Geomorphic Processes, Controls, and Transition Zones in the Lower Sabine River

Jonathan D. Phillips
Copperhead Road Geosciences, LLC
720 Bullock Place
Lexington, KY 40508
(also University of Kentucky)

Michael C. Slattery
Institute for Environmental Studies
Texas Christian University
Fort Worth, TX 76129
(also TCU Department of Geology)

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INTRODUCTION AND OVERVIEW

This report is based on a cooperative research study of the geomorphology of the Lower Sabine River, Texas (and Louisiana). The study focussed on delineating major geomorphic process zones, identification of major geomorphic controls, and determination the location and primary controls over key "hinge points" or transition zones.

The specific objectives of the project were to:

(1) Develop a baseline characterization of the condition and behavior of the lower Sabine River (downstream of Toledo Bend reservoir).

(2) Examine longitudinal (downstream) changes in flow processes and energetics, channel and valley morphology, and patterns of recent geomorphic change.

(3) Classify the lower Sabine (based on items 1, 2) into geomorphic process zones.

(4) Identify the primary controls—both contemporary and historic—of the geomorphic process zones.

(5) Identify the current location, primary controls over, and potential future changes in critical transition zones.

The report is presented in two parts. The first, *Flow and Sediment Transport Regimes in the Lower Sabine River,* provides the hydrologic framework for the study, with a specific emphasis on downstream changes in flow and sediment transport. The second part, *Geomorphic Controls on Transition Zones in the lower Sabine River, Texas-Louisiana*, presents the geomorphic zonation and interpretations of geomorphic controls.

TABLE OF CONTENTS

List of Tables

Section 1: Flow and Sediment Transport Regimes in the Lower Sabine River

Section 2: Geomorphic Controls on Transition Zones

List of Figures

Section 1: Flow and Sediment Transport Regimes in the Lower Sabine River

Section 2: Geomorphic Controls on Transition Zones

FLOW AND SEDIMENT TRANSPORT REGIMES IN THE LOWER SABINE RIVER

INTRODUCTION

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. The flow along the channel and valley is also influenced by (as well as influencing) the geomorphology. This section outlines and analyzes the flow regime of the river, in the context of a consideration of geomorphic controls on transition zones in the lower Sabine.

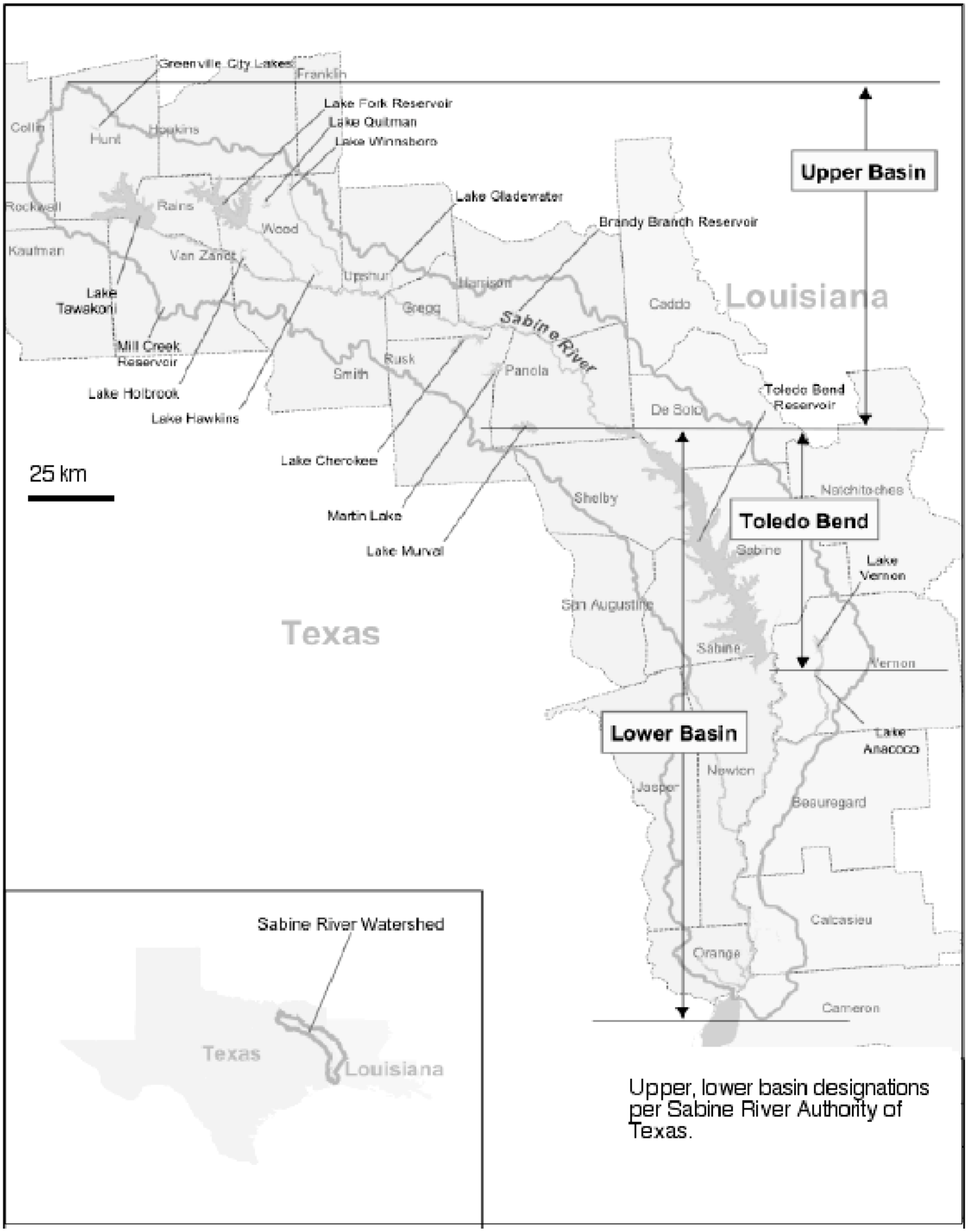
The study area includes the Sabine River from the Toledo Bend reservoir to the Sabine Lake estuary, along the border of Texas and Louisiana. The Sabine River has a total drainage area of 25,267 km^2, of which 6,676 km^2 (26%) is downstream of the Toledo Bend dam (Fig. 1). The climate is humid subtropical, with a mean annual precipitation of 1100 to 1200 mm. Precipitation is year-round, but mid-summer droughts and low flows are common. Land use is predominantly forest, but a significant amount of grazing land is present. Urban and industrial land uses are limited.

Monthly precipitation for the Sabine Lake area as a proportion of the 1941-2005 mean value is shown in Figure 2. A minor shift toward higher values is evident since the late 1970s. Total estimated inflow to the estuary from surface runoff is shown in Fig. 3.

Toledo Bend Reservoir and Dam

Toledo Bend Reservoir straddles the Louisiana-Texas border, and extends from the dam upstream about 105 km to Logansport, LA. The 750 km^2 surface area at normal water levels makes Toledo Bend the fifth largest artificial water body in the U.S.A. The controlled storage capacity is 5.522 km^3 (4,477,000 acre-feet). The project was constructed by the Sabine River Authority (SRA) of Texas and the SRA of Louisiana, with dam construction beginning in 1964, and completion in 1967. The hydroelectric power plant began operation in 1969. 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 earth fill Toledo Bend Dam is more than 3,400 m long, with a maximum height of about 34 m. The design flow of the 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}.



Upper, lower basin designations per Sabine River Authority of Texas.

Figure 1. Sabine River Basin.

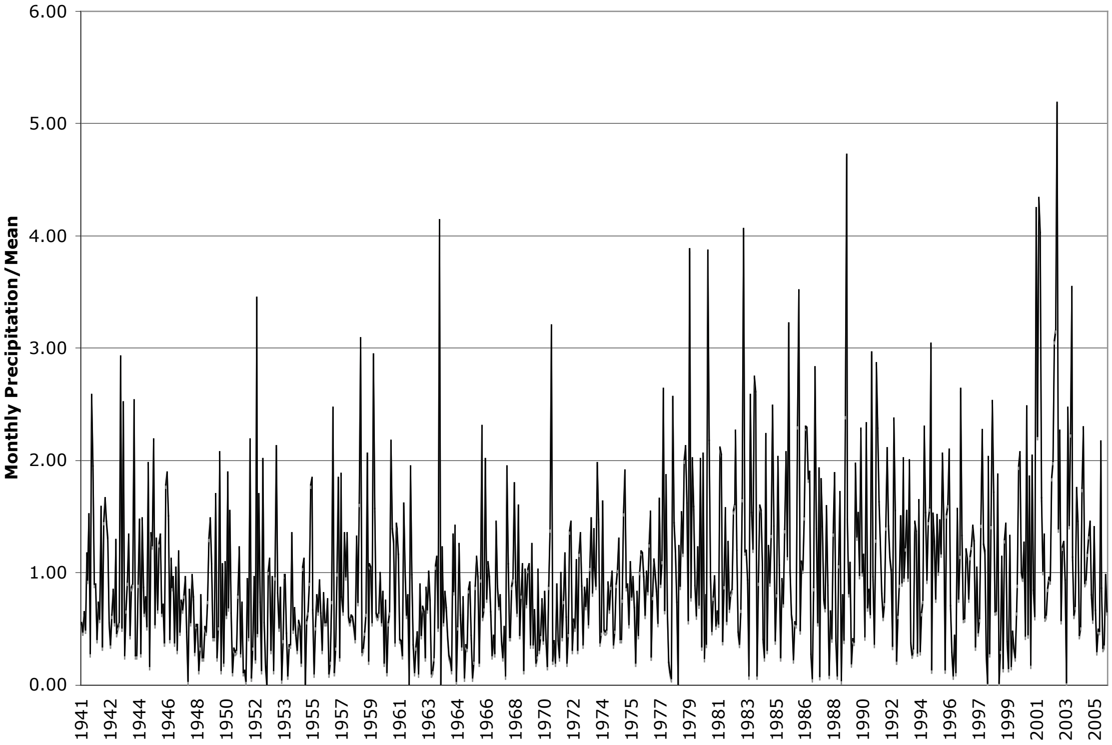


Figure 2. Monthly precipitation for the Sabine/Neches estuary as a proportion of the mean value. Based on data from the Texas Water Development Board (http://hyper20.twdb.state.tx.us/data/bays_estuaries/hydrologypage.html).

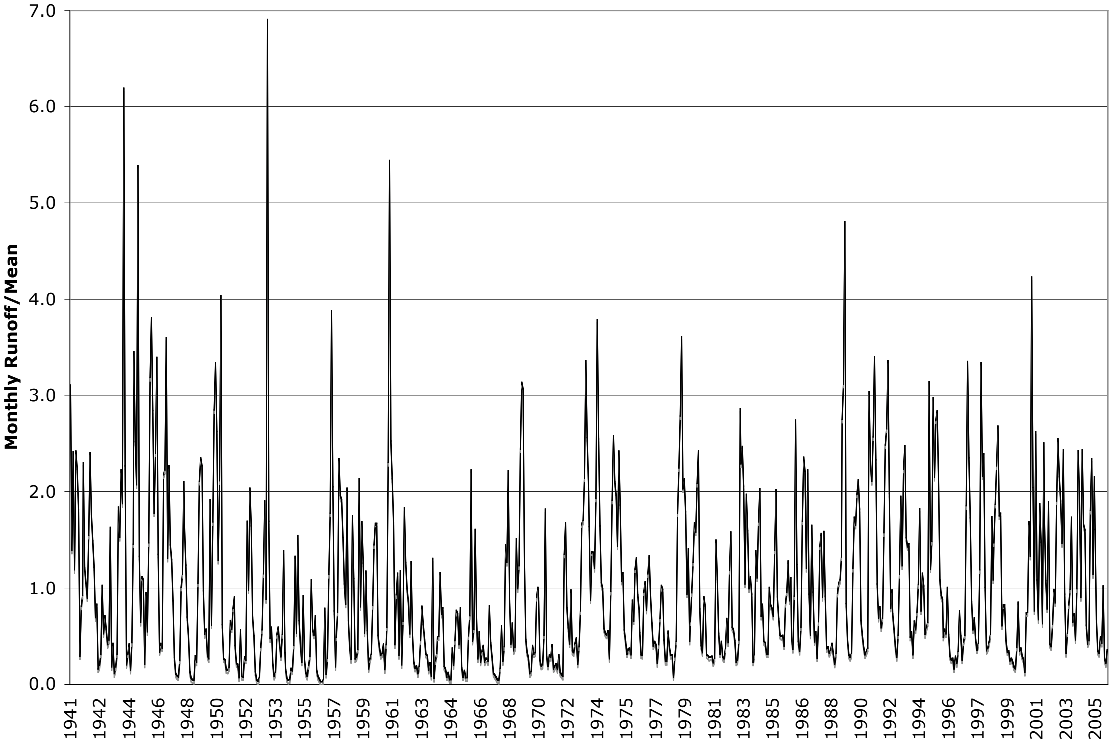


Figure 3. Surface runoff into the Sabine/Neches estuary as a percentage of the mean value. Based on monthly model calculations of the Texas Water Development Board (http://hyper20.twdb.state.tx.us/data/bays_estuaries/hydrologypage.html)

Withdrawals

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}, with water supplied primarily to industrial and municipal users. 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 4. The 1941-2005 trends in diversions as a percent of the mean, shown in Figure 5, 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.

