 50-years. Concept 4 assumes LID requirements are placed on the assumed 395 square miles of future development. Although this concept would have no immediate benefits to flood risk or water quality, as only future development is implemented following LID principles, there will a gradual improvement in water quality and flood risk as compared to the future development condition following traditional development principles.

3.4.1. Flood Risk

Traditional development increases impervious cover, which reduces the amount of stormwater infiltration and increases overall stormwater runoff volume. Traditional stormwater mitigation maintains pre-development peak outflow rates but doesn't necessarily maintain pre-development stormwater runoff volume. LID development criteria encourage development to implement stormwater BMPs that replicate the pre-development hydrologic process by mitigating both increased stormwater peak flow runoff rates and stormwater volume. Replication of pre-development stormwater runoff volume is achieved through the maintenance of pre-development stormwater infiltration rates. For instance, the LID manual for the San Antonio River Basin (San Antonio River Basin Low Impact Development Technical Guidance Manual, 2013) requires that LID BMPs treat the first 1.5 inches of rainfall. For the purpose of this analysis, treatment of the first 1.5 inches of rainfall is assumed to be equivalent to infiltrating the first 1.0 inch of stormwater runoff.

Capturing the first 1.0 inch of storm runoff from future LID development will likely have significant effects upon more frequent storm event flows. Concept 4 was simulated for the future condition to estimate its peak flow and flood stage reduction benefit potential.

3.4.1.1. Model Development

Atkins modified the Baseline Future condition hydrologic model to create the Concept 4 Future condition hydrologic model. The amount of future condition impervious cover, in excess of the existing condition impervious cover, was calculated for each HEC-HMS subbasin. As seen in Table 3-35, there is a total of 63.9 square miles of existing impervious cover in the watershed and an estimated 175.9 square miles of impervious cover under the future condition. The future condition will increase the watersheds impervious cover by approximately 112 square miles. The amount of runoff captured by stormwater BMPs was estimated for each subbasin by multiplying the increased impervious cover due to future development (assumed to be developed utilizing LID practices) by 1.0 inch. This calculation yields a runoff volume of 5,973 acre-feet that will be captured by BMPs from future LID development within the watershed.

Table 3-35 Existing and Future Condition Impervious Cover Summary

Total Watershed Area (square miles)	853.6
Existing Impervious Cover Area (square miles)	63.9
Future Impervious Cover Area (square miles)	175.9
Existing Watershed Impervious Percentage (%)	7.5%
Future Watershed Impervious Percentage (%)	20.6%

Initially, Atkins planned to add HEC-HMS diversions downstream of each subbasin with future LID design. The diversions would remove the first 1.0 inch of LID runoff from each subbasin's hydrograph. However, adding diversions to individual subbasins was laborious and caused HEC-HMS stability issues. Atkins instead added diversions at key locations throughout the watershed (see Figure 3-21 and Figure 3-22) to simulate the effects of LID development. The total area of future development, ignoring the area of future development accounted for in upstream diversions, was used to determine the diversion capacity (volume) of each diversion.

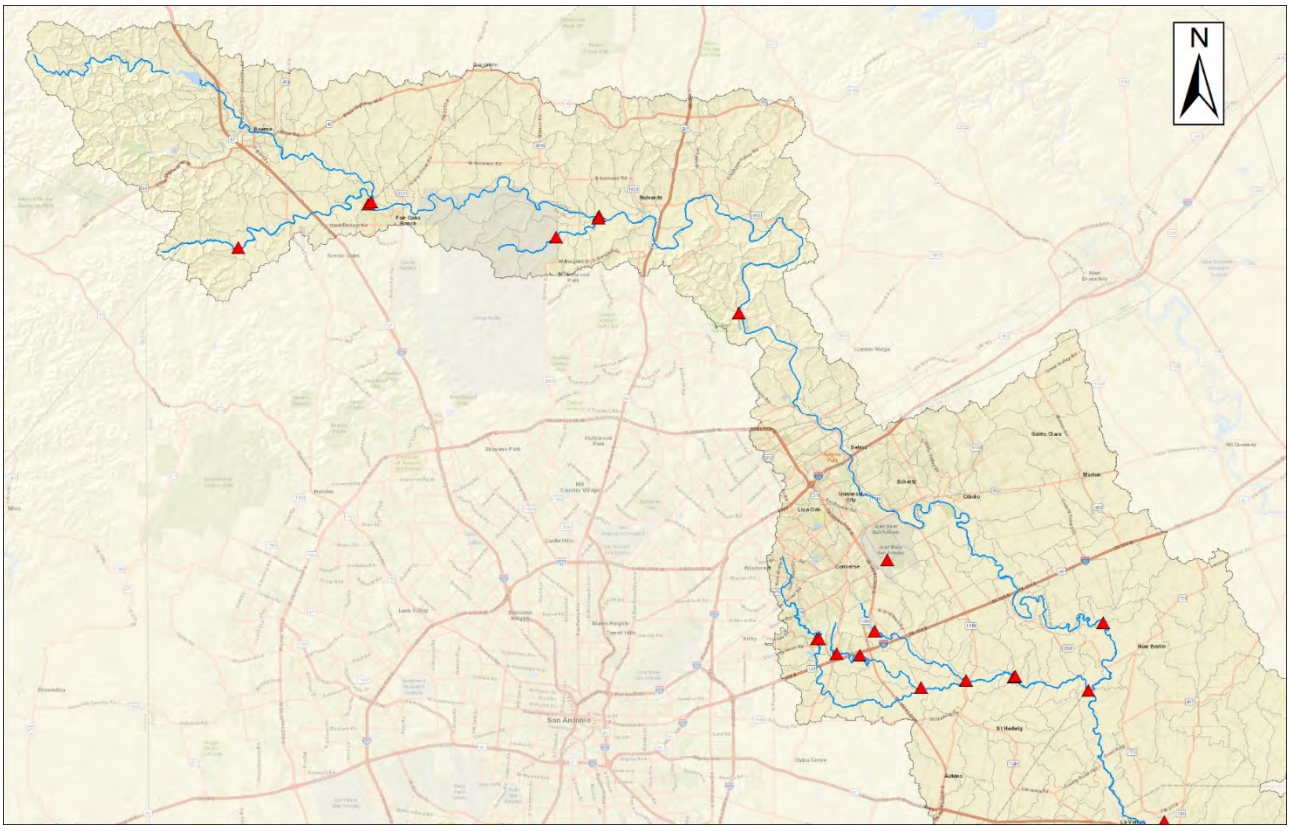


Figure 3-21 Diversion Locations Used to Simulate Effects of LID (Upper Cibolo)

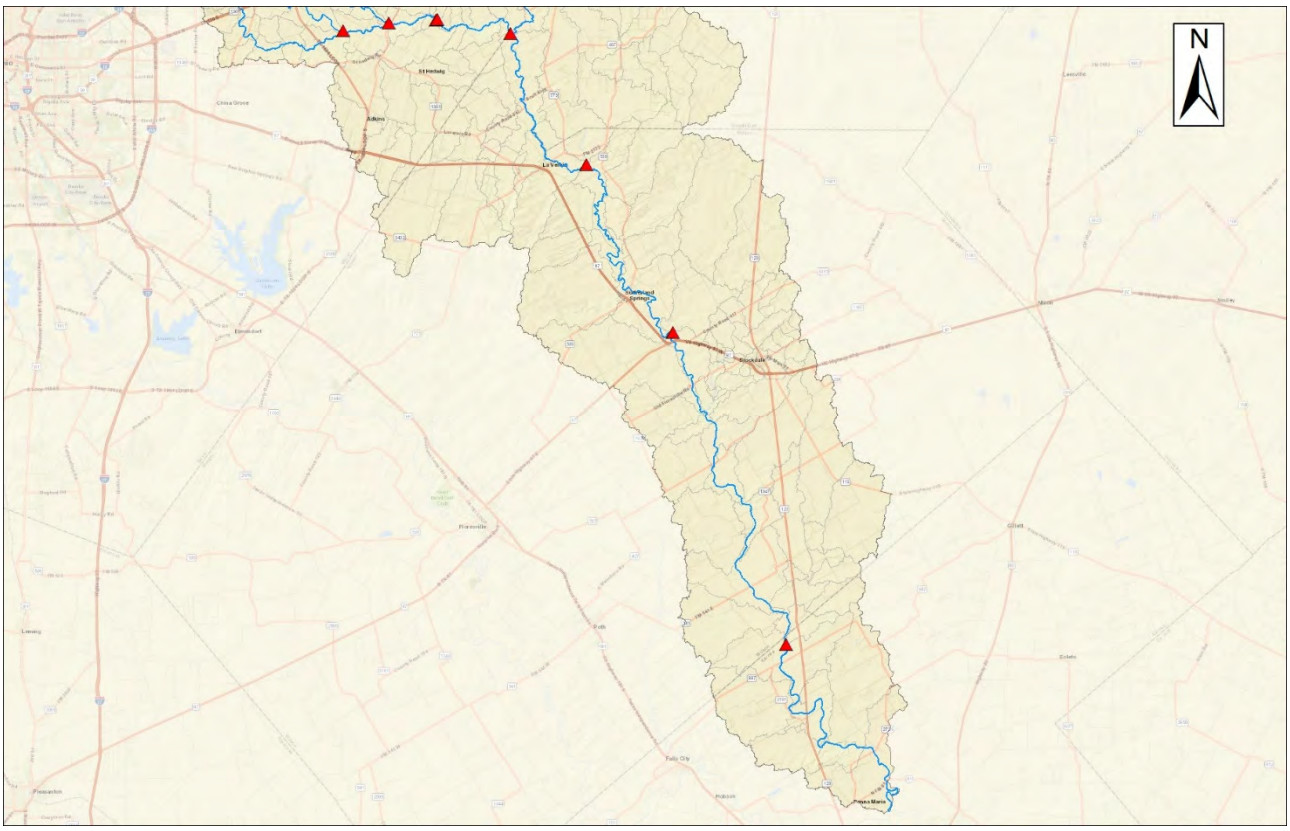


Figure 3-22 Diversion Locations Used to Simulate Effects of LID (Lower Cibolo)

The resulting future condition peak flows (50%, 10%, 4%, 2%, 1%, and 0.2% AEP event) were simulated with the hydraulic models for Cibolo Creek, Martinez Creek, Escondido Creek, Salitrillo Creek, Balcones Creek and Meusebach Creek, as the remaining studied streams showed no reduction in future condition peak flows due to the LID criteria.

3.4.1.2. Results

Table 3-36 compares the Baseline Future and Concept 4 Future condition 50%, 10% and 1% AEP event peak flows. The peak flows are compared at key locations along streams where the peak flow reductions are expected to result in lower damages (EAD and dangerous crossings). The table shows that peak flows within the watershed are lowered by the largest percentage for the 50% AEP event. Additionally, the peak flow reductions are generally greater in the downstream limits of the watershed. For instance, Concept 4 reduces the 50% AEP event peak flow on Cibolo Creek at its mouth by 33.3%, while the reduction on Cibolo Creek near Balcones Creek is 4.5% lower than the Baseline condition.

A complete comparison of Baseline Future condition and Concept 4 Future condition 50%, 10%, 4%, 2%, 1%, and 0.2% AEP event peak flows may be found in Appendix C.

Table 3-36 Concept 4 - Peak Flow Comparison (Future Condition)

		Baseline Future			*Concept 4 Future*			*% Difference*		
HEC-HMS Node	**Location**	**50% AEP Flow (ft^3/s)**	**10% AEP Flow (ft^3/s)**	**1% AEP Flow (ft^3/s)**	**50% AEP Flow (ft^3/s)**	**10% AEP Flow (ft^3/s)**	**1% AEP Flow (ft^3/s)**	**50% AEP Flow**	**10% AEP Flow**	**1% AEP Flow**
Cibolo Creek										
C4010231	U/S Balcones Creek	9,650	20,909	40,736	9,650	20,909	40,736	0.0%	0.0%	0.0%
C4010231A	D/S Balcones Creek	13,956	30,189	59,952	13,324	29,703	59,946	-4.5%	-1.6%	0.0%
C4010433	US 281	12,407	28,257	56,433	10,649	27,038	56,347	-14.2%	-4.3%	-0.2%
C4020213	FM 78	8,106	20,051	43,069	6,492	18,726	42,718	-19.9%	-6.6%	-0.8%
C4020235	IH-10	7,578	19,246	41,349	6,091	17,879	41,091	-19.6%	-7.1%	-0.6%
C4020621	U/S Martinez Creek	7,274	18,789	43,089	5,937	17,320	42,384	-18.4%	-7.8%	-1.6%
C4020621A	D/S Martinez Creek	12,710	25,845	50,744	8,967	22,988	49,647	-29.5%	-11.1%	-2.2%
C4030222A	D/S Elm Creek	13,357	28,840	56,978	9,759	26,095	55,440	-26.9%	-9.5%	-2.7%
C4030411	U/S of US 87	12,938	28,218	55,901	9,357	25,485	54,554	-27.7%	-9.7%	-2.4%
C4040503	SH 123	11,500	26,335	53,524	7,871	23,738	52,179	-31.6%	-9.9%	-2.5%
C4040508	Mouth Cibolo Creek	11,073	25,599	52,790	7,389	23,205	51,455	-33.3%	-9.4%	-2.5%
Balcones Creek										
C4010233A	D/S of Rundale Creek	6,680	11,275	18,951	6,680	11,275	18,951	0.0%	0.0%	0.0%
C4010241	IH-10	7,794	14,830	26,051	7,448	14,783	26,051	-4.4%	-0.3%	0.0%
C4010243	Mouth - Balcones Creek	6,240	12,634	23,751	5,773	12,429	23,750	-7.5%	-1.6%	0.0%
Escondido Creek										
C4020536	6,400' D/S of IH-10 EBFR	2,194	3,655	6,075	2,181	3,655	6,075	-0.6%	0.0%	0.0%
C4020537	Mouth - Escondido Creek	1,395	2,262	3,749	1,395	2,257	3,719	0.0%	-0.2%	-0.8%
Martinez Creek										
C4020540	Approx. 2,300' U/S of Dam No. 1	2,365	3,635	6,166	2,365	3,635	6,166	0.0%	0.0%	0.0%
C4020556	Approx.500' D/S of FM 1518	3,492	6,559	12,843	3,456	6,557	12,616	-1.0%	0.0%	-1.8%
C4020601A	Approx. 1,200' U/S of Miller Road	6,666	12,523	22,267	6,159	12,424	22,024	-7.6%	-0.8%	-1.1%
C4020614A	Approx. 5,200' U/S of Gable Road	9,675	19,063	31,910	8,829	18,731	31,716	-8.7%	-1.7%	-0.6%
C4020620	Mouth - Martinez Creek	9,002	17,726	32,018	8,266	17,107	31,911	-8.2%	-3.5%	-0.3%
Meusebach Creek										
C4010417	At Blanco Road	3,405	5,651	10,534	3,405	5,651	10,534	0.0%	0.0%	0.0%
C4010422	Mouth - Meusebach Creek	4,769	8,477	15,094	4,679	8,477	15,094	-1.9%	0.0%	0.0%
Salitrillo Creek										
C4020521		6,035	10,507	17,999	6,035	10,507	17,999	0.0%	0.0%	0.0%
C4020522	1000' D/S of Scenic Lake Road	736	1,136	6,663	722	1,114	6,062	-2.0%	-1.9%	-9.0%
C4020524	D/S of IH-10 EBFR	1,977	3,191	7,023	1,962	3,170	6,345	-0.8%	-0.7%	-9.6%
C4020534	Mouth – Salitrillo Creek	3,768	6,754	11,028	3,707	6,729	11,011	-1.6%	-0.4%	-0.1%

Atkins also compared the Baseline Existing and Concept 4 Future conditions results to determine if 1.0 inch of LID infiltration will offset the peak flow increases of future development. As shown in Table 3-37, Concept 4 Future condition peak flows are almost exclusively greater than Baseline Existing peak flows. The table shows that at the mouth of Cibolo Creek the Concept 4 10% AEP and 1% AEP event peak flows are 22.8% and 15.0% greater than those of the Baseline Existing condition. Baseline Future condition peak flows are 35.5% and 18.0% greater than the Baseline Existing condition peak flows at the same location (see Phase 2 Report). Similarly, at the mouth of Martinez Creek the Concept 4 10% AEP and 1% AEP event peak flows

are 12.7% and 5.8% greater, respectively, than those of the Baseline Existing condition. Baseline Future condition peak flows are 16.8% and 6.1% greater than the Baseline Existing condition peak flows at the same location (see Phase 2 Report) for the 10% and 1% AEP events. The results show that LID requirements result in infiltration of the first 1.0 inch of runoff from future development will only partially mitigate the peak flow increases resulting from the development.

