# Appendix A: Hydrology and Hydraulics

River Road Aquatic Ecosystem Restoration
San Antonio, TX

Continuing Authorities Program

November 2020

The following work was performed by the San Antonio River Authority and reviewed by the US Army Corps of Engineers Fort Worth District Office.

# HYDROLOGY AND HYDRAULICS APPENDIX

## STUDY PURPOSE

The River Road Ecosystem Restoration feasibility study was conducted under the re-evaluation of the San Antonio Channel Improvement Project (SACIP) authorized in 1954. Construction of the SACIP project was completed in 1986. This is a study to address opportunities relating to ecosystem restoration by removal of low water crossings , designing in-stream structures to establish pools, riffles and runs to enhance aquatic habitat as well as removal of invasive vegetation with an associated replanting with native riparian vegetation. The local sponsor for this project is the San Antonio River Authority (SARA).

## STUDY AUTHORITY

WRDA 2000, SEC. 335. SAN ANTONIO CHANNEL, SAN ANTONIO, TEXAS.

The project for flood control, San Antonio channel, Texas, authorized by section 203 of the Flood Control Act of 1954 (68 Stat. 1259) as part of the comprehensive plan for flood protection on the Guadalupe and San Antonio Rivers in Texas, and modified by section 103 of the Water Resources Development Act of 1976 (90 Stat. 2921), is further modified to include environmental restoration and recreation as project purposes.

## STUDY AREA

The study area is located entirely within Bexar County, Texas and encompassed with the San Antonio River watershed. The Olmos Creek-San Antonio River Watershed, a sub watershed to the San Antonio River watershed, covers the north portion of downtown San Antonio, Texas as well as areas to the west and north of downtown. The headwaters of the Olmos Creek-San Antonio River watershed are located on the north side of San Antonio with the mouth being at the confluence with the San Antonio River south of downtown. This study San Antonio River contained within the authorized and constructed SACIP. The study area is approximately 4.55 miles long and 0.80 miles wide at the widest point. The size of the study area is approximately 40.41 acres, or 0.063 square miles. Elevations within the study area range from 628 feet to 748 feet. On the following pages, Figure 1 identifies the constructed SACIP, and Figure 2 identifies the River Road study area within the San Antonio River Watershed.

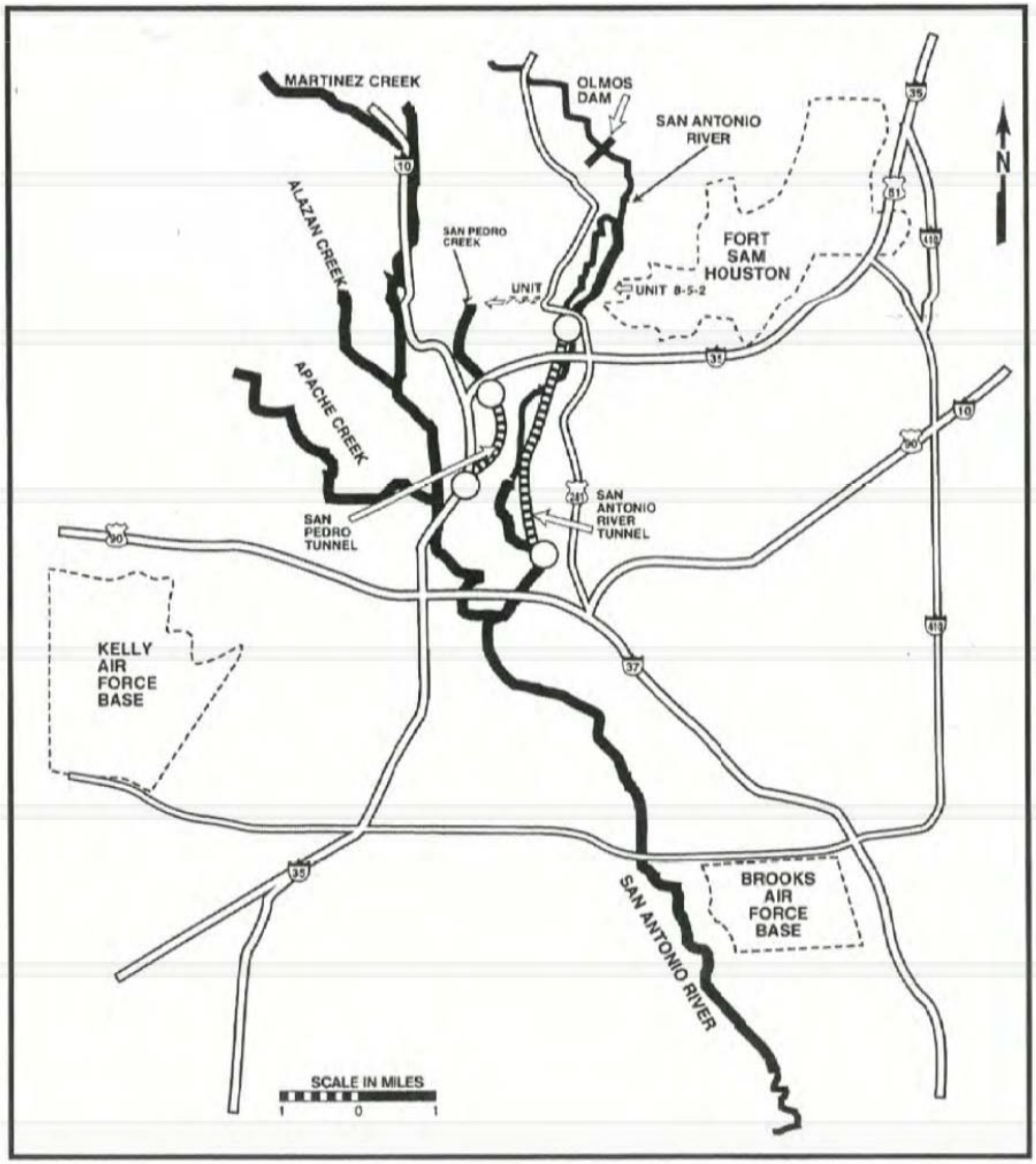


Figure 1 - SACIP Authorized & Constructed Project

Figure 2. River Road Project Location

## CLIMATE

Bexar County has a modified subtropical climate, predominately continental in winter and marine in summer. San Antonio is situated between a semi-arid climate to the west, and a wetter, more humid area to the east. This results in large variations in the monthly and annual precipitation amounts. Median annual rainfall is slightly less than 29 inches over a 141 year record (1871-2012). The range varies from 10 inches in 1917 to 52 inches in 1973. Mean rainfall is slightly over 29 inches. January is typically the driest month with an average of 1.61 inches of precipitation, and a median of 1.01 inches. May is the wettest month with a median of 3.48 inches and a mean of 2.84 inches of precipitation. The 30 year normals calculated beginning in 1921 and carrying forward to 2010 range from 27.5 inches in 1941-1970 to 32.9 inches in 1971- 2000 (Refer to Figure 3).