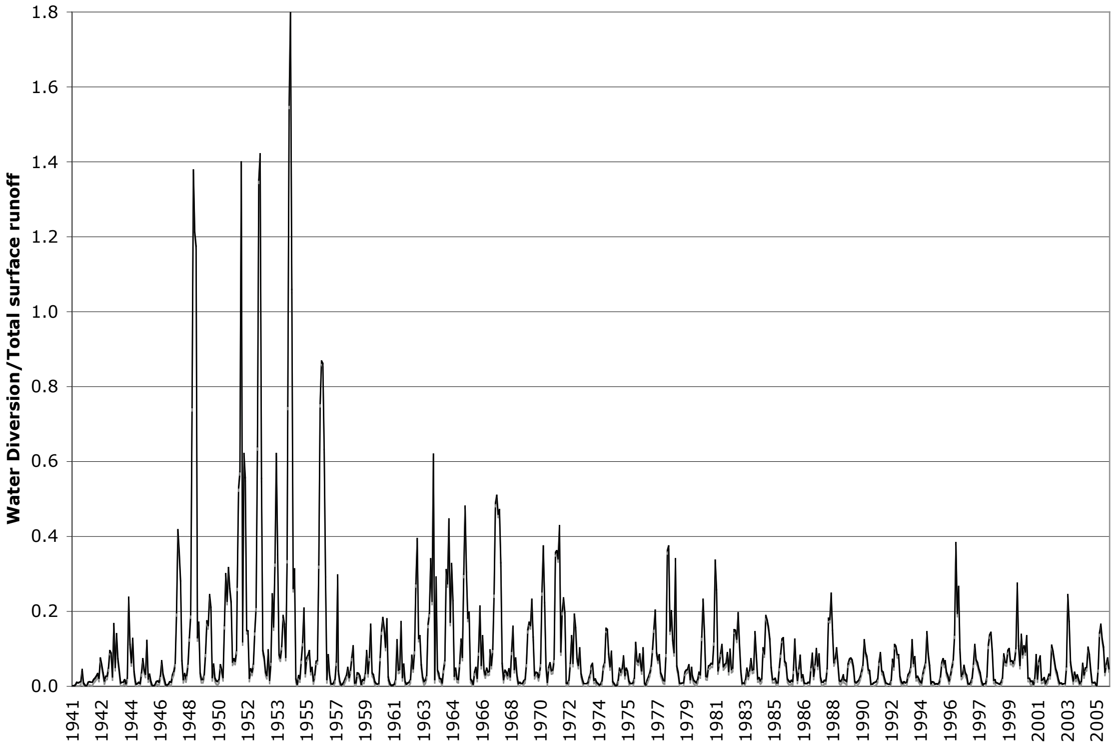


Figure 4. Water diversions for the Sabine/Neches estuary as a proportion of total surface runoff. Based on monthly model calculations of the Texas Water Development Board (http://hyper20.twdb.state.tx.us/data/bays_estuaries/hydrologypage.html)

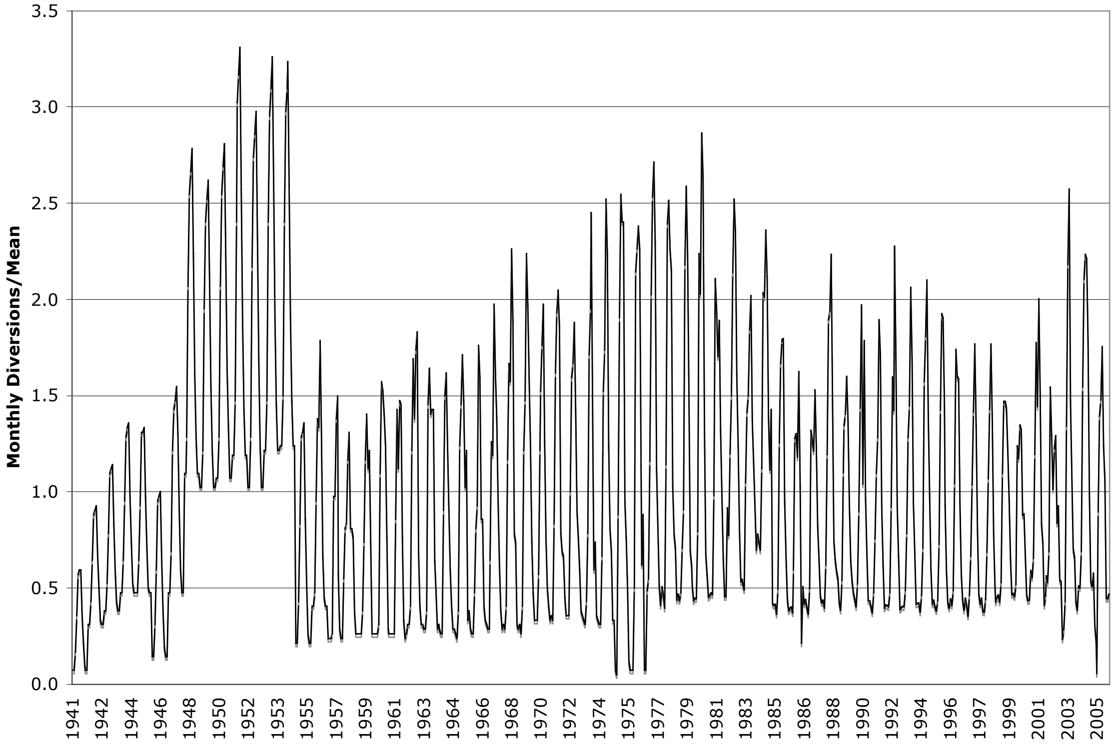


Figure 5. Water diversions for the Sabine/Neches estuary as a proportion of the mean monthly diversion. Seasonal patterns are readily apparent. Based on monthly model calculations of the Texas Water Development Board (http://hyper20.twdb.state.tx.us/data/bays_estuaries/hydrologypage.html).

RIVER DISCHARGE

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).

The U.S. Geological Survey maintains one reservoir stage and three stream discharge gaging stations on the lower Sabine River, and one each on the two largest tributaries, Anacoco Bayou (Louisiana), and Big Cow Creek (Texas). Characteristics of these stations are shown in Table 1, and their locations in Figure 6.

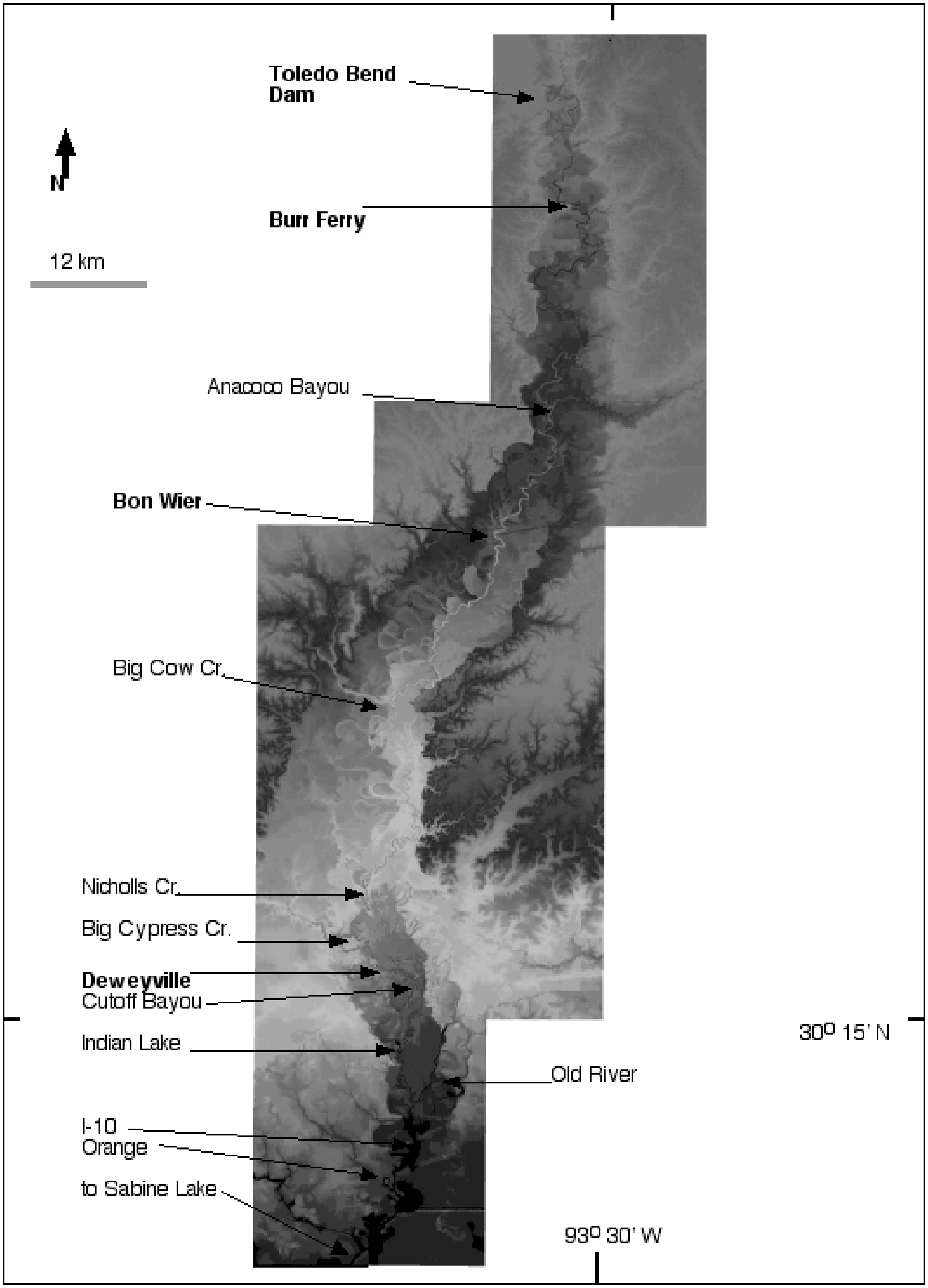


Figure 6. Gaging stations (**bold**), major tributaries, and other key locations in the study area. The Burr Ferry and Deweyville gages are referenced to as Burkeville and Ruliff, TX, respectively by the U.S. Geological Survey.

Mean daily flows in cubic feet per second for the period of record were used to determine reference flows for these stations, including the average or mean flow, the median, and mean daily flows with 10 and one percent exceedence probabilities. This approach is used instead of the annual or partial duration flood series to better represent the full range of flows, and to allow for better hydrological comparisons among sites, as the frequency of flows greater than or equal to bankfull varies greatly. Flood stage and the associated discharge was also determined where possible, and the exceedence probability of the flood discharge estimated. Note that probabilities and recurrence intervals using mean daily data will differ from those calculated using annual or partial duration peak flow series. The peak from an October, 2006 flood was also determined. These values are summarized in Table 2.

Table 1. U.S. Geological Survey gaging stations in the lower Sabine area, with hydrologic unit codes (HUC), upstream drainage area, gage datum, and year of earliest discharge records.

Station	**HUC**	**Area** (km^2)	**Elevation** (m)	**Date**
Toledo Bend	08025360	18,591	56.4*	1971
Burr Ferry (Burkeville)	08026000	19,378	18.5	1955
Bon Wier	08028500	21,313	10.2	1923
Deweyville (Ruliff)	08030500	24,162	-1.8	1924
Anacoco Bayou	08028000	945	36.0	1940
Big Cow Creek	08029500	332	41.1	1952

*top of dam elevation.

Mean and median flows and the one and ten percent probability flows increase as expected downstream from Burkeville to Bon Wier to Deweyville. The flood stage discharges, however, and thus the frequency 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, stream power 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; 2007).

Table 2. Lower Sabine River and tributary gaging stations (refer to table 1) reference flows.

Reference flow	ft^3 sec^{-1}	m^3 sec^{-1}	Probability/Recurrence interval
Burkeville (Burr Ferry)			
Mean daily	5,586	158	
Median	2,640	75	
10%	15,300	433	
1%	33,200	940	
Flood stage	66,400*	1880	(~0.1%, 2.75 yrs)
2006 peak	13,000	368	
Bon Wier			
Mean daily	6,953	197	
Median	3,420	97	
10%	17,900	507	
1%	38,600	1093	
Flood stage	28,000	793	(~3 %, 0.09 yrs)
2006 peak	35,400	1002	
Deweyville/Ruliff			
Mean daily	8,339	236	
Median	4,520	128	
10%	20,400	578	
1%	44,900	1272	
Flood stage	18,000	510	(~13%, 0.02 yrs)
2006 peak	88,400	2503	(~0.05%, 5.1 yrs)
Big Cow Creek			
Mean daily	131	3.1	
Median	65	1.5	
10%	229	5.5	
1%	1,240	29	
Flood stage	unknown		
2006 peak	41,500*	988	(instantaneous)
	23,200*	553	(mean daily)

*highest ever recorded

Table 2. continued.