Table 3-37 Peak Flow Comparison (Baseline Existing vs. Concept 4 Future)

		Baseline Existing			*Concept 4 Future*			*% Difference*		
HEC-HMS Node	**Location**	**50% AEP Flow (ft^3/s)**	**10% AEP Flow (ft^3/s)**	**1% AEP Flow (ft^3/s)**	**50% AEP Flow (ft^3/s)**	**10% AEP Flow (ft^3/s)**	**1% AEP Flow (ft^3/s)**	**50% AEP Flow**	**10% AEP Flow**	**1% AEP Flow**
Cibolo Creek										
C4010231	U/S Balcones Creek	8,024	19,271	39,638	9,650	20,909	40,736	**20.3%**	**8.5%**	**2.8%**
C4010231A	D/S Balcones Creek	11,515	27,479	57,929	13,324	29,703	59,946	**15.7%**	**8.1%**	**3.5%**
C4010433	US 281	9,539	24,816	53,644	10,649	27,038	56,347	**11.6%**	**9.0%**	**5.0%**
C4020213	FM 78	5,784	16,961	39,841	6,492	18,726	42,718	**12.2%**	**10.4%**	**7.2%**
C4020235	IH-10	5,480	16,148	39,073	6,091	17,879	41,091	**11.2%**	**10.7%**	**5.2%**
C4020621	U/S Martinez Creek	5,305	15,561	39,700	5,937	17,320	42,384	**11.9%**	**11.3%**	**6.8%**
C4020621A	D/S Martinez Creek	9,209	21,969	47,681	8,967	22,988	49,647	-2.6%	**4.6%**	**4.1%**
C4030222A	D/S Elm Creek	8,744	21,433	48,769	9,759	26,095	55,440	**11.6%**	**21.8%**	**13.7%**
C4030411	U/S of US 87	8,457	20,914	47,990	9,357	25,485	54,554	**10.6%**	**21.9%**	**13.7%**
C4040503	SH 123	6,991	19,352	45,475	7,871	23,738	52,179	**12.6%**	**22.7%**	**14.7%**
C4040508	Mouth Cibolo Creek	6,476	18,891	44,738	7,389	23,205	51,455	**14.1%**	**22.8%**	**15.0%**
Balcones Creek										
C4010233A	D/S of Rundale Creek	6,256	10,940	18,682	6,680	11,275	18,951	**6.8%**	**3.1%**	**1.4%**
C4010241	IH-10	6,892	14,040	25,499	7,448	14,783	26,051	**8.1%**	**5.3%**	**2.2%**
C4010243	Mouth - Balcones Creek	5,272	11,628	23,009	5,773	12,429	23,750	**9.5%**	**6.9%**	**3.2%**
Escondido Creek										
C4020536	6,400' D/S of IH-10 EBFR	2,070	3,566	6,002	2,181	3,655	6,075	**5.4%**	**2.5%**	**1.2%**
C4020537	Mouth - Escondido Creek	1,301	2,180	3,664	1,395	2,257	3,719	**7.2%**	**3.5%**	**1.5%**
Martinez Creek										
C4020540	Approx. 2,300' U/S of Dam No. 1	2,340	3,616	6,148	2,365	3,635	6,166	**1.1%**	**0.5%**	**0.3%**
C4020556	Approx.500' D/S of FM 1518	2,722	5,626	11,842	3,456	6,557	12,616	**27.0%**	**16.5%**	**6.5%**
C4020601A	Approx. 1,200' U/S of Miller Road	5,291	10,945	20,486	6,159	12,424	22,024	**16.4%**	**13.5%**	**7.5%**
C4020614A	Approx. 5,200' U/S of Gable Road	7,844	16,773	30,413	8,829	18,731	31,716	**12.6%**	**11.7%**	**4.3%**
C4020620	Mouth - Martinez Creek	7,291	15,174	30,164	8,266	17,107	31,911	**13.4%**	**12.7%**	**5.8%**
Meusebach Creek										
C4010417	At Blanco Road	3,326	5,552	10,357	3,405	5,651	10,534	**2.4%**	**1.8%**	**1.7%**
C4010422	Mouth - Meusebach Creek	4,635	8,345	14,892	4,679	8,477	15,094	**1.0%**	**1.6%**	**1.4%**
Salitrillo Creek										
C4020521		5,784	10,315	17,849	6,035	10,507	17,999	**4.3%**	**1.9%**	**0.8%**
C4020522	1000' D/S of Scenic Lake Road	693	1,096	5,910	722	1,114	6,062	**4.2%**	**1.7%**	**2.6%**
C4020524	D/S of IH-10 EBFR	1,787	3,026	6,112	1,962	3,170	6,345	**9.8%**	**4.7%**	**3.8%**
C4020534	Mouth – Salitrillo Creek	3,147	6,237	10,707	3,707	6,729	11,011	**17.8%**	**7.9%**	**2.8%**

The Concept 4 Future condition peak flow reductions were applied to the Baseline Future condition HEC-RAS steady flow distributions of the following streams, as these streams had hydraulic models and Baseline damages (flooded buildings or dangerous crossings):

- Cibolo Creek
- Balcones Creek
- Escondido Creek (Upper)
- Martinez Creek (Lower and Upper)
- Meusebach Creek
- Salitrillo Creek

Table 3-38 displays the Baseline Future and Concept 4 Future condition peak flood stages of the above streams at key locations. As with the peak flows in Table 3-36, the greatest peak flood stage reductions for the Concept 4 Future conditions is for more frequent storm events. For example, there is a 3.18', 1.09' and 0.17' reduction at the mouth of Cibolo Creek for the 50%, 10% and 1% AEP events, respectively. The Cibolo Creek peak flood stage reduction at Blanco Road is 0.42' and 0.20' for the 50% and 10% AEP events, respectively.

While Concept 4 reduces future condition peak flood stages on the tributaries of Cibolo Creek, the changes on tributaries are not as significant as on the main stem. At the mouth of Martinez Creek peak flood stages are reduced by 0.78', 0.40', and 0.03' for the 50%, 10% and 1% AEP events, respectively. At the mouth of Escondido Creek peak flood stages are reduced by 0.01' for the 1% AEP event. The 50% AEP event peak flood stage at the mouth of Meusebach Creek is reduced by 0.05'.

The Baseline Existing and Concept 4 Future condition peak flood stage results were compared to determine if 1.0 inch of LID infiltration will offset the peak flow increases of future development. As seen in Table 3-39, outside of several reductions due to bridge modeling anomalies, the Concept 4 Future condition peak flood stages are greater than the Baseline Existing condition peak flood stages. At the mouth of Cibolo Creek the Concept 4 Future peak flood stage is 2.28' and 0.65' higher than the Baseline Existing condition for the 10% AEP and 1% AEP events, respectively. At the mouth of Martinez Creek the Concept 4 Future peak flood stage is 1.27' and 0.44' higher than the Baseline Existing condition for the 10% AEP and 1% AEP events, respectively.

Table 3-38 Concept 4 - Peak Flood Stage Comparison (Future Condition)

HEC-RAS Station	Description	*Baseline Future (v4.1)*			*Concept 4 Future (v4.1)*			*Difference*		
		50% Stage (ft)	10% Stage (ft)	1% Stage (ft)	50% Stage (ft)	10% Stage (ft)	1% Stage (ft)	50% Stage (ft)	10% Stage (ft)	1% Stage (ft)
Cibolo Creek (Upper)										
413602.5	Battle Intense Road	1258.83	1263.35	1268.41	1258.56	1263.24	1268.43	-0.27	-0.11	0.00
346681.4	Blanco Road	1118.71	1122.55	1127.85	1118.29	1122.35	1127.87	-0.42	-0.20	0.00
314294	US 281	1048.09	1052.65	1058.47	1047.56	1052.32	1058.46	-0.53	-0.33	-0.01
261524.4	FM 1863	946.20	950.17	955.60	945.84	949.79	955.53	-0.36	-0.38	-0.07
179431	FM 2252	757.49	762.01	767.50	756.66	761.61	767.44	-0.83	-0.40	-0.06
171560.2	Lookout Road	742.57	747.57	753.76	741.37	747.15	753.70	-1.20	-0.42	-0.06
166745.8	IH-35 Mainlanes	733.61	739.35	746.32	732.51	738.85	746.24	-1.10	-0.50	-0.08
146732.9	FM 78	697.96	704.75	712.76	696.61	704.16	712.65	-1.35	-0.59	-0.11
80893.35	IH-10 Mainlanes	608.31	613.29	618.55	606.98	612.57	618.48	-1.33	-0.72	-0.07
73.82	@ Martinez Creek	503.17	511.48	520.89	501.14	510.44	520.73	-2.03	-1.04	-0.16
Cibolo Creek (Lower)										
301832	CR 352/CR 440	495.83	504.41	513.87	493.71	503.25	513.51	-2.12	-1.16	-0.36
267058	HWY 775	458.40	468.21	475.80	455.82	466.98	475.59	-2.58	-1.23	-0.21
202165	FM 539	404.33	411.45	417.81	402.02	410.60	417.60	-2.31	-0.85	-0.21
176421	HWY 87 US	383.82	390.92	397.36	381.38	390.10	397.17	-2.44	-0.82	-0.19
140167	FM 537	356.17	361.77	367.61	354.23	361.06	367.38	-1.94	-0.71	-0.23
101033	FM 541	322.35	328.50	333.75	320.26	327.74	333.57	-2.09	-0.76	-0.18
76686	FM 887	306.12	313.88	317.74	303.42	313.07	317.58	-2.70	-0.81	-0.16
56645	HWY 123	288.98	295.71	300.63	286.60	294.93	300.42	-2.38	-0.78	-0.21
13657	HWY81	258.15	264.13	267.68	255.87	263.46	267.53	-2.28	-0.67	-0.15
4215	Mouth	249.59	257.97	263.19	246.41	256.88	263.02	-3.18	-1.09	-0.17
Balcones Creek										
49787	Toutant Beauregard Road	1445.25	1446.59	1450.50	1445.28	1446.59	1450.50	0.00	0.00	0.00
31870	Boerne Stage Road	1362.14	1365.19	1368.22	1361.95	1365.18	1368.22	-0.19	-0.01	0.00
24033	IH-10 West Mainlanes	1335.14	1338.44	1344.83	1334.86	1338.40	1344.83	-0.28	-0.04	0.00
143	Mouth	1256.72	1258.91	1261.47	1256.53	1258.85	1261.47	-0.19	-0.06	0.00
Escondido Creek										
18387	LOOP 1604	611.45	612.05	620.96	611.41	611.84	620.90	-0.04	-0.21	-0.06
13009	Schuwirth Road	596.80	596.96	597.90	596.79	596.94	597.86	-0.01	-0.02	-0.04
3059	Mouth	568.12	568.99	569.87	568.12	568.99	569.86	0.00	0.00	-0.01
Martinez Creek										
115766	Putter Road	703.96	706.62	707.44	703.96	706.62	707.44	0.00	0.00	0.00
102874	Binz-Engleman Road	642.47	643.38	644.40	642.38	643.20	644.38	-0.09	-0.18	-0.02
96483	IH 10 Mainlanes	631.58	632.50	634.12	631.56	632.27	634.09	-0.02	-0.23	-0.03
63781	Loop 1604	577.47	578.76	580.57	577.47	578.75	580.53	0.00	-0.01	-0.04
42434	E. FM 1518	546.71	548.21	549.97	546.54	548.20	549.93	-0.17	-0.01	-0.04
16662	N. Gable Road	523.71	527.72	530.70	523.17	527.57	530.68	-0.54	-0.15	-0.02
2528	Mouth	509.18	516.18	522.48	508.40	515.78	522.45	-0.78	-0.40	-0.03
Meusebach Creek										
14503	Blanco Road	1136.11	1136.48	1138.89	1136.12	1136.48	1138.89	0.00	0.00	0.00
4396	Mouth	1102.00	1103.34	1104.95	1101.95	1103.34	1104.95	-0.05	0.00	0.00
Salitrillo Creek										
24431	IH-10 Mainlanes	587.05	588.07	590.83	587.03	588.06	590.33	-0.02	-0.01	-0.50
13811	Freudenburg Road	567.34	568.21	569.35	567.33	568.20	569.28	-0.01	-0.01	-0.07
3073	Mouth	549.09	550.21	551.42	549.08	550.20	551.41	-0.01	-0.01	-0.01

Table 3-39 Peak Flood Stage Comparison (Baseline Existing vs. Concept 4 Future)

HEC-RAS Station	Description	*Baseline Existing (v4.1)*			*Concept 4 Future (v4.1)*			*Difference*		
		50% Stage (ft)	10% Stage (ft)	1% Stage (ft)	50% Stage (ft)	10% Stage (ft)	1% Stage (ft)	50% Stage (ft)	10% Stage (ft)	1% Stage (ft)
Cibolo Creek (Upper)										
413602.5	Battle Intense Road	1257.93	1262.72	1268.15	1258.56	1263.24	1268.43	**0.63**	**0.52**	**0.28**
346681.4	Blanco Road	1117.92	1121.75	1127.44	1118.29	1122.35	1127.87	**0.37**	**0.60**	**0.43**
314294	US 281	1047.21	1051.71	1057.99	1047.56	1052.32	1058.46	**0.35**	**0.61**	**0.47**
261524.4	FM 1863	944.98	949.14	955.02	945.84	949.79	955.53	**0.86**	**0.65**	**0.51**
179431	FM 2252	756.19	761.04	766.86	756.66	761.61	767.44	**0.47**	**0.57**	**0.58**
171560.2	Lookout Road	740.81	746.71	753.00	741.37	747.15	753.70	**0.56**	**0.44**	**0.70**
166745.8	IH-35 Mainlanes	731.98	738.15	745.49	732.51	738.85	746.24	**0.53**	**0.70**	**0.75**
146732.9	FM 78	696.02	703.35	711.82	696.61	704.16	712.65	**0.59**	**0.81**	**0.83**
80893.35	IH-10 Mainlanes	606.36	611.57	617.92	606.98	612.57	618.48	**0.62**	**1.00**	**0.56**
73.82	@ Martinez Creek	500.53	509.48	520.03	501.14	510.44	520.73	**0.61**	**0.96**	**0.70**
Cibolo Creek (Lower)										
301832	CR 352/CR 440	493.19	502.32	512.96	493.71	503.25	513.51	**0.52**	**0.93**	**0.55**
267058	HWY 775	454.76	464.31	474.73	455.82	466.98	475.59	**1.06**	**2.67**	**0.86**
202165	FM 539	401.27	408.71	416.57	402.02	410.60	417.60	**0.75**	**1.89**	**1.03**
176421	HWY 87 US	380.69	388.24	395.96	381.38	390.10	397.17	**0.69**	**1.86**	**1.21**
140167	FM 537	353.71	359.54	366.32	354.23	361.06	367.38	**0.52**	**1.52**	**1.06**
101033	FM 541	319.69	326.04	332.76	320.26	327.74	333.57	**0.57**	**1.70**	**0.81**
76686	FM 887	302.61	310.77	316.92	303.42	313.07	317.58	**0.81**	**2.30**	**0.66**
56645	HWY 123	285.85	293.08	299.50	286.60	294.93	300.42	**0.75**	**1.85**	**0.92**
13657	HWY81	255.17	261.91	266.72	255.87	263.46	267.53	**0.70**	**1.55**	**0.81**
4215	Mouth	245.47	254.60	262.37	246.41	256.88	263.02	**0.94**	**2.28**	**0.65**
Balcones Creek										
49787	Toutant Beauregard Road	1445.15	1446.53	1449.51	1445.28	1446.59	1450.50	**0.13**	**0.06**	**0.99**
31870	Boerne Stage Road	1361.66	1364.85	1368.10	1361.95	1365.18	1368.22	**0.29**	**0.33**	**0.12**
24033	IH-10 West Mainlanes	1334.47	1338.05	1344.76	1334.86	1338.40	1344.83	**0.39**	**0.35**	**0.07**
143	Mouth	1256.32	1258.61	1261.34	1256.53	1258.85	1261.47	**0.21**	**0.24**	**0.13**
Escondido Creek										
18387	LOOP 1604	611.38	611.81	620.81	611.41	611.84	620.90	**0.03**	**0.03**	**0.09**
13009	Schuwirth Road	596.78	596.93	597.83	596.79	596.94	597.86	**0.01**	**0.01**	**0.03**
3059	Mouth	568.03	568.92	569.83	568.12	568.99	569.86	**0.09**	**0.07**	**0.03**
Martinez Creek										
115766	Putter Road	703.91	706.61	707.44	703.96	706.62	707.44	**0.05**	**0.01**	0.00
102874	Binz-Engleman Road	642.36	643.31	644.32	642.38	643.20	644.38	**0.02**	-0.11	**0.06**
96483	IH 10 Mainlanes	631.50	632.35	633.98	631.56	632.27	634.09	**0.06**	-0.08	**0.11**
63781	Loop 1604	577.15	578.49	580.38	577.47	578.75	580.53	**0.32**	**0.26**	**0.15**
42434	E. FM 1518	546.26	547.84	549.70	546.54	548.20	549.93	**0.28**	**0.36**	**0.23**
16662	N. Gable Road	522.39	527.01	530.37	523.17	527.57	530.68	**0.78**	**0.56**	**0.31**
2528	Mouth	507.31	514.51	522.01	508.40	515.78	522.45	**1.09**	**1.27**	**0.44**
Meusebach Creek										
14503	Blanco Road	1136.09	1136.51	1138.74	1136.12	1136.48	1138.89	**0.03**	-0.03	**0.15**
4396	Mouth	1101.93	1103.30	1104.90	1101.95	1103.34	1104.95	**0.02**	**0.04**	**0.05**
Salitrillo Creek										
24431	IH-10 Mainlanes	586.85	588.00	590.16	587.03	588.06	590.33	**0.18**	**0.06**	**0.17**
13811	Freudenburg Road	567.13	568.12	569.24	567.33	568.20	569.28	**0.20**	**0.08**	**0.04**
3073	Mouth	548.84	550.02	551.35	549.08	550.20	551.41	**0.24**	**0.18**	**0.06**

3.4.1.3. Damage Assessment

This section discusses the change to flood risk damages resulting from Concept 4 in terms of flooded buildings, estimated annual damages to buildings, and dangerous crossings.

3.4.1.3.1. Flooded Buildings

The number of buildings that are potentially flooded under the Baseline Future and Concept 4 Future condition for Cibolo Creek, Balcones Creek, Upper Escondido Creek, Martinez Creek, Meusebach Creek and Salitrillo Creek were quantified. As seen in Table 3-40 the majority of the reduced building flooding from Concept 4 occurs on the main channel of Cibolo Creek and Lower Martinez Creek. Concept 4 removes a total of 1, 3, 4, 6 and 4 buildings in the Cibolo Creek watershed from 10%, 4%, 2%, 1% and 0.2% AEP event floodplains, respectively.

Table 3-40 Concept 4 - Flooded Building Counts (Future Condition)

Condition	Number of Flooded Buildings (by Event)					
	50% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.2% AEP
Baseline Future						
Cibolo Creek (Upper)	0	3	13	31	63	283
Cibolo Creek (Lower)	0	0	9	24	38	116
Balcones Creek	0	4	4	7	8	11
Escondido Creek (Upper)	1	2	2	2	4	8
Martinez Creek (Upper)	1	4	11	18	28	97
Martinez Creek (Lower)	2	6	12	15	18	21
Meusebach Creek	0	0	0	0	0	1
Salitrillo Creek	0	0	1	1	1	3
Concept 4 Future						
Cibolo Creek (Upper)	0	2	13	30	62	282
Cibolo Creek (Lower)	0	0	6	21	34	113
Balcones Creek	0	4	4	7	8	11
Escondido Creek (Upper)	1	2	2	2	4	8
Martinez Creek (Upper)	1	4	11	18	28	97
Martinez Creek (Lower)	2	6	12	15	17	21
Meusebach Creek	0	0	0	0	0	1
Salitrillo Creek	0	0	1	1	1	3
Concept 4 Reduction in Flooded Structures						
Cibolo Creek (Upper)	0	-1	0	-1	-1	-1
Cibolo Creek (Lower)	0	0	-3	-3	-4	-3
Balcones Creek	0	0	0	0	0	0
Escondido Creek (Upper)	0	0	0	0	0	0
Martinez Creek (Upper)	0	0	0	0	0	0
Martinez Creek (Lower)	0	0	0	0	-1	0
Meusebach Creek	0	0	0	0	0	0
Salitrillo Creek	0	0	0	0	0	0
Total (Watershed) =	***0***	***-1***	***-3***	***-4***	***-6***	***-4***

The Concept 4 Future condition flood damages were estimated and compared against the Baseline Future condition. As seen in Table 3-41, there are reduced EAD values on Cibolo Creek, Balcones Creek, Lower Martinez Creek and Salitrillo Creek. The total reduction in EAD for the watershed is $11,225.

Table 3-41 Concept 4 - EAD Summary (Future Condition)

Condition	EAD ($)
Baseline Future	
Cibolo Creek (Upper)	$189,206
Cibolo Creek (Lower)	$49,330
Balcones Creek	$51,452
Escondido Creek (Upper)	$91,558
Martinez Creek (Upper)	$41,572
Martinez Creek (Lower)	$136,389
Meusebach Creek	$8
Salitrillo Creek	$1,848
Concept 4 Future	
Cibolo Creek (Upper)	$184,618
Cibolo Creek (Lower)	$44,174
Balcones Creek	$51,137
Escondido Creek (Upper)	$91,558
Martinez Creek (Upper)	$41,572
Martinez Creek (Lower)	$135,243
Meusebach Creek	$8
Salitrillo Creek	$1,828
Concept 4 Reduction	
Cibolo Creek (Upper)	($4,588)
Cibolo Creek (Lower)	($5,156)
Balcones Creek	($315)
Escondido Creek (Upper)	$0
Martinez Creek (Upper)	$0
Martinez Creek (Lower)	($1,146)
Meusebach Creek	$0
Salitrillo Creek	($20)
Total (Watershed) =	**($11,225)**

3.4.2. Water Quality

An HSPF simulation for the future condition was developed for this concept. This section discusses the development of the HSPF model, as well as the HSPF simulation results.

