WESTSIDE CREEKS ECOSYSTEM RESTORATION

Appendix B: Hydrology and Hydraulics

HYDROLOGY AND HYDRAULICS APPENDIX

STUDY PURPOSE

The Westside Creeks 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 multi-purpose study to address opportunities relating to flood risk management and ecosystem restoration by designing a pilot channel with pools, riffles and runs to enhance water features as well as adding tree plantings within the flood banks. The local sponsor for this project is the San Antonio River Authority (SARA). SARA contracted the development of the "Concept Restoration Plan", completed in 2011. The study is currently Planning Step 3, Formulating Alternative Plans.

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 San Pedro watershed, a sub watershed to the San Antonio River watershed, covers the western portion of the downtown San Antonio, Texas as well as areas to the west and south. The headwaters of the San Pedro watershed are located northwest of downtown San Antonio with the mouth being at the confluence with the San Antonio River south of downtown. This study focuses on segments of the Alazan, Apache, Martinez and San Pedro Creeks, also known as the Westside Creeks (WSC), contained within the authorized and constructed SACIP. Martinez Creek flows into Alazan Creek, which flows into Apache Creek, which in turn flows into San Pedro Creek. The study area is approximately 5.3 miles long and 2.5 miles wide at the widest point. The size of the study area is approximately 7410 acres, or 12 square miles. Elevations within the study area range from 558 to 732 feet. On the following pages, Figure 1 identifies the constructed SACIP, and Figure 2 identifies the Westside Creeks study area within the San Antonio River Watershed.