Anacoco Bayou

Mean daily	484	11	
Median	90	2.1	
10%	929	22	
1%	4,260	101	
Flood stage	3,700	88	(~1.3%, 0.22 years)
2006 peak	13,600	324	(~0.15%, 1.77 years)

Flood of 2006

Persistent precipitation in the lower Sabine basin in October, 2006 resulted in minor flooding at Bon Wier and more extensive flooding further downstream. At the gaging station at Bon Wier the river crested slightly above flood stage, and was at flood stage for about 18 hours. At Deweyville, the flood peaked at >1 m above flood stage, and was at flood stage for more than 13 days. The Big Cow Creek gaging station at Newton experienced a flood of record. The previous record instantaneous peak over 54 years was 609 m^3 sec^{-1}. On October 17, the station recorded an instantaneous peak of nearly double that (1175 m^3 sec^{-1}), and a mean daily flow of more than 650 m^3 sec^{-1}. While flooding occurred on Anacoco Bayou, no overbank flow occurred at the Burkeville station on the Sabine River.

Hydrographs for the October 2006 flows are shown in figure 7. This event illustrates several features of flows in the lower Sabine. The generally similar response at the three river stations illustrates that during wet periods runoff response rather than dam releases clearly dominate the hydrologic response. The spike in the Big Cow hydrograph is typical of tributary responses to storm events, as evidenced in studies of Trinity River and tributary responses to high flows from Hurricane Rita in 2005 (Phillips and Slattery, 2007). Note also the responsiveness of the Deweyville hydrograph to the peaks in the Big Cow Creek hydrograph. The more extensive flooding at Deweyville compared to Bon Wier also illustrates the greater tendency for overbank flow to occur at the downstream site.

Dam and Tidal Effects

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. Figures 8 and 9 show no obvious post-dam changes in discharge regimes at the two stations closest to the dam, despite the clear short-term influence of dam releases, particularly at lower flows.

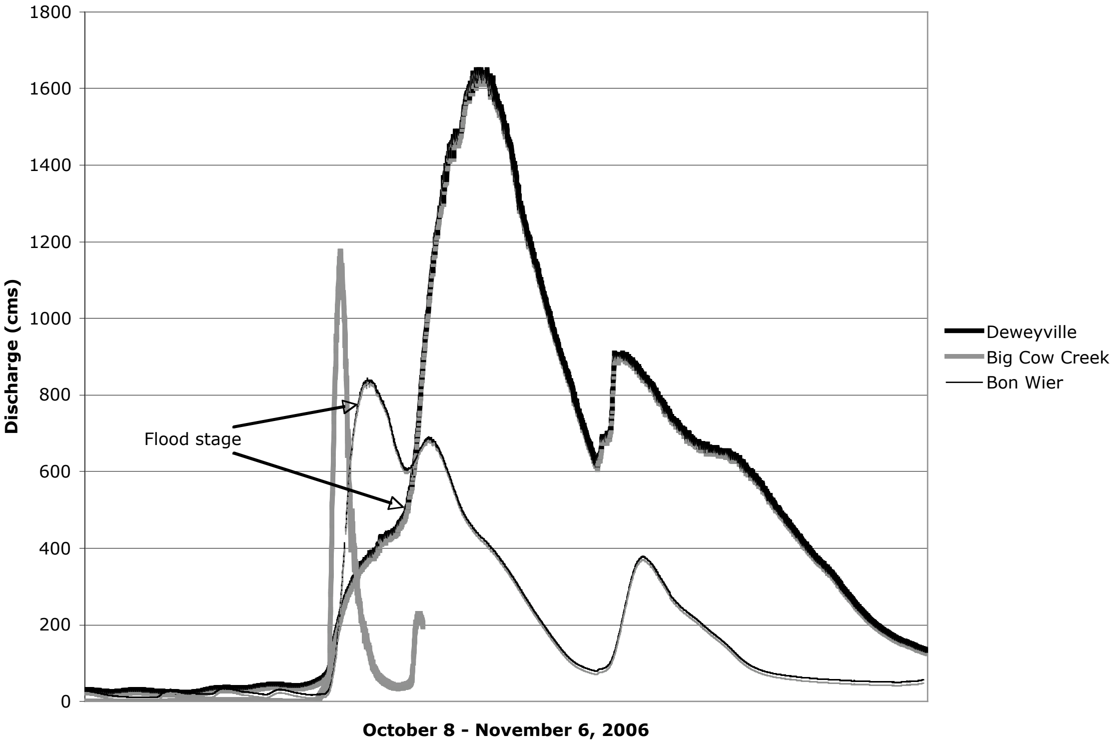


Figure 7. Hydrograph for the fall, 2006 flood event on the lower Sabine.

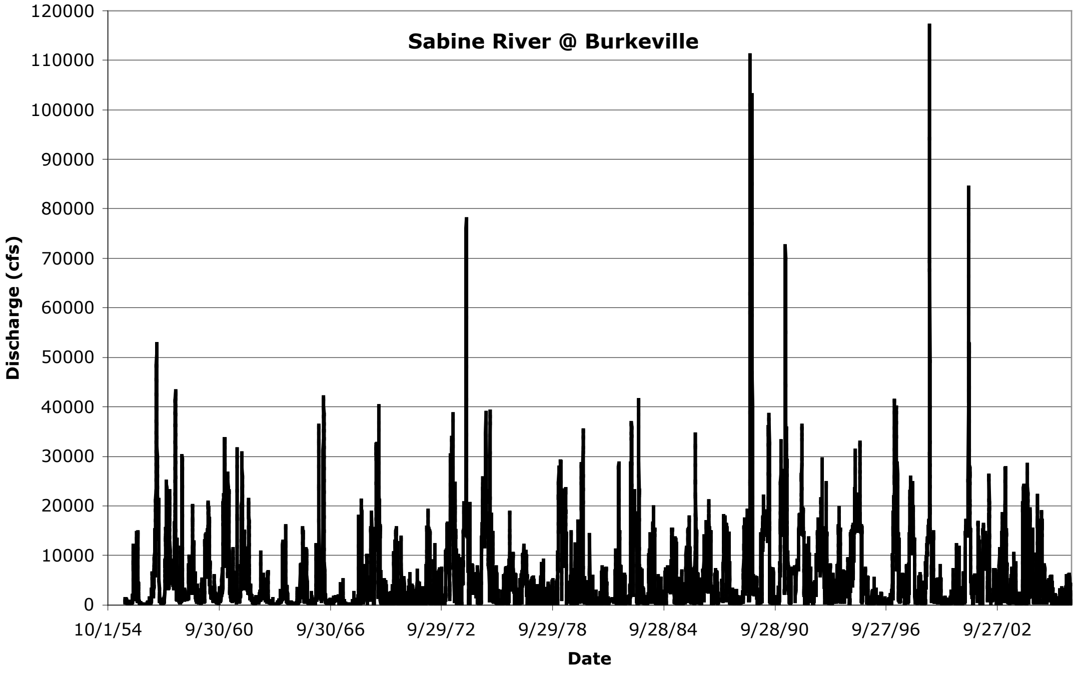


Figure 8. Mean daily flows for the period of record for the gaging station at SH 63 between Burkeville, TX and Burr Ferry, LA.

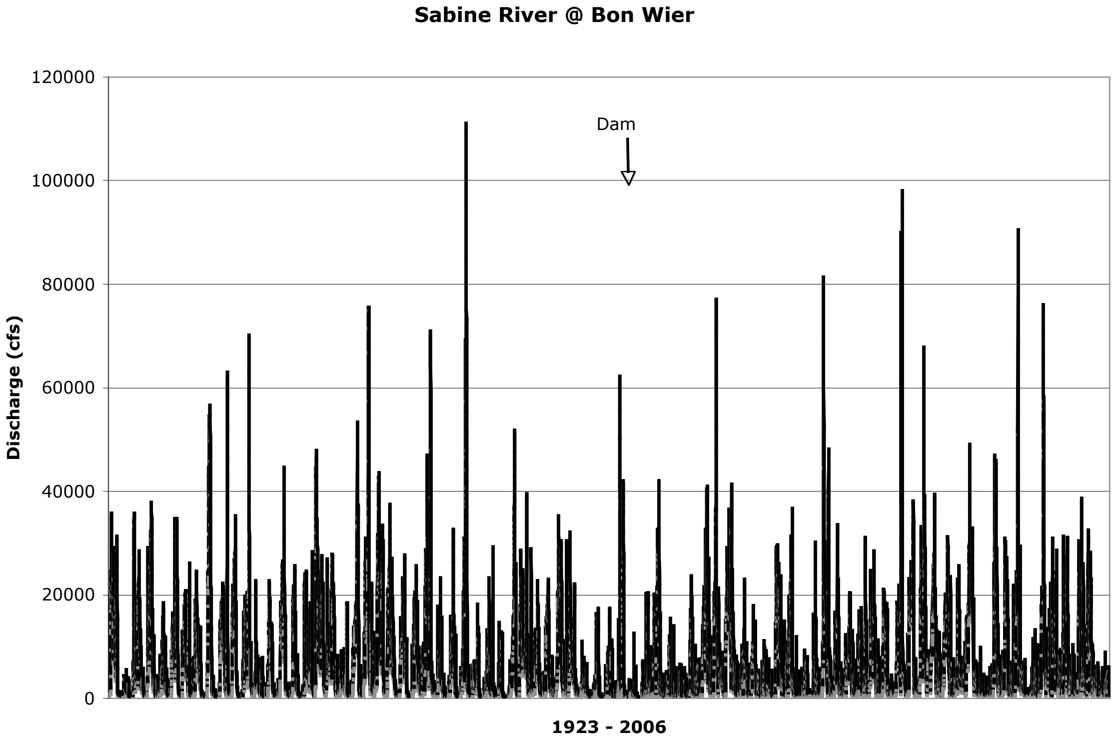


Figure 9. Mean daily flows for the period of record for the gaging station at US 190 between Bon Wier, TX and Merryville, LA.

Discharge records collected at 15 minute intervals for a 31-day period of relatively normal flows were examined to examine this effect. Over the period chosen (29 July to 29 August, 2006) discharge at Deweyville ranged from slightly greater than the long-term mean to slightly less than the long-term median. Figure 10 shows the highly pulsed releases from Toledo Bend, mirrored and only slightly subdued at the Burkeville station. The dam-release pulses are still evident, but increasingly smoothed, downstream at the Bon Wier and Deweyville stations. At Deweyville, in particular, the pulses are clearly imposed on a general downward trend in discharge.

At higher flows the dam releases are less noticeable. During the 2006 flood, for example, no dam-release pulses are obvious at Bon Wier and Deweyville, while peaks from Big Cow Creek—an unregulated tributary downstream of the dam—are clearly reflected in the river hydrographs (Fig. 7).

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 (see Fig. 10).

The coastal backwater effects are primarily physical rather than chemical. Saltwater intrusion does occur, but in most situations water upstream of Orange, TX is primarily fresh and net flow is downstream.

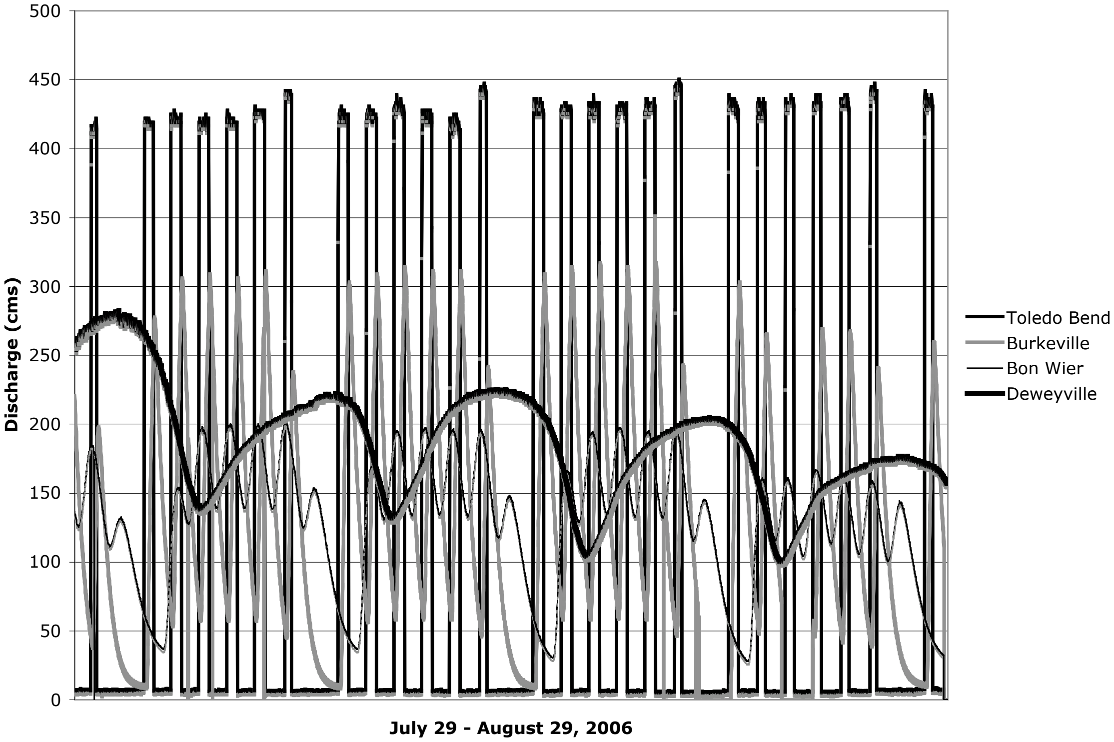


Figure 10. 31-day record of discharge (recorded at 15-minute intervals) in the lower Sabine River.