3.4.2.1. Model Development

The Concept 4 water quality model utilized the Baseline Future condition HSPF model assembled during Phase 2. For this concept, the anticipated pollutant load reductions from LID requirements would be applied to all future development, irrespective of the type of land use expected. LID BMPs were assumed to be sized sufficiently to remove 80% of the increased pollutant load due to new development. To meet this requirement a BMP load reduction was applied to each HSPF basin based upon the load reduction necessary to achieve the 80% removal of the pollutant load increase times the amount of future land use increase in each basin.

Using "brush" to represent undeveloped land use and "high density residential" to represent the developed land use, a typical BMP rate of 25% was applied to all future land uses. As seen in Table 3-42, Atkins determined the difference in loading between the undeveloped and developed land use for ammonia nitrogen, nitrate nitrogen and ortho-phosphorus. An 80% reduction in the load difference was calculated for each pollutant to replicate the treatment that might result from LID BMPs installed for new development. The table shows that reductions in the developed land use loading rates between 24.0% and 28.3% approximate an 80% reduction in the increased load resulting from the increased development. HSPF basins in Cibolo Creek watershed had new (future) development ranging from zero to 100 percent which corresponded to between zero and 25% load reduction. This reduction was applied in the model using the HSPF's BMPRAC module and setting each subbasin's removal factor to its corresponding load reduction for both flow and water quality constituents.

Table 3-42 Example Pollutant Load Reduction Rates

Pollutant	Undeveloped Land Use (Brush) Loading (lb/ac/day)	Developed Land Use (High Density Residential) Loading (lb/ac/day)	Increase in Load Due to Development (lb/ac/day)	Load Reduction for 80% Treatment (lb/ac/day)	Percent Reduction in Developed Land Use Load to Achieve 80% Treatment (lb/ac/day)
Ammonia Nitrogen	0.0050	0.008	0.003	0.00221	28.3%
Nitrate Nitrogen	0.0336	0.052	0.018	0.01472	28.3%
Ortho-Phosphorus	0.0105	0.015	0.005	0.00360	24.0%

It is of note that the 25% load reduction rate applied to Concept 4 is consistent with the BMP reduction rate derived for Concept 5 (see Section 3.5), in which the BMP tool, using EPA's System for Urban Stormwater Treatment and Analysis INtegration (SUSTAIN) engine, was used to simulate various retrofit alternatives and 25% was arrived at as an efficient and achievable BMP target.

3.4.2.2. Results

This concept assumed that all new development, beyond that included in the existing development condition, will be subjected to LID requirements. Existing development will not be subjected to LID retrofitting requirements. Therefore, only the future development condition shows changes to water quality results. Table 3-43 Table 3-33shows the future condition percent change (compared to the Baseline future condition) in pollutant loads at key locations along Cibolo Creek as a result of Concept 4. The table shows large reductions in all simulated constituents. At the mouth of Cibolo Creek nitrate nitrogen, ammonia nitrogen, organic phosphorus, ortho-phosphorus, chlorophyll-a, and bacteria loads are reduced by 46.2%, 39.8%, 27.1%, 31.3%, 28.3%, and 46.4%, respectively. Dissolved oxygen is negatively impacted by this concept, as its load is reduced by 29.8% at the mouth of Cibolo Creek. Outflow volume from Cibolo Creek is reduced by 28.1% due to the increased infiltration of the future LID development.

Table 3-43 Concept 4 - Load Change on Cibolo Creek (Future Condition)

HSPF Reach ID	Location	*Concept 4 Future - % Change in Load from Baseline Future*							
		Dissolved Oxygen	Nitrate Nitrogen (NO_3N)	Ammonia Nitrogen (NH_3N)	Organic P	Ortho P	Chl-a	Bacteria (E. Coli)	Runoff Volume
Cibolo Creek Mainstem									
39	*I-10 (near Boerne)*	-4.5%	-8.0%	-13.7%	-6.8%	-2.5%	-10.1%	-14.4%	-5.5%
61	*Boerne*	-4.1%	-7.0%	-15.0%	-5.3%	-2.4%	-7.9%	-13.6%	-4.7%
91	*Fair Oaks Ranch*	-12.0%	-17.4%	-30.2%	-12.2%	-7.0%	-10.5%	-26.6%	-11.3%
110	*West of Bulverde*	-21.1%	-26.0%	-46.4%	-20.3%	-11.9%	-16.9%	-41.2%	-20.4%
129	*Hwy 281*	-22.7%	-26.4%	-39.1%	-21.2%	-12.2%	-20.8%	-38.9%	-21.2%
140	*FM 1863*	-23.8%	-26.1%	-37.9%	-21.8%	-12.3%	-29.6%	-37.4%	-21.6%
159	*I-35 (near Selma)*	-24.7%	-26.2%	-30.6%	-22.6%	-12.7%	-36.4%	-40.0%	-22.5%
165	*Schertz*	-28.1%	-32.9%	-13.9%	-28.1%	-15.4%	-38.5%	-46.3%	-24.5%
185	*I-10 (near New Berlin)*	-27.6%	-17.1%	-65.6%	-24.6%	-12.1%	-18.8%	-49.7%	-26.4%
273	*U/S of Martinez Creek*	-25.1%	-11.5%	-26.9%	-16.3%	-10.1%	-10.8%	-40.3%	-24.0%
392	*D/S of Martinez Creek*	-27.2%	-16.3%	-55.0%	-17.7%	-17.3%	-10.7%	-50.9%	-26.7%
281	*CR 347/CR 417*	-27.4%	-16.5%	-54.3%	-15.4%	-18.1%	-9.2%	-52.8%	-26.9%
299	*La Vernia*	-26.7%	-16.6%	-48.6%	-15.0%	-17.2%	-8.6%	-45.8%	-26.0%
323	*Sutherland Springs*	-28.3%	-31.6%	-28.1%	-13.1%	-26.5%	-11.0%	-47.6%	-27.3%
327	*Hwy 87*	-29.1%	-36.7%	-35.4%	-16.0%	-28.5%	-15.7%	-49.9%	-27.9%
354	*FM 537*	-28.6%	-38.2%	-31.5%	-17.3%	-28.6%	-17.8%	-45.1%	-27.3%
360	*FM 541*	-29.4%	-43.1%	-41.8%	-21.1%	-30.8%	-22.3%	-48.4%	-27.9%
372	*FM 887*	-29.2%	-43.6%	-42.5%	-23.5%	-30.6%	-24.7%	-45.3%	-27.7%
375	*Hwy 123*	-29.4%	-44.6%	-37.6%	-24.7%	-30.7%	-26.0%	-45.6%	-27.7%
379	*U/S of San Antonio River*	-29.8%	-46.2%	-39.8%	-27.1%	-31.3%	-28.3%	-46.4%	-28.1%

Table 3-44 shows the effect that Concept 4 will have on mitigating potential constituent load increases from future development. In general, Concept 4 will maintain or reduce Baseline Existing condition ammonia nitrogen, ortho-phosphorus, and chlorophyll-a loads along most reaches of Cibolo Creek. In addition, Concept 4 will result in dissolved oxygen loads that exceed Baseline Existing conditions. However, Baseline Existing condition organic phosphorus and bacteria loads will be increased in the future, even if LID requirements are put in place.

Table 3-44 Load Change on Cibolo Creek (Concept 4 Future vs. Baseline Existing)

HSPF Reach ID	Location	*Concept 4 Future - % Change in Load from Baseline Existing*							
		Dissolved Oxygen	Nitrate Nitrogen (NO_3N)	Ammonia Nitrogen (NH_3N)	Organic P	Ortho P	Chl-a	Bacteria (E. Coli)	Runoff Volume
Cibolo Creek Mainstem									
39	*I-10 (near Boerne)*	**9.1%**	**5.0%**	**18.6%**	**9.6%**	**2.3%**	**1.8%**	**84.6%**	**7.8%**
61	*Boerne*	**7.1%**	**4.2%**	**8.2%**	**6.5%**	**0.3%**	**0.2%**	**44.2%**	**7.3%**
91	*Fair Oaks Ranch*	**14.4%**	**6.2%**	**1.9%**	**12.1%**	**2.9%**	-5.3%	**119.6%**	**14.4%**
110	*West of Bulverde*	**18.4%**	**1.2%**	-11.6%	**12.1%**	-2.7%	-9.0%	**155.6%**	**23.0%**
129	*Hwy 281*	**22.1%**	**4.6%**	**2.0%**	**15.9%**	-6.1%	-8.5%	**149.8%**	**27.9%**
140	*FM 1863*	**22.8%**	**7.7%**	**7.4%**	**17.6%**	-6.5%	-7.8%	**131.5%**	**30.4%**
159	*I-35 (near Selma)*	**24.0%**	**9.2%**	**40.3%**	**20.6%**	-6.3%	-10.5%	**121.6%**	**30.2%**
165	*Schertz*	**17.3%**	-0.4%	-7.3%	**10.0%**	-10.3%	-9.2%	**81.1%**	**21.2%**
185	*I-10 (near New Berlin)*	**16.0%**	-0.3%	-24.7%	**3.2%**	-9.7%	-8.6%	**75.3%**	**20.1%**
273	*U/S of Martinez Creek*	**25.5%**	**4.9%**	**19.0%**	**1.4%**	-11.2%	-6.2%	**101.6%**	**30.1%**
392	*D/S of Martinez Creek*	**20.6%**	**2.6%**	-32.2%	-0.2%	-26.1%	-5.6%	**62.8%**	**25.2%**
281	*CR 347/CR 417*	**19.9%**	**2.2%**	-34.1%	-0.8%	-26.8%	-4.8%	**56.2%**	**24.0%**
299	*La Vernia*	**23.2%**	**1.1%**	-23.5%	**0.2%**	-29.0%	-4.5%	**83.8%**	**27.5%**
323	*Sutherland Springs*	**16.6%**	-7.8%	-8.6%	**1.5%**	-38.2%	**2.2%**	**43.6%**	**18.1%**
327	*Hwy 87*	**15.6%**	-12.6%	-19.4%	**1.8%**	-40.9%	**3.0%**	**36.0%**	**16.5%**
354	*FM 537*	**16.0%**	-15.1%	-16.9%	**2.1%**	-41.4%	**3.5%**	**31.4%**	**16.8%**
360	*FM 541*	**12.7%**	-23.7%	-33.7%	**0.9%**	-44.5%	**3.0%**	**3.9%**	**13.3%**
372	*FM 887*	**10.3%**	-26.7%	-33.5%	-0.5%	-44.0%	**1.6%**	-2.2%	**11.0%**
375	*Hwy 123*	**9.5%**	-28.6%	-26.1%	-1.3%	-44.4%	**0.6%**	-4.2%	**10.3%**
379	*U/S of San Antonio River*	**7.6%**	-31.9%	-28.0%	-3.4%	-45.1%	-1.8%	-8.0%	**8.5%**

Table 3-45 shows the average reach load by constituent within the watershed for the Baseline Future and Concept 4 Future conditions. The average loads shown in this table are used to calculate the water quality benefits (see Section 4.1) of Concept 4.

Table 3-45 Concept 4 - Average Reach Loads (Future Conditions)

Condition	Dissolved Oxygen (lbs)	Nitrate Nitrogen (lbs)	Ammonia Nitrogen (lbs)	Organic P (lbs)	Ortho P (lbs)	Chl-a (lbs)	Bacteria (E. Coli) ($\#10^6$)	Runoff Volume (ac-ft)
Baseline Future	501,194	64,370	1,619	4,293	19,886	162,893	1,159,646,196	20,729
Concept 4 Future	372,594	46,509	1,137	3,475	15,506	133,116	707,711,759	15,699
Change	***-128,601***	***-17,861***	***-482***	***-818***	***-4,380***	***-29,777***	***-451,934,437***	***-5,031***

As discussed above, Concept 4 significantly reduced constituent loading throughout the Cibolo Creek watershed. The Concept 4 load reductions were also evaluated for their effect upon constituent concentrations, as seen in Table 3-46. The concentrations shown in the table are the average reach

concentrations for the entire Cibolo Creek watershed and show reductions in dissolved oxygen, nitrate nitrogen, ammonia nitrogen, ortho-phosphorus and bacteria. Average concentration for organic phosphorus and chlorophyll-a are increased. Although the average loads for organic phosphorus and chlorophyll-a decreased, the average concentrations of these two constituents increased. This is likely due to the reduced storm runoff volume resulting from the future LID BMPs.

Table 3-46 Concept 4 - Average Reach Constituent Concentrations (Future Conditions)

Condition	Dissolved Oxygen (mg/L)	Nitrate Nitrogen (NO3N) (mg/L)	Ammonia Nitrogen (NH3N) (mg/L)	Organic P (mg/L)	Ortho P (mg/L)	Chl-a (ug/L)	Bacteria (E. Coli) (#/dL)
Baseline Future	8.27	1.33	0.11	0.0366	0.3682	0.63	9886
Concept 4 Future	8.14	1.25	0.10	0.0368	0.3678	0.66	8996
Change	***-0.13***	***-0.08***	***-0.01***	***0.0001***	***-0.0004***	***0.03***	***-890***

The changes in constituent concentrations had an impact upon the number of reaches exceeding SARA's constituent screening levels shown in Table 3-47. Reaches with concentrations above the screening levels for nitrate nitrogen, ammonia nitrogen, organic phosphorus, ortho-phosphorus, chlorophyll-a and bacteria are considered "damaged". Reaches with dissolved oxygen concentrations below the screening level are considered "damaged". As seen in Table 3-48, there are a total of 428 reaches in the HSPF model. For the future condition the LID requirements concept (Concept 4) increased the number of damaged reaches by 1 and 18 for dissolved oxygen and ortho-phosphorus, respectively. The number of damaged reaches was reduced by 17 and 6 for nitrate nitrogen and ammonia nitrogen, respectively. The number of damaged reaches for the remaining constituents remained unchanged from the Baseline condition.

Table 3-47 Water Quality Constituent Screening Levels

Water Quality Constituent	Screening Level	Unit
Dissolved Oxygen	3.00	mg/L
Nitrate Nitrogen (NO3N)	1.95	mg/L
Ammonia Nitrogen (NH3N)	0.33	mg/L
Organic P	0.32	mg/L
Ortho P	0.37	mg/L
Chl-a	14.1	ug/L
Bacteria (E. Coli)	126	#/dL

Table 3-48 Concept 4 - Damaged Reach Counts

	Number of Damaged Reaches by Constituent						
Condition	**Dissolved Oxygen**	**Nitrate Nitrogen (NO3N)**	**Ammonia Nitrogen (NH3N)**	**Organic P**	**Ortho P**	**Chl-a**	**Bacteria (E. Coli)**
Baseline Future	0	40	6	0	114	0	428
Concept 4 Future	1	23	0	0	132	0	428
Change	***1***	***-17***	***-6***	***0***	***18***	***0***	***0***

The increase in the number of dissolved oxygen and ortho-phosphorus damage reaches may appear counterintuitive given that LID BMPs are expected to improve water quality. However, the reason for the increases have several causes. First, damage reach assessment is based upon flow weighted volume calculations, whereby if there is no flow, a pollutant concentration is not calculated. Second, the calculation is based upon the reach outlet flow, which is the combination of inflows to the reach, runoff from the reach, groundwater, interflow, and external sources (WWTP, springs, etc.). When the surface loading is reduced in flow and increased in quality, the flow weighted concentration is more heavily weighted towards the other constituents. In the case of dissolved oxygen, if the flow distribution shifts away from surface water to the more anoxic ground water, the flow weighted dissolved oxygen will drop. In a similar way Phosphorus, unlike nitrogen, having a component attached to the sediment load, would likely see that concentration has a stronger weight in the flow weighed concentration calculation if surface discharge were reduced. While the total load would be reduced for the reach, there is the potential that the flow weighed concentration would increase.

3.4.3. Cost Estimate

The San Antonio River Basin Low Impact Development Technical Guidance Manual (Dorman, et al., 2013) points out that development following LID techniques can often have lower initial construction costs and lower annual maintenance costs than development following traditional stormwater management techniques. However, data showing a direct comparison between the cost to construct and maintain development following LID and traditional stormwater techniques is limited, especially data specific to the San Antonio region. For this reason, this concept assumes that the cost to construct future development (public and private) using LID techniques will have no increased cost of construction or maintenance over development using traditional stormwater management techniques. Atkins assumed that any increased cost associated with this concept will be carried by various cities and counties and will be associated with maintaining LID criteria and reviewing LID projects. It was assumed that the equivalent of one additional part-time engineer can handle the increased workload. The cost of this engineer includes a $90,000 salary and an additional $135,000 (1.5 x salary as a rule of thumb) to account for overhead and employee benefits (retirement, insurance, vacation, etc.). The assumed annual cost to support future LID is $112,500 per year (half of $225,000). Assuming a project life of 50 years, an interest rate of 2%, and a growth rate of 2%, the present value of the annual cost was calculated to be $5,514,706. With a 20% contingency added, the overall cost to support future LID is $6,617,647.

3.5. Infiltration BMP Retrofit (Concept 5)

Concept 5 simulates the effects of implementing LID strategies to existing development on a localized scale to achieve water quality benefits. The LID retrofit concept was applied to HSPF basin 167, which is located in Selma along Dietz Creek (see Figure 3-23). Basin 167 is generally composed of residential development (51%), meadows/woods/brush (25%), transportation (14%), industrial (1%), and agricultural (9%) land uses. The current residential development is characterized by a tightly packed gridded street layout draining through swales into the main conveyance reach of Dietz Creek, which is a dry stream bed during most parts of the year.