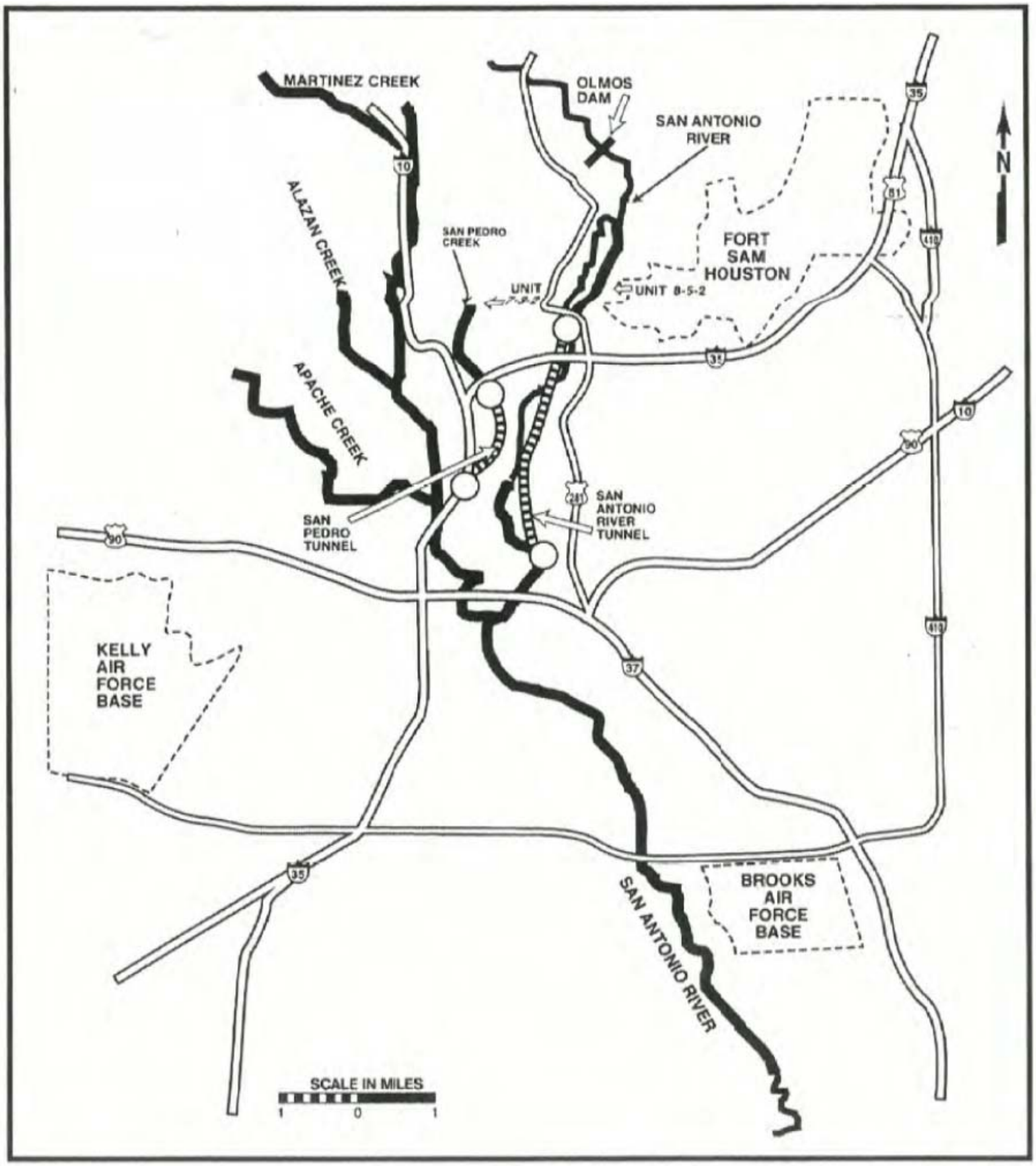

Figure 1 - SACIP Authorized & Constructed Project

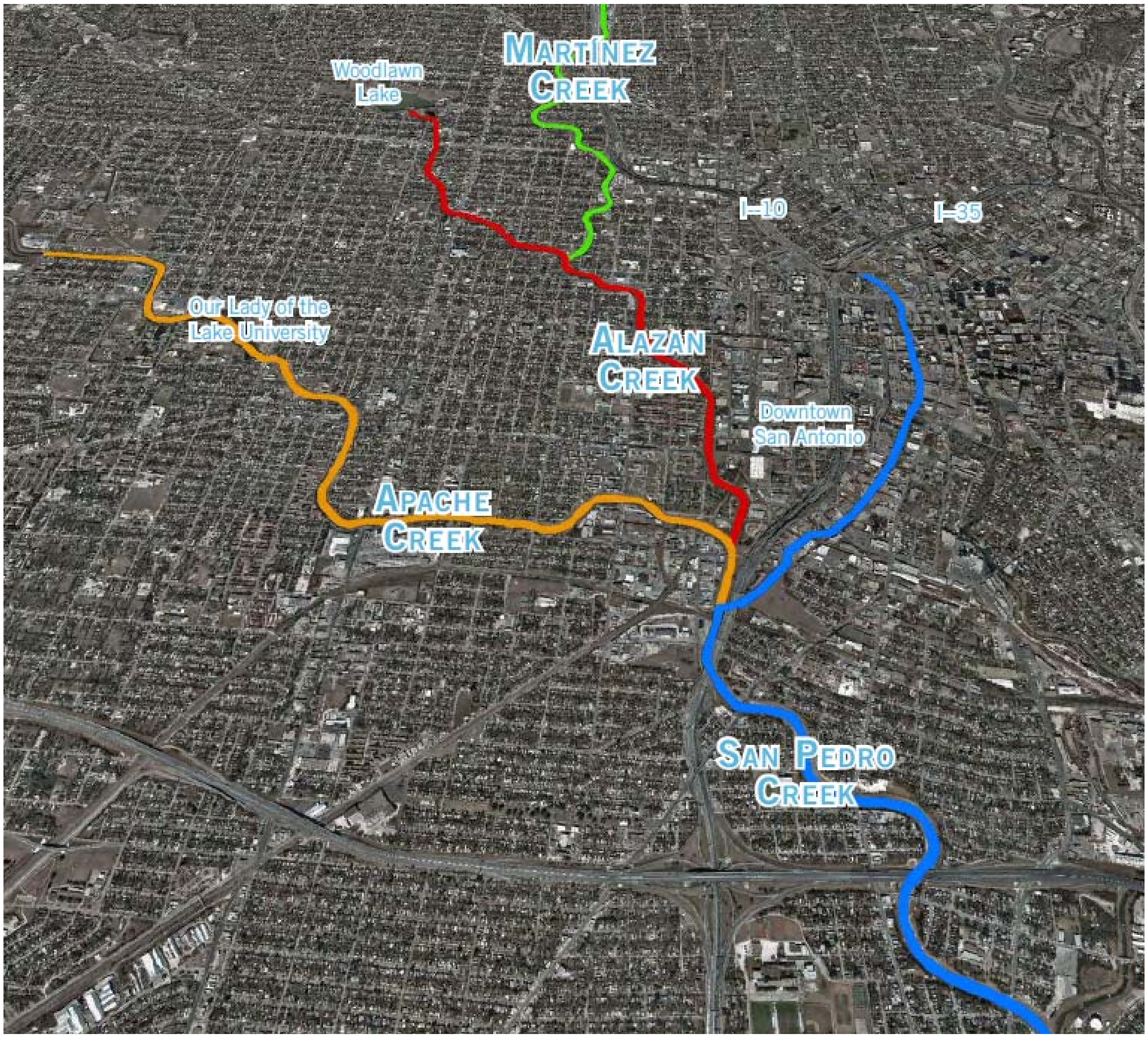

Figure 2. Westside Creeks Project Location

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.

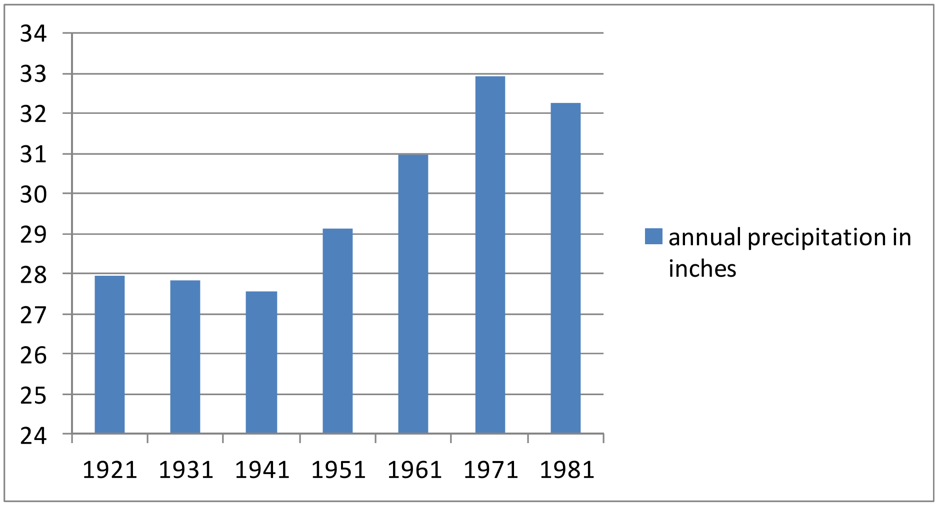

Figure 3. 30 Year Normal Average Annual Precipitation in Inches

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.

