Channel Change on the San Antonio River

Texas Water Development Board
Project 0604830638

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Project Task Summary

The tasks outlined in the "Tasks" section of the Scope of Work were completed. The chart below shows where the descriptions of the tasks are located within the project report.

Task	**Section Described**
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Task 2: Digitize the aerial photos and georectify all images	Section 3.2 (Georeferencing Aerial Photos)
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Task 8: Dissemination of Results	TWDB Project 0604830638 Data Catalog

INTRODUCTION

1.1 Channel Change

Channels naturally change through time. Floods produce change through sediment mobilization, transportation, and deposition. Floods can also create channel widening through bank erosion and subsequent bank failure. There are different types of channel adjustment depending on initial channel geometry (Brierley and Fryirs 2006, 163) (Figure 1). Naturally meandering streams migrate over time. As the outer bank of a meander bend erodes, sediment deposits on the inner bank creating a point bar. In all rivers, including meandering, the relative amounts of sediment load and flow rate can cause either deposition or erosion. Sediment load in excess of the transport capacity of the flow can lead to bed aggradation. In the opposite case, where the sediment load is much less than the carrying capacity of the flow, the channel is likely to erode and incise its bed. Varying flow rates cause sediment transport fluctuations and induce channel change (Brierley and Fryirs 2006, 162-163).

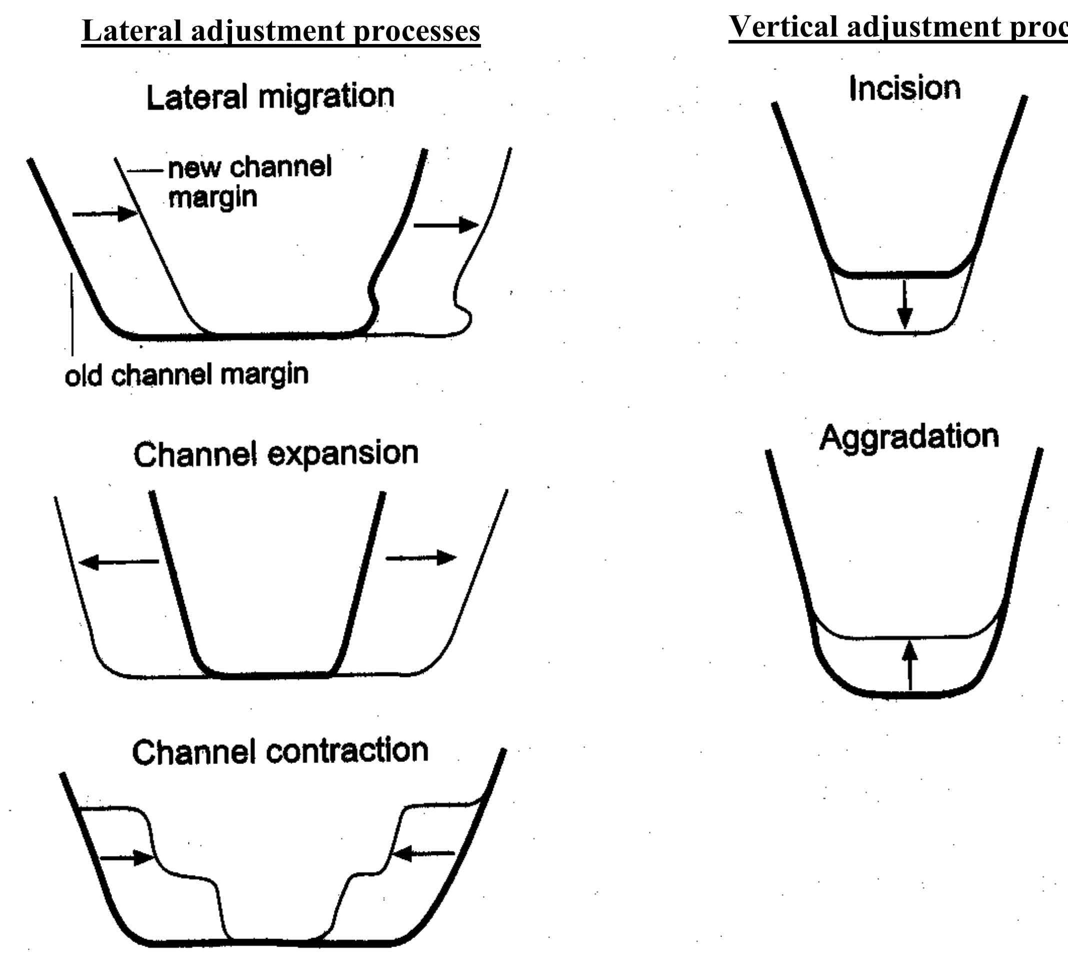


Figure 1. Examples of Channel Change. (Brierley and Fryirs 2005, 163)

1.11 Equilibrium

River equilibrium is a theoretical concept where a channel's dependent variables (stream width, depth, velocity, and slope) adjust over time to maintain a constant channel shape regardless of fluctuations in flow rate and sediment supply. Given enough time, the channel evolves to a stable condition (Brierley and Fryirs 2005, 72-73).

Natural channels are rarely in an equilibrium state due to fluctuating climate and rainfall patterns. The extreme rainfall events common in central Texas punctuate an otherwise arid flow regime. These variable flows prevent Central Texas rivers from developing a single equilibrium channel morphology. There may also be complicating factors not accounted for in the equilibrium model (Brierley and Fryirs 2005, 72). Rivers in Texas may not reach equilibrium because of yearly variable weather patterns, such as wet and dry periods (Earl and Kimmel 1995, 37). While the equilibrium concept can be a useful guide when assessing river behavior in the short term, it is less reliable in long-term studies.

Humans can affect a river's natural regime and initiate unnatural change. Urbanization creates impervious cover that increases runoff and flood peaks. By decreasing the amount of overland flow that travels through a natural environment, the flow reaching the channel during a rainfall event increases but the sediment supply decreases. This increase in flow leads to channel incision and expansion because the river must adjust to the new flow regime (Figure 2). Removing riparian bank vegetation for agricultural purposes is a common practice that can lead to increased bank erosion because tree roots are no longer helping to stabilize the bank (Brierley and Fryirs 2005, 218). Channelization projects are undertaken with the express purpose of increasing the speed with which floodwaters flow out of a city. This increases peak flow along the straightened reach and can cause bed aggradation downstream because of increased erosion upstream (Brierley and Fryirs 2005, 214).

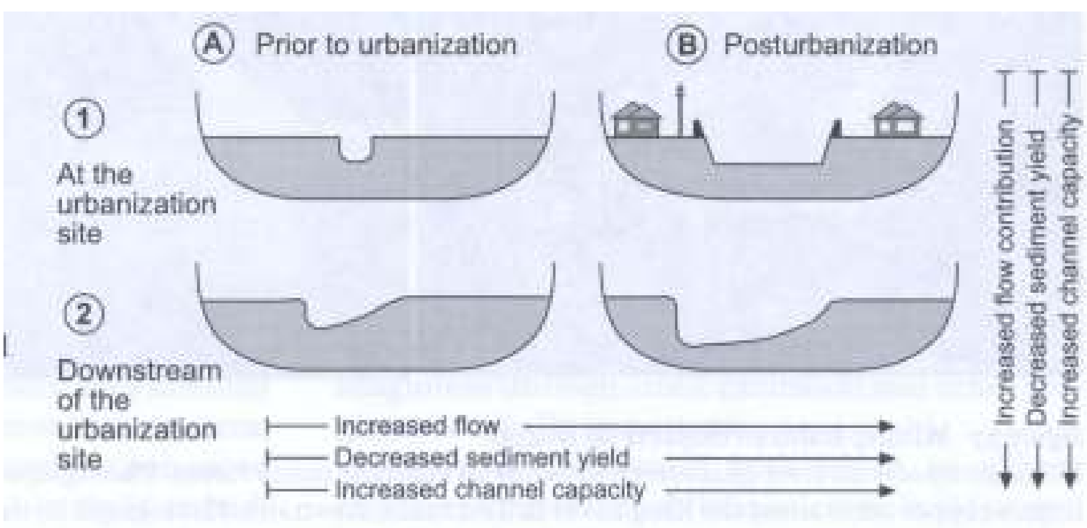


Figure 2. Effects of Urbanization. Increased flows due to urbanization initiate channel change (Brierley and Fryirs 2005, 23).

1.2 Factors Affecting Channel Change

1.21 Valley Setting

Valley setting is an important factor when assessing channel change. Rivers can be coarsely separated into three idealized regions: the source, transfer, and accumulation zones. The source zone is the headwater region. The channel is confined by steep valley walls and has little room for adjustment (Figure 3). In the transfer zone, the channel is partly-confined and starts to migrate across the valley floor. In the accumulation zone, usually located on the coastal plain, the river deposits eroded sediment from upstream and the valley widens. The river is unconfined and has a large potential for migration across the valley floor (Brierley and Fryirs 2005, 23).

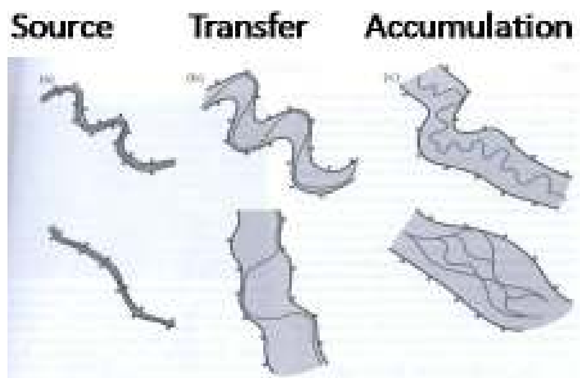


Figure 3. Examples of Valley Confinement. (Brierley and Fryirs 2005, 137).

1.22 Bank Material (Cohesive vs Non-Cohesive)

Erosion rates vary with the type of material comprising the channel bank. Major differences between the erosive behavior of cohesive and non-cohesive banks are documented (Brierley and Fryirs 2005, 93). Cohesive sediment is usually made up of clay and smaller sized sediment. Non-cohesive sediment contains larger particles such as sand (Brierley and Fryirs 2005, 93). Sediment entrainment and bank undercutting are the main mechanisms for bank retreat in non-cohesives. Mass failure such as rotational slumps and fluvial entrainment of aggregates are common mechanisms for cohesive bank retreat (Brierley and Fryirs 93, 98, 99).

The preconditioning of cohesive banks affects their propensity to fail. The susceptibility of a cohesive bank to failure is highly dependent on the physical properties of the bank. Dry hard banks do not fail as easily as wet banks that have experienced weakening because of wetting and drying cycles (Brierley and Fryirs 2005, 99). These cycles cause clay bank sediments to shrink and swell, weakening the bonds between sediment particles. Banks with high soil moisture content are heavier than dry banks and have a higher potential to fail (Brierley and Fryirs 2005, 99).

STUDY AREA

2.1 General

The study area includes the main stem of the lower San Antonio River from the FM 1604 bridge below San Antonio to the US 77 bridge along the Refugio/Victoria County border (Figure 4). Total length is 195mi. The beginning of the study reach has a drainage area of 1,743mi^2 that has increased to 4,134 mi^2 by the end.

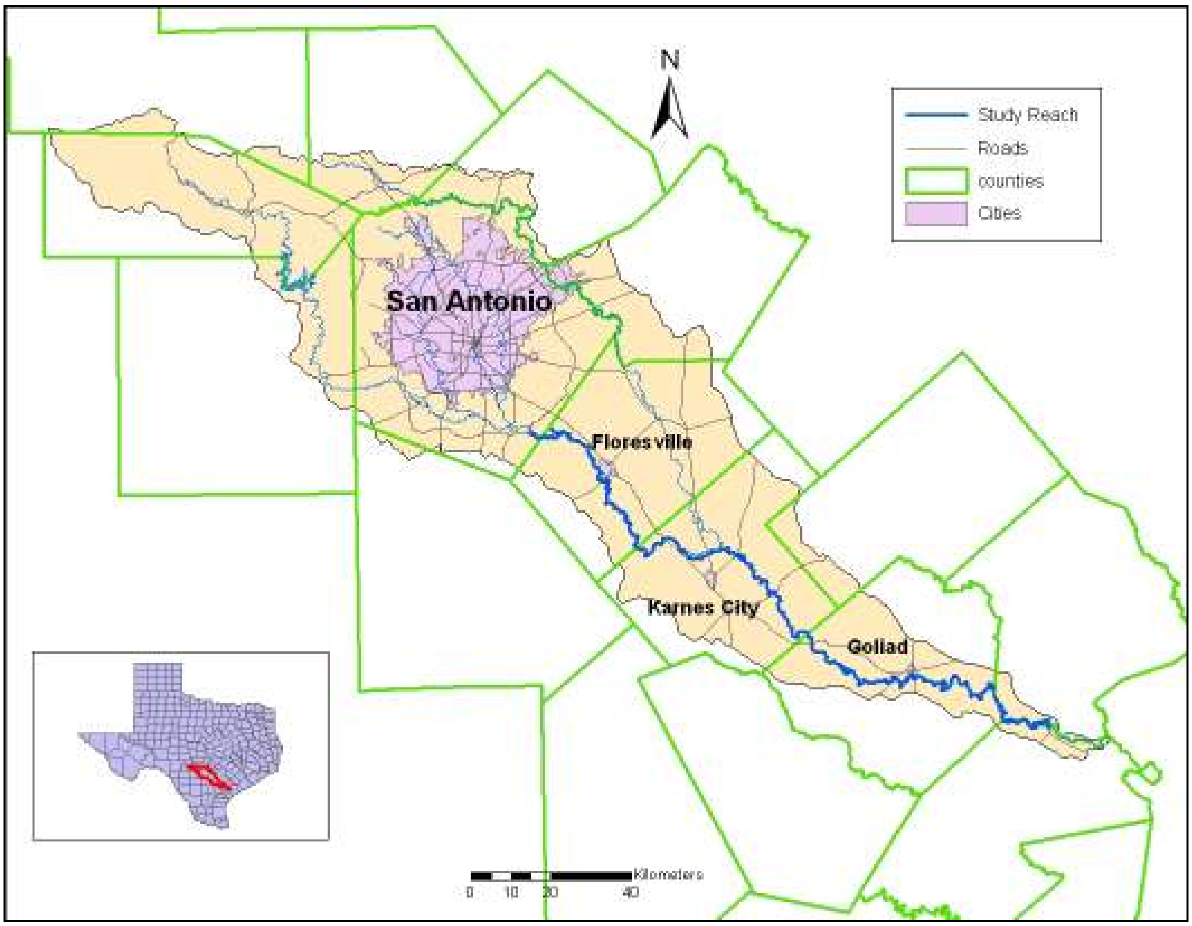


Figure 4. Study Area. The study reach is highlighted.

2.2 Climate

Climate for the study reach is subtropical sub-humid in the north and straddles the border between subtropical sub-humid and subtropical humid in lower Wilson County (Larkin and Bomar 1983). Average annual precipitation ranges from 28-32in. in the upper study reach to around 40in. in the lower portion. Precipitation is bimodal, with peaks in late spring and mid fall (NOAA 2007a). Extreme precipitation events are common because of spring thunderstorms and Gulf Coast hurricanes (Earl and Kimmel 1995, 31). In 1967, Hurricane Beulah dumped as much as 25 in. of rain in some areas of the San Antonio River basin (NOAA 2007b) and produced a flood of 138,000 cfs at the Goliad gage (USGS 2007). There has been a slight increase in the average yearly precipitation per decade since the 1970s (Figure 5). The 1970s, 1990s, and 2000s are the wettest decades of record excluding the 1880s (NOAA 2007c).

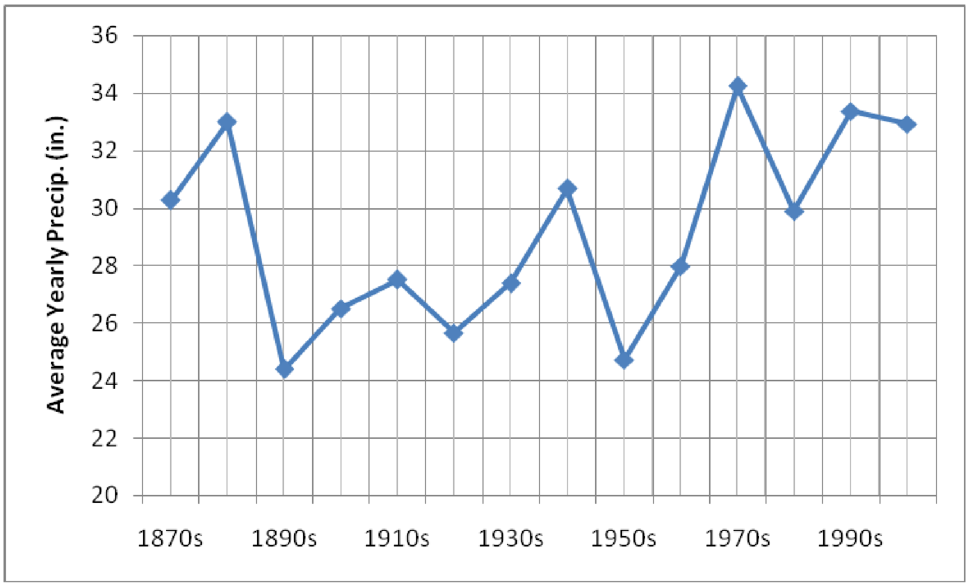


Figure 5. San Antonio Average Yearly Precipitation per Decade. (NOAA 2007c).

2.2 Geology

The study reach is underlain by marine sedimentary rocks from the Cenozoic Era that become progressively younger towards the coast (Barnes 1976; Barnes 1983; Barnes 1987). Along the Balcones Escarpment north of the study reach, Cretaceous aged Edwards limestone form the top of the escarpment. Downstream of the escarpment the study reach begins. Sandstone, marl, and shale dominate while the less erosive sandstone forms cuestas because of the gentle dip toward the coast. Along the San Antonio River are Pleistocene terrace deposits (Barnes 1976; Barnes 1983; Barnes 1987). The river is greatly incised and some portions of the study reach have incised into bedrock. Directly above Falls City the river flows over a geologic outcrop. Bedrock forced riffles and a waterfall occur along this river section. This outcrop prevents channel incision, and the channel widens in response.

2.4 Physiography

The San Antonio River watershed can be coarsely divided into two physiographic provinces, the Edwards Plateau and the Gulf Coastal Plains (Figure 6) (Wermund 1996). The Balcones Escarpment separates the two provinces. Thin soils and steep topography are characteristics of the Edwards Plateau and are known to produce impressive peak discharges from flood events near the Balcones Escarpment (Baker 1977). The Gulf Coastal Plains are subdivided into three subprovinces called the Blackland Prairies, Interior Coastal Plains, and Coastal Prairies (Wermund 1996). The Blackland Prairies are southeast of the Edwards Plateau. The terrain is low rolling hills and deep clay soils dominate. Southeast, the Interior Coastal Plains begin. Cuestas and valleys are characteristic of the topography, and shallow sand and clay soils dominate. Near the coast, the Coastal Prairies begins. Recently deposited clays, silts, and sands are characteristic. Treeless grasslands make up a majority of the land. The study reach is completely within the Interior Coastal Plains and the Coastal Prairies.