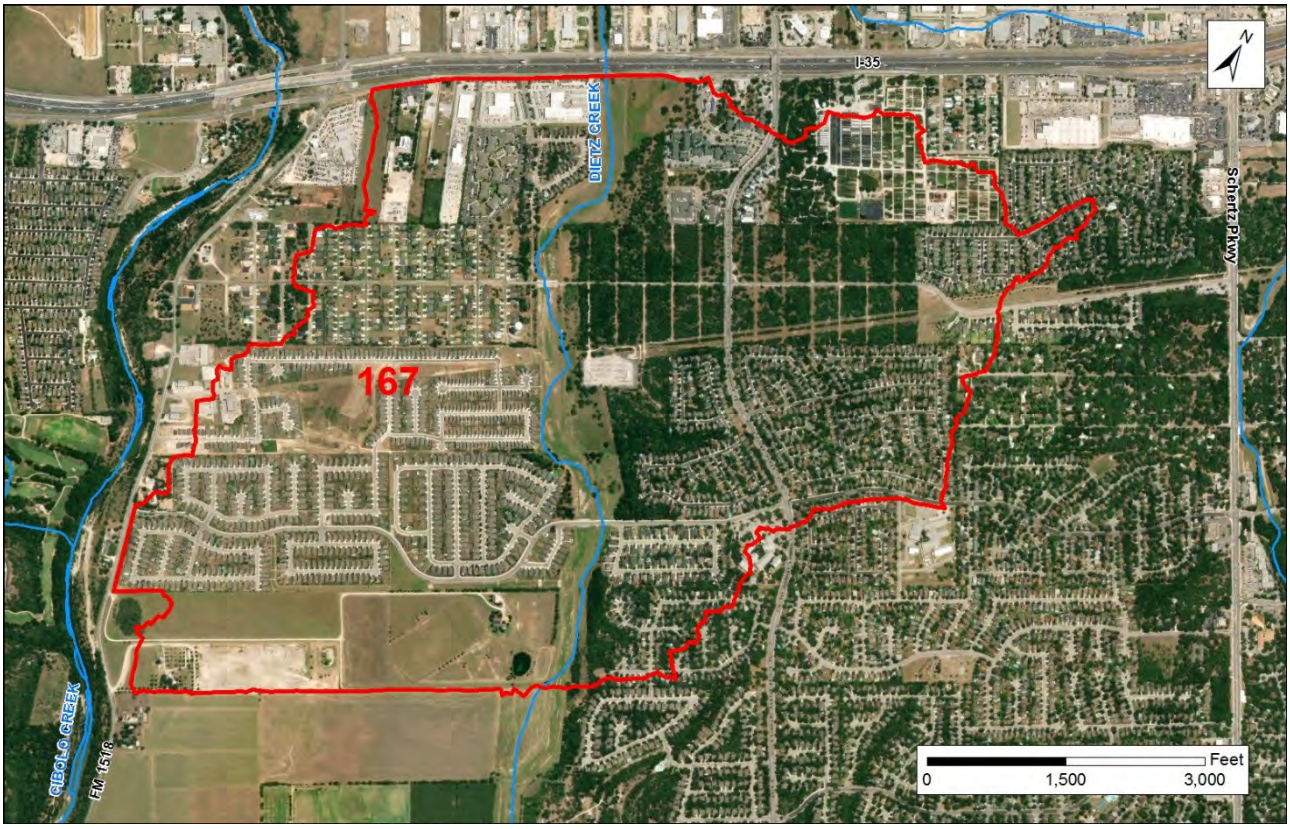


Figure 3-23 BMP Retrofit (Concept 5) Location

3.5.1. Flood Risk

Flood risk benefits for this concept are anticipated to be minimal. Therefore, a flood risk simulation was not performed for Concept 5.

3.5.2. Water Quality

An existing and future condition HSPF simulation was performed for this concept. This section discusses the modeling approach and water quality simulation results.

3.5.2.1. Model Development

The first step in the water quality modeling was to utilize SARA's Enhanced BMP Tool, with EPA's SUSTAIN engine to evaluate a range of BMP combinations on basin 167. The considered BMPs included bio-retention basins, vegetated swales, infiltration trenches, and catch basins/vortex (coarse materials separator). For the high density residential and transportation land use areas street sweeping was also considered. The BMP

tool calculated the approximate cost of implementing these BMPs and evaluated their effectiveness in terms of pollutant removal percentage simulating the BMPs in series as treatment trains as appropriate. The final out pout of the tool was a BMP cost versus pollutant removal plot as shown in Figure 3-24.

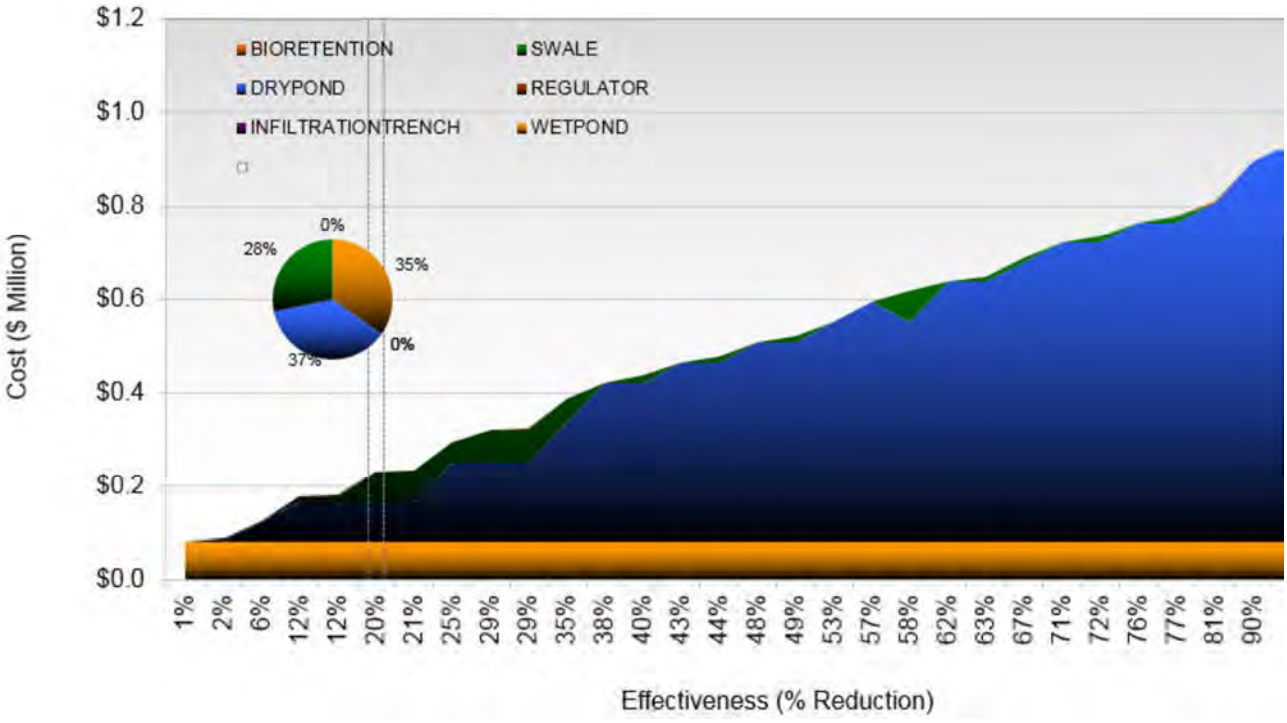


Figure 3-24 BMP Optimization Model

Based upon the BMP cost vs pollutant removal plot, there is a breakpoint near the 25% reduction level, whereby the cost momentarily flattens out prior to continuing on a steeper trajectory. It Is for this reason that a target effectiveness (percent pollution reduction) of 25% was chosen for the basin 167 BMP retrofit. After this target was set, the basin was reviewed to determine the feasibility of implementing the BMPs recommended by the BMP Tool. The BMP Tool was then run a final time to simulate a series of 13 dry ponds (see Figure 3-25) that service the residential development with the BMP reduction applied to both the load and flow volume. The total dry pond volume recommended was approximately 66 acre-feet. The reduced load and flow volume was then incorporated back into the Concept 5 Existing condition HSPF model in place of the Baseline load and flow volume for reach 167. The Concept 5 Existing model was the same as the Baseline Existing condition HSPF models, except the land uses in basin 167 reflected BMP reduction in loading and flow. No other HSPF reaches or basins were modified.

The Concept 5 Future condition for this concept was modeled by utilizing the same process described above for the existing condition, and assuming no LID was implemented for the new development. Therefore, the only difference between the existing and future conditions would be an increase in impervious area without additional treatment.

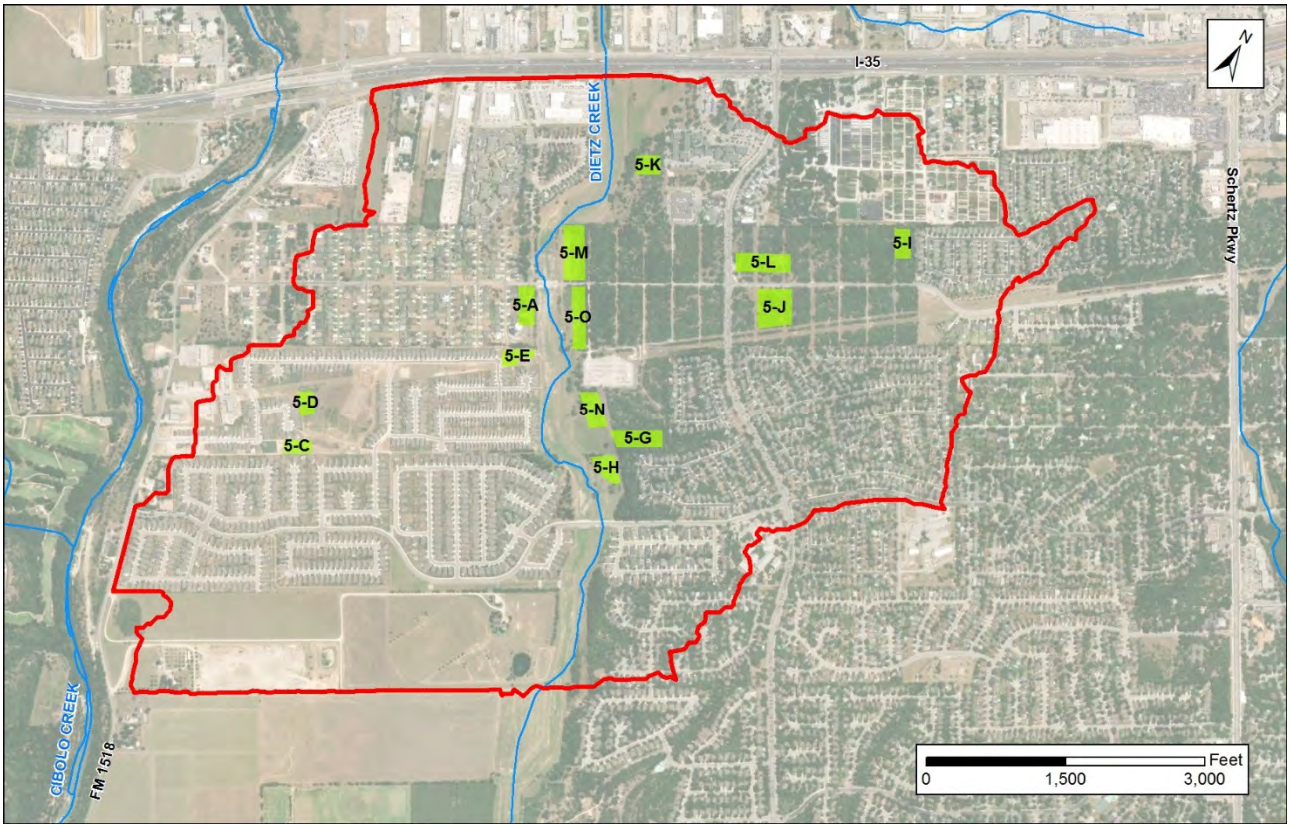


Figure 3-25 Concept 5 - Proposed Pond Locations

3.5.2.2. Results

As seen in Table 3-49, the BMP retrofit concept has slight reductions in the level of all modeled constituents. As expected, the reductions occur downstream of the confluence of Dietz Creek and Cibolo Creek. Under the existing condition the dissolved oxygen load is reduced by a maximum of 0.3%, nitrate nitrogen is reduced by a maximum of 0.2%, ammonia nitrogen is reduced by a maximum of 0.2%, organic phosphorus is reduced by a maximum of 0.4%, ortho-phosphorus is reduced by a maximum of 0.3%, chlorophyll-a is reduced by a maximum of 0.4% and bacteria is reduced by a maximum of 0.9%. The proposed BMP retrofit increases infiltration and, as a result, decreases runoff volume on Cibolo Creek by a maximum of 0.3%.

Table 3-49 Concept 5 - Load Change on Cibolo Creek (Existing Condition)

HSPF Reach ID	Location	*Concept 5 Existing - % Change in Load from Baseline Existing*							
		Dissolved Oxygen	Nitrate Nitrogen (NO_3N)	Ammonia Nitrogen (NH_3N)	Organic P	Ortho P	Chl-a	Bacteria (E. Coli)	Runoff Volume
Cibolo Creek Mainstem									
39	*I-10 (near Boerne)*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
61	*Boerne*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
91	*Fair Oaks Ranch*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
110	*West of Bulverde*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
129	*Hwy 281*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
140	*FM 1863*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
159	*I-35 (near Selma)*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
165	*Schertz*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
185	*I-10 (near New Berlin)*	-0.3%	-0.2%	-0.2%	-0.4%	-0.3%	-0.4%	-0.9%	-0.3%
273	*U/S of Martinez Creek*	-0.2%	0.0%	-0.1%	-0.3%	-0.1%	-0.4%	-0.3%	-0.2%
392	*D/S of Martinez Creek*	-0.1%	0.0%	-0.1%	-0.2%	-0.1%	-0.2%	-0.2%	-0.1%
281	*CR 347/CR 417*	-0.1%	0.0%	-0.1%	-0.2%	-0.1%	-0.2%	-0.2%	-0.1%
299	*La Vernia*	-0.1%	0.0%	-0.1%	-0.2%	-0.1%	-0.2%	-0.1%	-0.1%
323	*Sutherland Springs*	-0.1%	-0.1%	0.0%	0.0%	-0.1%	0.0%	-0.1%	-0.1%
327	*Hwy 87*	-0.1%	-0.1%	0.0%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%
354	*FM 537*	-0.1%	-0.1%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
360	*FM 541*	-0.1%	-0.1%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
372	*FM 887*	-0.1%	-0.1%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
375	*Hwy 123*	-0.1%	-0.1%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
379	*U/S of San Antonio River*	-0.1%	-0.1%	0.0%	-0.1%	-0.1%	-0.1%	0.0%	-0.1%

As seen in Table 3-50, Concept 5 has similar future condition benefits as under the existing condition. The primary difference is that Concept 5 increases chlorophyll-a levels near Martinez Creek under the future condition.

Table 3-50 Concept 5 - Load Change on Cibolo Creek (Future Condition)

HSPF Reach ID	Location	*Concept 5 Future - % Change in Load from Baseline Future*							
		Dissolved Oxygen	Nitrate Nitrogen (NO_3N)	Ammonia Nitrogen (NH_3N)	Organic P	Ortho P	Chl-a	Bacteria (E. Coli)	Runoff Volume
Cibolo Creek Mainstem									
39	*I-10 (near Boerne)*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
61	*Boerne*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
91	*Fair Oaks Ranch*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
110	*West of Bulverde*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
129	*Hwy 281*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
140	*FM 1863*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
159	*I-35 (near Selma)*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
165	*Schertz*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
185	*I-10 (near New Berlin)*	-0.3%	-0.4%	-0.9%	-0.2%	-0.1%	0.0%	-0.7%	-0.3%
273	*U/S of Martinez Creek*	-0.2%	-0.2%	-0.1%	0.0%	-0.1%	**0.1%**	-0.3%	-0.2%
392	*D/S of Martinez Creek*	-0.1%	-0.2%	0.0%	0.0%	-0.1%	0.0%	-0.2%	-0.1%
281	*CR 347/CR 417*	-0.1%	-0.2%	0.0%	0.0%	-0.1%	0.0%	-0.2%	-0.1%
299	*La Vernia*	-0.1%	-0.1%	0.0%	0.0%	0.0%	0.0%	-0.1%	-0.1%
323	*Sutherland Springs*	-0.1%	-0.2%	0.0%	0.0%	0.0%	0.0%	-0.1%	-0.1%
327	*Hwy 87*	-0.1%	-0.2%	0.0%	0.0%	0.0%	0.0%	-0.1%	-0.1%
354	*FM 537*	-0.1%	-0.2%	0.0%	0.0%	0.0%	0.0%	-0.1%	-0.1%
360	*FM 541*	-0.1%	-0.2%	0.0%	-0.1%	0.0%	-0.1%	-0.1%	-0.1%
372	*FM 887*	-0.1%	-0.2%	0.0%	-0.1%	0.0%	-0.1%	-0.1%	-0.1%
375	*Hwy 123*	-0.1%	-0.2%	0.0%	-0.1%	0.0%	-0.1%	-0.1%	-0.1%
379	*U/S of San Antonio River*	-0.1%	-0.2%	0.0%	-0.1%	0.0%	-0.1%	-0.1%	-0.1%

Table 3-51 shows the average reach load by constituent within the watershed for the Baseline and Concept 5 conditions. The average loads shown in this table are used to calculate the water quality benefits (see Section 4.1) of Concept 5.

Table 3-51 Concept 5 - Average Reach Loads

Condition	Dissolved Oxygen (lbs)	Nitrate Nitrogen (lbs)	Ammonia Nitrogen (lbs)	Organic P (lbs)	Ortho P (lbs)	Chl-a (lbs)	Bacteria (E. Coli) ($\#10^6$)	Runoff Volume (ac-ft)
Baseline Existing	320,200	48,992	1,077	3,414	22,614	132,429	419,535,137	13,222
Concept 5 Existing	319,907	48,946	1,076	3,411	22,596	132,316	418,958,363	13,210
Baseline Future	501,194	64,370	1,619	4,293	19,886	162,893	1,159,646,196	20,729
Concept 5 Future	500,760	64,255	1,616	4,290	19,880	162,833	1,158,403,952	20,711
Concept 5 Change (Existing)	***-293***	***-46***	***-1***	***-3***	***-18***	***-113***	***-576,775***	***-12***
Concept 5 Change (Future)	***-434***	***-114***	***-3***	***-2***	***-6***	***-59***	***-1,242,244***	***-18***

Average reach constituent concentrations are displayed in Table 3-52. Concept 5 reduces the average ortho-phosphorus concentration by 0.0004 mg/l under the existing condition and increases the average ortho-phosphorus concentration by 0.0001 mg/l under the future condition. Bacteria is reduced by 3 #/dl for both the existing and future condition.

Table 3-52 Concept 5 - Average Reach Constituent Concentrations

Condition	Dissolved Oxygen (mg/l)	Nitrate Nitrogen (mg/l)	Ammonia Nitrogen (mg/l)	Organic P (mg/l)	Ortho P (mg/l)	Chl-a (ug/l)	Bacteria (E. Coli) (#/dl)
Baseline Existing	8.42	1.55	0.11	0.0404	0.5819	0.77	6,151
Concept 5 Existing	8.42	1.55	0.11	0.0404	0.5815	0.77	6,148
Baseline Future	8.27	1.33	0.11	0.0366	0.3682	0.63	9,886
Concept 5 Future	8.27	1.33	0.11	0.0366	0.3683	0.63	9,883
Concept 5 Change (Existing)	***0.00***	***0.00***	***0.00***	***0.0000***	***-0.0004***	***0.00***	***-3***
Concept 5 Change (Future)	***0.00***	***0.00***	***0.00***	***0.0000***	***0.0001***	***0.00***	***-3***

Table 3-53 displays the number of damaged reaches by constituent for the Baseline and Concept 5 condition under both existing and future development. The table shows that Concept 5 only reduces the number of ortho-phosphorus reaches by two for the existing condition.