The most recent 30 year normal (1981-2010) is 32.27 inches. On average, the heaviest rains fall in May, September, and October. The wettest month on record is October 1998 in which San Antonio received over 18 inches of rainfall. The rain event occurring October 17-18, 1998 is the event of record, exceeding the 1% Annual Chance Exceedance for this area according to the United States Geological Survey (USGS). The driest months are usually December through March, and July. However, rainfall is sporadic, so the wettest or driest month in any one year may occur in any season and vary greatly from year to year. Small hail is frequent with springtime thunderstorms, though it has been known to occur in other seasons. Measurable snowfall usually occurs once every 3 to 4 years, with snowfall as high as 2-4 inches occurring about once every 10 years.

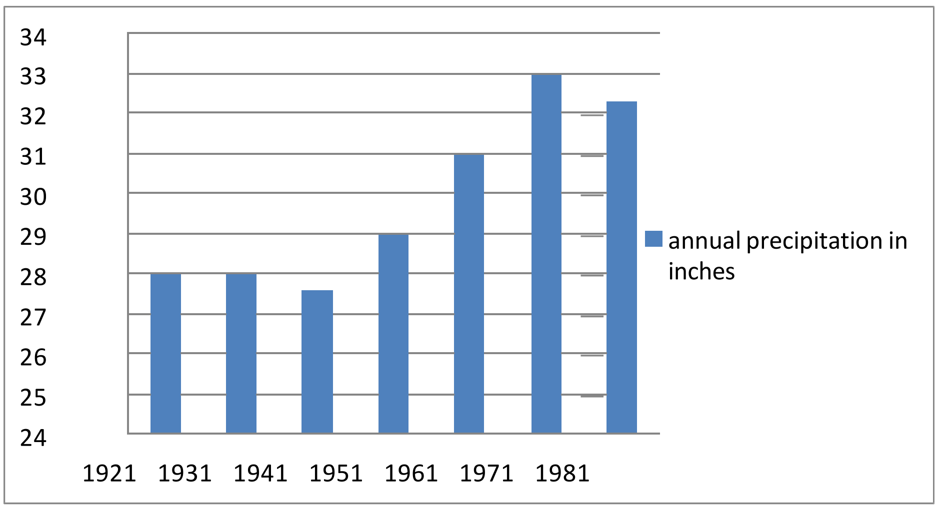


Figure 3. 30 Year Normal Average Annual Precipitation in Inches

The mean and median annual temperature over a 127 year period (1885-2012) is 69.1°F, with normal temperatures ranging from a mean/median daily high of 84°F in July and August to an mean/median daily high of 52° F in January Refer to Figure 4). Mild weather prevails most of the winter, with freezing temperatures only occurring approximately 20 days per year. The coldest low of record was 0˚F on January 31, 1949. Temperature levels can vary as much as 40-50 degrees in a day allowing for 100 degree winter temperatures as experienced 21 February 1996 and 6 March 1991. Summers are usually long and hot with daily maximum temperatures over 90˚F roughly 80% of the time. The highest temperature of record is 111˚F on 5 September 2000. Occasionally, cool fronts move through the area dropping overnight lows into the 50's and 60's for a cooling period that only lasts a day or two.

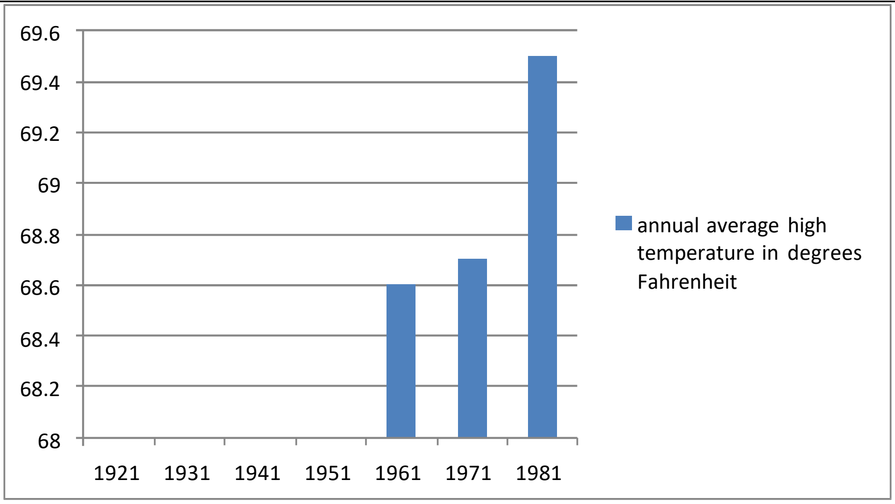


Figure 4. 30 Year Normal Average Annual High Temperature in Degrees Fahrenheit

# FLOOD HISTORY

There have been 189 flood events in Bexar County between May 1993 and May 2011, of which 19 of these affected the WSC study area. The three most influential events are documented below:

**October16-18, 1998** – SACIP prevented an estimated $296 Million (1998 dollars) in damages for this event of record. The following account is taken from the USGS, NOAA website:

> In advance of a very slow-moving upper level trough of low pressure over West Texas, a cold front drifted slowly southeastward into West Central Texas during the evening of Friday, October 16th. Deep moisture was in place across South Central Texas as the two systems approached, being fed at the mid and upper levels by two nearly stationary hurricanes, Madeline near the tip of Baja Mexico, and Lester, anchored just off Acapulco, Mexico, and in the low levels by a strong flow from the Gulf of Mexico. A very moisture-rich environment was in place across South Central Texas as the event developed. Near 3 am CST, with the cold front still west of San Angelo, scattered showers and thunderstorms began to break out over Bexar County beneath the mid and upper level moisture plume. They quickly became widespread as a low level rain-cooled boundary formed along the south and east edge of the county. It was upon this boundary that subsequent showers and thunderstorms continued to form. By 6 am CST, rainfall of up to 4 inches had been reported in Western Bexar County. By 8 am CST that morning, heavy rain continued over Bexar County. Amounts at this time were approaching 8 inches. The heavy rain continued through the morning period.
>
> All rivers, creeks and streams along and east of a San Antonio to Austin line remained at or above flood stage from Saturday, October 17th through Sunday, October 18th, with a majority continuing to flood through Monday, October 19th. On Tuesday, October 20th and Wednesday, October 21st, flooding was confined to rivers, streams and creeks along and east of a LaGrange-Gonzales-Karnes City line.
>
> This event broke rainfall records across South Central Texas, producing 18 floods of record in South Central Texas streams. October became the wettest of any month in climate records for San Antonio since 1885. October 17th became the wettest day and wettest 24-hour period in San Antonio climatic records, nearly doubling both previous records. Rivers across the area reached or exceeded record stage heights, resulting in widespread flooding in the flood plains of streams, creeks and rivers. Rainfall amounts on October 17 and 18th from northern Bexar County to southeast Kendall County, most of Comal County and southern Hays County ranged from 15 to 22 inches. Damage and destruction to livestock and agriculture, roads and bridges and both public and private property and buildings significantly exceeded that of previous flooding. Thousands to tens of thousands of livestock were killed, as nearly 3000 homes were destroyed and another 8000 or so homes were damaged. Nearly 1000 mobile homes were destroyed and another 3000 were damaged. Twenty-five people drowned as a direct result of the flooding in October in South Central Texas.