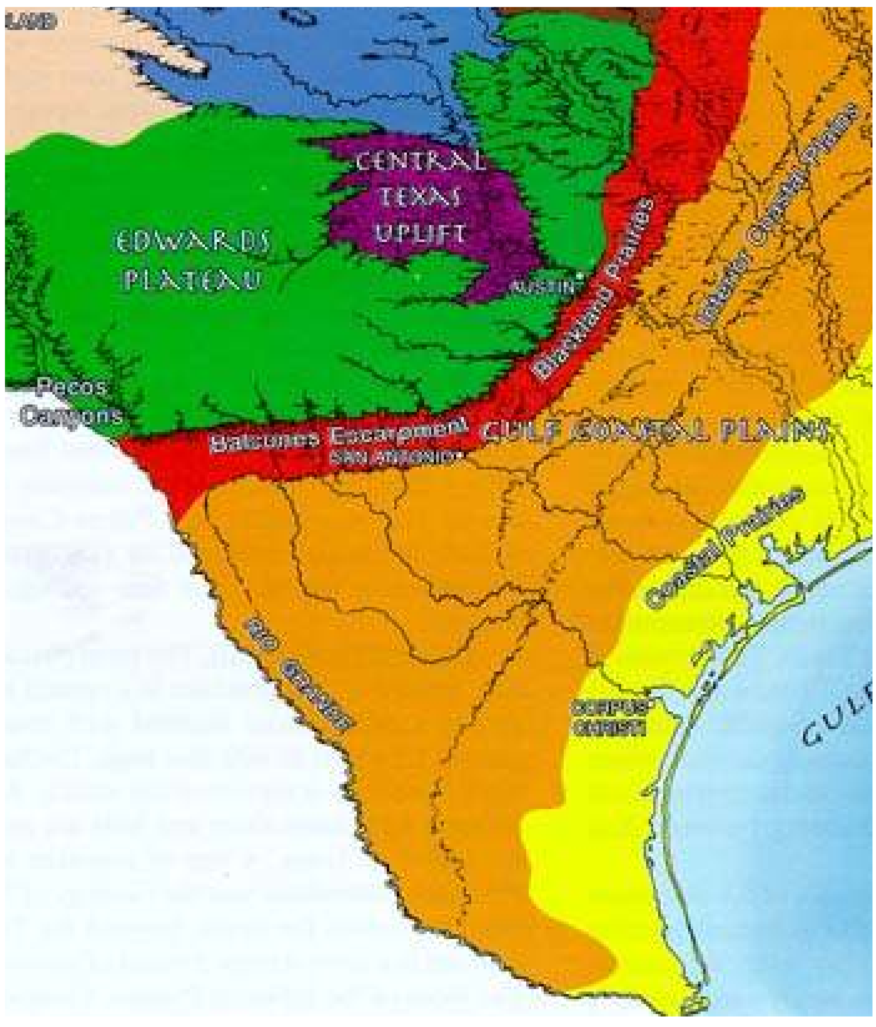


Figure. 6. Physiographic Map of Texas. The study reach lies within the Interior Coastal Plains and the Coastal Prairies (Wermund 1996).

2.5 Land Use

Land use and land cover are important considerations when analyzing the hydrologic regime and processes operating in a watershed. Land use influences rates of both erosion and runoff. Urbanization can cause a significant increase in runoff because of the addition of impermeable surfaces, as well as stormwater and sewer connections that flow into a river.

The 1992 land use map for the watershed is shown in Figure 7 (USGS 2000). Land use percentages for the watershed were derived from the 1992 land use data layer (Table 1). Ashe juniper (*Juniperus ashei*) forest land covers the majority of the uppermost part of the watershed, which coincides with the Edwards Plateau. The city of San Antonio is located directly downstream of the Edwards Plateau. The middle of the basin is largely agricultural interspersed with rangeland, and the lower basin consists of mostly rangeland.

Population and development have exploded in the watershed over the last one hundred years (Table 2). The growth between 1950 and 2000 is particularly great and has probably had a profound effect on the system.

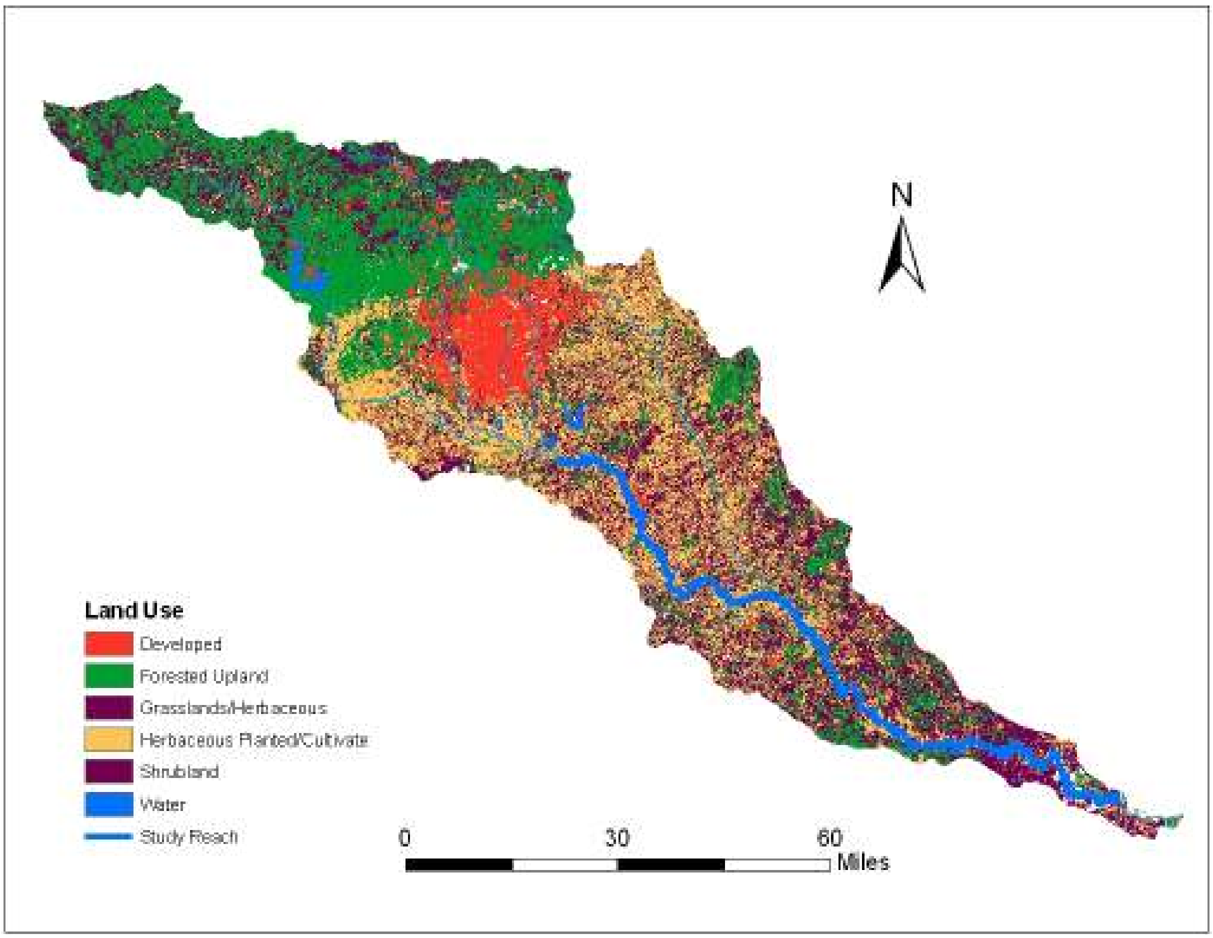


Figure. 7. 1992 Land Use. (USGS 2000)

Table 1. 1992 Land Use Percentages. Determined from the original land use data layer (USGS 2000).	
Land Use (1992)	**Percent Coverage (%)**
Water	1
Developed	7
Barren	1
Forested Upland	31
Shrubland	18
Grasslands/Herbaceous	14
Herbaceous Planted/Cultivated	27
Wetlands	1

Table 2. San Antonio Population. (Handbook of Texas 2007)		
Year	**Population**	**% Increase**
1900	53,321	
1910	96,614	81%
1920	161,379	67%
1940	245,065	52%
1950	392,104	60%
1960	587,718	50%
1990	935,933	60%
2000	1.14 million	22%

METHODS

3.1 Gathering Aerial Photos

GIS base layers such as roads, counties, and tributaries were obtained, including 2003 aerial photos from the San Antonio River Authority and 2004 NAIP orthophotos from the USDA. Because each county in the study reach commissions aerial photo missions separately, it was not possible to obtain complete aerial coverage of the river for the same year. Table 3 lists the aerial photos gathered, and there is aerial photo coverage of most of the study reach from years near the 1940s. The 1958 aerial photos were the earliest found for Victoria County. Most aerial photos were scanned from original hard copies at the Texas Natural Resources Information System office in Austin, TX. Most aerial photos are available at a scale of 1:20000, and at this scale, bank delineation is possible (Hughes, McDowell, and Marcus 2006). Aerial photos were scanned at 600dpi which provides aerial photos with a pixel resolution just under a meter.

Original scanned aerial photos are located on the Original Scanned Aerials disk accompanying this project.

3.2 Georeferencing Aerial Photos

Georeferencing assigns a coordinate system to scanned images (ESRI 2007). To georeference, a recent aerial photo with an associated coordinate system is chosen for use as a base layer. For this project, 2003 black and white, 1ft resolution aerial photos from the San Antonio River Authority (SARA), were used as the base layer. In the few areas where the 2004 NAIP orthophotos provide clearer views of the river bank, these were used as the base layer. All aerial photos and base layers were assigned the "NAD 1983 State Plane Texas South Central FIPS 4204" coordinate system and georeferenced using ArcView 9.2.

Ground Control Points (GCPs) are used to match the spatial location of the river between photos from different years. A GCP is any unchanged point that can be viewed on both images (ESRI 2007). Building corners, property corners, and trees are examples of GCPs. Hard points such as building corners and property corners are best to use because they have sharp edges (Hughes, McDowell, and Marcus 2006). Soft points such as trees are not as good but are used in rural areas because of a lack of hard points.

Due to the rural character of much of the San Antonio watershed, trees were often used as GCPs. During the time between aerial photos, many buildings had been torn down and property boundaries had changed. Care was taken to position GCPs close to the channel to enhance accuracy near the channel, as suggested by Hughes, McDowell, and Marcus (2006). A minimum of 6 GCPs were used for georeferencing each photo, as this enables the use of a second order polynomial conversion. Quadratic functions correct for geometric error due to lens distortion and natural topography and for radial error caused by the earth's curvature (Hughes, McDowell, and Marcus 2006). These functions produce rectified maps that have similar characteristics to orthorectified images (Hughes, McDowell, and Marcus 2006).

Table 3. Aerial Photo Information							
County	Year	Organization	Mission	Obtained at	River Miles Covered	Scale	Pixel Resolution (ft)
Wilson	1938	NRCS	BRL	TNRIS	44	1:20000	2.1
Wilson	1948	NRCS	BRL	TNRIS	55	1:20000	2.9
Wilson	1959	USGS	CIS	TNRIS	6	1:18400	2.7
Karnes	1950	NRCS	CLI	TNRIS	57	1:20000	2.9
Karnes	1959	USGS	CIS	TNRIS	8	1:18400	3.5
Karnes	1960	NRCS	BRL	TNRIS	8	1:20000	2.6
Karnes	1975	USGS		USGS (EROS)	5	1:21000	1.2
Goliad	1940	NRCS	CLH	TNRIS	68	1:20000	2.5
Goliad	1959	USGS	VZO	TNRIS	50	1:21000	2.7
Goliad	1974	USGS	NASA JSC	USGS (EROS)	33	1:124282	8.7
Goliad	1981	USGS	NHAP	USGS (EROS)	18	1:58000	4.3
Victoria	1958	NRCS	BRK	TNRIS	25	1:20000	3.1
Victoria	1966	NRCS	BRK	TNRIS	9	1:20000	3.1
Victoria	1972	USGS	NASA MSC	USGS (EROS)	14	1:63210	4.1
Victoria	1983	USGS	NHAP	USGS (EROS)	16	1:58000	4.1
Victoria	1987	TxDot	358591	TNRIS	34	1:20000	5

3.3 Bank Delineation

There are different methods to delineate channel banks. The brightness contrast between a bank slope (appears lighter when lit by the sun) and the bank top (appears darker) can be used to find the bank edge when a bank is devoid of vegetation (Lagasse et al. 2004, B-1). If a slope is not lit by the sun, it will appear darker than the bank top because of shadow. If banks are heavily forested, then tree centers can be used to approximate the bank location. This assumes the tree trunk is at the edge of the bank (Lagasse et al. 2004, B-1). Topographic data is extremely useful when delineating a bank. LIDAR provides elevation data in two-foot contour intervals. The 2004 LIDAR data provided by SARA were useful during bank delineation.

For most of the study reach, tree centers were used to delineate the banks. Where trees were not present, the contrast between light and dark was used. In Wilson County trees do not necessarily indicate the morphologic bank because large slumps and high banks are common. Following a bank slumping, vegetation grows along the slope and stabilizes the bank rather than marking the top of the bank. LIDAR data was used for bank delineation in Wilson County. Elevation data were not available for the 1938 and 1948 photos for Wilson County, and the LIDAR was used to help interpret general channel form.

3.4 Analysis

ArcGIS provides three ways to display vector data: points, lines, and polygons. Polygons were chosen to represent the channel because they allow for GIS overlay analysis. Overlying polygon layers can be used to quantify total change between the layers. To visualize and quantify areas of change, channel polygon layers that were delineated using the 1940s and 1950s images were erased from the delineated 2003/2004 channel polygon layer (Figure 8). This creates a new polygon layer showing areas of erosion. By erasing the 2003/2004 channel from the 1940s and 1950s channel, a layer showing areas of deposition and channel aggradation is created (Mossa and Coley 2004).

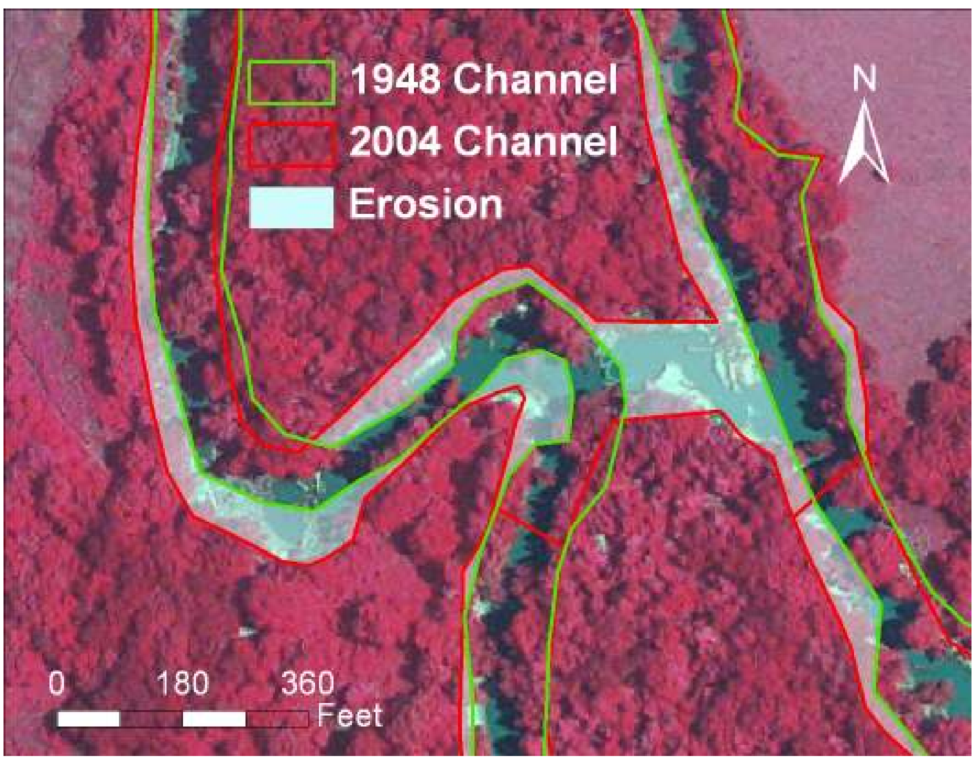


Figure 8. Polygon Erase Analysis.

Erosion and deposition indexes were created for the San Antonio River by first dividing the river into 2km segments. The total erosional area for each 2km segment was divided by the total 2003/2004 channel area for that same 2km segment. This produced a dimensionless number that could be used to compare amounts of erosion between different 2km segments (Figure 9). The process was repeated for deposition. Both indexes range from 0-1, where higher numbers indicate greater channel lateral change. An erosion index value of 1 indicates the channel has shifted its position entirely.