Table 3-53 Concept 5 - Damaged Reach Counts

Condition	Dissolved Oxygen	Nitrate Nitrogen	Ammonia Nitrogen	Organic P	Ortho P	Chl-a	Bacteria (E. Coli)
Baseline Existing	0	93	7	0	271	0	427
Concept 5 Existing	0	93	7	0	270	0	427
Baseline Future	0	40	6	0	114	0	428
Concept 5 Future	0	40	6	0	114	0	428
Concept 5 Change (Existing)	***0***	***0***	***0***	***0***	***-1***	***0***	***0***
Concept 5 Change (Future)	***0***	***0***	***0***	***0***	***0***	***0***	***0***

3.5.3. Cost Estimate

Although the HSPF model for Concept 5 did not require specific locations for the proposed dry detention facilities, for cost estimating purposes, locations were required. Atkins developed schematic-level layouts for 13 proposed dry detention ponds (A – O), as seen in Figure 3-25. The layouts considered factors such as available outfall depth and natural ground elevations so estimated detention volume and cut/fill estimates could be developed.

As seen in Table 3-54, construction cost and annual maintenance estimates were developed for each of the 13 detention facilities. The total construction cost for the 13 detention facilities is $6,772,516. Mowing was assumed to be done twice a year at $120/acre. Since the facilities all differed in size, an aggregate cost for mowing was determined and then evenly distributed to each facility. With the 13 facilities collectively equalling up to 24.18 acres in size, the annual cost for mowing each detention facility was calculated to be $446.40 ($450 for estimation purposes). Assuming a fixed cost of $400/day for quarterly inspections, an additional $1,600 was added to each facility. These factors bring a total of about $26,650 in annual maintenance fees ($2,050 per pond). Assuming a project life of 50 years, an interest rate of 2%, and a growth rate of 2%, the total present value of annual maintenance was calculated to be $1,306,373. Detailed cost estimates may be found in Appendix B.

Table 3-54 Concept 5 - Construction and Maintenance Estimates

Construction	
Pond A	$605,189
Pond C	$136,856
Pond D	$109,643
Pond E	$98,797
Pond G	$429,824
Pond H	$270,727
Pond I	$194,081
Pond J	$748,567
Pond K	$240,484
Pond L	$737,719
Pond M	$349,614
Pond N	$220,789
Pond O	$195,101
Construction Total =	$4,337,391
Annual Maintenance	
Pond A	$2,050
Pond C	$2,050
Pond D	$2,050
Pond E	$2,050
Pond G	$2,050
Pond H	$2,050
Pond I	$2,050
Pond J	$2,050
Pond K	$2,050
Pond L	$2,050
Pond M	$2,050
Pond N	$2,050
Pond O	$2,050
Annual Maintenance Total =	$26,650
Total PV of Annual Maint. =	$1,306,373
Project Total =	$5,643,764
20% Contingency =	$1,128,753
Project Grand Total =	**$6,772,516**

3.6. Regional Water Quality Pond (Concept 6)

This concept proposes the installation of two regional water quality ponds on Elm Creek and Dry Hollow Creek to improve water quality in the Cibolo Creek watershed. Specifically, the ponds are intended to capture excess nutrient loads from upstream agricultural areas. The ponds are envisioned as in-line wet ponds and will be constructed to take advantage of the existing topography to impound water at two localized areas. The ponds will result in minimal increases to upstream flood stages and, as a result, are not expected to provide significant flood reduction benefits due to increased floodplain storage capacity. The ponds will likely have a negative impact upon pulse flows.

The water quality ponds were sited using aerial photos and contours to locate vacant areas of frequent inundation, where the water impoundment could be located with no impacts to adjoining agricultural areas. Based on that analysis, two areas were identified along Dry Hollow Creek and Elm Creek, prior to their confluence with Cibolo Creek (Figure 3-26).



Figure 3-26 Concept 6 - Regional Water Quality Pond Locations

The impoundment for the Elm Creek water quality pond will be constructed with an earthen embankment. The top of the embankment will have an elevation of 450 feet, which is approximately 21 feet above the flowline of Elm Creek. A riser pipe structure will pass normal flows and will be set to produce a permanent pool depth of 10 feet at an elevation of 439 feet. Less frequent storm event flows will be conveyed by a 50 feet bottom width trapezoidal spillway. The bottom of the spillway will be set at an elevation of 440 feet. A section of the structure is displayed in Figure 3-27 and a more detailed layout may be found in Appendix A.

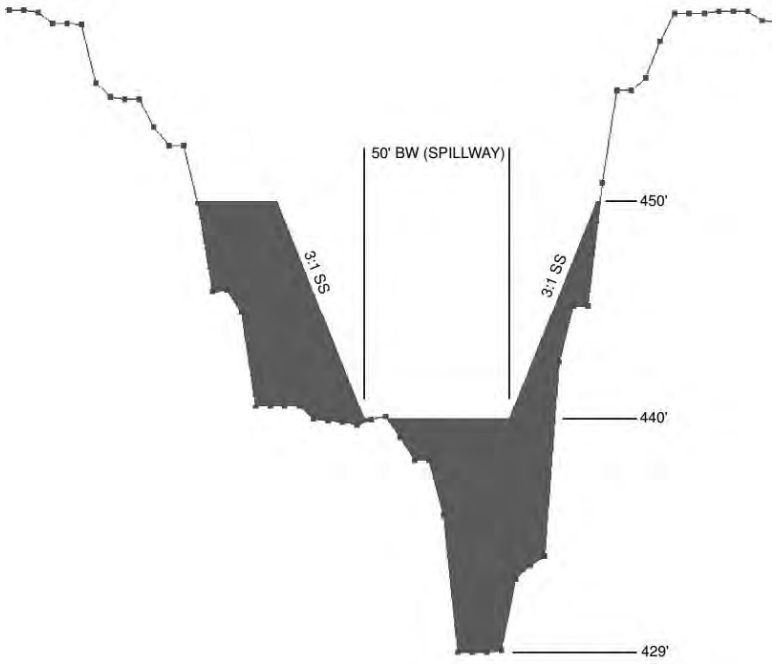


Figure 3-27 Elm Creek Water Quality Pond Outfall

The impoundment for the Dry Hollow Creek water quality pond will be constructed with an earthen embankment. The top of the embankment will have an elevation of 462 feet, which is approximately 18 feet above the flowline of Dry Hollow Creek. A riser pipe structure will pass normal flows and will be set to produce a permanent pool depth of 9 feet. Less frequent storm event flows will be conveyed by a 60 feet bottom width trapezoidal spillway. The bottom of the spillway will be set at an elevation of 454 feet. A section of the structure is displayed in Figure 3-28 and a more detailed layout may be found in Appendix A.

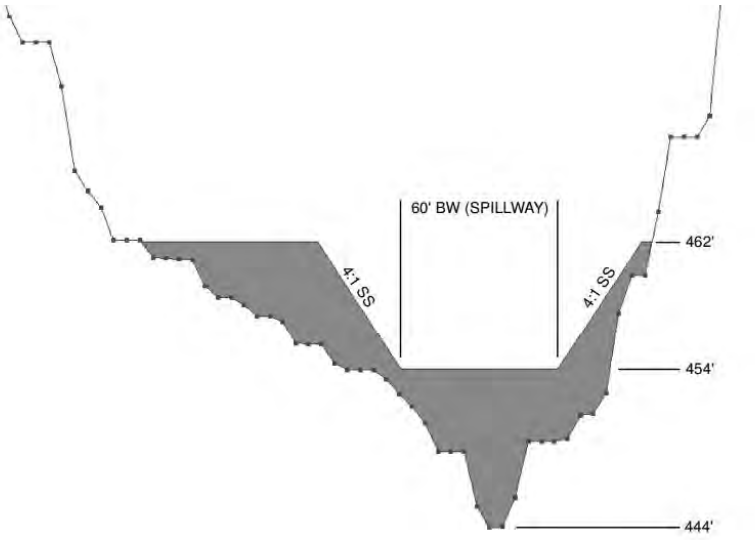


Figure 3-28 Dry Hollow Creek Water Quality Pond Outfall

3.6.1. Flood Risk

Flood risk benefits for this concept are anticipated to be minimal. Therefore, a flood risk simulation was not performed for Concept 6.

3.6.2. Water Quality

An existing and future condition HSPF simulation was performed for this concept. This section discusses the modeling approach and water quality simulation results.

3.6.2.1. Model Development

The Baseline Existing and Baseline Future condition HSPF models were modified to produce the Concept 6 Existing and Concept 6 Future condition HSPF models. The only difference between the Baseline and Concept 6 models is that the FTables of Elm Creek and Dry Hollow Creek were modified to reflect the water quality pond embankments shown in Figure 3-27 and Figure 3-28, respectively. The FTables have a depth versus storage versus outflow relationship to reflect channel routing. The water quality ponds were reflected in the FTables by changing the outflow values for depths below the embankment overflow to zero. For depths above the embankment elevation, flows matched existing condition outflow rates.

3.6.2.2. Results

Table 3-55 shows the percent change in constituent loads at selected locations along Cibolo Creek for the existing condition. Elm Creek and Dry Hollow Creek outfall to Cibolo Creek near La Vernia and, as a result, no changes to constituent loads are noted upstream of La Vernia. However, constituent load changes are noted from La Vernia downstream to the mouth of Cibolo Creek. In this reach nitrate nitrogen load is reduced by a maximum of 8.5%, ammonia nitrogen is reduced by a maximum of 13.9%, ortho-phosphorus is reduced by a maximum of 1.8%, and bacteria is reduced by a maximum of 10.3%. The ponds also produce negative impacts. Dissolved oxygen load is reduced in Cibolo Creek between La Vernia and the mouth by a maximum of 0.5%, ammonia nitrogen load is increased by a maximum of 0.7%, organic phosphorus is increased by a maximum of 1.3% and chlorophyll-a is increased by a maximum of 3.0%.

Constituent load changes for Concept 6 for the future condition (see Table 3-56) are similar to the existing condition. Downstream of La Vernia on Cibolo Creek nitrate nitrogen load is reduced by a maximum of 8.5%, ammonia nitrogen is reduced by a maximum of 12.5%, ortho-phosphorus is reduced by a maximum of 2.5%, and bacteria is reduced by a maximum of 9.4%. The ponds also produce negative impacts. Dissolved oxygen load is reduced in Cibolo Creek between La Vernia and the mouth by a maximum of 0.3%, ammonia nitrogen load is increased by a maximum of 1.3%, organic phosphorus is increased by a maximum of 1.8% and chlorophyll-a is increased by a maximum of 3.8%.

The results can be explained by the following observations:

1. The water quality ponds capture upstream nutrients (nitrate nitrogen, ammonia nitrogen and ortho-phosphorus).

2. The captured nutrients encourage the growth of algae in the water quality ponds, which is indicated by increased chlorophyll-a loads in the water quality ponds and downstream.

3. The increased algae growth has a negative impact upon dissolved oxygen levels.

4. Organic phosphorus is likely a result of the increased organic growth in the water quality ponds.

Table 3-55 Concept 6 - Load Change on Cibolo Creek (Existing Condition)

HSPF Reach ID	Location	*Concept 6 Existing - % Change in Load from Baseline Existing*							
		Dissolved Oxygen	Nitrate Nitrogen (NO_3N)	Ammonia Nitrogen (NH_3N)	Organic P	Ortho P	Chl-a	Bacteria (E. Coli)	Runoff Volume
Cibolo Creek Mainstem									
39	*I-10 (near Boerne)*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
61	*Boerne*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
91	*Fair Oaks Ranch*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
110	*West of Bulverde*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
129	*Hwy 281*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
140	*FM 1863*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
159	*I-35 (near Selma)*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
165	*Schertz*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
185	*I-10 (near New Berlin)*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
273	*U/S of Martinez Creek*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
392	*D/S of Martinez Creek*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
281	*CR 347/CR 417*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
299	*La Vernia*	-0.5%	-1.2%	-13.9%	**0.7%**	-0.6%	**2.4%**	-8.5%	-0.1%
323	*Sutherland Springs*	-0.4%	-6.3%	-0.9%	**1.2%**	-1.7%	**3.0%**	-10.3%	-0.3%
327	*Hwy 87*	-0.3%	-7.5%	**0.7%**	**1.3%**	-1.8%	**3.0%**	-9.1%	-0.2%
354	*FM 537*	-0.3%	-7.8%	**0.7%**	**1.3%**	-1.7%	**2.9%**	-6.6%	-0.2%
360	*FM 541*	-0.2%	-8.7%	**0.6%**	**1.3%**	-1.6%	**2.7%**	-4.8%	-0.2%
372	*FM 887*	-0.2%	-8.4%	**0.6%**	**1.2%**	-1.5%	**2.3%**	-3.6%	-0.2%
375	*Hwy 123*	-0.2%	-8.5%	**0.6%**	**1.0%**	-1.4%	**1.7%**	-3.4%	-0.2%
379	*U/S of San Antonio River*	-0.2%	-8.2%	**0.3%**	**0.4%**	-1.3%	**0.6%**	-3.2%	-0.2%

Table 3-56 Concept 6 - Load Change on Cibolo Creek (Future Condition)

HSPF Reach ID	Location	*Concept 6 Future - % Change in Load from Baseline Future*							
		Dissolved Oxygen	Nitrate Nitrogen (NO_3N)	Ammonia Nitrogen (NH_3N)	Organic P	Ortho P	Chl-a	Bacteria (E. Coli)	Runoff Volume
Cibolo Creek Mainstem									
39	*I-10 (near Boerne)*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
61	*Boerne*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
91	*Fair Oaks Ranch*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
110	*West of Bulverde*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
129	*Hwy 281*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
140	*FM 1863*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
159	*I-35 (near Selma)*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
165	*Schertz*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
185	*I-10 (near New Berlin)*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
273	*U/S of Martinez Creek*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
392	*D/S of Martinez Creek*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
281	*CR 347/CR 417*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
299	*La Vernia*	-0.3%	-1.5%	-12.5%	**0.8%**	-1.0%	**3.5%**	-9.4%	-0.1%
323	*Sutherland Springs*	-0.2%	-5.4%	-0.9%	**1.3%**	-2.4%	**3.7%**	-8.2%	-0.2%
327	*Hwy 87*	-0.2%	-6.3%	**0.7%**	**1.4%**	-2.5%	**3.8%**	-7.3%	-0.2%
354	*FM 537*	-0.2%	-6.6%	**0.8%**	**1.5%**	-2.4%	**3.8%**	-6.0%	-0.1%
360	*FM 541*	-0.2%	-7.6%	**1.3%**	**1.7%**	-2.4%	**3.7%**	-5.1%	-0.1%
372	*FM 887*	-0.2%	-7.7%	**1.2%**	**1.8%**	-2.2%	**3.6%**	-4.3%	-0.1%
375	*Hwy 123*	-0.2%	-8.1%	**1.4%**	**1.7%**	-2.2%	**3.3%**	-4.2%	-0.1%
379	*U/S of San Antonio River*	-0.2%	-8.5%	**1.3%**	**1.5%**	-2.1%	**2.7%**	-4.0%	-0.1%

Table 3-57 shows the average reach loads by constituent within the Cibolo Creek watershed for the Baseline Existing, Concept 6 Existing, Baseline Future, and Concept 6 Future conditions. The average reach loads shown in the table are used to calculate the water quality benefits (see Section 4.1) of Concept 6.

Table 3-57 Concept 6 - Average Reach Loads

Condition	Dissolved Oxygen (lbs)	Nitrate Nitrogen (lbs)	Ammonia Nitrogen (lbs)	Organic P (lbs)	Ortho P (lbs)	Chl-a (lbs)	Bacteria (E. Coli) ($\#10^6$)	Runoff Volume (ac-ft)
Baseline Existing	320,200	48,992	1,077	3,414	22,614	132,429	419,535,137	13,222
Concept 6 Existing	319,471	47,295	1,065	3,448	22,392	135,810	404,253,403	13,205
Baseline Future	501,194	64,370	1,619	4,293	19,886	162,893	1,159,646,196	20,729
Concept 6 Future	500,395	62,347	1,605	4,349	19,618	168,705	1,124,885,837	20,712
Concept 6 Change (Existing)	***-729***	***-1,698***	***-12***	***35***	***-222***	***3,382***	***-15,281,735***	***-17***
Concept 6 Change (Future)	***-800***	***-2,023***	***-14***	***56***	***-268***	***5,812***	***-34,760,359***	***-17***

The reach constituent average concentrations were determined for the Baseline Existing, Concept 6 Existing, Baseline Future, and Concept 6 Future conditions. As seen in Table 3-58, average concentrations for nitrate nitrogen were reduced by 0.01 mg/l for the existing and future conditions. Concept 6 increased organic phosphorus concentrations by 0.0002 mg/l and chlorophyll-a by 0.02 ug/l for the existing and future conditions. Concept 6 reduced ortho-phosphorus concentrations by 0.0007 mg/l and 0.0006 mg/l for the existing and future conditions, respectively. Concept 6 reduced bacteria concentrations by 19 #/dl and 27 #/dl for the existing and future conditions, respectively.

Table 3-58 Concept 6 - Average Reach Constituent Concentrations

Condition	Dissolved Oxygen (mg/l)	Nitrate Nitrogen (mg/l)	Ammonia Nitrogen (mg/l)	Organic P (mg/l)	Ortho P (mg/l)	Chl-a (ug/l)	Bacteria (E. Coli) (#/dl)
Baseline Existing	8.42	1.55	0.11	0.0404	0.5819	0.77	6,151
Concept 6 Existing	8.41	1.54	0.11	0.0405	0.5812	0.79	6,132
Baseline Future	8.27	1.33	0.11	0.0366	0.3682	0.63	9,886
Concept 6 Future	8.27	1.33	0.11	0.0368	0.3676	0.65	9,859
Concept 6 Change (Existing)	***0.00***	***-0.01***	***0.00***	***0.0002***	***-0.0007***	***0.02***	***-19***
Concept 6 Change (Future)	***0.00***	***-0.01***	***0.00***	***0.0002***	***-0.0006***	***0.02***	***-27***

Constituent concentrations of all reaches were compared against the screening levels shown in Table 3-47 to determine the number of damaged reaches after Concept 6 was simulated. As seen in Table 3-59, Concept 6 had no effect upon the number of reaches that exceed constituent screening levels under the existing condition. Under the future condition Concept 6 removed one reach from the nitrate nitrogen damage category.

Table 3-59 Concept 6 - Damaged Reach Counts

Condition	Dissolved Oxygen	Nitrate Nitrogen	Ammonia Nitrogen	Organic P	Ortho P	Chl-a	Bacteria (E. Coli)
Baseline Existing	0	93	7	0	271	0	427
Concept 6 Existing	0	93	7	0	271	0	427
Baseline Future	0	40	6	0	114	0	428
Concept 6 Future	0	39	6	0	114	0	428
Concept 6 Change (Existing)	***0***	***0***	***0***	***0***	***0***	***0***	***0***
Concept 6 Change (Future)	***0***	***-1***	***0***	***0***	***0***	***0***	***0***

3.6.3. Cost Estimate

Construction cost and annual maintenance estimates were developed for the Elm Creek Water Quality Pond (see Table 3-60) and the Dry Hollow Creek Water Quality Pond (see Table 3-61). The Elm Creek pond has an estimated construction cost of $1,628,520, and the Dry Hollow Creek pond has an estimated construction cost of $1,492,301.