FLOWS IN THE SABINE DELTA

The lowermost of the Sabine River is a deltaic system, with complex flow patterns, numerous distributary channels, and considerable historic change. Distributary flow begins as far as ~70 km upstream, in the vicinity of Nicholls Creek.

Cutoff Bayou, 47 km upstream of Sabine Lake, connects the Sabine River to Old River. Cutoff Bayou is a critical hydrological point, as more than half of the Sabine River flow is diverted through the cutoff to Old River. This lower portion of the Sabine valley is the deltaic section of the river, as it marks the point at which a divergent, distributary network is present at all flow levels.

The Cutoff/Sabine confluence is atypical in terms of channel network geometry, as the flow from the Sabine into Cutoff Bayou is essentially upvalley, and the Sabine appears to be a much more direct and hydraulically efficient path. However, field measurements showed depths just inside the Cutoff at the Sabine River to be about 2 m deeper than in the adjacent river. The Old River channel is both deeper, and its bed at a lower elevation, than the Sabine. At the Old River/Sabine junction, Old River and the Sabine downstream are both about 6-7 m deep in midstream at normal water levels, while the Sabine upstream has a typical depth of about half that.

Cutoff Bayou

Measurements of flows by the SRA of Texas at the Sabine River/Cutoff Bayou confluence in early October, 2005 using an acoustic doppler current profiler showed a discharge of 2,639 immediately upstream of the bayou and 736 cfs downstream, indicating that 72% of the flow was diverted through Cutoff Bayou to Old River. Based on the Deweyville gaging station, this was not an unusually high flow regime; less than the median mean daily discharge. Several earlier measurements in 1966 and 1967, during generally low flow periods, indicate 43 to 63 percent of flow through Cutoff Bayou, with six of eight measurements indicating more than half the flow through the bayou (Rawson et al., 1967; 1969). Field measurements by the authors in June, 2006 indicated 73 percent of total flow (4155 cfs) passing through Cutoff Bayou.

The Old River channel is wider, deeper, and has a steeper slope, consistent with higher discharges via this channel than the Sabine River/Indian Bayou/Swift Slough route.

A U.S. Army Corps of Engineers survey in 1873 maps the Sabine River channel as the main channel with respect to navigation purposes, but associated maps show Old River to be wider and deeper (Leavenworth, 1873), as is the case today. The Sabine River below the cutoff is referred to as "the Narrows," in common with other 19th century maps.

Stateline Channel and Indian Bayou

The Sabine River comprises the Texas/Louisiana border in the study area. About 1.5 km downstream of Cutoff Bayou, the Sabine River as shown on most maps, and the state boundary, forks to the left (east), while the right fork is Indian Bayou. At present, however, the former Sabine Channel, which we call the Stateline Channel, is dry at normal flow levels, and the Indian Bayou channel is the main channel of the Sabine River. A barge was sunk at the mouth of the Stateline Channel sometime in the 1930s to divert more flow toward the Texas side of the river valley. By 1979 this feature was mostly covered with sediment, and in 2006 was undetectable.

As of the late 1960s, all of the Sabine flow below Cutoff Bayou at low flows entered the Indian Bayou anabranch (Rawson et al., 1969), but at high flows some water apparently still passed through the Stateline Channel. Aerial photographs from the mid 1990s show the Indian Bayou channel to be clearly dominant, but water is evident in the Stateline Channel, as well as in various oxbows and other former channels. A high-resolution Oct. 2005 photograph shows the entrance to Stateline Channel fully blocked by a sandbar. Discontinuous pools or reaches of water are apparent along the channel.

As of 2006, the entrance to Stateline Channel was completely blocked, with no field evidence of recent flow into it. The lower (downstream) end of the channel had standing water, but no flow, in June, 2006.

SEDIMENT TRANSPORT

Sediment Discharge

Measurements of sediment concentration and transport are rare for the lower Sabine River. The U.S. Geological Survey collected depth-integrated suspended sediment samples at the Deweyville station for the 1974-1995 period. A summary of these measurements is given in Table 3. Using reservoir survey data from the upper Sabine basin to estimate delivery of eroded sediment to streams, Phillips (2003) found that if all sediment delivered to channels were transported by the river it would imply sediment yields of more than 400 t km^{-2} yr^{-1}. This is at least an order of magnitude higher than is typical of the region, and is larger than the 159 t km^{-2} a^{-1} recorded in the Trinity River over the 1936-1946 period, which represents the highest suspended sediment yield for the lower reaches of a major river in Texas over a period of years (Solis et al., 1994). The low sediment yield at Deweyville (8.9 t km^{-2} yr^{-1}) is not unusual for streams in the southeast Texas coastal plain (Table 4).

Table 3. Suspended sediment transport in the Sabine River at Deweyville (calculated from USGS data).

Number of measurements	136	
Mean sediment concentration	39	mg l^{-1}
Mean daily sediment transport	589	t d^{-1}
Mean annual sediment yield	215,132	t
Mean annual specific sediment yield	8.9	t km^{-2} yr^{-1}

Table 4. Measurements and estimates of fluvial sediment yields in southeast Texas.

Location	Yield (t km^{-2} yr^{-1})	Source
Sabine R. at Deweyville	**8.9**	**this study**
Sabine R. at Tatum (upper Sabine basin)	89	Coonrod et al., 1998
B.A. Steinhagen Lake (Neches R.)	50	Austin et al., 2004*
Neches R. at Diboll	47	Coonrod et al., 1998
Angelina R. basin, forested	3.3	Blackburn et al., 1986
Angelina R. basin, logged	19 to 294	Blackburn et al., 1986
Angelina National Forest	2 to 70	Blackburn et al., 1990
Piney Cr. at Groveton	99	Coonrod et al., 1998
Trinity R. at Romayor	76	Phillips et al., 2004
Lower Trinity River basin	36	Greiner, 1982
Trinity R. at Liberty	1.6	Phillips et al., 2004
San Jacinto R. at Cleveland	188	Coonrod et al., 1998
Lower San Jacinto R. basin	143	Greiner, 1982
Houston Lake (San Jacinto R.)	6	TWDB reservoir survey data*

*Yield calculated from data in this source.

Double-mass curves plotting cumulative sediment loads (y-axis) against cumulative discharge (x-axis) were constructed for downstream gaging stations on nine Texas rivers by Solis et al. (1994). A break in slope indicating a change in sediment regimes toward lower sediment loads was found for the Trinity, Nueces, and Lavaca rivers, but not the Sabine. No temporal trend was noted in the USGS sediment data for Deweyville. Phillips (2003) found no evidence of reduced sediment transport or alluvial sedimentation attributable to Toledo Bend dam in the lower Sabine, except for a short scour zone immediately downstream of the dam.

Note that some of the data in Table 4 are based on measurements of suspended sediment. The sediment data from Deweyville indicates that the suspended sediment is overwhelmingly fine, with 81 percent, on average, finer than 0.063 mm in diameter (standard deviation 16.9; range 27 to 100 percent). Given the sandy bed of much of the river in the study area, and the presence of active, downstream-migrating bedforms such as sandy point bars (Phillips, 2003), it is apparent that some, and likely a significant amount, of sediment is transported as (presumably sandy) bed load. No reliable bedload measurements are available for the Sabine, and few any other sand-bed river. This situation may be improved in the near future with the completion of ongoing work in the Trinity River, Texas.

Estuary Sediment Delivery

Ravichandran et al. (1995) determined sedimentation rates in Sabine Lake using ^{239,240}Pu profiles, which were 4 to 5 mm yr^{-1} in both the upper and lower estuary. If this is extrapolated over the entire 53,349 ha surface area of the estuary, assuming a density of 0.7 t m^{-2}, it implies a sediment yield of nearly 37 t km^{-2} yr^{-1} for the entire upstream drainage area of Sabine Lake, which includes the Neches as well as the Sabine River—if all the sediment comes from those two rivers. A significant portion of the sedimentation, however, likely comes from autochthonous organic matter, shoreline erosion, marine and coastal sources, reworking of bed sediments, and local fluvial inputs from coastal watersheds (Phillips and Slattery, 2006).

According to TCB (2006: p. 6-6), the Sabine and Neches Rivers discharge "large quantities of fine muddy sediment" into Sabine Lake, with "very little bedload sand . . . transported along the lower Neches and Sabine Rivers." Mud-rich freshwater, especially during floods, spreads extensively across upper lake area and reduces salinity. During floods, suspended sediment may reach the Gulf, but most is deposited within Sabine Lake. Within the lake, sandy bedload sediment is generally restricted to small areas near river mouths (TCB, 2006: p. 6-6). However, the extent to which suspended sediment in the lake is derived from river inputs is unknown.

Stream Power

The relative sediment transport capacity of streams is directly related to stream power, which for a cross-section is given by

$$\Omega = \gamma\ Q\ S$$

where γ is specific gravity of water, Q is discharge, and S is energy grade slope.

For the gaging stations at Burr Ferry, Bon Wier, and Deweyville, stream power for the bankfull, flood stage discharges were calculated, using channel bed slopes calculated from the DEM in the immediate vicinity of the gaging stations (from three to four meander wavelengths upstream to a similar distance downstream of the site). As discussed earlier, bankfull or flood stage flows occur at different frequencies at each site. However, beyond being a convenient reference, bankfull flow may represent the maximum net downstream sediment transport.

Results (Table 5, Fig. 11) show a significant decrease in stream power between Burr Ferry and Bon Wier, with an increase at Deweyville, due to channel slopes about double those at the upstream sites. At the Deweyville station, however, channel slope from the DEM likely overestimates the energy grade slope due to the thalweg being cut to below sea level, and the tidal backwater effects. Similar calculations for 50, 10, and 1 percent probability flows show comparable stream power at Burkeville and Bon Wier, with apparently higher power at Deweyville.

To overcome the limitations of using channel slopes calculated from digital elevation data, stream power was calculated for several specific times during the October 2006 flood event. For any specific time, gage heights at the Bon Wier and Deweyville stations, the gage datums, and the distance between stations allows calculation of the mean water surface slope. These calculations were made for the point at which flow at Deweyville went overbank (Q = 516 m^{-3} sec^{-1}), the peak flow at the site (Q = 1640), and the beginning of the falling limb (Q = 492). Results (Table 6) show stream powers at near bankfull flow (Q_{bf} = 510 m^{-3} sec^{-1}) considerably lower than bankfull stream power at the upstream stations. Such a reduction in sediment transport capacity downstream is common in the lower coastal plain reaches of other rivers in Texas and elsewhere (Phillips and Slattery, 2006; 2007).

Table 5. Cross-sectional stream power (Ω) for bankfull flows, based on channel slopes.

	Burr Ferry	Bon Wier	Deweyville
Slope	0.0004	0.00034	0.00079
Q (m^3 sec^{-1})	1880	793	510
Ω (W m^{-1})	7.3696	2.6423	3.9484

Table 6. Cross-sectional stream power at Deweyville during Oct. 2006 flood event, based on water surface slopes.

	Slope	Q (m^3 sec^{-1})	Ω (W m^{-1})
Beginning of overbank flow	0.00015	516	0.7452
Peak flow	0.00013	1640	2.0374
Receding limb	0.00010	492	0.5068

SUMMARY AND CONCLUSIONS

Flows in the lower Sabine River are affected by the climate and hydrologic response of the drainage basin, releases from Toledo Bend Reservoir, water withdrawals, and tidal and coastal backwater effects. Releases from Toledo Bend create a highly pulsed discharge regime, but the effects exhibit both spatial and temporal decay. The influence of dam releases on flow is reduced downstream—dam releases dominate flow at the Burr Ferry gaging station, but are superimposed on patterns determined by watershed runoff at Deweyville. Dam releases are most influential during dry, low-flow periods, and hydrographs reflect runoff responses during wet, high-flow periods. The effects of the dam are most evident on an hour and daily time scale, and do not substantially influence monthly or annual mean flows, or peak flows.

Water diversions have significant impacts on flows, but such effects have been less in recent decades (see fig. 4), and either do not have discernible effects on freshwater inflows to Sabine Lake, or any effects have been offset by climatic trends. Coastal backwater effects are strongest at Sabine Lake, declining in importance upstream. These effects are evident, however, as far upstream as Deweyville and beyond.

Overbank flow—and the associated alluvial sedimentation—is increasingly common further downstream of Toledo Bend. The most important feature of the lowermost, deltaic portion of the river is the complex and changing patterns and routing of flow. A majority of flow between Cutoff Bayou and the Sabine/Old River confluence is carried by the Old River channel. The potential geomorphic causes and implications of this are addressed in the next section.