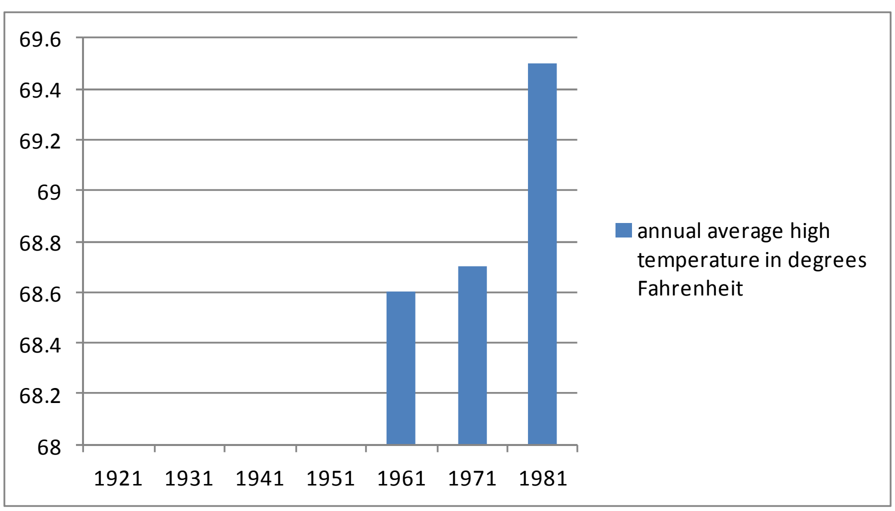

Figure 4. 30 Year Normal Average Annual High Temperature in Degrees Fahrenheit

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 and flood risk, 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 14 miles of creeks within the San Antonio Channel Improvement Project, but no changes will be made to the San Pedro Creek hydraulic model upstream of the San Pedro tunnel outlet (covers approximately 1.4 miles).
- Right of Way expansion will be considered only for areas where the San Antonio Watershed Master Plan has indicated the potential for expansion. If any of the locations identified for Right-of-Way expansion are utilized, the planning level study will assume that a slope geometry no steeper than 4H:1V will be required and will consult the geotechnical engineers to confirm whether a flatter slope is recommended given the information currently known.
- 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.
- No trees will be placed within the flood banks (side slope banks of the FRM study) within 100 feet upstream or downstream of bridges.
- All material defined in the hydraulic model under all bridge crossings will consist of concrete in order to protect the integrity of the bridge. The bankfull pilot channel is configured as a trapezoidal channel with 1 on 2.5 side slopes, a bottom width which varies from 15 feet to 45 feet, a top width which varies from 25 feet to 67 feet, and a depth which varies from 2 feet to 5 feet. The bankfull pilot channel will consist of native grasses and the bridge piers which line up in the bankfull pilot channel will be protected.
- All excavation quantities will be determined by the use of the hydraulic model.
- No pools, riffles, and runs will be designed in the hydraulic model in order to expedite the planning and modeling process.

HYDROLOGY

The contributing watershed area for the Westside Creeks is highly developed, with extensive residential areas, and some retail and industrial zoning. Contributing Watershed Areas include:

- Alazan Creek, 17.5 square miles;
- Apache Creek, 40.3 square miles;
- Martinez Creek, 7.3 square miles; and
- San Pedro Creek, 44.9 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 Westside Creeks was reduced as a result of the channelization and other modifications that were constructed in the 1960s and '70s; however, additional development in the area adjacent to the creeks as well as within the upstream portions of the contributing watershed has increased impervious cover (see Figure 5 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. These updated models indicate that the existing channelized creeks will not contain the 1% ACE event.

For the purposes of this restoration analysis, the hydrology was derived from 2 different sources. The first was an estimation of the 1.5-year design discharges through empirical methods, such as regression analysis of gauge data that was developed by the USGS for the urban areas of Austin, TX, which was assumed to be a close approximation for the San Antonio urban watersheds, since no local urban equations have been developed. The 1.5-year discharges calculated by these equations were utilized to develop stable bankfull channel designs for the Westside Creeks.

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). The Flood Insurance Study/DFIRM flows include a diversion in the upstream flows on San Pedro Creek, accounting for the bypass tunnel which discharges back into San Pedro Creek just downstream of El Paso Street.