**September 27, 1946 –** This was the worst flood since the flood of 1921 hit San Antonio.

> Damage was estimated to be 2.1 million in 1946 dollars with a death toll of six. A total of 6.74 inches of rain fell on the city in a 12-hour period. Some hotels experienced 3-4 feet of water in their lobbies. It is estimated that 700-1200 people were displaced by the floods. Fort Sam Houston ordered 400 soldiers to duty to help with rescue and recovery efforts. North of San Antonio sits Olmos Dam (built 22 years prior) with a height of 52 feet. Water reached the 37 foot mark according to Fire and Police Commissioner P. L. Anderson. The dam is credited with saving lives and preventing even more damage. Two bridges on West Houston Street Bridge crossing over Alazan Creek were both destroyed. Other bridges were damaged as well. While an event frequency was not estimated at the time, later work indicated that this was something more frequent than a 1% Annual Chance Exceedance Probability. This event precipitated the USACE study that resulted in the authorization of the SACIP, which was designed to the transposed 1946 storm.

**September 10, 1921 -** Flood waters claimed the lives of 51 people and left behind an estimated $3.7 million in property damage.

Water rose suddenly as precipitation ranged from 6.1-8 inches over a 48 hour period. Water along River Avenue was reportedly 8 feet deep. Parts of the city were under water by 10-15 feet. Rain in the Olmos Valley, north of San Antonio, flooded the San Antonio River. The flood waters of the San Antonio River joined with the already flooded Alazan and San Pedro Creeks on the west side of San Antonio and inundated a large part of the business section as well as residential areas. Flood waters, mainly from the San Antonio River and Alazan Creek, inundated an area approximately two miles long by one half mile wide which included the business section along River Avenue as well as the Westside. In some areas of San Antonio, rushing walls of water were described as 10-30 feet high.

## STUDY FOCUS

As a result of the identified resource significance, the study documented in this report formulates for ecosystem restoration only. However in recognition of the residual flood risk, the ecosystem restoration formulation will remain cognizant of the water surface elevations such that the functionality of the existing flood risk management project remains intact.

### FLOOD RISK

This study takes place within the footprint of an existing FRM project. The existing FRM project was designed to capture the 1946 flood. The existing FRM project does not contain the 1% ACE flood according to the FEMA flood maps. The PDT performed a sensitivity analysis to determine if the residual flooding issue warrants Federal participation consistent with USACE policy. The HEC-RAS model for existing conditions calculated the 1% ACE water surface elevations at each cross section throughout each reach for each of the four creeks. These elevations were provided to calculate the depths of flooding at structures and were calculated using floor corrections ranging from 1.5 feet to 3 feet to obtain a range of finished floor elevations. In GIS, using outlined rooftops, topography and these estimated flood depths, the PDT determined that while the repercussions to specific neighborhood segments are significant to that portion of the population affected, the flood risk to the study area as a whole will not support a USACE flood risk management solution.

## CONSTRAINTS

Constraints are restrictions that limit the planning process. Universal constraints apply to every USACE planning study. They include USACE guidance, regulations, policies and authorities or are defined by laws and regulations of the Federal, State and/or local governments. Study-specific constraints are unique to a specific planning study, and are statements of potential issues that the study team should work to avoid while formulating alternative plans. The following constraint is applicable to this study.

- Avoid increasing water surface elevations as established by the DFIRM mapping completed for FEMA, effective date 29 September 2010.

## ASSUMPTIONS

Assumptions are made to help reduce scope to the appropriate level of detail for the plan formulation and analysis consistent with the new planning paradigm. The following is a list of the critical assumptions used in the development of the Project Management Plan (PMP), the selection of measures, and the combination of measures reflected in the alternatives for detailed analysis:

- The study applies to approximately 4,150 linear feet of the San Antonio River within the San Antonio Channel Improvement Project, but no changes will be made to the San Antonio River hydraulic model upstream of Mulberry Avenue (covers approximately 1.4 miles).
- No Right of Way expansion will be considered.
- All existing and future without project conditions hydrology and hydraulic modeling completed by the sponsor is sufficient to proceed through the feasibility study phase of the project. This includes the assumption that all the required hydraulic structures such as bridges, drop inlets, outfalls, detention areas, and bypass channels are included in the models as well as the accuracy of all utility crossings, bridge surveys and property boundaries.
- The use of Manning's "n" roughness coefficients for proposed woody vegetation zones from the Mission Reach SACIP document will be used throughout the hydraulic model.
- All excavation quantities will be determined by the use of the hydraulic model.
- No pools, riffles, and runs or natural channel design structures will be designed in the hydraulic model in order to expedite the planning and modeling process.
- The low water crossings will be replaced with a 10 ft wide pedestrian bridge.

## HYDROLOGY

The contributing watershed area for the Olmos Creek-San Antonio River basin is highly developed, with extensive residential areas, some commercial and industrial zoning, as well as some park areas. The Contributing Watershed Area includes:

- Olmos Creek-San Antonio River, 43.2 square miles;

As the result of the community's efforts to mitigate frequent flooding conditions and to provide improved storm water management practices for the area, a significant transformation was accomplished in the 1960s and '70s, changing the channels from natural to widened and rectified drainage systems. Through a comprehensive channelization project, the USACE transformed the natural creeks into efficient drainage channels for the purposes of conveying flood waters out of the neighborhoods as quickly as possible. The project was based on the volume of water that occurred in the 1946 flood. The channelization is effective and for many years has provided adequate protection for the area. In many areas, the floodplain was subsequently filled to allow for additional urban development. These changes resulted in creeks that are far from their natural state.

The flooding that had impacted residents and businesses along the San Antonio river was reduced as a result of the channelization and other modifications that were constructed throughout the 20th century, additional development in the area (see Figure 5 for existing land use) adjacent to the River as well as within the upstream portions of the contributing watershed has increased impervious cover (see Figure 6 for existing impervious cover) resulting in greater volumes of storm water runoff. In addition, improved technology to better capture topography and land use to simulate the effects of rain events on the creeks have led to the creation of updated engineering models (See Figure 7 for Watershed Sub Basin Map). These updated models indicate that the existing channelized creeks will not contain the 1% ACE event. The below summary table demonstrates watershed parameters used for runoff calculations.