Sediment transport data are scarce, but records from the Deweyville station indicate low sediment yields that are considerably less than delivery of sediment to the fluvial system. This in turn suggests significant alluvial sediment storage, which is consistent with the extensive and active alluvial floodplains in the lower Sabine, and increasing overbank flow occurrence and decreasing stream power further downstream.

REFERENCES

Austin, B., Thomas, D., Burns, R., Sansom, M. 2004. Volumetric Survey of B.A. Steinhagen Lake. Austin: Texas Water Development Board, 42 p.

Blackburn, W.H., Wood, J.C., DeHaven, M.G., 1986. Stormflow and sediment losses from site-prepared forestland in east Texas. Water Resources Research 22, 776 – 784.

Blackburn, W.H., Knight, R.W., Wood, J.C., Pearson, H.A., 1990. Stormflow and sediment loss from intensively managed forest watersheds in east Texas. Water Resources Bulletin 26, 465 – 477.

Coonrod, J.E.A., Holley, E.R., Maidment, D.R., Ward, G.H. 1998. Suspended Sediment Yield in Texas Watersheds. Austin: Univ. of Texas Center for Research in Water Resources, technical report CRWR 270.

Greiner, J.H., 1982. Erosion and Sedimentation by Water in Texas. Austin: Texas Water Development Board.

Leavenworth, F.P. 1873. Survey of Sabine River from Belzora, Texas, to Sabine Lake. Washington: U.S. Army Corps of Engineers.

Phillips, J.D. 2003. Toledo Bend Reservoir and geomorphic response in the lower Sabine River. River Research and Applications 19: 137-159.

Phillips, J.D., Slattery, M.C. 2006. Sediment storage, sea level, and sediment delivery to the ocean by coastal plain rivers. *Progress in Physical Geography* 30, 513-530.

Phillips, J.D., Slattery, M.C., 2007. Downstream trends in discharge, slope, and stream power in a coastal plain river. *Journal of Hydrology* 334, 290-303.

Phillips, J.D., Slattery, M.C., Musselman, Z.A. 2004. Dam-to-delta sediment inputs and storage in the lower Trinity River, Texas. Geomorphology 62, 17-34.

Ravichandran, M., Baskaran, M., Santschi, P.H., Bianchi, T.S. 1995. Geochronology of sediments in the Sabine-Neches estuary, Texas, U.S.A. *Chemical Geology* 125, 291-306.

Rawson, J., Johnson, S.L., Smith, R.E. 1969. Quantity and Quality of Low Flow in Sabine and Old Rivers Near Orange, Texas, September 12-15, 1967. Austin: Texas Water Development Board Report 90 (available via http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/GWreports.asp).

Rawson, J., Reddy, D.R., Smith, R.E. 1967. Low-Flow Studies, Sabine and Old Rivers Near Orange, Texas, Quantity and Quality, April 12, October 31 – November 4, 1966. Austin: Texas Water Development Board Report 56 (available via http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/GWreports.asp).

Solis, R.S., Longley, W.L., Malstaff, G., 1994. Influence of inflow on sediment deposition in delta and bay systems. In Freshwater Inflows to Texas Bays and Estuaries, Longley WL (ed.). Texas Water Development Board: Austin; 56 – 70.

Sullivan, S., Thomas, D. Segura, S., Hulton, S., Elliott, W., Robichaud, M. 2003. Volumetric Survey of Lake Conroe. Austin: Texas Water Development Board

TCB (Turner, Collie, Bladen, Inc.). 2006. Sabine Lake. Ecological Condition of the Sabine-Neches Estuary. Prepared for Sabine River Authority of Texas & Lower Neches Valley Authority.

Geomorphic Controls on Transition Zones in the Lower Sabine River, Texas-Louisiana

INTRODUCTION

Transition zones in river systems are often associated with direct geomorphological or geological controls such as lithology, structure, inherited topography and landforms, and transitions in geomorphological resistance. Fluvial and alluvial landforms and morphology also reflect changes associated with hydrologic, land use, and other forcings. Controls on transition zones thus encompass both static (on human time scales) factors such as geological boundaries, and dynamic factors such as upstream or downstream propagation of effects of, e.g., sea level rise or below-dam scour zones. Controls also reflect more-or-less continuous (or at least chronic) phenomena such as deltaic sedimentation, singular events such as effects of major storms, and inherited features such as paleoshorelines and alluvial terraces.

Over historic to Quaternary (and longer) time scales, rivers respond primarily to base level, climate, and tectonic forcings. Over contemporary to historic time frames, rivers also respond to shorter-term climate and hydrologic fluctuations, land use and vegetation cover changes, and various human impacts. In either case the drivers of change influence, and are reflected by, fluvial geomorphology. Thus the identification of geomorphic controls on transition zones facilitates assessment of trajectories and probabilities of future changes and migrations in these critical locations.

Water, wetland, and riparian resource management require some subdivision or classification of channels, networks, and watersheds. Practical considerations dictate units of manageable size and complexity, but even more importantly, the variation in hydrological, ecological, and geomorphological boundary conditions, issues, and opportunities within and between fluvial systems need to be accounted for. The identification of key transition zones not only facilitates logical subdivisions, but is directly relevant to pinpointing potential "hotspots" of high resource value and vulnerability. Such transition zones are also sensitive indicators of changes triggered by, for example, climate, sea level, and land use change. Thus efforts to discover geomorphic controls of transition zones, rather than simply identifying form and process differences between reaches, facilitates understanding of the history and dynamics of fluvial change. This is particularly important in streams such as the Sabine River (Texas and Louisiana), subject to a variety of forcings and disturbances over Quaternary, historical, and contemporary time scales, including climate change, sea level oscillations, neotectonics, and human agency.

The purpose of this study is to identify important morphological, hydrologic, and ecological boundaries along the lower Sabine River, Texas and Louisiana, identify the relevant geomorphic controls, and assess the recent and potential future trajectories of change.

Geomorphology and River Zonation

The most obvious differences between fluvial systems—or different portions of the same fluvial system—are geomorphological. Characteristics such as channel width and depth, bank type and steepness, floodplain morphology, slope, bed and bank material, valley wall confinement, and other features are relevant not only to fluvial geomorphologists, but also to river engineering and to any human access to or use of river resources. Further, fluvial geomorphology both affects and reflects hydrology. The type and quality of aquatic and riparian habitats are also directly related to specific landforms and geomorphic processes (e.g., Hupp and Osterkamp, 1996; Scott et al., 1996; Robertson and Augspurger, 1999; Johnston et al., 2001; Gumbricht et al., 2004; Moret et al. 2006). There is little or no dispute of this contention. Statements such as Montgomery's (1999), for example, that "spatial variations in geomorphic processes govern temporal patterns of disturbances that influence ecosystem structure and dynamics," have never been seriously challenged. The widespread acceptance of geomorphology-based classification systems by ecologists, hydrologists, and water resource managers is evidence of the general realization of the critical role of geomorphic properties for essentially all aspects of river systems (Newson and Newson, 2000; Parsons et al. 2002; Brierly and Fryirs, 2005). Geomorphology is also critical to classification, delineation, and impact analysis of wetlands. U.S. government agencies charged with wetlands regulatory and assessment programs, for example, have adopted an explicitly geomorphic/hydrologic approach to wetland identification and characterization known as the Hydrogeomorphic Method (Brinson, 1993; Johnson, 2005).

Rivers typically exhibit systematic changes in the upstream-downstream direction, overlaid by local spatial variability in forms, processes, and controls. In some cases, however, due to thresholds or to the transgression of key environmental boundaries, distinct zones characterized by specific hydrological, ecological, and geomorphic characteristics can be identified--even though the boundaries between those zones may be gradual and indistinct. Because of the interrelationships among geomorphology, hydrology, and ecology in river systems, such boundaries or transitions will have a geomorphic expression—and thus can be linked to geomorphic controls.

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. 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 (see section 1).

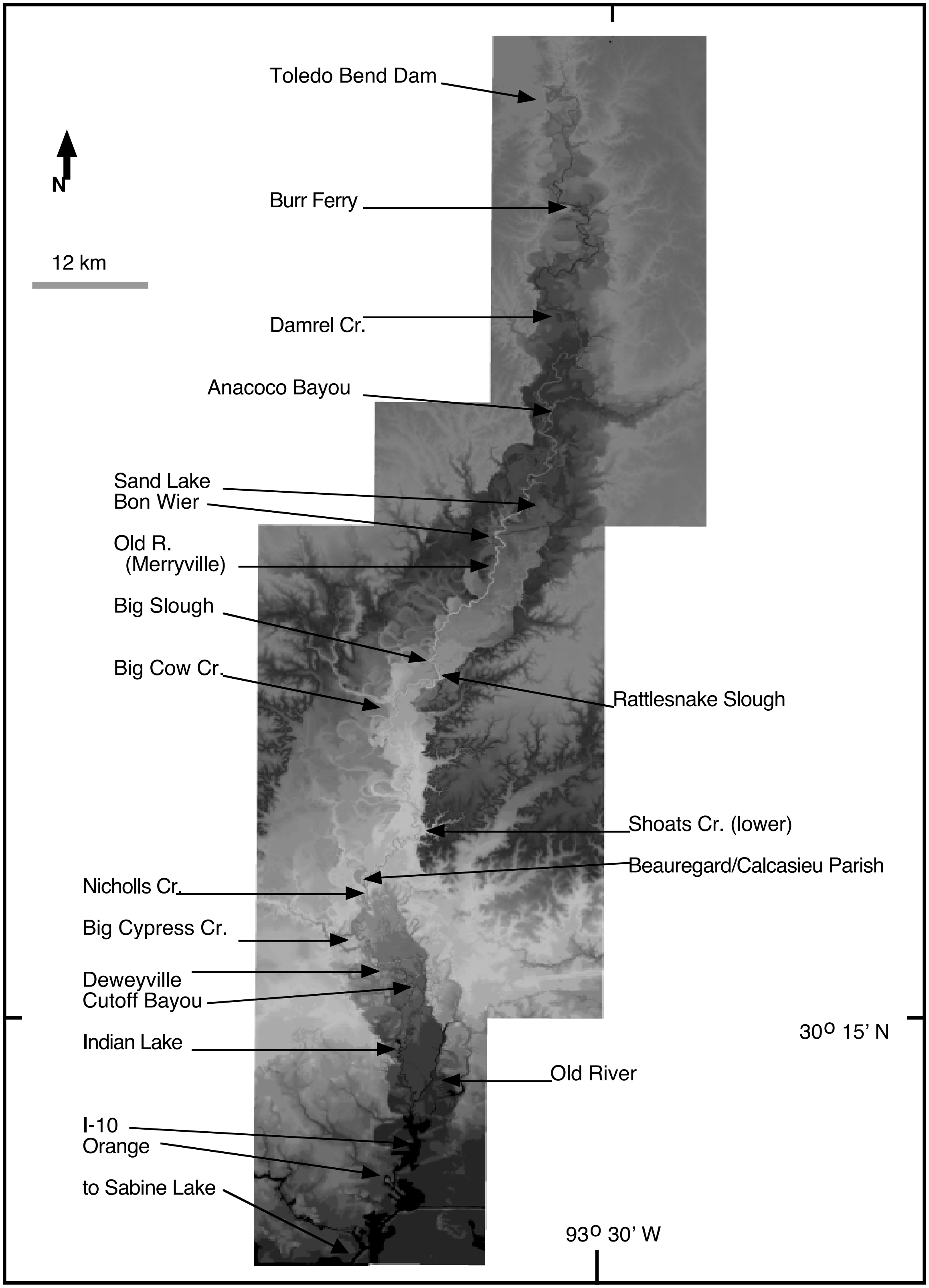


Figure 1. Study area, showing locations referred to in the text. Base map is is density plot derived from 30-m DEM data.

Channel and Valley Geomorphology

The Sabine River downstream of Toledo Bend Dam 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).

From Toledo Bend for more than 100 km downstream, the Sabine channel is a single-thread meandering channel with large, sandy point bars. The morphology of these bars and the associated cutbanks, vegetation indicators, and comparison of recent field observations and mapping with historical aerial photographs indicates a highly active channel (Phillips 2003). The channel is characterized by point bar accretion and cutbank erosion, and by downstream migration of several point bars, as indicated by the encroachment of the bars on former bank scarps. Further downstream of Toledo Bend, the 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, the Sabine takes on a different character, with a wider floodplain, and a transition from a dominantly convergent to a dominantly divergent network. In other words, 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 (backflooded from the river even at low flows).

The Sabine River channel 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). 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 70 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 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. This appears to be the case for the Texas side of the valley, at least, particularly downstream of the intake canal of the Sabine River Authority.

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

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 (Fig. 2). 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).

Figure 2. Several generations of paleomeanders are evident on this aerial photograph of the Sabine River floodplain near Bon Wier, TX.

In the lower Sabine, Alford and Holmes (1985) date the Deweyville terraces 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, based on optically stimulated luminescence dating, by entrenchment from 20 to 18 Ka and aggradation from 18 to 2 Ka (Otvos 2005: 102). The Sabine 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. Blum et al. (1995) estimate the incision associated with the Beaumont terraces at about 100 ka, associated with marine oxygen isotope stage 5 (115 to 75 Ka). 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).

