Geomorphic Units
Of the Lower Sabine River

Project Report for the Texas Water Development Board and Texas Instream Flow Program, TWDB contract number 0704830782

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BACKGROUND AND PURPOSE

This report addresses the subreach-scale landforms of the lower Sabine River, Texas/Louisiana from Toledo Bend Dam to Sabine Lake. Building on previous work delineating geomorphic zones or reaches (river styles) and associated environmental controls and hydrologic and geomorphic processes (Phillips, 2008a; Phillips and Slattery, 2007a), this study addresses the characteristic landforms within those zones. The goals were to identify and describe the dominant (in terms of size, frequency of occurrence, and influence on hydrologic and ecological conditions) geomorphic units, to relate these to hydrologic and geomorphic processes and controls, and to link the geomorphic units (GUs) to the river styles zonation. A particular emphasis was placed on transverse bars. These (more-or-less cross-channel) sand bars are important bedforms and aquatic habitat elements in rivers.

The specific objectives of the study were to:

(1) Identify and describe major geomorphic units associated with the geomorphic zones identified in previous work (Phillips 2008a; Phillips and Slattery 2007a).

(2) Describe geomorphic units with respect to size, form, origin, longevity (e.g., typical time scales or persistence) and relationships to particular fluvial or ecological processes.

(3) Assess the geography of geomorphic units with respect to environmental settings, longitudinal (up-downstream) distribution, and association with geomorphic zones.

(4) Test a hypothesis regarding transverse bars. Some point bars in the Sabine show evidence of downstream translation. If the rate of such movements exceeds the rate of overall meander bend migration, then the extensions of the point bar into the channel (i.e., the transverse bar) should occur downstream of the bend apex. The hypothesis was that the sandy bars are mobilized at lower shear stresses than those required for bank erosion, and thus bar mobility occurs more often than cutbank erosion, which is required for migration of the meander as a whole.

Early results showed the hypothesis above to be false, and efforts were refocused on a general study of the occurrence and formation of cross-channel bars.

STUDY AREA

The study area encompasses the lower Sabine River from the Toledo Bend reservoir to the Sabine Lake estuary, along the border of Texas and Louisiana (Fig. 1). The Sabine River has a total drainage area of 25,267 km^2, of which 6,676 km^2 (26%) is downstream of the Toledo Bend dam. The area has a humid subtropical climate.

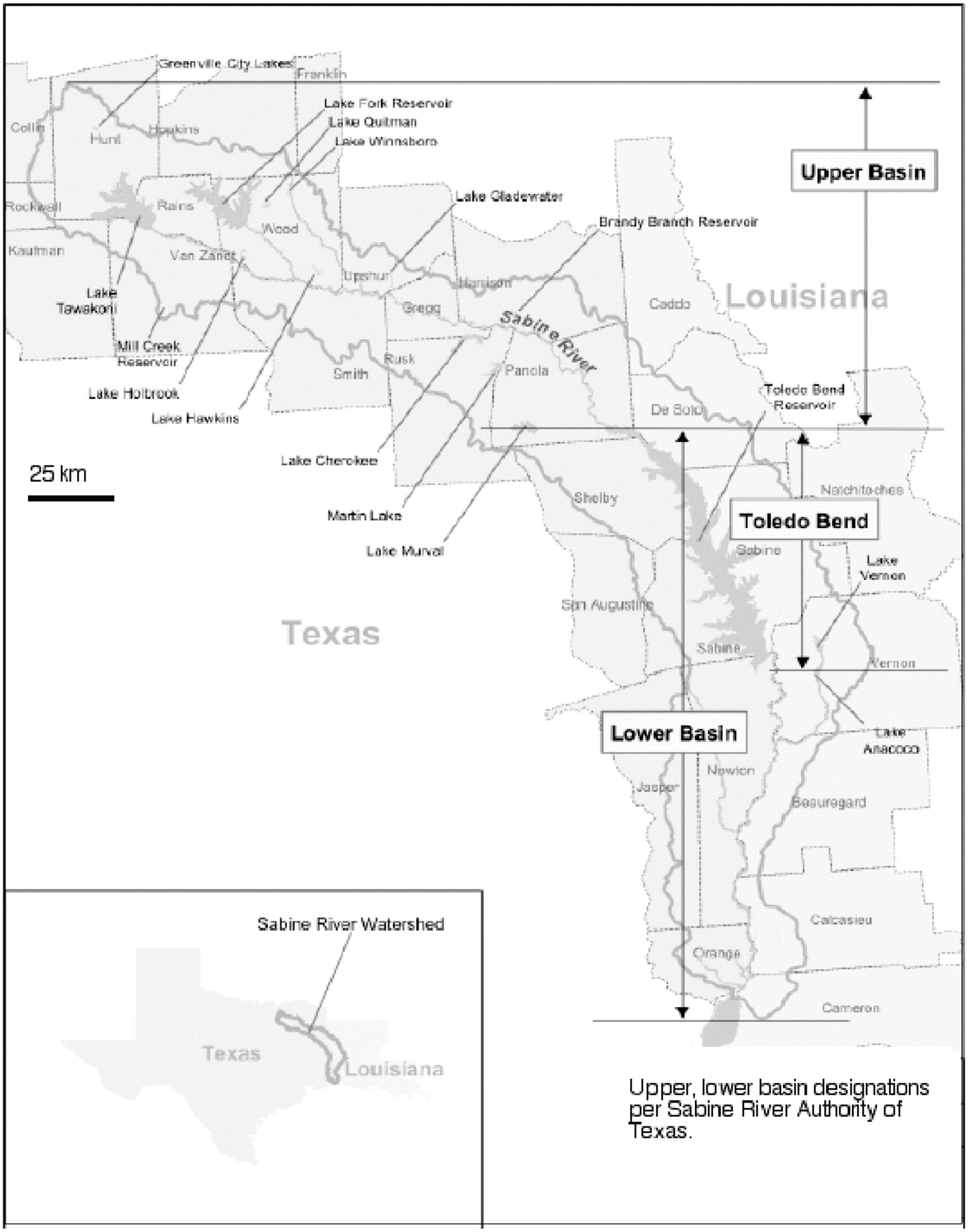

Figure 1. Sabine River drainage basin.

Toledo Bend reservoir, completed in 1967, has a surface area of about 735 km^2 and a capacity of > 5.5×10^9 m^3 at normal water levels. Toledo Bend is the largest and lowermost impoundment on the river. The primary purpose is hydropower generation, and it is not designed or operated as a flood control reservoir. Though a small constant flow-through release is maintained via a spillway, dam releases are highly pulsed in conjunction with power generation.

Channel and Valley Geomorphology

The lower Sabine is an active alluvial river. A scour zone exists downstream of the dam spillway, as is typical in such situations, with evidence of both post-dam channel widening and incision. However, the erosional effects of the dam are greatly diminished more than 24 km downstream of the dam (Phillips 2003; Phillips and Musselman 2003).

For more than 100 km downstream of the dam, the Sabine channel is a single-thread meandering channel with large, sandy point bars. Morphology, vegetation indicators, and historical comparisons all indicate a highly active channel (Phillips 2003; 2008a). Dominant forms of activity include point bar accretion and cutbank erosion, downstream migration of meanders, and other forms of lateral channel migration. Further downstream of Toledo Bend, sandy point bars are generally smaller, but the general indications of channel activity are the same. The numerous oxbows, meander scars, and sloughs on the floodplain indicate that the Sabine has been an active, meandering river throughout historical and Holocene times.

In the vicinity of Sudduth Bluff and the junction of Nicholls Creek (figure 2), the Sabine takes on a different character, with a wider floodplain, and a transition from a dominantly convergent to a dominantly divergent network. Rather than tributaries which normally flow into to the Sabine, connecting waterways are dominantly distributaries to which the Sabine contributes water (particularly at higher flows), or streams which may function as tributaries or distributaries, directing flow to or away from the main river channel. Major tributary mouths are also embayed.

The Sabine from Nicholls Creek to the Cutoff Bayou is, like the channel upstream, an actively meandering channel, with abundant field and aerial photographic evidence of recent point bar accretion and cutbank erosion, as well as point bar migration. Numerous oxbows and meander scars again testify to the historical and Holocene activity of the channel (Phillips 2003, 2008a). Unlike the upstream reaches, however, during flood events a number of distributary, yazoo, and tie channels are activated to convey the water downstream.

The junction of the Sabine River and Cutoff Bayou is about 180 km downstream of Toledo Bend. The majority of the flow (about 50 to nearly 80 percent, according to measurements from the Sabine River Authority of Texas) is diverted to the east toward the Old River channel. The Old River and Sabine channels are relatively stable in the sense of lacking evidence of recent erosion, infilling, or migration, with the exception of the Sabine in the vicinity of Jackson cutoff, where several oxbows occur. However, this reach of the valley is essentially an anastamosing system characterized by a dominant

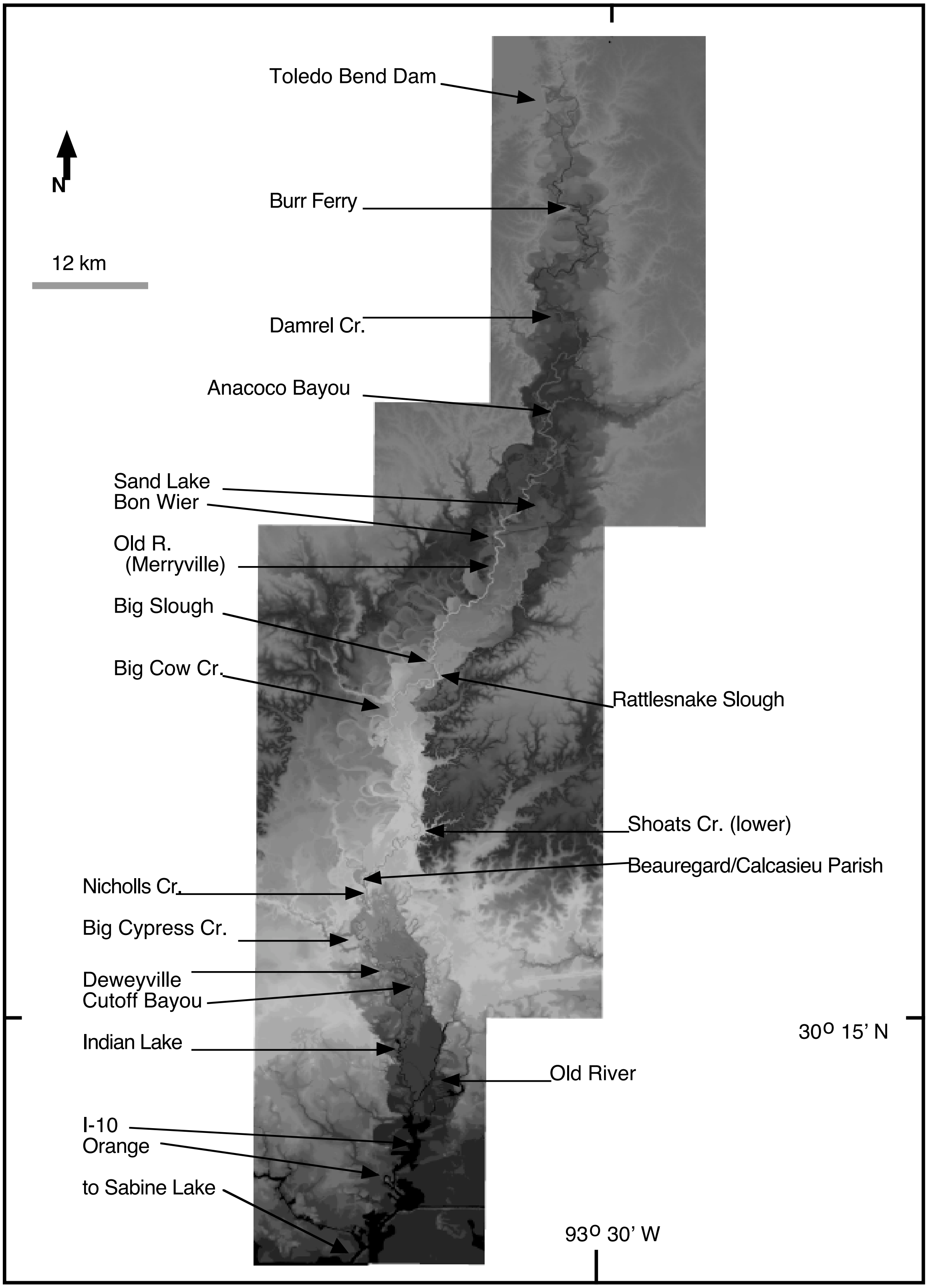

Figure 2. Study area, showing locations referred to in the text. Base map is is density plot derived from 30-m DEM data.

channel (Old River) but with several active subchannels. These systems are typically characterized by changes in the relative importance of subchannels, as the latter gain or lose flow in response to erosion or sedimentation during flood events. The avulsion regime of the Sabine and other rivers of southeast Texas is discussed in detail by Phillips (2008b).

In the vicinity of West Bluff (about 30 km upstream of Sabine Lake) the Old River and Sabine channels rejoin. From here, past Orange to Sabine Lake, the river is a low-gradient, meandering, tidally-influenced stream with an active channel.

Late Pleistocene and Holocene Context

The modern Sabine River valley is incised into the Pleistocene Beaumont formation (correlative with the Prairie Formation in Louisiana). Between the Beaumont surface which makes up the valley margins of much of the lower Sabine valley, and often merging into the modern floodplain, are a series of up to three alluvial terraces. These are usually referred to as Deweyville, though they are not now generally believed to be part of a single terrace system (Blum et al. 1995; Morton et al. 1996). In most locations two or three separate Deweyville surfaces are recognized. In Louisiana the Deweyville formations are divided into three alloformations--the Fredonia, Sandjack, and Merryville (youngest to oldest; Heinrich et al., 2002; Snead et al., 2002).