Table 1. Hydrology Parameters

| Watershed Sub Basin Name | Drainage Area (sq mi) | Curve Number | Impervious % | Lag Time (Minutes) |
|---|---|---|---|---|
| O1 | 1.27 | 77 | 20 | 36 |
| O2a | 0.18 | 77 | 33 | 7.2 |
| O2b | 0.32 | 74 | 36.1 | 21.6 |
| O3 | 1.13 | 78 | 31 | 37 |
| O3a | 1.44 | 79 | 36 | 39 |
| O3b-1 | 0.85 | 76 | 57 | 44 |
| O3b-2 | 1.10 | 78 | 39 | 16 |
| O3c | 0.83 | 76 | 41 | 23 |
| O4-1 | 0.81 | 71 | 28 | 45 |
| O4-2 | 1.44 | 78 | 48 | 33 |
| O4a | 1.71 | 76 | 62 | 18 |
| O4b | 1.53 | 77 | 56 | 29 |
| O5-1 | 1.21 | 77 | 50 | 31 |
| O5-2 | 0.78 | 79 | 59 | 37 |
| O6 | 0.90 | 79 | 63 | 25 |
| O7 | 0.20 | 70 | 64 | 10 |
| O8-1 | 1.44 | 76 | 75 | 43 |
| O8-2 | 1.21 | 77 | 74 | 25 |
| O8-3 | 0.86 | 72 | 76 | 29 |
| O9 | 1.39 | 73 | 69 | 32 |
| O9A | 1.88 | 75 | 65 | 39 |
| O10-1 | 1.09 | 78 | 70 | 31 |
| O10-2 | 0.65 | 78 | 75 | 17 |
| O11 | 0.83 | 79 | 81 | 24 |
| O12 | 0.16 | 80 | 69 | 16 |
| O13-1 | 0.57 | 77 | 79 | 29 |
| O13-2 | 0.88 | 77 | 79 | 19 |
| O13-3 | 0.86 | 79 | 79 | 14 |
| O13-4 | 0.98 | 78 | 66 | 18 |
| O13-R | 0.35 | 64 | 80 | 28 |
| O14 | 0.20 | 80 | 21 | 28 |
| O15-1 | 1.34 | 76 | 55 | 42 |
| O15-2 | 1.07 | 77 | 49 | 60 |
| SA1-1 | 0.41 | 80 | 74 | 37 |
| SA1-2 | 0.67 | 79 | 72 | 19 |
| SA1-3 | 0.80 | 78 | 65 | 23 |
| SA2 | 0.56 | 78 | 54 | 29 |
| SA3 | 1.66 | 76 | 61 | 34 |
| SA3a | 0.07 | 76 | 38 | 14 |
| SA4 | 0.69 | 79 | 55 | 31 |
| SA5 | 0.37 | 74 | 56 | 20 |
| SA6 | 0.50 | 78 | 38 | 33 |
| SA7 | 0.26 | 77 | 69 | 21 |
| SA8 | 0.23 | 76 | 76 | 13 |
| SA8a | 0.12 | 79 | 70 | 14 |
| SA8b | 0.27 | 77 | 77 | 17 |
| SA8c | 0.69 | 79 | 78 | 20 |

| Watershed Sub Basin Name | Drainage Area (sq mi) | Curve Number | Impervious % | Lag Time (Minutes) |
|---|---|---|---|---|
| SA8d | 0.32 | 80 | 78 | 17 |
| SA8e | 0.51 | 80 | 83 | 20 |
| SA8f | 0.18 | 80 | 85 | 13 |
| SA9 | 0.33 | 80 | 84 | 14 |
| SA10 | 0.56 | 79 | 83 | 20 |
| SA10a | 0.09 | 70 | 78 | 9 |
| SA10b | 0.28 | 75 | 76 | 21 |
| SA10c | 0.62 | 77 | 69 | 21 |
| SA11 | 2.09 | 74 | 74 | 42 |
| SA12 | 0.39 | 63 | 78 | 27 |

For analysis of the water surface elevations that could be expected during a 1% ACE (100-yr) event, discharges were used that matched those developed for the FEMA Flood Insurance Study (Bexar County FIS, Sept 2010). Storm runoff for the 1% ACE (100-yr) storm was calculated using Atlas 14 rainfall depth values and utilized a depth of 11.97 in . for the 24-hour storm.