Morton et al.'s (1996) analysis implies Trinity River incision sometime after about 13 Ka, with aggradation triggered by sea level rise and progressive onlap and burial of Deweyville surfaces sometime during isotope stage 1, from about 10 Ka. This is consistent with analyses of offshore and estuarine sediments, which indicate that Galveston Bay began forming initially by flooding of incised valleys about 8 Ka, with subsequent, apparently rapid inundation of valleys creating the approximate modern version of Galveston Bay about 4 Ka (Anderson et al. 1992). Rodriguez et al. (2005) identified flooding surfaces in Galveston Bay from decreases in sedimentation rates and changes from delta plain to central estuarine basin facies in cores. Formation of these surfaces dates to 8.2 and 7.7 Ka, at depths matching the elevations of relatively flat alluvial terraces.

METHODS

Data Sources

The identification of transition zones and potential geomorphic controls was made using a combination of field investigations and analysis of digital elevation data, aerial photography, and other data sources.

Digital data was obtained primarily from the Texas Natural Resources Information System and the Louisiana Statewide Atlas GIS. Digital elevation model (DEM) data at a 30 m resolution was obtained for the entire study area, and higher-resolution data (10 m or 5 m) for some specific subareas. The primary aerial imagery used was 2.5 m resolution color digital orthophotoquads (DOQs), based on photography acquired in 1994-5. In areas where additional information was required or recent change was apparent, this was supplemented with 1-m DOQs acquired in 2004, and 0.3 m aerial photography flown after Hurricane Rita passed through the area in 2005. Topographic maps (1:24,000 scale) were obtained in DLG (digital line graph) form.

Geological mapping of the area exists at the 1:250,000 scale for the Texas side and at the 1:100,000 scale for most of the Louisiana side of the Sabine valley. These maps were obtained from the Texas Bureau of Economic Geology (Geologic Atlas of Texas) and the Louisiana Geological Survey, respectively. The Tectonic Map of Texas (Ewing et al. 1991) was also used.

The entire Sabine River and Old River channels from Bon Wier (131 km upstream of Sabine Lake) to Interstate 10 near Orange, Texas in the tidal reach of the river (17 km upstream of the estuary) was traversed by small boat in March and June, 2006, supplemented by additional land-based investigations at other sites. Additional sites between Toledo Bend dam (213 km upstream of Sabine Lake) and Bon Wier were accessed by small boat in 2005, and by land and canoe in 2000 and 2001 in conjunction with earlier studies (Phillips 2003; Phillips and Musselman 2003).

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 point bars was assessed on the basis of visible bedforms, vegetation cover, and evidence of downstream encroachment, lateral growth, or erosional diminution. Grab samples of bar sediments were also taken.

Based on initial reconnaissance and preliminary data analysis, potential geomorphic controls and indicators were identified. The study reach was then subdivided on the basis of each of these, and the boundaries compared. For convenience, this procedure is referred to as boundary coincidence analysis (BCA).

Boundary Criteria

The geomorphological framework of the lower Sabine River valley includes topographic, geologic, and hydrological controls and influences. From Toledo Bend Dam to Sabine Lake, discharge and cross-sectional area generally increase downstream as expected. Elevations decrease and valley width increases, on average, along the upstream-downstream axis. Between the Gulf of Mexico and Sabine Lake on the lower end and Toledo Bend on the upper end there is also a general gradient from a system dominated by coastal hydrodynamics to increasing fluvial influence, to total fluvial domination. In the downstream direction, both the hydrologic and geomorphic impacts of releases from Toledo Bend decrease relative to climate- and runoff-driven flow variations.

Eight criteria were selected for BCA, based on reconnaissance of the study area, previous experience in the lower Sabine and Trinity River basins, and the literature on the fluvial geomorphology of Gulf Coastal Plain rivers: surficial geology, valley width, valley confinement, network characteristics (divergent vs. convergent), sinuousity, slope, paleomeanders, and point bars.

Structure and lithology do no exert the same level of control in coastal plain rivers such as the Sabine as they do in other geological settings. Nevertheless, geologic constraints on channel and valley processes, specific inherited features, and the recent geologic history can exert significant controls over river morphology and processes in the Texas/Louisiana coastal plain. In the Trinity River, for example, inherited features and antecedent morphology formed during lower sea levels earlier in the Quaternary have important influences on the modern Trinity River and Bay (Morton et al. 1995; Rodriguez et al. 2005; Phillips et al. 2005; Phillips and Slattery 2007).

Valley confinement refers the extent to which lateral migration and channel change is inhibited by contact with the walls of the alluvial valley. Following Brierly and Fryirs (2005), valley segments were classified as confined if the channel is in contact with the valley wall for 90 percent or more of its length, partly confined if the contact is 10 to 90 percent, and unconfined if the channel is in contact with the valley wall over less than 10 percent of its length. The lower Sabine is entirely partly- and unconfined. The ratio of floodplain and/or valley to channel width is also a common discriminant factor used in geomorphic classifications. However, these ratios—though variable—are uniformly large in the lower Sabine and are not a useful discriminator within the study area.

Network characteristics refers to convergent or divergent connections between the trunk stream and tributaries (or distributaries), and single- vs. multi-thread channel patterns. Low-gradient coastal plain rivers often have a transition point or zone in which they change from a convergent, flow-collecting network to a divergent, flow-distributing network. There may also be important transitions with respect to the presence of multiple high flow channels. This was determined from DOQs, digital elevation models, and field observations of flow patterns in the reach from Nicholls Creek to the Old River/Sabine junction.

Sinuousity is the "curviness" of the river, computed by dividing river channel distance by valley distance. Beyond being a distinctive geometric characteristic of rivers, sinuousity changes in coastal plain rivers often represent different forms of adjustment to base (sea) level change. In response to sea level rise or fall, coastal plain streams with limited capacity to degrade or aggrade their channels can adjust the hydraulic slope by increasing or decreasing the channel length. Zones of varying sinuousity were identified visually from DOQs, and the sinuousity was calculated from DEM data.

On an instantaneous basis, the relevant slope in fluvial hydraulics is the energy grade or friction slope, typically approximated by water surface slope. Over longer time scales, these are controlled by channel bed and valley slopes. Water surface slopes can be determined from gaging station data for a given time (see section 1 and Phillips and Slattery, 2006), but given the paucity of gaging stations the resolution is not particularly good, and the representativeness questionable. For this study, valley and channel slopes were calculated from the DEM for pre-determined reaches between major morphological features, tributary junctions, and bridge crossings. Adjacent reaches where channel and valley slopes were both within 25 percent were aggregated to produce the slope zonation.

The rivers of southeast Texas in general, and the Sabine in particular, are characterized by large (relative to the modern river) meander scars in the river valley (Alford and Holmes, 1985; Blum et al., 1996). Evidence of at least three different sets of these paleomeanders can be seen in the lower Sabine valley. These are a distinctive feature of the floodplain and valley, and can strongly influence the location and characteristics of tributaries (Nicholls Creek, for example, occupies a paleomeander). The paleomeanders, often associated with flats or depressions in the alluvial valley, may also significantly influence floodplain connectivity and flow patterns at high flows (Phillips and Slattery, 2007). The presence or absence of different "generations" of paleomeanders may also reflect the aggradational history of the valley. DOQs and DEMs were examined to determine how many distinct sets of paleomeanders could be identified, in terms of relative distance from the modern river and valley side, size or magnitude, and juxtaposition and geometry indicating separate meander trains.

Point bars—typically sand in the lower Sabine—are important fluvial bed forms, and key indicators of lateral channel migration. They also reflect the type and general supply of sediment in the river. DOQs and field observations were used to identify the number of point bars (i.e., whether they occur on the inside of all, most, some, few, or none of the channel bends), general size (small bars occurring only at the apex; large bars extending to both the up- and downstream limbs), composition (sand vs. mud), and stability, primarily indicated by vegetation establishment, but also by the formation of secondary features such as transverse gullies on the point bars.

In each case, the identified reaches and zones were identified by nearby prominent landmarks such as tributaries and bridge crossings, and by approximate up- and downstream distances from Sabine Lake using both measurements from the DEM, and approximate river mileages from Sabine River Authority of Texas maps, because the latter are widely used by field personnel. The distances differ (even discounting the different units) partly due to inherent measurement imprecision and error, the dynamic nature of the channel, and the measurement methods. The SRA river mileages are based on the most prominent visible channels on DOQs, whereas the DEM measurements are based on a flow routing algorithm. In the results below the DEM measurements will be given in the text, with reference to distance upstream from Sabine Lake.

RESULTS

The results of each assessment are given in a series of tables below. Table 1 lists the general geological zones, based on the surficial formation comprising the surrounding uplands outside the river valley, and the valley side itself, and on the Pleistocene alluvial terraces present within the valley. The reaches associated with the geological zones are shown in Table 2. Tables 3-9 show the identified reaches or zones based on valley confinement, network characteristics, sinuousity, slope, paleomeanders, and point bars.

Geology and Valley Confinement

Six geological zones (Table 1) can be identified, based on the mapped formations of the upland areas encompassing the river valley, the formations comprising the valley walls, and the alluvial terraces mapped within the valley. The uppermost segment—about half the study reach (Table 2)—consists of a valley incised into the early Pleistocene Willis formation. From about 113 to 58 km, the valley is incised into the middle Pleistocene Lissie formation, and the remainder of the valley is cut into the Late Pleistocene Beaumont formation or younger Holocene materials.

Table 1. Geological zones of the lower Sabine River. See table two for specific reaches. Willis, Lissie, Beaumont: Early, middle, and late Pleistocene formations, respectively. Pdf, Pds, Pdm: Fredonia, Sandjack, and Merryville alloformations of the late Pleistocene Deweywille alluvial terraces.

Zone	*Upland*	*Valley side*	*Terraces*	*Other*
1	Willis	Willis	Pdf, Pdm, Pds	
2	Lissie	Beaumont	Pdf, Pdm, Pds	Valley constricted by Lissie fmn; fault
3	Lissie	Beaumont	Pdf, Pdm, Pds	
4	Beaumont	Beaumont	Pdf, Pdm, Pds	Lower boundary corresponds with trend of Houston Ridge/Ingleside barrier
5	Beaumont	Beaumont	Pdm, Pds	
6	Beaumont	Beaumont, Holocene	None	Marsh, coastal lowlands

Table 2. Geological zonation. DEM D: distance (km) derived from digital elevation model flow paths. River miles: Sabine River Authority of Texas designations, measured from aerial photographs.

Upstream	Downstream	DEM D	River miles	Geologic Zone
Toledo Bend	Big Slough	213-113	146-77	1
Big Slough	Beauregard/ Calcasieu line	113-71	77-48	2
Beauregard/ Calcasieu line	Big Cypress Cr.	71- 58	48-39	3
Big Cypress Cr.	Cutoff	58- 47	39-29	4
Cutoff	Orange	47- 18	29-11	5
Orange	Sabine Lake	18- 0	11- 0	6
Old River		33		4, 5

The late Pleistocene Deweyville alluvial terraces (Fredonia, Sandjack, and Merryville alloformations) are all present from the dam (213 km) to about 47 km, with the highest, oldest Fredonia and eventually all three buried by Holocene alluvium further downstream. The geologic zonation is also influenced by a valley constriction and mapped fault zone, and by the trend of a Pleistocene barrier ridge, and presence of coastal landforms (Table 1).

With respect to valley confinement, no confined reaches exist in the study area (Table 3). The lowermost 79 km, and the reach from 168 to 110 km are unconfined; the remainder is partly confined. Some significant local constrictions, exist, however, associated with geological features. Examples are Runyon Hills, just north of the Burr Ferry site, and in the vicinity of the confluence of Big Cow Creek.

Table 3. Valley Confinement. DEM D: distance (km) derived from digital elevation model flow paths. River miles: Sabine River Authority of Texas designations, measured from aerial photographs.

Upstream	*Downstream*	*DEM D*	*River miles*	*Valley Confinement*
Toledo Bend	Damrel Creek	213-168	146-114	Partly confined
Damrel Crk.	Rattlesnake Slough	168-110	114- 76	Unconfined
Rattlesnake	Shoats Cr. Lower	110- 79	76- 54	Partly confined
Shoats Cr.	Sabine lake	79- 0	54- 0	Unconfined

Network Characteristics

From Toledo Bend downstream, the Sabine River transforms from a single-thread channel to a single-thread with multiple distributaries at high flows, to a fully distributary network (Table 4). However, the dominant network geometry is convergent at normal flows down to 47 km. From about 128 km some larger tributaries are anastamosed.

Table 4. Network characteristics.

