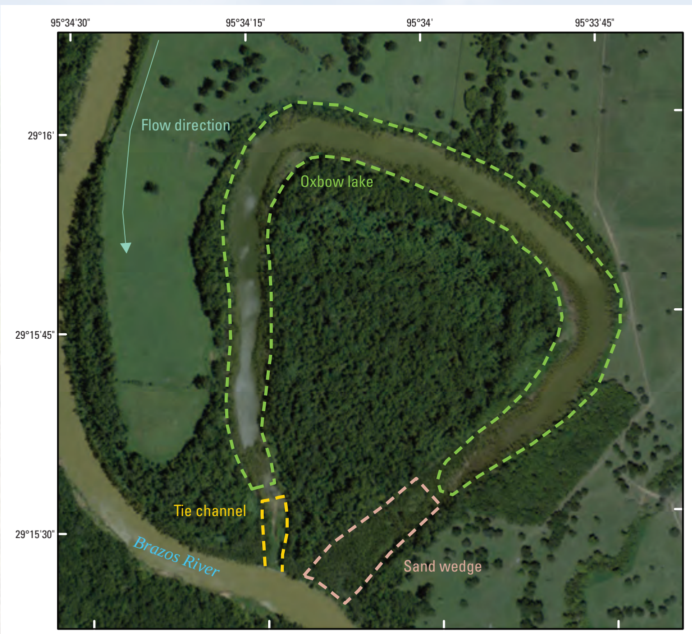
In cooperation with the Texas Water Development Board

Characterization of Geomorphic Units in the Alluvial Valleys and Channels of Gulf Coastal Plain Rivers in Texas, with Examples from the Brazos, Sabine, and Trinity Rivers, 2010



Scientific Investigations Report 2011–5067

U.S. Department of the Interior
U.S. Geological Survey

Front cover:

Left, Example of an oxbow lake with a tie channel and sand wedge on the Brazos River near Otey, Texas.

Right, Example of a neck cutoff at a meander on the Sabine River near Salem, Texas.

Back cover:

Top, Example of an unvegetated cutbank on the outside of a meander bend along the Trinity River near Massey Lake, Texas (photograph courtesy of Webster Mangham, Trinity River Authority, 2010).

Middle, Example of a bank failure on the cutbank of the Trinity River near Massey Lake, Texas (photograph courtesy of Webster Mangham, Trinity River Authority, 2010).

Bottom, Simplified representation of bench deposits and an erosional ledge in a river channel.

Characterization of Geomorphic Units in the Alluvial Valleys and Channels of Gulf Coastal Plain Rivers in Texas, with Examples from the Brazos, Sabine, and Trinity Rivers, 2010

By David K. Coffman, Greg Malstaff, and Franklin T. Heitmuller

In cooperation with the Texas Water Development Board

Scientific Investigations Report 2011–5067

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2011

This and other USGS information products are available at http://store.usgs.gov/
U.S. Geological Survey
Box 25286, Denver Federal Center
Denver, CO 80225

To learn about the USGS and its information products visit http://www.usgs.gov/
1-888-ASK-USGS

Suggested citation:
Coffman, D.K., Malstaff, Greg, and Heitmuller, F.T., 2011, Characterization of geomorphic units in the alluvial valleys and channels of Gulf Coastal Plain rivers in Texas, with examples from the Brazos, Sabine, and Trinity Rivers, 2010: U.S. Geological Survey Scientific Investigations Report 2011–5067, 31 p.

Acknowledgments

The authors express gratitude to Mark Wentzel, Texas Water Development Board, and Jonathan Phillips, University of Kentucky, for support and technical guidance during the course of this project.

Contents

Figures

Tables

Conversion Factors and Datum

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Characterization of Geomorphic Units in the Alluvial Valleys and Channels of Gulf Coastal Plain Rivers in Texas, with Examples from the Brazos, Sabine, and Trinity Rivers, 2010

By David K. Coffman, Greg Malstaff,[1] and Franklin T. Heitmuller

Abstract

The U.S. Geological Survey, in cooperation with the Texas Water Development Board, described and characterized examples of geomorphic units within the channels and alluvial valleys of Texas Gulf Coastal Plain rivers using a geomorphic unit classification scale that differentiates geomorphic units on the basis of their location either outside or inside the river channel. The geomorphic properties of a river system determine the distribution and type of potential habitat both within and adjacent to the channel. This report characterizes the geomorphic units contained in the river channels and alluvial valleys of Texas Gulf Coastal Plain rivers in the context of the River Styles framework. This report is intended to help Texas Instream Flow Program practitioners, river managers, ecologists and biologists, and others interested in the geomorphology and the physical processes of the rivers of the Texas Gulf Coastal Plain (1) gain insights into how geomorphic units develop and adjust spatially and temporally, and (2) be able to recognize common geomorphic units from the examples cataloged in this report. Recent aerial imagery (high-resolution digital orthoimagery) collected in 2008 and 2009 were inspected by using geographic information system software to identify representative examples of the types of geomorphic units that occurred in the study area. Geomorphic units outside the channels of Texas Gulf Coastal Plain rivers are called “valley geomorphic units” in this report. Valley geomorphic units for the Texas Gulf Coastal Plain rivers described in this report are terraces, flood plains, crevasses and crevasse splays, flood-plain depressions, tie channels, tributaries, paleochannels, anabranches, distributaries, natural levees, neck cutoffs, oxbow lakes, and constructed channels. Channel geomorphic units occur in the river channel and are subject to frequent stresses associated with flowing water and sediment transport; they adjust (change) relatively quickly in response to short-term variations in flow. Channel geomorphic units described in this report are channel banks, benches and ledges, bank failures, point bars, cross-bar channels, channel bars, exposed bedrock, pools, runs, and crossovers.

Introduction

The Texas Instream Flow Program (TIFP) is a river health monitoring program. It was enacted by the Texas Legislature in 2001 to assess the amount of water needed in rivers to maintain a sound ecological environment (Texas Instream Flow Program, 2008). Thompson and others (2001, p. 374–375) provide the following description of the role of geomorphic assessments in river health monitoring programs such as the TIFP:

> In river health monitoring programs, habitat assessments provide information about the proximal causes of biotic impairment or early warnings of as yet undetected biotic impairment, particularly if biological monitoring is restricted to limited taxonomic groups. * * * Without a means of grouping rivers of equivalent physical form and function, habitat assessments [might] be based on erroneous assumptions about what constitutes a good physical condition.
>
> Geomorphological river characterizations provide a potential means of overcoming these shortcomings, and as such are integral to the TIFP. As geomorphic processes that operate over an array of scales determine the physical structure of rivers, geomorphological principles form a logical basis for characterizing and assessing river habitat. In the short term, spatial and temporal variability of instream habitat is determined by the interaction of channel morphology and substrate characteristics with discharge. Flow hydraulics are strongly influenced by channel cross-section shape, clast size, bed roughness and bed slope. Channel morphology and substrate

[1] Texas Water Development Board.

> character are in turn dependent on longer-term and larger-scale processes, including sediment supply and flood history. Geomorphic processes combined with valley geometry also determine the type and extent of floodplain habitats, such as * * * [the area of a floodplain between the top of the channel and the edge of the floodplain], wetlands and * * * [oxbow lakes], and the connectivity between channel and floodplain habitats. * * *
>
> * * * hierarchical geomorphological schemes provide a framework for developing multi-scalar, process-based habitat surveys that allow appropriate comparisons between functionally similar systems.
>
> * * *Without geomorphological context of river character and behavior, habitat assessment procedures cannot meaningfully be interpreted.

Geomorphic assessments can be done in the context of the River Styles framework, which was developed as a river management tool and utilizes concepts of fluvial geomorphology (the study of the interactions between river forms and processes over a range of space and time scales [Charlton, 2008]) to classify river systems by using a hierarchical structure that starts with the watershed and scales down to microhabitat features, such as logs and individual rocks (fig. 1) (Brierley and Fryirs, 2005). River styles, one of the hierarchical categories of the River Styles framework classification system, contains unique assemblages of geomorphic units, which often determine physical habitat type within the river valley and channel (Oregon State University, 2010). Thompson and others (2001) provide the following description of the River Styles framework:

> The River Styles framework (Brierley and Fryirs, 2000) is an open ended, generic geomorphological framework that has been applied to several coastal river systems in New South Wales (Brierley and others, 1999; Brierley and Fryirs, 2000). The procedure entails interpretation of river character and behavior at four interrelated scales: catchments, landscape units, River Styles and geomorphic units. Linkage of reach-scale geomorphic structure to local hydraulic habitat provides a basis for habitat assessment at smaller scales. The critical stage of analysis of River Styles lies in the interpretation of form-process associations of geomorphic units (pools, riffles, chute channels, levees, benches, bar types, backswamps, paleochannels, among others) which are the fundamental building blocks of river systems (Brierley, 1996). Because associations between individual landforms and their formative processes are specific, analysis of assemblages of geomorphic units along a reach provides a basis to interpret river behavior (Brierley and Fryirs, 2000).

The River Styles framework differentiates between geomorphic units on the basis of their location either outside or

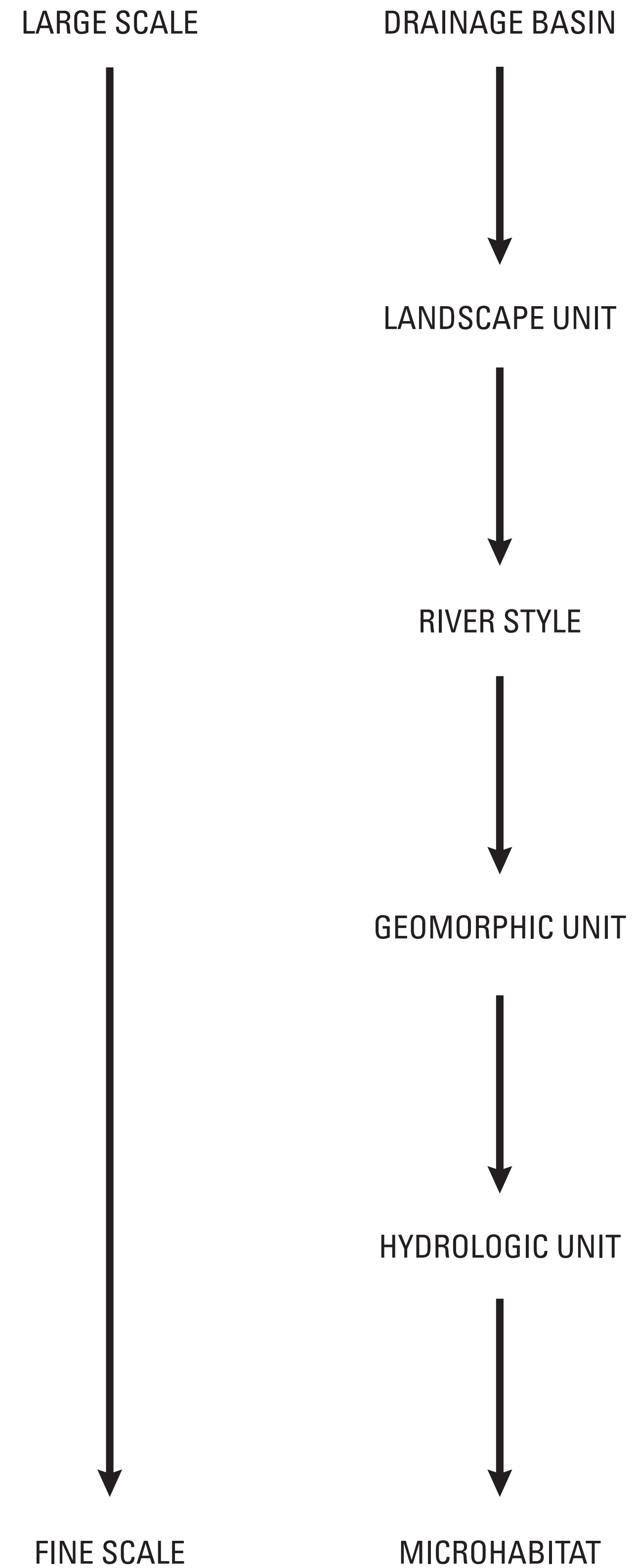


Figure 1. Hierarchical relation of the mapping categories in the River Styles framework.

inside the river channel—those outside the river channel are classified as flood-plain geomorphic units, and those inside the river channel are classified as channel geomorphic units. A similar classification scheme is used by the Oregon Department of Fish and Wildlife during stream habitat surveys for the State's Aquatic Inventories Project (Moore and others, 2010).

Geomorphic units are defined by Brierley and Fryirs (2005, p. 19) as "landform-scale features" that "reflect formative processes that determine river structure and function." Formed and adjusted by depositional and erosional processes, geomorphic units are related to streamflow, sediment transport, and other geological processes, and are associated with biological habitats that interactively characterize the instream and riparian ecological environment. Geomorphic units within a river channel (channel geomorphic units) adjust differently to changes in streamflow and sediment load compared to those located above the channel within the alluvial valley. As part of the physical template for aquatic and riparian ecosystems, the characteristics and hydrologic connectivity of channel and flood-plain geomorphic units determine structure, ecological functions, and levels of biotic activity of certain species (Winemiller and others, 2000; Li and Gelwick, 2005; Zeug and others, 2005; Dauwalter and others, 2007; Zeug and Winemiller, 2007). Channel geomorphic units are erosional or depositional features that occur between the banks of the river channel and typically undergo relatively rapid adjustment in response to short-term variations in flow conditions. Flood-plain geomorphic units are relatively large in comparison to channel geomorphic units, and they are in contact with the river only during infrequent, overbanking high-flow events. Flood-plain units are differentiated primarily by the general shape (areal or linear) and spatial extent. Channel geomorphic units are grouped as bank-attached or midchannel on the basis of their location in the channel during base-flow conditions (Brierley and Fryirs, 2005).

The fluvial geomorphic features of the Texas Gulf Coastal Plain river systems form the habitats to which all living organisms in the river ecosystem have adapted and become dependent (Texas Instream Flow Program, 2008). Identifying examples of flood-plain and channel geomorphic units allows for further insight into the patterns of habitat structure and the past and present processes responsible for the formation of a river's current geomorphic setting. Cataloging examples of the geomorphic features of a river is one of the first steps in assessing the ecological status of the system and can provide insight toward the system's expected future condition (Brierley and Fryirs, 2005; Phillips, 2006, 2007a). Accordingly, the U.S. Geological Survey (USGS), in cooperation with the Texas Water Development Board, documented examples of geomorphic units in the channels and alluvial valleys of Texas Gulf Coastal Plain rivers. The alluvial valley is the principal region of water and sediment transport in a river system (Coleman and Wright, 1971).

Purpose and Scope

This report characterizes the geomorphic units in the river channels and alluvial valleys of Texas Gulf Coastal Plain rivers using methods modified from the River Styles framework (Brierley and Fryirs, 2005). Examples of geomorphic units that exist in the alluvial valleys of the Gulf Coastal Plain rivers in Texas are described by using a geomorphic unit classification scheme that differentiates geomorphic units on the basis of their location either outside or inside the river channel. Geomorphic units existing outside the river channel are further designated as areal or linear on the basis of their general shape and extent. Detailed descriptions and example images of geomorphic units are included to help Texas Instream Flow Program (TIFP) practitioners, river managers, ecologists and biologists, and others interested in the geomorphology and the physical processes of the rivers of the Texas Gulf Coastal Plain (1) gain insights into how geomorphic units develop and adjust spatially and temporally, and (2) be able to recognize common geomorphic units from the examples cataloged in this report. This discussion of geomorphic units is applicable only to the alluvial valleys of Gulf Coastal Plain river systems in Texas, although the geomorphic units presented here can also occur within the upper watershed or deltaic plain of a Texas river system. Because of the relatively small scale of channel geomorphic units, few characteristics and dimensions of channel geomorphic units could be determined using the aerial imagery methods relied upon for this report.

Previous Studies

Phillips (2006, 2007a) assessed the geomorphic context, constraints, and change of the Lower Brazos River and Navasota River between Bryan, Tex., and the Gulf of Mexico and collected field data in support of a geomorphic classification scheme. Phillips (2006) discussed the importance of classifying river systems, along with the benefits of using geomorphology as a basis for classification, which he patterned after Parsons and others (2002).

Phillips (2006) segmented the Brazos and Navasota Rivers into river reaches relevant to an instream flow assessment on the basis of the geomorphic characteristics of alluvial valleys and channels of the rivers. Geomorphic transition zones separating individual reaches were determined by using publicly available digital resources, including geologic maps, digital elevation models (DEMs), USGS topographic quadrangles, tectonic maps, soil maps, and a land resources map. Specific transition zone indicators included changes in surface geology, valley width, valley confinement, network characteristics, sinuosity, slope, paleomeanders, avulsions, and point bars (Phillips, 2007a). Locations along the river course that contained multiple transition zone indicators were considered important transition zones and divided reaches displaying different geomorphic character.

Phillips (2006, 2007a) adapted the geomorphology-based classification scheme described in the River Styles framework

(Brierley and Fryirs, 2005) to define and map distinct geomorphic units in the lower Brazos River. The majority of geomorphic units listed in Phillips (2006, 2007a) were discernible from digital orthoimagery. In large rivers like the Brazos, some smaller channel geomorphic units are visible on high-resolution digital orthoimagery.

The TIFP (Texas Instream Flow Program, 2008, p. 10) describes the purpose of the Texas Instream Flows Program: "[to] perform scientific and engineering studies to determine flow conditions necessary to support a sound ecological environment in the river basins of Texas," as established under the authority of Texas Senate Bill 2, enacted by the 77th Texas legislature in 2001. The TIFP has decided to apply a hierarchical approach to geomorphological river classification and characterization, adapted from the River Styles framework (Brierley and Fryirs, 2005), to separate study watersheds into mapped units of manageable scales for ecological field investigations. Phillips (2006; 2007a, b, d; 2008) and Phillips and Slattery (2007) have developed methods to define and map river styles in Texas Gulf Coastal Plain rivers.