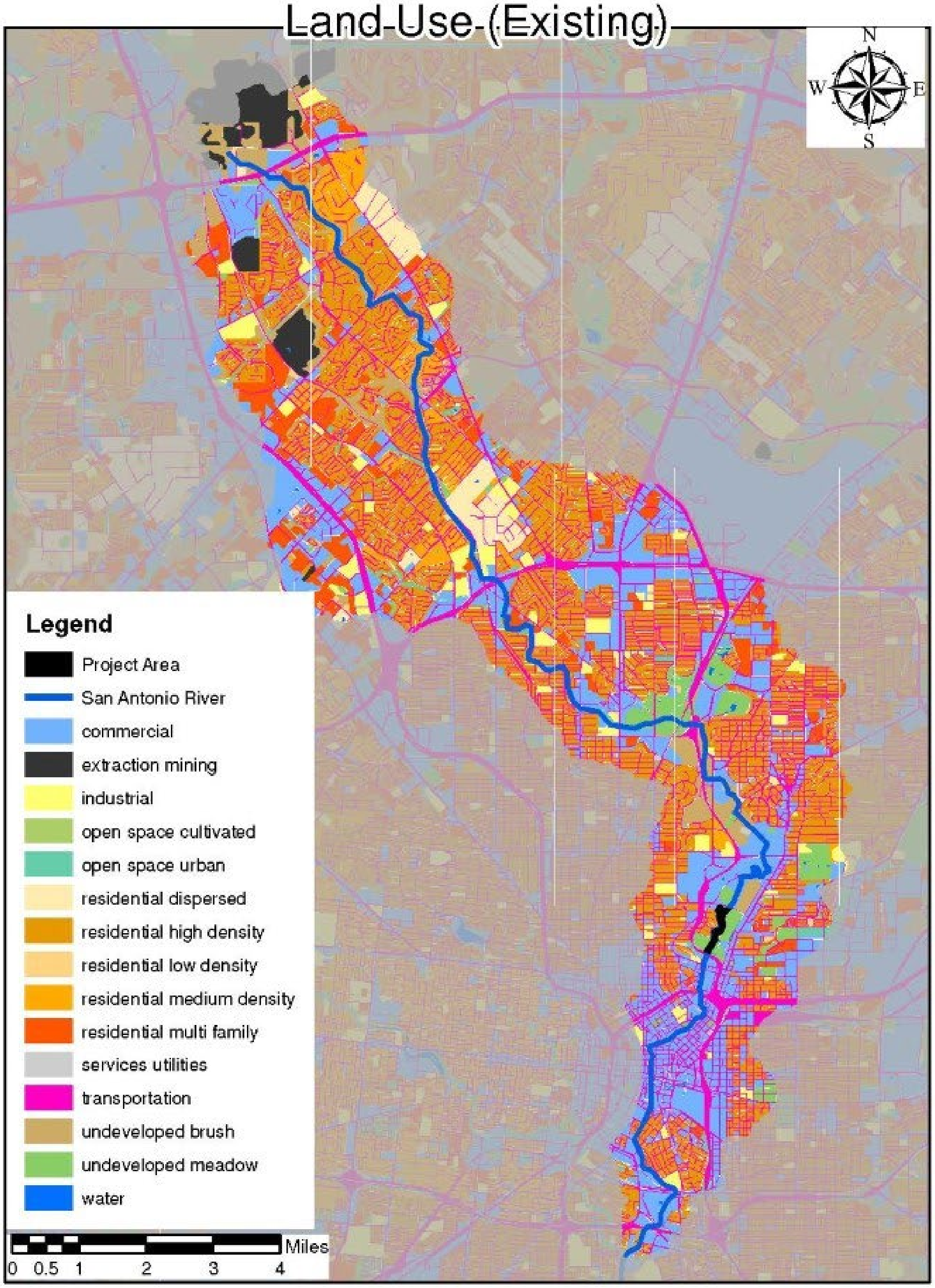


Figure 5. Land Use (Existing)

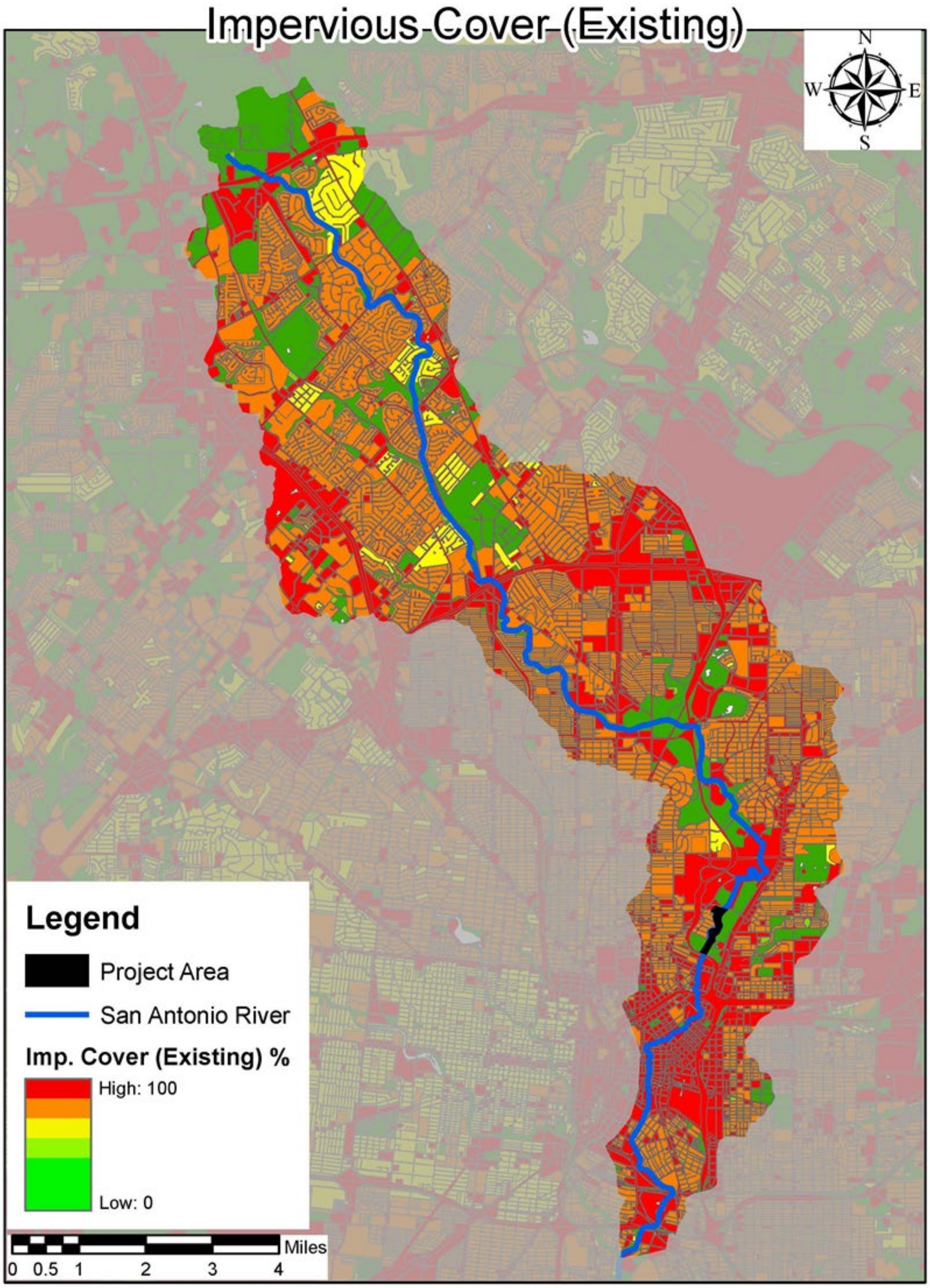

Figure 6. Existing Conditions Impervious Cover


Figure 7. Watershed Sub Basins

# HYDRAULICS

## EXISTING CONDITIONS

This section of the San Antonio river has a natural meander with gradual bank slopes. The vegetation of the banks is natural with non-native species of trees, shrubs, and grass. Some sections of the reach are maintained as manicured lawn due to an adjacent golf course. The section of the San Antonio river also has a series of inline structures, bridge and culvert crossings, and pedestrian (golf cart) bridge structures.

There is a 10 cfs minimum base flow within the San Antonio River that is approximately at WSE 655.45 feet. The water surface elevation for the base flow is maintained by the introduction of recycled waste water treatment effluent upstream of the project area as well as natural springs present near the Upper San Antonio River. This base flow continues to flow downstream where it enters the San Antonio River Tunnel Inlet. The tunnel inlet is approximately 775 feet downstream of the project limits.