Upstream	*Downstream*	*DEM D*	*River miles*	*Network characteristics*
Toledo Bend	Old R. nr Merryville	213-128	146-88	Convergent, single-thread
Old R. nr Merryville	Nicholls Cr.	128-69	88-46	Convergent; multiple distributary high flow channels; anastamosed tributaries
Nicholls Cr.	Cutoff	69-47	46-29	Dominantly convergent; multiple distributary high flow channels
Cutoff	I-10	47-17	29-13	Delta; distributary at all flows
I-10	Sabine Lake	17- 0	13 –0	Tidal

In the lower 60 km of the river (from Big Cypress Creek to Orange) eight cross-sections of the lower Sabine valley from the junction of Big Cypress Creek (upstream of Deweyville and SH 12) to Orange were examined using the digital elevation data. These were oriented either normal to the general trend of the valley, or in two cases, parallel to SH 12 and the Kansas City Southern Rail line which cross the valley.

These indicate that the modern, active floodplain is typically 8 to 8.5 km wide in this reach. The number of channels on each transect was estimated from the profiles (field experience shows that not all channels show up as "blue lines" on topographic maps or are clearly visible on aerial photographs). From Big Cypress Creek, past SH 12 and down to the Indian Lake Community (about 44 km upstream of Sabine Lake) there are 13 to

15 channels in the modern, active floodplain, along with two to six channels on terrace surfaces.

Further downstream there are fewer channels, but a lower, wider valley bottom. It is likely that Holocene sea level rise has resulted in the infilling and beveling of the anastomosing channels in these lowermost reaches. The valley crosses five to eight channels between Indian Lake and Blue Elbow Swamp (upstream of IH 10), but only one in the Orange transect.

Sinuousity

Mean sinuousity for the entire study area is 1.44, but sinuousity of individual reaches varies from 1.35 to 2.32 (Table 5). Sinuousity values of 1.2 to 1.3 are often used to distinguish between straight and meandering channels, and sinuosity >1.5 is sometimes used to indicate very high sinuousity (e.g. Rosgen 1996). Thus the entire river is sinuous and meandering, while the lower 79 km are highly sinuous to varying degrees. Old River has a sinuousity more similar to the Sabine River upstream of Cutoff Bayou than to the section of the river it parallels.

Table 5. Sinuousity zonation. DEM D: distance (km) derived from digital elevation model flow paths. River miles: Sabine River Authority of Texas designations, measured from aerial photographs.

Upstream	*Downstream*	*DEM D*	*River miles*	*Sinuousity*
Toledo Bend	Shoats Cr. lower	213-79	146-54	1.35
Shoats Creek	Big Cypress Creek	79-58	54-39	1.68
Big Cypress	Cutoff	58- 47	39-29	1.78
Cutoff	Old R. Jct.	47- 27	29-18	2.32
Old R. Jct.	I-10	27- 17	18-13	2.04
I-10	Sabine Lake	17- 0	13- 0	2.24
Old River		33		1.35
Toledo Bend	Sabine Lake	213- 0	146- 0	1.44

Slope

Table 6 shows channel slopes derived from calculated flow paths in the DEM, and valley slopes based on downvalley transects calculated from the DEM. The zones were identified based on initial visual inspection of the longitudinal profile (Fig. 3). Eleven distinct slope zones were identified. Slopes generally but irregularly decrease down to 58 km, but increase further downstream.

Table 6. Slope zonation. DEM D: distance (km) derived from digital elevation model flow paths. River miles: Sabine River Authority of Texas designations, measured from aerial photographs.

Upstream	*Downstream*	*DEM D*	*River miles*	*Slope* ($\times10^{-4}$)	
				Channel	*Valley*
Toledo Bend	SH 63	213-192	146-131	9.789	11.779
SH63	Anacoco Bayou	192-151	131-104	4.583	6.874
Anacoco	Bon Wier	151-131	104- 91	8.230	10.966
Bon Wier	Big Cow Cr.	131-103	91- 70	2.786	3.432
Big Cow	Shoats Cr. lower	103- 79	79- 54	5.570	8.015
Shoats Cr.	Nicholls Creek	79- 69	54- 46	0.966	2.179
Nicholls	Big Cypress Cr.	69- 58	46- 39	0.913	1.235
Big Cypress	Cutoff	58- 47	39- 29	7.916	10.000
Cutoff	Old R. Jct.	47- 27	29- 18	3.503	8.130
Old R. Jct.	Sabine Lake	27- 0	18- 0	1.493	2.181
Old River		33		6.066	8.197
Toledo Bend	Sabine Lake	213- 0	146- 0	4.605	6.083

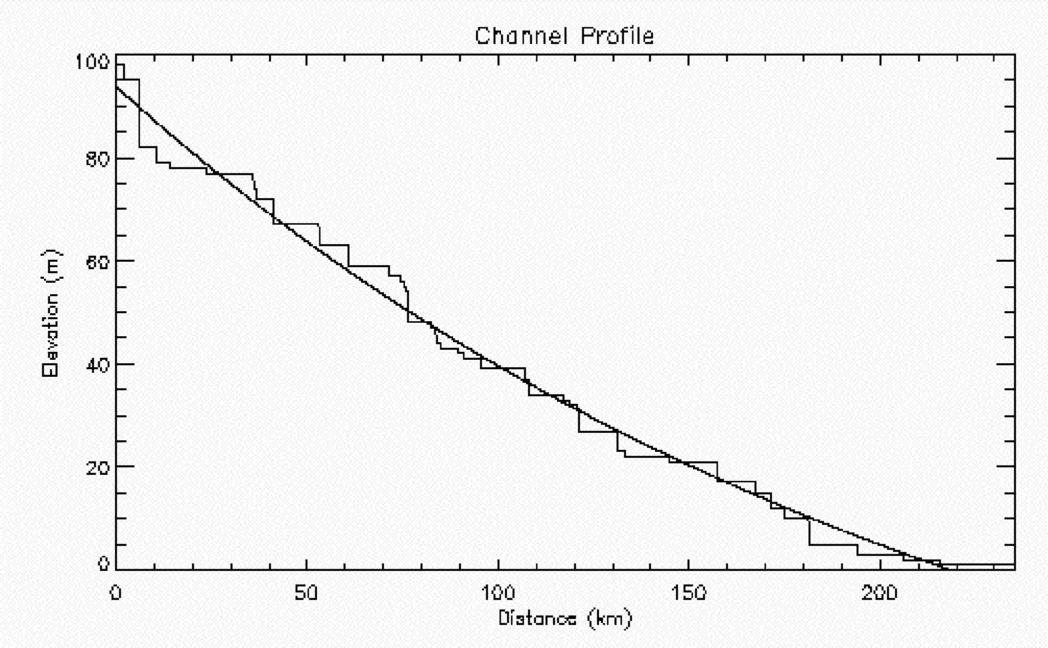


Figure 3. Longitudinal profile of the Sabine River from Toledo Bend to Sabine Lake. The irregular line is from raw DEM data; the smoothed curve is an exponential fit to the data: $Y = (150.62\ e^{-0.00000446\ X}) - 56.806$.

Field surveys to pinpoint the location at which the channel thalweg is cut to sea level are lacking. However, the datum of the gage at Deweyville (SH 12), which is above the level of the thalweg, is 1.8 m below sea level. Based on this, and the slope of the channel in this reach, the Sabine is cut to sea level or below at least as far upstream as Big Cypress Creek (58 km), and perhaps as far as Nicholls Creek (69 km).

Paleomeanders

The arcuate shapes of former river meanders are readily recognized in DOQs and topography. The paleomeanders not associated with the modern river are distinguishable from modern oxbows and meander scars due to their different sizes, as well as distance from, and elevation relative to, the modern river and active floodplain (Alford and Holmes 1985; Blum et al., 1995). These are important not only as distinctive morphological features of the floodplain, but also because of their effects on tributary locations, and river-floodplain flows and connectivity. Table 7 shows subdivisions based on the number of paleomeander scar sets identified within the valley. These increase from one to three sets down to 79 km, and then decrease again further downstream.

Table 7. Number of sets or generations of paleomeander scars evident within the river valley (excluding oxbows and cutoff channels associated with the modern channel).

Upstream	*Downstream*	*DEM D*	*River miles*	*Scar sets*
Toledo Bend	SH 63	213-192	146-131	1
SH63	Bon Wier	192-131	131- 91	2
Bon Wier	Shoats Cr. lower	131- 79	91- 54	3
Shoats Cr.	Cutoff	79- 47	54- 29	2
Cutoff	Sabine Lake	47- 0	29- 0	1
Old River		33		2

Two topographic quadrangles where three sets of meander scars were identified (Bon Wier and Merryville North) were analyzed with respect to the amplitude and wavelength of the modern river meander loops and paleomeanders, and the wavelength of the modern and paleomeander trains. Measurements were based on DEM data, and are shown in Table 8. The paleomeander sets are ordered relative to their distance from the modern river channel, with set 1 being the closest. All the paleomeanders have larger amplitudes (base-to-peak distance of an individual loop or bend) and wavelengths (distance between apices of adjacent loops) than the contemporary Sabine River, attributed to higher mean flows at the time these meanders were formed (Alford and Holmes, 1985; Blum et al., 1995).

Table 8. Dimensions of modern river meanders and paleomeanders. Only two loops of paleomeander set 3 were on the Bon Wier and one on the Merryville North quads.

Quadrangle	*Meander Train*	*Amplitude (km)*		*Wavelength (km)*	
		Range	*Mean*	*Range*	*Mean*
Bon Wier	Modern	0.15-0.41	0.29	0.72-1.48	1.13
	Paleo 1	1.24-3.33	1.90	2.66-2.81	2.73
	Paleo 2	3.53-4.40	3.44	2.41-3.72	2.95
	Paleo 3	1.45-1.57	1.50		2.72
Merryville North	Modern	0.33-1.10	0.60	0.62-1.70	1.30
	Paleo 1	1.66-1.95	1.80	2.58-3.42	3.00
	Paleo 2	2.08-3.89	3.03	3.16	
	Paleo 3	3.45		unknown	

Point Bars

The lower Sabine is renowned, at least from an aesthetic and recreational standpoint, for its abundance of large, sandy point bars (Fig. 4). Active point bars indicate active lateral channel migration and meander growth or translation, as well as bedload sediment transport. The characteristics of point bars on the lower Trinity River, Texas, were found to correspond closely with changes in hydrodynamic and sedimentary regimes (Morton et al., 1996). Phillips (2003) found relatively large sandy point bars migrating downstream in the lower Sabine, and Sabine River Authority personnel have noted a reduction in sandbar size and frequency in recent decades between Toledo Bend dam and Burr Ferry.

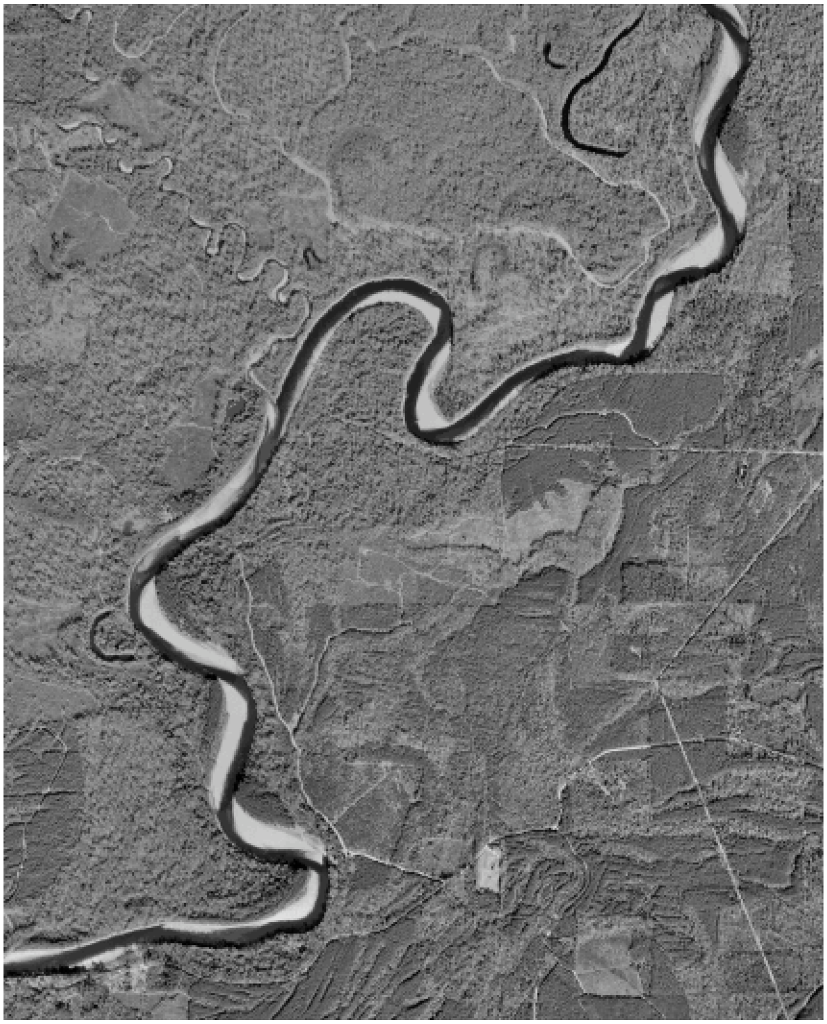


Figure 4. Aerial photograph showing large point bars on the Sabine River between Burr Ferry and Anacoco Bayou.