Description of Study Area

The Gulf Coastal Plain physiographic province of Texas includes three subprovinces: the Coastal Prairies, the Interior Coastal Plains, and the Blackland Prairies. The Gulf Coastal Plain physiographic province covers approximately one-third of the land surface of Texas, stretching from the Texas-Louisiana state line southwest along the Gulf of Mexico coast to the Rio Grande River (fig. 2). The climate of the Gulf Coastal Plain is characterized as subtropical to humid subtropical, with average annual rainfall exceeding 56 inches near the Texas-Louisiana state border, ranging to semiarid or arid, with approximately 20 inches annual rainfall in the Rio Grande River valley (Texas Forest Service, 2008). Most rainfall results from low-pressure systems with circulating air patterns bringing moisture northward from the Gulf of Mexico or from convective thunderstorms that form frequently in the afternoons between May and September. Hurricanes, tropical storms, and tropical depressions occasionally make landfall along the Texas coast and bring large amounts of rainfall, resulting in localized or widespread flooding (Bomar, 2011). Vegetation of the Interior Coastal Plains ranges from pine and hardwood forests in the east to chaparral brush and grasses in the southwest. The Coastal Prairies are grass-covered expanses of low-slope terrain. The Blackland Prairies contain rich, black clay soils that have weathered from underlying Cretaceous sandstone, limestone, and marl (loose, earthy deposits of clay and calcium carbonate [Neuendorf and others, 2005]). Since the settlement of Texas, the Blackland Prairies have been cleared of most native vegetation for agricultural purposes. The sand, silt, and clay substrate in this province is almost entirely deltaic in origin and was transported by rivers as suspended and bedload sediment toward the coast from the elevated Texas interior over geologic time (Wermund, 1996).

The Gulf Coastal Plain of Texas contains several major rivers between the Texas-Mexico border and the Texas-Louisiana state border; from west to east, they are the Nueces, San Antonio, Guadalupe, Lavaca, Colorado, Brazos, San Jacinto, Trinity, Neches, and Sabine (fig. 2). The rivers of the Texas Gulf Coastal Plain are alluvial systems; alluvial river systems continually adjust their geometry according to differential rates of streamflow (discharge) and sediment load, and these changes in geometry are expressed in a variety of fluvial features which can be grouped as geomorphic units (Heitmuller and Greene, 2009; Knighton, 1998). Each of the large rivers of the Texas Gulf Coastal Plain has a drainage basin, alluvial valley, deltaic plain, river delta, and receiving basin, in one form or another. The alluvial valley is the principal region of water and sediment transport in the fluvial system (Coleman and Wright, 1971). The alluvial valley accepts flow and sediment discharges from the upper drainage basin and tributary watersheds and transports them to the deltaic plain, river delta, and receiving basin (fig. 3).

The large rivers of the Texas Gulf Coastal Plain occupy broad alluvial valleys shaped by the rivers over tens of millions of years; they contain a variety of fluvial geomorphic features that reflect historic and contemporary hydrologic conditions (Phillips, 2006, 2007a). Human activities in the past 120 years have altered the amount of sediment and water in all the large rivers of the Texas Gulf Coastal Plain, resulting in accelerated changes in the geomorphic characteristics of these rivers (Heitmuller and Green, 2009; Phillips, 2007a, c).

Methods

A modified version of the geomorphic unit scale of the River Styles framework (Brierley and Fryirs, 2005) was used to distinguish geomorphic units on the basis of their location either outside or inside the channel. The River Styles framework differentiates geomorphic units as either flood-plain geomorphic units (geomorphic units found outside the channel) or channel geomorphic units (geomorphic units that occur inside the channel). During this study, the authors determined that geomorphic units outside the channel did not always occur on the flood plain, but occasionally at elevations higher than the flood-plain surface yet still within the alluvial valley. For this reason, geomorphic units that are located outside the channels of Texas Gulf Coastal Plain rivers are called "valley geomorphic units" in this report. Valley geomorphic units outside the channel are further classified as areal or linear on the basis of their general shape and extent. Channel geomorphic units can be further classified as midchannel or bank-attached (fig. 4), but this designation can only be made on a case-by-case basis under base-flow conditions. Information gained from literature reviews was used to help describe the various geomorphic units. Descriptions are provided of how each geomorphic unit develops and adjusts spatially and temporally. Visual analysis of the occurrence of geomorphic units in the alluvial valleys and channels of Gulf Coastal Plain rivers in Texas was done by using recent aerial imagery

Figure 2. Texas Gulf Coastal Plain physiographic province, including major river basins.

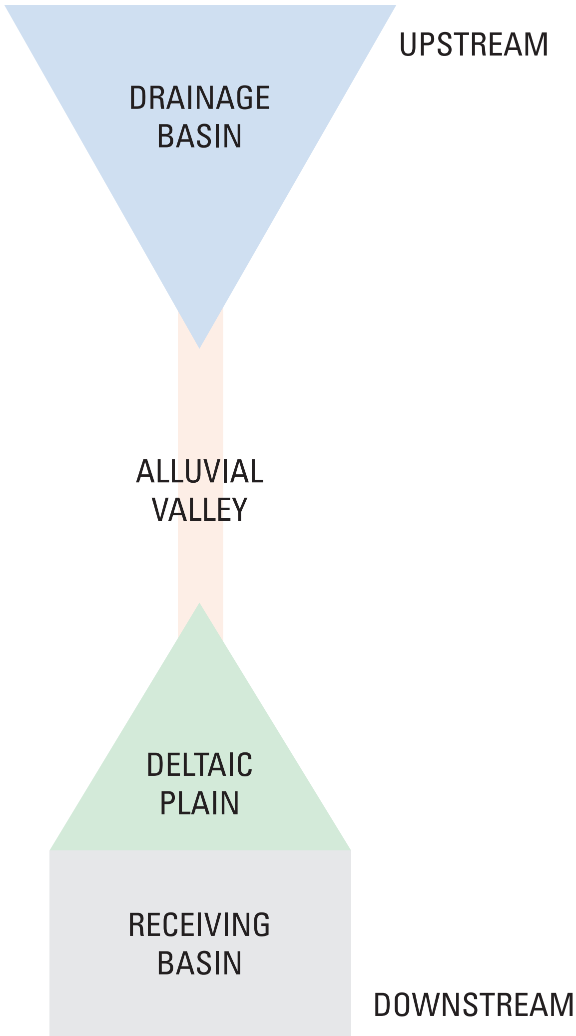


Figure 3. Schematic illustrating the three main components of a river system: drainage basin, alluvial valley, and deltaic plain (modified from Coleman and Wright, 1971).

(high-resolution digital orthoimagery) collected in 2008 and 2009 through the National Agriculture Imagery Program (U.S. Department of Agriculture, Farm Service Agency, 2009). Both natural color and color infrared imagery were used at 0.5- to 1-meter resolution. The aerial photographs were thoroughly inspected by using geographic information system (GIS) software to identify representative examples for geomorphic units that occurred in the study area.

Characterization of Geomorphic Units in Texas Gulf Coastal Plain Rivers, with Examples from the Brazos, Sabine, and Trinity Rivers

Fluvial geomorphic units of the alluvial Texas Gulf Coastal Plain rivers occur either outside or inside the river channel and are separated into two categories: valley geomorphic units and channel geomorphic units. Flow-related disturbances occur less often for those units found above bankfull stage (valley geomorphic units) than for those found below bankfull stage (channel geomorphic units). The bankfull stage of a river often is difficult to determine (Leopold and others, 1964). It is identified on the basis of a reach-scale investigation, because localized variability in channel bank conditions and natural levee elevations will determine the stage at which water inundates the flood plain (Leopold, 1994).

Relatively large valley geomorphic units (size measured in miles) exist in flood-plain and valley environments. They typically require considerable time to form and adjust, on the order of decades to hundreds of years, and only during overbanking high-flow events (Brierley and Fryirs, 2005). Valley geomorphic units were grouped into two broad types on the basis of their shape when viewed on aerial imagery: areal or linear (table 1). Areal valley geomorphic units covered large areas of the valley floor, and linear valley geomorphic units were those that follow active or abandoned channel courses.

Relatively small channel geomorphic units (size measured in feet) exist in the channel. Channel geomorphic units

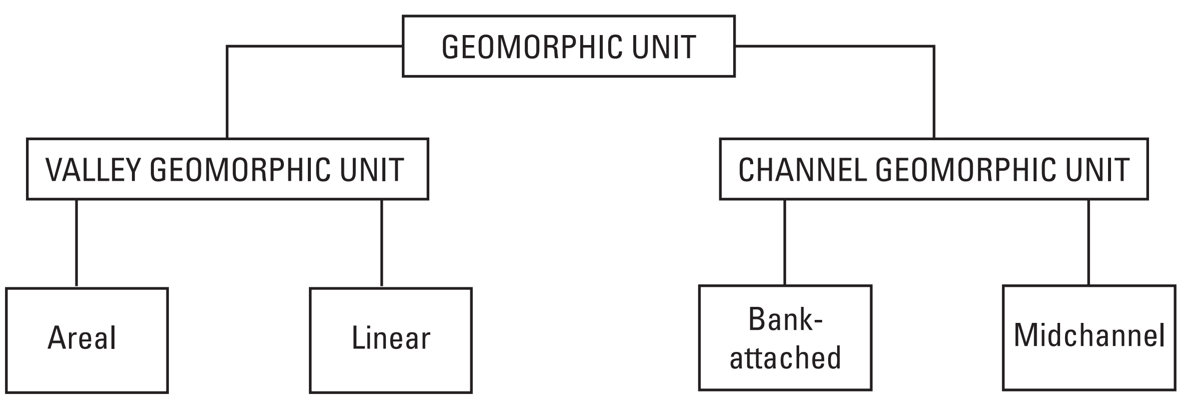


Figure 4. Subdivisions of geomorphic units in Texas Gulf Coastal Plain rivers.

Table 1. Valley geomorphic units of Texas Gulf Coastal Plain rivers.

Unit name	Shape	Description
Fluvial terrace	Areal	Abandoned flood-plain surface, activity dependent on distance from and elevation above top of channel banks.
Topographic flood plain	Areal	Land surface inundated by a flood of a specific magnitude and frequency (100-year flood[1], for example).
Hydrologic flood plain	Areal	Level area adjacent to a river channel, constructed by the river in the present climate and overflowed during moderate flow events.
Crevasse and crevasse splay	Areal	Narrow channel scoured though natural levees and subsequent deposits.
Flood-plain depression	Areal	Lowest point on valley floor; activity dependent on distance from and elevation above top of channel banks.
Tie channel	Linear	Conveys water and sediment from the main channel to floodplain depressions during high-flow events; flow direction in tie channel can reverse as flood flows in the main channel recede.
Tributary	Linear	Supplies water and sediment to the main channel and might contain its own channel geomorphic units.
Paloechannel	Linear	Abandoned channel course; occasionally occupied by tributaries, anabranches, or distributaries.
Anabranch	Linear	Conveys water and sediment away from main channel and back to main channel downvalley.
Distributary	Linear	Conveys water and sediment away from the channel to distal parts of the valley floor.
Natural levee	Linear	Natural deposit of coarse-grained material deposited adjacent to channel.
Neck cutoff	Linear	Intersection of two meanders, shortens channel, increases slope.
Oxbow lake	Linear	Result of a neck cutoff. If the arms of the cut-off meander fill with sediment, an oxbow lake can form.
Constructed channel	Linear	Conveys water from channel for irrigation or water supply or to the channel as drainage.

[1] A flood with a 1-percent annual exceedence probability (Holmes and Dinicola, 2010).

were grouped into two types on the basis of their location in the channel: bank-attached or midchannel (table 2). Channel geomorphic units adjust during a wide range of in-channel flows and, therefore, adjust more frequently than valley geomorphic units (Brierley and Fryirs, 2005).

Valley Geomorphic Units in Lowland, Coastal Plain Environments

Valley geomorphic units of lowland, coastal plain rivers are typically larger than channel geomorphic units, and their typical lateral dimensions occur on the order of 1,000 to 10,000 feet. Many valley geomorphic units can be identified and mapped using aerial imagery and later verified in the field, although this becomes increasingly difficult in forested environments. For lowland, coastal plain rivers, GIS applications and digital aerial imagery can be used to describe the characteristics and measure the dimensions of valley geomorphic units. Field investigations of valley geomorphic units are useful for accomplishing several important tasks including, for example, accurately delineating geomorphic units, determining unit composition (for example, particle-size distribution and composition), identifying points of hydrologic connectivity to the main channel, and assessing localized variations in geomorphic unit form and vegetation characteristics.

Valley geomorphic units do not always occur on the hydrologic flood plain. The hydrologic flood plain, also known as the active flood plain, is a level area adjacent to a river channel, constructed by the river in the present climate and overflowed during moderate flow events (Leopold, 1994). Fluvial terraces, for example, are typically located at higher elevations than the topographic flood plain. The topographic flood plain refers to the area of land inundated by a flood of a specific magnitude and frequency, such as the 100-year flood (Federal Interagency Stream Restoration Working Group, 1998). A 100-year flood has 1 percent chance of occurring in a given year, referred to as the 1-percent annual exceedance probability (Holmes and Dinicola, 2010). Valley geomorphic units proximal to the channel are typically hydrologically connected to the channel at lower flood stages than are those units farther from the channel. The authors determined that valley geomorphic units could be further classified as “active” or “inactive” on the basis of their frequency of connectivity to the main river channel by flowing water. Classifying valley geomorphic units as “active” or “inactive” was beyond the scope of this report. This differentiation would be made on a case-by-case basis and would depend on the location of the specific valley geomorphic unit being described. The frequency of inundation of a valley geomorphic unit and, therefore, its activity (“active” or “inactive”), is dependent on its elevation relative to the top of the channel bank (“high” or “low”) and

Table 2. Channel geomorphic units of Texas Gulf Coastal Plain rivers.

Unit name	Location	Description
Channel bank	Bank-attached	Erosional or depositional indicated by presence or absence of vegetation.
Bench	Bank-attached	Depositional feature within the channel occuring below the bankfull stage, commonly exists on convex side of meander bend.
Ledge	Bank-attached	Erosional scarp within the channel occuring below the bankfull stage, composed of erosion-resistant materials.
Bank failure	Bank-attached	Indicates bank instability and potential channel migration.
Point bar	Bank-attached	Depositional feature on inside of meander bend.
Cross-bar channel	Bank-attached	Bifurcates point bar during high flows.
Channel bar	Bank-attached and/or midchannel	Depositional feature on channel bottoms, includes longitudinal bars, transverse bars (also referred to as linguoid bars), tributary mouth bars, and so forth.
Exposed bedrock	Bank-attached and/or midchannel	Exposure of erosion-resistant bedrock alters flow conditions.
Pool	Midchannel	Section of channel with deepest water and slowest flow velocities. Commonly occurs on the cutbank side of a meander bend.
Run	Midchannel	Moderate depth and velocity connecting pools and crossovers.
Crossover	Midchannel	Shallow, fast-flow pool, typically at meander inflection point.

its distance from the top of the channel bank (“proximal” or “distal”). For the Texas Gulf Coastal Plain rivers, valley geomorphic units at elevations closest to the top-of-bank elevation and those located least distant from the top of the channel bank are subject to the most frequent fluvial stresses associated with flowing water and sediment transport.

Terraces

Sumner (2000, p. E-26), describing other investigators’ findings, noted that “terraces are defined as a part of the fluvial system that no longer actively experiences fluvial modification (Ruhe, 1975), [that is] no longer aggrading.” Terraces are commonly encountered in the alluvial valleys of Texas Gulf Coastal Plain rivers and often take the form of abandoned flood plains representative of previous hydrologic and sedimentary environments. Terraces indicate periods of relative vertical stability, allowing flood-plain formation, followed by a period of channel incision and flood-plain abandonment. The incised channel eventually forms a new flood plain, with the abandoned flood plain becoming a terrace, and the cycle continues (Leopold and others, 1964). Abandoned flood plains formed over relatively long geomorphic timescales, on the order of hundreds to thousands of years, might have been abandoned comparatively rapidly (on the order of years or decades) as a result of channel incision (Leopold, 1994). Factors controlling the amount of channel incision (downcutting or deepening of the channel resulting from erosion of the channel bottom) include tectonic uplift, base level (sea level) fluctuation, or changes in flow regime resulting from climate variability or human activities (Phillips, 2007a, c). As topographic features, terraces generally are flat to gently sloping and are bounded by an elevated valley or terrace wall and a terrace bank that slopes down to the lower active flood plain or a lower terrace. In some cases, lower terraces are partially buried by modern fluvial sediment deposits. As a sedimentary body, terraces are typically characterized by a fining-upward sequence of deposited sediment capped by finer overbank sediment. Some terraces display no evidence of fine overbank sediment (Blum and Straffin, 2001). Terraces commonly are oriented parallel with the river valley but also can exist as isolated “islands” surrounded by the active flood plain or river channel (Leopold and others, 1964). Large terraces near the coastal margin often extend laterally considerable distances away from the flood plain. Although not considered part of the flood plain, terraces can be subject to inundation and overbank sedimentation during infrequent high-magnitude floods.

Fluvial terraces are composed of fluvial sediment deposits of different ages and can sometimes be distinguished by soil development. In tilled agricultural areas, fluvial terraces can be distinguished from active flood plains in the Texas Gulf Coastal Plain on the basis of their appearance in aerial photographs (for example, reddish color associated with prolonged oxidation). Fluvial terrace deposits commonly occur at various elevations above the active river channel, and changes in vegetation can indicate a terrace boundary (fig. 5). High-resolution DEMs derived from ground surveys or airborne-lidar data can be used successfully to identify fluvial terraces; soil survey maps are also helpful for this purpose. Precise identification of fluvial terrace deposits requires field verification, including topographic surveys and collection of sediment samples for compositional analysis and age determination (Blum, 1994).