The lowermost Deweyville surfaces are only slightly higher than the modern floodplain, and in some cases are buried by the latter, with natural levees of the modern floodplain higher than backswamps of the lower Deweyville (Alford and Holmes 1985; Blum et al. 1995; Rodriguez et al. 2005). Aerial photographs show obvious paleomeanders in the Sabine Valley, expressed as swampy depressions or meander scrolls. These occur on the Deweyville surfaces, sometimes cut laterally into the Beaumont, with radii of curvature and amplitudes suggesting significantly larger paleodischarges than at present (Alford and Holmes 1985; Blum et al. 1995).

Alford and Holmes (1985) date the Deweyville terraces of the lower Sabine valley at 4 to 9 Ka. Otvos' (2005: 102) chronology indicates entrenchment of the Sabine from about 100 to 50 Ka, and aggradation, producing two terraces, from 40 to 20 Ka. These were followed by entrenchment from 20 to 18 Ka and aggradation from 18 to 2 Ka (Otvos 2005: 102). The Sabine, Neches, and Trinity River systems were connected during lower sea level stands on what is now the continental shelf, and Thomas et al. (1994) date the oldest incision of the Trinity-Sabine system at about 110 Ka. Other studies are consistent in placing the incision within a 75-115 ka time frame (Blum et al. 1995; Otvos, 2005). Multiple episodes of lateral channel migration, degradation, and aggradation occurred within those incised valleys during isotope stages 4, 3, and 2 glacials as channels graded to shorelines further out on the current continental shelf (Blum et al. 1995; Morton et al. 1996; Rodriguez et al., 2005).

Hydrology

Runoff and discharge in the lower Sabine River is influenced by the climate and hydrologic response of the drainage basin, releases from Toledo Bend Reservoir, water withdrawals, and tidal and coastal backwater effects (e.g., temporary ponding or upstream flow). The hydrologic framework is described in more detail in an earlier report (Phillips and Slattery, 2007a), from which this section is condensed.

Toledo Bend Reservoir has a controlled storage capacity of 5.522 km^3 (4,477,000 acre-feet). The primary purposes are water supply, hydroelectric power generation, and recreation. The dam is not operated to perform flood control functions. The SRA of Texas estimates a dependable water yield of 7.07 million cubic meters per day (818 m^3 sec^{-1}). The design flow of the Toledo Bend spillway is 8,212 m^3 sec^{-1} (290,000 cfs). A minimum constant flow of about 5.7 m^3 sec^{-1} (200 cfs) is maintained via the spillway, but most of the flow is passed through the hydroelectric turbines. Maximum recorded release was 3,239.5 m^3 sec^{-1}, and a typical flow during turbine operation is 200 to 300 m^3 sec^{-1}.

The SRA of Texas operates an intake canal on one of the distributary channels of the lower Sabine between Deweyville and Orange. The Gulf Coast Canal system has a capacity of about 16 m^3 sec^{-1}. This maximum capacity represents about 12.5 percent of median and 6.7 percent of mean flow at the Deweyville gage.

Some diversions occur on the Louisiana side, but no data on these could be obtained. The Texas Water Development Board conducted inflow and water balance studies for the Sabine Lake (Sabine/Neches) estuary, which includes both the Sabine and Neches Rivers and some small coastal basins. The known or estimated total diversions relative to inflow (gaged river flows plus model estimates of ungaged areas) is shown in figure 3. The 1941-2005 trends in diversions as a percent of the mean, shown in Figure 4, show obvious seasonal patterns associated primarily with agricultural irrigation. Significant diversions between Toledo Bend and Sabine Lake occur only downstream of Cutoff Bayou on both the Texas and Louisiana sides. Hydrologic influences on the lower Sabine are summarized in Table 1.

Table 1. Influences on the hydrologic regime of the lower Sabine. See next section for definition of reaches/river styles.

Hydrologic Influence	River Style (reach)
Local runoff, precipitation, tributary inputs	1,2,3,4,5,6
Dam releases	1,2,3
Backwater effects	4,5,6
Tidal influence	5,6
Water diversions	6

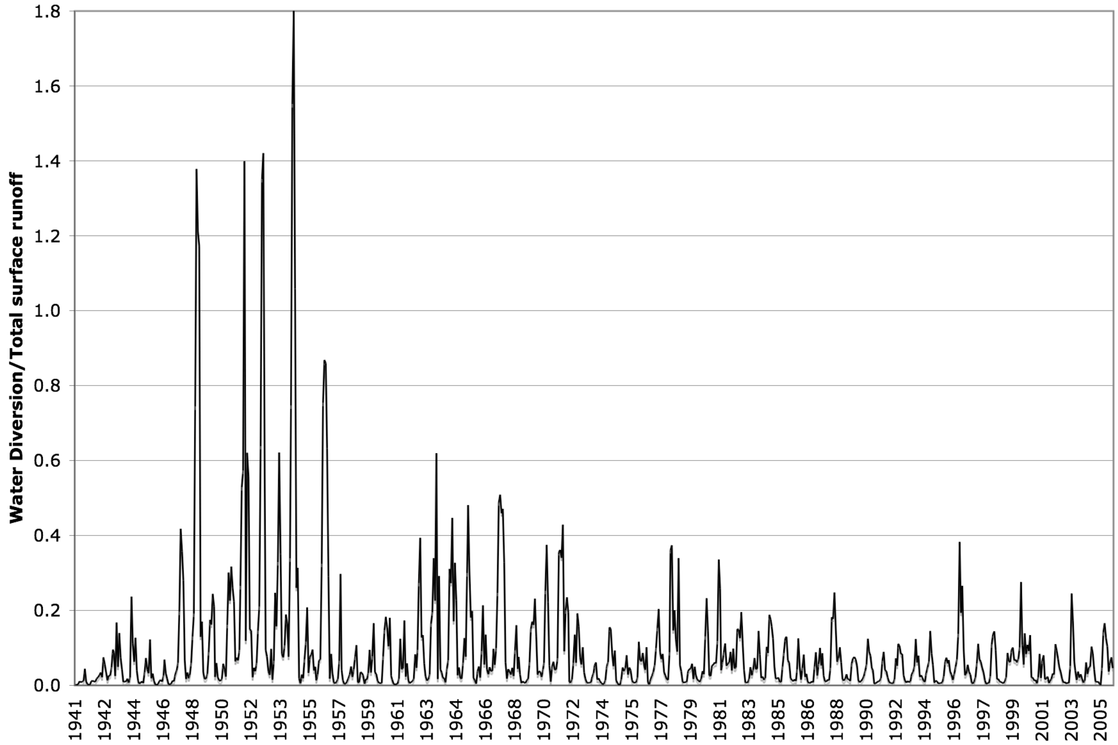

Figure 3. Water diversions for the Sabine/Neches estuary as a proportion of total surface runoff. Based on monthly model calculations of the Texas Water Development Board (http://hyper20.twdb.state.tx.us/data/bays_estuaries/hydrologypage.html)

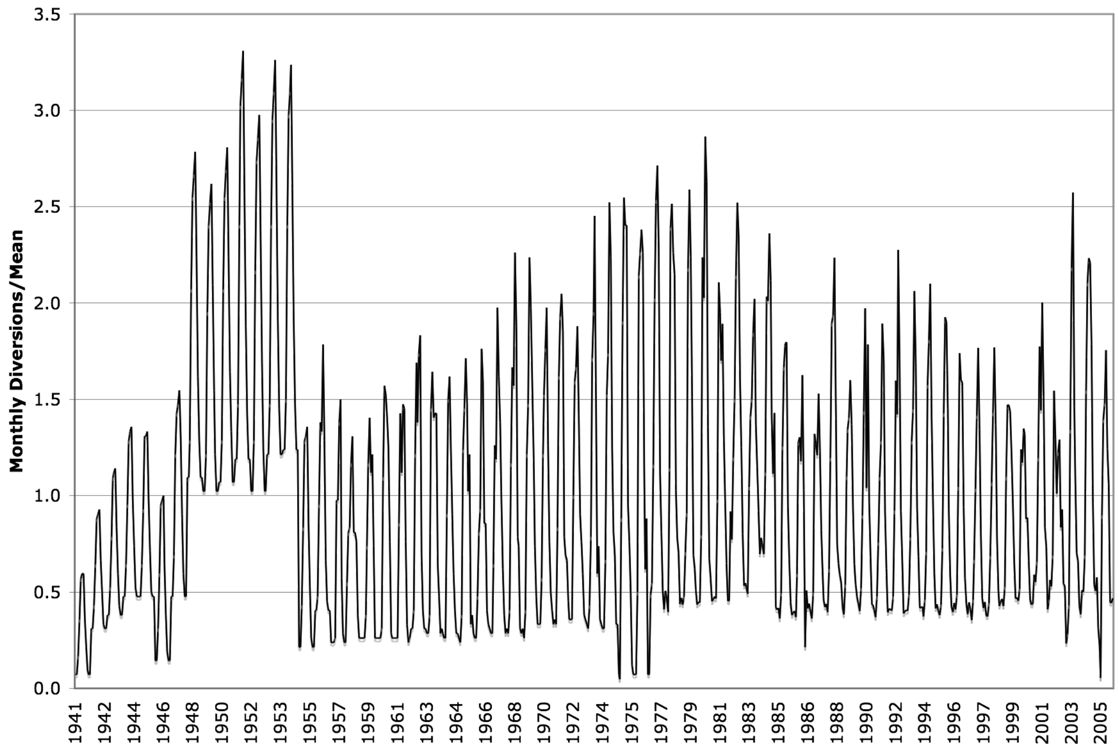

Figure 4. Water diversions for the Sabine/Neches estuary as a proportion of the mean monthly diversion. Seasonal patterns are readily apparent. Based on monthly model calculations of the Texas Water Development Board (http://hyper20.twdb.state.tx.us/data/bays_estuaries/hydrologypage.html).

The Sabine River supplies about 46 percent of the freshwater inflow to Sabine Lake (TCB, 2006). Calculations based on data presented by TCB (2006) show that mean flows at Beckville, upstream of Toledo Bend reservoir, account for about 30 percent of the total outflow of the river. Discharge at Toledo Bend dam represents about 64.5 percent of the flow, with the area beween Beckville and the dam contributing about 34.5 percent. The Sabine at Deweyville, about 47 km upstream of the mouth, discharges nearly 95 percent of the total flow, with the basin between Toledo Bend and Deweyville contributing about 30 percent of that. The area downstream of Deweyville contributes about 5 percent of the river outflow estimated by TCB (2006).

Mean and median flows and the one and ten percent probability flows increase as expected downstream from Burkeville to Bon Wier to Deweyville (see figure 2). The flood stage discharges, however, and thus the recurrence interval of overbank flow, decline. Flood stage at Burkeville is 1,880 $m^3 sec^{-1}$. The probability of mean daily flow exceeding that value is only about 0.1 percent, with a recurrence interval of 2.75 years. At Bon Wier, flood stage is less than half that, with mean daily flows exceeding flood stage about 3 percent of the time. Deweyville flood stage is lower still (510 $m^3 sec^{-1}$), with a 13 percent probability.

The hydrologic and geomorphic implications are that as one proceeds further downstream, overbank flow occurs more often, and channel-floodplain connectivity is greater. Further, cross-sectional stream power (the produce of discharge, slope, and specific weight of water) for a given discharge is lower at overbank flow levels, and this plus the floodplain inundation reduces sediment transport capacity and increases alluvial deposition opportunities. These trends are not unusual for the lower reaches of low-gradient coastal plain rivers (Phillips and Slattery, 2006; 2007b).

Previous studies have suggested that releases from Toledo Bend Dam have not significantly changed the discharge regime at Deweyville or inputs into Sabine Lake (Solis et al., 1994; Phillips, 2003; TCB, 2006), and that peak flows and mean flows have been minimally influenced. However, dam releases do clearly influence flows on hourly and daily time scales, and the seasonality of flow. Dam release effects on hydrology diminish downstream from Toledo Bend, and vary inversely with discharge.

Diurnal tidal ranges in the northern Gulf of Mexico are small—generally less than 0.6 m, and in the Sabine are further filtered by Sabine Lake. Nevertheless, the Sabine River channel is cut to below sea level upstream of Deweyville (where the gage datum is -1.8 masl), to at least Big Cypress and perhaps Nicholls Creek. The tidal signal in the discharge record at Deweyville is barely discernible as a subtle "sawtooth" pattern superimposed on the discharge and stage record.

GEOMORPHOLOGICAL ZONATION AND RIVER STYLES

In earlier work (Phillips and Slattery, 2007a; Phillips, 2008a) a geomorphological zonation was developed for the lower Sabine. Boundaries were delineated based on surficial geology, valley width, valley confinement, network characteristics (divergent vs. convergent), sinuousity, slope, paleomeanders, and point bars. The coincidence of multiple boundaries revealed five key transition zones separating six reaches of distinct hydrological and geomorphological characteristics. Geologic controls and gross valley morphology play a major role as geomorphic controls, as does an upstream-to-downstream gradient in the importance of pulsed dam releases, and a down- to upstream gradient in coastal backwater effects. Geomorphic history, both in the sense of the legacy of Quaternary sea level changes, and the effects of specific events such as avulsions and captures, are also critical. The transition zones delineate reaches with distinct hydrological characteristics in terms of the relative importance of dam releases and coastal backwater effects, single vs. multi-channel flow patterns, frequency of overbank flow, and channel-floodplain connectivity. The transitional areas also represent sensitive zones which can be expected to be bellwethers in terms of responses to future environmental changes.