The ponds will likely require normal maintenance activities such as routine inspections, mowing, repairs, etc. Mowing was assumed to be done twice a year at $120/acre. Inspections were assumed to be done quarterly at a fixed cost for a day's rate of $400. The ponds are about 1 acre in size each, and so at $120/acre it will cost about $240 to mow one pond twice a year. It will cost about $1,600 a year for inspections to be performed. With the cost of repairs depending on the probability and severity of an issue happening, a lump sum of $15,000 was assumed. These factors bring a total of about $16,840 in annual maintenance fees for each pond. Assuming a project life of 50 years, an interest rate of 2%, and a growth rate of 2%, the present value of annual maintenance for each pond was calculated to be $825,490.

Table 3-60 Concept 6 - Elm Creek W.Q. Pond Construction and Maintenance Estimate

Construction Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
TREE REMOVAL & CLEARING/GRUBBING		LS	-	$9,700
EXCAVATION	2717	CY	$20	$54,340
EMBANKMENT (DENS CONT TYP C)	2600	CY	$12	$31,200
CMP (GAL STL 36 IN)	120	LF	$120	$14,400
CONCRETE LINED CHANNEL	211	CY	$400	$84,400
STONE RIPRAP (1.5' THICK)	363	CY	$115	$41,745
FERTILIZER	0.75	AC	$800	$600
BROADCREST SEED (PERM)	0.75	AC	$500	$375
WATERING	66	MG	$11	$726
TRAFFIC CONTROL		LS	-	$6,100
			Construction Total	$243,586
Fringe Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
INUNDATION EASEMENT ACQUISTION	16.0	AC	$2,113	$33,800
RIGHT-OF-WAY ACQUISITION	2.0	AC	$42,250	$84,500
ENVIRONMENTAL PERMITTING		LS	-	$107,000
MOBILIZATION		LS	10%	$24,359
ENGINEERING		LS	15%	$36,538
SURVEYING (5% OF ENGINEERING)		LS	5%	$1,827
			Fringe Total	$288,023
Continuation Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ANNUAL MAINTENANCE COST		LS	-	$16,840
			Continuation Total, 50-Year Project Life (Present Value)	$825,490
			Project Total (Construction + Fringe + Continuation)	$1,357,100
			20% Contingency on Conceptual Estimates	$271,420
			PROJECT GRAND TOTAL	**$1,628,520**

Table 3-61 Concept 6 - Dry Hollow Creek W.Q. Pond Construction and Maintenance Estimate

Construction Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
TREE REMOVAL & CLEARING/GRUBBING		LS	-	$9,700
EXCAVATION	1986	CY	$20	$39,720
EMBANKMENT (DENS CONT TYP C)	2325	CY	$12	$27,900
CMP (GAL STL 36 IN)	84	LF	$120	$10,080
CONCRETE LINED CHANNEL	137	CY	$400	$54,800
STONE RIPRAP (1.5' THICK)	600	CY	$115	$69,000
FERTILIZER	0.75	AC	$800	$600
BROADCREST SEED (PERM)	0.75	AC	$500	$375
WATERING	66	MG	$11	$726
TRAFFIC CONTROL		LS	-	$6,100
			Construction Total	$219,001
Fringe Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
INUNDATION EASEMENT ACQUISTION	2.0	AC	$850	$1,700
RIGHT-OF-WAY ACQUISITION	2.0	AC	$17,000	$34,000
ENVIRONMENTAL PERMITTING		LS	-	$107,000
MOBILIZATION		LS	10%	$21,900
ENGINEERING		LS	15%	$32,850
SURVEYING (5% OF ENGINEERING)		LS	5%	$1,643
			Fringe Total	$199,093
Continuation Costs				
Description	Approximate Quantity	Unit	Average Unit Price	Amount
ANNUAL MAINTENANCE COST		LS	-	$16,840
			Continuation Total, 50-Year Project Life (Present Value)	$825,490
			Project Total (Construction + Fringe + Continuation)	$1,243,584
			20% Contingency on Conceptual Estimates	$248,717
			PROJECT GRAND TOTAL	**$1,492,301**

3.7. Fertilizer Management & Education (Concept 7)

The purpose of fertilizer management is to encourage residents in the Cibolo Creek watershed to utilize fertilizer application techniques that limit the runoff of excess nutrients into the stormwater system. These techniques may include proper application timing, rate and placement that increase fertilizer uptake efficiency. Managing fertilizer not only reduces the amount of nutrients (nitrogen and phosphorous) reaching the streams, but it also reduces the amount of algae growth promoted by such nutrients. Therefore, levels of chlorophyll-a are also expected to be directly and positively impacted, which in turn could also indirectly benefit dissolved oxygen levels.

This concept assumes the following actions are taken:

- A fertilizer management instructor is retained to develop and present fertilizer management instruction for the community. Targeted audiences may include the schools, homeowners' associations and commercial lawn services in the community, as well as the agricultural community.
- Materials that promote proper fertilizer application techniques are produced for local radio advertisements.
- One billboard display promoting proper fertilizer application techniques is rotated on a yearly basis throughout the watershed.
- Educational flyers, a website and a social media (Facebook, Instagram, Twitter, etc.) campaign are prepared and distributed.

3.7.1. Flood Risk

Flood risk benefits are not anticipated for this concept. Therefore, a flood risk simulation was not performed for Concept 7.

3.7.2. Water Quality

An existing and future condition HSPF simulation was performed for this concept. This section discusses the modeling approach and water quality simulation results.

3.7.2.1. Model Development

The Baseline Existing and Baseline Future condition HSPF models were modified to create the Concept 7 Existing and Concept 7 Future HSPF simulations. The Concept 7 simulations modified the Baseline condition loading rates of agricultural, residential and commercial land uses throughout the watershed to reflect a more efficient application of fertilizers, and thus, a reduced nutrient loading rate. Specifically, nitrogen and phosphorus PERLND parameters were modified to reflect changes in fertilizer practices including accumulation, storage, interflow, and groundwater monthly varying model inputs.

The amount of nitrogen and phosphorus being applied through fertilizer to agriculture, residential and commercial land use was determined by comparing the nitrogen and phosphorus loading rates of residential and commercial land uses against a base land use. While a base land use may have naturally generated nitrogen and phosphorus loading, it is not expected to have nitrogen and phosphorus loading due to the application of fertilizer. The residential dispersed land use was assumed to be the base land use for nitrogen and phosphorus reductions on residential land uses, and the barren land use was assumed to be the base land use for the reductions on agricultural land.

Concept 7 assumed a 20% reduction in the amount of nitrogen and phosphorus loading to the various agricultural, commercial and residential land uses throughout the watershed to reflect more efficient fertilizer application. This 20% reduction is assumed to be the highest level of nutrient reduction that could be achieved through education.

3.7.2.2. Results

The Concept 7 Existing condition model considered the current land use for the watershed and modeled reduction of pollutants based on the assumptions described above. As seen in Table 3-62, Concept 7 reduced nitrate nitrogen, ammonia nitrogen, organic phosphorus, ortho-phosphorus, and chlorophyll-a loads for the existing condition along the mainstem of Cibolo Creek. The concept also produced slight increases to existing condition dissolved oxygen loads. The concept had a limited area of negative impacts in terms of chlorophyll-a. Under the existing condition chlorophyll-a loads increased slightly in upper reaches of Cibolo Creek. The largest percent change in loads was generally observed at the confluence with the San Antonio River, where nitrogen loads were reduced by 9.8%, ammonia nitrogen by 2.0%, organic phosphorous by 2.4%, ortho-phosphorous by 3.4%, and chlorophyll-a by 2.5%. Dissolved oxygen showed a slight increase (0.1%) around the confluence with Martinez Creek and near La Vernia. Bacteria and volume do not benefit from Concept 7.

Table 3-62 Concept 7 - Load Change on Cibolo Creek (Existing Condition)

HSPF Reach ID	Location	*Concept 7 Existing - % Change in Load from Baseline Existing*							
		Dissolved Oxygen	Nitrate Nitrogen (NO_3N)	Ammonia Nitrogen (NH_3N)	Organic P	Ortho P	Chl-a	Bacteria (E. Coli)	Runoff Volume
Cibolo Creek Mainstem									
39	*I-10 (near Boerne)*	0.0%	-0.5%	-0.4%	-0.2%	-0.3%	**0.5%**	0.0%	0.0%
61	*Boerne*	0.0%	-1.1%	-0.7%	-0.6%	-0.8%	0.0%	0.0%	0.0%
91	*Fair Oaks Ranch*	0.0%	-1.0%	-0.4%	-0.9%	-0.7%	0.0%	0.0%	0.0%
110	*West of Bulverde*	0.0%	-0.6%	-0.2%	-0.7%	-0.4%	**0.1%**	0.0%	0.0%
129	*Hwy 281*	0.0%	-0.7%	-0.7%	-1.0%	-0.5%	0.0%	0.0%	0.0%
140	*FM 1863*	0.0%	-0.8%	-0.5%	-1.1%	-0.5%	-1.3%	0.0%	0.0%
159	*I-35 (near Selma)*	0.0%	-0.9%	-1.8%	-1.2%	-0.5%	-1.4%	0.0%	0.0%
165	*Schertz*	0.0%	-1.4%	-0.3%	-1.1%	-0.7%	-1.5%	0.0%	0.0%
185	*I-10 (near New Berlin)*	0.0%	-1.0%	-4.8%	-1.0%	-0.8%	-1.0%	0.0%	0.0%
273	*U/S of Martinez Creek*	**0.1%**	-1.1%	-2.1%	-0.7%	-1.3%	-0.5%	0.0%	0.0%
392	*D/S of Martinez Creek*	**0.1%**	-2.1%	-1.8%	-0.9%	-1.9%	-0.5%	0.0%	0.0%
281	*CR 347/CR 417*	**0.1%**	-2.1%	-1.4%	-0.7%	-1.9%	-0.4%	0.0%	0.0%
299	*La Vernia*	**0.1%**	-2.5%	-1.3%	-0.8%	-2.1%	-0.4%	0.0%	0.0%
323	*Sutherland Springs*	0.0%	-5.5%	-0.9%	-0.8%	-2.8%	-0.6%	0.0%	0.0%
327	*Hwy 87*	0.0%	-6.5%	-1.1%	-1.0%	-2.9%	-0.9%	0.0%	0.0%
354	*FM 537*	0.0%	-7.1%	-1.4%	-1.1%	-2.9%	-1.1%	0.0%	0.0%
360	*FM 541*	0.0%	-8.3%	-1.9%	-1.5%	-3.2%	-1.5%	0.0%	0.0%
372	*FM 887*	0.0%	-9.0%	-1.9%	-1.8%	-3.3%	-1.8%	0.0%	0.0%
375	*Hwy 123*	0.0%	-9.4%	-1.9%	-2.0%	-3.4%	-2.0%	0.0%	0.0%
379	*U/S of San Antonio River*	0.0%	-9.8%	-2.0%	-2.4%	-3.4%	-2.5%	0.0%	0.0%

As with the Concept 7 Existing condition model, the Concept 7 Future condition model assumed reduced nitrogen and phosphorus loads from all agricultural, residential and commercial development in the watershed. For the future condition, the model predicts a similar behavior in the load reduction to those of the existing condition. As seen in Table 3-63, the highest change in loads was generally observed at the confluence with the San Antonio River, where nitrogen loads were reduced by 7.9%, ammonia nitrogen by

2.0%, organic phosphorous by 2.4%, ortho-phosphorous by 4.0%, and chlorophyll-a by 2.5%. Dissolved oxygen and bacteria will not benefit from Concept 7 under future conditions.

Table 3-63 Concept 7 - Load Change on Cibolo Creek (Future Condition)

HSPF Reach ID	Location	*Concept 7 Future - % Change in Load from Baseline Future*							
		Dissolved Oxygen	Nitrate Nitrogen (NO_3N)	Ammonia Nitrogen (NH_3N)	Organic P	Ortho P	Chl-a	Bacteria (E. Coli)	Runoff Volume
Cibolo Creek Mainstem									
39	*I-10 (near Boerne)*	0.0%	-1.6%	-1.0%	-1.7%	-1.1%	-2.6%	0.0%	0.0%
61	*Boerne*	0.0%	-1.9%	-1.0%	-1.6%	-1.5%	-2.5%	0.0%	0.0%
91	*Fair Oaks Ranch*	0.0%	-2.7%	-0.9%	-2.3%	-2.1%	-3.1%	0.0%	0.0%
110	*West of Bulverde*	0.0%	-2.2%	-0.5%	-2.1%	-1.6%	-3.8%	0.0%	0.0%
129	*Hwy 281*	0.0%	-2.2%	-0.8%	-2.1%	-1.6%	-4.2%	0.0%	0.0%
140	*FM 1863*	0.0%	-2.2%	-0.6%	-2.1%	-1.6%	-5.5%	0.0%	0.0%
159	*I-35 (near Selma)*	0.0%	-2.3%	-2.1%	-1.9%	-1.5%	-4.7%	0.0%	0.0%
165	*Schertz*	0.0%	-2.7%	-0.5%	-1.8%	-1.7%	-4.9%	0.0%	0.0%
185	*I-10 (near New Berlin)*	0.0%	-1.9%	-3.9%	-1.6%	-1.7%	-1.9%	0.0%	0.0%
273	*U/S of Martinez Creek*	0.0%	-2.0%	-2.5%	-1.2%	-2.2%	-0.8%	0.0%	0.0%
392	*D/S of Martinez Creek*	0.0%	-2.7%	-2.2%	-1.5%	-2.7%	-0.9%	0.0%	0.0%
281	*CR 347/CR 417*	0.0%	-2.7%	-1.9%	-1.3%	-2.7%	-0.8%	0.0%	0.0%
299	*La Vernia*	0.0%	-2.7%	-1.8%	-1.3%	-2.8%	-0.8%	0.0%	0.0%
323	*Sutherland Springs*	0.0%	-4.7%	-1.1%	-1.2%	-3.5%	-1.1%	0.0%	0.0%
327	*Hwy 87*	0.0%	-5.3%	-1.2%	-1.4%	-3.6%	-1.3%	0.0%	0.0%
354	*FM 537*	0.0%	-5.6%	-1.3%	-1.5%	-3.6%	-1.5%	0.0%	0.0%
360	*FM 541*	0.0%	-6.5%	-1.9%	-1.8%	-3.8%	-1.8%	0.0%	0.0%
372	*FM 887*	0.0%	-7.1%	-1.9%	-2.1%	-4.0%	-2.0%	0.0%	0.0%
375	*Hwy 123*	0.0%	-7.4%	-2.0%	-2.2%	-4.0%	-2.2%	0.0%	0.0%
379	*U/S of San Antonio River*	0.0%	-7.9%	-2.0%	-2.4%	-4.0%	-2.5%	0.0%	0.0%

Table 3-64 shows the average reach loads by constituent within the Cibolo Creek watershed for the Baseline Existing, Concept 7 Existing, Baseline Future, and Concept 7 Future conditions. The average reach loads shown in the table are used to calculate the water quality benefits (see Section 4.1) of Concept 7.

Table 3-64 Concept 7 - Average Reach Loads

Condition	Dissolved Oxygen (lbs)	Nitrate Nitrogen (lbs)	Ammonia Nitrogen (lbs)	Organic P (lbs)	Ortho P (lbs)	Chl-a (lbs)	Bacteria (E. Coli) (#10^6)	Runoff Volume (ac-ft)
Baseline Existing	320,200	48,992	1,077	3,414	22,614	132,429	419,535,137	13,222
Concept 7 Existing	320,229	46,772	1,061	3,369	22,053	130,864	419,535,137	13,222
Baseline Future	501,194	64,370	1,619	4,293	19,886	162,893	1,159,646,196	20,729
Concept 7 Future	501,212	61,573	1,588	4,216	19,247	160,293	1,159,646,196	20,729
Concept 7 Change (Existing)	***29***	***-2,220***	***-15***	***-44***	***-561***	***-1,565***	***0***	***0***
Concept 7 Change (Future)	***17***	***-2,797***	***-31***	***-77***	***-639***	***-2,600***	***0***	***0***

The reach constituent average concentrations were determined for the Baseline Existing, Concept 7 Existing, Baseline Future, and Concept 7 Future conditions. As seen in Table 3-65, average concentrations for nitrate nitrogen were reduced by 0.07 and 0.06 mg/l for the existing and future condition, respectively. Concept 7 also slightly decreased concentrations of organic phosphorus by 0.0008 and 0.0010 mg/L for the existing and future conditions, respectively; for the ortho-phosphorus by 0.0173 and 0.0143 mg/L for the existing and future conditions, respectively; and chlorophyll-a by 0.01 for both the existing and future conditions. Dissolved oxygen and bacteria were not affected by Concept 7.

Table 3-65 Concept 7 - Average Reach Constituent Concentrations

Condition	Dissolved Oxygen (mg/l)	Nitrate Nitrogen (mg/l)	Ammonia Nitrogen (mg/l)	Organic P (mg/l)	Ortho P (mg/l)	Chl-a (ug/l)	Bacteria (E. Coli) (#/dl)
Baseline Existing	8.42	1.55	0.11	0.0404	0.5819	0.77	6,151
Concept 7 Existing	8.42	1.47	0.11	0.0396	0.5646	0.76	6,151
Baseline Future	8.27	1.33	0.11	0.0366	0.3682	0.63	9,886
Concept 7 Future	8.27	1.27	0.11	0.0356	0.3539	0.62	9,886
Concept 7 Change (Existing)	***0.00***	***-0.07***	***0.00***	***-0.0008***	***-0.0173***	***-0.01***	***0***
Concept 7 Change (Future)	***0.00***	***-0.06***	***0.00***	***-0.0010***	***-0.0143***	***-0.01***	***0***

Constituent concentrations of all reaches were compared against the screening levels shown in Table 3-47 to determine the number of damaged reaches after Concept 7 was simulated. Concept 7 had minimal effect upon the number of reaches that exceed constituent screening levels. As seen in Table 3-66, there were improvements in damaged reach counts for both the existing and future condition after implementation of Concept 7, including 22 and 19 nitrate nitrogen damaged reaches removed for existing and future condition, respectively; 2 and 3 ammonia nitrogen damaged reaches removed for existing and future condition, respectively; and 6 and 1 removed from ortho-phosphorous for existing and future condition, respectively.

Table 3-66 Concept 7 - Damaged Reach Counts

Condition	Dissolved Oxygen	Nitrate Nitrogen	Ammonia Nitrogen	Organic P	Ortho P	Chl-a	Bacteria (E. Coli)
Baseline Existing	0	93	7	0	271	0	427
Concept 7 Existing	0	71	5	0	265	0	427
Baseline Future	0	40	6	0	114	0	428
Concept 7 Future	0	21	3	0	113	0	428
Concept 7 Change (Existing)	***0***	***-22***	***-2***	***0***	***-6***	***0***	***0***
Concept 7 Change (Future)	***0***	***-19***	***-3***	***0***	***-1***	***0***	***0***

3.7.3. Cost Estimate

Several assumptions were made to develop an estimated annual cost for implementing a fertilizer management program:

- A part-time fertilizer management trainer will be hired. The cost of this employee includes a $60,000 salary and an additional $90,000 (1.5 x salary as a rule of thumb) to account for overhead and employee benefits (retirement, insurance, vacation, etc.).
- 50,000 single-sided full color flyers will be produced and distributed with water bills on a yearly basis.
- Preparation and airing of 30 seconds radio spots in 4 local radio stations. It is estimated that 500 adds will be broadcasted per year at each of these radio stations.
- Social media banners and adds and websites would be generated by a third party.
- A website will be maintained for the fertilizer management program.
- One billboard display promoting proper fertilizer application techniques is rotated on a yearly basis throughout the watershed.