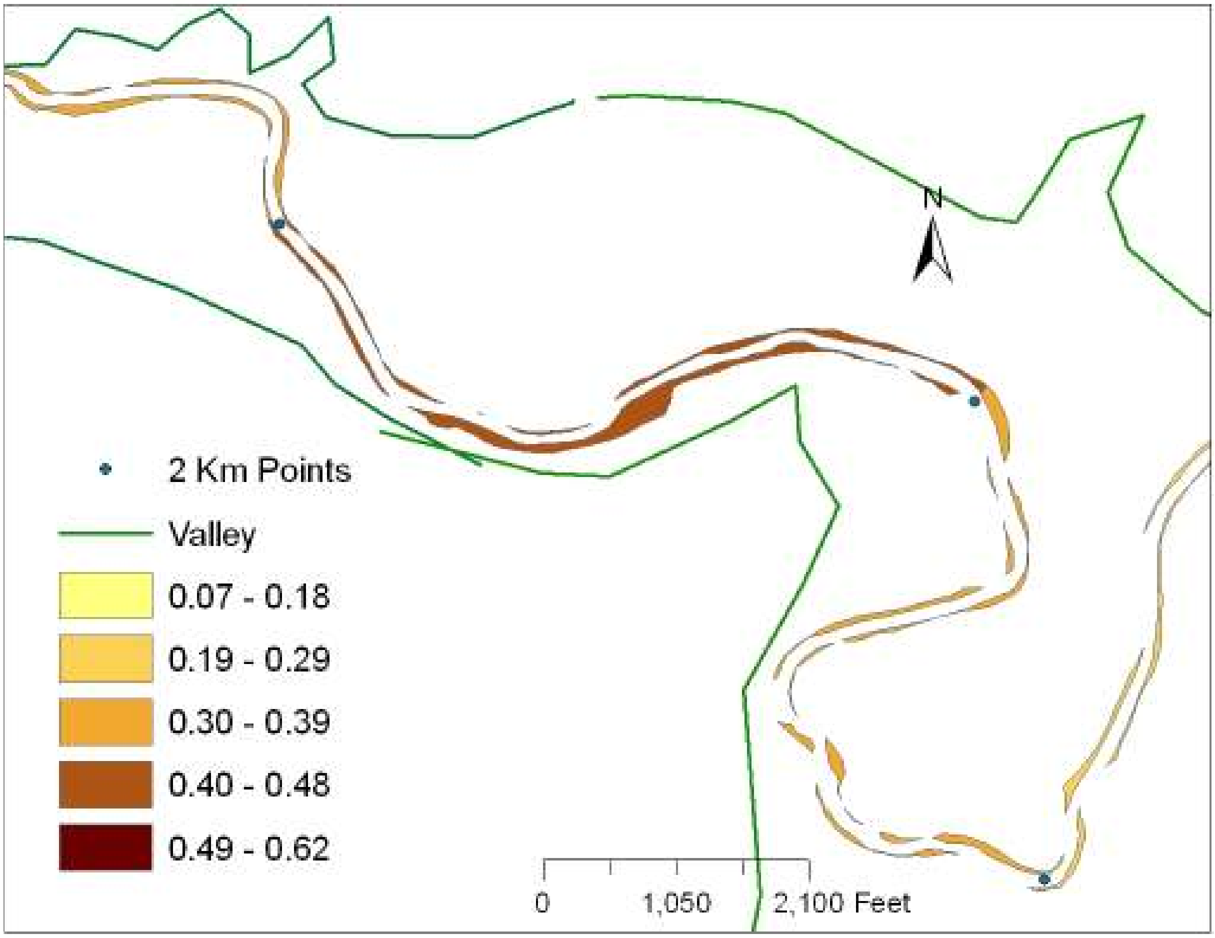
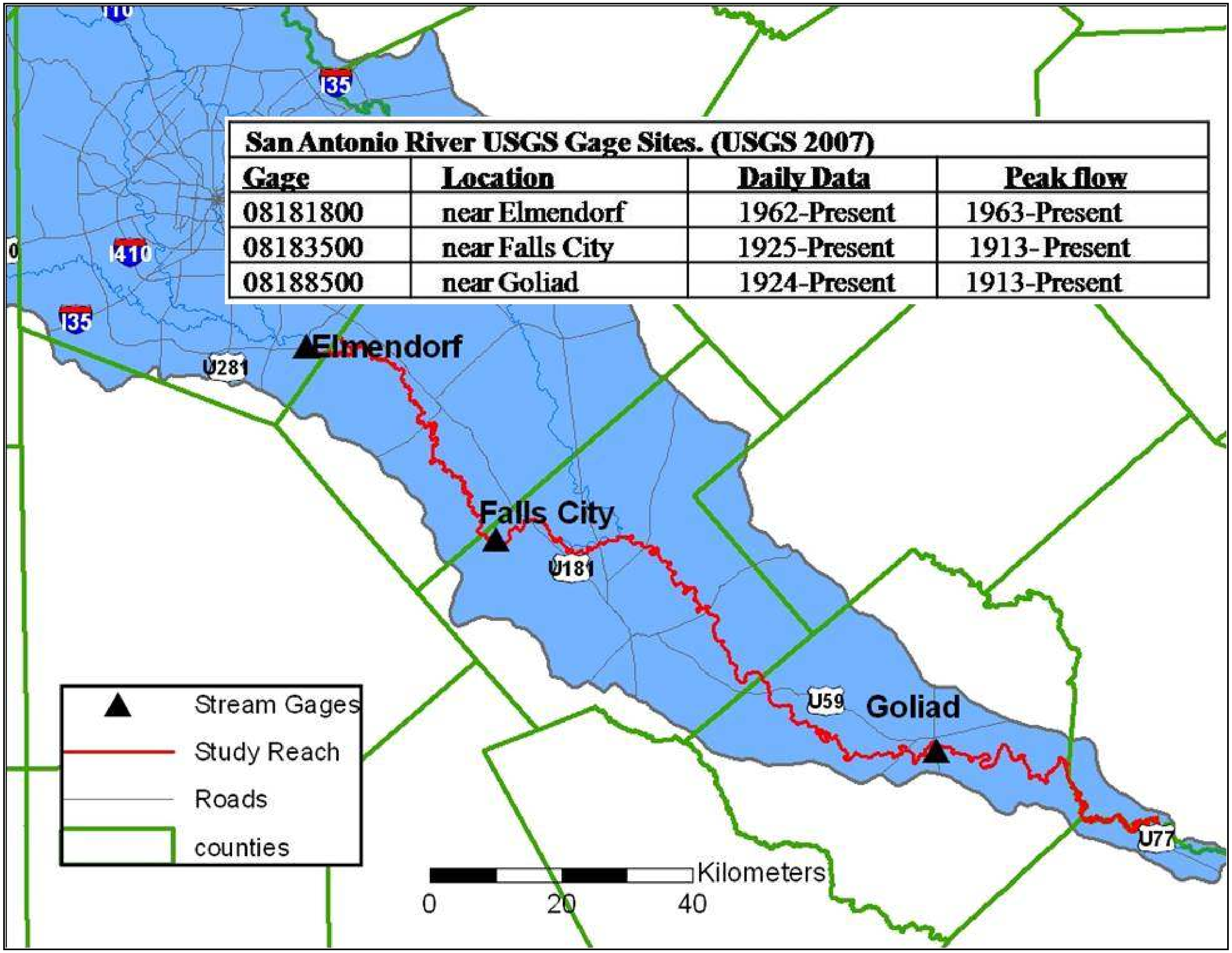


Figure 9. Erosion Index.

3.5 Hydrological Analysis

Flow records of three USGS gages (Elmendorf, Falls City, and Goliad) (Figure 10) were analyzed for any significant flow changes or large floods that might have impacted channel morphology. Mean monthly discharges were calculated. Mean daily flow percentiles per decade were calculated for the Falls City and Goliad gages from the 1920s until present (Figures 11 and 13). Significant increases in the 80^{th} – 98^{th} percentile flows are observed at the Falls City gage after the 1960s and 1970s (Figure 12). The Goliad gage shows an increase in the 80^{th}-98^{th} percentile flows after the 1970s (Figure 14). These high percentile flows are associated with storm runoff. The increase in flow rates associated with storm runoff events can be partially attributed to the increase in impervious cover with urbanization in and around San Antonio. The increase can also be attributed to an increase in precipitation. Three of the last four decades have been among the wettest since the 1870s (NOAA 2007) (Refer to Figure 5).



San Antonio River USGS Gage Sites. (USGS 2007)			
Gage	**Location**	**Daily Data**	**Peak flow**
08181800	near Elmendorf	1962-Present	1963-Present
08183500	near Falls City	1925-Present	1913- Present
08188500	near Goliad	1924-Present	1913-Present

Figure 10. USGS Gage Sites.

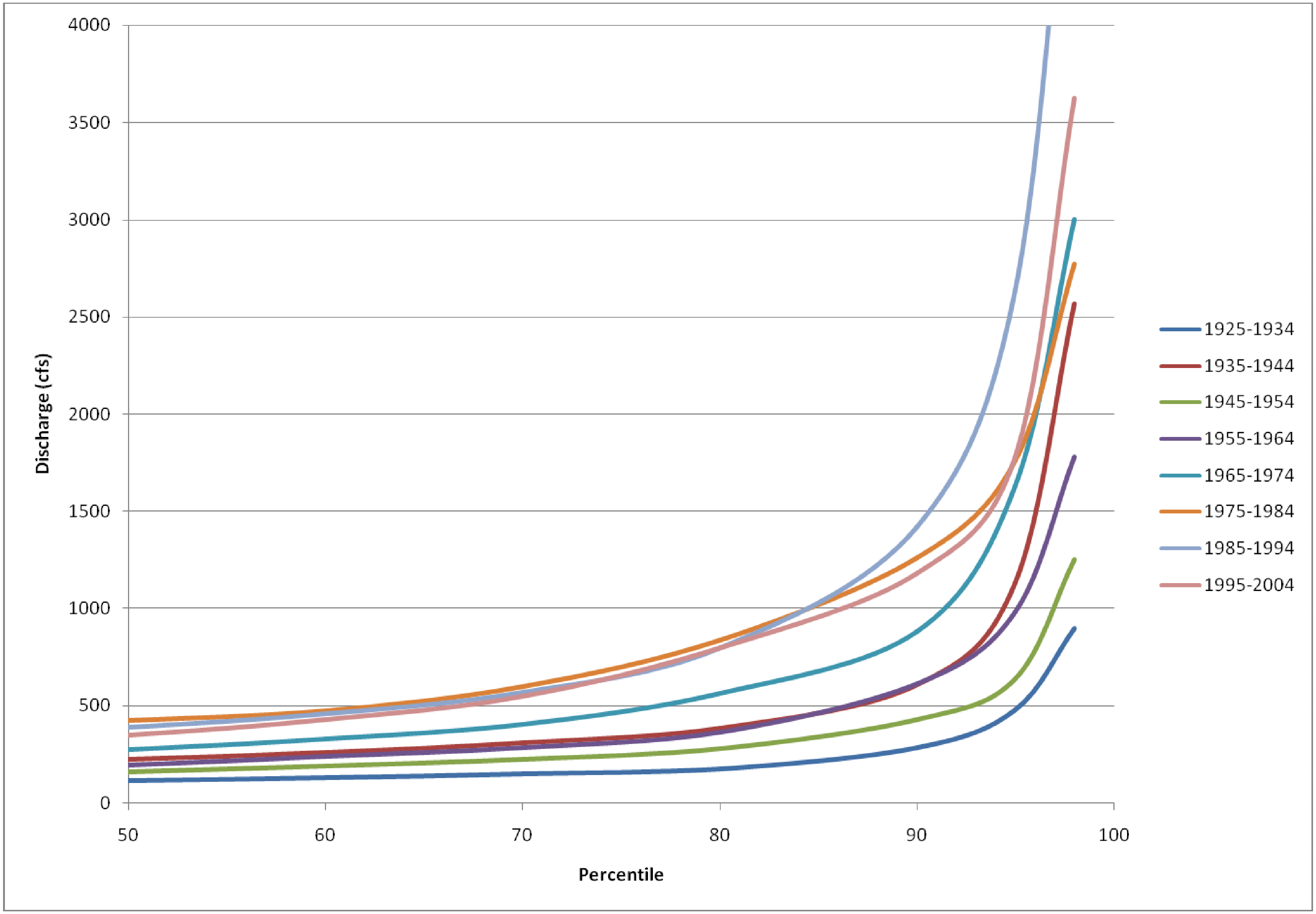


Figure 11. Falls City Flow Percentiles per Decade.

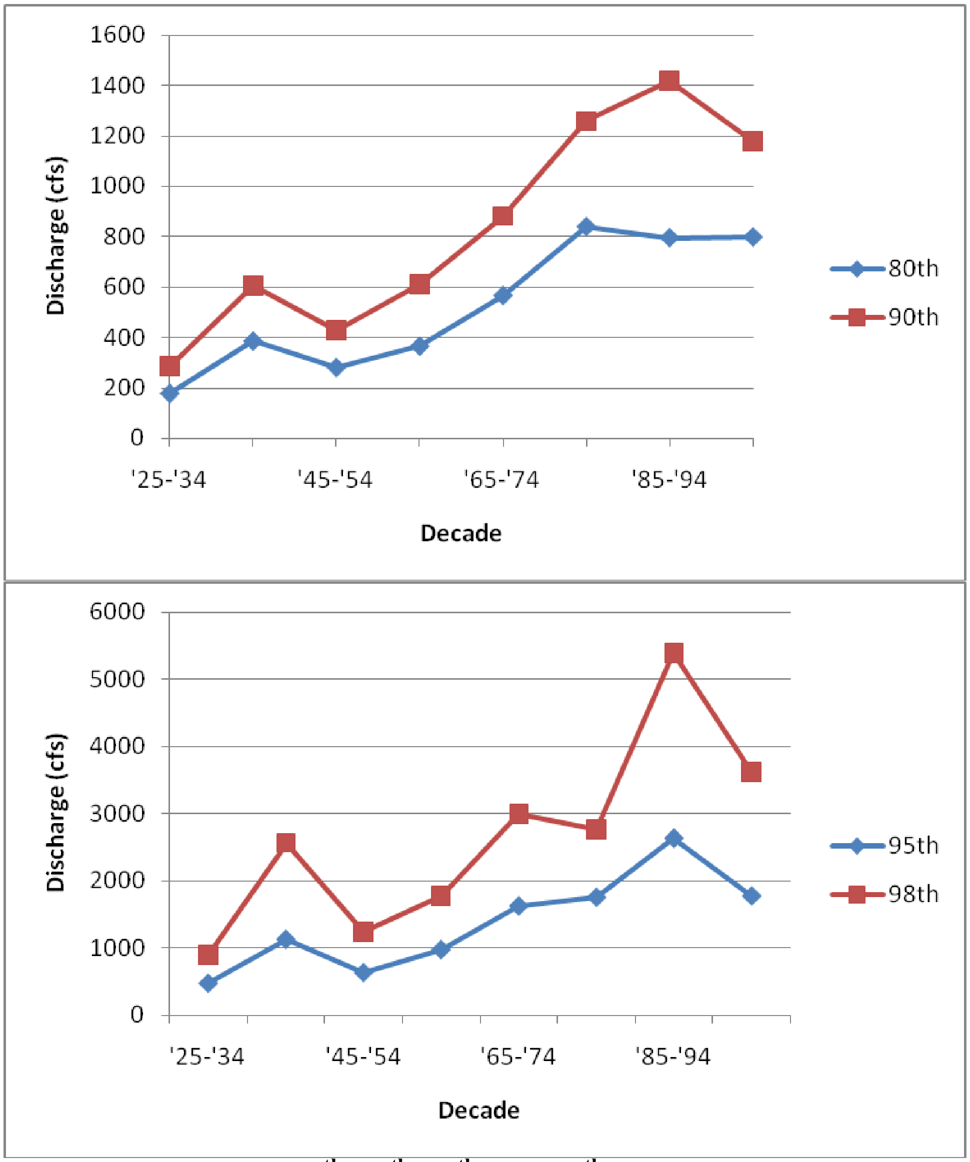


Figure 12. Falls City 80th, 90th, 95th, and 98th Percentile Flows.

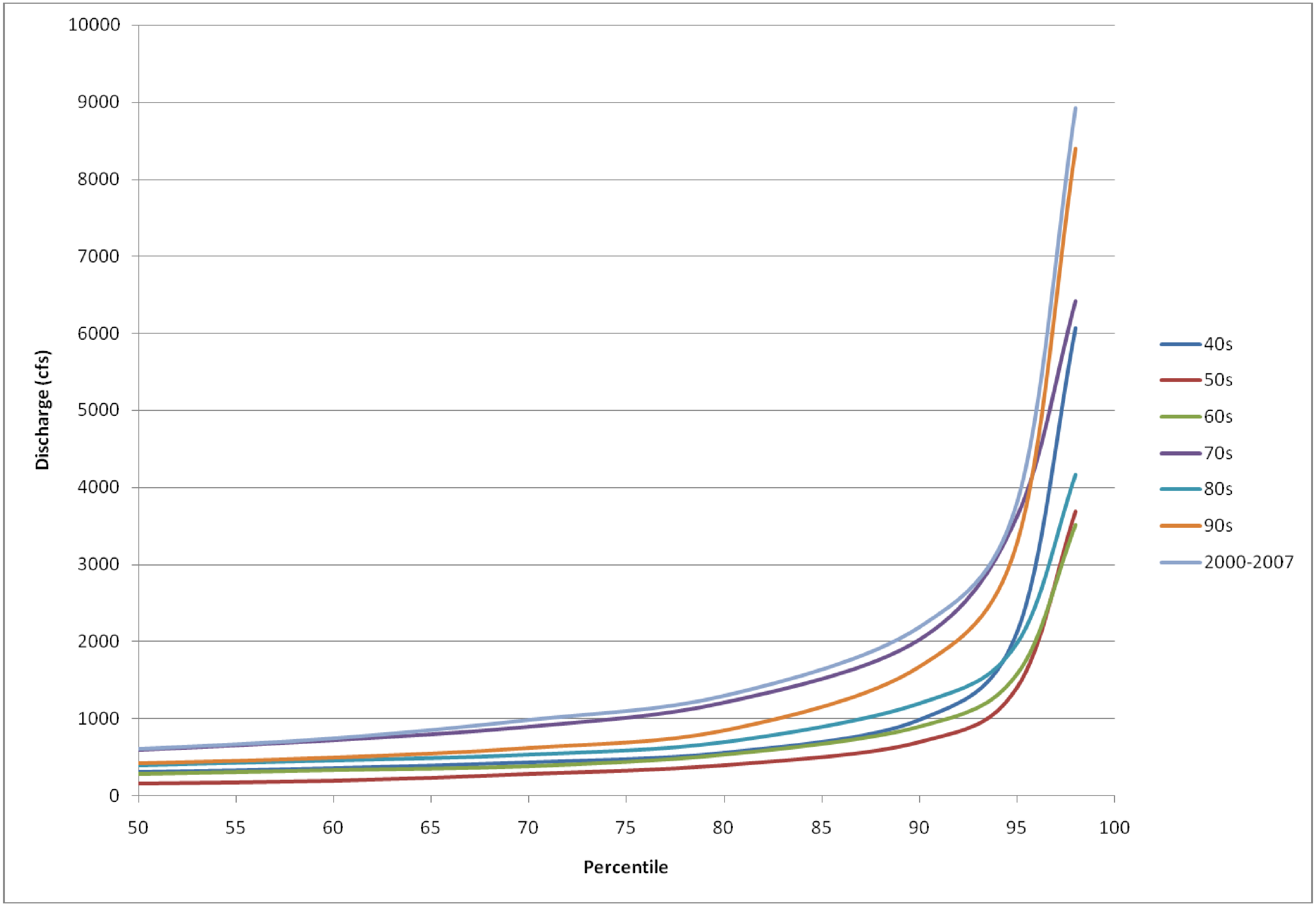


Figure 13. Goliad Flow Percentiles per Decade.