A schematic diagram of the boundaries associated with geology, valley confinement, network geometry, slope, paleomeanders, and point bars is shown in Figure 5. Some obvious critical transition points are evident at 47 and 71 km where four different boundaries coincide. At 79 km three different boundaries coincide.

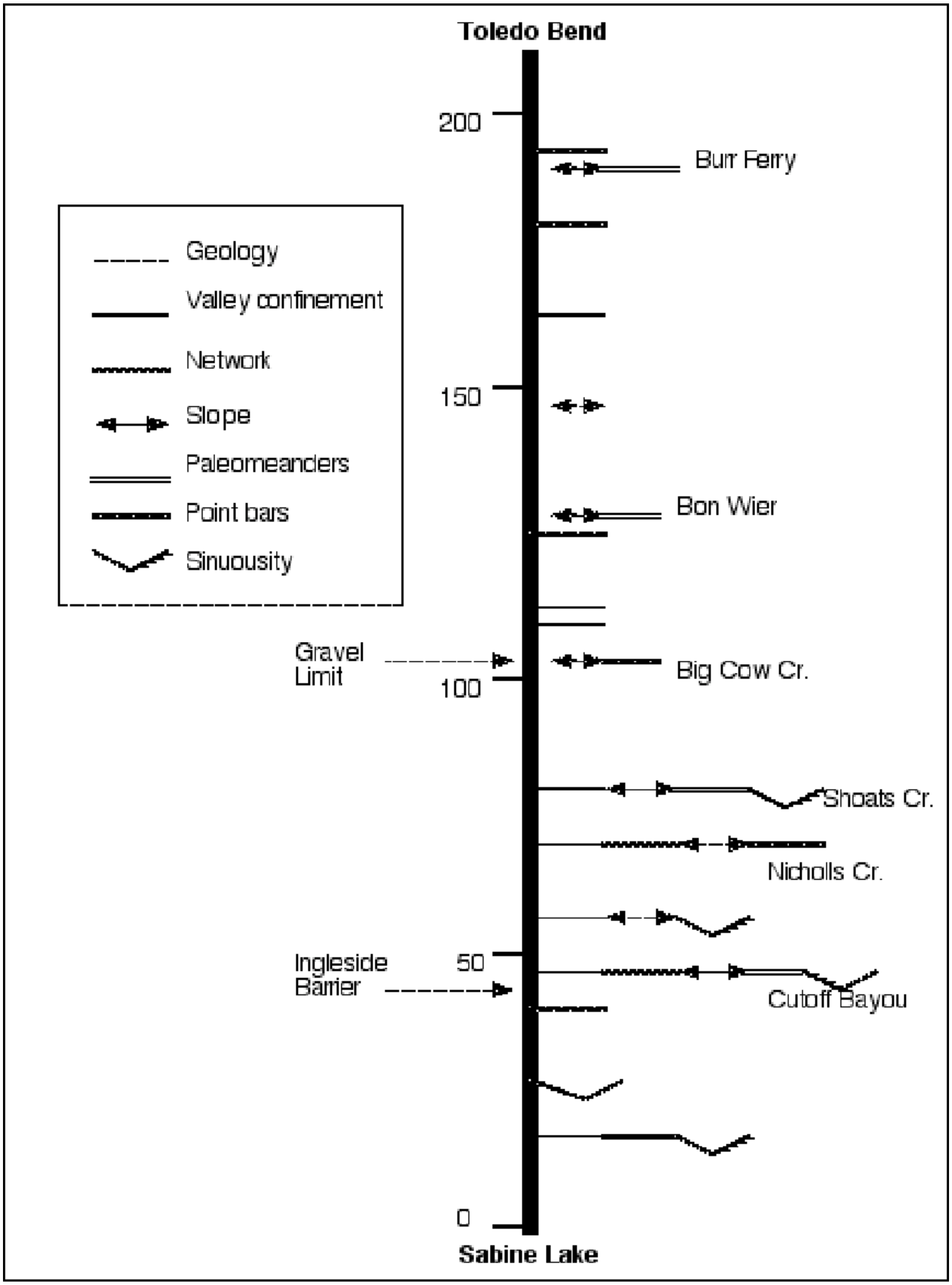

Figure 5. Schematic diagram of upstream/downstream river zonation based on various criteria. The locations of the downstream limit of Deweyville gravel deposits on point bars, and the intersection of the river channel and trend of the Pleistocene Ingleside barrer are also shown. Approximate distances (km) upstream of Sabine Lake are shown to the left. From Phillips and Slattery (2007a).

From Toledo Bend Dam to Burr Ferry (highway 63 crossing, and site of the Burkeville gaging station), the channel is characterized by a pronounced scour zone immediately downstream of the dam, and a generally incising regime throughout. Deweyville terrace deposits are being mobilized by lateral channel migration. The reach is relatively steep, with few point bars. Sediment loads are low due to trapping of sediment in Toledo Bend reservoir, and flows are highly pulsed due to dam releases. Bedrock control of the channel bed is evident in some locations, indicating limits on incision, and a valley constriction exists at the lower end. The primary controls on this reach are thus the geologic framework, and the operation of Toledo Bend Reservoir.

In the reach from Burr Ferry to the transition zone in the vicinity of Bon Wier, active lateral channel migration is dominant, characterized by large, active point bars and cut banks. The valley is generally wider than upstream, resulting in multiple generations of paleomeander scars being evident. An apparent avulsion near the lower end of the reach marks a transition in network geometry and floodplain-channel connectivity, with increased connectivity downstream of this reach.

From the Bon Wier vicinity to Big Cow Creek many aspects of the river are similar to those upstream, but with increased hydraulic connection between the Sabine River and former river channels now present as sloughs, yazoos, or oxbows. The number of paleomeander scars increases from two to three, and slope is less than that of the upstream and downstream reaches. Valley width and the avulsion site at the upstream end of the reach are important controls, along with neotectonics (a fault) at the lower end.

In the next major reach, from Big Cow to Shoat's Creek, slope increases, and the number and size of point bars declines. Gravels derived from Deweyville deposits disappear from point bars. The increased flow from Big Cow Creek is a significant control, as is apparent neotectonic activity on the upper end and coastal plain paleogeography at the lower end.

The reach from Shoats Creek Lower (and Devil's Pocket) to Cutoff Bayou marks a significant change in valley confinement associated with a geological boundary, which is in turn associated with coastal plain paleogeography (a Pleistocene shoreline). Sinuousity is significantly higher than upstream, and within this reach multiple high flow distributary channels become prominent. The increased sinuousity, apparent burial of one generation of paleomeander scars, increasing incidence of muddy rather than sandy point bars, and drowning of tributary creek mouths are all consistent with effects of Holocene sea level rise and the beginning of a fluvial/deltaic/coastal transition zone. In addition, the capture and diversion away from the Sabine of the Houston River by Pleistocene fault reactivation is an important control. This reach can be subdivided on the basis of slope, which first decreases relative to upstream sections, and then increases significantly in the lower portion of the reach.

The lowermost major reach, which could be subdivided according to increasing prevalence of coastal landforms and tidal influences in the lower portion, begins at Cutoff Bayou. This is the head of the delta, and the flow network is distributary at all flows. The current network geometry and flow patterns are influenced by the Houston

River capture (see Phillips, 2008a), and flow diversions between channels have been influenced by both natural and human activity.

The major zones (reaches or river styles) are shown in Table 2, and their associated hydrologic characteristics and controls in Table 3.

Table 2. Major reaches (river styles) of the lower Sabine River. Locations are in river distance upstream of Sabine Lake in kilometers (Sabine River Authority of Texas river mileages in *italics*).

Reach	*Location*	*Distinguishing Characteristics*	*Primary Geomorphic Controls*
1 Toledo Bend to Burr Ferry	213-192 *146-131*	Incision, steep slope, bedrock control, valley constriction, low sediment loads, pulsed flows	Geologic framework; Toledo Bend Dam releases
2 Burr Ferry to Bon Wier	192-131 *131-91*	Active lateral migration, ubiquitous large point bars, wider valley, larger sediment load	Valley width; avulsion
3 Bon Wier to Big Cow Creek	131-103 *91-70*	Active lateral migration, ubiquitous large point bars, wider valley, larger sediment load; high floodplain/channel connectivity; low slope	Valley width; avulsion; neotectonics
4 Big Cow Cr. to Shoats Creek lower	103-79 *70-54*	Active lateral migration, fewer point bars, high floodplain/channel connectivity, low slope	Neotectonics; valley width; coastal plain paleogeography
5 Shoats Cr. to Cutoff Bayou	79-47 *54-29*	Few and finer-grained point bars, high floodplain/channel connectivity with multiple high flow distributary channels, high sinuousity, embayed tributary mouths	Holocene sea level rise; geology & coastal plain paleogeography; Pleistocene stream capture
6 Cutoff Bayou to Sabine Lake	47-0 *29-0*	Rare point bars; distributary flow network; very high sinuousity; deltaic; tidal influence	Holocene sea level rise; tidal and coastal influences; Pleistocene stream capture

Table 3. Hydrologic regimes in major reaches of the lower Sabine River. Coastal effects refers to influence of tides and coastal backwater effects.

Reach	Dam pulses	Channels	Overbank flow	Connectivity	Coastal Effects
1 Toledo Bend to Burr Ferry	Flow dominated by dam releases	Single channel	Rare	Low channel-floodplain connectivity	None
2 Burr Ferry to Bon Wier	Flow strongly influenced by dam releases	Single channel	Occasional	Low channel-floodplain connectivity	None
3 Bon Wier to Big Cow Creek	Flow strongly influenced by dam releases	Multiple channels at high flows	Occasional	Moderate channel-floodplain connectivity	None
4 Big Cow Cr. to Shoats Creek lower	Strong influence of dam releases at low flow	Multiple channels at high flows	Occasional	High channel-floodplain connectivity	None
5 Shoats Cr. to Cutoff Bayou	Minor influence	Multiple channels	Common	Extensive connectivity	Minor
6 Cutoff Bayou to Sabine Lake	Minor influence at low flows	Multiple distributary channels	Common	Extensive connectivity	Significant

Geomorphic zones or river styles may be characterized by distinctive suites of geomorphic units. These are described and related to the zones above in the next chapter.

Chapter 2: Geomorphic Units

INTRODUCTION

This project is conducted in the context of the *river styles* approach to the assessment and management of rivers. A detailed exposition of the river styles framework is given by Brierly and Fryirs (2005), and an application to the Brazos River, Texas by Phillips (2006; 2007).

The river styles (RS) approach is hierarchical, with the catchment (watershed or drainage basin) as the broadest unit. Within watersheds are landscape units, which in the lower Sabine translates to physiographic units of middle and lower coastal plain and deltaic/coastal units. Within landscape units are the RS themselves, defined at the reach scale. The geomorphic zones described in the previous chapter are examples. *Geomorphic units* are specific landforms within reaches, e.g. point bars, natural levees, riffle-pool sequences. Hydraulic and microhabitat units are the most detailed level in the RS scheme, comprising specific hydrological and ecological elements such as large woody debris, bedforms, aquatic vegetation, and individual flow obstructions or roughness elements.

Geomorphic units are erosional, depositional, or transportational landforms, referred to by Brierly and Fryais (2005: 26) as "the building blocks of river systems." Each GU represents a distinct form-process association. GU's are generally capable of significant change on the scale of ~1 year, but may range from ephemeral to persistent due to the episodic, threshold-dependent nature of geomorphic change.

METHODS

The entire Sabine River and Old River channels from Burr Ferry to the Interstate 10 bridge was examined by boat at various times between 2005 and 2008; some reaches on multiple occasions. In addition, much of the reach from Toledo Bend Dam to Burr Ferry was also examined by small boat, canoe, or via land access in 2000-2001 and in 2006. Sections of the river between I-10 and Sabine Lake, and of various tributaries, distributaries, sloughs, and anabranches were also examined in the field via land access and canoe.

Over most of the sections traversed by boat, continuous digital photography was taken. Field investigations included detailed field mapping of specific cross sections, and general assessments of bed substrate and bank material, bank stability and vegetation, and the geometry and bedforms at tributary junctions. Measurements of bank height and channel width at selected cross-sections were made with a laser level, and of depth with a hand-held SONAR depth finder. The activity and stability of channel features was assessed on the basis of visible bedforms, vegetation cover, and evidence of downstream encroachment, lateral growth, or erosional diminution. Bank-attached and channel features were assessed on the basis of morphology, composition, and vegetation indicators of erosion-deposition processes and hydroperiod.

Hurricane Rita struck southeast Texas/Southwest Louisiana, making landfall in the Sabine Lake area, in September, 2005. Shortly thereafter the U.S. Army Corps of Engineers produced 0.3 m (1 ft) resolution vertical color aerial photography of much of the region, including the Sabine River from upstream of Bon Wier to Sabine Lake. This imagery was particularly useful in identifying floodplain and valley GUs difficult to observe in the field at such a broad scale.

In late October, 2007 low-flow and clear-water conditions allowed an opportunity for exceptional aerial observation of channel forms. A small-plane flight from Toledo Bend Dam to Deweyville was conducted, with continuous photography of the channel using a GPS-enabled digital camera. This oblique photography was obtained from a variable altitude of <200 m (~600 ft).

From these observations the variety of landforms was inventoried and either specifically mapped or assigned to the six geomorphological zones described in Chapter 1.

RESULTS

Geomorphic units were categorized as mid-channel, bank or bank-attached, and floodplain/valley. There is inevitably some fuzziness and overlap in these distinctions—point and lateral bars, for instance, connect mid-channels and banks, while crevasse-related features transcend banks and floodplains. These distinctions are, however, a convenient tool for organizing results.