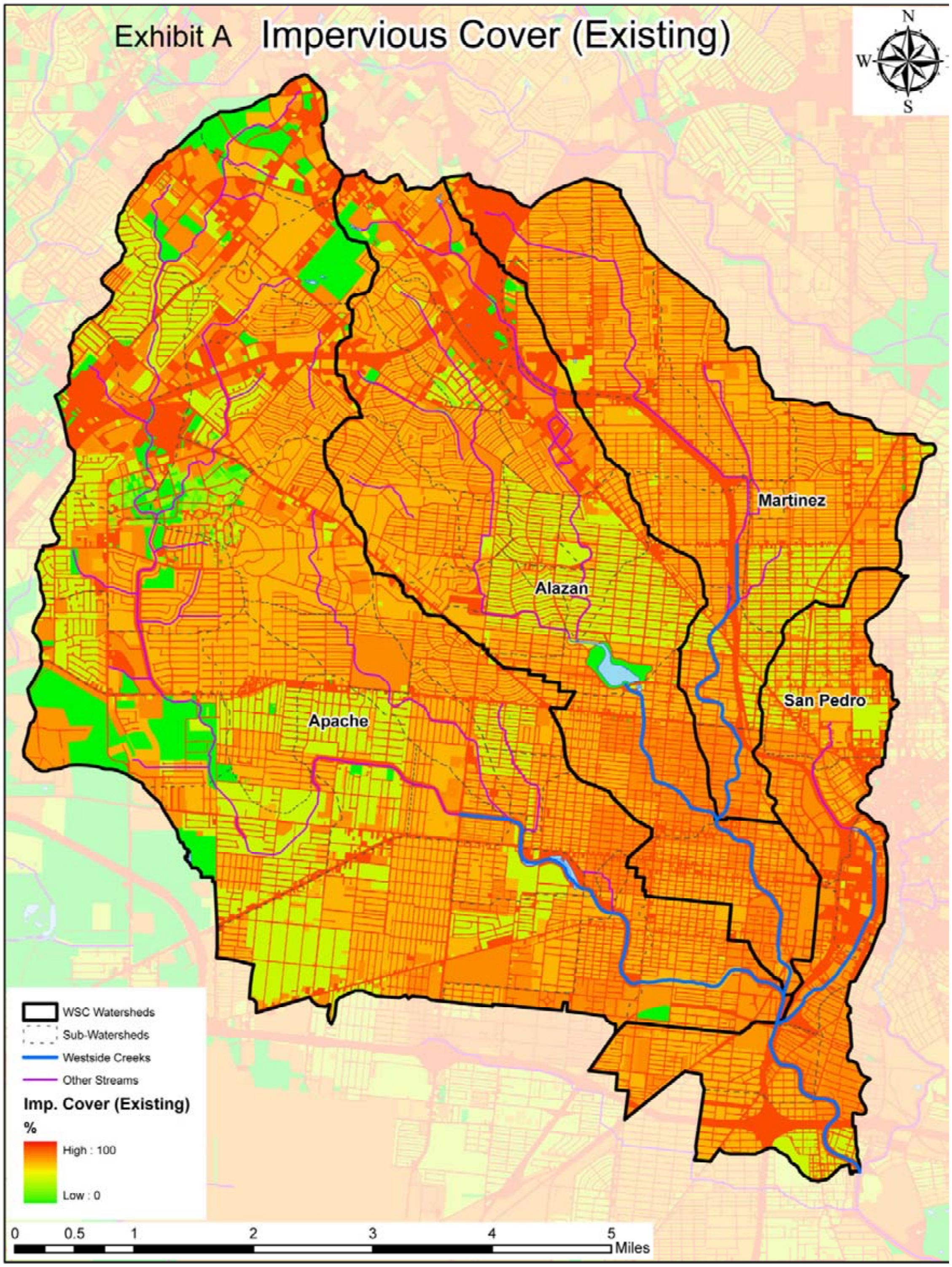

Figure 5. Existing Conditions Impervious Cover

Studies have found that the bankfull discharge is typically associated with a 67% Annual Chance Exceedance (ACE) or 1.5-year return period flow (US Army Corps of Engineers, 2001); however, this can vary greatly given differing hydrologic and geologic parameters.

Several methods were compared to determine the correct bankfull discharge on each stream reach and are described in more detail as follows:

San Antonio and the Westside Creeks project locations fall within the Texas Hydrologic Region 5 according to the USGS (USGS, 1997) (Table SCD-1 and Table SCD-2). There are two sets of regression equations for Region 5: one set for locations with less than 32 square miles of contributing drainage areas, and the second for locations with more than 32 square miles of contributing drainage area. The 75% ACE discharge was calculated by plotting the Region 5 discharges and using a power-trend line for each stream. It was determined that the Region 5 regression equations were underestimating discharges because the equations do not account for urbanization.

The Austin Urban Regional Regression Equations (USGS Report 94-4002) yield discharges for the 50% to 1% ACE (2- to 100- year) recurrence intervals. The equation's inputs are contributing drainage area and total percent impervious of the contributing basin. The equations are applicable to sites with drainage areas of 2 to 20 square miles. Apache Creek's and San Pedro Creek's drainage areas fall outside the range of drainage areas recommended for the equations; however, the equations were used for this analysis because they yielded results that were comparable to the effective discharges.

The effective FIS discharges for return periods of the 10%, 2%, and 1% return intervals were plotted. Since there are no effective discharges for low flows (less than 10-year return periods), the shape of the regression curve was shifted and fitted to the FIS data in order to estimate the 75% ACE discharges. When compared to the 75% ACE discharges yielded from the Austin Urban Regional Regression Equations, the shifted effective FIS discharges were in the same range.

When comparing the effective FIS discharges to the discharges calculated using the regression equations, it was determined that the interpolated Austin Urban Regional Regression Equations yielded the best results.

At this conceptual level of study, the bankfull discharge analysis is limited in terms of methods that could be analyzed. During detailed project design, more methodologies to determine the design discharge should be analyzed. Frequency analyses should be performed on local USGS stream gages as another source of data to compare. Also, discharge analyses from previous studies in the area should be compared to the design discharge. Data could be developed to produce discharges for return periods less than the 10% ACE using the effective FIS hydrology model. This information would be used to refine the 75% ACE discharge; however, further analysis should also be conducted to determine the appropriate return period to use in the final design. Studies of the appropriate return interval to be used for urban areas in other Texas cities have been closer to the 90-95% ACE return interval.

HYDRAULICS

EXISTING CONDITIONS

The evolution of the Westside Creeks over the last half-century is largely due to shifts in urbanization and in flood control and maintenance practices. Earlier cross sections depict a more natural stream, consisting of a baseflow channel, a wider channel and a large floodplain. Straightening and channelization of the creeks yielded grass-lined trapezoidal channels (that delineate most of the creeks), dramatic concrete banks and underground bypass tunnels (San Pedro Creek). The channel substrate consists of unfractured Cretaceous limestone that covers the Edwards Group limestone and is overlaid by a thin soil cap. The high intensity precipitation coupled with urbanized, rocky terrain, makes the Westside Creeks prone to flash floods which rise and fall in rapid response to storms.