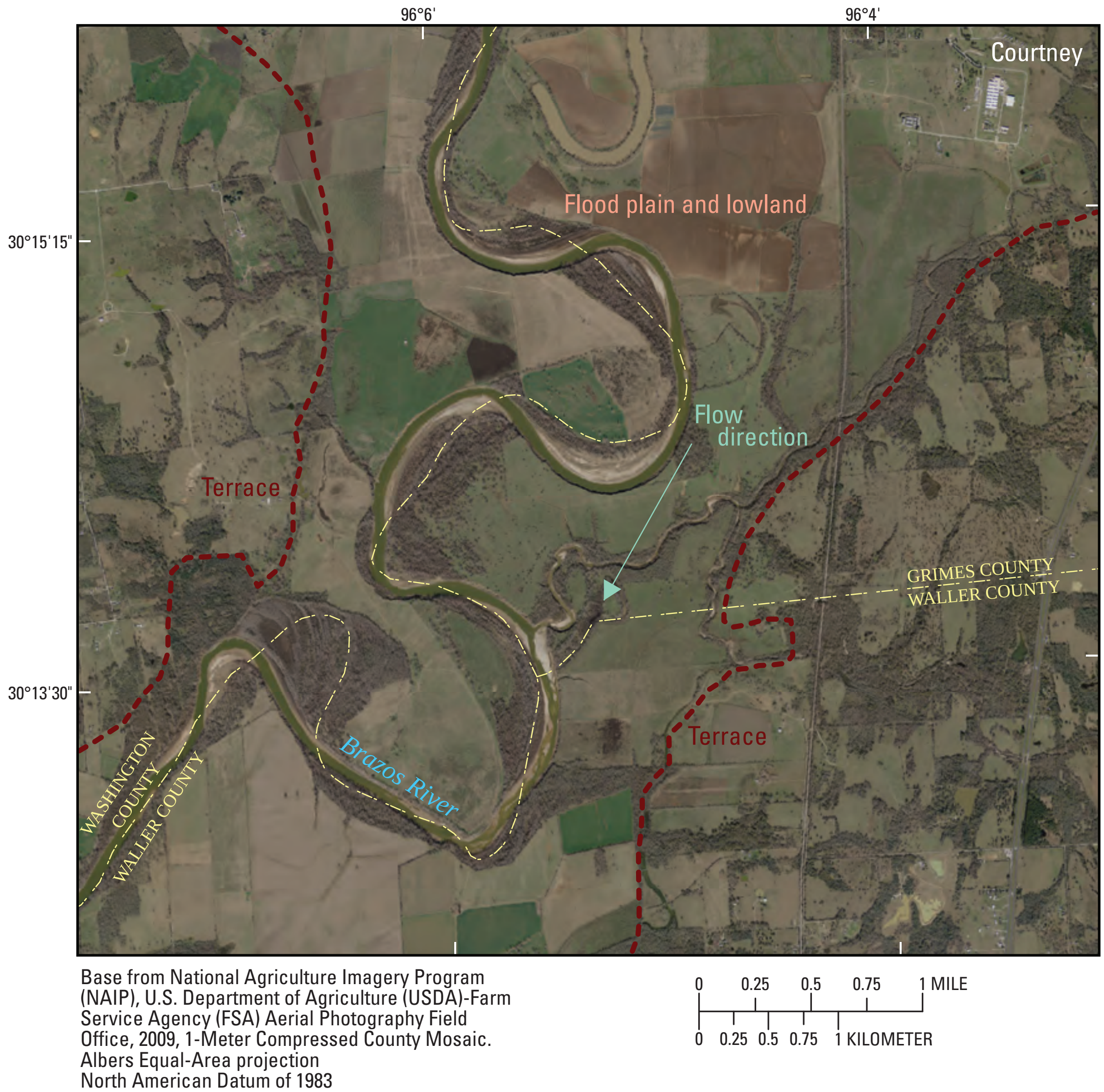


Figure 5. Example of fluvial terraces mapped adjacent to the flood plain and lowlands of the Brazos River near Courtney, Texas.

Flood Plains

In some instances, the alluvial valley floor does not contain a specific geomorphic unit; in these instances, we refer to the alluvial valley floor as the flood plain. There are two different types of flood plains. The topographic flood plain is the area of land inundated by a flood of a specific magnitude and frequency, such as the 100-year flood (Federal Interagency Stream Restoration Working Group, 1998). The topographic flood plain is of primary interest to engineers and flood-plain managers concerned with flooding in developed areas.

The second type of flood plain is the hydrologic flood plain. Schumm and Lichty (1963) and Burkham (1972) suggest that hydrologic flood plains are present only along natural channels not affected by human activity. Hydrologic flood plains are not present in all reaches of some Texas Gulf Coastal Plain rivers. The incised nature of many of the Texas Gulf Coastal Plain rivers, whether naturally incised or incised in response to human activity in the watershed, allows connectivity with the flood plain only during relatively high-flow events.

Crevasses and Crevasse Splays

A crevasse is a local breach in a natural levee. Crevasses can result in crevasse channels, crevasse splays, or a combination of the two. Narrow flood-scoured crevasse channels are capable of transmitting flow and sediment away from the main river channel at high-flow stages (Brierley and Fryirs, 2005). Crevasse splay deposits have been found along the outside of meander bends in Texas Gulf Coastal Plain rivers (fig. 6). Crevasse channels commonly cut through natural

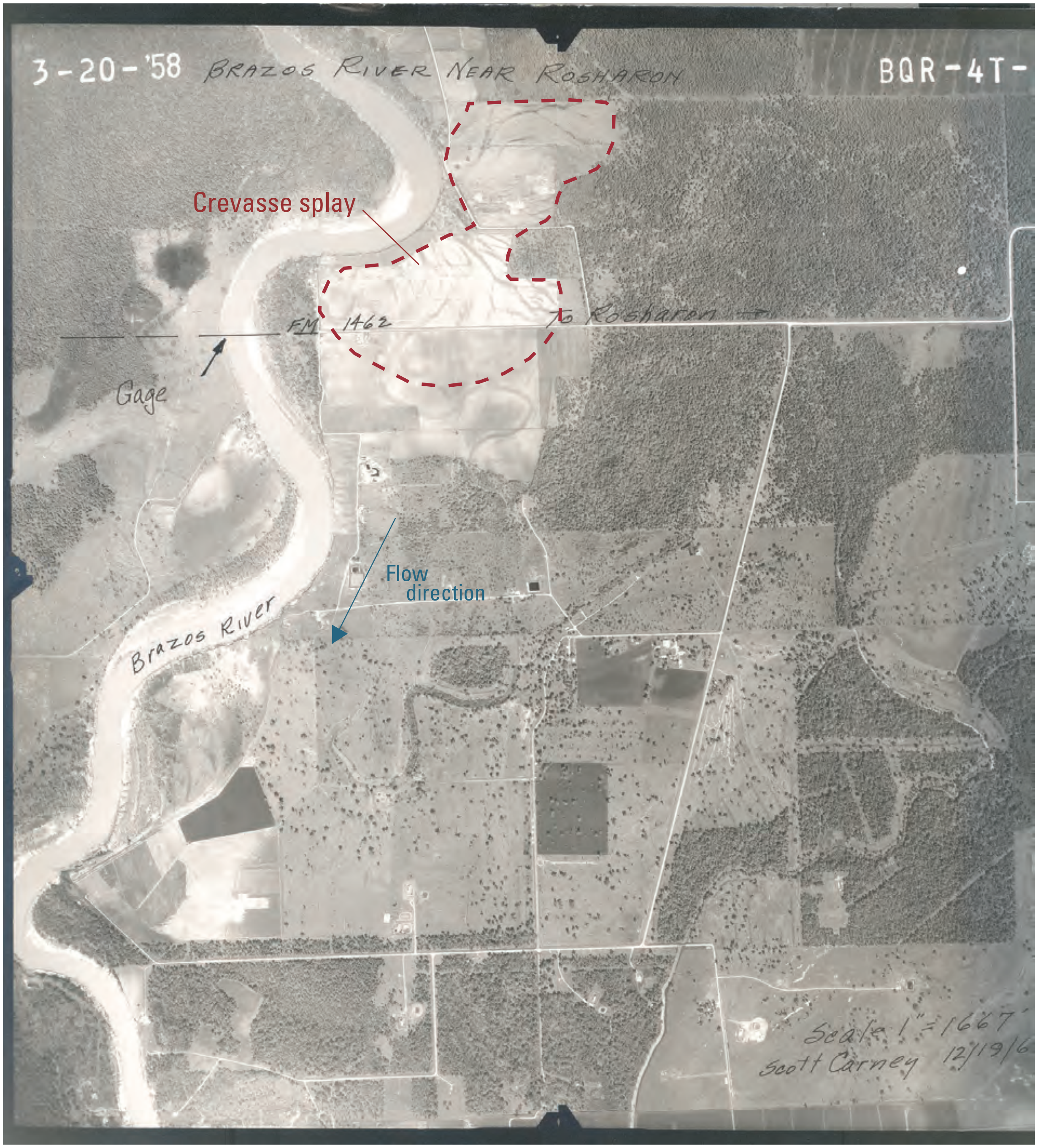


Figure 6. Example of a well-developed crevasse splay deposit along the concave side of the northernmost meander bend of the Brazos River deltaic plain near Rosharon, Texas (from Heitmuller and Greene, 2009).

levees on the outside of meander bends, and can result in a considerable amount of flood-plain deposition. Small, shallow channels sometimes radiate away from the crevasse location (Saucier, 1994), transporting flow and sediment during floods. Deposition results when the sediment-laden water leaves the main channel and spreads out in a fan-like pattern on the distal side of the levee. Crevasse channels can be distinguished from local tributaries and gullies by their downward slope away from and perpendicular to the levee. Persistent crevasse channels can become somewhat permanent distributaries (Jackson, 1997).

Crevasse splays are accumulations of overbank sediment (sand and silt) that are the result of the rapid deposition from laterally spreading and decelerating flows (fig. 6) and exhibit a fining-outward (away from the levee) sequence. Farrell (1987) shows that crevasse splay sedimentary characteristics are mostly associated with sheet flow, and sequential deposits typically reflect the following progression: (1) the onset of crevassing, (2) full development, and (3) crevasse abandonment. Crevasses and crevasse splays have the potential to occur along Texas Gulf Coastal Plain rivers anywhere a natural levee is present.

Flood-Plain Depressions and Tie Channels

Flood-plain depressions are the lowest areas of the valley floor, located between elevated natural levees and the valley wall or terrace, where water and sediment are stored during and after overbanking flow events. Water and sediment are sometimes transferred to flood-plain depressions from the main river channel during relatively high-flow events through tie channels (fig. 7). High rates of sediment deposition are typical in flood-plain depressions (Schenk and Hupp, 2010; Walling and He, 1997). When floodwater moves away from the main channel into the depression, it loses energy and is only capable of carrying a suspended load. As water in the depression infiltrates to the subsurface or evaporates, fine sediment and organic matter are deposited (Walling and He, 1997).

A wide variety of topographic lows occur in alluvial flood plains, but two are particularly important in Texas Coastal Plain rivers. One type of topographic low is prominent meander-scar depressions that occur in conjunction with the fluvial terraces, particularly in the Trinity, Neches, and Sabine River systems. These reflect previous higher discharge regimes and are appreciably larger than active or abandoned meanders associated with the modern river. These meander-scar depressions are often evident in crescentic scallops in the valley wall (similar in shape and form to present-day cutbanks) despite being distal from the channel, and are valley geomorphic units which are frequently flooded (sometimes by local runoff or tributaries). Swales, another type of topographic low, are somewhat linear depressions that occur between old, elevated point-bar deposits as a result of lateral channel migration, in a pattern typically called ridge-and-swale topography (Smith, 1996; Brierley and Fryirs, 2005).

Low-energy environments such as the flood-plain depressions found in parts of the Texas Gulf Coastal Plain rivers can become colonized by wetland and swamp vegetation that traps additional fine- grained sediments delivered by flood waters. In addition, flood-plain depressions can be associated with abandoned channels (discussed in the Paleochannels section of this report), artificial impoundments, and borrow or gravel pits (Wilcox, 1993).

Tributaries

In Texas Gulf Coastal Plain rivers, tributaries draining upland areas adjacent to the main river valley can extend for considerable distances through the valley before joining the main river at a confluence. The upland tributaries thus sustain their own channel geomorphic units, as well as some of their own valley geomorphic units, within the alluvial valleys of the larger rivers. In lowland alluvial valleys, tributaries can run parallel to the main river for considerable distances where they occupy former channels of the main river. Phillips (2006, 2007a) noted this occurrence in the Brazos alluvial valley where the Navasota River occupies a Brazos River paleochannel.

Meander migration occasionally allows main river channels to capture tributary channels. This truncation can result in rapid changes in the lower tributary and at the tributary confluence caused by the increased hydraulic slope of the tributary channel. Tributary confluences are typically areas of high geomorphic and hydraulic unit diversity (Rice and others, 2001; Torgersen and others, 2008; Best, 1986, 1988; Rhoads, 1987; Richards, 1980; Benda and others, 2003, 2004a, 4b).

Paleochannels

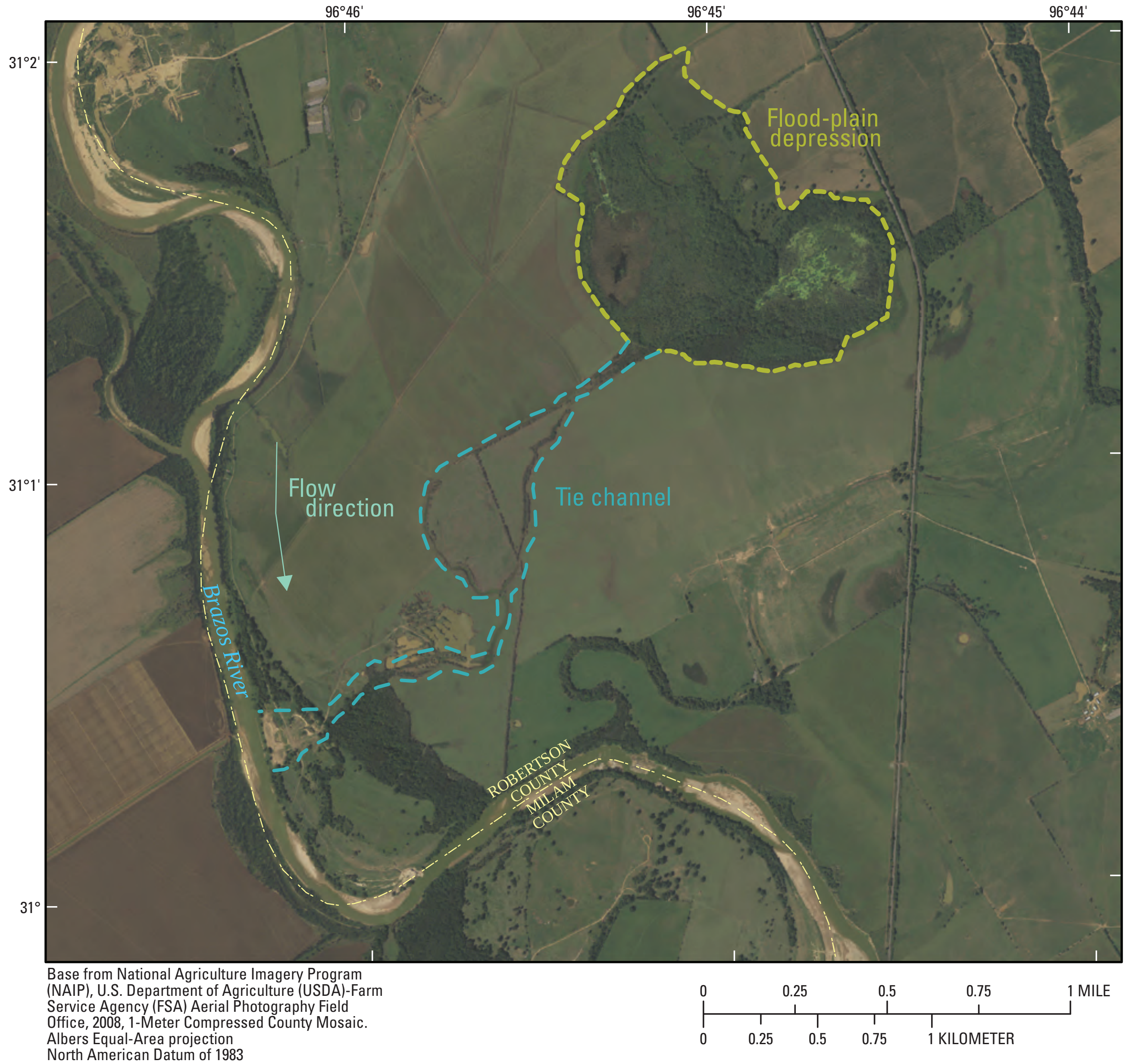
Abandoned channel courses, or paleochannels, are former positions of the main river that extend over one meander wavelength in distance (Brierley and Fryirs, 2005) and occasionally extend for considerable lengths, sometimes tens of miles in the alluvial valleys of Texas Gulf Coastal Plain rivers (fig. 8). The exception is cutoffs of individual bends or meanders, discussed separately below. For meandering rivers, paleochannels typically include multiple meander bends. Paleochannels either convey flood flow and sediment load down the valley, or are infilled with overbank sediment in a fining-upward sequence and found on the land surface or preserved as part of the geologic record (Saucier, 1994). Similar to the main river, abandoned channels can intercept and convey drainage and sediment load from upland-draining tributaries and local flood-plain sources. In some cases, older paleochannels of the Brazos River are reoccupied by tributaries (Phillips, 2006).