In this section a general discussion and inventory of GUs is given, while separate appendices provide photographic examples of each GU.

Channel Units

Channels themselves are landforms, but specific features within them represent specific process-form associations and/or diagnostics of fluvial processes and evolution. The channel units can be roughly categorized as thalwegs, bedrock outcrops, bars, pool-related units, and large woody debris jams. The channel GUs are shown in Table 4.

Thalweg. The thalweg is the deepest portion of the channel, defined by connecting the lowest points at any cross-section, and is often thought of as a channel within the channel. All channels contain a thalweg, by definition.

Bedrock Outcrops. Resistant exposures or outcrops of pre-Quaternary bedrock locally limit the rate of bed and bank incision or erosion, and generally indicate recent erosional removal of Quaternary alluvium. These occur only in the reach from Toledo Bend to Burr Ferry, where scour following dam construction has exposed outcrops of Miocene material, mainly sandstones of the Fleming Group. These outcrops are particularly common immediately downstream of the dam. The bedrock GUs include mid-channel, channel margin, and cross-channel features.

Table 4. Mid-channel Geomorphic Units of the Lower Sabine River and their association with zones or river styles (see Table 2). Styles in italics indicate that the GU is significantly rarer than in the other listed styles. See Appendix A for examples.

Geomorphic Unit	River Style
Thalweg	1,2,3,4,5,6
Bedrock	
Mid-channel	1
Marginal	1
Cross-channel	1
Bars	
Marginal	
Point bar (normal and breached)	
Dominantly sand	1,2,3,4,*5,6*
Dominantly mud (fine-grained)	*5*,6
Lateral bar (normal and breached)	1,2,3,*4*
Tributary mouth (normal and breached)	1,2,3,4,5,6
Diagonal	1,2,3,*4*
Forced	1,2,3,4,*5,6*
Mid-channel	
Forced	1,2,3,*4,5*
Transverse (linguoid)	1,2,3
Compound	1,2,3
Longitudinal	1,2,3
Sand sheet	2
Connector	1,2,3,*4*
Pools	
Riffle-pool sequence	1,2,3,*4*
Circular meander pool	6
Forced pool	
Downstream	1,2,3
Backwater	*1,2,3,4*,5,6
Glide (run)	1,2,3,4,5,6
Large Woody Debris Jams	1,2,3,4,5,6

Bars. Bars are treated separately in Chapter 3, and are discussed briefly below for the sake of completeness. Bars in the lower Sabine river are dominantly sandy, though some mud (fine grained) point bars occur in the lowermost reaches, and bars in reaches 1, 2, and 3 may include small amounts of gravel derived from erosion of Deweyville terrace deposits. Bars may be marginal, mid-channel, or connector type.

Point bars occur on the inside of meander bends, and are a common feature of laterally migrating meandering rivers. Point bars are dominantly lateral accretion deposits, associated with erosion of the outside (cutbank) of the bend and deposition on the inside. In general coarser materials tend to be deposited from traction bed load on the upstream end of the bar, and the finest from suspension on the distal end. Thus point bars may have gravel or coarse sand on the upstream end and mud drapes or alternating mud/sand layers are the downstream end. In the lowermost reaches (5, 6) finer-grained point bars occur. Point bars may occasionally be breached by flow along the upper edge of the bar, often by high river flows in combination with surface runoff or tributary inputs. Downstream movement of point bars is indicated by encroachment at the distal end on steep banks with tilted trees.

Lateral bars occur along banks in low-sinuousity reaches. Classic alternate-side lateral bars are rare in the Sabine, but lateral bars do occur in short relatively straight reaches between meanders. These may occasionally be breached, as with the point bars above. Lateral bars are most common in reaches 1, 2, and 3.

Tributary mouth bars are essentially deltaic features which may occur as deltas *per se* at the tributary mouth, or as spit-like bars aligned with the river channel and oriented downstream. These bars may be breached by tributary or river flow, and are associated with backwater effects on the tributary from the river.

Diagonal bars are usually bank-attached in the Sabine, but may also occur as cross-channel features. They are oriented diagonally to banks, with elongate, oval, or rhomboid planform shapes. Diagonal bars are formed where flow is oriented obliquely to the longitudinal axis of the bar, and may indicate reworking of riffles. While diagonal bars are usually associated with gravel or mixed-bed channels, those in the Sabine are predominantly sandy.

Forced bars are associated with sediment trapping behind obstructions, and may occur in mid-channel or attached to banks. All forced bars observed in the study area were associated with large woody debris.

The term transverse bar is used in a general way to refer to cross-channel bars, and in a more specific way in reference to mid-channel bars oriented perpendicular to flow and occupying most of the channel width. These are also referred to as linguoid bars. Linguoid bars are often lobate in shape and have a slip or avalanche face on the downstream end. They are often found at points of relatively abrupt flow expansion, and in the lower Sabine often occur just downstream (or at the downstream end of) flow constrictions associated with point or lateral bars. Linguoid bars are associated with diverging low with high availability of sand.

Longitudinal bars are mid-channel features oriented parallel to flow and more-or-less streamlined, often with a downstream-oriented teardrop shape. Longitudinal bars are deposited when transport capacity is exceeded by sediment supply in mid channel.

Changing flow and sediment transport conditions may lead to the formation of several generations of different types of bars in the same location. Further, downstream translation of midchannel bars may result in the welding together of various combindations of point, lateral, diagonal, linguoid, and longitudinal bars. In either case the result may be compound bars, characterized by traits of two or more of the types described above.

Sand sheets are more or less uniform tabular sand sheets occupying the entire channel. They are associated with bedload deposition where sediment supply exceeds transport capacity, and may exhibit a variety of bedforms. At low water, they may resemble braided channels with multiple intertwining subchannels. Sand sheets are readily reworked, and may be translated downstream during floods. Several sand sheets were noted in tributaries throughout reaches 1-5, but in the main river they were restricted to reach 2.

All the bar types discussed above are generally recognized in the geomorphology literature (see, e.g., Brierly and Fryirs, 2005). In the lower Sabine an additional class of bar was indentified, termed connector bars. Connector bars extend from the downstream end of a point or lateral bar to the upstream end of a point or lateral bar downstream. They are distinct from the linguoid bars that sometimes occupy the gaps between marginal bars in that they lack obvious downstream slip faces, and are oriented parallel or diagonal to flows.

Pools. Pools are sections of channel with greater depths and lower velocities than adjacent sections. They are often associated with riffle-pool sequences, characterized by shallower, higher-velocity, higher-roughness patches (riffles) alternating with pools. In the study area riffles may be associated with linguoid or connector bars or sand sheets, while pools are often associated with outer portion of meander bends. Riffle-pool sequences are most typically associated with velocity reversal, whereby at lower flows the higher velocities in riffles keep them clear of finer materials, which may accumulate in pools. At higher flows, velocity increases faster in pools than riffles, and a relative velocity reversal occurs. Thus material entrained from riffles is transported through pools, maintaining the sequence. This phenomenon is described in more detail in any fluvial geomorphology text (e.g. Knighton, 1998; Brierly and Fryirs, 2005). A glide or run is a plane-bed section of channel which is neither pool nor riffle, associated with an approximate balance between transport capacity and sediment supply.

Forced pools are associated with flow obstructions—in the study area, often large woody debris. These units may be scour features downstream of resistant bedrock outcrops or large debris pieces, or backwater pools from ponding behind these obstructions. Backwater forced pools are also found immediately downstream of some point bars.

Circular meander pools were first recognized in the Houston River (Calcasieu Parish, LA), by Alford et al. (1982), who also found evidence for their occurrence in some other southeastern rivers. These pools are, in planform, approximately circular enlargements at the apices of tight meander bends. They are also characterized by unusually high depths, more so than normal meander pools—as much as three times the maximum depth of adjacent sections. Because the Houston River was apparently once a Sabine River tributary (Phillips 2008a), the possibility of these features in the study area was investigated. Though they had not specifically investigated these features, SRA-Texas field personnel indicated they encountered unusually deep holes at some meander apices in the tidal portion of the river. At least one circular meander pools is at Blue

Elbow bend, where maximum depths of nearly 20 m are thee times that of upstream sections. Aerial photography suggests other possible occurrences in reach 6.

Alford et al. (1982) found circular meander pools on very tight bends on low gradient rivers with large backswamp areas, and suggested that the pools are formed by counter-currents developed during high flow. Andrle's (1994) study of circular meander pools elsewhere also noted large countercurrents occupying about half the pool, on the outside of bends. He also noted an association with cohesive banks which slow channel migration and inhibit cutoffs.

Large woody debris (LWD; logs, trees, large limbs) is generally considered as hydraulic or microhabitat units rather than a geomorphic unit. However, significant LWD accumulations (jams), as opposed to individual pieces of wood, represent form/process interactions and are thus legitimate GUs. Beyond the importance of LWD for aquatic habitat and river ecology, LWD jams may play a role in avulsions (Phillips, 2008b), influence channel hydraulics, and are indicative of hydrodynamic conditions. The largest LWD jams occur in tributary mouths, where they may pond or deflect tributary inflow, and reflect backwater flooding and recirculating eddies at high flows, where floating wood is deposited as flows recede. The second largest class of LWD jams occurs along eroding river banks, where rapid recruitment of toppled trees, coupled with entanglement of floating debris, creates the jams. Mid-channel LWD jams are associated with entanglement of LWD with large trees embedded in the bed. These are both smaller and less frequent than the tributary mouth or bank jams.

Bank-Attached Units

Bank-attached geomorphic units (Table 5) include the channel banks themselves, and significant subunits along the banks. Geomorphic units that lie partly within the channel (such as marginal bars) are treated in the section on mid-channel units, while GUs connecting the banks and floodplain (such as natural levees and crevasses) are covered under floodplain/valley units.

Benches and Ledges. Benches and ledges are low-relief shelf-like features along channel banks and margins. These features are sometimes termed channel shelves, particularly when no inference about their origins are drawn.

Benches are depositional features related to infilling that may be associated with lateral channel migration where they occur on only one side of the channel, or with channel narrowing where they occur on both sides. They are composed of the same general type of sediments normally comprising the channel bed, bars, and banks, which is typically sand in the Sabine. Buried or partially buried vegetation or organic layers, sedimentary stratification, and other typical indicators of deposition are often present.

Ledges are morphologically similar, but are erosional features. Bank erosion may encounter resistant layers which retreat more slowly than less-resistant overlying layers. Ledges of this type are therefore often composed of bedrock or cohesive clays underlying sandier material. Ledges may also occur where an episode of incision cuts a narrower channel into the former channel bed. Remnants of the former bed appear as ledges inset into the channel banks. Ledges of the latter type were not observed on the Sabine, but have been documented on tributaries of the Trinity and Angelina Rivers (Phillips, 2001; Phillips et al., 2005), and may exist on some lower Sabine tributaries, particularly in reaches 1 and 2.

Table 5. Bank-attached Geomorphic Units of the Lower Sabine River and their association with zones or river styles (see Table 2). Styles in italics indicate that the GU is significantly rarer than in the other listed styles. See Appendix A for examples.

Geomorphic Unit	River Style
Bench (depositional)	3,4,5,6
Ledge (erosional)	*1*,2
Bedrock bank	1
Concave bank	1,2,3,4,5,6
Convex bank	1,2,3,4,5,6
Straight bank	1,2,3,4,5,6
Convexo-concave	1,2,3,4,5,6
Concavo-convex	1,2,3,4,5,6
Buttressed (cypress)	3,4,5,6
Slump	1,2,3,4,5,6
Slump scar	1,2,3,4,5,6
Chute channel	4
Sand rampart	2

Unconsolidated Banks. Compositionally, geomorphic units associated with sandy and muddy material reflect the variety of soils and sediments in the Sabine valley. Banks reflect a vast number of combinations of material, morphology, and vegetation cover. The units were identified here primarily on the basis of profile (bank top to channel bed) shape. The profile shape reflects the cumulative impacts of the interactions among channel and riparian hydrology, bank materials, vegetation, and slope processes.

Concave banks indicate active or recent erosion, and are often found on cutbanks. Most commonly they indicate lateral channel migration, but if they occur on both sides of the channel indicate widening. Vegetation cover is typically minimal. Convex banks are usually well vegetated, and indicate stable or accreting banks. Where convex upper banks occur with concave lower banks (convexo-concave), this may indicate a transition from a stable or accreting to an erosional state, preferential erosion of the lower bank due to lower resistance (e.g., associated with vertical variations in shear strength), the removal of protective features from the lower bank (e.g., vegetation cover or LWD), or locally higher shear stress during lower flows, perhaps due to flow deflections or accelerations. Continuation of whatever processes create this bank morphology may result in conversion to concave banks as the upper convex section is undermined. A subclass of this GU—undercut banks, where a portion of the bank overhangs and shades the water—may be of particular interest for aquatic habitats. Concavo-convex banks, with a concave upper and convex lower section, are indicative of recovering cutbanks, where active erosion and bank retreat have ceased.

Bald cypress (*Taxodium distichum*) is a common riparian and wetland tree in the lower Sabine, which can grow in saturated or flooded conditions and develops characteristic rampart-like subaerial roots called knees. The wide, buttressed cypress trunks and knees, where they occur along banks, provide a measure of erosion protection. Bald cypress is an obligate wetland plant (grows naturally only in wetlands), but cannot germinate in inundated conditions. Thus cypress growing in conditions of normally standing water indicates a local rise in water level subsequent to tree establishment, or distinct seasonal variations in water level.

Buttressed banks upstream of the delta (reaches 3,4,5) are most often associated with local channel aggradation. As the bed accretes, displacing flow upward, banks and benches with cypress become inundated, creating buttressed banks. In the delta area (reach 6) buttressed banks may be associated with seasonal water level changes (seedlings may become established during the low water period), or with gradual lateral migration of low-relief banks.