While long-time area residents recall base flow that was perennial (continual), site inspections and anecdotal reports indicate that base flow for most of the Westside Creeks has been reduced to either intermittent (during wet periods of the year only) or ephemeral (only immediately following storm events). There is no gauge data available to accurately determine the current base flow category for the Westside Creeks.

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 River and San Pedro Creek hydraulic models were combined into one model and the work was completed by Pape-Dawson Engineering, Inc and submitted to FEMA December 2006. Apache Creek, Alazan Creek, and Martinez Creek models were completed by Halff and Associates and submitted to FEMA in May 2007. All base work maps were generated from 2005 aerial 2 foot topographic data.

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 all bridges and culverts. As-built plans were not needed, since detailed survey information was available. This includes the collection of existing ground, structure and underwater elevations.

The Environmental Systems Research Institute (ESRI) ArcMap, Version 9.0, along with the HEC-GeoRAS Version 3.1 were used for the integration of geospatial data into the United States Army Corps of Engineers' (USACE), Hydrologic Engineering Center River Analysis System (HEC-RAS), Version 3.1.2. HEC-RAS, accepted by FEMA for hydraulic analysis, performs one-dimensional hydraulic calculations to model the water surface elevations. HEC-GeoRAS along with the 3D Analyst and Spatial Analyst extensions was used to create the stream centerline and cross sections that were imported into HEC-RAS.

The locations for cross sections were identified to capture the critical hydraulic features within a study reach. The cross sections were spaced to achieve target spacing of not more than 1000 feet between the cross sections in rural areas and spacing of 500 feet or less in urban areas, as recommended in the Hydrologic and Hydraulic modeling guidelines set by SARA. The spacing of cross sections was reduced as necessary to model significant hydraulic features. The cross sections were extended to the limits of the topographic data on both sides of the stream. The location of the tributaries contributing to the study streams was also considered for choosing appropriate cross section locations.

All existing bridges and culverts in the studied reaches were modeled in HEC-RAS in order to determine their affect on water surface profiles and the resulting floodplain. The culvert dimensions were obtained from field survey measurements. The Federal Highway Administration (FHWA) chart and scale numbers were appropriately chosen based on the observed culvert entrance designs from field visits. The upstream invert elevations and the hydraulic widths were obtained from approximate survey methods. Bridges were also modeled using the information obtained from approximate surveys. The approximate bridge survey included obtaining pier shapes and dimensions, upstream invert elevations, deck thickness, channel top and bottom widths, distance between the toes of the abutments and the hydraulic widths.

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 1 “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 United States Geological Survey Water-supply Paper 2339, “Guide for Selecting Manning’s Roughness Coefficients for Natural Channels and Flood Plains,” was also referenced. The energy loss coefficients at cross sections, bridges and culverts were chosen as recommended in the HEC-RAS manual.

Table 1. 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 Pedro Creek, Apache Creek, Alazan Creek and Martinez Creek were all provided to the Corps as separate models. . For this study, these individual stream models were all combined into a dendritic system hydraulic model to properly account for tributary confluence impacts. The Hydrologic Engineering Center River Analysis System (HEC-RAS), Version 4.1 was used for this analysis. Martinez Creek flows into Alazan Creek, which flows into Apache Creek, which flows into San Pedro Creek which flows into the San Antonio River. All models are connected with junctions at each confluence. All flows in this model remain unchanged from the existing condition models, as well as most parameters. The modeling includes the 10%, 2%, 1%, and the 0.2% Annual Exceedance Probability (AEP) flood events based on peak discharges.

WITH-PROJECT CONDITIONS

The development of proposed plans for restoration of Westside Creeks required the development of hydraulic models to determine the water surface elevation impacts due to implementation of the bankfull pilot channel 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 geometry configuration of the proposed bankfull pilot channel was input and subsequently 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

The design team (PDT) tested the hydraulic model with a sensitivity analysis, which involved the placement of different types of woody vegetation configurations into the model. The initial assumption of undertaking this sensitivity analysis was to reduce the number of iterations, thus reducing the time and cost associated with the hydraulic modeling effort for this pilot study. Through discussion and professional judgment, hydraulic engineers and biologists agreed that a planting regime could be developed such that the hydraulic affects 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 for each creek. A representative stream segment (sensitivity reach) was selected for each of the four creeks. Selection of the reach was based on obtaining a stream segment representative of the entire creek in terms of a constant slope with similar number of bridge crossing. The resulting assumption is that, while some variation is expected, the results for the sensitivity reach are generally representative of the model behavior for the entire creek.

Three configurations, shown below, were tested using woody vegetation densities of 30 trees per acre (manning's roughness coefficient of 0.055) and 70 trees per acre (manning's roughness co-efficient of 0.085). For purposes of the analysis, continuous placement of the woody vegetation along the entire sensitivity reach was placed within the model for each creek. Each of the configurations tested resulted in a computed water surface elevation, which was compared to the existing conditions water surface elevations.