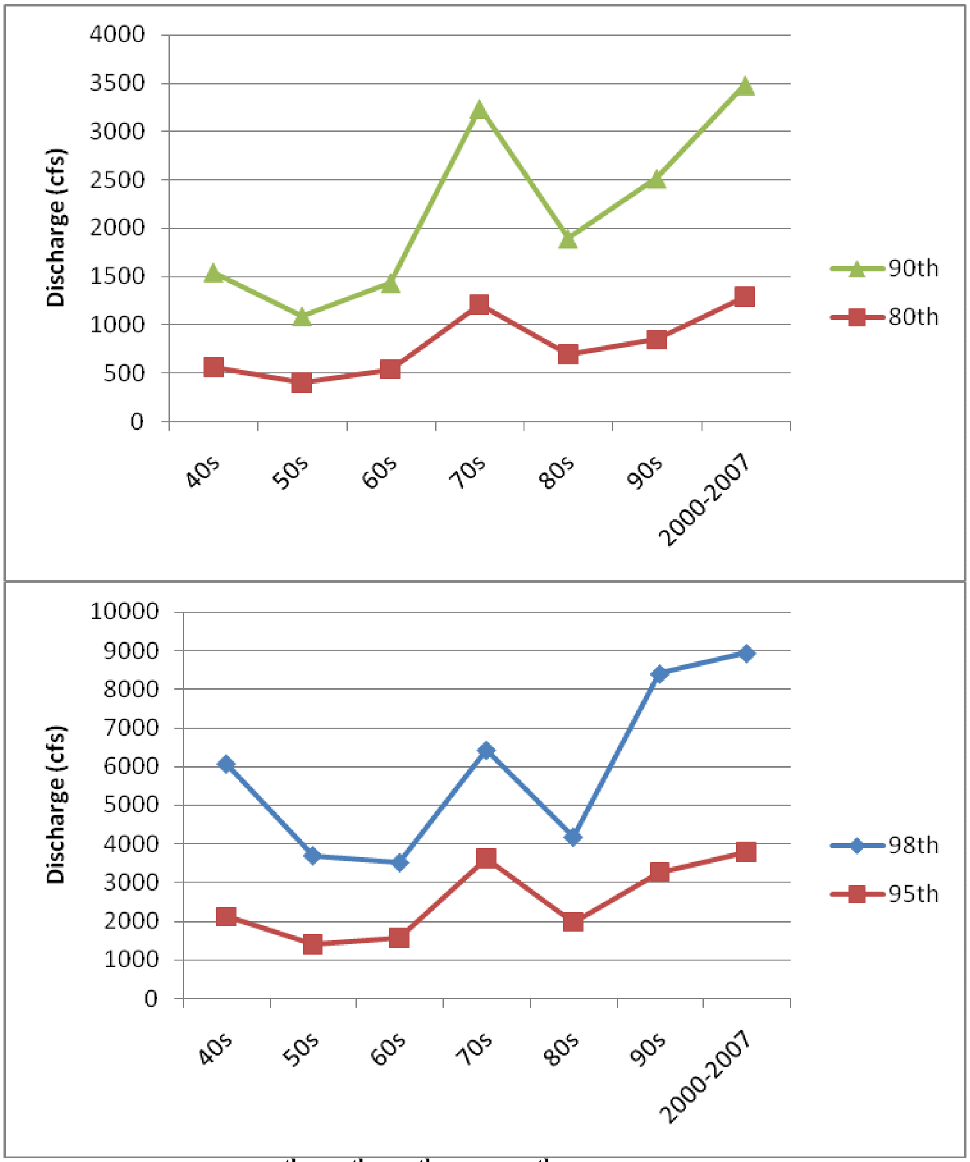


Figure 14. Goliad 80th, 90th, 95th and 95th Percentile Flows.

3.51 Major Floods

Figures 15 and 16 show the peak flows for the Falls City and Goliad gages. A large flood occurred at the Falls City gage in 1946. However, this flood had almost completely dissipated by the time it reached the Goliad gage. In September 1967, Hurricane Beulah drenched the lower study reach from about the middle of Karnes County to the coast, with some places receiving as much as 24 in. of rain (NOAA 2007b). The resultant flood was twice as large as any other flood recorded at the Goliad gage. Because the majority of the rain fell in the lower part of the watershed, there was not a corresponding flood at the Falls City gage. Two more large floods occurred in 1998 and 2002. These are the largest floods recorded at the Falls City gage and the second and third largest after the 1967 flood at the Goliad gage.

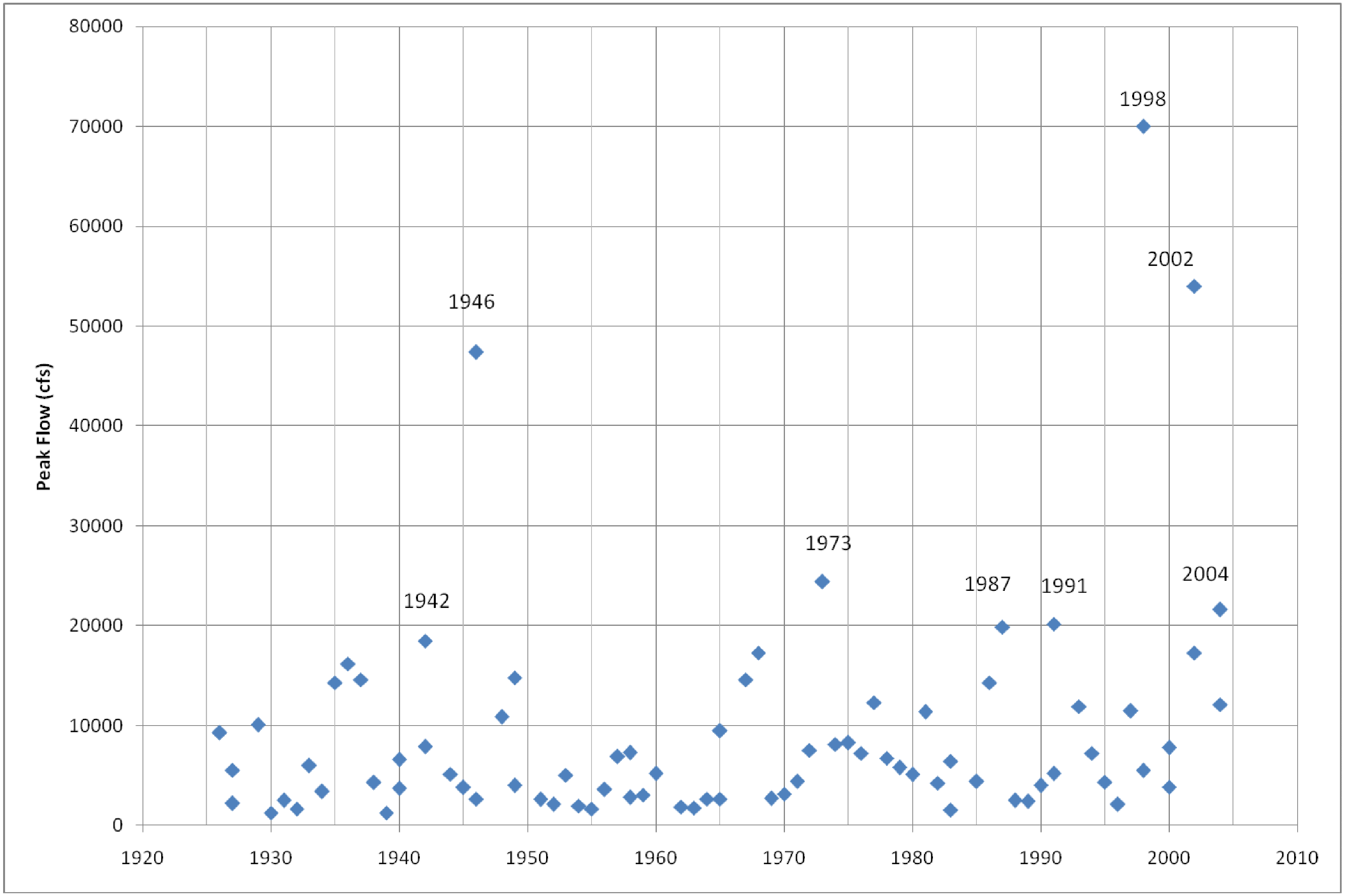


Figure 15. Falls City Peak Flows. (USGS 2007)

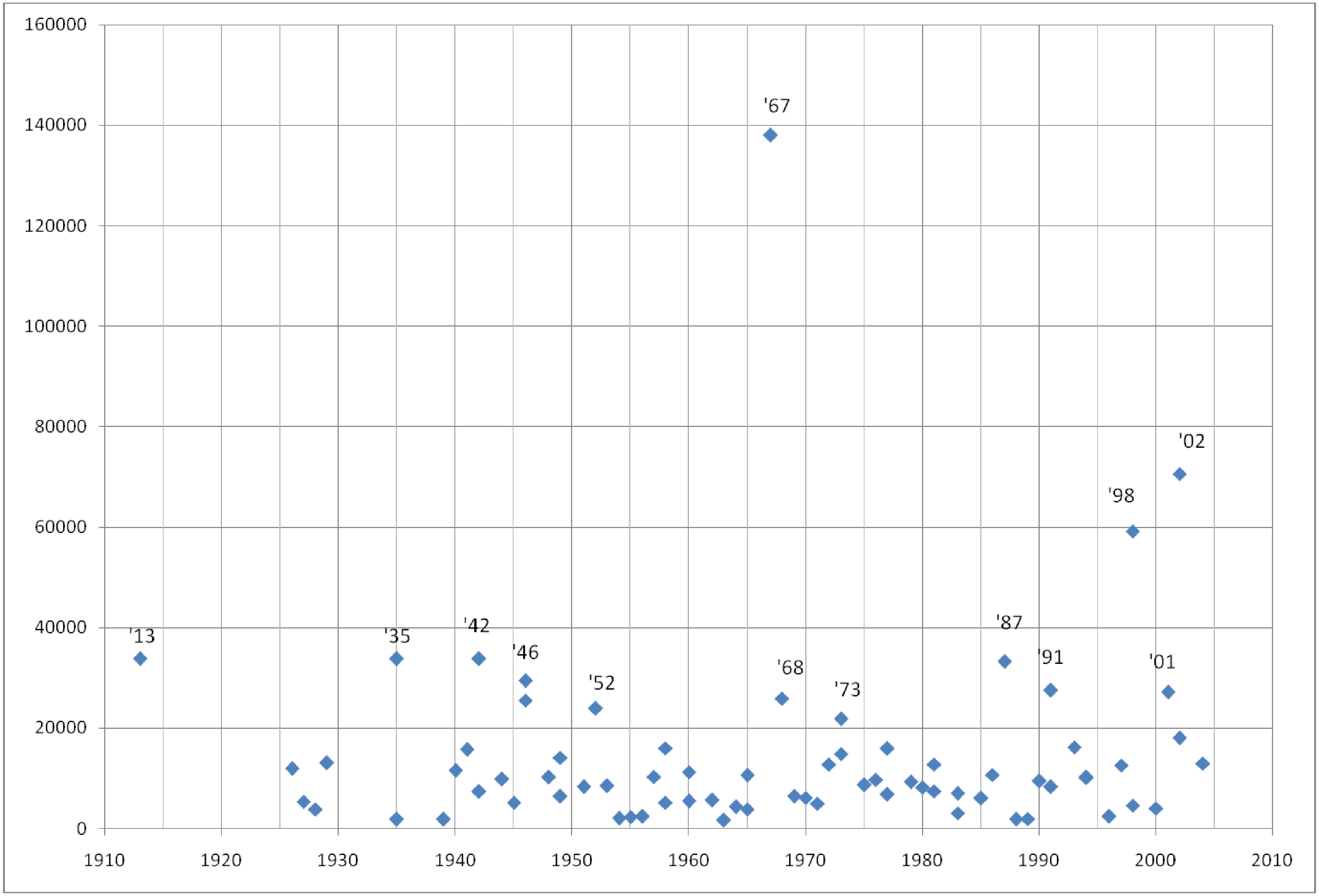


Figure 16. Goliad Peak Flows. (USGS 2007)

3.6 Repeat Cross-Sections

Historical data allowed for the repetition of channel cross-sections at two bridges in the study reach. Repeat cross-sections provide detailed field analysis of channel change and the most accurate method for assessing channel incision. Repeat cross-sections are also useful for detailing channel area change in specific locations. Historic cross-sections were taken at the USGS gage at FM 775 bridge near Floresville (Site 1) and the USGS gage at FM 791 bridge near Falls City (Site 2). The cross-section sites are shown in Figure 17.

The original cross-section at site 1 was taken in 1920 on the downstream side of an old bridge adjacent to the current FM 775 bridge. The old bridge is still there, but it is no longer in use and has been allowed to decay. The USGS gage at this site was abandoned sometime around 1925. The top of the old bridge handrail is included in the original cross-section, and is used as a datum to connect the old cross-section to the new cross-section. The new cross-section was taken on April 13, 2007. A tape measure and stadia rod were used to measure heights on the floodplain and in the channel. The height from the top of the handrail to the ground was measured at one of the bridge piers. The cross-sections and aerial photos from 1938-2003 for Site 1 are shown in Figure 18. The channel migrated 95ft over 87 years. This is a rate of 1.09ft/yr. The channel cross-sectional area nearly doubled from 900ft^2 to 1,630ft^2, and channel width increased by 40ft. The old 775 bridge has been standing since at least 1920. The aerial photos show a greater amount of migration and widening near the bridge when compared to the upstream and downstream channel banks. Bridge pylons have probably caused the flow to divert towards the banks, which has increased erosion locally. Flow diversions will have been exacerbated by the increase in 80th – 99th percentile flows since the 1960s and 1970s (Refer to Figure 11).

The original cross-section at Site 2 was taken in 1950 on the upstream side of the current 791 bridge. The gage at this site is still in use. The handrail is included in the original cross-section and is used as the datum for the newer cross-section. The new cross-section was taken on May 9, 2007. A measuring tape was laid across the upstream side of the bridge and heights from the bridge handrail to the ground were taken at a specified interval using a measuring tape. The height to the water level was measured and then water depths were measured across the channel using a stadia rod. The 791 cross-sections and aerial photos from 1950 and 2003 are shown in Figure 19. The channel widened by 40ft and channel cross-sectional area increased from about 1,340ft^2 to 1,980ft^2. The channel incised by about 4ft in contrast to about only 1ft of incision at Site 1.

A large slump was observed adjacent to the right bridge pylon. Because this is an isolated slump, it is reasonable to assume that flow diversion by the bridge pylon initiated the slump. Increased 80th – 99th percentile flows have contributed to general channel widening and incision at the site.

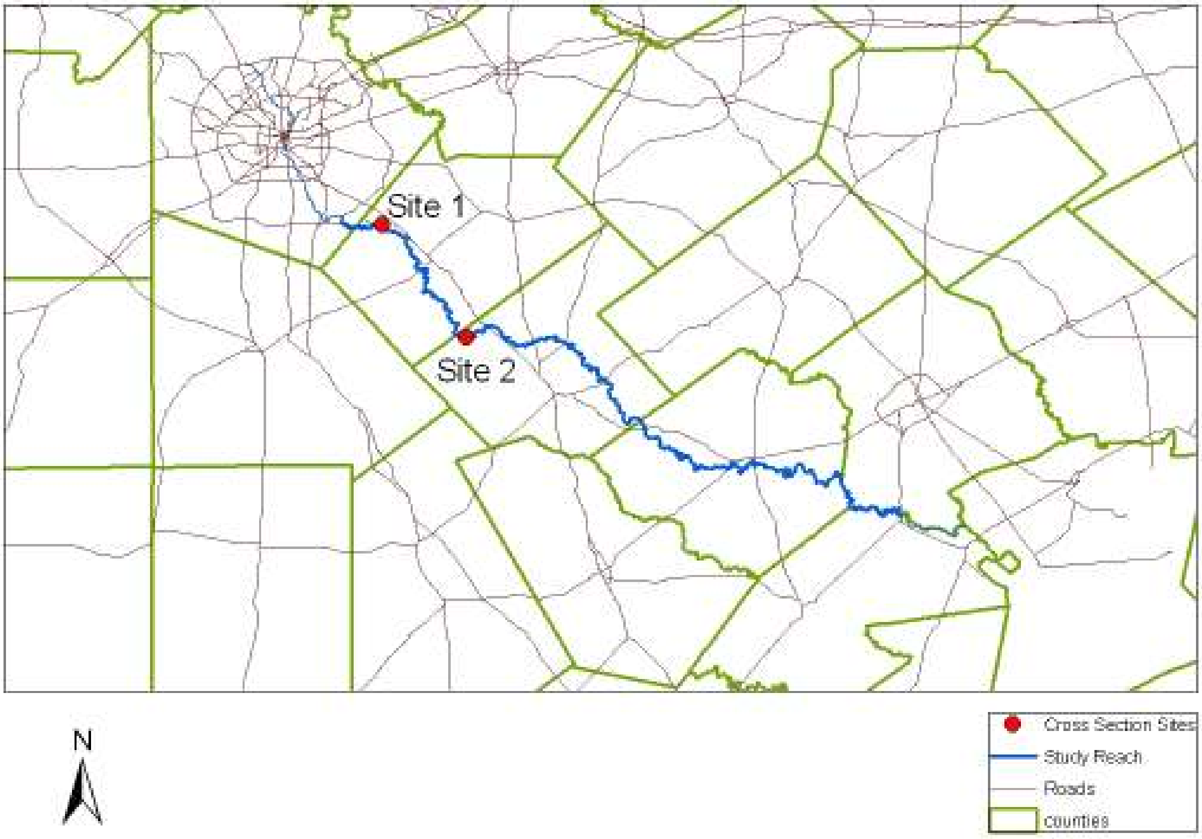


Figure 17. Cross-Section Sites.