Rotational slumps may occur along eroding concave banks, where significant vertical variations in material properties due to soil strength and/or root mats results in rotational failures. Active slumps are typically characterized by one or more trees and associated understory vegetation with a root mat holding the slumped material together. Active slumps without root mats, composed of sandy material over clay failure planes, have been observed on the lower Trinity River, but were not documented on the lower Sabine during this study. Eventual removal or dispersal of the slumped material leaves a characteristic scallop-shaped slump scar.

Other Bank-Attached Units. Bedrock banks occur in reach 1, associated with the bedrock channel units, and are likewise associated with post-dam channel scour.

Chute channels are high-water channels across point bars, which may eventually lead to chute cutoffs.

Sand ramp is a termed coined in this study to describe sandy bank deposits observed in reach 2 which extend from channel to the natural levee. These are distinct from marginal bars in that the latter do not extent to the top of the banks, and from point bars in that the sand ramps are much narrower and do not occur on the inside of meander bends. Little is known of these features, but their position in the channel and the presence of organic layers within the sand suggest that they result from flow obstructions and temporary backwater effects during high flows.

Floodplain/Valley Units

Abandoned Channels. Channel shifts or relocations significantly longer than a single meander loop are called avulsions, and leave abandoned or paleochannels. In some cases both the new and old channel persist, resulting in development of an anabranch if the channels rejoin downstream, or a distributary otherwise. The latter include deltaic distributaries which terminate within the delta, and alluvial distributaries which terminate in flood basins (floodplain depressions).

The distinction among other abandoned channels depends on their age, rate of infilling, and frequency of flow. Infilled abandoned channels have accreted to nearly the level of the surrounding floodplain surface, and do not convey flow, except perhaps as part of general down-valley flow during extreme floods. Semi-active channels convey flow during high flow events (but not necessarily overbank), but are dry during low and normal flows. Billabongs are channel remnants which are not fully infilled and usually hold ponded water, but have no hydraulic connection to the main channel except during floods. The term billabong rather than slough is employed because the latter term is used to refer to a variety of different features.

Evidence of avulsions occurs throughout the study area, with the exception of reach 1. More detailed discussion of avulsions in Texas Coastal Plain rivers and their geomorphic significance is provided by Aslan and Blum (1999) and Phillips (2008b).

Table 6. Floodplain and alluvial valley Geomorphic Units of the Lower Sabine River and their association with zones or river styles (see Table 2). Styles in italics indicate that the GU is significantly rarer than in the other listed styles. See Appendix A for examples.

Geomorphic Unit	River Style
Abandoned channel (infilled)	2,3,4,5,6
Abandoned channel (semi-active, high flow)	2,3,4,5,6
Anabranch	5,6
Delta distributary	5,6
Alluvial distributary	3,4
Billabong (slough)	2,3,4,5,6
Low-flow tributary/high-flow distributary or anabranch	3,4
Tie (batture) channel	2,3
Alluvial/colluvial fans or wedges (valley wall)	1,2,3,4,5,6
Backswamp, ridge-and-swale	1,2,3,4,5
Backswamp, flat	4,5,6
Pleistocene meander scars/depressions	1,2,3,4,5
Cutoff meander	3,4,5
Oxbow lakes or swamp	1,2,3,4,5,6
Infilled oxbow	1,2,3,4,5,6
Crevasse splay	1,2,3,4,5,6
Crevasse channel	2,3,4
Natural levee	1,2,3,4,5,6
Island	5,6
Tributary	1,2,3,4,5,6
Alluvial terrace	1,2,3,4,5,6

Cutoffs and Oxbows. Cutoff meanders as listed in Table 6 refers to recently cut off features which are still within a few channel widths of the (new) active channel. Older cutoffs (oxbows) occur in various states of infilling—oxbow lakes, swamps, and infilled oxbows. This depends partly on local sediment dynamics, but mainly reflects the age or time since the cutoff occurred. In some cases tie channels (or batture channels) connect oxbows or billabongs to the river. These channels may alternately drain or fill the floodplain features, depending on hydraulic conditions.

Meander cutoffs (as well as meander growth indicated by active point bars and cutbanks) are common and expected features in alluvial rivers such as the Sabine, and occur throughout the study area.

Levees and Crevasses. Natural levees are ridges just above the bank tops, at the outer edge of the floodplain. They form due to localized sediment deposition when flows go overbank. Natural levees are an expected feature along alluvial rivers, and occur throughout the study area.

Breaches of the levee from the river side are crevasses. Where flows diverge on the floodplain side of the levee, flow decelerates rapidly and sediment is deposited in fan-like deposits called crevasse splays. Splays are undoubtedly present in the lower Sabine, but none were documented in this study. Crevasse splays cannot be observed from aerial photography in forested environments, and the lower Sabine floodplain is almost entirely forested. Because of rapid vegetation establishment and litter coverage, splays are also difficult to observe in the field in forested settings unless they were recently deposited.

When crevasses lead to concentrated flow and channels are incised, crevasse channels result. Larger, persistent crevasse channels result in avulsions (see abandoned channels above). Because crevasse channels slope away from the natural levee, they are important for channel-floodplain hydrologic connectivity during floods. These channels may locally reduce the likelihood of levee breaches nearby, but may represent future potential avulsion sites if cross-valley slope advantages exist and aggradation is occurring within the river channel (see Jerolmack and Mohrig, 2007; Phillips, 2008b).

Floodplain Depressions. Alluvial floodplain evolution may result in depressional areas in the valley bottom other than oxbows, billabongs, and abandoned channels. Backswamp is a general term for lower areas behind the natural levee, but more specific backswamp features are associated with ridge-and-swale topography. The latter results from lateral channel migration, with former natural levees appearing as slightly higher ridges separated by intervening linear swales. These features create local variations in hydroperiod, water tables, and soil moisture which are important in vegetation and other ecological patterning on the floodplain. Backswamps in general occur throughout the study area. Reaches 1-3 are dominated by ridge-and-swale topography, and reach 6 by generally lower-elevation flat backswamps with few ridges. Reaches 4-5 are transitional, and include both general types of backswamp.

Rivers of the southeast Texas coastal plain experienced higher mean discharges during the Pleistocene, with larger channels and meanders with substantially larger amplitudes and wavelengths than the contemporary rivers. In the Brazos and Colorado Rivers these have largely been buried by subsequent valley aggradation, but their legacy is sometimes evident in large scallops in the valley wall which represent former cutbanks of the paleochannel. In the Trinity-Neches-Sabine system these "Deweyville" paleomeander features are quite common. They occur as large depressions, evident from aerial and satellite images due to their distinctive topography, hydrology, soil, and vegetation patterns. These paleomeander depressions, beyond being significant landforms and habitats in their own right, exert important influences on local water flows, routing and distribution of flood waters, and contemporary geomorphic evolution of the fluvial system (Blum et al. 1995; Morton et al., 1996; Blum and Aslan, 2006; Sylvia and Galloway, 2006; Phillips and Slattery, 2007b, 2008; Phillips, 2008a, 2008b).

The paleomeander depressions occur throughout the study area, though in the delta (reach 6) they are evident only on the valley margins due to burial by Holocene sedimentation. Three separate generations of paleomeanders can be found within the lower Sabine valley, but not all are evident in every reach, as described by Phillips (2008a).

Other Valley Features. Remnants of previous floodplain levels—alluvial terraces—occur throughout the lower Sabine valley, except in the delta where these features are buried. These are generally referred to as "Deweyville" terraces, though at three separate generations or alloformations are recognized. One to three terrace surfaces are evident at various points along the valley, roughly coincident with the generations of paleomeander features exposed, as outlined by Phillips (2008a). The terraces are slightly higher and relatively drier components of the valley, except in the case of the youngest and lowest terraces, which may be only slightly higher than, or at the same elevation as, the modern floodplain.

Tributary channels occur throughout the study area. Valley-wall colluvial and alluvial sediment accumulations (fans or wedges) are also no doubt common, but difficult to identify in forested environments for the same reasons as crevasse splays.

Islands are semi-stable, vegetated land surfaces in anabranching reaches of the Sabine and its tributaries which are not inundated except during floods. These occur in the delta (reach 6), in conjunction with the multiple high flow channels in reach 5, and in some larger tributaries in reach 5.

RELATIONSHIPS WITH INSTREAM FLOWS

The geomorphic units of the lower Sabine River valley occur at various elevations from the lowest points of the river channel to the margins of the valley. Accordingly, the GUs are inundated at various flow levels, which in turn influences their hydrologic functions, habitat characteristics, and rates and frequency of geomorphic change.

Five fundamental instream flow levels can be identified from a hydrogeomorphic perspective. The lowest, *thalweg connectivity,* is the minimum amount of discharge required to maintain continuous downstream water movement. *Bed inundation* is the flow level at which the entire channel bed is underwater and all mid-channel features are at least partially inundated. The *sub-bankfull* level is the higher range of flows which can occur before overbank flow begins to occur. *Channel-floodplain connectivity* flows are those which result in river-to-floodplain flow via crevasse and tie channels, high-flow distributaries and anabranches, and tributary backwater flooding. Depending on local channel and levee morphology, this may occur at sub-bankfull levels. *Flood* flows are defined in this sense as those which result in levee overtopping.

Table 7 below relates these flow levels to the geomorphic units which become inundated.

Table 7. Inundation of geomorphic units (see tables 4-6) at various instream flow levels.

Thalweg Connectivity
Thalweg
Pools
Bed Inundation
All channel units except upper portions of marginal bars
Sub-Bankfull
All channel units
All bank-attached units
Channel-Floodplain Connectivity
Semi-active abandoned channels
Anabranches
Distributaries
Low-flow trib/high-flow distributaries/anabranches
Tie channels
Flood
All units except terraces and valley-wall fans (minor to moderate flood)
All units (major flood)

Chapter 3: Transverse Bars

BACKGROUND

Field research in the lower Sabine River prior to this project noted the presence of a number of cross-channel or transverse bars. These bars, in addition to being significant geomorphic and hydraulic units, are also likely to be significant as aquatic habitat. Even more than the geomorphic units described in Chapter 2 (except for perhaps some pools), bars are transitory features with respect to location, size, and their very existence. Bars and associated features such as pools and bedforms may appear, disappear, and undergo modifications in response to individual flow events, season flow patterns, and over longer time scales.

Mobile-bed streams, particularly sand-bed rivers such as the lower Sabine, may exhibit a hierarchy of bed forms, ranging from highly transient, centimeter-scale ripples to bars which occupy the majority of the channel, and which may be relatively persistent. In the Sabine and other sandy rivers it is not unusual to have three hierarchical levels of bed forms at a single site, with ripples superimposed on dunes or lobes which are in turn superimposed on bars.

The term "transverse" is used in a general sense to refer to bars which extend across, or nearly across, the entire channel width. The term is also sometimes used to refer to a specific type of transverse bar which is also called a linguoid bar. In this report the term "transverse bar," without modification, should be understood in the general sense.

Some observations from TWDB field work indicated that transverse bars occurred in association with, but downstream of, the apex of sandy point bars. This, combined with the morphology and apparent evolution of meander bends on the Sabine River, led to the hypothesis that the transverse bars are related to downstream migration of meander bends. If the rate of movement of point bars exceeds the overall rate of downstream migration of the meander bend, it was hypothesized, then the extensions of the point bar into the channel (i.e., the transverse bar) should occur downstream of the bend apex. The reasoning was that the sandy bars are mobilized at lower shear stresses than those required for bank erosion, and thus bar mobility occurs more often than cutbank erosion, which is required for migration of the meander as a whole. As indicated below, this hypothesis was abandoned early in the project, and this portion of the study was reoriented toward a general study of the occurrence and geomorphic interpretation of cross-channel bars.

Meander Translation Hypothesis

Field measurements of shear strength of sandy point bars and adjacent bank material were made in October, 2007. Vertical shear strength was measured with a hand-held penetrometer, and horizontal shear strength with a shear vane apparatus. Each sample site was 0.35 m^2 in area, and 10 readings were taken with each instrument and averaged. Bar measurements were taken on lower, wet sand areas.

As expected, shear strength of bank materials was significantly higher than that of bars, due to greater cohesion and plant root binding. Vertical shear strength for the bars was uniformly <1 kg cm^{-2}, with mean values for specific sites ranging from 0.51 to 0.68. Bank materials had vertical shear strength values significantly higher (182 to 286 percent greater), with mean values ranging from 1.24 kg cm^{-2} for sandy banks to 1.46 in finer, more cohesive material. Horizontal shear strength as indicated by shear vane tests showed the same general trends, ranging from 162 percent higher in sandy bank materials than on the bars, to 328 percent greater for cohesive banks.

However, both river-level (on foot and by boat) and aerial observations indicated that:

(1) A variety of cross-channel bars exist in the lower Sabine River.

(2) Most of the transverse bars have no apparent direct relationship to downstream meander translation.

(3) Few, if any of the transverse bars exhibited morphology and geometry associated with the hypothesis.

Therefore it was determined that even if the hypothesis that point bars move more rapidly than other portions of meander forms during downstream translation is true, this is not an adequate explanation of transverse bars in the lower Sabine River.

METHODS

Several reaches of the lower Sabine were traversed by boat or accessed via land in October, 2007 to examine transverse bars. A total of 34 bars were examined in the field, in the general vicinities of Burr Ferry, Harvey Creek, Red Bank Creek, Anacoco Bayou, Palmer Lake, Bon Wier, Deweyville, Cutoff Bayou, and Indian Bayou. The upstream terminus was mapped using a GPS receiver. The orientation of the bar, and of the channel, was determined by compass azimuth. An *ad hoc* classification or description was derived in the field, for later refinement.