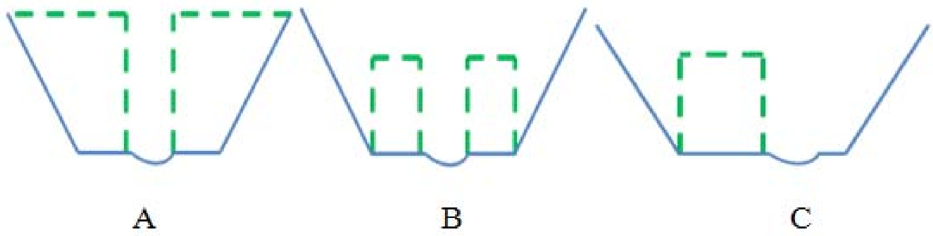

Figure 6. Tree Vegetation Configurations used for the Sensitivity Analysis

Configuration A - Consists of woody vegetation from the top edges of the bankfull pilot channel to the top of the flood banks on both sides of the existing creek. This is the maximum extent of vegetation within the existing Right of Way (ROW) for the SACIP flood control channel. This configuration has the largest surface area for the increase in roughness values and therefore, as expected, the largest adverse affect on water surface elevation. The average increase in the water surface elevation ranged between 3.0 to 6.0 feet based on the 1% ACE flood event for each creek.

Configuration B – Consists of woody vegetation from the top edge of the bankfull pilot channel along the invert, to the toe of the flood banks on both sides of the existing creek. Configuration B has a lesser impact than Configuration A. This configuration provides a significant coverage of woody vegetation along the entire invert, which surrounds the bankfull pilot channel, with significant increase on the water surface elevations. The average increase in the water surface elevation ranged between 1.7 to 4.0 feet based on the 1% ACE flood event for each creek.

Configuration C – Consists of woody vegetation from the top edge of the bankfull pilot channel along the invert, to the toe of the left flood bank of the existing creek. This configuration had the lease amount of impact on the water surface elevation. The average increase in the water surface elevation ranged between 0.9 to 2.3 feet based on the 1% ACE flood event for each creek.

Table 2. Water Surface Increases due to Tree Vegetation Configurations used for the Sensitivity Analysis

Vegetation Configuration	30 stems per acre (n-Value = 0.055)	70 stems per acre (n-value = 0.085)
A	+ 3.0 feet	+ 6.0 feet
B	+ 1.7 feet	+ 4.0 feet
C	+ 0.9 feet	+ 2.3 feet

Each configuration listed in Table 2 represents the average results of the woody vegetation placement for a particular reach for each of the four creeks. These results are used only as a guide to help determine how sensitive the model behaved in this particular reach and will vary in the final model analysis. Each cross section of the working model, starting from the downstream end of the project and working upstream, will depend on the specific excavation amount necessary to place the bankfull pilot channel. Therefore, it is anticipated that placement of a diverse mix of woody vegetation and riparian meadow in combination with the excavation necessary for placement of the bankfull pilot channel will be accomplished without any increases in water surface elevation.

DETAILED MODELING DESCRIPTION

A geomorphology study, completed by Baker and Associates used a reference reach and a regression equation analysis to develop the approximate dimensions for a bankfull pilot channel (Refer to the Geomorphology Appendix). This analysis has estimated uncertainties for design channel flow between 20-30 percent. This uncertainty was assumed consistent with the level of design analysis required at his stage of this study and the assumed cost risk associated with the bankfull pilot channel sizing. More detailed hydrologic analysis for the pilot channel sizing is recommended as the project moves into the detailed design phase. The bankfull pilot channel is configured as a trapezoidal channel with 1 on 2.5 side slopes, a bottom width which varies from 15 feet to 45 feet, a top width which varies from 25 feet to 67 feet, and a depth which varies from 2 feet to 5 feet. The bankfull pilot channel consists of native grasses and the bridge piers which line up in the bankfull pilot channel will be protected. This bankfull pilot channel was placed into the model for all four creeks at the existing invert elevation. The following discussion will define the placement of this bankfull pilot channel into each creek separately. In reaches where the bankfull pilot channel cannot be placed at the invert elevation, required excavation will be necessary to avoid the use of adding earth fill quantities to each creek. Even though pools, riffles and runs are assumed to be an intricate part of the bankfull pilot channel final design, these structures were not placed into the model in order to expedite the hydraulic analysis for this pilot study utilizing the new paradigm.

The FRM project floodway channel side slopes are to remain unmodified in most locations. The proposed bankfull pilot channel benches contact the toe of the floodway channel side slopes in some locations, in which case, the existing slope is to be maintained. All models have assumed roughness values for concrete channel paving under all bridge crossings, except for the bankfull pilot channel, in order to provide protection and maintain the integrity of the bridge structure. All models for design of the bankfull pilot channel initially included trees on the left bench with a density of 30 trees per acre. For a final detailed description of the placement of trees, refer to the Environmental Appendix.

SAN PEDRO CREEK

San Pedro Creek study reach began at the junction with the San Antonio River and continued to just upstream of Camp Street with a total study length of 12,676 feet. The starting water surface elevation for San Pedro Creek at the junction with San Antonio River was based on the 1% ACE flood elevation of the San Antonio River model, elevation 595.98 feet. The downstream channel bottom elevation with the bankfull pilot channel in place is 570.29 feet. The upstream invert elevation is 619.34 feet. The top of bank elevations range from 598.79 feet downstream to 632.79 feet upstream.

Water surface elevations with the woody vegetation in place, for the 1% ACE flood event, range from 595.98 feet at the downstream end to 634.89 feet at the upstream end of the study reach.

Flows for the 1% ACE flood event are approximately 6,896 cfs at the upstream, increasing to 49,312 at the confluence with San Antonio River.

The placement of the bankfull pilot channel was accomplished in two reaches, Reach 3 and Reach 4, using the dimensions provided by the geomorphology study. The bankfull pilot channel was placed into the model at or below the existing invert of the flood control channel. The excavation required for this placement, in most cases, allowed for additional flood space, and provided opportunities for the placement of trees with various densities. The sensitivity of the model for each reach determined the densities of trees to be placed onto the benches of the bankfull pilot channel.