The estimated annual cost for a fertilizer management program is $187,000, as seen in Table 3-67. Assuming a project life of 50 years, an interest rate of 2%, and a growth rate of 2%, the present value of the annual cost was calculated to be $9,166,667. With a 20% contingency added, the overall cost to support a fertilizer management program is $11,000,000.

Table 3-67 Concept 7 - (Fertilizer Management) Annual Cost Estimate

Description	Approximate Quantity	Unit	Average Unit Price	Amount
PERMANENT BILLBOARD (14' x 48') (YEARLY)	0.5	EA	$65,000	$32,500
FLYER ADVERTISING (ONE-SIDED)	50000	EA	$0.58	$29,000
RADIO STATION ADVERTISING (30-SECONDS)	500	EA	$81	$40,500
SOCIAL MEDIA MARKETING	0.5	MO	$5,000	$2,500
WEBSITE	1	LS	$7,500	$7,500
FERTILIZER MANAGEMENT INSTRUCTOR	0.5	LS	$150,000	$75,000
			Annual Cost	$187,000
			50-Year Project Life (Present Value)	$9,166,667
			Project Total	$9,166,667
			20% Contingency on Conceptual Estimates	$1,833,333
			PROJECT GRAND TOTAL	**$11,000,000**

4. Scoring

This section discusses the benefit criteria scoring of each concept, concept scores, and the overall ranking of the improvement concepts.

4.1. Benefit Criteria Scores

This section presents the benefit criteria scoring of each concept based upon the methodology discussed in Section 2.2.

4.1.1. Avoided Annual Damages

As seen in Table 4-1, only Concept 1, 2 and 4 had reductions to estimated annual damages. Although minor, the Upper Martinez Creek improvement produced the largest EAD reduction of $10,133. The low water crossing replacement concept (Concept 3A, 3B, 3C and 3D), the BMP Retrofit concept (Concept 5), regional water quality pond concept (Concept 6) and the fertilizer management concept (Concept 7) had no measurable flood damage reduction benefits.

Table 4-1 EAD Reduction Summary

		EAD		*EAD Reduction*			
Condition	**Description**	**Existing**	**Future**	**Existing**	**Future**	**Avg. EAD Reduction (Existing & Future)**	**Normalized Score**
Baseline	No Improvements	$189,351	$658,231	-	-	-	
Concept 1	Restrictor S-191	$187,899	$652,684	$1,452	$5,547	$3,500	0.9
Concept 2	Upper Martinez Improvements	$179,253	$630,865	$10,098	$27,366	$18,732	5.0
Concept 3A	LWC Replacement (FM 1863)	$189,351	$658,231	$0	$0	$0	0.0
Concept 3B	LWC Replacement (CR 352/CR 440)	$189,351	$658,231	$0	$0	$0	0.0
Concept 3C	LWC Replacement (CR 347/CR 417)	$189,351	$658,231	$0	$0	$0	0.0
Concept 3D	LWC Replacement (FM 537)	$189,351	$658,231	$0	$0	$0	0.0
Concept 4	LID Requirements	$189,351	$647,005	$0	$11,225	$5,613	1.5
Concept 5	BMP Retrofit	$189,351	$658,231	$0	$0	$0	0.0
Concept 6	Regional Water Quality Pond	$189,351	$658,231	$0	$0	$0	0.0
Concept 7	Fertilizer Mgmt. & Education	$189,351	$658,231	$0	$0	$0	0.0

4.1.2. Reduced Dangerous Crossing Factor

Table 4-2 shows the total of the DCF values for the Cibolo Creek watershed for the Baseline condition and the various improvement concepts under existing and future development. Most concepts, except Concept 5, 6 and 7, had at least a minor improvement in crossing safety (lowered DCF). The four low water crossing replacements (Concept 3A, 3B, 3C and 3D) were in the top 5 scores. The LID requirements concept (Concept 4) had the third highest scored as it had small DCF reductions in the future for many crossings.

Table 4-2 Reduced DCF Summary

		Watershed Total DCF		*Watershed Total DCF Reduction*			
Condition	**Description**	**Existing**	**Future**	**Existing**	**Future**	**Avg. DCF Reduction (Existing & Future)**	**Normalized Score**
Baseline	No Improvements	193.8	218.1	-	-	-	
Concept 1	Restrictor S-191	193.8	218.0	0.0	0.1	0.1	0.0
Concept 2	Upper Martinez Improvements	192.6	216.9	1.2	1.2	1.2	0.4
Concept 3A	LWC Replacement (FM 1863)	184.6	207.7	9.2	10.4	9.8	3.4
Concept 3B	LWC Replacement (CR 352/CR 440)	181.0	203.7	12.8	14.4	13.6	4.7
Concept 3C	LWC Replacement (CR 347/CR 417)	180.3	202.7	13.6	15.4	14.5	5.0
Concept 3D	LWC Replacement (FM 537)	186.6	209.3	7.2	8.8	8.0	2.8
Concept 4	LID Requirements	193.8	197.1	0.0	21.0	10.5	3.6
Concept 5	BMP Retrofit	193.8	218.1	0.0	0.0	0.0	0.0
Concept 6	Regional Water Quality Pond	193.8	218.1	0.0	0.0	0.0	0.0
Concept 7	Fertilizer Mgmt. & Education	193.8	218.1	0.0	0.0	0.0	0.0

4.1.3. Increased Dissolved Oxygen

Concepts 4, 5, 6 and 7 are focused on providing water quality benefits. However, only Concept 7 provides, although minimal, an increase in average reach loading for dissolved oxygen (Table 4-3). Concepts 4, 5, and 6 have a negative impact on average dissolved oxygen loads.

Table 4-3 Increased Dissolved Oxygen Summary

		Avg. Reach DO Load (lbs)		*Avg. Reach DO Load Increase (lbs)*			
Condition	**Description**	**Existing**	**Future**	**Existing**	**Future**	**Avg. Load Increase (Existing & Future)**	**Normalized Score**
Baseline	No Improvements	320,200.3	501,194.4	-	-	-	
Concept 1	Restrictor S-191	320,200.3	501,194.4	0.0	0.0	0.0	5.0
Concept 2	Upper Martinez Improvements	320,200.3	501,194.4	0.0	0.0	0.0	5.0
Concept 3A	LWC Replacement (FM 1863)	320,200.3	501,194.4	0.0	0.0	0.0	5.0
Concept 3B	LWC Replacement (CR 352/CR 440)	320,200.3	501,194.4	0.0	0.0	0.0	5.0
Concept 3C	LWC Replacement (CR 347/CR 417)	320,200.3	501,194.4	0.0	0.0	0.0	5.0
Concept 3D	LWC Replacement (FM 537)	320,200.3	501,194.4	0.0	0.0	0.0	5.0
Concept 4	LID Requirements	320,200.3	372,593.7	0.0	(128,600.7)	(64300.3)	0.0
Concept 5	BMP Retrofit	320,200.3	500,760.4	0.0	(433.9)	(217.0)	5.0
Concept 6	Regional Water Quality Pond	319,471.0	500,394.8	(729.2)	(799.6)	(764.4)	4.9
Concept 7	Fertilizer Mgmt. & Education	320,229.5	501,211.8	29.2	17.4	23.3	5.0

4.1.4. Decreased Nitrate Nitrogen

Concepts 4, 5, 6 and 7 are focused on providing water quality benefits and they all provide reductions in average nitrate nitrogen loads (see Table 4-4). Concept 4 provides the most reduction, but only provides that reduction in the future condition. Concept 5, 6 and 7 provide minimal reductions to nitrate nitrogen loads. Concepts 1, 2, 3A, 3B, 3C and 3D are primarily flood risk concepts and do not provide any reductions to nitrate nitrogen loads.

Table 4-4 Decreased Nitrate Nitrogen Summary

		Avg. Reach Nitrate Nitrogen Load (lbs)		*Avg. Reach Nitrate Nitrogen Load Decrease (lbs)*			
Condition	**Description**	**Existing**	**Future**	**Existing**	**Future**	**Avg. Load Decrease (Existing & Future)**	**Normalized Score**
Baseline	No Improvements	48,992.3	64,369.9	-	-	-	
Concept 1	Restrictor S-191	48,992.3	64,369.9	0.0	0.0	0.0	0.0
Concept 2	Upper Martinez Improvements	48,992.3	64,369.9	0.0	0.0	0.0	0.0
Concept 3A	LWC Replacement (FM 1863)	48,992.3	64,369.9	0.0	0.0	0.0	0.0
Concept 3B	LWC Replacement (CR 352/CR 440)	48,992.3	64,369.9	0.0	0.0	0.0	0.0
Concept 3C	LWC Replacement (CR 347/CR 417)	48,992.3	64,369.9	0.0	0.0	0.0	0.0
Concept 3D	LWC Replacement (FM 537)	48,992.3	64,369.9	0.0	0.0	0.0	0.0
Concept 4	LID Requirements	48,992.3	46,509.1	0.0	17,860.8	8930.4	5.0
Concept 5	BMP Retrofit	48,946.5	64,255.4	45.8	114.5	80.1	0.0
Concept 6	Regional Water Quality Pond	47,294.5	62,346.8	1,697.8	2,023.1	1860.4	1.0
Concept 7	Fertilizer Mgmt. & Education	46,771.8	61,573.1	2,220.5	2,796.8	2508.6	1.4

4.1.5. Decreased Ammonia Nitrogen

As seen in Table 4-5, Concept 4 provides the largest reduction in average ammonia nitrogen loading throughout the watershed. The remaining water quality focused concepts (5, 6 and 7) provide only minimal reductions to average ammonia nitrogen loads.

Table 4-5 Decreased Ammonia Nitrogen Summary

		Avg. Reach Ammonia Nitrogen Load (lbs)		*Avg. Reach Ammonia Nitrogen Load Decrease (lbs)*			
Condition	**Description**	**Existing**	**Future**	**Existing**	**Future**	**Avg. Load Decrease (Existing & Future)**	**Normalized Score**
Baseline	No Improvements	1,076.6	1,619.0	-	-	-	
Concept 1	Restrictor S-191	1,076.6	1,619.0	0.0	0.0	0.0	0.0
Concept 2	Upper Martinez Improvements	1,076.6	1,619.0	0.0	0.0	0.0	0.0
Concept 3A	LWC Replacement (FM 1863)	1,076.6	1,619.0	0.0	0.0	0.0	0.0
Concept 3B	LWC Replacement (CR 352/CR 440)	1,076.6	1,619.0	0.0	0.0	0.0	0.0
Concept 3C	LWC Replacement (CR 347/CR 417)	1,076.6	1,619.0	0.0	0.0	0.0	0.0
Concept 3D	LWC Replacement (FM 537)	1,076.6	1,619.0	0.0	0.0	0.0	0.0
Concept 4	LID Requirements	1,076.6	1,136.6	0.0	482.4	241.2	5.0
Concept 5	BMP Retrofit	1,075.8	1,616.2	0.9	2.8	1.9	0.0
Concept 6	Regional Water Quality Pond	1,064.7	1,605.5	11.9	13.5	12.7	0.3
Concept 7	Fertilizer Mgmt. & Education	1,061.2	1,588.0	15.4	31.0	23.2	0.5

4.1.6. Decreased Organic Phosphorus

As seen in Table 4-6, Concept 4 provides the largest reduction in average organic phosphorus loading throughout the watershed. Concept 5 (BMP retrofit) and Concept 7 (fertilizer management) provide minimal reductions to average organic phosphorus loads. Concept 6 (Regional Water Quality Ponds) increases average organic phosphorus loads in the watershed. The remaining concepts have no effect on organic phosphorus loads.

Table 4-6 Decreased Organic Phosphorus Summary

		Avg. Reach Organic Phosphorus Load (lbs)		*Avg. Reach Organic Phosphorus Load Decrease (lbs)*			
Condition	**Description**	**Existing**	**Future**	**Existing**	**Future**	**Avg. Load Decrease (Existing & Future)**	**Normalized Score**
Baseline	No Improvements	3,413.8	4,292.6	-	-	-	
Concept 1	Restrictor S-191	3,413.8	4,292.6	0.0	0.0	0.0	0.5
Concept 2	Upper Martinez Improvements	3,413.8	4,292.6	0.0	0.0	0.0	0.5
Concept 3A	LWC Replacement (FM 1863)	3,413.8	4,292.6	0.0	0.0	0.0	0.5
Concept 3B	LWC Replacement (CR 352/CR 440)	3,413.8	4,292.6	0.0	0.0	0.0	0.5
Concept 3C	LWC Replacement (CR 347/CR 417)	3,413.8	4,292.6	0.0	0.0	0.0	0.5
Concept 3D	LWC Replacement (FM 537)	3,413.8	4,292.6	0.0	0.0	0.0	0.5
Concept 4	LID Requirements	3,413.8	3,474.9	0.0	817.6	408.8	5.0
Concept 5	BMP Retrofit	3,411.1	4,290.5	2.7	2.1	2.4	0.5
Concept 6	Regional Water Quality Pond	3,448.3	4,348.6	(34.5)	(56.1)	(45.3)	0.0
Concept 7	Fertilizer Mgmt. & Education	3,369.5	4,215.9	44.3	76.6	60.5	1.2

4.1.7. Decreased Ortho-Phosphorus

As seen in Table 4-7, Concept 4 (LID Requirements) provides the largest reduction in average ortho-phosphorus loading throughout the watershed. The remaining water quality focused concepts (5, 6 and 7) provide minimal reductions to average ortho-phosphorus loads.

Table 4-7 Decreased Ortho-Phosphorus Summary

		Avg. Reach Ortho Phosphorus Load (lbs)		*Avg. Reach Ortho Phosphorus Load Decrease (lbs)*			
Condition	**Description**	**Existing**	**Future**	**Existing**	**Future**	**Avg. Load Decrease (Existing & Future)**	**Normalized Score**
Baseline	No Improvements	22,614.0	19,886.3	-	-	-	
Concept 1	Restrictor S-191	22,614.0	19,886.3	0.0	0.0	0.0	0.0
Concept 2	Upper Martinez Improvements	22,614.0	19,886.3	0.0	0.0	0.0	0.0
Concept 3A	LWC Replacement (FM 1863)	22,614.0	19,886.3	0.0	0.0	0.0	0.0
Concept 3B	LWC Replacement (CR 352/CR 440)	22,614.0	19,886.3	0.0	0.0	0.0	0.0
Concept 3C	LWC Replacement (CR 347/CR 417)	22,614.0	19,886.3	0.0	0.0	0.0	0.0
Concept 3D	LWC Replacement (FM 537)	22,614.0	19,886.3	0.0	0.0	0.0	0.0
Concept 4	LID Requirements	22,614.0	15,506.5	0.0	4,379.8	2189.9	5.0
Concept 5	BMP Retrofit	22,595.8	19,880.1	18.1	6.1	12.1	0.0
Concept 6	Regional Water Quality Pond	22,391.9	19,618.3	222.1	268.0	245.1	0.6
Concept 7	Fertilizer Mgmt. & Education	22,052.8	19,247.3	561.1	639.0	600.1	1.4

4.1.8. Decreased Chlorophyll-a

As seen in Table 4-8, Concept 4 provides the largest reduction in average chlorophyll-a loading throughout the watershed. Concept 5 (BMP retrofit) and Concept 7 (fertilizer management) provide minimal reductions to average chlorophyll-a loads, while Concept 6 shows an increase in chlorophyll-a. This increase is a by-product of the increased detention time provided by the water quality reservoir. In practice this additional chlorophyll-a would be mitigated by the increased plant growth. Due to this increase however, the normalized score for Concept 6 was set to zero.

Table 4-8 Decreased Chlorophyll-a Summary

		Avg. Reach Chlorophyll-a Load (lbs)		*Avg. Reach Chlorophyll-a Load Decrease (lbs)*			
Condition	**Description**	**Existing**	**Future**	**Existing**	**Future**	**Avg. Load Decrease (Existing & Future)**	**Normalized Score**
Baseline	No Improvements	132,428.8	162,892.8	-	-	-	
Concept 1	Restrictor S-191	132,428.8	162,892.8	0.0	0.0	0.0	1.2
Concept 2	Upper Martinez Improvements	132,428.8	162,892.8	0.0	0.0	0.0	1.2
Concept 3A	LWC Replacement (FM 1863)	132,428.8	162,892.8	0.0	0.0	0.0	1.2
Concept 3B	LWC Replacement (CR 352/CR 440)	132,428.8	162,892.8	0.0	0.0	0.0	1.2
Concept 3C	LWC Replacement (CR 347/CR 417)	132,428.8	162,892.8	0.0	0.0	0.0	1.2
Concept 3D	LWC Replacement (FM 537)	132,428.8	162,892.8	0.0	0.0	0.0	1.2
Concept 4	LID Requirements	132,428.8	133,115.7	0.0	29,777.2	14888.6	5.0
Concept 5	BMP Retrofit	132,316.2	162,833.4	112.6	59.4	86.0	1.2
Concept 6	Regional Water Quality Pond	135,810.4	168,705.2	(3,381.6)	(5,812.4)	(4597.0)	0.0
Concept 7	Fertilizer Mgmt. & Education	130,864.0	160,292.7	1,564.8	2,600.1	2082.5	1.7

4.1.9. Decreased Bacteria

Concept 4, as shown in Table 4-9, provides the largest average bacteria reduction throughout the watershed. Concept 5 (BMP retrofit) and Concept 6 (regional water quality pond) provide much less reduction to average bacteria loads.

Table 4-9 Decreased Bacteria Summary

		Avg. Reach Bacteria Load (#10^6)		*Avg. Reach Bacteria Load Decrease (#10^6)*			
Condition	**Description**	**Existing**	**Future**	**Existing**	**Future**	**Avg. Load Decrease (Existing & Future)**	**Normalized Score**
Baseline	No Improvements	419,535,137	1,159,646,196	-	-	-	
Concept 1	Restrictor S-191	419,535,137	1,159,646,196	0	0	0	0.0
Concept 2	Upper Martinez Improvements	419,535,137	1,159,646,196	0	0	0	0.0
Concept 3A	LWC Replacement (FM 1863)	419,535,137	1,159,646,196	0	0	0	0.0
Concept 3B	LWC Replacement (CR 352/CR 440)	419,535,137	1,159,646,196	0	0	0	0.0
Concept 3C	LWC Replacement (CR 347/CR 417)	419,535,137	1,159,646,196	0	0	0	0.0
Concept 3D	LWC Replacement (FM 537)	419,535,137	1,159,646,196	0	0	0	0.0
Concept 4	LID Requirements	419,535,137	707,711,759	0	451,934,437	225,967,219	5.0
Concept 5	BMP Retrofit	418,958,363	1,158,403,952	576,775	1,242,244	909,509	0.0
Concept 6	Regional Water Quality Pond	404,253,403	1,124,885,837	15,281,735	34,760,359	25,021,047	0.6
Concept 7	Fertilizer Mgmt. & Education	419,535,137	1,159,646,196	0	0	0	0.0

4.1.10. Compatibility with Park Plan

Table 4-10 displays the scoring for each concept regarding its compatibility with the plan presented in the Phase 2 report.