On 31 October, 2007 low-flow and clear-water conditions allowed an opportunity for exceptional aerial observation of channel forms. A small-plane flight from Toledo Bend Dam to Deweyville was conducted, with continuous photography of the channel using two digital cameras, one of which was GPS-enabled. This oblique photography was obtained from a variable altitude of <200 m (~600 ft).

A classification of bar types was developed, based on Brierly and Fryirs (2005, p. 86-97), with some expansion for bar types observed in the Sabine which did not fit in the Brierley/Fryirs typology. The aerial photography was then used to classify the bars from Toledo Bend to Deweyville to determine the relative proportion of each type.

Geomorphic interpretations of the bar types were based on standard fluvial geomorphology principles (e.g., Brierely and Fryirs, 2005, p. 86-97), on the geomorphic context of the bars observed in the Sabine, and on field indicators of processes and history as described in earlier work (Phillips, 2003; 2008a).

BAR TYPES

Bank-Attached Bars

Marginal or bank-attached bar types in the lower Sabine include point and lateral bars, tributary mouth bars, diagonal bars, and forced bars (Figure 6). Examples of each type are shown in Appendix B.

Figure 6. Point and lateral bars in the Sabine River near Brushy Creek. Photographic examples of all major bar types in the study area are shown in Appendix B.

Point bars are arcuate-shaped bars developed on the convex inside banks of meander bends, generally following the alignment of the bend. They may be active, as indicated by minimal vegetation cover and smaller scale bed forms superimposed on the bar. Active bars may also exhibit encroachment on downstream banks. Stabilized point bars are characterized by vegetation cover, and sometimes by incised gullies across the bar. Point bars are dominantly sandy in river styles 1-4, while reaches 5-6 include both sandy and fine-grained point bars. Bars are mostly active in reaches 1-3, with reaches 4-5 featuring a combination of active and stabilized bars. Bars in reach 6 are dominantly stabilized.

Lateral bars, also called alternate or side bars, occur along banks in low-sinuousity reaches. In many cases the development of lateral bars on alternate sides of the channel is the first stage in the eventual development of meanders. Lateral bars are mainly confined to river styles 1-3, though they do occur infrequently in reaches 4 and 5.

Both point and lateral bars may be breached by channels incised during the rising stage of high flows. If such channels persist, and are cut to the level of the river bed, they may result in chute cutoffs of point bars, or the development of short-lived mid-channel bars from lateral bars. Otherwise, the breaches infill over time.

Tributary mouth bars are deltaic features which occur as tributary flow is impeded by backwater effects from the dominant channel. While the general presence of a tributary mouth bar is often consistent over time, the specific shape, size, and location (upstream vs. downstream relative to the river, inside or outside of the tributary mouth) are typically quite dynamic, depending on the relative flow dynamics of the river and tributary. These occur in all reaches of the study area.

Diagonal bars are oriented diagonally to the banks, and are considered mid-channel units by Brierly and Fryirs (2005, p. 88). They have been classified as bank-attached units in the Sabine because all observed diagonal bars in the study area are bank attached, and some are confined to channel margin areas. Diagonal bars generally form due to dissection and reworking of riffles or lateral bars. They were observed in reaches 1-3.

Bank-attached forced bars occur sporadically throughout the lower Sabine. These are local deposition associated with obstacles to flow, most often toppled trees oriented more-or-less perpendicular to the banks.

The geomorphic interpretation of bank-attached bars is summarized in Table 8. None of the bank-attached bars except some diagonal bars are cross-channel features, but point and lateral bars are often associated with transverse bars.

Table 8. Geomorphic interpretation of marginal (bank attached) bars.[a]

Gemorphic Unit (bar type)	*Process Interpretation*	*Geomorphic History/Development*
Point Bar (active)	Meander growth & migration; deposition at bend apex coupled with cutbank erosion	Meandering, lateral channel migration
Point Bar (stabilized)	Sedimentation dominated by vertical accretion; limited lateral migration; vegetation establishment	Meander stabilization
Lateral Bar	Lateral accretion associated with meandering of thalweg within banks	Possible precursor to meander formation & growth
Breached Point or Lateral Bar	Erosional dissection of bar during rising stage of high flow	Possible precursor to chute cutoff
Tributary Mouth	Deposition associated with reduced stream power at junction; short-term changes reflect relative dominance of river and tributary flows	Lags in watershed sediment transport; adjustment of junction angles
Diagonal	Oblique flow relative to bank	May be associated with high sediment loads relative to transport capacity, or reworking of riffles
Forced	Deposition due to reduced stream power upstream of an bank-attached obstacle	NA1

[a] [a]NA1: not applicable due to a large number of possibilities or complex relationships between forms, processes, and history. NA2: not applicable due to insufficient knowledge or information.

Mid-Channel Bars

Mid-channel bars found in the lower Sabine River include forced, linguoid, longitudinal, and compound bars, and sand sheets (Figure 7). Examples of each type are shown in Appendix B.

Forced bars are sediment accumulations behind flow obstructions; typically large woody debris. These occur throughout the study area, but are less common in reaches 1 and 6.

Figure 7. Mid-channel bars in a straight reach of the lower Sabine River. Photographic examples of all major bar types are given in Appendix B.

Linguoid transverse bars are oriented perpendicular to flow, usually with a lobate but occasionally with a sinuous form. Linguoid bars have a slip face on the downstream end, and generally occur at points of abrupt flow expansion. In the study area, they typically occur in the vicinity of point or lateral bars, downstream of the widest point of the latter. Linguoid bars are associated with flow divergence in situations of high sediment load relative to transport capacity.

Longitudinal bars are droplet-shaped, with the lobate end upstream and the pointed end downstream. Coarser sand or gravel is typically found at the upstream end. This type of bar is associated with mid-channel deposition where either the size or amount of sediment exceeds transport capacity. As heavier material is deposited mid-channel, some finer particles are trapped in the wake.

Compound mid-channel bars are combinations of two or more of linguoid, longitudinal, forced, or breached marginal bars. They may be formed by welding of bars due to differential rates of downstream migration, or as a result of dissection of sand sheets. The latter are general bank-to-bank sand accumulations. Sand sheets are relatively uniform and tabular, but typically have a variety of superimposed smaller bedforms, and braided subchannels. Sand sheets reflect sediment supply greatly in excess of transport capacity.

The geomorphic interpretations of mid-channel bars is summarized in Table 9. Linguoid bars, sand sheets, and some compound bars are cross-channel, while longitudinal and forced bars are not transverse.

Table 9. Geomorphic interpretation of mid-channel bars.[a]

Gemorphic Unit (bar type)	*Process Interpretation*	*Geomorphic History/Development*
Forced bar	Deposition due to reduced streampower upstream of an obstacle	NA1
Linguoid (transverse) bar	Flow divergence in conditions of high sand bed load supply; abrupt flow expansion	High sand sediment supply; downstream bar migration
Longitudinal bar	Sediment supply exceeding transport capacity; flow divergence following deposition of coarser sediment the flow is not competent to transport	High sand and/or gravel sediment supply
Compound Bar	Recent variation in flow & sediment transport regime; welding of different bar types due to differential downstream migration	NA1; NA2
Sand Sheet	Local increase in sand supply or decrease in flow competence	Channel aggradation or pulsed bedload transport

[a]NA1: not applicable due to a large number of possibilities or complex relationships between forms, processes, and history. NA2: not applicable due to insufficient knowledge or information.

Connector Bars

Connector bars are not recognized in the Brierly and Fryirs (2005) typology, though some individual connector bars could be classified as riffles, linguoid, longitudinal, or compound bars. Connector bars are treated separately here because some of those observed in the study area do not conform to the typical morphology of other bar types, and because they have a unique geomorphic interpretation. Several additional examples are shown in Appendix B.

Connector bars (Figure 8) connect point and/or lateral bars to each other. They may be lobate, elongated, or amorphous, but extend from the downstream end of one bar to the upstream end of the next. Connector bars may be distinguished from linguoid bars or riffles, which are oriented perpendicular or parallel to the axis of the channel (figure 9). Connector bars are oriented diagonally to the channel axis, and appear to be associated with bar-to-bar sand transfer.

A sub-type is an extender bar, which extends from the downstream end of a point or lateral bar toward a downstream marginal bar, but does not cross the channel.

Figure 8. Connector bar, indicated by box.

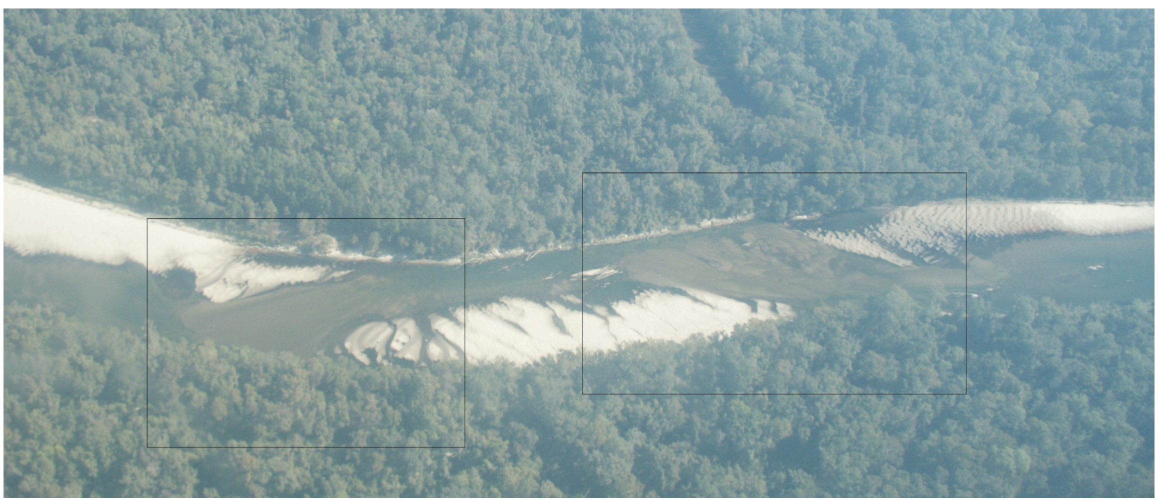

Figure 9. Linguoid bar (left box) and riffle bar (right box) connecting lateral bars. Contrast with the connector bar in figure 8.

The compass azimuths of the general flow/channel direction, and of the bar orientation (along the axis from the connected point and/or lateral bars) was measured in the field for 16 connector bars (some of these were downstream of Deweyville and thus not included in the inventory described in the next section). The angular differences ranged from a minimal 2^o, with bar orientation almost parallel to the axis of the channel, to 90^o, indicating bar orientation at a right angle to the axis of flow. The mean difference was 44^o (median 45.5^o), with bar orientations both left and right of the channel axis, with no apparent dominant trend.

Many connector bars appear streamlined (Figure 8) or are composed of a series of cuspate bedforms (Figure 10). Others, particularly when observed at ground/river level, appear to have originally had such forms, with subsequent modifications by cross-bar flows and reworking (Figure 11).

Figure 10. Cuspate bedforms on an extender type of connector bar.

Figure 11. Connector Bar showing evidence of cross-bar flow and reworking.

RELATIVE ABUNDANCE

The 155 km of river channel for which the low-altitude aerial photographs were inventoried contained 266 visible large bars (defined as bars which, at their widest or longest point, occupied at least half the channel width). Due to the low, clear, water conditions it is likely that few, if any large bars bars were missed.

Bank attached bars were by far the most common, with 166 point bars (62 percent of total bars) and 53 lateral (20 percent) counted. In addition, several breached point bars were noted. The relative abundance of bar types is shown in table 10.

Table 10. Bar types in the Sabine River, Toledo Bend to Big Cypress Creek. Cross-channel bars are shown in *italics.* Note that only large bars, as defined in the text, were included.

Type of Bar	Number
Active Point Bar	166
Breached Point Bar	7
Lateral Bar	53
Diagonal Bar	5
Tributary Mouth	3
Compound Mid-channel Bar	14
Mid-channel Forced Bar[a]	13
Sand Sheet	*12*
Longitudinal Bar	3
Linguoid	*30*
Point Bar Connector	*7*
Lateral Bar Connector	*2*
Total	266
Total transverse	*51*

[a]Bank-attached forced bars were observed in the field, but were too small to be included in the aerial photograph inventory

The sand sheets identified in Table 10 may be mobilized during higher flows, but are likely to be a common feature at low flows, given the transport-limited nature of the lower Sabine River in all river styles except reach 1 (Phillips, 2003; 2008a). Of the 30 linguoid transverse bars identified, all but one occurred in the riffle zone between point and/or lateral bars.

The study reach contained 51 transverse bars, a mean of about one for each 3 km of river channel. Note that while point and lateral bars are not transverse, connector and linguoid bars generally link the larger marginal bars, making the latter key in transverse bar development.

DISCUSSION

Transverse Bars

Transverse bars are common features in the lower Sabine River, particularly in reaches 1-3 where there is about one cross-channel bar for every 3 km of river channel. Transverse bars were also observed in reaches 4 and 5.

The transverse bars are dominantly linguoid bars essentially connecting closely-spaced point bars. Flow constriction occurs where the upstream end of one marginal bar is close to the downstream end of another. Bed load transported through the constriction is deposited as a linguoid bar as flow diverges and decelerates at the downstream end of the local constriction (Figure 12). All but one of the linguoid bars observed in the October 2007 aerial photographs were formed in this way. Another seven transverse bars are connector-type bars, chiefly connecting point bars. Thus, while the original hypothesis regarding transverse bars was not supported, clearly point (and to a lesser extent, lateral) bars play a critical role in developing transverse bars—based on the sample above, nearly 75 percent of the cross-channel bars connect marginal bars. The others—sand sheets and one of the observed linguoid bars—are likely to be more temporally ephemeral and spatially mobile. Therefore, relatively persistent or recurring transvserse bars are directly related to point and other marginal bars, and are likely to be present in rough proportion to the number of point and lateral bars.