REACH 4 – JUNCTION WITH SAN ANTONIO RIVER TO RIVER STATION 95+00

Reach 4 began at the junction with San Antonio River, and continued upstream to the junction with Apache Creek. The bankfull pilot channel for this reach has a bottom width of 44.7 feet with side slope of 1V on 2.5H, a depth of 4.5 feet and a top width of 67.1 feet. From the junction with the San Antonio River to Station 50+48, the bankfull pilot channel is placed at the existing channel invert elevation, with banks on either side of the bankfull pilot channel. The resulting water surface elevation is lower than the existing condition water surface elevation by an average of 3 to 4 inches before the placement of trees on the benches. From Station 50+48 to 95+00, the bankfull pilot channel is placed below the existing invert elevation by an average of 1 to 2 feet, with banks on both sides of the bankfull pilot channel. The resulting water surface elevation is lower than the existing condition water surface elevation by an average of 4 to 8 inches before the placement of trees on the benches.

REACH 3 - RIVER STATION 95+00 TO 126+76

Reach 3 began at Station 95+00 and continues to the upstream end of the project at Station 126+76. The bankfull pilot channel for this reach has a bottom width of 14.7 feet with side slope of 1V on 2.5H, a depth of 1.7 feet and a top width of 21.8 feet. The bankfull pilot channel is placed below the existing invert elevation by an average of 2 to 4 feet, with very narrow banks on both sides of the bankfull pilot channel. The resulting water surface elevation is lower than the existing condition water surface elevation by an average of 12 to 16 inches before the placement of trees on the benches.

APACHE CREEK

Apache Creek study reach began at the junction with San Pedro Creek continuing upstream to Southwest 19th Street with a total study length of 14,344 feet. The downstream channel bottom elevation with the bankfull pilot channel in place is 601.63 feet. The upstream invert elevation is approximately 635.13 feet. The top of bank elevations range from 629.02 feet downstream to 652.59 feet upstream.

Water surface elevations with woody vegetation in place, for the 1% ACE flood event, range from 628.17 feet at the downstream end to 657.97 feet at the upstream end of the study reach. Flows for the 1% ACE flood event, range from 21,229 cfs, at the Elmendorf Lake Dam, increasing to 46,726 cfs at the confluence with San Pedro Creek.

According to the geomorphology study, Apache Creek has three reaches. The placement of the bankfull pilot channel was accomplished in only two of these three reaches, Reach 3 and Reach 4, using the dimensions provided by the geomorphology study. The bankfull pilot channel was placed into the model at or below the existing invert of the flood control channel. The excavation required for this placement, in most cases, allowed for additional flood space, and provided opportunities for the placement of trees with various densities. The sensitivity of the model for each reach determined the densities of trees to be placed onto the benches of the bankfull pilot channel.

This channel contains significantly more concrete within the flood banks than any of the other three creeks studied. The base flow channel of Apache is predominantly concrete. The largest challenge was trying to provide native grasses and remove the concrete from the existing pilot channel without creating a rise in the water surface elevation. As a result, Reach 2 and part of Reach 3 contained too much concrete to effectively place a bankfull pilot channel.

REACH 4 – JUNCTION WITH SAN PEDRO CREEK TO RIVER STATION 13+00

Reach 4 began at the junction with San Pedro Creek, and continued upstream to River Station 13+00, which is at the junction with Alazan Creek. The bankfull pilot channel for this reach has a bottom width of 41.6 feet with side slope of 1V on 2.5H, a depth of 4.2 feet and a top width of 62.4 feet. From the junction with San Pedro Creek to Station 13+00, the bankfull pilot channel is placed at the existing channel invert elevation, with banks on either side of the bankfull pilot channel. The resulting water surface elevation is lower than the existing condition water surface elevation by an average of 2 to 3 inches before the placement of trees on the benches.

REACH 3 - RIVER STATION 13+00 TO 124+69 (SOUTH HAMILTON AVENUE)

Reach 3 began at Station 13+00 and continued upstream to River Station 124+69. The bankfull pilot channel extends up into this reach to station 42+70, 688 feet upstream of South Brazos Street. Modeling of the bankfull pilot channel further upstream in this reach was attempted but the various models' outputs indicated a water surface elevation increase. The bankfull pilot channel for this reach has a bottom width of 33.8 feet with side slope of 1V on 2.5H, a depth of 3.4 feet and a top width of 50.7 feet. The bankfull pilot channel was placed below the existing invert elevation by an average of 2 to 3 feet, with very narrow banks on both sides of the bankfull pilot channel. The resulting water surface elevation is lower than the existing condition water surface elevation by an average of 0.02 to 0.04 inches before the placement of trees on the benches.

REACH 2 - RIVER STATION 124+69 (SOUTH HAMILTON AVENUE) TO RIVER STATION 143+44 (SOUTH OF 19TH STREET)

Reach 2 began at Station 124+69 and continued upstream to River Station 143+44. Modeling of the bankfull pilot channel further upstream into this reach was attempted but the various models' outputs indicated an increase of the water surface elevation.

ALAZAN CREEK

Alazan Creek study reach began at the junction with Apache Creek and continued upstream to the outlet of Woodlawn Lake Dam with a total study length of 17,571 feet. The starting water surface elevation for Alazan Creek at the junction with Apache Creek is an elevation of 630.34 feet. The downstream channel bottom elevation with the bankfull pilot channel in place is 605.06 feet. The upstream invert elevation is 661.21feet. The top of bank elevations range from 628.07 feet downstream to 679.64 feet upstream.

Water surface elevations with the woody vegetation in place, for the 1% ACE flood event, range from 630.34 feet at the downstream end to 672.53 feet at the upstream end of the study reach.