Table 4-10 Compatibility with Park Plan Scoring

Concept	Description	Score	Explanation
Concept 1	Restrictor S-191	4	The restrictor structure is just upstream of the park plan and could provide a trail crossing over Cibolo Creek
Concept 2	Upper Martinez Improvements	0	Not near park plan and no potential for recreation enhancements
Concept 3A	LWC Replacement (FM 1863)	0	Not near park plan and no potential for recreation enhancements
Concept 3B	LWC Replacement (CR 352/CR 440)	0	Not near park plan and no potential for recreation enhancements
Concept 3C	LWC Replacement (CR 347/CR 417)	0	Not near park plan and no potential for recreation enhancements
Concept 3D	LWC Replacement (FM 537)	0	Not near park plan and no potential for recreation enhancements
Concept 4	LID Requirements	0	No potential for recreation enhancements
Concept 5	BMP Retrofit	0	No potential for recreation enhancements
Concept 6	Regional Water Quality Pond	3	Not near park plan, but potential for recreation enhancements
Concept 7	Fertilizer Mgmt. & Education	0	No potential for recreation enhancements

4.1.11. Environmental Impacts

Table 4-11 explains the scoring for each concept regarding its positive or negative impacts on the environment.

Table 4-11 Environmental Impacts Scoring

Concept	Description	Score	Explanation
Concept 1	Restrictor S-191	3	No impact to the environment
Concept 2	Upper Martinez Improvements	3	No impact to the environment
Concept 3A	LWC Replacement (FM 1863)	3	No impact to the environment
Concept 3B	LWC Replacement (CR 352/CR 440)	3	No impact to the environment
Concept 3C	LWC Replacement (CR 347/CR 417)	3	No impact to the environment
Concept 3D	LWC Replacement (FM 537)	3	No impact to the environment
Concept 4	LID Requirements	5	Positive environmental enhancement in the future
Concept 5	BMP Retrofit	4	Some environmental enhancements depending on BMP
Concept 6	Regional Water Quality Pond	5	Positive environmental enhancements
Concept 7	Fertilizer Mgmt. & Education	4	Some environmental enhancements

4.1.12. Ease of Permitting

Table 4-12 explains the scoring for each concept regarding its perceived ease or difficulty of permitting.

Table 4-12 Ease of Permitting Scoring

Concept	Description	Score	Explanation
Concept 1	Restrictor S-191	2	Some permitting challenges
Concept 2	Upper Martinez Improvements	4	Straightforward permitting
Concept 3A	LWC Replacement (FM 1863)	4	Straightforward permitting
Concept 3B	LWC Replacement (CR 352/CR 440)	4	Straightforward permitting
Concept 3C	LWC Replacement (CR 347/CR 417)	4	Straightforward permitting
Concept 3D	LWC Replacement (FM 537)	4	Straightforward permitting
Concept 4	LID Requirements	3	Minimal permitting challenges
Concept 5	BMP Retrofit	3	Minimal permitting challenges
Concept 6	Regional Water Quality Pond	2	Some permitting challenges
Concept 7	Fertilizer Mgmt. & Education	3	Minimal permitting challenges

4.1.13. Stream Stabilization

Table 4-13 explains the scoring for each concept regarding its potential to improve stream function and its potential compatibility with future channel rehabilitation or restoration plans.

Table 4-13 Stream Stabilization Scoring

Concept	Description	Score	Explanation
Concept 1	Restrictor S-191	4	Some improvement to stream stabilization
Concept 2	Upper Martinez Improvements	4	Potential to include meandering or step-pool designs in channel improvement.
Concept 3A	LWC Replacement (FM 1863)	4	The replacement of culverts with bridges will provide some benefit in terms of reduced sedimentation. The bridge crossings will also be more compatible with any future channel restoration project.
Concept 3B	LWC Replacement (CR 352/CR 440)	3	No effect - Stream reach is currently stable
Concept 3C	LWC Replacement (CR 347/CR 417)	3	No effect - Stream reach is currently stable
Concept 3D	LWC Replacement (FM 537)	3	No effect - Stream reach is currently stable
Concept 4	LID Requirements	4	Some improvement to stream stabilization
Concept 5	BMP Retrofit	3	No effect
Concept 6	Regional Water Quality Pond	4	Some improvement to stream stabilization
Concept 7	Fertilizer Mgmt. & Education	3	No effect

4.1.14. Public Support

Table 4-14 explains the scoring for each concept regarding its perceived level of public support.

Table 4-14 Public Support Scoring

Concept	Description	Score	Explanation
Concept 1	Restrictor S-191	3	Indifferent
Concept 2	Upper Martinez Improvements	4	Some support
Concept 3A	LWC Replacement (FM 1863)	5	Very supportive
Concept 3B	LWC Replacement (CR 352/CR 440)	5	Very supportive
Concept 3C	LWC Replacement (CR 347/CR 417)	5	Very supportive
Concept 3D	LWC Replacement (FM 537)	5	Very supportive
Concept 4	LID Requirements	4	Some support
Concept 5	BMP Retrofit	2	Unsupportive
Concept 6	Regional Water Quality Pond	3	Indifferent
Concept 7	Fertilizer Mgmt. & Education	3	Indifferent

4.2. Concept Scores

The benefit criteria scores discussed in Section 4.1 were used to calculate concept scores. The individual benefit criteria scores (0-5) for each concept were multiplied by the weight of each benefit criteria (see Table 4-15). The sum-product of each concepts benefit criteria scores and weights yielded a "concept score" for each concept.

Table 4-15 Benefit Criteria Weights

Benefit Criteria	Weight
Flood Damage Reduction (EAD)	20
Public Safety (Crossings)	20
Dissolved Oxygen (DO) Reduction	5
Nitrate Nitrogen (NO3-) Reduction	5
Ammonia Nitrogen (NH3-N) Reduction	5
Organic Phosphorus (OP) Reduction	5
Ortho-Phosphorus (PO4) Reduction	5
Chlorophyll-a Reduction	5
Bacteria (E. Coli) Reduction	10
Compatibility with Park Plan	5
Environmental Enhancements	5
Ease of Permitting	3
Stream Stabilization	5
Public Support	2
Total =	**100**

The Concept Scores for each concept are displayed in Table 4-16. Concept 4 (LID Requirements) has the highest score as it provided both flood risk and water quality benefits. Concept 2, the Upper Martinez Creek Improvements, has the second highest score. Concept 3C (Replacement of CR 357 crossing of Cibolo Creek) and Concept 3B (Replacement of CR 352 crossing of Cibolo Creek) have the third and fourth highest scores as these concepts yield significant reduction to DCF. The lowest scoring concept is Concept 5 (BMP Retrofit), which is logical given that it only provides very small and localized benefits to water quality.

Table 4-16 also provides a concept ranking that considers the present value cost of each concept over a 50-year period. The rankings are based upon the Concept Score divided by the present value cost of the concept (in $100,000).

Table 4-16 Concept Scores and Ranks

Concept	Description	Rank	Concept Score	Cost (PV)	Concept Score / $100,000
Concept 3B	LWC Replacement (CR 352/CR 440)	1	179.2	$1,393,824	12.9
Concept 3C	LWC Replacement (CR 347/CR 417)	2	185.4	$2,498,909	7.4
Concept 4	LID Requirements	3	339.7	$6,617,647	5.1
Concept 2	Upper Martinez Creek Improvements	4	196.7	$3,848,751	5.1
Concept 6	Regional Water Quality Pond	5	111.6	$3,120,820	3.6
Concept 3D	LWC Replacement (FM 537)	6	140.6	$3,970,548	3.5
Concept 3A	LWC Replacement (FM 1863)	7	158.3	$8,022,084	2.0
Concept 5	BMP Retrofit	8	82.3	$6,772,516	1.2
Concept 1	Restrictor (S-191)	9	119.5	$10,550,440	1.1
Concept 7	Fertilizer Management & Education	10	105.7	$11,000,000	1.0

The ranking showed that, in general, the low water crossing replacements had the most benefits (concept score) per $100,000 of assumed cost. Specifically, the replacement of County Road 352/County Road 440 in Wilson and Guadalupe County, which happens to be the most dangerous crossing in the watershed, has a concept score per $100,000 of assumed cost of 12.9. The replacement of County Road 347/County Road 417 (Wilson/Guadalupe County) has a concept score per $100,000 of assumed cost of 7.4. The benefits of these crossing replacements are driven almost solely by increased safety.

The implementation of LID requirements for future development produces significant benefits for the future condition. Flood damage reduction and low water crossings safety benefits are moderate for this concept. Water quality benefits are the largest driver of this concept. This concept has a concept score per $100,000 of assumed cost of 5.1.

The Upper Martinez Creek conveyance improvements provides the most benefits of all the concepts in terms of flood damage reduction. However, the concept provides only minimal improvement to crossing safety and no water quality benefits. This concept has a concept score per $100,000 of assumed cost of 5.1.

The proposed regional water quality pond concept produces no flood reduction or crossing safety benefits. The water quality benefits are moderate along lower Cibolo Creek but are only minor when the entire watershed is considered. However, the low construction and maintenance cost of this concept yields a concept score per $100,000 of assumed cost of 3.6.

The replacement of the County Road 537 crossing of Cibolo Creek in Wilson County has a concept score per $100,000 of assumed cost of 3.5.

The remaining concepts (the replacement of the FM 1863 crossing of Cibolo Creek, BMP Retrofit, Restrictor S-191, and Fertilizer Management and Education) all had concept scores per $100,000 of assumed cost of 2.0 or less.

5. Conclusion

In Phase 1 of the C2MP Atkins collected stakeholder input and relevant data for the Cibolo Creek watershed related to flood risk, water quality, stream health and recreation. This information was used in Phase 2 to identify Damage Centers, which are areas with significant flood risk, water quality, and/or stream health concerns that are of an intensity and contiguity to potentially warrant an improvement project. Phase 2 was concluded by identifying potential Opportunity Centers which are areas with positive features to be preserved or enhanced. In Phase 3 Atkins developed and evaluated a list of proposed concepts based upon their ability to reduce flood risk, provide water quality benefits, provide recreational enhancements, and improve stream function.

The evaluated project concepts included:

- Restrictor S-191
- Upper Martinez Creek Improvements
- Low Water Crossing Replacements (5 crossings)
- LID Requirements for Future Development
- Infiltration BMP Retrofit
- Regional Water Quality Pond
- Fertilizer Management & Education

Atkins developed scores for both quantitative and qualitative benefits for each concept based upon the benefits provided over a 50-year timeframe. The quantitative benefits of each concept, which were calculated using modeling results, were normalized against the results of all concepts to produce a score between 0 and 5. The project team scored each concepts' qualitative benefit criterion between 0 to 5.

Each benefit criterion was given a weight between 0% and 100% to reflect its perceived importance by stakeholders. The sum of the criterion weights is 100%. An overall score was generated for each concept by calculating the sum-product of the benefit criterion scores and weights. Finally, a benefit-to-cost ratio was calculated for each concept by dividing each concept's benefit score by the present value of the cost to implement the concept. Table 5-1 displays the ranking of the various improvement concepts analyzed in Phase 3.

Table 5-1 Concept Ranking

Rank	Concept	Description	Concept Score / $100,000 Cost
1	Concept 3B	LWC Replacement (CR 352/CR 440)	12.9
2	Concept 3C	LWC Replacement (CR 347/CR 417)	7.4
3	Concept 4	LID Requirements	5.1
4	Concept 2	Upper Martinez Creek Improvements	5.1
5	Concept 6	Regional Water Quality Pond	3.6
6	Concept 3D	LWC Replacement (FM 537)	3.5
7	Concept 3A	LWC Replacement (FM 1863)	2.0
8	Concept 5	BMP Retrofit	1.2
9	Concept 1	Restrictor (S-191)	1.1
10	Concept 7	Fertilizer Management & Education	1.0

Although the concepts were modeled with a specific set of assumptions (location, size, cost, etc.), the rankings and concept results can, in many cases, be extrapolated to other parts of the watershed and used to direct future planning efforts. In addition, Atkins recommends that the following be considered for any future planning efforts:

- Dangerous low water crossings are a significant concern in the watershed. Approximately 42% of the modeled creek crossings in the watershed are dangerous during the 50% AEP event. Additional dangerous low water crossing replacements should be evaluated using methodologies outlined in the C2MP.

- The Upper Martinez Creek Improvements (Concept 2) concept can likely be optimized. The current concept includes a replacement of the Gibbs Sprawl Road low water crossing, which provides only minimal flood damage reduction and safety benefits. Stand-alone channel improvements to Upper Martinez Creek may score better without the added expense of the Gibbs Sprawl Road replacement.

- The Upper Martinez Creek Improvements (Concept 2) concept includes a reach of Upper Martinez Creek that was assigned a category of NCD1 in the Phase 2 stream restoration potential assessment since it has the potential to be restored or rehabilitated using NCD techniques based on existing constraints. Any channel improvements in this reach should consider using NCD techniques such as meandering or step-pool designs to restore stream function and provide improved geomorphic stability.

- Restrictor S-191 may perform better if it is simulated as a reservoir instead of a restrictor. Although a reservoir might have impacts to pulse flows, it would likely have some water quality benefits and aquifer recharge benefits in addition to flood risk reduction and safety improvement benefits.

- The pending update to NOAA Atlas 14 will likely increase rainfall depths across the upper portion of the Cibolo Creek watershed, which may affect flood damage and dangerous crossings in the watershed. The concepts that have at least some flood risk benefits (Concept 1, 2, 3 and 4) may score better with larger baseline flood damages and more dangerous crossings.

- The implementation of LID across the watershed as applied to future development is shown to provide significant improvements in water quality conditions. Encouraging communities to incorporate these practices in their development codes, should result in significant improvements in watershed water quality. While the current standard addresses treatment of 80% of the increase in new loading, considering more stringent criteria or applying the criteria to redevelopment will have benefits. Alternatively, providing incentives to implement these practices as retrofit alternatives is a cost-effective way to increase water quality conditions and enhance landscapes.

- The BMPs proposed for Concept 5 (BMP Retrofit) are applicable to the entire watershed, particularly where urban development exists. Depending on the right-of-way availability, enhancement of existing swales areas may be a low-cost alternative to provide water quality treatment. Encouraging retrofits at the local or homeowner level through grants or regulation would have a beneficial impact on the watershed.

- Effective fertilizer and land tilling practices, achieved through education and community ordinances, provide both a beneficial impact to water quality and reduces overall fertilizer application rates. The low cost to implement these practices makes it a valuable element of the holistic watershed improvement plan.

- Water quality reservoirs, both small and large, provide opportunities for ecological restoration and aquifer recharge without claiming significant amounts of land that is otherwise barren or allocated to agriculture use or ranching applications. These reservoirs can be constructed in minor creeks and dry riverbeds through check dams. Water quality reservoirs can both enhances the existing land and provides for water quality treatment.

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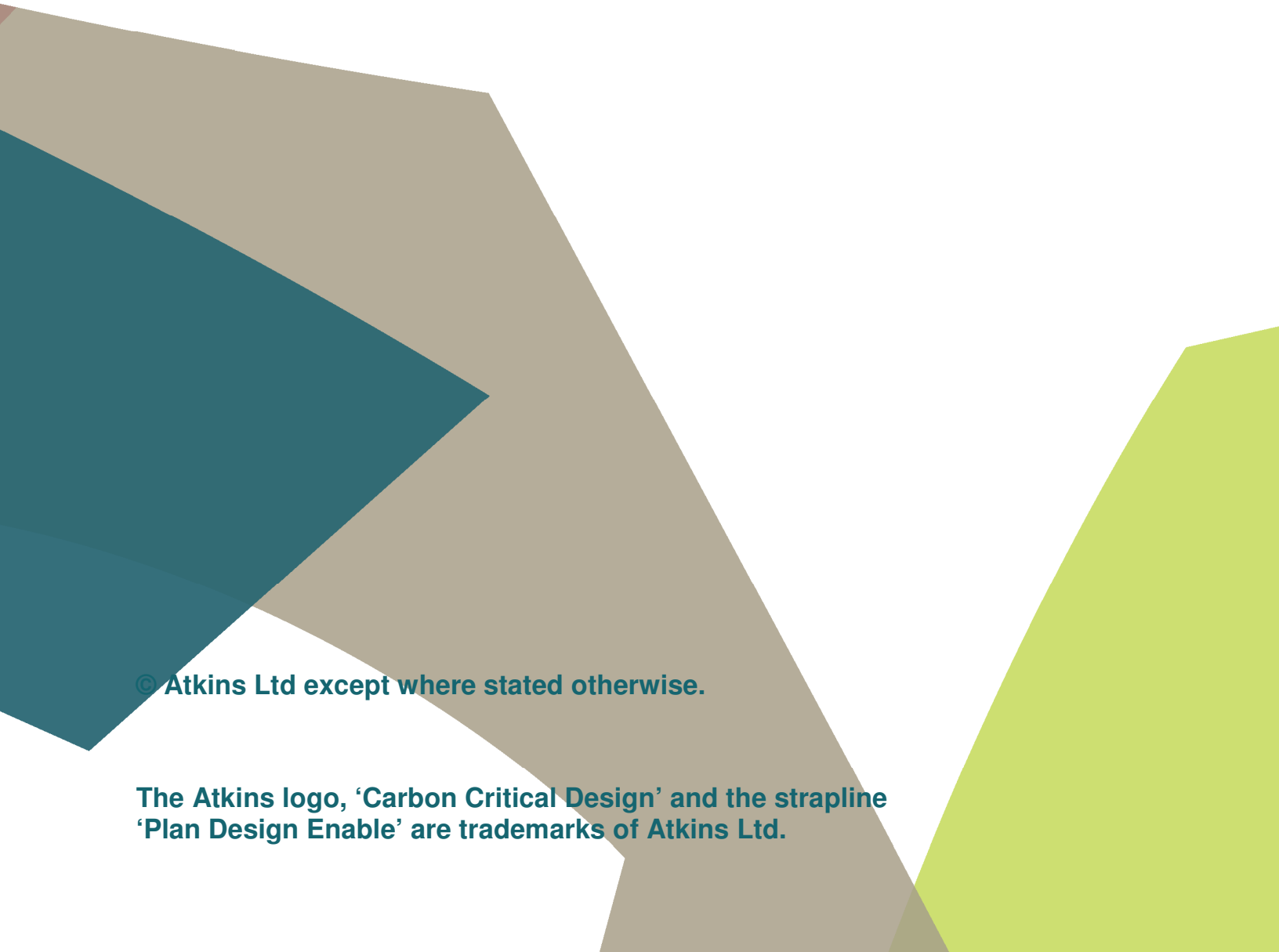
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