Paleochannels can exist in several different states or conditions, with several different varieties sometimes occurring along the same length of abandoned channel (Phillips, 2008). Common paleochannel types in the Gulf Coastal Plain include the following:

- anabranches and distributaries (discussed separately below)
- sloughs—these contain water at all times (except perhaps during extreme droughts) but are not connected to the active channel and do not convey flow except during floods
- semiactive anabranches or flood channels—these channels do not convey flow under normal or low-flow conditions, but are activated at high flows, often at subbankfull levels
- infilled paleochannels—these are shallow linear depressions inundated only during floods

Anabranches

Anabranches are channels that connect to the main river at their upstream and downstream end and are separated from



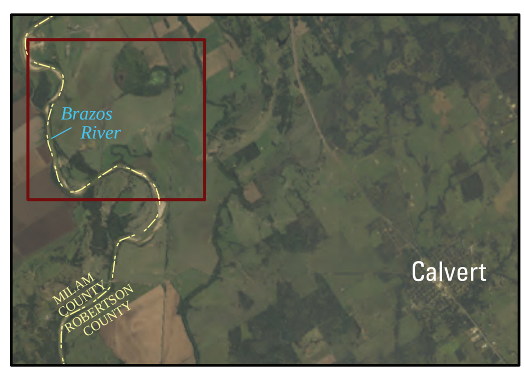


Figure 7. Example of a tie channel that conveys water and sediment from the main channel of the Brazos River to a flood-plain depression near Calvert, Texas.

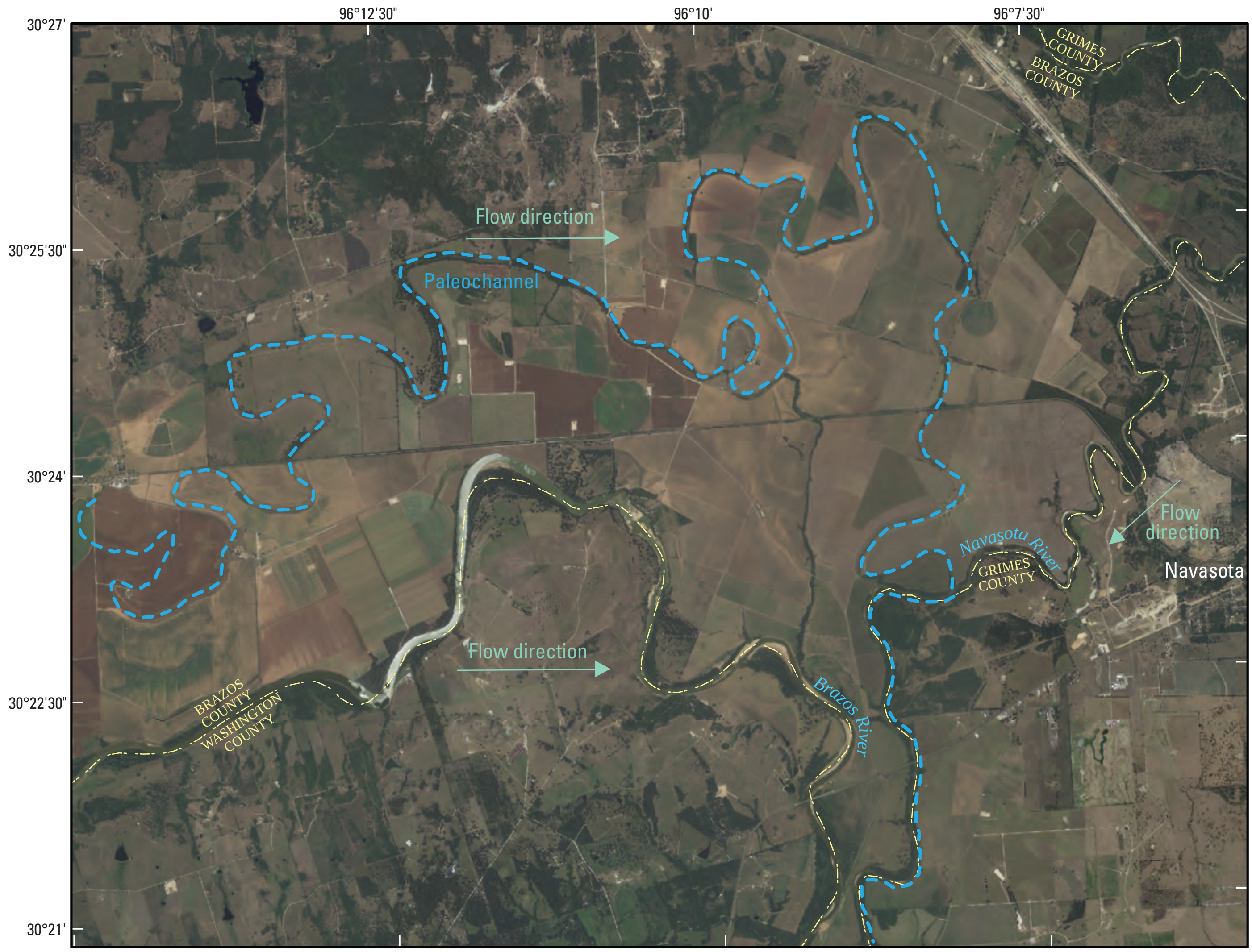


Figure 8. Example of the sinuous course of a Texas Gulf Coastal Plain river and its paleochannel (Brazos River near the confluence of the Brazos and Navasota Rivers) near Navasota, Texas.

the main river channel(s) and one another by vegetated floodplain islands (fig. 9). They are typically active at all but the lowest flows and commonly are formed by avulsion processes that are promoted by aggradation and/or benching of sediment in the main channel (Makaske, 2001; Phillips, 2009). Wende and Nanson (1998, p. 205) provide the following description of anabranching rivers:

> Anabranching rivers form a highly diverse group of streams that, despite their occurrence worldwide, remain the last major category of alluvial system to be thoroughly described and explained (Nanson and Knighton, 1996). They consist of multiple channels separated by vegetated semipermanent alluvial islands or ridges, and provide a marked contrast to most rivers that flow in single channels in order to maintain an efficient conveyance of water and sediment. It is well understood that alluvial rivers generally respond to changes in environmental conditions by adjusting their hydraulic geometry and planform with the result that river morphology can vary across a wide spectrum. Anabranching rivers are no exception and as a consequence they add greatly to the diversity of river systems.

In fine-grained, lowland, coastal plain environments, a network of connected anabranches and the main river channel(s) is referred to as an anastomosing river system

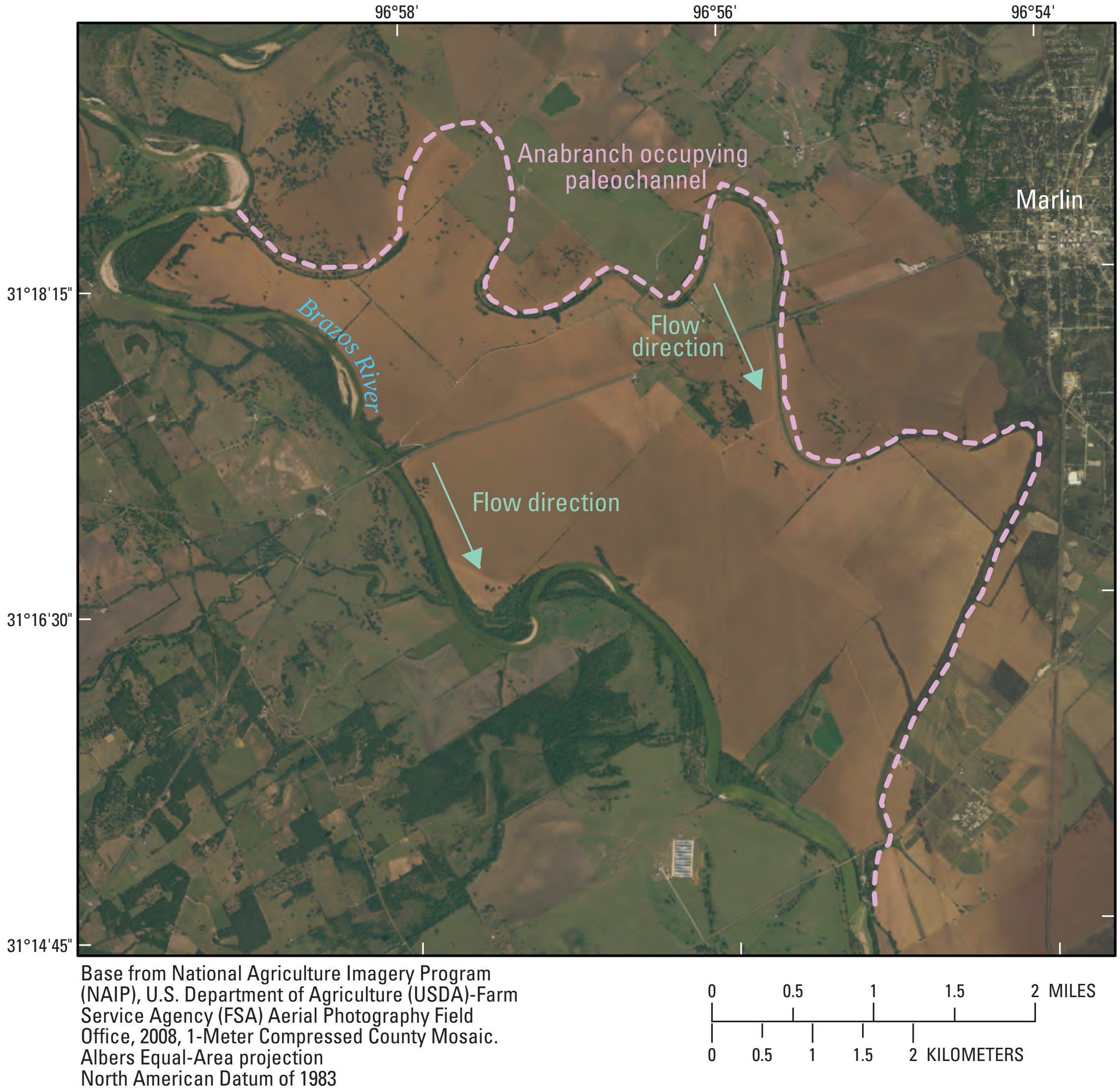


Figure 9. Example of an anabranch on a Texas Gulf Coastal Plain river from the Brazos River near Marlin, Texas.

(Nanson and Knighton, 1996). Phillips (2006, 2007a) describes the reach of the Navasota River between Lake Limestone and Navasota, Tex., as an anastomosing river with high channel-flood plain connectivity.

Distributaries

Distributaries commonly occur in deltaic plain environments and can develop when a midchannel bar divides flow in an actively enlarging delta. A different type of distributary can exist in nondeltaic parts of the valley when a crevasse is persistent enough to scour a channel capable of conveying flow and sediment away from the main river during even moderate and low flows (Saucier, 1994). These are referred to as “tie channels” (fig. 7). Distributaries can range from very small to near the size of the main channel. When they become as large as the main river channel and can sustain a steeper slope than the main channel, a bar will form in the old main channel, causing it to convey a smaller proportion of flow and sediment load as the distributary channel takes over as the main channel.

Natural Levees

Natural levees are slightly elevated ridges, displaying a fining-upward sequence of mostly sand and silt that gently slope away from the river channel to lower areas of the flood plain (Brierley and Fryirs, 2005). They occur as a result of overbank flooding and the general decrease in flow velocity and stream power with distance away from the channel, promoting deposition of suspended sediment. Natural levees are best developed along cutbanks and generally extend farther into the flood plain at meander bends of low curvature (Hudson and Heitmuller, 2003). Relatively coarse-grained natural levees tend to be steeper and narrower than relatively fine-grained natural levees (Saucier, 1994). As natural levees grow in height and width over time, they gradually establish the spatial limits over which the river migrates by meandering processes, referred to as a meander belt.

Natural levees can be difficult to identify from aerial imagery for some Texas Gulf Coastal Plain rivers. Various clues can help the practitioner determine if natural levee deposits are well developed or underdeveloped. Because natural levees are coarse-grained relative to surrounding overbank deposits, they are less saturated by water and often appear lighter in tone on aerial imagery when vegetation is absent. When present, different types of vegetation might preferentially become established on the well-drained levee deposits when compared to the surrounding areas. Artificial levees are similar in form to natural levees but have been constructed along river courses by humans for flood protection purposes. They are easily distinguished from natural levees by their spatial extent, material composition, and uniform shape.

Neck Cutoffs and Oxbow Lakes

Neck (meander) cutoffs are somewhat different from abandoned channel courses in that they only affect one meander bend instead of an entire length of channel. Neck cutoffs form when the cutbanks of two actively eroding meander bends intersect, initially leaving behind an oxbow (fig. 10). Neck cutoffs result in decreased sinuosity and increased channel slope (Brierley and Fryirs, 2005). The arms of a cutoff meander (oxbow) first begin to fill in with relatively coarse sand near the active river channel, termed a sand wedge (Saucier, 1994). This infilling typically occurs in the downstream arm of the oxbow. As the river migrates farther away from the oxbow, a small tie channel can form in the upstream arm of the oxbow and convey local drainage from the oxbow to the river and floodwater from the river to the oxbow (fig. 11). Over time, fine-grained overbank sediment settles into the tie channel, resulting in the formation of an oxbow lake. An oxbow becomes an oxbow lake once it is able to retain water after flood flows recede. If an oxbow lake becomes completely infilled with fine-grained sediments, it will serve as an erosion-resistant, cohesive clay unit that will slow channel migration if the river switches back to that location. The longevity of an oxbow lake depends on how rapidly and how far the active river migrates away; the farther the river is located from the oxbow, the less frequently it is inundated by flood flows and sediment, and the longer it will take to fill with sediment. Sediment transported to the oxbow from surrounding hill slopes by overland flow can continue to fill the lake until it is virtually indistinguishable from the surrounding terrain.

There are generally five stages in the lifecycle of an oxbow (Saucier, 1994). They are as follows:

1. Flow-through cutoff meander (oxbow) with both ends still connected to the main channel at all but the lowest flows
2. Formation of a sand wedge and tie channel
3. Filling of the tie channel and formation of an oxbow lake
4. Filling of the oxbow lake resulting in an oxbow swamp
5. Completely filled oxbow swamp evident as a meander scar (infilled depression).

Oxbows and oxbow lakes can be easily mapped from aerial imagery (fig. 12). For lowland, coastal plain, meandering rivers, oxbow lakes usually retain water, but their beds can be exposed during abnormally dry conditions. Neck cutoffs are commonly short-lived because they transition to the main river channel as sediment is deposited in both arms of the oxbow.

Constructed Channels

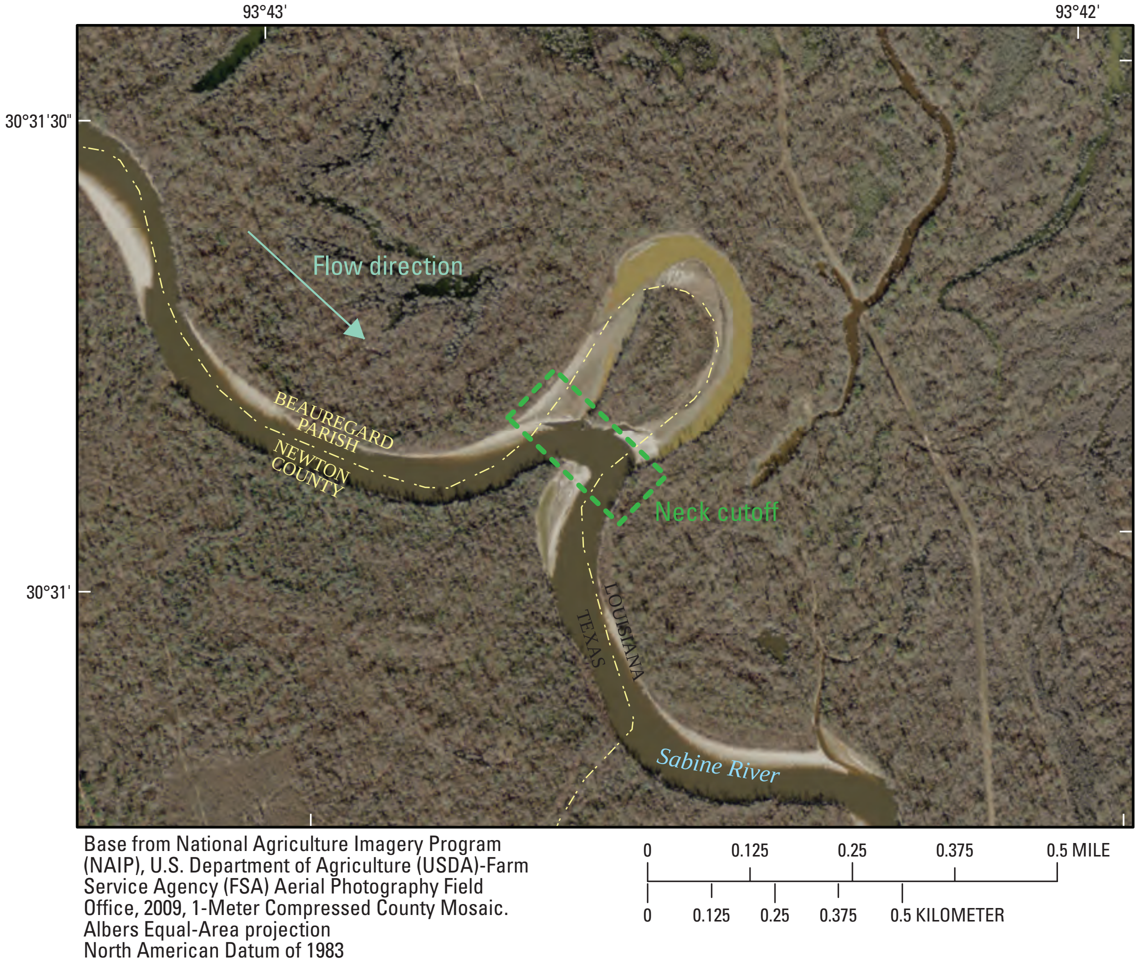
A constructed channel is considered a valley geomorphic unit when it is used to link the main channel to another part of the alluvial surface (fig. 13). Constructed channels have been used for navigation, flood control, and agriculture (Brierley and Fryirs, 2005). Constructed channels have been used for various purposes on the major rivers of the Texas Gulf Coastal Plain. For example, along the Brazos River, constructed channels have been used to drain wetlands, so they could be used for agricultural purposes, and to speed the drainage of existing low-lying agricultural areas. Constructed channels have also been used to straighten river courses in attempts to reduce the affects of floods (U.S. Department of Agriculture, Natural Resources Conservation Service, 2007). Constructed channels can result in a number of negative effects, including increased bed erosion rates, bank instability and widening, loss of complexity of other geomorphic units, and loss of riverine habitat (Brierley and Fryirs, 2005).