Figure 12. Linguoid bar formed due to constriction between two closely-spaced alternate side marginal bars.

Connector Bars

The connector bars identified in this study have not been discussed in the literature, though they are likely present in other meandering sand-bed rivers. Based on their form and orientation relative to the bars and the river channel, a reasonable hypothesis is that they result from flow/bedform interactions. At high discharges, flow in the vicinity of the downstream edge of a point bar is deflected by the bar itself, resulting in sand transport in a direction determined by the orientation of the distal end of the marginal bar. As discharge and stream power declines on the falling stage, the flow is no longer competent to transport this bedload, resulting in deposition of the connector (or extender) bar. At this point flow deflection by the marginal bar is no longer significant, and lower-discharge dissection or reworking of the connector bar may occur.

The sequence described above is purely speculative at this point, and could be tested by a combination of sequential observations of bar development and process measurements during high and low flows.

Further study is also needed to determine the circumstances under which linguoid vs. connector bars form between marginal bars. An initial hypothesis is that the linguoid bars are associated with a closer spacing between alternate-side marginal bars.

Geomorphic Interpretations

The point bars are expected features in a meandering river such as the lower Sabine, as are the alternate side lateral bars in relatively straight reaches. The trend toward fewer, finer-grained, and more stable bars in reaches 4-6 is also expected, and occurs in similar situations on other rivers such as the Neches and Trinity (Morton et al., 1996; Phillips and Slattery, 2008).

With the exception of the connector bars discussed above, the types of bars found in the lower Sabine are common types recognized in sand-bed streams. The mid-channel bars are associated with conditions where flows are not competent to transport some of the bedload, and/or where sediment supply significantly exceeds transport capacity. The latter is far more likely in the Sabine, where the gravel content of bedload is small and highly localized. This is consistent with previous work on the lower Sabine (with the exception of the scour zone in reach 1) showing it to be a transport-limited fluvial system (Phillips, 2003; 2008a).

While the presence, prevalence, and nature of the bars in the study area reflect a transport-limited situation, the bars are mobile, and feature smaller superimposed bedforms which indicate sediment movement. This suggests that a significant portion of the Sabine River sediment transport is moved as bed load, and that measurements of suspended load may significantly underestimate sediment transport in the Sabine River. The limited available measurements are not sufficient to confirm or refute this, however.

CONCLUSIONS

The major findings and conclusions of this chapter are as follows:

•The lower Sabine River includes several different types of marginal or bank-attached bars, especially point and lateral bars. Almost all of these in reaches 1-3 are active, as are many in reaches 4 and 5. Other bank-attached bar types include diagonal and forced bars.

•None of the bank-attached bars are cross-channel or transverse, but marginal bars, particularly point bars, play a key role in the development of transverse bar forms.

•The study area includes several different types of mid-channel bars, including longitudinal, linguoid, compound, and forced bars. The linguoid bars are transverse, and the overwhelming majority in the lower Sabine are directly associated with marginal bars.

•The mid-channel bars are mainly associated with conditions where sediment supply exceeds transport capacity, consistent with the characterization of most of the lower Sabine as a transport-limited fluvial system. These bars and their superimposed bedforms also suggest that a significant portion of sediment transport is in the form of sandy bed load.

•An apparently previously unrecognized bar type is relatively common in the study area; connector bars which link marginal bars. The formation of these needs further study, but they are apparently involved in bar-to-bar sediment transfer, and may be related to flow-bedform interactions at the downstream end of marginal bars.

•Most of the transverse bars—particularly the ones likely to be most persistent or recurrent—are linguoid or connector bars linking marginal bars. This affirms the important role of active point bars in the development of transverse bars, and suggests that transverse bars will occur roughly in proportion to the spatial density of active point bars.

Chapter 4
Geomorphic Interpretations

INTRODUCTION

Short of continuous direct monitoring or observation, fluvial and alluvial landforms are the single best indicator of hydrological and ecological processes and regimes in river systems. Additionally, relationships between forms and processes allow for assessment of the geomorphic condition of a river reach or cross-section, and for assessing trajectories of geomorphic change. This is the basis for the broad-scale geomorphic characterization of the lower Sabine (Phillips and Slattery, 2007a; Phillips, 2008a). This section focuses on the interpretation of geomorphic units at more detailed scales.

As a caveat, note that while there exist systematic relationships between landforms and geomorphic processes, these are *not* uniformly one-to-one. That is, sometimes multiple processes or causes (or combinations thereof) can result in the formation of a particular feature. Thus, for example, concave banks usually represent bank erosion due to hydraulic stress from river flows, but may also reflect groundwater and slope processes resulting in bank failure. Thus, whenever possible, multiple features or lines of evidence should be used in making geomorphic inferences.

Most of the form-process relationships described below are based on standard principles of fluvial geomorphology (see, e.g., Knighton, 1998; Brierly and Fryirs, 2005, Schumm, 2005), and/or previous work in southeast Texas.

In addition, many of the environmental indicators used to delineate wetlands may be applied to make inferences about hydrologic regimes. These are discussed in detail by Brinson (1993) and Johnson (2005).

GEOMORPHIC UNITS

The geomorphic implications of bars are discussed in Chapter 3. Tables 11-13 below summarize the interpretations of the GU's in Chapter 2. Note that these are based on the presence the specific features. The size, morphology, and context of individual GU's, as well as presence/absence and characteristics of smaller scale features (hydraulic and habitat units) can clarify or modify inferences and deductions. The specifics of riparian vegetation as geomorphic indicators are reviewed by Hupp and Osterkamp (1996).

The contemporary processes column indicates what recent or ongoing processes are reflected by the unit, and the geomorphic history column shows what the feature may indicate with respect to recent landform change and landscape evolution. The possible transformations column indicates potential near-future transformations.

In some cases a number of different processes or historical pathways, separately, or in combination, can result in the formation of a given unit. Thus the presence of a thalweg, for example, does not reveal anything about contemporary processes or geomorphic history. In a few cases (e.g. islands) there is simply not enough known to make confident geomorphic interpretations.

Table 11. Geomorphic interpretation of mid-channel geomorphic units.[a] Bars are treated separately in Chapter 3.

Geomorphic Unit(s)	*Contemporary Processes*	*Geomorphic History*	*Possible Transformations Or Changes*
Thalweg	NA1	NA1	Lateral migration; sinuousity
Bedrock outcrops	Minimal channel incision	Channel incision	Expansion or burial
Riffle-pool	Selective bedload transport	NA1	NA1
Glide (run)	Steady-state sediment transport	NA2	Development of bars, riffle-pool sequences
Circular meander pool	High-flow countercurrents	Slow lateral migration; inhibition of cutoffs	NA2
Downstream forced pool	Scour downstream of obstacle	NA1	Infilling, smoothing
Forced backwater pool	Flow obstruction and ponding	NA1	Infilling, smoothing
LWD jams	Bank erosion, LWD transport, logging waste	NA1	Removal by transport; local bank or bed scour; local backwater effects; avulsion due to flow deflection

[a]NA1: not applicable due to a large number of possibilities or complex relationships between forms, processes, and history. NA2: not applicable due to insufficient knowledge or information.

Table 12. Geomorphic interpretation of bank-attached geomorphic units.[a] Bars are treated separately in Chapter 3. ([a]NA1: not applicable due to a large number of possibilities or complex relationships between forms, processes, and history. NA2: not applicable due to insufficient knowledge or information).

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Geomorphic Unit(s)	*Contemporary Processes*	*Geomorphic History*	*Possible Transformations Or Changes*
Bench	Infilling	NA1	NA1
Ledge	Bank or bed erosion	Incision into former channel bed	NA1
Bedrock bank	Minimal bank erosion	Channel widening and/or downcutting	NA1
Concave bank	Erosion and bank retreat	Lateral channel migration or widening	Stabilization and recovery to concavo-convex
Convex bank (vegetated)	Bank stability or slow accretion	NA1	Conversion to concave, straight, or complex erosional forms
Convex bank (unvegetated)	Recent or chronic accretion; marginal bar development	NA1	Stabilization to vegetated convex bank
Straight bank (vegetated)	Stable or slowly eroding banks in cohesive materials	NA1	Conversion to concave, straight, or complex erosional forms; conversion to stable convex form
Straight bank (unvegetated)	Bank erosion, lateral channel migration	NA1	Conversion to concave, or complex erosional forms; stabilization to vegetated straight bank
Convexo-concave bank	Erosion of banks of variable resistance; removal of lower bank vegetation or LWD; local low-flow acceleration or deflection	Transition from stable or accreting to eroding bank	Conversion to concave erosional bank
Concavo-convex bank	Recent cessation or deceleration of bank erosion	Recovering cutbank	Conversion to stable convex or concave erosional bank
Cypress buttress	Recent channel aggradation; or seasonal water level variation	Channel aggradation	Erosion, drowning of cypress
Slumps & slump scars	Rotational bank slope failures	Channel incision and/or lower bank erosion	Conversion to or incorporation into concave erosional bank
Chute channel	Concentrated high flow across point bar	Meander development and migration	Chute cutoff or point bar breaching
Sand rampart	Localized marginal deposition	NA2	Removal

.

Table 13. Geomorphic interpretation of floodplain and valley geomorphic units.[a]

Geomorphic Unit(s)	*Contemporary Processes*	*Geomorphic History*	*Possible Transformations Or Changes*
Infilled abandoned channel	Vertical accretion	Avulsion and channel abandonment	Reoccupation by future avulsions (sand filled); inhibition of future avulsions (clay plugs)
Semi-active abandoned channel	High-water flow	Avulsion and channel abandonment	Infilling, or reoccupation by future avulsions or by tributaries
Anabranch	NA1	Valley aggradation & avulsion	Abandonment
Delta distributary	Deltaic sedimentation and divergent flow	Delta development	Abandonment; growth by flow capture
Alluvial distributary	Sediment and water dispersion to floodplain	Flood basin development plus avulsion	Abandonment; growth by flow capture
Billabong	Water storage	Avulsion	Infilling; reactivation by future avulsion or tributary occupation
Low-flow trib/ high-flow distributary	Influx to river at low flows; divergent fluxes from river at high flows	Tributary occupation of abandoned channels following avulsion	Infilling; coversion to tributary or distributary
Tie channel (batture)	Oxbow to river flux at low flows; opposite at high flows	Recent cutoff; crevasse channel cut to oxbow	Infilling; avulsion
Ridge-and-swale backswamp	Vertical accretion	Lateral channel migration	Burial by vertical accretion
Flat backswamp	Vertical accretion	Burial of ridge-and-swale; infilling of floodplain depressions	Alluvial terrace
Pleistocene meander scars/depressions	Infilling	Incision of pre-Holocene valleys formed during higher discharges	Infilling
Cutoffs, oxbows	Infilling, water storage	Meander cutoff	Lakes to swamps to infilled
Continued on	Following Page		

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Natural levee	Ongoing or recent deposition	Overbank deposition	NA1
Crevasse splay	NA1	Levee breaching with decelerating sheet flow	NA1
Crevasse channel	High-water river to floodplain flow	Levee breaching with concentrated flow	Infilling; avulsion
Tributary channels	Water, sediment flux to river	NA1	NA1
Islands	NA2	Valley aggradation and anabranching; inheritance from Pleistocene anabranching	NA2
Alluvial terraces	NA1	Quaternary aggradation-degradation sequences	Burial of lower terraces; erosional dissection of higher terraces

[a]NA1: not applicable due to a large number of possibilities or complex relationships between forms, processes, and history. NA2: not applicable due to insufficient knowledge or information.

BANK GEOMORPHIC INDICATORS

Mid-channel geomorphic units may be difficult to observe except at low flows, and floodplain/valley features may be both difficult to observe or access, and of less direct relevance to instream flows. Bank conditions are the most readily assessed at bed inundation to sub-bankfull flow levels. The following keys are thus offered as an aid to the geomorphic assessment of bank conditions.

Table 14 is a key for interpreting morphology of banks at individual cross-sections and reaches. Table 15 then indicates what comparisons of left and right banks infer about channel behavior.

Table 14. Key for interpreting bank profile morphology.

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1. Bank profile morphology
   Simple (entire bank convex, concave, straight): 2
   Complex: 5

2. Concave?
   Yes: *eroding cutbank*
   No: 3

3. Convex?
   Yes: *stable or accreting bank*: 3.1
      3.1. Vegetated?
         Yes: *stable bank or stabilized bar*
         No, or minimal vegetation cover: *accreting bar or infilling bank*
   No: 4

4. Straight?
   Yes: 4.1
      4.1. Vegetated, or with coating of algae, lichens, or biofilm?
         Yes: *stable bank*
         No: *eroding bank*
   No: 5

5. Upper bank/lower bank
   Convex/concave: 6
   Concave/convex: *Recovering cutbank*
   Other: 7

6. Convex upper bank, concave lower bank: possible causes; requires detailed investigation
   Transition, stable or accreting to eroding bank
   Resistance variations, upper vs. lower bank
   Removal of lower bank protection
   Locally higher shear stress
      Low-flow acceleration
      Flow deflection

7. Channel shelf?
   Yes: 8
   No: requires detailed investigation

8. Bench (depositional): *Infilling bank*
   Ledge (erosional): 9

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9. Ledge composition
    Similar to bed, banks: *incision into former channel bed*
    Resistant material: *bank erosion*

Table 15. Key for inferring channel behavior based on left:right bank comparison.