Flows for the 1% ACE flood event are 18,331 cfs at the upstream, increasing to 38,745 at the confluence with Apache Creek.

The placement of the bankfull pilot channel was accomplished in two reaches, Reach 1 and Reach 2, using the dimensions provided by the geomorphology study. The bankfull pilot channel was placed into the model at or below the existing invert of the flood control channel. The excavation required for this placement, in most cases, allowed for additional flood space, and provided opportunities for the placement of trees with various densities. The sensitivity of the model for each reach determined the densities of trees to be placed onto the benches of the bankfull pilot channel.

Reach 2 – Junction with Apache Creek to River Station 96+27 (Junction with Martinez Creek)

Reach 2 began at the junction with Apache Creek, and continued upstream to River Station 96+27, which is at the junction with Martinez Creek. The bankfull pilot channel for this reach has a bottom width of 30.6 feet with side slope of 1V on 2.5H, a depth of 3.1 feet and a top width of 45.9 feet. From the junction with Apache Creek to Station 96+27, the bankfull pilot channel is placed at the existing channel invert elevation, with banks on either side of the bankfull pilot channel. The resulting water surface elevation is lower than the existing condition water surface elevation by an average of 2 to 3 inches before the placement of trees on the benches.

Reach 1 – River Station 96+27 to River Station 175+71)

Reach 1 began at the junction with Martinez Creek, and continued upstream to River Station 175+71, which is at the outlet of Woodlawn Lake. The bankfull pilot channel for this reach has a bottom width of 24.2 feet with side slope of 1V on 2.5H, a depth of 2.4 feet and a top width of 36.2 feet. From the junction with Martinez Creek to Station 175+71, the bankfull pilot channel is placed at the existing channel invert elevation, with banks on either side of the bankfull pilot channel. The resulting water surface elevation is lower than the existing condition water surface elevation by an average of 2 to 3 inches before the placement of trees on the benches.

Martinez Creek

Martinez Creek study reach began at the junction with the Alazan Creek and continued to just downstream of West Hildebrand Avenue with a total study length of 14,726 feet. The starting water surface elevation for Martinez Creek at the junction with Alazan Creek is 656.69 feet. The downstream channel bottom elevation with the bankfull pilot channel in place is 633.79 feet. The upstream invert elevation is 682.97 feet. The top of bank elevations range from 646.14 feet downstream to 696.27 feet upstream.

Water surface elevations with the woody vegetation in place, for the 1% ACE flood event, range from 656.69 feet at the downstream end to 697.72 feet at the upstream end of the study reach. Flows for the 1% chance flood event are approximately 8,229 cfs at the upstream, increasing to 17,823 at the confluence with Alazan Creek.

The placement of the bankfull pilot channel was accomplished in three reaches, Reach 1, Reach 2, and Reach 3, using the dimensions provided by the geomorphology study. The bankfull pilot channel was placed into the model at or below the existing invert of the flood control channel. The excavation required for this placement, in most cases, allowed for additional flood space, and provided opportunities for the placement of trees with various densities. The sensitivity of the model for each reach determined the densities of trees to be placed onto the benches of the bankfull pilot channel.

Reach 3 – Junction with Alazan Creek to River Station 46+53

Reach 3 began at the junction with Alazan Creek, and continued upstream to River Station 46+53, which is at Culebra Avenue Bridge crossing. The bankfull pilot channel for this reach has a bottom width of 22.3 feet with side slope of 1V on 2.5H, a depth of 2.2 feet and a top width of 33.4 feet. The bankfull pilot channel is placed at the existing channel invert elevation, with banks on either side of the bankfull pilot channel. The resulting water surface elevation is lower than the existing condition water surface elevation by an average of 2 to 3 inches before the placement of trees on the benches.

Reach 2 - River Station 46+53 to River Station 122+65 (I-10 Bridge)

Reach 2 began at Station 46+53 and continued upstream to the I-10 Bridge at River Station 122+65. The bankfull pilot channel extends up into this reach to station 122+65 immediately upstream of the I-10 Bridge. The bankfull pilot channel for this reach has a bottom width of 21.7 feet with side slope of 1V on 2.5H, a depth of 2.2 feet and a top width of 32.6 feet. The bankfull pilot channel was placed below the existing invert elevation by an average of 2 to 3 feet, with wider banks on both sides of the bankfull pilot channel. The resulting water surface elevation is lower than the existing condition water surface elevation by an average of 4 to 6 inches before the placement of trees on the benches.

Reach 1 - River Station 122+65 (I-10 Bridge) to River Station 147+26 (W. Hildebrand Avenue)

Reach 1 began at Station 122+65 and continued upstream to W. Hildebrand Avenue at River Station 147+26. The bankfull pilot channel extends up into this reach to station 147+26 which is the upstream limit at the downstream face of the W. Hildebrand Avenue Bridge. The bankfull pilot channel for this reach has a bottom width of 21.0 feet with side slope of 1V on 2.5H, a depth of 2.1 feet and a top width of 31.5 feet. The bankfull pilot channel was placed below the existing invert elevation by an average of 2 to 3 feet, with wider banks on both sides of the bankfull pilot channel. The resulting water surface elevation is lower than the existing condition water surface elevation by an average of 3 to 4 inches before the placement of trees on the benches.

Summary and Conclusion

The Hydraulic modeling process was completed using the Geomorphology stream data defining the sizes of each pilot channel for all four creeks for the Westside Creeks Pilot Study. The data utilized in the study was the most up-to-date and the water surface elevations computed for each alternative met the criteria of not allowing the water surface elevation to exceed those published in the 2010 DFIRM.