Channel Geomorphic Units

Channel geomorphic units of alluvial, coastal plain rivers are typically smaller than valley geomorphic units, with dimensions on the order of 10 feet to less than 1 mile. Channel geomorphic units occur in the river channel and are subject to frequent stresses associated with flowing water and sediment transport; they adjust (change) relatively quickly in response to short-term variations in flow (Brierley and Fryirs, 2005). Relatively few characteristics of the channel geomorphic units can be determined or measured from aerial imagery. Field observations useful for interpreting channel geomorphic units include measurements of their length, width, height, thickness, composition (particle-size distribution and mineralogy), orientation, and vegetation characteristics, among others (Brierley and Fryirs, 2000, 2005).

Channel Banks

The channel banks of Texas Gulf Coastal Plain rivers consist mostly of combinations of other channel geomorphic units and alluvial deposits. Alluvial channel banks of lowland,



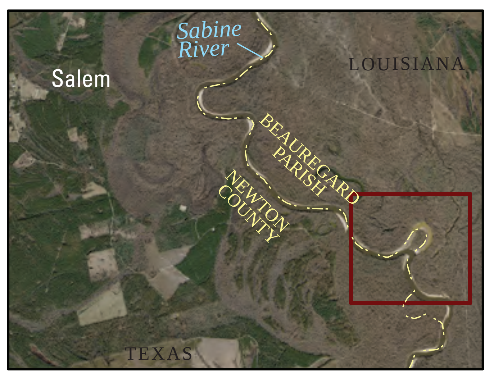


Figure 10. Example of a neck cutoff on a Texas Gulf Coastal Plain river at a meander on the Sabine River near Salem, Texas.

actively meandering rivers such as the rivers of the Texas Gulf Coastal Plain are generally categorized as depositional, erosional, or stable. Depositional channel banks typically consist of convex, gradually sloping upper banks and low-sloped lower banks leading to the water's edge (fig. 14). Depending on flow conditions, depositional banks typically contain vegetation all or part of the year. Erosional channel banks (cutbanks) are identified by relatively steep concave faces and a lack of permanent vegetation and are most common on the outside of meander bends (fig. 15). Cutbanks typically indicate active channel erosion and meander migration. Stable channel banks are typically vegetated, with no evidence of ongoing deposition or erosion. Channel banks are categorized on the basis of convexity, concavity, irregularity, angle, and interpreted formative process. Brierley and Fryirs (2005) and Phillips (2008) provide detailed information regarding the categories of alluvial banks and their formative processes.

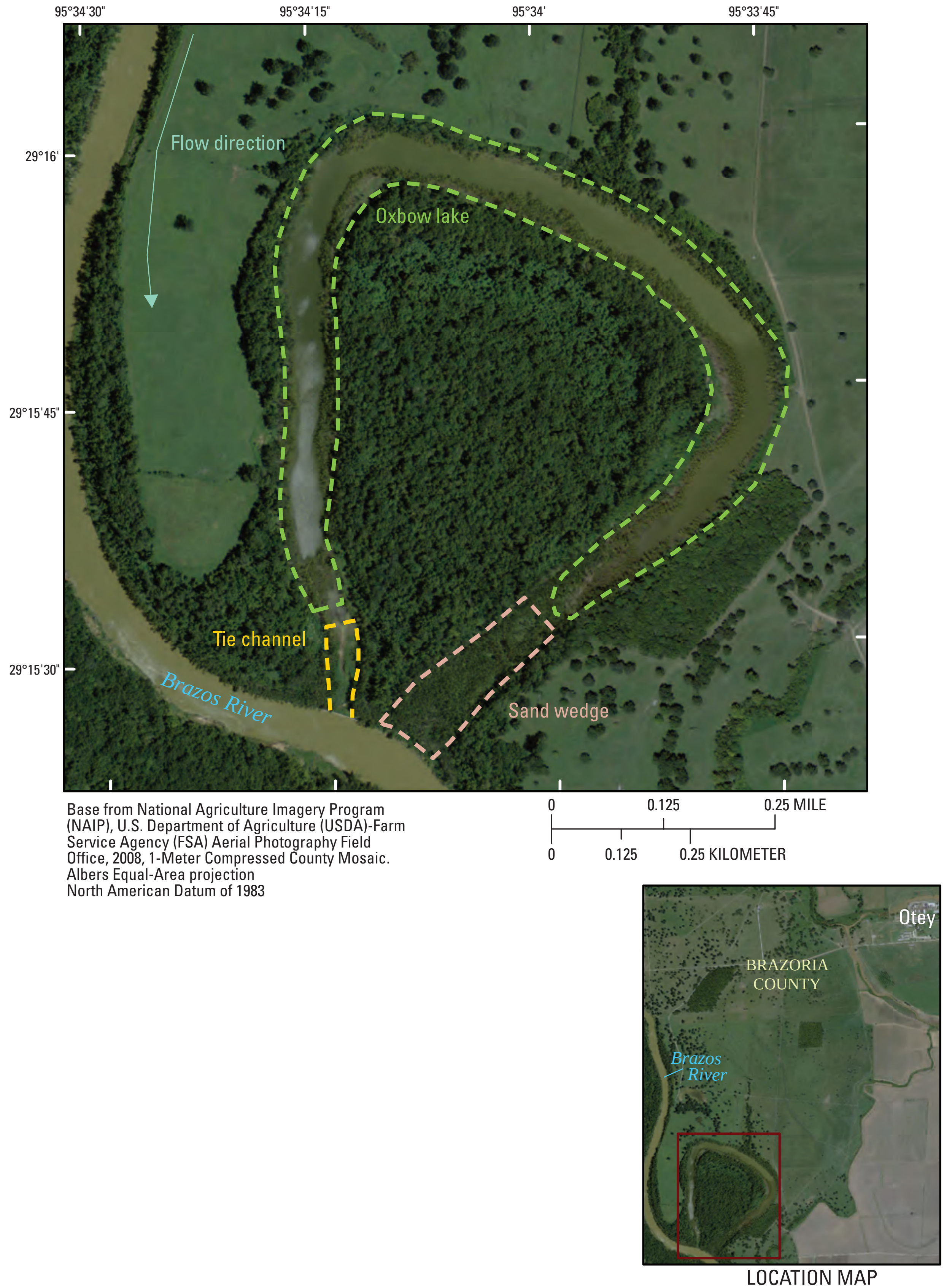


Figure 11. Example of an oxbow lake with a tie channel and sand wedge on a Texas Gulf Coastal Plain river from the oxbow lake on the Brazos River near Otey,Texas.

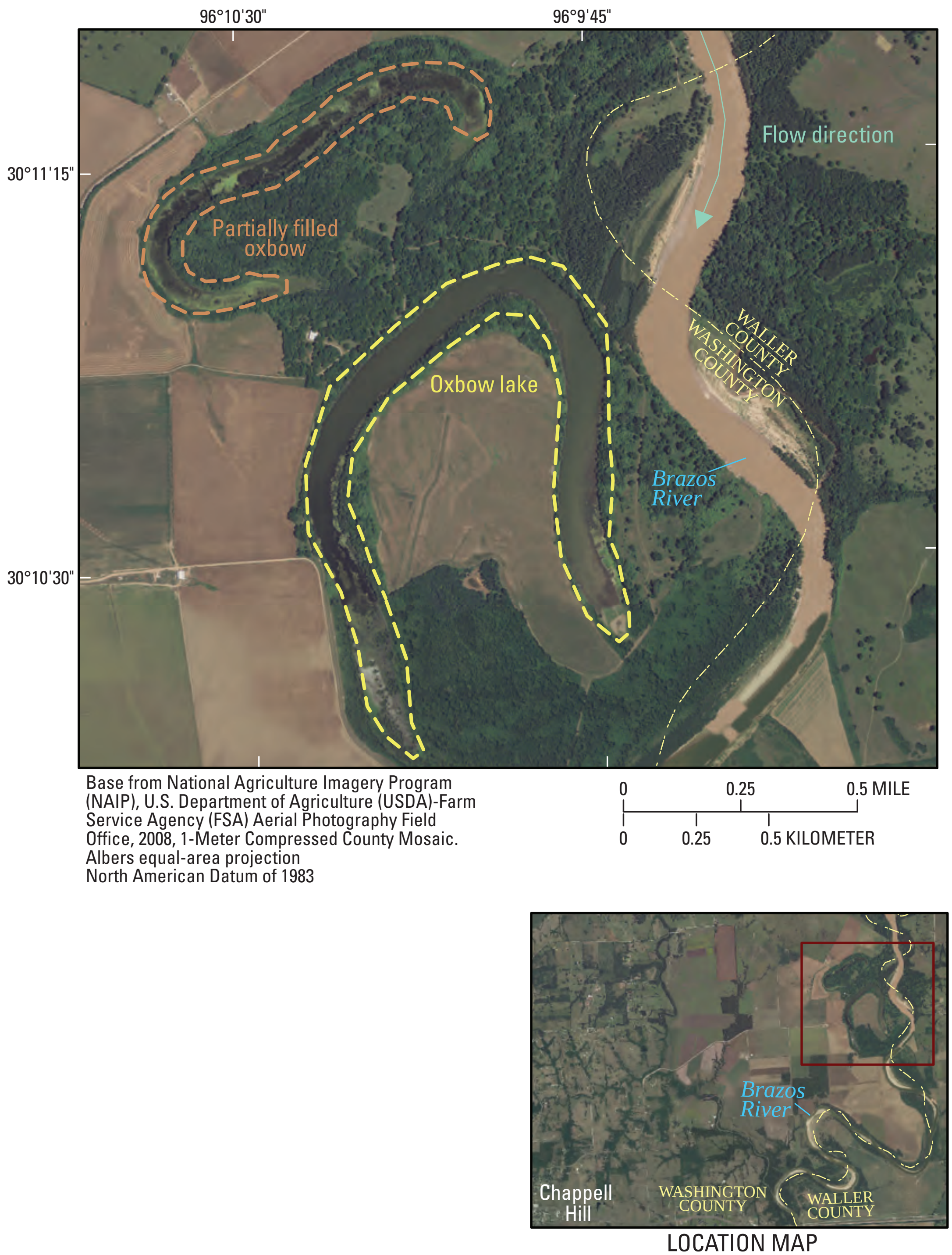


Figure 12. Example of an older, partially filled oxbow swamp north of a more recent oxbow lake on a Texas Gulf Coastal Plain river from the sequence of oxbow lakes on the Brazos River near Chappell Hill, Texas.

Benches and Ledges

Benches are depositional geomorphic units occurring below bankfull stage (fig. 16). The flat surface at the top of the bench is sometimes referred to as an “inset flood plain” (Brierley and Fryirs, 2005). Benches serve as important sediment storage features in river channels and commonly exist on the inside of a meander bend. Heitmuller and Greene (2009) found evidence that benches have formed on point bars of the lower Brazos River during the last 50 years and, combined with vegetation encroachment, have reduced bankfull channel width.

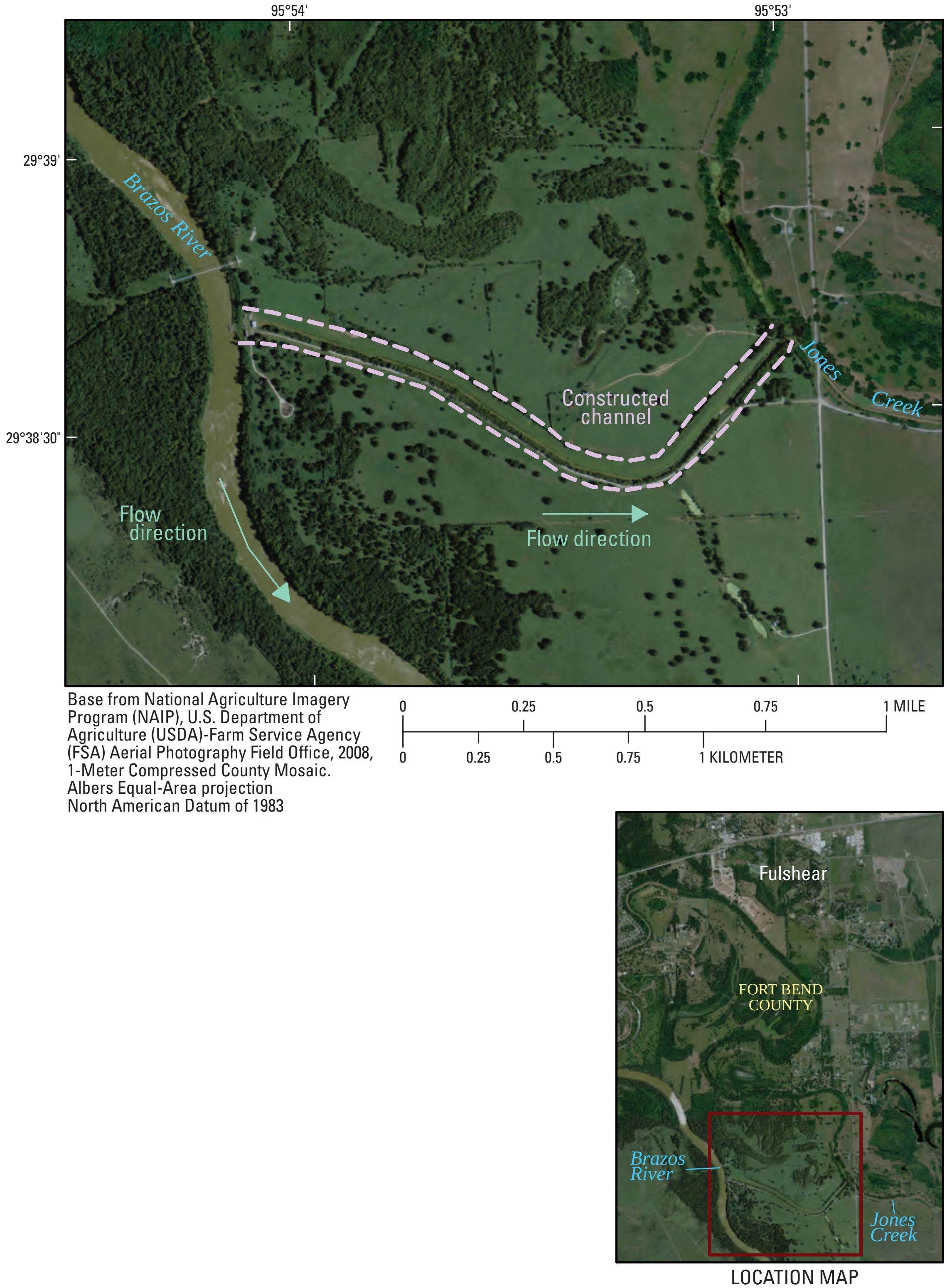


Figure 13. Example of a constructed channel conveying flow from the main channel of the Brazos River to Jones Creek near Fulshear, Texas.

Figure 14. Example of a depositional bank of the Trinity River with a vegetated upper bank and a point-bar surface below the bankfull elevation near St. Paul, Texas (photograph courtesy of Webster Mangham, Trinity River Authority, 2010).

Figure 15. Example of an unvegetated cutbank on the outside of a meander bend along the Trinity River near Massey Lake, Texas (photograph courtesy of Webster Mangham, Trinity River Authority, 2010).

Ledges, although similar in form to benches, are erosional scarps occurring below the bankfull stage. Ledges indicate channel incision and/or expansion (Brierley and Fryirs, 2005) and often occur when bank erosion processes encounter resistant layers that erode less easily than overlying units. In Texas Gulf Coastal Plain alluvial rivers, ledges are typically composed of bedrock or cohesive clays, overlain by less-resistant, noncohesive sandy soils or alluvium (Phillips, 2008). Ledges also occur when a period of incision downcuts a narrow channel into the former channel bed. These types of ledges were documented by Phillips and others (2005) in the Trinity River. When present, benches and ledges form a series of risers from the river channel to the active flood plain.