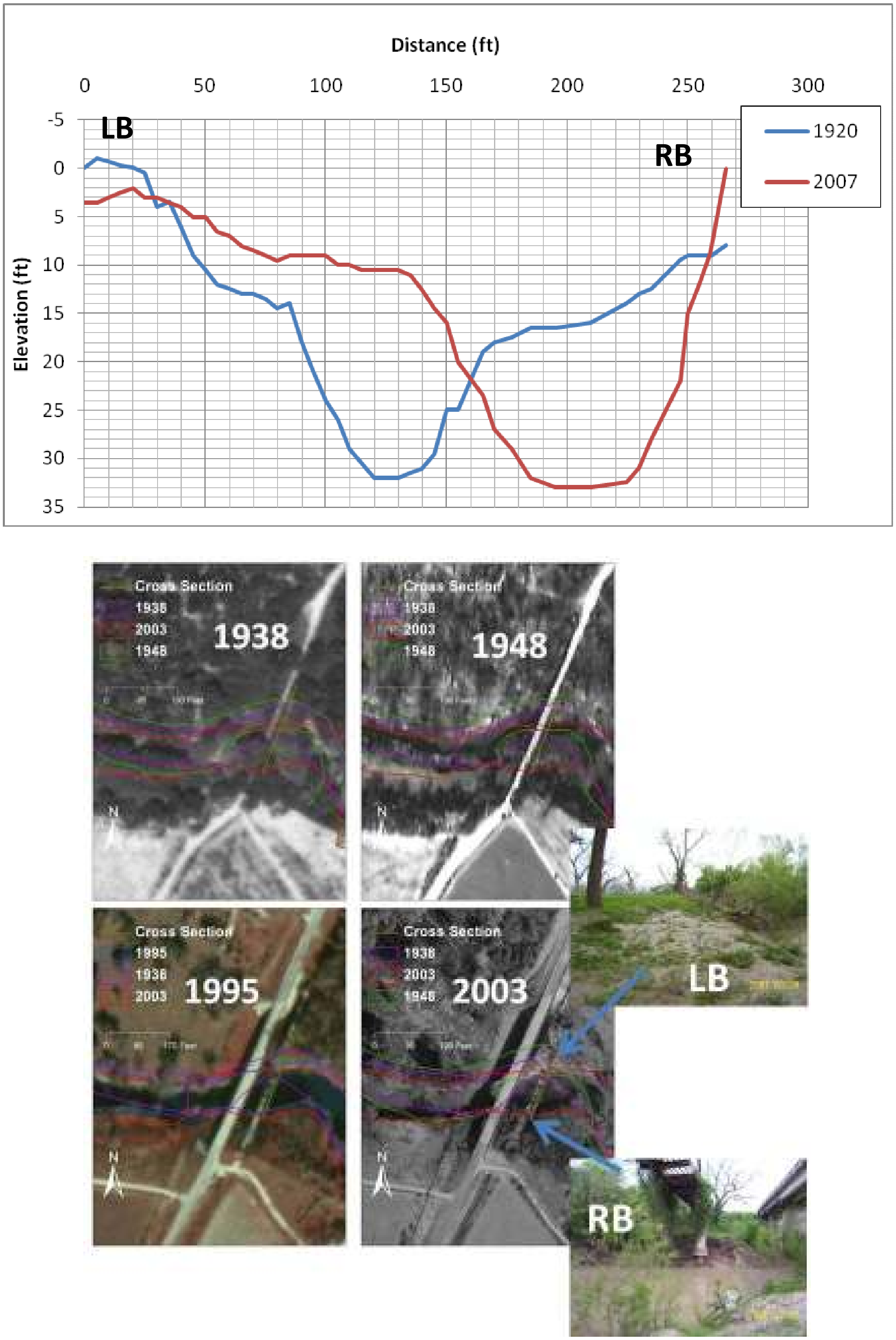


Figure 18. 775 Cross-Section. Cross-Section at the downstream side of the old FM 775 bridge.

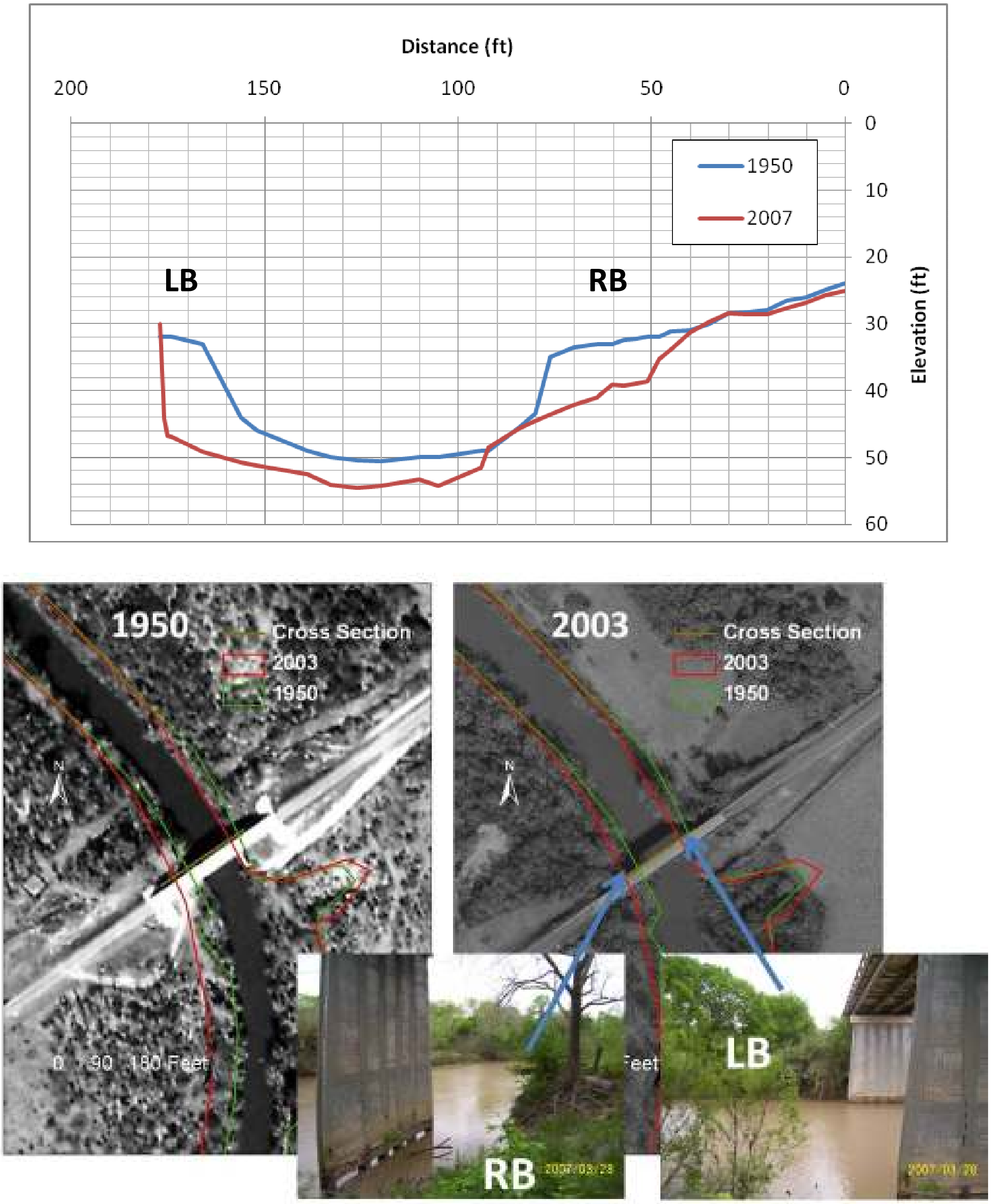


Figure 19. 791 Cross-Section. Site near Falls City at FM 791 bridge. Cross-section taken on upstream side of bridge.

3.7 Log Jams

A site with a large, channel spanning log jam was monitored in the field at the FM 775 bridge. The full channel jam was first observed on March 29, 2007. When the site was revisited on April 13, 2007, the jam was gone. The flow record between the two dates was examined using records from the USGS gage near Floresville to determine at what flow rate the jam mobilized and transported downstream. The peak flow from this time period was 6,357cfs. This peak flow is exceeded by 70% of the other yearly peak flows for the Elmendorf gage.

Fieldwork to map in-channel log jams was conducted from November 2006 – February 2007 between the FM 1604 bridge below San Antonio and the FM 541 bridge near Poth. Visible log jams from the same river reach were mapped on aerial photos obtained from SARA for December 7, 2003. The 2003 jam locations were compared to the field mapped locations. Flows were analyzed to determine the flow rates at which jams had transported, if they had moved. It is assumed that jams moved during the peak flow for this period.

Of the log jams mapped using the December 7, 2003 aerial photos, 90% had moved by the time the sites were visited in the field. Only 10% of the jams in the field and on the aerial photos were near enough to each other to be considered stable jams. Of the seven channel-spanning jams, all had moved. The peak flow during this time was 20,800cfs on November 23, 2004. This peak flow exceeds only 14% of the yearly peak flows for the Elmendorf gage. In-channel log jams have a very high mobility in this reach of the study area. Thus, log jam influence on channel morphology in this reach is probably minimal.

3.8 Natural Regime Channel Change Assessment

3.81 Terrace and Valley Confinement

Terrace and valley confinement create boundaries to channel migration and are important when assessing long term channel change (Brierley and Fryirs 2005, 136). Terraces along the study reach were mapped using the 2004 LIDAR data. Reaches where terraces are near the channel are assumed to have less natural migration than less confined reaches. A steep first terrace was observed throughout most of the upper study reach. This first terrace started to widen and then disappear in the lower study reach.

3.82 Original Survey Maps

Original property survey maps from the 1830s were downloaded from the Texas General Land Office website. These were used to assess major channel movements and to estimate dates of meander cutoffs. Only general assessments are possible when using these maps.

3.9 Bridge Analysis

A general assessment of the effects of bridges on channel morphology was conducted using aerial photo comparison. A point layer of bridges was created, and bridges were assigned into three different categories: No Change, Possibly Minimal, and Change (Table 4).

Only 6 bridges out of the 28 examined showed a greater amount of channel change at the bridge when compared to channel change downstream or upstream. Two of the bridges in the Change category are the FM 775 old and new bridges.

Table 4. Bridge Categories			
Category	Description	Total	Percent
No Change	The channel immediately adjacent to the bridge did not appear to change unnaturally from the channel upstream and downstream.	10	36%
Possibly Minimal	Minimal change could be caused by the bridge, but the change was very small and hard to determine for sure.	12	43%
Change	The channel appeared to change unnaturally adjacent to the bridge, and not change as much upstream or downstream.	6	21%

RESULTS/DISCUSSION

4.1 Erosion Index

An erosion index was calculated for each 2km segment, as described in Section 3.4. Figure 20 shows the erosion index per kilometer downstream. Total erosion is variable throughout the study reach, but there is a significant increase at 185km. The mean erosion index value increases from about 0.2 to about 0.4. The river can be broken into groups based on the mean erosion index

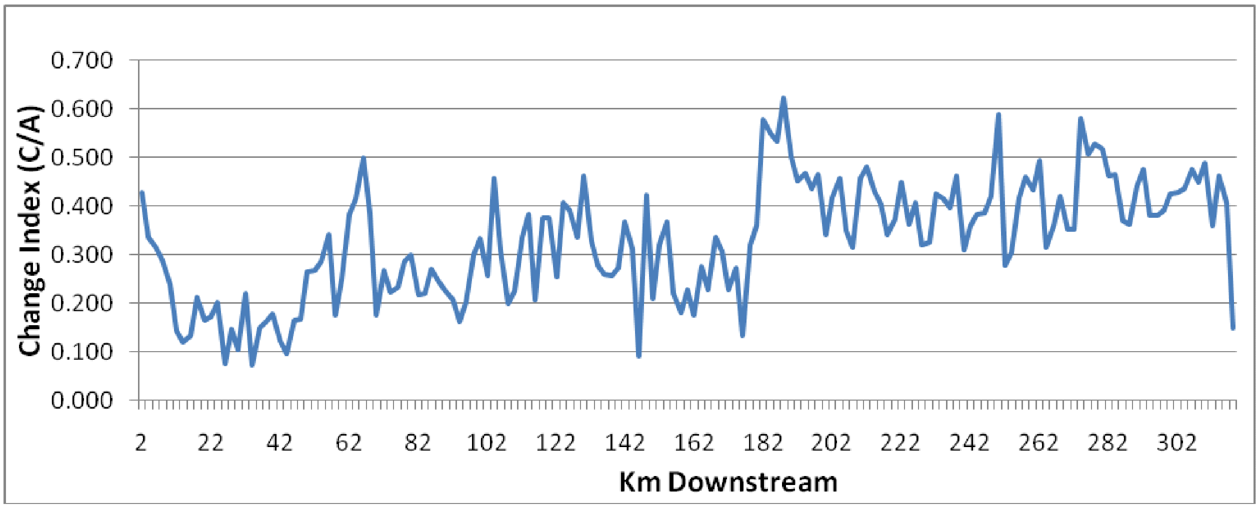


Figure 20. Erosion Index per Kilometer Downstream. The index was calculated every 2km.

4.11 Erosion Index Groups

Groups were formed from the erosion index chart (Figure 21). Because of typical errors involved with georeferencing aerial photos and bank delineation, caution is taken when interpreting these results. Comparison of erosion indexes between counties yields unavoidable error because one continuous year of air photos could not be obtained for the entire study reach.

In Wilson County, erosion increases at the third group downstream. This corresponds to an area with increased sand and bar development. Sandier banks are more easily eroded than clay banks because they are less cohesive.

In Karnes County, the erosion index increases slightly and the mean remains fairly constant.

In Goliad County, a large increase in the erosion index occurs at river km 185 where the river valley starts to widen. Upstream of this point the river is confined with little room for adjustment. When the river enters the widened valley it has a wide plain over which it can meander and alter its planform morphology. The change in erosion index and river valley width occurs 7.4 miles into Goliad County.

In Victoria County, the erosion index remains about the same as in Goliad County. However, this is the most dynamic area of the study reach. Because of the difference in the years that photos were available for the different counties, 1958 photos for Victoria County are compared to1940 photos for Goliad County. Therefore, any erosion in Victoria County that occurred from 1940-1958 is not included in this analysis.

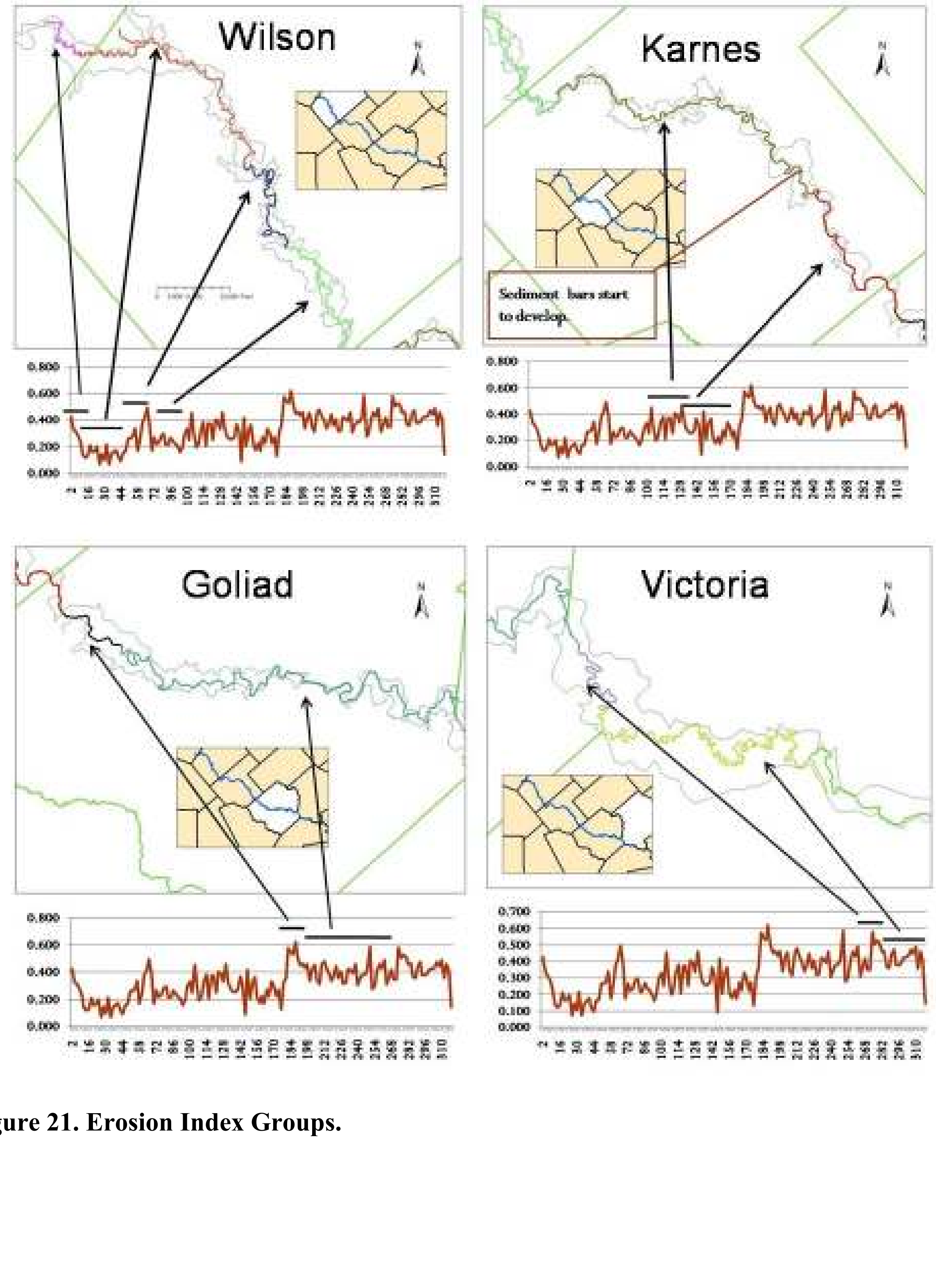


Figure 21. Erosion Index Groups.

4.2 Deposition Index

A deposition index was calculated for each 2km segment, following the same procedure as for the erosion index as outlined in Section 3.4. Figure 23 shows the deposition index per kilometer downstream.

There is a significant increase in the deposition index at kilometer 284 (Figure 23). This increase coincides with valley widening and a decrease in channel slope, which together create a favorable depositional environment. In the idealized river model, this area is the accumulation zone. Stream sinuosity increases downstream of the increase in deposition index.

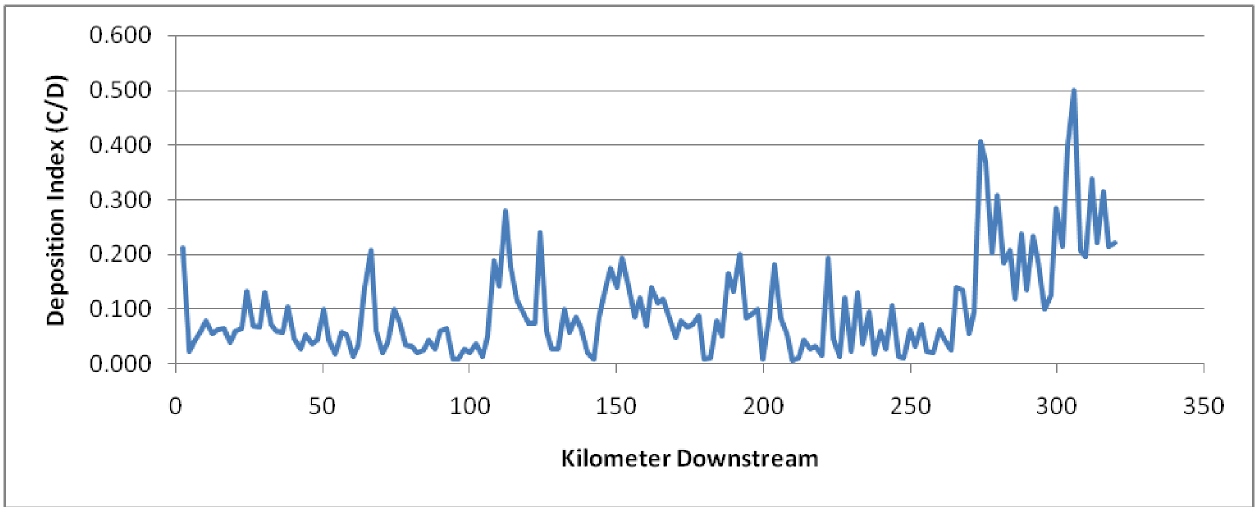


Figure 22. Deposition Index per Kilometer. A significant increase occurs at km 274.