## MODELING METHODOLOGY FOR FEMA

The study streams for existing conditions were completed for the Bexar County Hydraulic and Mapping Technical Support Data Notebook (TSDN) which consisted of streams located in the Upper San Antonio River Watershed that were identified by the San Antonio River Authority (SARA) and the Federal Emergency Management Agency (FEMA). The San Antonio LMMP hydraulic model was first updated from the physical FIRM maps back in September 29, 2010 when Bexar County introduced the DFIRM maps. This model has since been updated and manipulated at various points of the model. The model is split into sections labeled, upper, mid, lower, Catalpa Channel, and Catalpa Spill. The sections of the San Antonio River that this project will be studying is the Upper and Mid sections. These sections also incorporate the Catalpa Channel and the Catalpa Spill, but the study limits do not extend into these areas since they are east of the project limits. When the DFIRM model was completed, the cross-section data was based on 2005 two-foot contours, and the channel section of the San Antonio river has not changed extensively since the creation of the model. There has been multiple letter of map revisions (LOMR) within the Upper San Antonio Basin. There are two LOMRs that are within the study limits, LOMR 13-06-3484 and 11-06-0604P with effective dates of August 25, 2014 and March 12, 2012 respectively. These new map revisions supersede the previously accepted LMMP San Antonio River model accepted on September 29, 2010.

The detailed hydraulic study for FEMA consists of hydraulic models based on detailed survey information that will produce new base flood elevations. Hydraulic structure information was obtained from precise and detailed field surveys of the channel banks, base flow, and sub-aquatic terrain. The study also incorporates an updated topographic data based on the 2017 LiDAR Data. The as-built data was not obtained for the series of culverts, bridges, and inline structure because the data has not been changes since the approval of the most recent LOMR within the study limits (LOMR 13-06-3484P). However some additional survey data was incorporated in order to provide additional density of data.

Army Corps of Engineers' (USACE), Hydrologic Engineering Center River Analysis System (HEC-RAS), Version 5.0.7. HEC-RAS, accepted by FEMA for hydraulic analysis, performs one-dimensional hydraulic calculations to model the water surface elevations. RAS Mapper was used to analyze the 2017 LiDAR and convert into terrain surface to update the existing cross sections and stream centerline. AutoCAD Civil 3D was used to analyze all survey data obtained in the field.

The locations for cross sections were not significantly manipulated from the previously FEMA approved LOMR locations since they were properly spaced. Additional cross sections were added to incorporate proper spacing for future structures. There were certain cases where the cross section spacing did not adequately represent the structure, so slight modifications were made.

The inline structures, bridges, and culverts were in place of the recently FEMA approved model. The inline structures demonstrated proper spacing and widths in most cases. The bridges and culverts matched what was evaluated in Aerial Imagery.

The effective flow areas were identified around the bridges and culverts by defining the limits of ineffective flow per the HEC-RAS modeling standards. Ineffective flow areas were delineated in HEC-RAS to identify areas of a cross section in which the flow of water is not effectively conveyed.

Hydraulic models are calibrated using observed high-water marks, measured profiles, and stage information at stream gauges.

Manning's roughness coefficients were determined from field visits and surveys, and ground and aerial photographs. Typical Manning's roughness coefficients used in the HEC-RAS models were based on Table 2 "Manning's Roughness Coefficients", of the San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulics Models Floodplain Mapping, and are represented in the table below. The energy loss coefficients at cross sections, bridges and culverts were chosen as recommended in the HEC-RAS manual.

Table 2. Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Floodplains

| **Channel Description** | **Average n Value** | **Minimum n Value** | **Maximum n Value** |
|---|---|---|---|
| Concrete Lined Channel | 0.015 | 0.010 | 0.020 |
| Grass Lined Channel with regular maintenance | 0.035 | 0.030 | 0.040 |
| Gravel or Outcropping Stone Channel with some Vegetation | 0.045 | 0.040 | 0.050 |
| Grass Lined Channel without recent maintenance | 0.050 | 0.045 | 0.055 |
| Vegetated Channel with trees, little or no underbrush | 0.055 | 0.050 | 0.060 |
| Natural Channel with trees, moderate underbrush | 0.075 | 0.070 | 0.080 |
| Natural Channel with trees, dense underbrush | 0.090 | 0.085 | 0.095 |
| Natural Channel with dense trees and dense underbrush | 0.100 | 0.100 | 0.100 |
| **Overbank Description** | | | |
| Pasture | 0.045 | 0.035 | 0.055 |
| Trees, little or no underbrush, scattered structures | 0.070 | 0.060 | 0.075 |
| Dense vegetation, multiple fences and structures | 0.085 | 0.075 | 0.100 |
| Buildings inundated by floodplains | 0.085 | 0.075 | 0.100 |

## WITHOUT-PROJECT CONDITIONS

The existing conditions hydraulic models for San Antonio River LMMP (LOMR 13-06-3484P) model was provided to the Corps. The Hydrologic Engineering Center River Analysis System (HEC-RAS), Version 5.0.7 was used for this analysis. The changes made from the effective model (LOMR 13-06-3484P) were adjusted to incorporate updated 2017 LiDAR data and field survey. All flows in this model remain unchanged from the existing condition models, as well as most parameters. The modeling includes the 50%,10%, 2%, 1%, 1% Future Conditions and the 0.2% Annual Exceedance Probability (AEP) flood events based on peak discharges.

## WITH-PROJECT CONDITIONS

The development of proposed plans for the restoration of River Road required the development of hydraulic models to determine the water surface elevation impacts due to removal of an inline weir structure, culvert crossings replacement with pedestrian bridges, and placement of woody vegetation zones. The water surface profiles for “With-Project” conditions were then compared to the water surface profiles for “Without-Project” conditions to determine the impacts and ensure that “hydraulic neutrality” was maintained with respect to the existing FRM performance of the floodway at the 1% AEP flood level. Using the “Without-Project” HEC-RAS models as a base, the replacement of three in-line structures with bridges was modeled. In addition, the woody vegetation zones were modeled by means of changes in Manning’s roughness coefficients associated with proposed vegetation zones. To facilitate the hydraulic modeling for the woody vegetation zones, a previously prepared Manning’s roughness guide was used to guide the selection of Manning’s roughness coefficients for the woody vegetation zones. This guide is referred to as the “Memorandum for Assigning Manning’s “n” Values for Vegetation Associations”. The document was used for the prior USACE ecosystem restoration study for the San Antonio River Mission Reach Project in San Antonio. The memorandum was developed specifically for the purpose of woody vegetation design and was coordinated extensively with the USACE, the local sponsor, the San Antonio River Authority (SARA), the sponsor’s A/E, the City of San Antonio, and Bexar County.

## SENSITIVITY ANALYSIS

A sensitivity analysis was preformed to determine the impacts the proposed project may create by altering the existing conditions of the stream. The section of the San Antonio River identified for additional vegetation zones is located from just upstream of the U.S. HWY 281 bridge to approximately 680 feet upstream of the 281 bridge (See Figure 6). The focus of the analysis will concentrate on the right bank of the San Antonio River. This side of the bank is not as steep as the left bank, which would help promote stronger vegetation. In addition, the sensitivity analysis will also incorporate structure replacement and excavation.