Bank Failures

Bank failure, or mass failure, is a geomorphic process that is useful in determining bank type. Bank failure features and remnants are bank-attached channel geomorphic units. According to Brierley and Fryirs (2005, p. 99) "the susceptibility of banks to mass failure depends on their geometry, structure, and material properties". In Texas Gulf Coastal Plain alluvial rivers, bank material weathering occurs in the form of soil desiccation, wetting/drying cycles, and to a lesser extent, freeze/thaw cycles. Thorne (1982) describes in detail how wetting and drying cycles weaken bank material, thus making it more susceptible to mass failure. Typical methods of mass failure in alluvial rivers include slab failure, beam

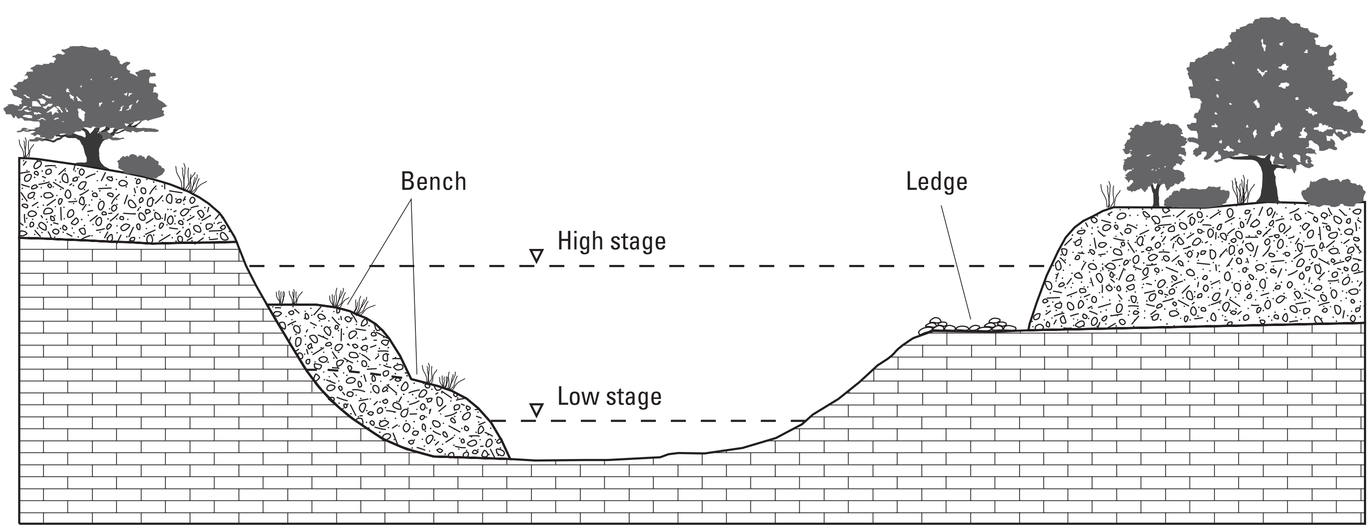


Figure 16. Simplified representation of bench deposits and an erosional ledge.

failure, and rotational slip, or slumping (Brierley and Fryirs, 2005). Undercutting of the channel banks increases their susceptibility to mass failure and is typical on cutbanks of alluvial, coastal plain rivers. Bank failure material and remnants that are not immediately entrained by flow can become vegetated and temporarily stable, providing habitat and armoring the bank from additional undercutting and subsequent failure. Bank failures are most easily located and described in the field (fig. 17), but large failures are sometimes visible in high-resolution aerial photography.

Point Bars and Cross-Bar Channels

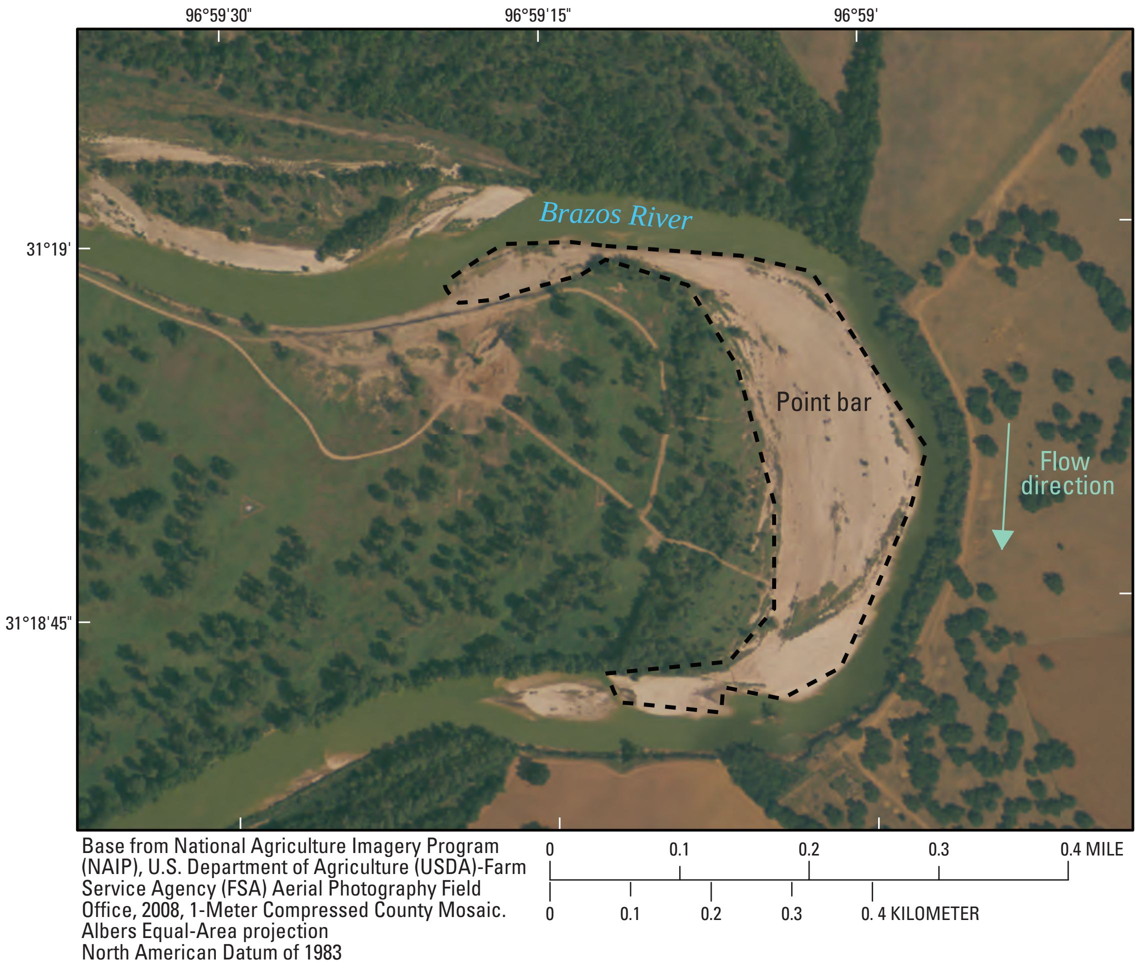
A point bar is an arc-shaped deposit along the inside of a meander bend and is tilted upward away from the river channel (Brierley and Fryirs, 2005; fig. 18). Point bars are fairly common in Texas Gulf Coastal Plain rivers. They are frequently inundated, often more than once per year, and, therefore, much of their surface is sparsely vegetated. Secondary flow currents at a meander bend, perpendicular to the general downstream flow direction, erode sediment from the outside of the bend, forming a cutbank and pool, and transport and deposit bed sediment toward the inside of the bend, forming a point bar with a fining-upward sequence (Brierley and Fryirs, 2005). Higher distal sections of the point bar are capped with fine-grained (silt and clay) sediment. Point bars also exhibit a longitudinal grading, with relatively coarse-grained material deposited on the upstream end of the bar and relatively fine-grained sediment on the downstream end of the bar. Eventually, distal, older parts of the point bar merge with the elevation of surrounding flood-plain deposits. When overbank deposits comprise the majority of sediment along a point-bar surface, it can be considered a valley geomorphic unit, as opposed to a channel geomorphic unit. Portions of point bars, or sometimes entire bars, may become permanently or semipermanently vegetated either because of accretion above regular flow levels or during prolonged low-flow periods.

Figure 17. Example of a bank failure on the cutbank of the Trinity River near Massey Lake, Texas (photograph courtesy of Webster Mangham, Trinity River Authority, 2010).

Cross-bar channels can be found on the inside meander bends on Texas Gulf Coastal Plain rivers and form when a low swale in a point bar is inundated during high-flow events and becomes the preferential flow path, thereby slightly shortening the channel and reducing sinuosity (fig. 19). The shortened channel length leads to higher flow energies and the reworking of the bar and other channel geomorphic units. Cross-bar channels are differentiated from neck cutoffs in that they do not circumvent an entire meander, but only the surface of the point bar.

Other Channel Bars

A variety of channel bar deposits can occur in Texas Gulf Coastal Plain rivers, including longitudinal, transverse, and tributary mouth bars. Longitudinal bars are elongated deposits of bed sediment oriented parallel to flow. They form when relatively coarse sediment deposited in the channel diverts flow and promotes further sediment deposition immediately downstream (Leopold and Wolman, 1957). They can occur in the middle of the channel or attached to the bank, with the latter situation being more common with increasing downstream distance (Church and Jones, 1982) and decreasing bed-material size. A midchannel longitudinal bar can develop into an island with an elevation exceeding bankfull stage if channel-bed degradation occurs, or the rate of sediment aggradation on the bar exceeds the rate of erosion, or sufficient vegetation is established that promotes vertical growth and stability (Brierley and Fryirs, 2005) (fig. 20). In contrast to longitudinal bars, transverse bars are oriented perpendicular to the flow and span across the river. Transverse bars specifically refer to midchannel bars oriented perpendicular to flow and occupying most of the channel width (also referred to as linguoid bars). They typically have a lobate shape with a steep face on the downstream end (fig. 21). They tend to occur where there is an increase in channel width that locally reduces flow velocity and promotes sediment deposition. Transverse channel bars will begin migrating downstream at varying flow rates depending on their grain-size distribution and composition (Cant and Walker, 1978). Tributary mouth bars form in the main river channel as a result of converging flow at a tributary confluence (fig. 21). Flow separation and secondary current generation allow for the formation of a backwater zone immediately downstream from the tributary mouth on the same side of the channel. The lower flow velocities present in the backwater zone promote deposition of larger particles, even during periods of high flows. Tributary mouth bars are typically composed of poorly sorted sediment and organic debris. Other types of channel bars occur in Texas Gulf Coastal Plain rivers, including lateral bars, diagonal bars, forced bars, and sand sheets. Phillips (2008) provides detailed discussions and photographs of the different types of channel bars.



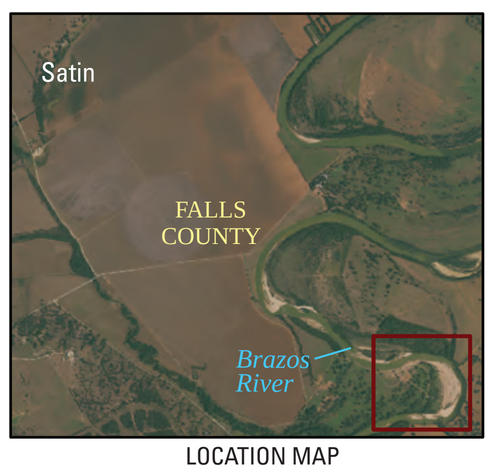


Figure 18. Example of a large point bar on the inside of a meander bend of the Brazos River near Satin, Texas.

Exposed Bedrock

Resistant bedrock becomes exposed when overlying alluvial material is eroded and transported downstream. Bedrock exposures can influence local flow patterns and, thus, other channel geomorphic units. Exposed bedrock geomorphic units can be described by their position and orientation in the channel (Phillips, 2008). Hidalgo Falls is a unique geomorphic feature on the Brazos River that Phillips (2006, 2007a) characterizes as an individual river style (fig. 22). Here, the river falls approximately 11.5 vertical feet in 1,800 linear feet. This feature is one of the only places on the Brazos River alluvial

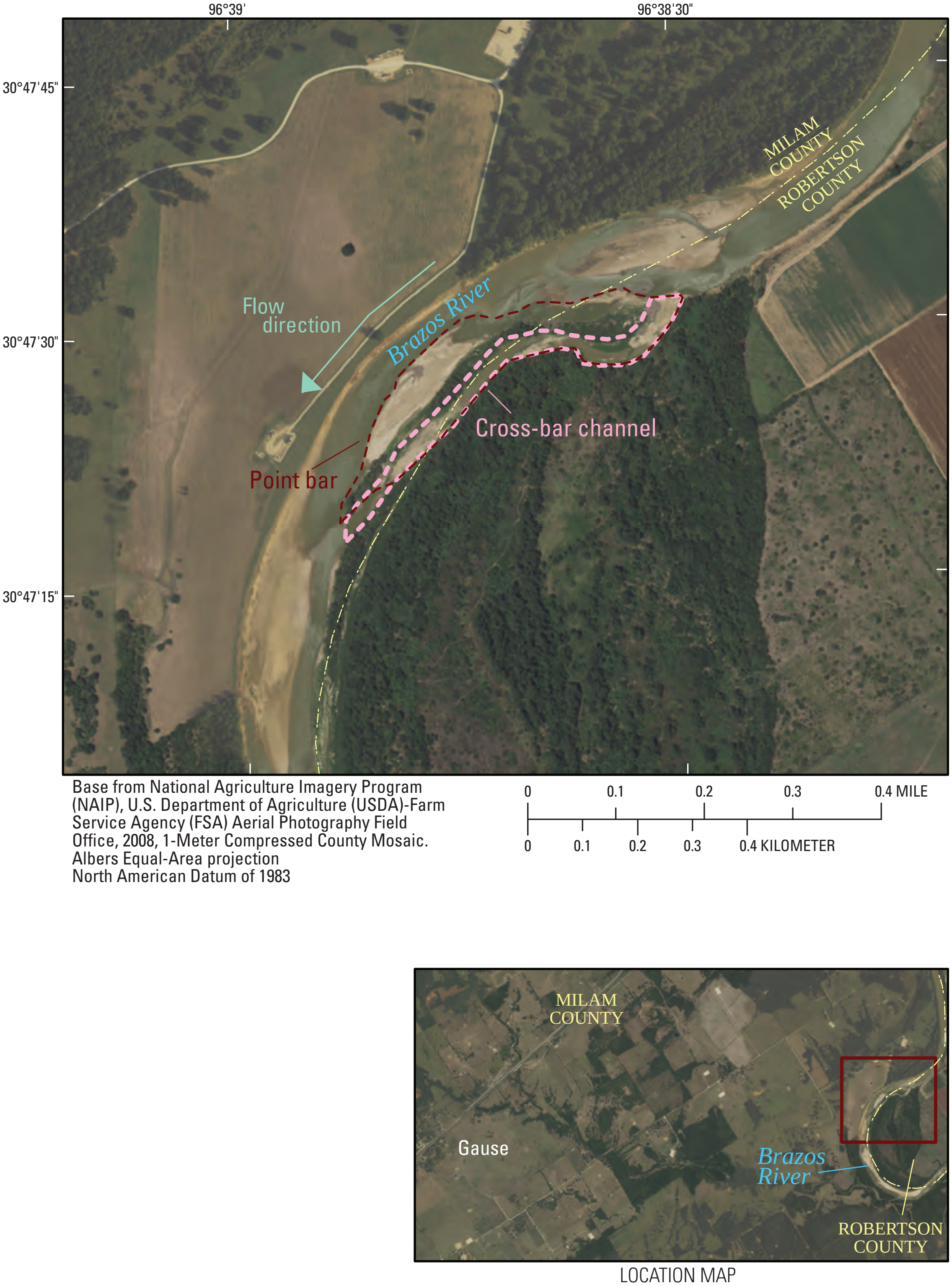


Figure 19. Example of a cross-bar channel formed across a point bar on the inside of a meander bend of the Brazos River near Gause, Texas.

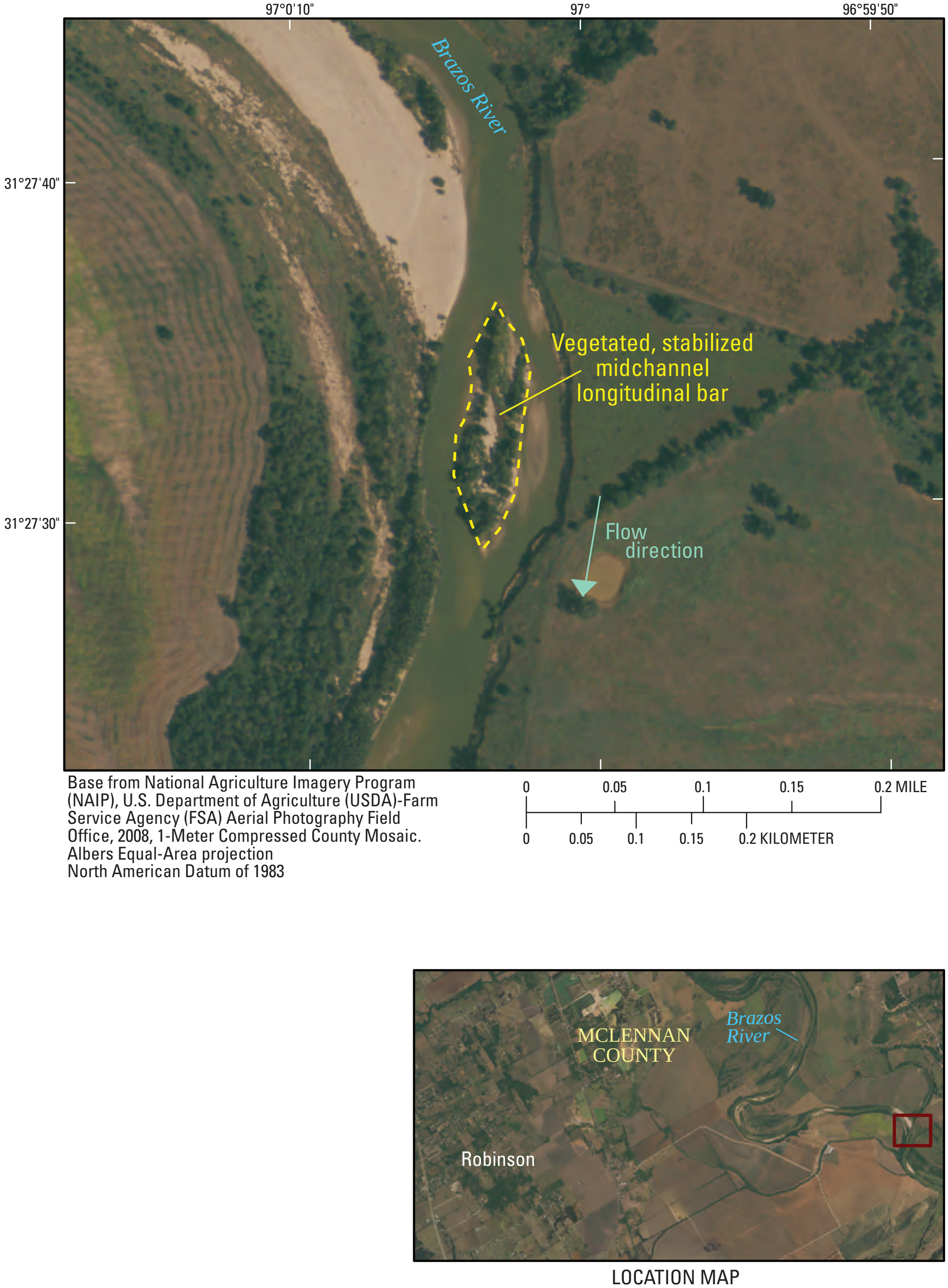


Figure 20. Example of a vegetated, stabilized midchannel longitudinal bar that has developed into an island in the channel of the Brazos River near Robinson, Texas.