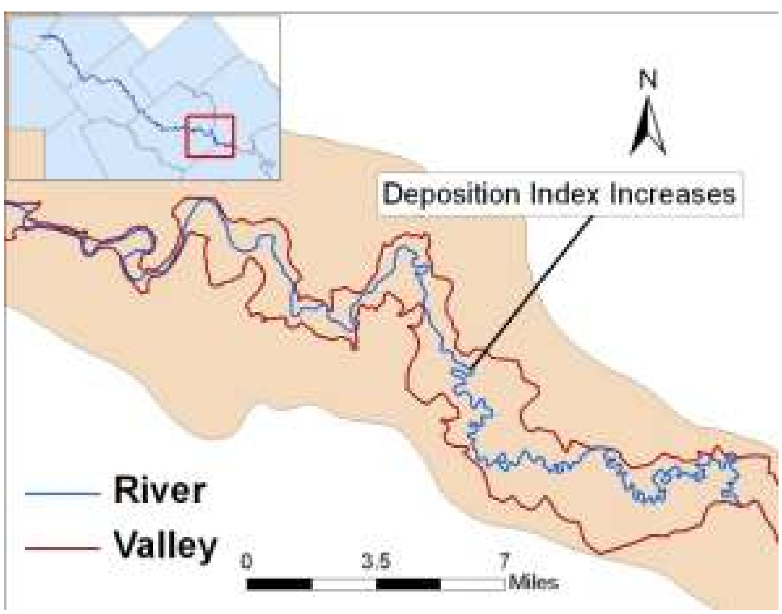


Figure 23. Deposition Index Increase. The index increases at river kilometer 284.

4.3 General Change Trends by County

4.31 Wilson and Lower Bexar County

Tight bends and high sinuosity are characteristic of the study reach near the bottom of Bexar County and at the top of Wilson County. The river then straightens until near Floresville where river sinuosity increases for a short distance but straightens again downstream. Channel banks as high as 40ft are characteristic throughout Wilson County, and the channel is confined by a high terrace near the channel. Flood flows rarely overtop this terrace. Channel banks are mostly silty clay loam, with sections of sandier banks interspersed (Taylor 1977).

Little channel migration is observed when comparing the 1938 channel to the 2003 channel (Figure 24). Banks on the outside of meander bends have widened, but there has been little deposition at the inner banks. Widening has occurred primarily through large bank slumps and failures because of the presence of cohesive banks.

The largest floods in the County occurred in 1913, 1946, 1998, and 2004 (Refer to Figure 15). The 1946 flood had a significant impact on the channel. Figure 25 compares the erosion indexes from 1938 to present and from 1948 to present, illustrating a large amount of change between 1938 and 1948. Figure 26 shows a typical bank slump from the 1948 photos following the 1946 flood. Numerous bank slumps are visible on the 1948 aerial photos and all are devoid of vegetation, indicating recent occurrence. On the 2003 aerial photos, the same slumps appear stabilized with growing vegetation. The 1995 aerial photos were analyzed to compare the impact of the more recent floods to the impact of the 1946 flood. The 1998 and 2003 floods did not have as significant of an impact as the 1946 flood. A possible reason is that the banks had become oversteepened and unstable prior to the 1946 flood. After the slumping associated with the 1946 flood, the banks re-stabilized as vegetation grew on the lower bank slope. Because of the impact of the 1946 flood, it is hypothesized that large floods will have a significant impact on channel morphology in the upper study reach.

4.32 Karnes County

In northern Karnes County, above Falls City, there is a reach that flows over a bedrock exposure. The river becomes wider in this reach because the bedrock prevents incision and the channel adjusts to increased flows by widening. Riffles are common and there is a large waterfall. Downstream of Falls City the bedrock exposure ends. Clay banks with interspersed sections of sandier banks become common in Karnes County (Molina 2000). Sediment bar formation begins in the middle of the county.

When comparing the 1950 and 2003 aerial photos, a general trend of widening becomes apparent. Significant migration begins at channel bends (Figure 24). Bank heights remain fairly high in upper Karnes County but begin to lessen in the middle of the county.

The Falls City gage was used to assess peak flows for upper Karnes County and the Goliad gage was used to assess peak flows for lower Karnes County. The 1913, 1946, 1998, and 2002 floods are the largest recorded at the Falls City gage, and the 1967, 1998, and 2002 are the largest recorded at the Goliad gage. The 1946 flood was a large flood at the Falls City gage, but had attenuated before reaching the Goliad gage. The 1967 Hurricane Beulah flood was large in lower Karnes County and Goliad but did not impact Falls City.

4.33 Goliad County

Large meander bends are frequent in the San Antonio River in Goliad County. At the top of the county, the valley widens and bank erosion increases. The banks reach heights of 20 ft and flood flows overtop these banks frequently. Channel widening occurs throughout the county as channel migration is common. There is a considerable increase in the total amount of channel change when compared to the river upstream. The channel is less incised in this area, enabling rapid migration.

The three largest floods in Goliad occurred in 1967, 1998, and 2002 (Refer to Figure 16). The 1967 flood appears to have had the most impact on the channel.

4.34 Victoria County

River planform characteristics change significantly along the Goliad/Victoria border. The bends become very tight and radius of curvatures decrease (Figure 24). The valley widens significantly, the channel slope is low, and a large amount of sediment deposition takes place. This area corresponds to the final reach of the San Antonio River before entering tidal areas. Banks are clay (Miller 1979) and about the same height or less than Goliad County.

This is the most dynamic area of the study reach with a large amount of migration. Migration was observed at almost all channel bends, and channel widening was common. The largest peak flows are assumed to be the peak flows observed at the Goliad gage: 1967, 1998, and 2004.

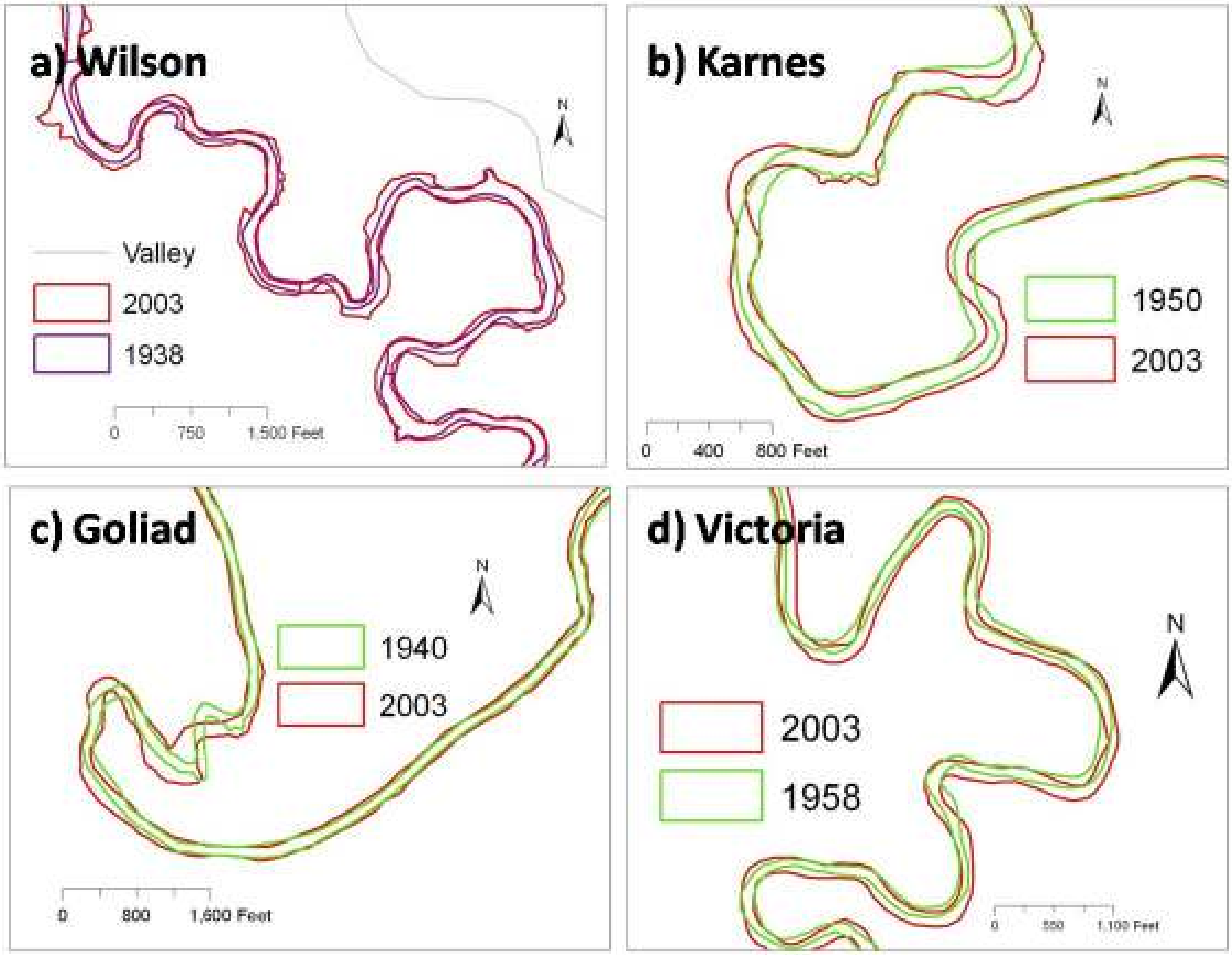


Figure 24. County Channel Change. a) Large slumps, widening, and little migration are common in Wilson County. b) Widening and migration at a few bends was observed in Karnes County. c) Migration and channel widening were observed in Goliad County. d) The fastest migration rates were observed in Victoria County. Nearly all of the bends had migrated.

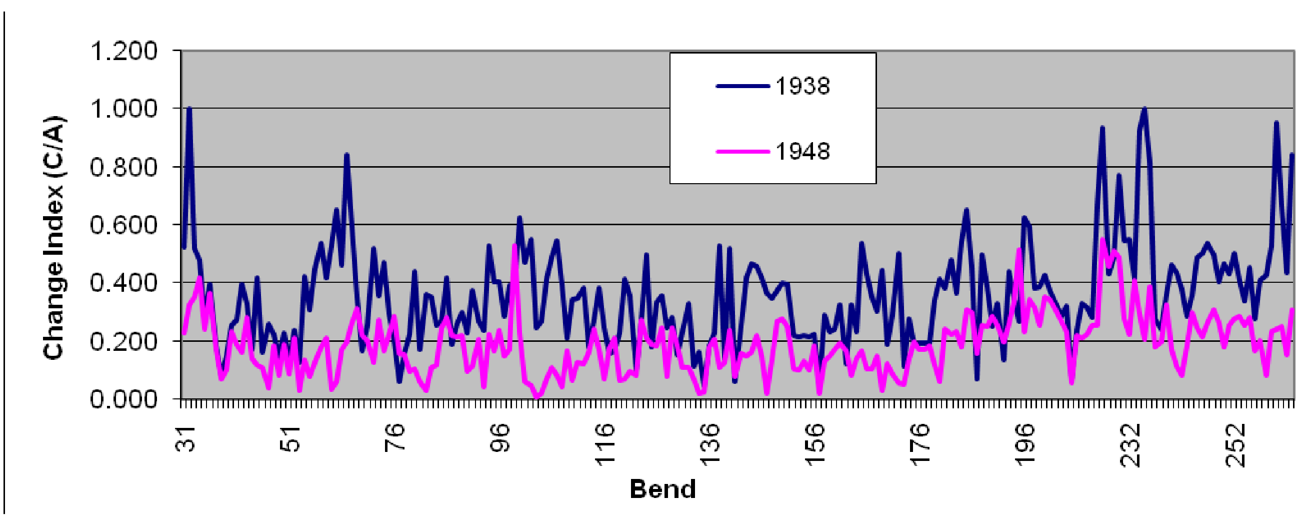


Figure 25. Erosion Index Comparison for Wilson County (1938 and 1948). A large amount of change occurred between 1938 and 1948.

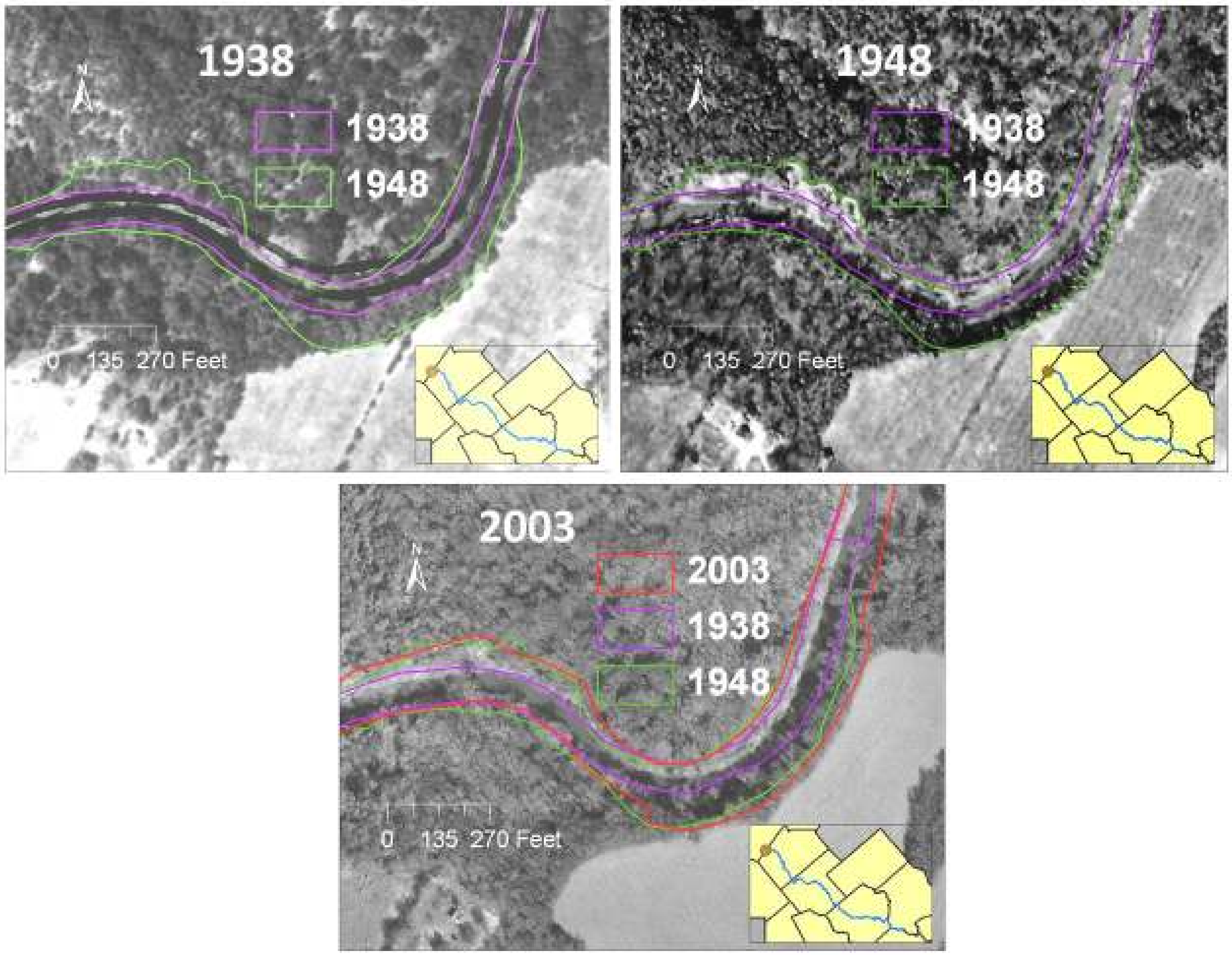


Figure 26. South Bexar County Change From 1938-1948.

4.4 Change Site Examples

An annotated map containing a point layer of change sites is included with the project data. Change sites have links to pictures showing a sequence of aerial photos for the site. Selected sites are described in the following text.

4.41 Change Site 1

Site 1 is at the top of Karnes County (Figure 27). From 1950-1995, the channel widened considerably. The right bank was deforested sometime after 1958. Between 1995 and 2003, two large bank slumps occurred on the right bank. The two largest floods of record (1998 and 2002) occurred during this period. The floods and bank deforestation probably contributed to the slumps. Similar slumping was observed between 1995 and 2003 directly below Falls City.

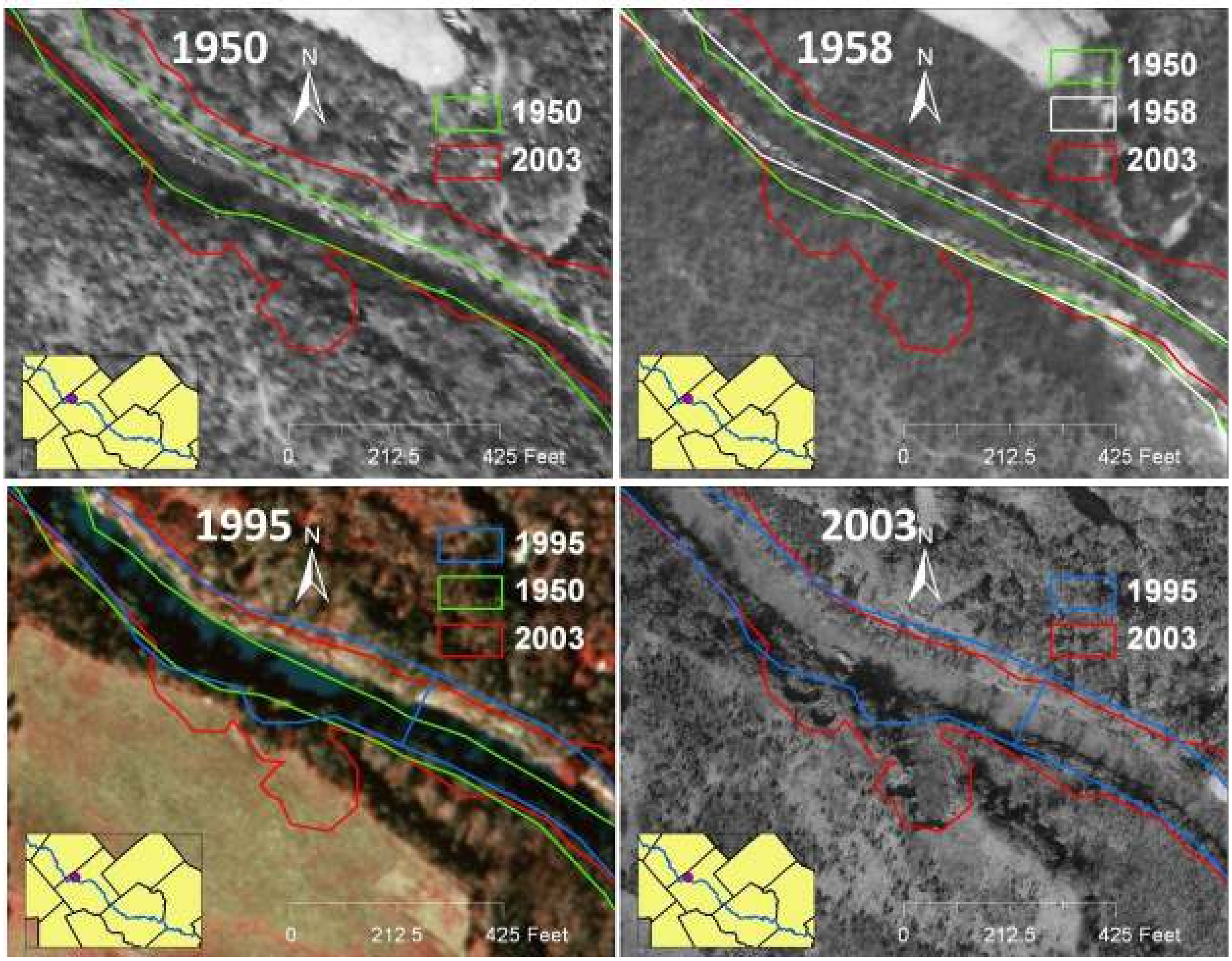


Figure 27. Change Site 1.