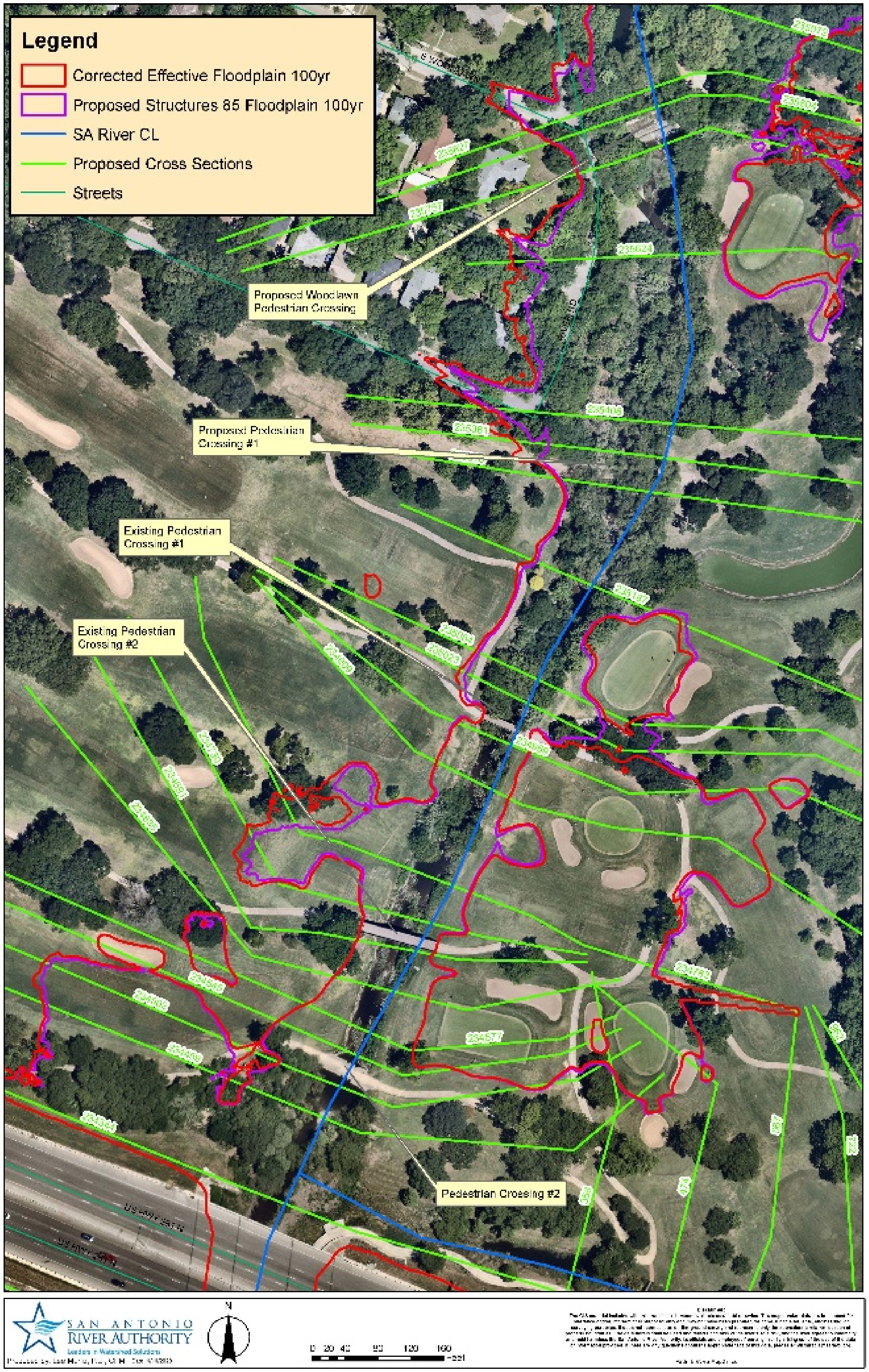


Figure 8: Sub-section of Study Area with proposed and existing structures, model cross-sections, and floodplain impacts identified.

Through discussion and professional judgment, hydraulic engineers and biologists agreed that a planting regime could be developed such that the hydraulic effects of planting riparian meadow would be insignificant. The sensitivity analysis helped define how the placement of additional woody vegetation would affect the water surface elevations of the San Antonio River. The analysis will also incorporate hydraulic structures that may create a rise and/or drop in water surface elevation by altering how the structure manipulate the flow dynamic. In certain cases, there was a need for excavation that will help mitigate the raise in water surface elevation.

The analysis of vegetation zones only modifies the right bank of the San Antonio River. The left bank will remain as existing conditions. This will help isolate the changes in the water surface elevations to only the right bank. The following options will make up the sensitivity analysis:

Option 1 will consist of replacing three structures with single span pedestrian bridges (See Table 2), and planting the right bank with a planting regiment of 70 stems per acre. The resulting planting regiment results in a Manning's n value of .085 for the right bank in the HEC-RAS model. This option will help reduce the impoundment of floodplain due to multiple inline weir structures and stabilize the right bank in the area of the San Antonio River.

Table 3. Proposed and Existing Bridge Structures in Option 1

| Bridge | Span (Feet) | Width (Feet) |
|---|---|---|
| Proposed Woodlawn Bridge | 68 | 12 |
| Proposed Pedestrian Bridge 1 | 76 | 12 |
| Existing Pedestrian Bridge 1 | 122 | 10 |
| Existing Pedestrian Bridge 2 | 159 | 12 |
| Proposed Pedestrian Bridge 2 | 67 | 12 |

Option 2 is the same as option one but has a planting regimen of 60 stems per acre. This results in a Manning's "n" value of .065.

Option 3 is the same as option one, but does not include the planting regiment. This option is to identify how the structures alone will change the water surface elevation.

Option 4 s a combination of Option 2 with associated cut located in strategic places to help mitigate the increase in WSE due to structure replacement. The excavation occurred in the right bank and left bank near the upstream portion of the U.S. HWY 281 bridge to approximately upstream of the second replaced crossing.

Option 5 is a combination of Option 3 with a planting regiment on the right bank consisting of 70 stems per acre. This will result in a Manning's n value increase to .085 for the right bank in the HEC-RAS model.

The maximum water surface elevation (WSE) changes resulting from each option are summarized in Table 3.