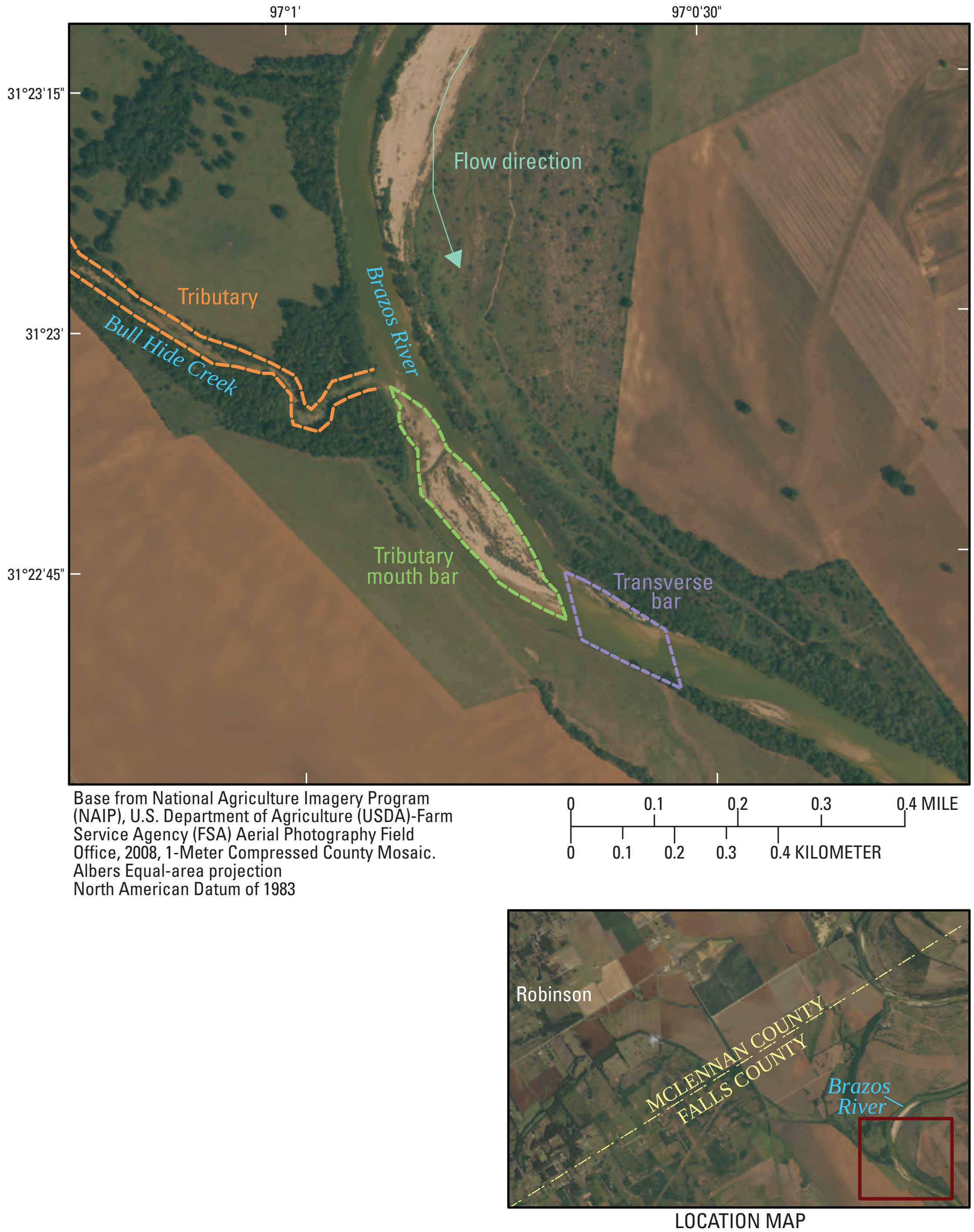


Figure 21. Example of a transverse (linguoid) bar and a tributary mouth bar formed downstream from the confluence of Bull Hide Creek and the Brazos River near Robinson, Texas.

plain where the channel bed and banks consist of resistant, Tertiary sandstone bedrock (U.S. Department of Agriculture, Natural Resources Conservation Service, 2002). Other areas of exposed bedrock, both consolidated or unconsolidated, exist in the channels of Texas Gulf Coastal Plain rivers and are classified individually as channel geomorphic units (Phillips, 2008).

Another class of channel geomorphic unit forms as a result of exposed bedrock in Texas Gulf Coastal Plain rivers. Depending on flow conditions, bedrock rapids form as water flows across irregular surfaces of exposed bedrock. The flow conditions associated with rapids can cause increased erosion of a river’s bed and banks in the vicinity of the bedrock outcrop.

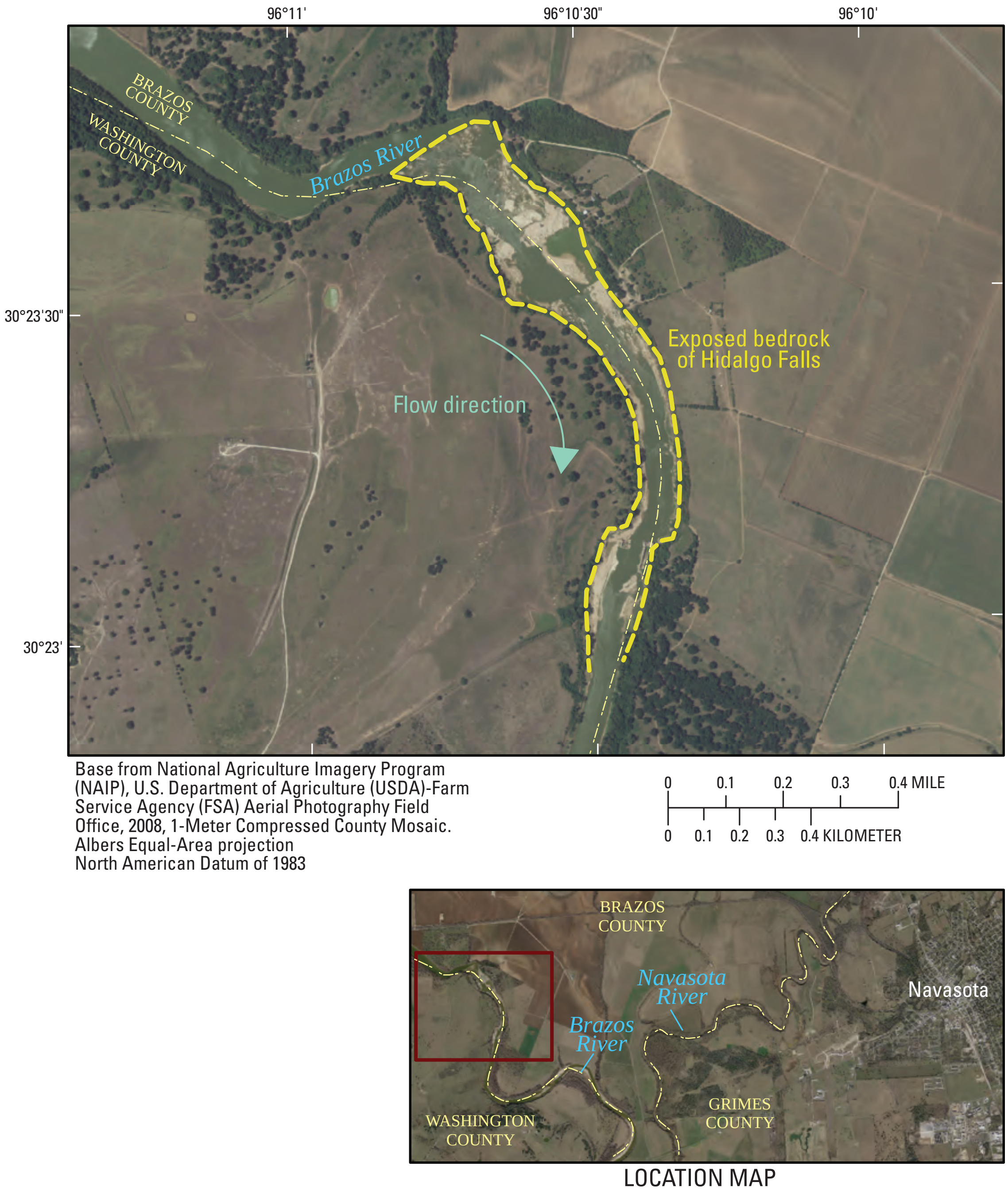


Figure 22. Exposed bedrock of Hildago Falls on the Brazos River between Washington County and Brazos County near Navasota, Texas.

Pools, Runs, and Crossovers

Pools are the sections of channel with the deepest water and slowest flow velocities, when compared to adjacent upstream and downstream sections. Alternating pool/riffle sequences refer to successive deep and shallow lengths of the river channel, respectively, and are commonly associated with gravel-bed rivers. In the sand-bed rivers of the Texas Gulf Coastal Plain, the shallow sections between pools with higher flow velocities are called crossovers, because there is not sufficient gravel present to form riffles. Runs are the sections of channels of moderate depth and velocity that connect pools and crossovers. Isolated riffles can form in the channels of Texas Gulf Coastal Plain rivers near locations where coarse gravels originating from upstream igneous intrusions or paleochannel deposits eroded from the banks. There is typically not enough gravel and other large clasts to form pool/riffle sequences.

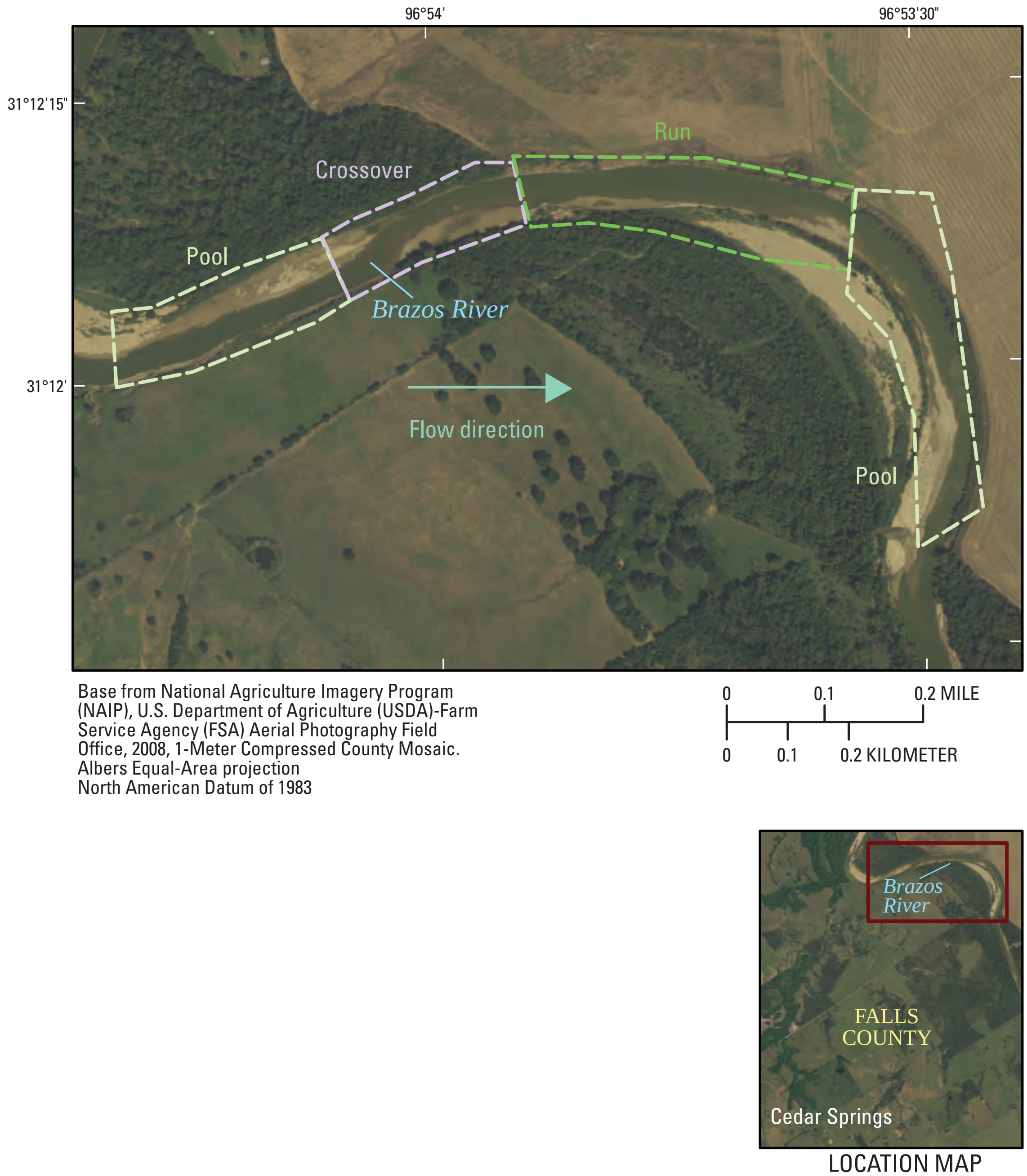


Figure 23. Example of a pool-run-crossover sequence on the Brazos River near Cedar Springs, Texas.

In lowland, meandering river channels, a pool commonly is located on the cutbank side of a meander bend, and crossovers occur between meander bends (fig. 23). Pools at meander cutbanks are maintained by secondary flow circulation, which occurs when flow is deflected down towards the channel bed by the cutbank, enabling localized scour of the bed. Sediment scoured at cutbank pools can then be transported across the channel and downstream and deposited as various types of channel bars. Other types of pools occur on small scales. These include forced pools associated with flow obstructions, scour pools resulting from turbulent flow around obstructions such as bridge piers, and solution pools that are dissolved into bedrock (Brierley and Fryirs, 2005). Crossovers occur between pools and can manifest as various channel-bar forms (Phillips, 2008), including transverse bars. Channels tend to be wider at crossovers than at pools for a given straight reach of channel as a result of their need to accommodate streamflow in the shallow crossovers. For a detailed explanation of categories of pools and runs in Texas Gulf Coastal Plain rivers, see Phillips (2008).

Summary

The U.S. Geological Survey, in cooperation with the Texas Water Development Board, described and characterized examples of geomorphic units (pools, riffles, cross-bar channels, levees, benches, bar types, paleochannels, among others) within the channels and alluvial valleys of Texas Gulf Coastal Plain rivers by using a geomorphic unit classification scale that differentiates geomorphic units on the basis of their location either outside or inside the river channel. Geomorphic unit mapping is an integral part of the Texas Instream Flow Program (TIFP) designed to maintain a sound ecological environments in rivers. The River Styles framework was adapted by the TIFP to more directly address the needs of instream flow studies. The River Styles framework provides a method to geomorphologically characterize river systems using a hierarchical structure that starts with the watershed and scales down to microhabitat features. The geomorphic properties of a river system determine the distribution and type of potential habitat both within and adjacent to the channel. River styles, one of the hierarchical categories of the River Styles framework classification system, contain unique assemblages of geomorphic units, which often determine physical habitat type within the river valley and channel. This report characterizes the geomorphic units contained in the river channels and alluvial valleys of Texas Gulf Coastal Plain rivers in the context of the River Styles framework. Concepts of the River Styles framework are used to clearly differentiate between the different spatial scales of geomorphic units on the basis of their location either outside or inside the river channel.

This report is intended to help TIFP practitioners, river managers, ecologists and biologists, and others interested in the geomorphology and the physical processes of the rivers of the Texas Gulf Coastal Plain (1) gain insights into how geomorphic units develop and adjust spatially and temporally, and (2) be able to recognize common geomorphic units from the examples cataloged in this report. This discussion of geomorphic units is applicable only to the alluvial valleys of Texas Gulf Coastal Plain rivers, although the geomorphic units presented here can also occur within the upper watershed or deltaic plain of a Texas river system.

Recent aerial imagery (high-resolution digital orthoimagery) collected in 2008 and 2009 were inspected by using geographic information system software to identify representative examples of the types of geomorphic units that occurred in the study area. Whereas the River Styles framework differentiates geomorphic units as flood-plain geomorphic units or channel geomorphic units on the basis of their location inside or outside of the channel, the authors determined that in the study area, geomorphic units did not always occur on the flood plain, but occasionally at elevations higher than the flood-plain surface yet still within the alluvial valley. For this reason, geomorphic units that are located outside the channels of Texas Gulf Coastal Plain rivers are called “valley geomorphic units” in this report. Valley geomorphic units are either areal or linear, depending on their general shape and extent; they are in contact with the river only during periodic flow events when channel-flood plain connectivity is achieved. Valley geomorphic units for the Texas Gulf Coastal Plain rivers described in this report are terraces, flood plains, crevasses and crevasse splays, flood-plain depressions, tie channels, tributaries, paleochannels, anabranches, distributaries, natural levees, neck cutoffs, oxbow lakes, and constructed channels. Channel geomorphic units occur in the river channel and are subject to frequent stresses associated with flowing water and sediment transport; they adjust (change) relatively quickly in response to short-term variations in flow. Channel geomorphic units can be grouped as bank-attached or midchannel, depending on their location within the channel under base-flow conditions. Channel geomorphic units described in this report are channel banks, benches and ledges, bank failures, point bars, cross-bar channels, channel bars, exposed bedrock, pools, runs, and crossovers.