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1. Both banks in same state
    Yes: 3
    No: 2

2. One eroding, one stable: *channel widening*
   One eroding, one accreting: 2.1
    2.1 Erosion > accretion: *channel widening & lateral migration*
        Erosion < accretion: *channel narrowing & lateral migration*
        Erosion ≈ accretion: *lateral migration*
   One stable, one accreting: *channel narrowing*

3. Both stable: *stable channel*
   Both accreting: *channel narrowing*
   Both eroding: *channel widening*

INCISION AND AGGRADATION

Channel incision is caused by vertical erosion into the channel bed and is also known as downcutting or degradation. Any channel—particularly alluvial channels such as the lower Sabine—can experience short-term, local erosion (and deposition) in the channel bed. The indicators in Table 16 are suggestive of general, net incision independent of more localized changes.

Table 16. Field indicators of channel incision. None of the following is caused exclusively by general channel incision; two or more indicators should be present for confident interpretations. Potential alternate causes for the indicators are given in [brackets].

•*Exposure or undercutting of cultural features* such as bridge pilings, boat ramps, docks, pilings, etc. [localized flow or slope increases or flow deflections]

•*Exposure of bedrock* or pre-Quaternary material in bed [lithological variations]

•*Knickpoints* [lithological or structural variations; antecedent morphology; local sediment inputs]

•*Channel ledges or paleobanks* [lateral infilling]

•*Obligate hydrophytes* well above normal water levels [perched ground water]

•*Back-tilted riparian trees* (tilted away from river) [wind throw]

•*Evidence of reduced overbank flow*, e.g., reduced sedimentation, soil formation, soil redox features, vegetation changes [vertical floodplain accretion]

•*Channel narrowing* without evidence of significant changes in discharge, stream power, or sediment supply. [local slope failures]

•*Tributary downcutting* (indicators above observed in tributaries)

Table 17 lists field indicators of channel aggradation, characterized by persistent net deposition or infilling of the channel. While all are linked to deposition or aggradation, multiple locations should be assessed to distinguish between general reach-scale aggradation and temporary local deposition.

With respect to floodplains, stability or slow accretion is indicated by soil development and minimal presence of the aggradation indicators in Table 18. Floodplain erosion or stripping is indicated by exposed tree roots, truncated soil profiles, and rills, gullies, or erosion pavements on the floodplain surface. Recent accretion or aggradation is signified by the indicators in Table 18.

Table 17. Field indicators of recent channel aggradation. While all the following are associated with aggradation, they may be related to localized deposits rather than general aggradation. Therefore multiple locations should be assessed.

•*Burial or partial burial of channel and lower-bank vegetation.*

•*Burial of LWD.*

•*Island formation* (relatively young islands as indicated by vegetation and soil characteristics)

•*Sand sheets.*

•*Cypress buttressed-banks* in non-deltaic or fluvial/estuarine transition zones.

•*Crevasses and avulsions* [local levee damages or flow diversions]

•*Evidence of increased frequency of overbank flow*, e.g., increased floodplain sedimentation, soil redox features, vegetation changes, floodplain flow and hydrologic indicators [erosional floodplain stripping; increased discharge]

•*Tributary aggradation* (indicators above observed in tributaries)

•*Increased tributary backflooding* (indicators of floodplain or channel aggradation along lower tributary reaches; organic deposits near tributary mouths)

Table 18. Field indicators of recent floodplain aggradation. While all the following are associated with aggradation, they may be related to localized deposits rather than general aggradation. Therefore multiple locations should be assessed.

•*Burial of understory vegetation.*

•*Burial of tree root crowns and basal flares*

•*Burial of leaf and litter layers*

•*Fresh sediment deposits*

•*Stratified or massive surficial sediments* with minimal pedogenic development.

•*Burial or partial burial of cultural features,* e.g. buildings, pilings, fences, etc.

•*Recent cultural materials in sediment deposits*, with stratification preserved; e.g., plastic and synthetic materials, recent glass, electronic components, appliances

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OTHER INDICATORS

Several features are found in the lower Sabine River valley which do not meet the definition of geomorphic units, but which are useful diagnostics or indicators of geomorphic and hydrologic processes.

One of these is the presence of identifiable buried soils or paleosols in the floodplain. This indicates that the floodplain experienced a period of relative stability (limited or slow accretion or erosion) which allowed a soil profile to form. Subsequent deposition—either from one or more large events, or a general increased deposition rate—resulted in the burial of the profile (Figures 13-14). Buried soils or analogous stratigraphic unconformities may also be associated with deposition of dredge spoil.

Such buried soils do occur in the lower Sabine valley, but they have not been extensively studied or inventoried and their distribution is unknown.

Figure 13. The dark layer is the organic-rich A-horizon of a soil profile buried by subsequent floodplain deposition.

Figure 14. A paleosol in the Sabine delta. A horizontal line has been drawn at the approximate top of the buried soil. In some cases detailed examination and significant pedological expertise is needed to recognize buried soils.

Fluvially-transported organic matter generally floats, and even when waterlogged has a very low settling velocity. The deposition of fine macroscopic organic matter (twigs, leaves, small wood fragments, etc.) in layers more than about a cm thick generally represents either sites of ponded water, or situations where water levels decline rapidly, leaving organic matter accumulations in a manner roughly analogous to a bathtub ring. Thick organic accumulations (>15 cm) are usually associated with backwater conditions or recirculating eddies, where organic matter accumulates in the flow before being deposited as water levels fall.

Several examples of such deposits were found during fieldwork in the lower Sabine; some are shown in Figures 15-17.

Figure 15. The thick organic layers in this sand ramp downstream of Burr Ferry indicate relatively rapid water level changes.

Figure 16. The thick, minimally decomposed organic layer in the Sabine delta, overlain by sand, suggests recent changes in the hydrogeomorphic dynamics at this site, from a backwater to a more energetic flow regime.

Figure 17. Thick organic layers just inside Cutoff Bayou at its confluence with the Sabine suggest that recirculating eddies may form during high flows.

Some bars and bedforms exposed in the lower Sabine during low flow conditions have extensive algal mats. Such mats cannot form in high-energy environments or on highly mobile sediments. Thus these algal mats—some of which oxidize to orange, brown, or red colors when exposed to the air—may indicate at least temporary stabilization of bedforms (figures 18-19).

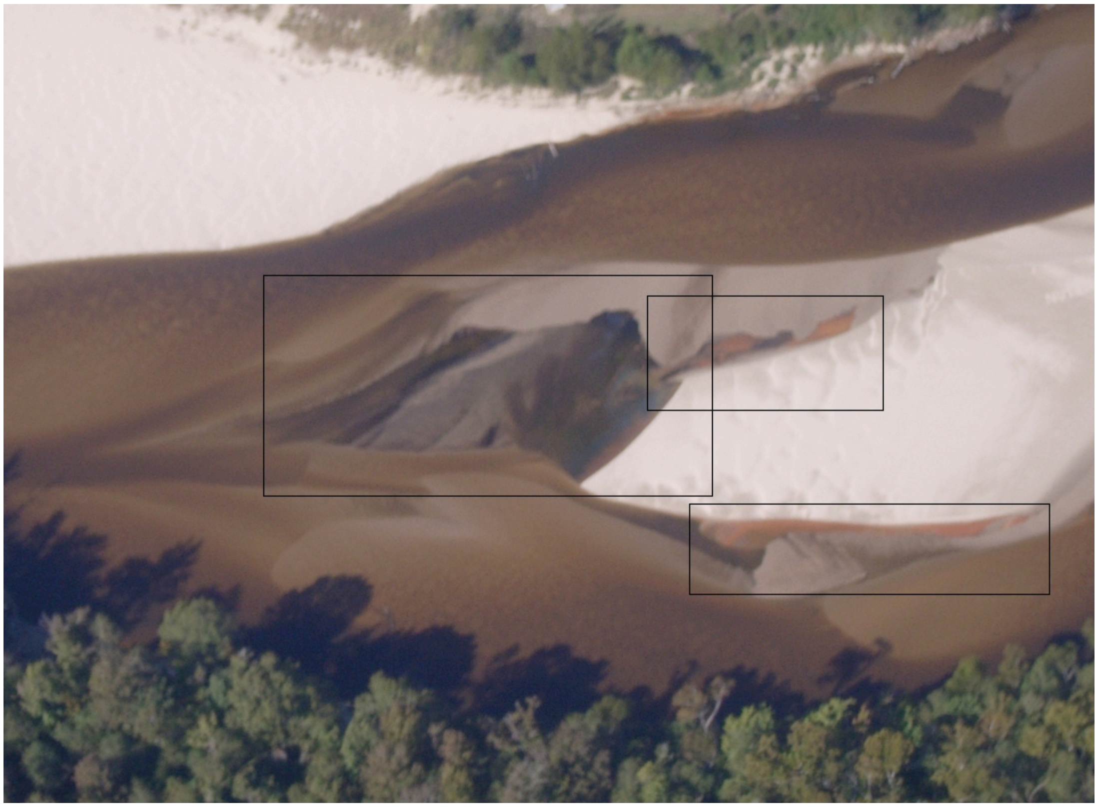

Figure 18. Algal mats (boxes) on mid-channel bars.

Figure 19. Algal mats (orange colors) on an exposed portion of the upstream end of a marginal bar.

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Scope of Work

SCOPE OF WORK PLAN

Geomorphic Units of the Lower Sabine River

Jonathan D. Phillips

August 2007

<u>Overview</u>

This work plan addresses a cooperative research study of the subreach-scale landforms of the lower Sabine River, Texas/Louisiana from Toledo Bend Dam to Sabine Lake. Building on previous work delineating geomorphic zones or reaches (river styles) and associated environmental controls and hydrologic and geomorphic processes, this study addresses the characteristic landforms within those zones. The dominant (in terms of size, frequency of occurrence, and influence on hydrologic and ecological conditions) geomorphic units will be identified, described, and related to hydrologic and geomorphic processes and controls and the river styles zonation. Particular emphasis will be placed on transverse bars. These (more-or-less cross-channel) sand bars are important bedforms and aquatic habitat elements in rivers. In meandering coastal plain streams such as the lower Sabine River, transverse bars are usually associated with point bars on the inside of bends, and typically occur at or near the apex of the bend. In the lower Sabine, however, transverse bars have been found downstream of the meander inflection points. The goal of this study is to predict the location and future migration of transverse bars in the lower Sabine, and to test a hypothesis regarding the bars' occurrence downstream of the bend apex.

The specific objectives are to:

(1) Identify and describe major geomorphic units associated with the geomorphic zones identified in previous work (Phillips 2007; Phillips and Slattery 2007).

(2) Describe geomorphic units with respect to size, form, origin, longevity (e.g., typical time scales or persistence) and relationships to particular fluvial or ecological processes.

(3) Assess the geography of geomorphic units with respect to environmental settings, longitudinal (up-downstream) distribution, and association with geomorphic zones.

(4) Test the hypothesis below regarding transverse bars.

<u>Transverse Bars</u>

Some point bars in the Sabine show evidence of downstream translation. If the rate of such movements exceeds the rate of overall meander bend migration, then the extensions of the point bar into the channel (i.e., the transverse bar) should occur downstream of the bend apex. I hypothesize that the sandy bars are mobilized at lower shear stresses than those required for bank erosion, and thus bar mobility occurs more often than cutbank erosion, which is required for migration of the meander as a whole.

Results will provide an assessment of the current state of point and transverse bars in the study area, predictions of trajectories of change, and guidelines for field and GIS-based assessment of bars to facilitate samplng and resource assessments.

Methods

Geomorphic unit inventories and characterizations will be based on the following data sources:

•Map, aerial photography, digital elevation model, hydrologic, soil, and geologic data collected in connection with previous projects (Phillips 2003; 2007; Phillips and Musselman 2003; Phillips and Slattery 2007).

•Field measurements, observations, and photographs collected in connection with previous projects (Phillips 2003; 2007; Phillips and Musselman 2003; Phillips and Slattery 2007).

•0.3 m (1 foot) resolution aerial photography flown in September, 2005 (post Hurricane Rita).

•Field measurements and observations, with sampling stratified by identified geomorphic zones.

The transverse bars will be approached thus: The size and geometry of all point bars between Burr Ferry (SH 63 crossing near Burkeville, TX) and Big Cow Creek will be examined via digital orthophotoquads (2004 images) to determine the correspondence between bend apices and transverse bars. A sample of 20 bars will be examined in the field. Geomorphic and vegetation evidence of downstream translation will be examined, and point bar and cutbank sediments will be sampled. Shear strength tests of cutbanks will be performed using a shear vane and penetrometer, and cross-sections will be surveyed. Cross-sectional data and flow data from gaging stations at Burr Ferry and Bon Wier will be used to relate the critical shear stresses for sand mobility and bank erosion to flow frequencies.

Personnel and Responsibilities

TWDB will oversee the activities of the project and serve as contract manager. Dr. Jonathan Phillips/Copperhead Road Geosciences (University of Kentucky, but functioning as an independent contractor) will be principal investigator, with research assistants.

Tasks

(1) Synthesis and assessment of existing data.
(2) Acquisition and processing of 2005 high-resolution aerial photography.
(3) Field data collection.

(4) Data analysis and interpretation.
(5) Produce report.

Timeline

The timeline is based on a September 1, 2007 start date and should be adjusted proportionally for any later start.

Task	Time Frame
(1)	September-November, 2007
(2)	September-December, 2007
(3)	October, 2007-May, 2008*
(4)	May-July, 2008
(5)	July-August, 2008

*Dates contingent on travel schedules, weather, and coordination with Sabine River Authority of Texas.