Table 4 Water Surface Increases due to Tree Vegetation Configurations, Structures, and Excavation used for the Sensitivity Analysis

| Project Option maximum/minimum | WSE change (feet) |
|---|---|
| 1 | 0.33 increase |
| 2 | 0.13 increase |
| 3 | 0.11 increase |
| 4 | 1.68 decrease |
| 5 | 0.21 increase |

# DETAILED MODELING DESCRIPTION

There was not a geomorphology study conducted for the project limits. This study reflected the multiple changes to the San Antonio River and demonstrated what impacts it will have with the floodplain. There were certain assumptions with the project modeling, which include that 2017 LiDAR data as the best available data in places that survey was not obtained. The single span bridges for the project are assumed to be 12 feet in width, and assuming no piers will be required. All construction disturbances are assumed to be graded and vegetated to existing conditions at the time of the disturbance. The excavation is assumed to take place in locations that allow cut within adjacent properties, such as the golf course surrounding the site location. The proposed excavation occurs between cross sections 234459 to 234739 on the right bank and left bank. The proposed vegetation locations will range from cross section 234969 to 234577 on the right bank. The vegetation planting height will vary based on the right bank slope and will end at the base flow water surface elevation. Elevation was based on 2017 LiDAR. The proposed vegetation is assumed to continue under proposed span bridges. Portions of the bank that already have an active stem count consistent with the proposed vegetation plan will remain un-altered. Ineffective flow areas were assumed to be placed in areas where proposed bridges joined the left and right bank. Weir coefficients were not adjusted and the HEC-RAS default value of 2.6 was maintained.

The corrected effective model was modified from the model obtained from SARA D2MR website and modified to add cross section for proposed bridge crossings. Cross sections 234502,234577, 234635, 234691, 234730, 234969, 235318, 235361, 235757, and 235804 were added to the effective model using the 2017 LiDAR topography, and the remaining existing crossings were updated to the 2017 LiDAR topography. All the cross-section stream lengths were updated to reflect 2017 LiDAR, which resulted in revised stream cross section stationing and an updated steady state flow data. Cross section geometry modifications were made including:

- Cross section 234459 was modified on the left bank to better represent the overbank elevations.
- Cross section 234545 was shifted slightly downstream to represent better data at the proposed bridge face on the upstream.
- Cross section 236279 and 236623 were also modified on the left bank to better represent the contour data.
- Cross Section 237595 and 237921 were extended to match the adjacent cross section on the upstream and downstream end.
- Cross sections 238530 and 238611 were modified to better represent the model’s left bank.
- Cross section 238634 was slightly shifted downstream to better reflect the upstream face of the existing E Mulberry Avenue bridge.

A structure was added to the effective model, which was identified using aerial photography and survey data. The structure was located between cross sections 235023 and 235969. The structure is a 10 foot wide single span pedestrian bridge. The existing inline low water structure between cross sections 235757 and 235804 creates a backwater effect all the way to crossing 238443 with a water surface elevation of 654.82. This water surface elevation matches the top deck of the low water crossing, which was represented in all upstream cross sections via block obstruction. The same behavior occurs for the inline structure in between cross sections 234502 and 234545, which has an elevation of 650.12. This elevation was represented as a blocked obstruction to cross section 235318.

The extent of the Upper San Antonio River reach consists of 14,946 feet, which ends at the Olmos Dam. The flows for the Atlas 14 1% ACE are approximately 6,122 cfs on the upstream and increase to 3,362 cfs on the downstream. These flows are consistent will all options. The resulting WSE for the upstream section of the Upper San Antonio River reach is 689.69 at cross section 249649 and WSE 658.97 at cross section 234459 on the downstream end.

Option 1 with a HEC-RAS plan name of “Proposed Structures 85” is a copy of the corrected effective model, but with removal of the inline structures located between cross sections 235757 and 235804; and cross sections 234502 and 234545. A culvert crossing was removed between 235361 and 235318. The bridge structures between cross sections 235023 and 234969; 234730 and 234691 remained the same since the existing pedestrian bridges were adequate crossings that convey the floodplain. All the proposed structures from cross section 253804 to 234502 were modified to a single span pedestrian bridge with a 12-foot width. This option will also incorporate a planting regiment that will reflect a 70 stem per acre on the right bank of cross sections 234577 to 234969. The planting regiment will vary in how far up it will go along the right bank, but has an average length of 14.13 feet. This regiment is reflected it the hydraulic model by changing the Manning's n values to .085. The existing condition of the majority of the areas of proposed change were previously modeled with a Manning's n values were .035, which represents no stems per acre. It is assumed that for this option, the project will maintain the existing slope of the planted area. The flows from the corrected effective model remain the same. The resulting WSE for the upstream section of the Upper San Antonio River reach is 689.69 at cross section 249649 and WSE 658.97 at cross section 234459 on the downstream end.

Option 2 with a HEC-RAS plan name of "Proposed Structures 65" is a copy option 1, but uses a planting regiment of 60 stems per acre. This will result in a Manning's "n" value of .065. The structure replacements will match that of Option 1. The resulting WSE for the upstream section of the Upper San Antonio River reach is 689.69 at cross section 249649 and WSE 658.97 at cross section 234459 on the downstream end.

Option 3 with a HEC-RAS plan name of "Proposed Structures " is a copy option 1, but does not include the planting regiments. The resulting WSE for the upstream section of the Upper San Antonio River reach is 689.69 at cross section 249649 and WSE 658.97 at cross section 234459 on the downstream end.

Option 4 with a HEC-RAS plan name of "Proposed Structures CUT" is an identical copy of option 2 but include areas of excavation. The area of excavation is located at cross section 234459 to 234739. The excavation proposed will occur on the left bank, but will shift to the right bank at cross section 234545. The amount of excavation will vary, with an extreme distance of 30 plus horizontal foot shift within the right bank. The excavation will only occur on average five vertical feet up the bank. The resulting WSE for the upstream section of the Upper San Antonio River reach is 689.69 at cross section 249649 and WSE 658.8 at cross section 234459 on the downstream end.

Option 5 with a HEC-RAS plan name of "Proposed Structures CUT 85" is an identical copy of option 3 but include a planting regiment of 70 stems per acre on the right bank. The area of planting is located at cross section 234691 to 234969. The planning area varies along the right bank, but has an average horizontal length of 23.4 feet and an approximate vertical foot of 7. The resulting WSE for the upstream section of the Upper San Antonio River reach is 689.69 at cross section 249649 and WSE 658.8 at cross section 234459 on the downstream end.

## SUMMARY AND CONCLUSION

The Hydraulic modeling process was completed to demonstrate the impacts of the Atlas 14 1% ACE with various options. Although some of the options do show increases in WSE, they are minimal. In order to maintain local regulations, a variance may be required to all the slight rise in water surface elevation due to the proposed project. The local floodplain administrator has been included as a stakeholder in the feasibility study and has advised that the City of San Antonio Unified Development Code provides a process for the project to be permitted with an increase in the water surface elevations provided the impacts do not occur on private property or endanger a roadway and if the appropriate Conditional Letter of Map Revision (CLOMR) be submitted to the community and FEMA.