References Cited

Benda, Lee, Andras, Kevin, Miller, Daniel, and Bigelow, Paul, 2004a, Confluence effects in rivers: Interactions of basin scale, network geometry, and disturbance regimes: Water Resources Research, v. 40, W05402, doi: 10.1029/2003WR002583.

Benda, Lee, Poff, L.N., Miller, Daniel, Dunne, Thomas, Reeves, Gordon, Press, George, and Pollock, Michael, 2004b, The network dynamic hypothesis—How channel networks structure riverine habitats: BioScience, v. 54, no. 5, p. 413–427.

Benda, Lee, Veldhuisen, Curt, and Black, Jenelle, 2003, Debris flows and agents of morphological heterogeneity at low-order confluences, Olympic Mountains, Washington: Geological Society of America Bulletin, v. 115, p. 1,110–1,121.

Best, J.L., 1986, The morphology of river channel confluences: Progress in Physical Geography, v. 10, p. 157–174.

Best, J.L., 1988, Sediment transport and bed morphology at river channel confluences: Sedimentology, v. 35, p. 481–498.

Blum, M.D., 1994, Genesis and architecture of incised valley fill sequence—A Late Quaternary example from the Colorado River, Gulf Coastal Plain of Texas, *in* Weimer, P., and Posamentier, H.W., eds., Siliciclastic sequence stratgraphy—Research developments and application: American Association of Petroleum Geologists Memoir 58, p. 259–283.

Blum, M.D., and Straffin, E.C., 2001, Fluvial responses to external forcing—Examples from the French Massif

Central, the Texas Coastal Plain (USA), the Sahara of Tunisia, and the Lower Mississippi Valley (USA), *in* Maddy, D., and Macklin, M.A., eds., River basin sediment systems—Archives of environmental change: Rotterdam, The Netherlands, Balkema, p. 195–228.

Bomar, G.W., 2011, Weather: Handbook of Texas Online, accessed January 11, 2011, at *http://www.tshaonline.org/handbook/online/articles/yzw01*.

Brierley, G.J., 1996, Channel morphology and element assemblages—*A* constructivist approach to facies modeling, *in* Carling, P.A., Dawson, M.R., eds., Advances in Fluvial Dynamics and Stratigraphy: Chichester, England, Wiley, p. 263–298.

Brierley, G.J., Ferguson, R.J., Lampert, G., Cohen, T., Fryirs, K., Reinfelds, I., Goldrick, G., Crighton, P., Batten, P., and Jansen, J., 1999, Summary overview of River Styles in north coast catchments of New South Wales: Sydney, Macquarie University, Macquarie Research Ltd Report for NSW Department of Land and Water Conservation.

Brierley, G.J., and Fryirs, K.A., 2000, River styles, a geomorphic approach to catchment characterization—Implications for river rehabilitation in Bega Catchment, New South Wales, Australia: Environmental Management, v. 25, p. 661–679.

Brierley, G.J., and Fryirs, K.A., 2005, Geomorphology and river management—Applications of the River Styles Framework: Malden, Mass., Blackwell Publishing, 398 p.

Bureau of Economic Geology, 1996, Geology of Texas: Austin, Tex., University of Texas at Austin, Physiographic Subprovinces of Texas map, scale 1:250,000.

Burkham, D.E., 1972, Channel changes of the Gila River in Safford Valley, Arizona, 1846–1970: U.S. Geological Survey Professional Paper 655–G, 24 p.

Cant, D.J., and Walker, R.G., 1978, Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada: Sedimentology, v. 25, p. 625–648.

Charlton, Ro, 2008, Fundamentals of fluvial geomorphology: Routledge, N.Y., 234 p.

Church, M., and Jones, D., 1982, Channel bars in gravel-bed rivers, *in* Hey, R.D., Bathurst, J.C., and Throne, C.R., eds., Gravel-bed rivers: Chichester, England, Wiley, p. 291–338.

Coleman, J.M., and Wright, L.D., 1971, Analysis of major river systems and their deltas—Procedures and rationale: Louisiana State University, Coastal Studies Institute Technical Report 95, 125 p.

Dauwalter, D.C., Splinter, D.K., Fisher, W.L., and Marston, R.A., 2007, Geomorphology and stream habitat relationships with smallmouth bass (*Micropterus dolomieu*) abundance at multiple spatial scales in eastern Oklahoma: Canadian Journal of Fisheries and Aquatic Sciences, v. 64, p. 1,116–1,129.

Farrell, K.M., 1987, Sedimentology and facies architecture of overbank deposits of the Mississippi River, False River Region, Louisiana, *in* Ethridge, F.G., Flores, R.M., and Harvey, M.D., eds., Recent developments in fluvial sedimentology: Society for Sedimentary Geology, Special Publication 39, p. 111–120.

Federal Interagency Stream Restoration Working Group, 1998, Stream corridor restoration—Principles, processes and practices: Federal Interagency Stream Restoration Working Group (FISWG), GPO Item No. 0120–A; SupDocs No. 57.6/2:EN 3/PT.653, ISBN–0–934213–59–3.

Heitmuller, F.T., and Greene, L.E., 2009, A retrospective analysis of channel morphology and estimates of selected hydraulic values in the lower Sabine and lower Brazos river basins, Texas and Louisiana, 1898–2009: U.S. Geological Survey Scientific Investigations Report 2009–5174, 144 p.

Holmes, R.R., Jr., and Dinicola, K., 2010, 100-Year flood—It's all about chance: U.S. Geological Survey General Information Product 106, 1 p.

Hudson, P.F., and Heitmuller, F.T., 2003, Local- and watershed-scale controls on the spatial variability of natural levee deposits in a large, fine-grained flood plain—Lower Pánuco basin, Mexico: Geomorphology, v. 56, p. 255–269.

Jackson, J.A., 1997, ed., Glossary of geology: Alexandria, Va., American Geological Institute, 769 p.

Knighton, D., 1998, Fluvial forms and processes—A new perspective: London, Arnold, 383 p.

Leopold, L.B., 1994, A view of the river: Cambridge, Mass., Harvard University Press, 298 p.

Leopold, L.B., and Wolman, M.G., 1957, River channel patterns—Braided, meandering, and straight: U.S. Geological Survey Professional Paper 282–B, p. 39–85.

Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964, Fluvial processes in geomorphology: San Francisco, Freeman, 522 p.

Li, R.Y., and Gelwick, F.P., 2005, The relationship of environmental factors to spatial and temporal variation of fish assemblages in a flood plain river in Texas, USA: Ecology of Freshwater Fish, v. 14, p. 319–330.

Makaske, Bart, 2001, Anastomosing rivers—A review of their classification, origin and sedimentary products: Earth-Science Reviews, v. 53, p. 149–196.

Moore, Kelly, Jones, Kim, Dambacher, Jeff, and Stein, Charlie, 2010, Methods for stream habitat surveys, version 20.1—Aquatic Inventories Project: Corvallis, Oreg., Oregon Department of Fish and Wildlife, Natural Production Program, accessed January 19, 2011, at *http://oregonstate.edu/dept/ODFW/freshwater/inventory/pdffiles/hmethd10_woFISHMANUAL.pdf*.

Nanson, G.C., and Knighton, A.D., 1996, Anabranching rivers—Their cause, character, and classification: Earth Surface Processes and Landforms, v. 21, p. 217–239.

National Agriculture Imagery Program, 2008, 1-Meter compressed county mosaic map: U.S. Department of Agriculture Farm Service Agency, Aerial Photography Field Office, scale 1:3,780.

National Agriculture Imagery Program, 2009, 1-Meter compressed county mosaic map: U.S. Department of Agriculture Farm Service Agency, Aerial Photography Field Office, scale 1:3,780.

Neuendorf, K.K.E., Mehl, J.P., Jr., and Jackson, J.A., eds., 2005, Glossary of geology (5th ed.): Alexandria, Va., American Geological Institute, 799 p.

Oregon State University, 2010, Sample ArcView analysis using habitat data: Oregon Department of Fish and Wildlife, Aquatic Inventories Project, accessed December 8, 2010, at *http://oregonstate.edu/dept/ODFW/freshwater/inventory/av.html*.

Parsons, Melissa, Thoms, Martin, and Norris, Richard, 2002, Australian river assessment system—Review of physical river assessment methods; a biological perspective: Canberra, Australia, University of Canberra, Monitoring River Health Initiative Technical Report 21, 59 p.

Phillips, J.D., 2006, Geomorphic context, constraints, and change in the lower Brazos and Navasota Rivers, Texas: Texas Water Development Board contract number 2005483564, accessed November 20, 2009, at *http://www.twdb.state.tx.us/RWPG/rpgm_rpts/2005483564_Phillips.pdf*.

Phillips, J.D., 2007a, Field data collection in support of geomorphic classification of the lower Brazos and Navasota Rivers, Texas: Texas Water Development Board contract number 0604830639, accessed December 10, 2009, at *http://www.twdb.state.tx.us/RWPG/rpgm_rpts/0604830639_BrazosY2rept.pdf*.

Phillips, J.D., 2007b, Geomorphic controls and transition zones in the lower Sabine River: Hydrological Processes, v. 22, p. 2,424–2,437.

Phillips, J.D., 2007c, Geomorphic equilibrium in southeast Texas rivers—Final report: Texas Water Development Board Contract number 0605830636, accessed January 21, 2010, at *http://www.twdb.state.tx.us/RWPG/rpgm_rpts/0605830636_geomorphicEquilibrium.pdf*.

Phillips, J.D., 2007d, Perfection and complexity in the lower Brazos River: Geomorphology, v. 97, p. 364–377.

Phillips, J.D., 2008, Geomorphic units of the lower Sabine River: Texas Water Development Board contract number 0704830782, accessed January 25, 2010, at *http://www.twdb.state.tx.us/RWPG/rpgm_rpts/0704830782SabineGeomorphic.pdf*.

Phillips, J.D., 2009, Avulsion regimes in southeast Texas rivers: Earth Surface Processes and Landforms, v. 34, p. 75–87.

Phillips, J.D., and Slattery, M.C., 2007, Geomorphic processes, controls, and transitions zones in the lower Sabine River: Texas Water Development Board contract number 0600010595, accessed December 23, 2009, at *http://www.twdb.state.tx.us/RWPG/rpgm_rpts/0600010595_Sabine.pdf*.

Phillips, J.D., Slattery, M.C., and Musselman, Z.A., 2005, Channel adjustments of the lower Trinity River, Texas, downstream of Livingston Dam: Earth Surface Processes and Landforms, v. 30, p. 1,419–1,439.

Rhoads, B.L., 1987, Changes in stream channel characteristics at tributary junctions: Physical Geography, v. 8, p. 346–361.

Rice, S.P., Greenwood, M.T., and Joyce, C.B., 2001, Tributaries, sediment sources, and the longitudinal organization of macroinvertebrate fauna along river systems: Canadian Journal of Fisheries and Aquatic Sciences, v. 58, p. 824–840.

Richards, K.S., 1980, A note on changes in channel geometry at tributary junctions: Water Resources Research, v. 16, p. 241–244.

Ruhe, R.V., 1975, Geomorphology—Geomorphic processes and surficial geology: Boston, Houghton Mifflin, 246 p.

Saucier, R.T., 1994, Geomorphology and Quaternary geologic history of the Lower Mississippi Valley: Vicksburg, Miss., U.S. Army Engineer Waterways Experiment Station, 398 p.

Schenk, E.R., and Hupp, C.R., 2010, Flood plain sediment trapping, hydraulic connectivity, and vegetation along restored reaches of the Kissimmee River, Florida: Proceedings of the 4th Federal Interagency Hydrologic Modeling Conference and of the 9th Federal Interagency Sedimentation Conference, Las Vegas, Nev., June 27–July 1, 2010, 12 p.

Schumm, S.A., and Lichty, R.W., 1963, Channel widening and flood-plain construction along the Cimmaron River in southwestern Kansas: U.S. Geological Survey Professional Paper 352–D, p. 71–88.

Smith, L.M., 1996, Fluvial geomorphic features of the Lower Mississippi Alluvial Valley: Engineering Geology, v. 46, p. 139–165.

Sumner, M.E., 2000, Handbook of soil science: Boca Raton, Fla., CRC Press.

Texas Forest Service, 2008, Texas eco-regions—Western Gulf Coastal Plain: accessed March 2010 at *http://texastreeid.tamu.edu/content/texasEcoRegions/WesternGulfCoastalPlain/*.

Texas Instream Flow Program, 2008, Texas instream flow studies—Technical overview: Texas Water Development Board Report 369.

Texas Water Development Board, 2002, GIS data—Major Texas rivers: accessed November 2010, at *http://www.twdb.state.tx.us/mapping/gisdata.asp*.

Thompson, J.R., Taylor, M.P., Fryirs, K.A., and Brierley, G.J., 2001, A geomorphological framework for river characterization and habitat assessment: Aquatic Conservation—Marine Freshwater Ecosystems, v. 11, p. 373–389, accessed January 21, 2011, at *http://www.riverstyles.com/Download/applications%20page%20pdfs/Thomson%20Taylor%20Fryirs%20Brierley.pdf*.

Thorne, C.R., 1982, Processes and mechanisms of river bank erosion, *in* Hey, R.D., Bathurst, J.C., and Thorne, C.R., eds., Gravel-bed rivers: Chichester, England, Wiley, p. 125–144.

Torgersen, C.E., Gresswell, R.E., Bateman, D.S., and Burnett, K.M., 2008, Spatial identification of tributary impacts in river networks, chapter 9, *in* Rice, S.P., Roy, A.G., and Rhodes, B.L., eds., River confluences, tributaries, and the fluvial network: Chichester, England, Wiley, p. 159–181.

U.S. Department of Agriculture, Farm Service Agency, 2009, National Agriculture Imagery Program: U.S. Department of Agriculture, Farm Service Agency, accessed November 10, 2010, at *http://www.apfo.usda.gov/FSA/apfoapp?area=home&subject=prog&topic=nai*.

U.S. Department of Agriculture, Natural Resources Conservation Service, 2002, Soil survey of Brazos County, Texas: Washington, D.C., U.S. Department of Agriculture, Natural Resources Conservation Service, 268 p.

U.S. Department of Agriculture, Natural Resources Conservation Service, 2007, Chapter 10—Two-stage channel design: National Engineering Handbook, Part 654, Natural Resources Conservation Stream Restoration Design.

Walling, D.E., and He, Q., 1997, The spatial variability of overbank sedimentation on river flood plains: Geomorphology, v. 24, p. 209–223.

Wende, Rainer, and Nanson, G.C., 1998, Anabranching rivers—Ridge-form alluvial channels in tropical northern Australia: Journal of Geomorphology, v. 22, p. 205–224.

Wermund, E.G., 1996, Physiographic map of Texas: Austin, Tex., Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin. (Reprinted 2000.)

Wilcox, D.B., 1993, An aquatic habitat classification system for the Upper Mississippi River System: U.S. Fish and Wildlife Service, Long Term Resource Monitoring Program Technical Report 93–T003, 31 p.

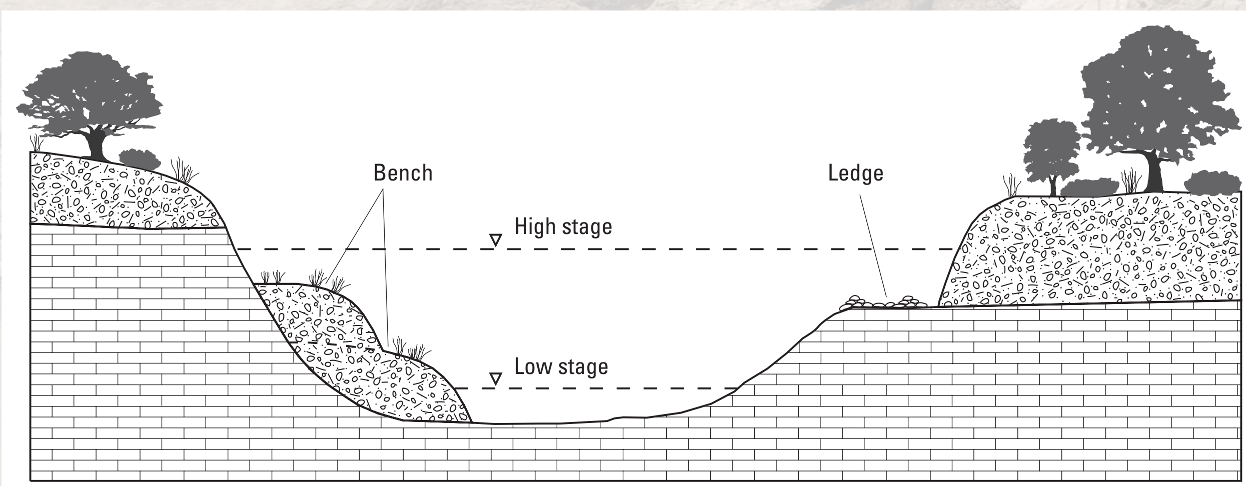
Winemiller, K.O., Tarim, S., Shormann, D., and Cotner, J.B., 2000, Fish assemblage structure in relation to environmental variation among Brazos River oxbow lakes: Transactions of the American Fisheries Society, v. 129, p. 451–468.

Zeug, S.C., and Winemiller, K.O., 2007, Ecological correlates of fish reproductive activity in flood plain rivers—A life-history-based approach: Canadian Journal of Fisheries and Aquatic Sciences, v. 64, p. 1,291–1,301.

Zeug, S.C., Winemiller, K.O., and Tarim, S., 2005, Response of Brazos River oxbow fish assemblages to patterns of hydrologic connectivity and environmental variability: Transactions of the American Fisheries Society, v. 134, p. 1,389–1,399.

Publishing support provided by
Lafayette Publishing Service Center

Information regarding water resources in Texas is available at
http://tx.usgs.gov/



ISBN 978-1-4113-3129-7

Printed on recycled paper

Coffman, Malstaff, and Heitmuller—Characterization of Geomorphic Units in the Alluvial Valleys and Channels of Gulf Coastal Plain Rivers in Texas—SIR 2011–5067