4.42 Change Site 2

This site is located next to the city of Goliad (Figure 28). Between 1940 and 1959, sediment deposited and accumulated at the tributary confluence and directly upstream of the bridge. The sediment accumulation at the bridge appears unnatural, and it may be part of an erosion control project by the city of Goliad. In the 1995 and 2003 photos, a large sediment bar can be seen at the tributary confluence along with significant channel widening. The tributary appears to have increased its sediment input to the main channel since 1940. This tributary flows through the city of Goliad where bank erosion common with urbanization may have caused the increase in sediment carrying capacity.

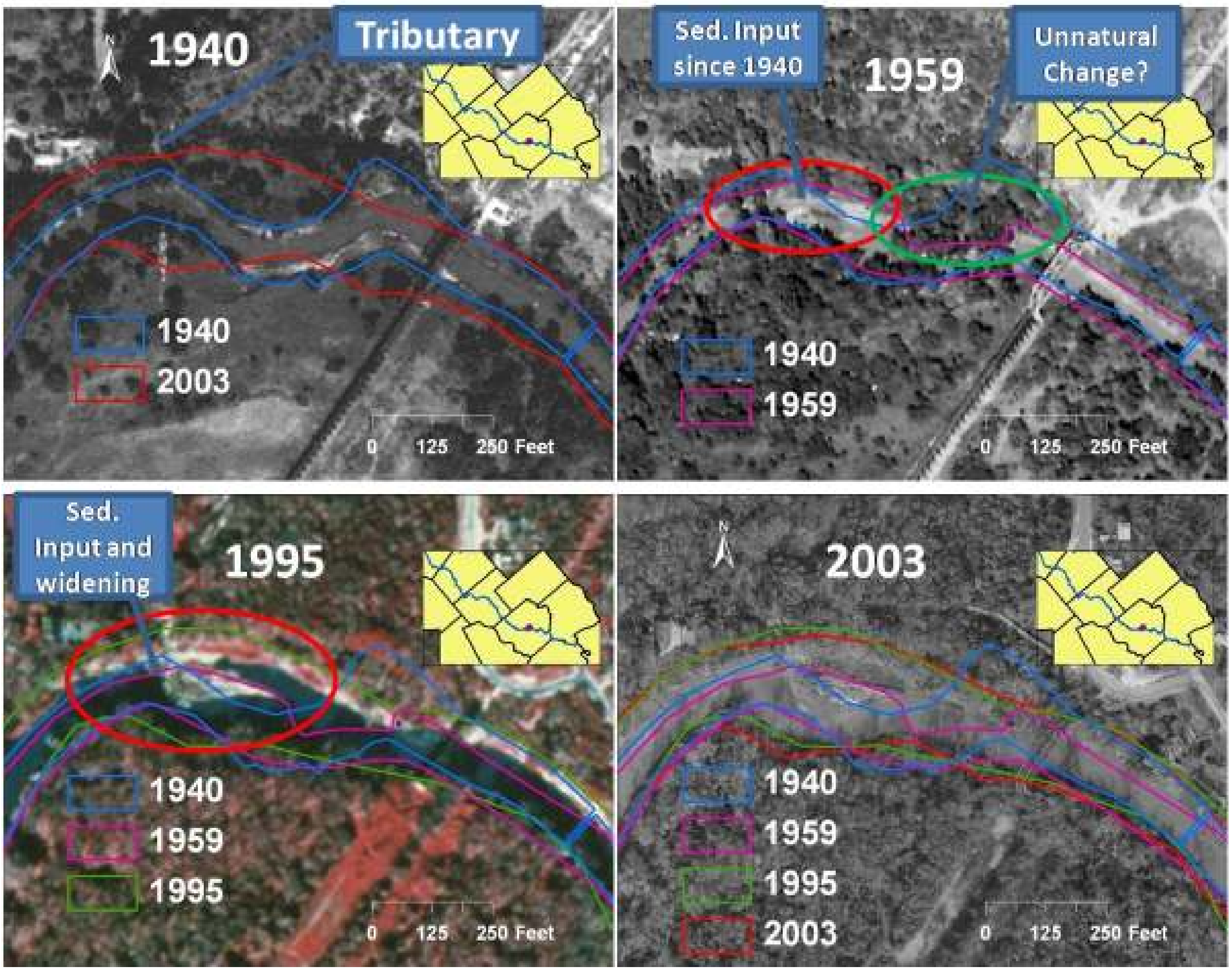


Figure 28. Change Site 2.

4.43 Change Site 3

This site is near the top of Goliad County (Figure 29), where both migration and widening are observed. Limited channel migration occurred between 1940 and 1959 at the first bend. A similarly small amount of change was observed from 1974 to 1995. However, between 1959 – 1974 and 1995 - 2003, the channel migrated and widened significantly. The three largest floods occurred during these period (1967, 1998, and 2002), and they appear to have had a significant impact. Meander bends at the site are very tight, and it was noticed that tight, small bends experienced greater erosion throughout the lower San Antonio River.

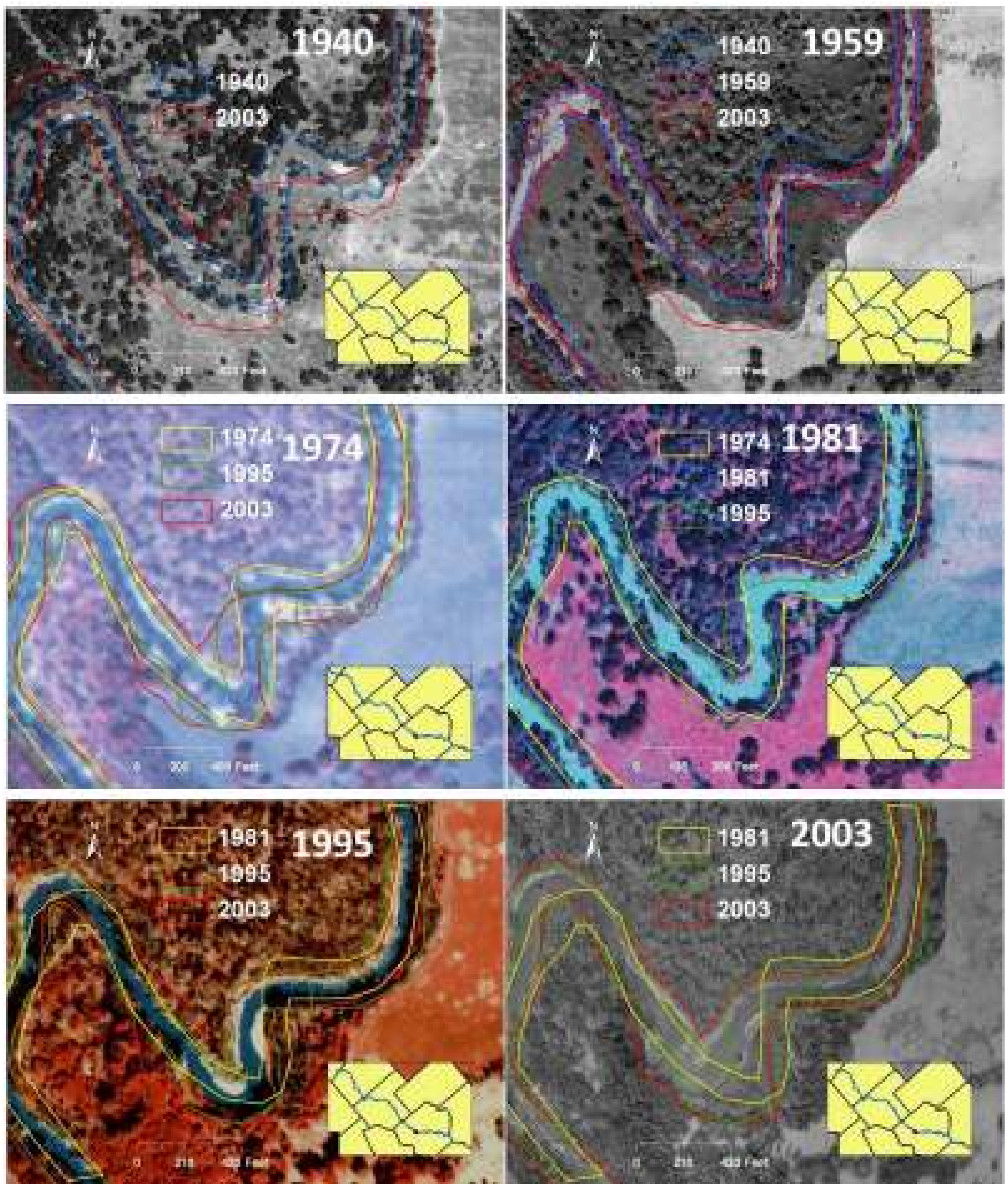


Figure 29. Change Site 3.

4.44 Change Sites 4 and 5

Change site 4 is near the bottom of Karnes County (Figure 30). It is directly downstream of the Ecleto Creek confluence. Since 1950, this site has significantly widened and the channel changed its position. Little of this change occurred prior to 1975. Between 1975 and 1995, amounts of both sediment erosion and sediment deposition are large, and between 1995 and 2003, the meander bend was cutoff. Change site 5 is directly downstream of change site 4 (Figure 31). Again, most of the migration occurred between 1975 and 1995.

Channel adjustments between 1975 and 1995 can be attributed to a flood on Ecleto Creek in 1981 (Figure 32), as a large amount of channel change occurred directly downstream of Ecleto Creek. Channel erosion and deposition between 1975 and 1995 can be attributed to the increase in the 80th – 99th percentile flows since the late 60s (Refer to Figure 11). The meander cutoff at site 4 is a result of the high percentile flow increase combined with the 1998 and 2002 floods.

Sediment input from Ecleto Creek is first observed as a point bar on the 1975 photo of site 4. Between 1995 and 2003 there was continued bar development at the confluence of Ecleto Creek and the San Antonio River. It is likely that Ecleto Creek has experienced an increase in its sediment carrying capacity since 1975.

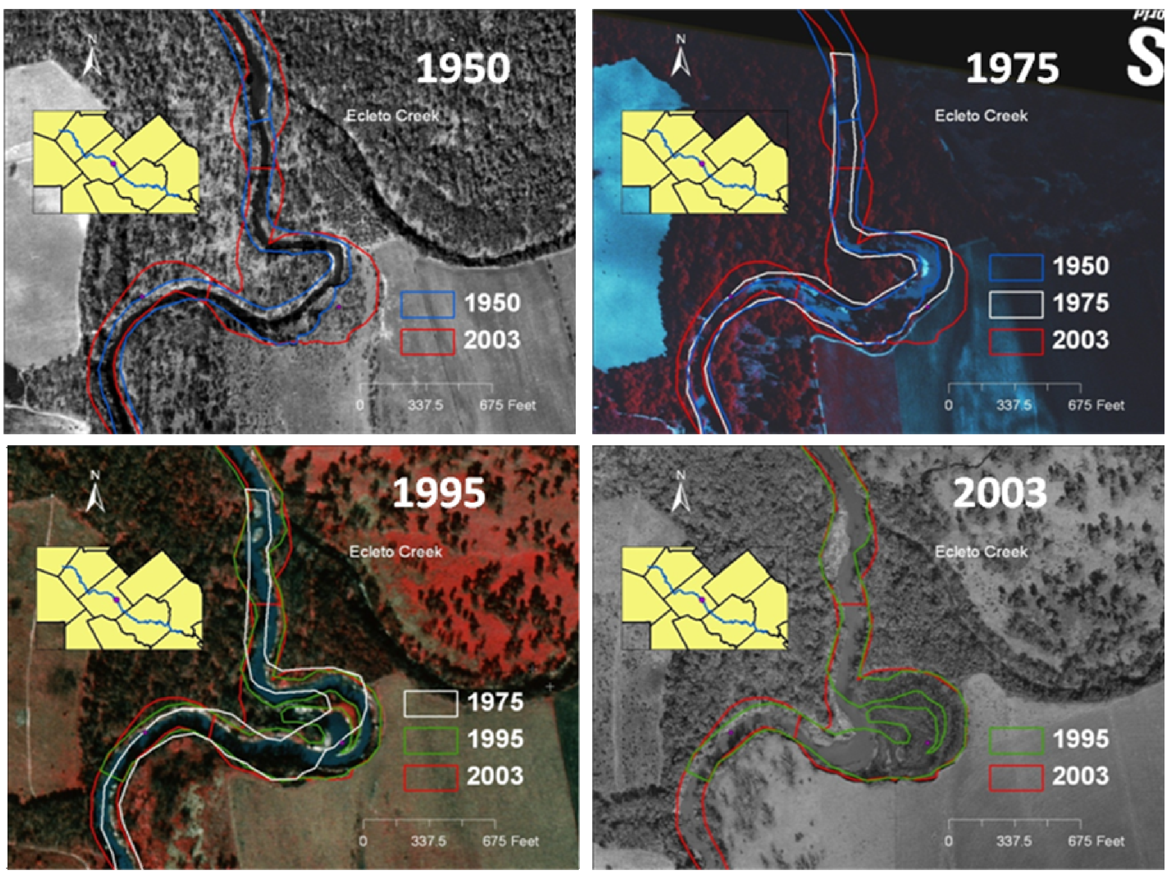


Figure 30. Change Site 4.

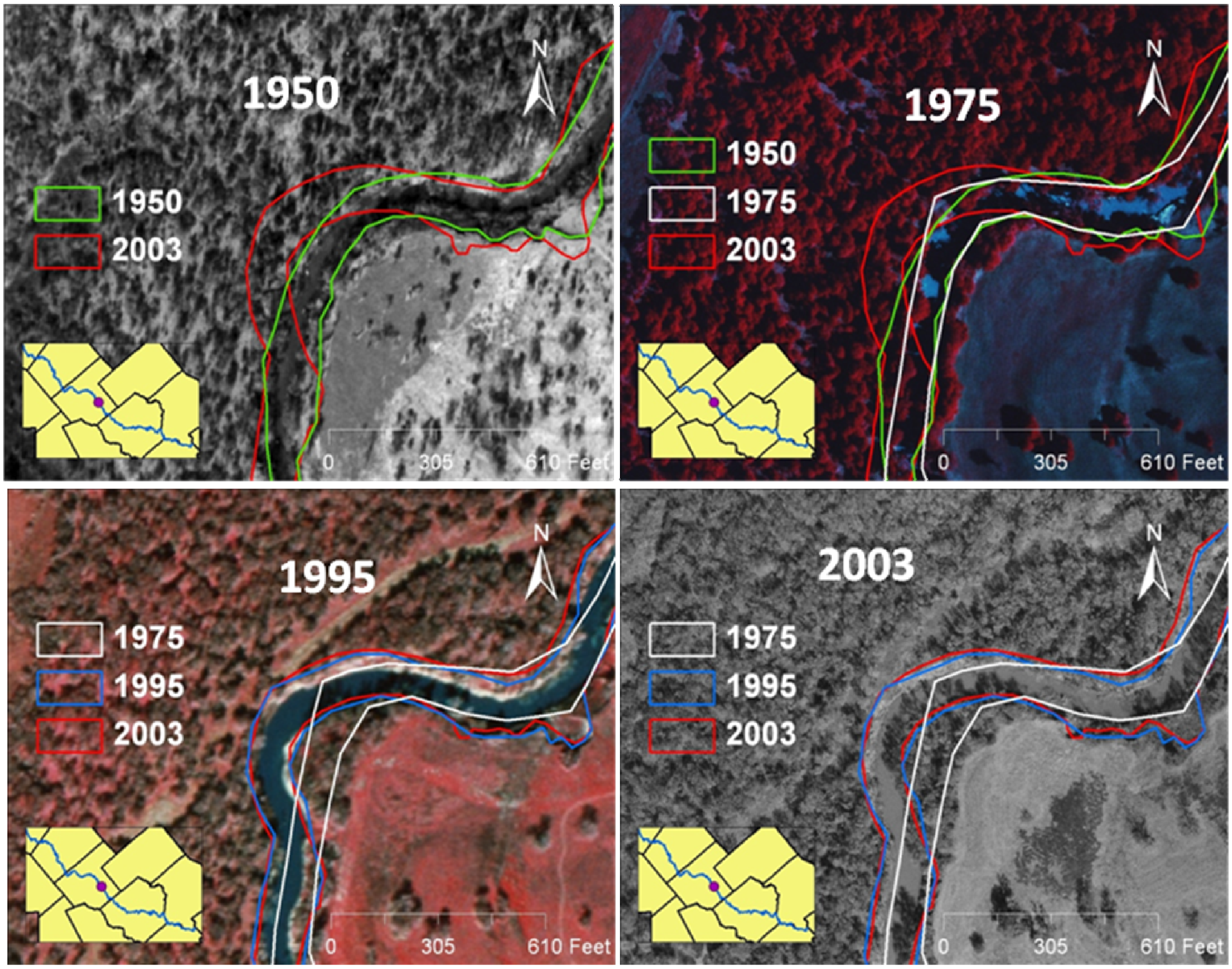


Figure 31. Change Site 5.

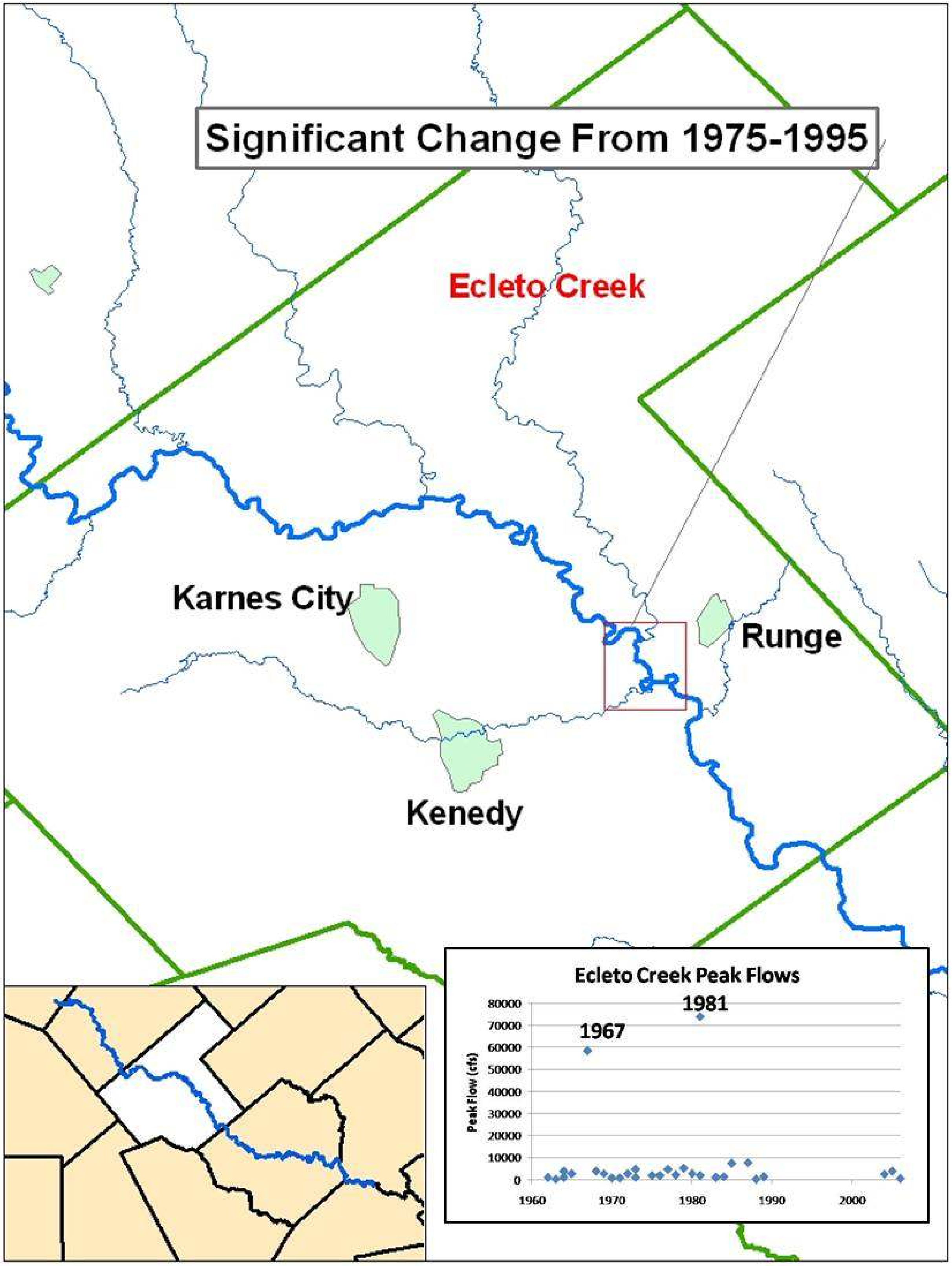


Figure 32. Significant Change Downstream of Ecleto Creek Confluence From 1975-1995.

4.45 Change Site 6

Site 6 is at the bottom of the study reach along the border of Victoria and Refugio County (Figure 33). The channel was relatively stable from 1958 to 1972. After 1972 but before 1983, the meander bend cutoff and changed the channel geometry. Channel widening occurred after 1983, as the channel adjusted to its new course. There has been an increase in the 80th – 99th percentile flows at this site since the 1970s. The largest peak flow between 1972 and 1983 occurred in 1973 (Refer to Figure 16). The meander bend cutoff is likely to have occurred during this flood, although it appears recent in the 1983 photo.

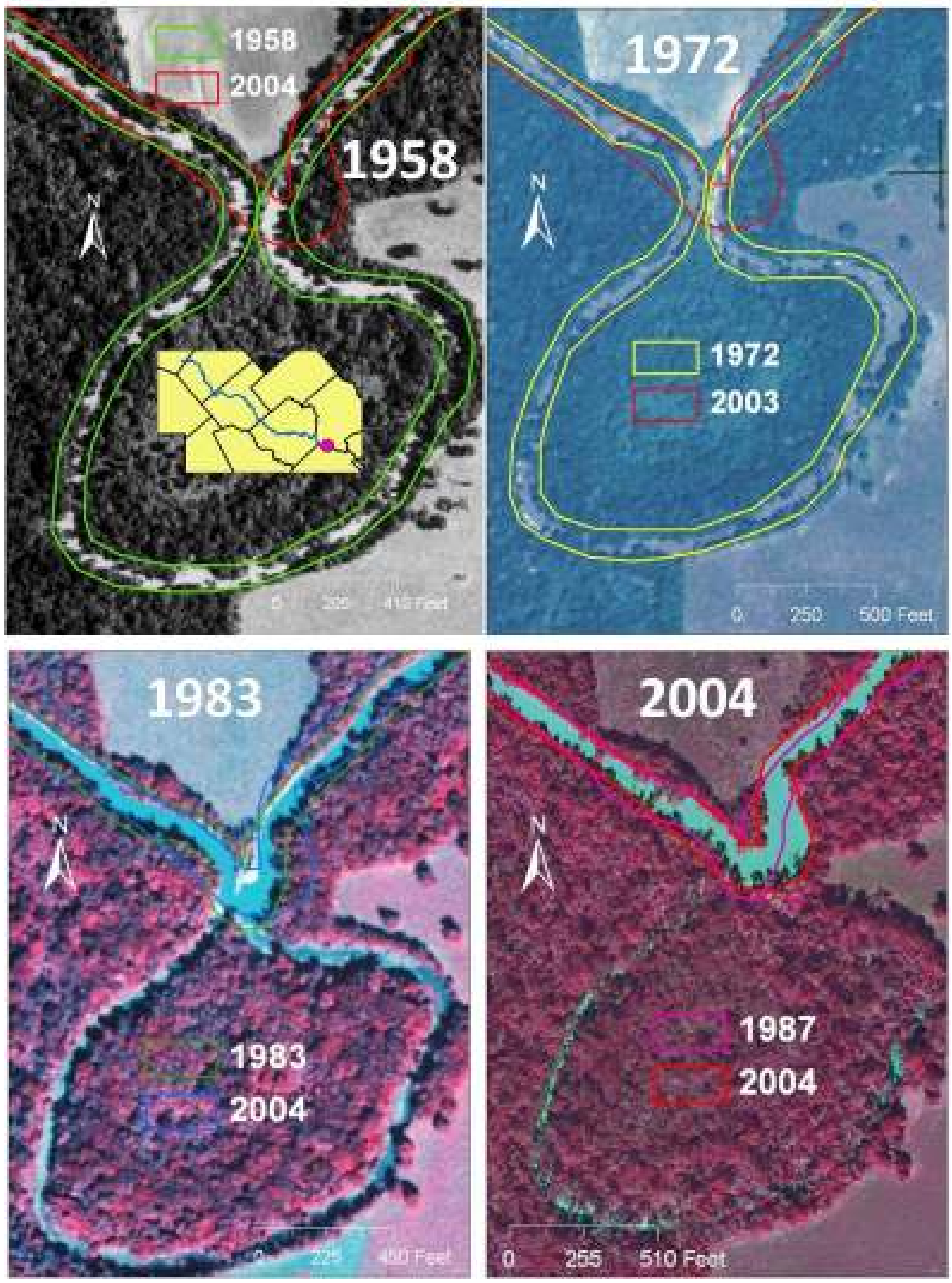


Figure 33. Change Site 6.

4.46 Change Site 7

Site 7 is also along the Victoria/Refugio County border. The majority of channel migration and change occurred between 1972 and 1983. Unlike at other sites, there was not a significant flood during this period which could be considered the instigating event for channel change. Instead, the channel change is attributed to increases in the 80th-99th percentile flows since the 1970s.

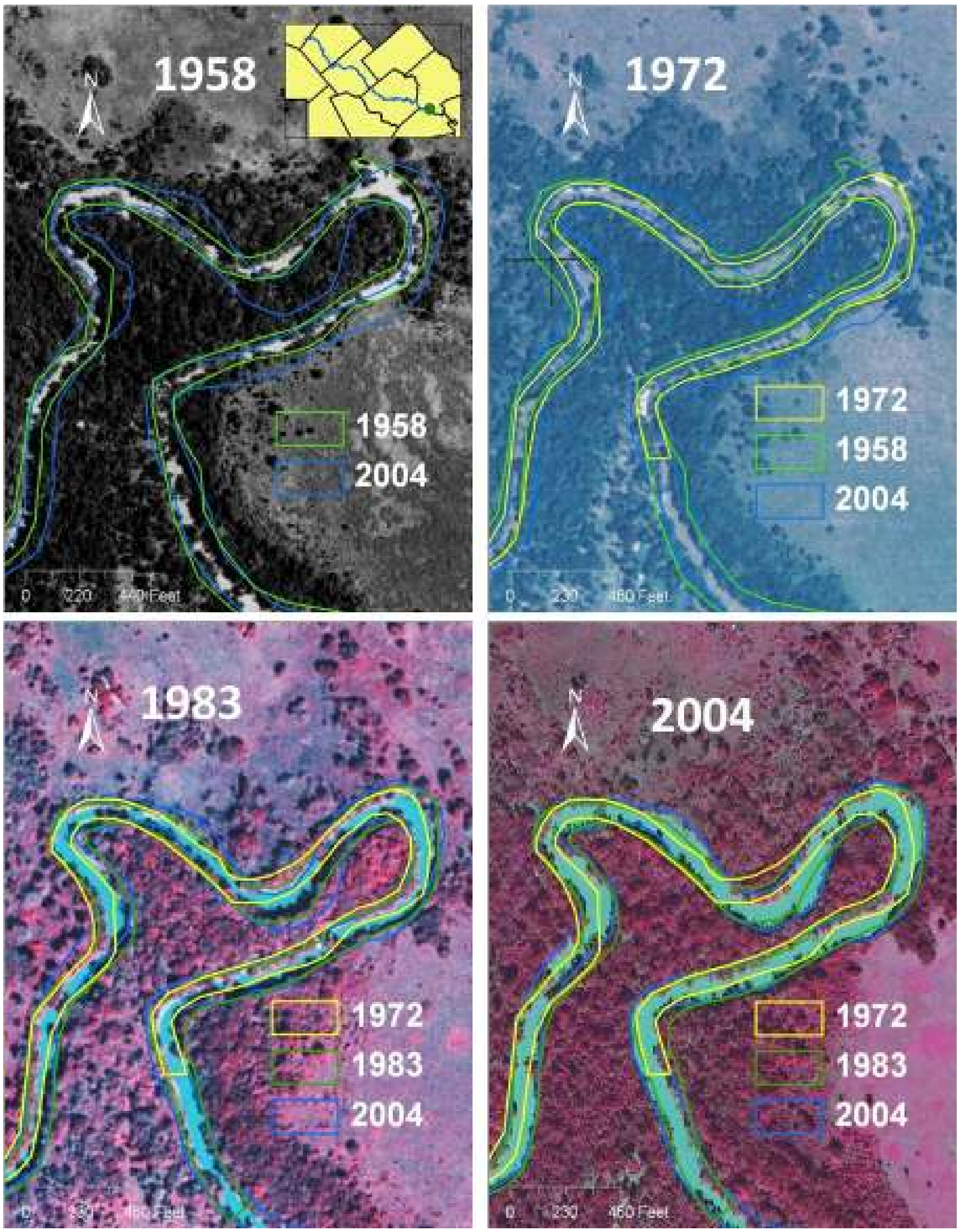


Figure 34. Change Site 7

4.47 Change Site 8

This site is at the top of Goliad County (Figure 35). Significant channel migration and sediment deposition occurred between1981-1995. A tributary upstream of the site may have increased its sediment contribution to the channel after 1981, causing much of the deposition at this site. Increases in the 80^{th}-99^{th} percentile flows have probably contributed to the change.

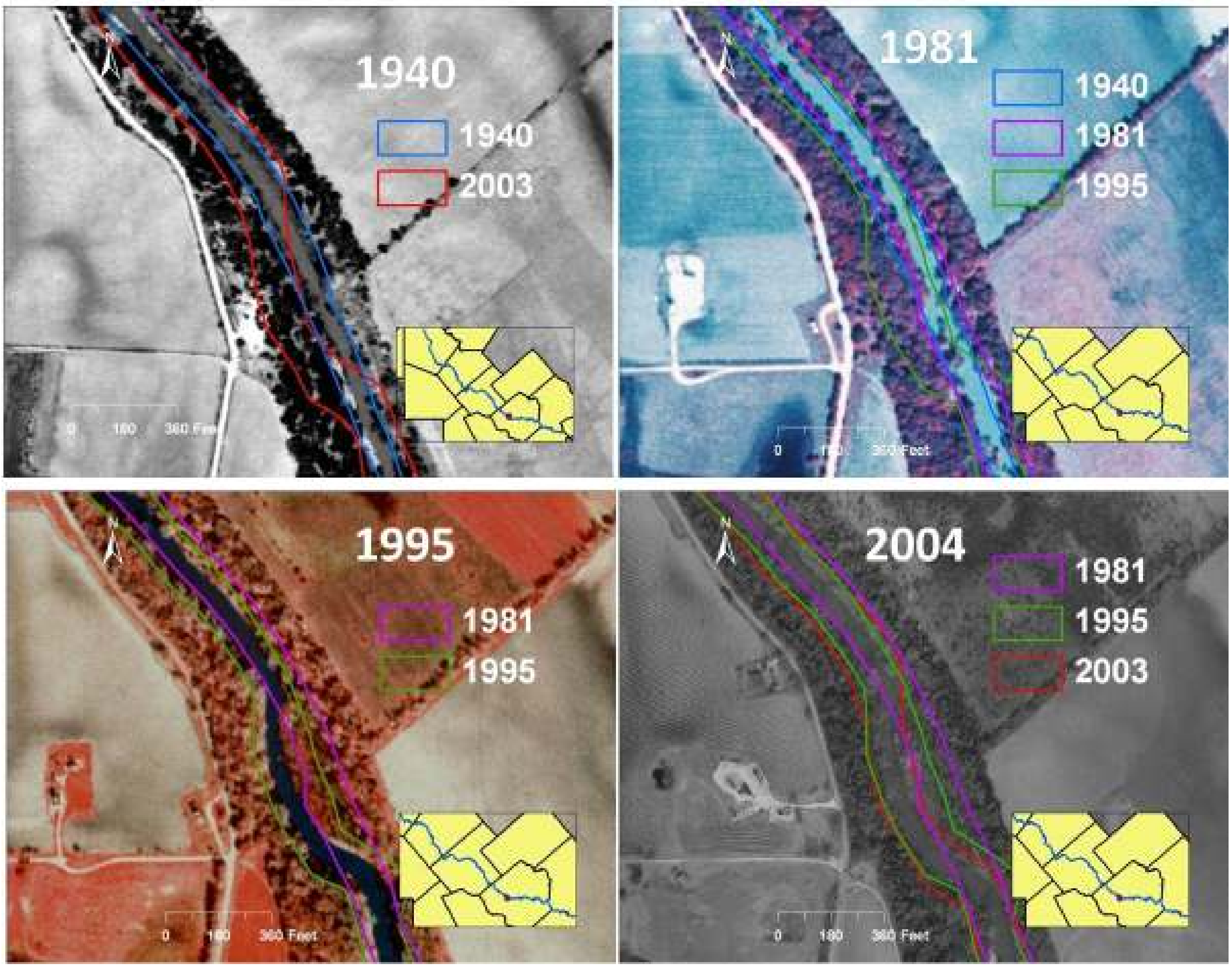


Figure 35. Change Site 8.

SUMMARY

The study reach has undergone a great deal of change, with much of it occurring in the past 30-40 years. Alterations to the study reach are not uniform, as isolated areas have experienced significant sediment deposition and erosion. However, there is a general trend of widening throughout the study reach. While some areas have widened more than others, the width has increased almost all along the channel.

One significant finding of this study is the large impact of the 1946 flood on channel morphology in the upper study reach. A number of contributing factors are responsible for the large scale bank slumping and channel erosion that occurred with this flood. Channel banks had probably become oversteepened and unstable prior to the flood. The month the flood occurred (September 1946) was the 2nd wettest month on record for the lower San Antonio (NOAA 2007). The banks were saturated before the flood, increasing the probability for failures. There has not been an any event causing as much bank slumping since the 1946 flood, although the 1998 and 2002 floods were larger. This can be attributed to the state of the banks when the floods occurred. After the 1946 flood, the banks vegetated and stabilized with lower slopes. They were not oversteepened and unstable in either 1998 or 2002. While these were significant floods and some bank slumping occurred, they did not cause channel change equal to that associated with the 1946 flood.

In the lower study reach, the valley widens and the channel is no longer tightly confined. Most floods attenuate before reaching the lower part of study reach. The 1967 Hurricane Beulah flood caused the greatest amount of change in the lower reaches, but did not have as significant of an influence as the 1946 flood had on the upper study reach. The more common, smaller floods have a greater overall effect on channel morphology in the lower study reach than the large floods.

The channel alters its planform differently in the lower part of the study reach when compared to the upper part. The upper study reach is confined by a steep terrace, preventing large scale channel migration. Most channel change in the upper study reach is due to bank slumping. While there is slumping in the lower reach, it is neither as extensive nor as erosive. Bank height decreases downstream, increasing the likelihood that a flood will overtop the bank. With increased bank overtopping, the channel adjusts by increasing its rate of migration. The largest migration rates are in Victoria County, where the channel appears to have changed position. This is the most dynamic area of the study reach, and oxbow lakes are documented back to the 1830s.

Humans have influenced the river through the direct and indirect effects of urbanization. The direct increase in impervious cover creates indirect increases in both the amount of water reaching the channel during rainfall events and the peak flow rates associated with rainfall. Increases in the 80th-99th percentile flows are calculated at all the gages since 1970. To accommodate this increase in peak flow events, the channel width and wetted area have increased, as documented at two repeat cross-section sites. Bridges contribute to localized increases in channel width and erosion rates. The 1998 and 2002 floods are floods of record and affected channel change throughout the study reach. Both had the greatest effect below Falls City, where large bank slumps occurred.

Urbanization indirectly affects the main channel through tributary input. Tributaries experience an increase in flow as impervious cover increases in the watershed, and this increase in flow rate increases the sediment carrying capacity of the tributaries. Localized channel widening and sediment deposition is observed to have increased at tributary confluences throughout the timeframe of the aerial photos. An overall increase in both the number and size of sediment bars is observed between the early aerial photos and the newer aerial photos.

A GIS layer of channel change sites with links to pictures showing a sequence of aerial photos was created. This is useful for analyzing change, and can be updated in the years to follow with new aerial photos of the sites. This along with other GIS layers and data are cataloged within a separate document accompanying this report. All of the project data can be found on DVD-Rs accompanying this project.

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