Table 9 shows that the scour zone below the dam is characterized by relatively few and small point bars. Below 196 km the bars become larger, and occur on most but not all river channel bends. Between 183 and 103 km, large, apparently active bars were found on all bends. Downstream of the Big Cow Creek confluence to 71 km, active point bars are common, but do not occur on every bend and are smaller than upstream of the creek. Further downstream point bars are far less common, and most appear stable rather than actively migrating. All point bars upstream of 71 km are dominantly sandy. In the lower 71 km some point bars are fine-grained, but sandy point bars occur, though small and rare, as far downstream as 40 km.

Table 9. River zonation according to point bar characteristics.

Upstream	*Downstream*	*DEM D*	*River miles*	*Point Bars*
Toledo Bend	Jones Creek	213-196	146-137	Few, small, sandy
Jones Creek	Red Bank Creek	196-183	137-126	Larger, most but not all bends
Red Bank Cr.	Big Cow Creek	183-103	126- 70	Large, active, sandy, all bends
Big Cow	Beauregard/ Calcasieu line	103- 71	70- 48	Sandy, active, smaller, not all bends
Beauregard/	Indian Lake	71- 40	48- 27	Rare to occasional; mostly stable
Indian Lake	Sabine Lake	40- 0	27- 0	None
Old River		33		Rare, stable

Point bars were also examined in the field for the presence of the distinctive gravels associated with Deweyville terraces. Essentially no particles >2 mm diameter occur in the Holocene alluvial deposits in the lower Sabine, and little or no gravel is found in the upland soils of the lower Sabine basin. Rounded fluvial gravels with a provenance from the upper Sabine basin are common in Deweyville deposits, however. These Deweyville gravels are sometimes found as a lag deposit on the upstream end of sandy point bars, but were noted to be common in the uppermost and absent in the lowermost portions of the study area. The presence of these gravels indicates mobilization and reworking of the terrace deposits. Thus the downstream limit of these gravels was identified by examining each point bar between 113 and 75 km. Upstream and downstream of these points the gravels had already been determined to be present and absent, respectively. The lowermost extent of the gravels was found to be a sandy point bar, immediately downstream of Big Cow Creek, at 102 km.

Boundaries

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. These locations correspond, respectively, with Cutoff Bayou (connecting the Sabine and Old River channels), the approximate location of the Beauregard/Calcasieu Parish (LA) line upstream of Nicholls Creek, and lower Shoats Creek. The boundaries and transition zones will be discussed more fully and interpreted in the next section.

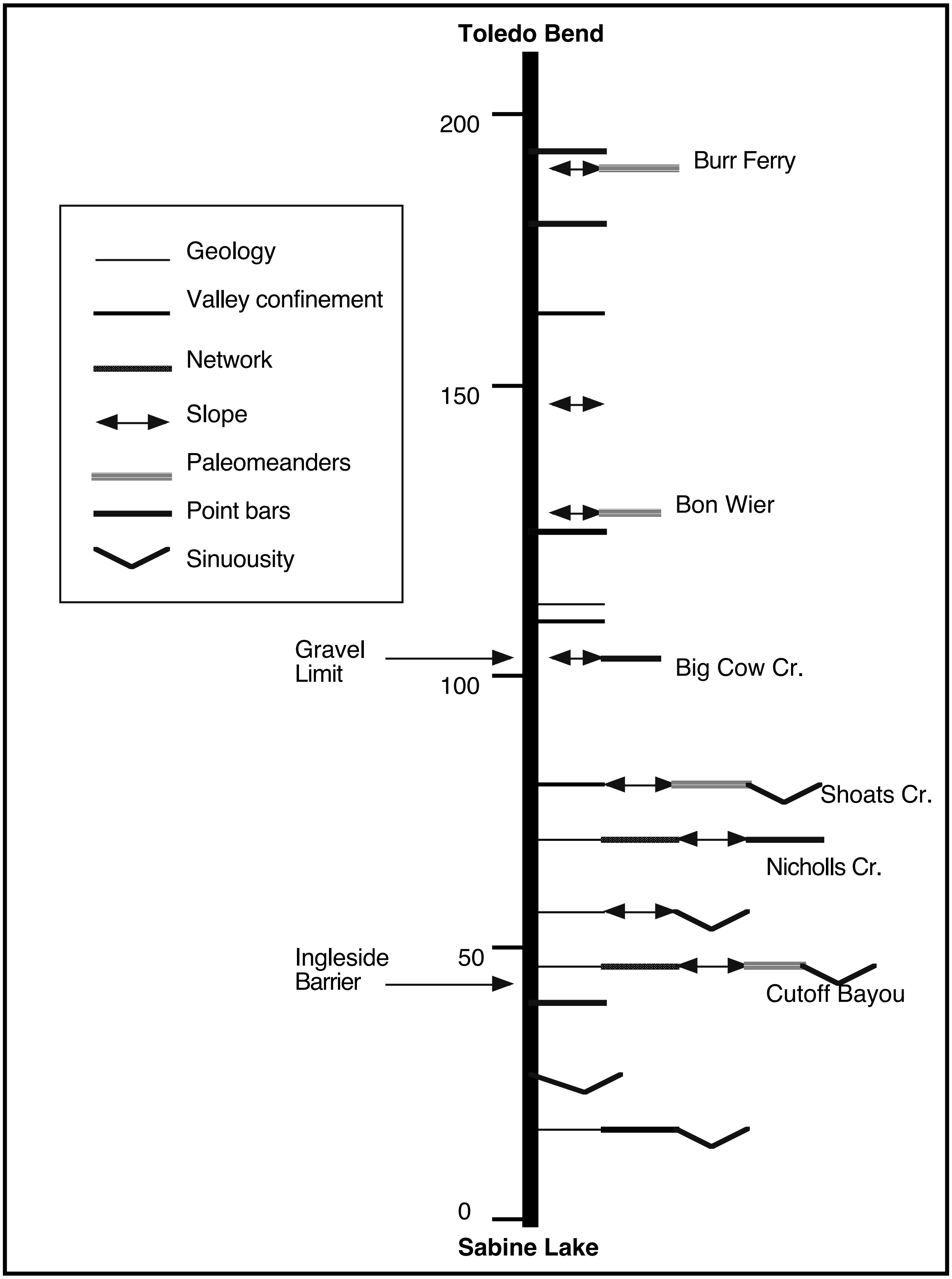


Figure 5. Schematic diagram of upstream/downstream river zonation based on various criteria as described in the text. The locations of the downstream limit of Deweyville gravel deposits on point bars, and the intersection of the river channel and trend of the Pleistocene Ingleside barrer are also shown.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

INTERPRETATIONS

Figure 5 reveals several key boundaries and transition zones, as outlined below.

Cutoff Bayou

Cutoff Bayou, connecting the Sabine River to Old River, is a key, clear boundary in the lower valley. This location corresponds with geological, network geometry, slope, paleomeander, and sinuousity boundaries. Cutoff Bayou is also a critical hydrological point, as about 70 percent of the Sabine River flow is diverted through the cutoff to Old River. This lower portion of the Sabine valley is the deltaic section of the river, as it marks the point at which a divergent, distributary network is present at all flow levels.

The Cutoff/Sabine confluence is atypical, as the flow from the Sabine into Cutoff Bayou is essentially upvalley, and geometrically, the Sabine appears to be a much more direct and hydraulically efficient path. However, field measurements showed depths just inside the Cutoff at the Sabine River to be about 2 m deeper than in the adjacent river. The Old River channel is both deeper, and its bed at a lower elevation, than the Sabine. Further, though the valley slopes are similar for Old River and the Cutoff to Old River junction reach, the channel slope of Old River is significantly greater (Table 6). At the Old River/Sabine junction, Old River and the Sabine downstream are both about 6-7 m deep in midstream at normal water levels, while the Sabine upstream has a typical depth of about half that.

The Houston Ridge barrier in Louisiana is considered by some to be a continuation of the Ingleside Pleistocene barrier trend in Texas. Connecting the trend of the Houston Ridge with that of the Ingleside Barrier in Texas from the geologic maps shows a crossing just downstream of Cutoff Bayou. While no beach ridge is obvious in the field in this vicinity, cutbanks on the Sabine at this point are sandy, and about 2.5 m higher than immediately up- or downstream, which is consistent with the presence of a former beach ridge at this location.

However, the preliminary interpretation is related to stream capture rather than antecedent coastal features. The Houston River appears to have once been a tributary of the Sabine, entering the Sabine on the east side of the valley, approximately opposite Big Cypress Creek, which joins the modern Sabine on the west side of the valley (Figures 6, 7). The Houston River now takes a sharp bend to the east near this point, and flows eastward to the Calcasieu River near Sulphur, LA. The capture was apparently triggered by fault movement along the DeQuincy fault trace, shown on the geologic map of Heinrich et al. (2002). The downthrown side of the fault, a Tertiary feature reactivated during the Pleistocene, created a steeper gradient to the east, leading to the capture. The reduced flow led to abandonment of the upper portion of the Old River channel, and allowed or triggered avulsion to the more easterly course now followed by the modern Sabine. Subsequently, an avulsion or diversion through Cutoff Bayou (perhaps due to one of the large woody debris dams or rafts which are common in the region) may have allowed the deeper Old River paleochannel to (re)capture most of the flow.

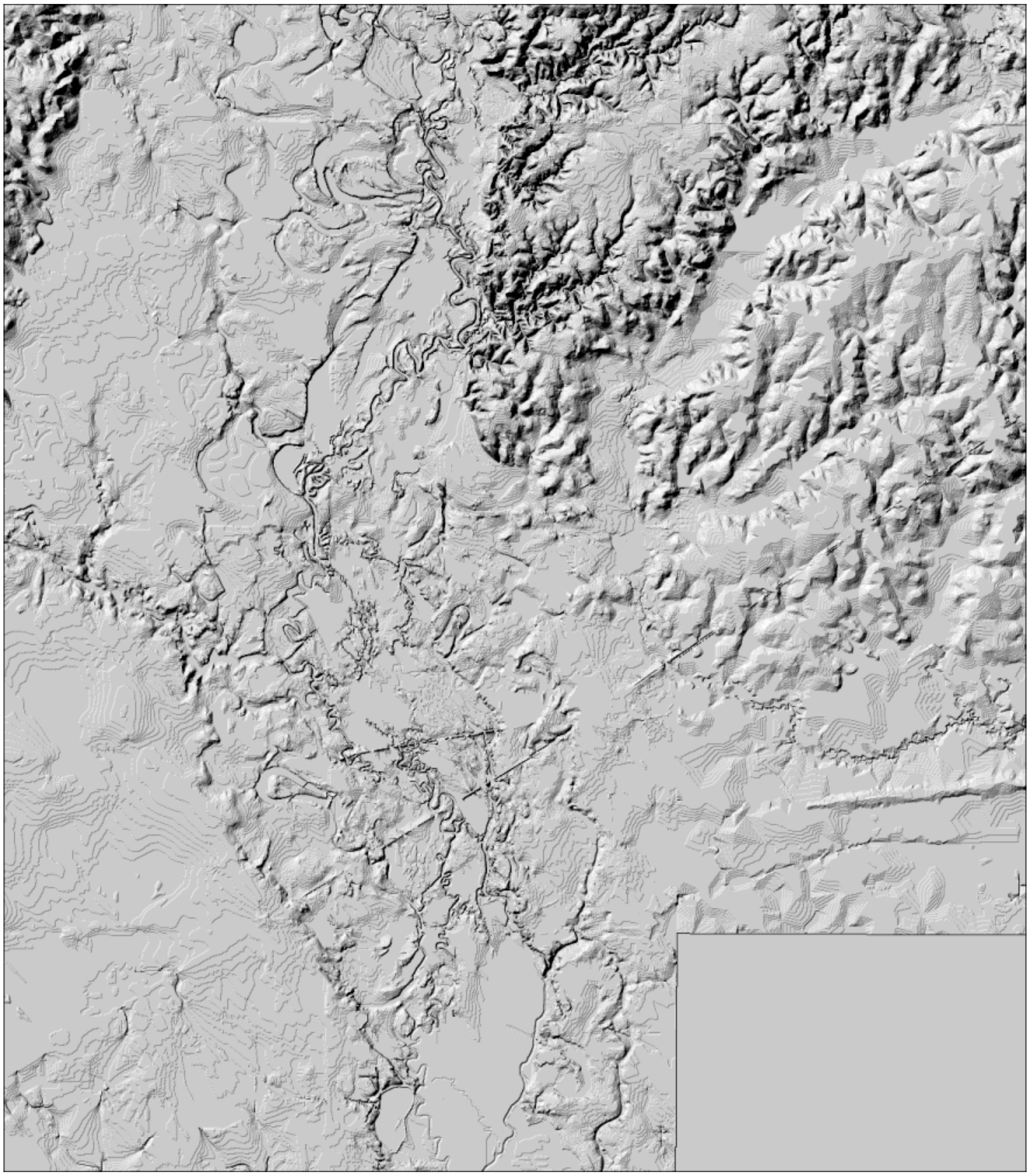


Figure 6. Shaded relief (50X vertical scale) of the Sabine River valley area in the vicinity of Cutoff Bayou, the Houston River, and Old River. Geomorphic interpretation is shown in Figure 7.

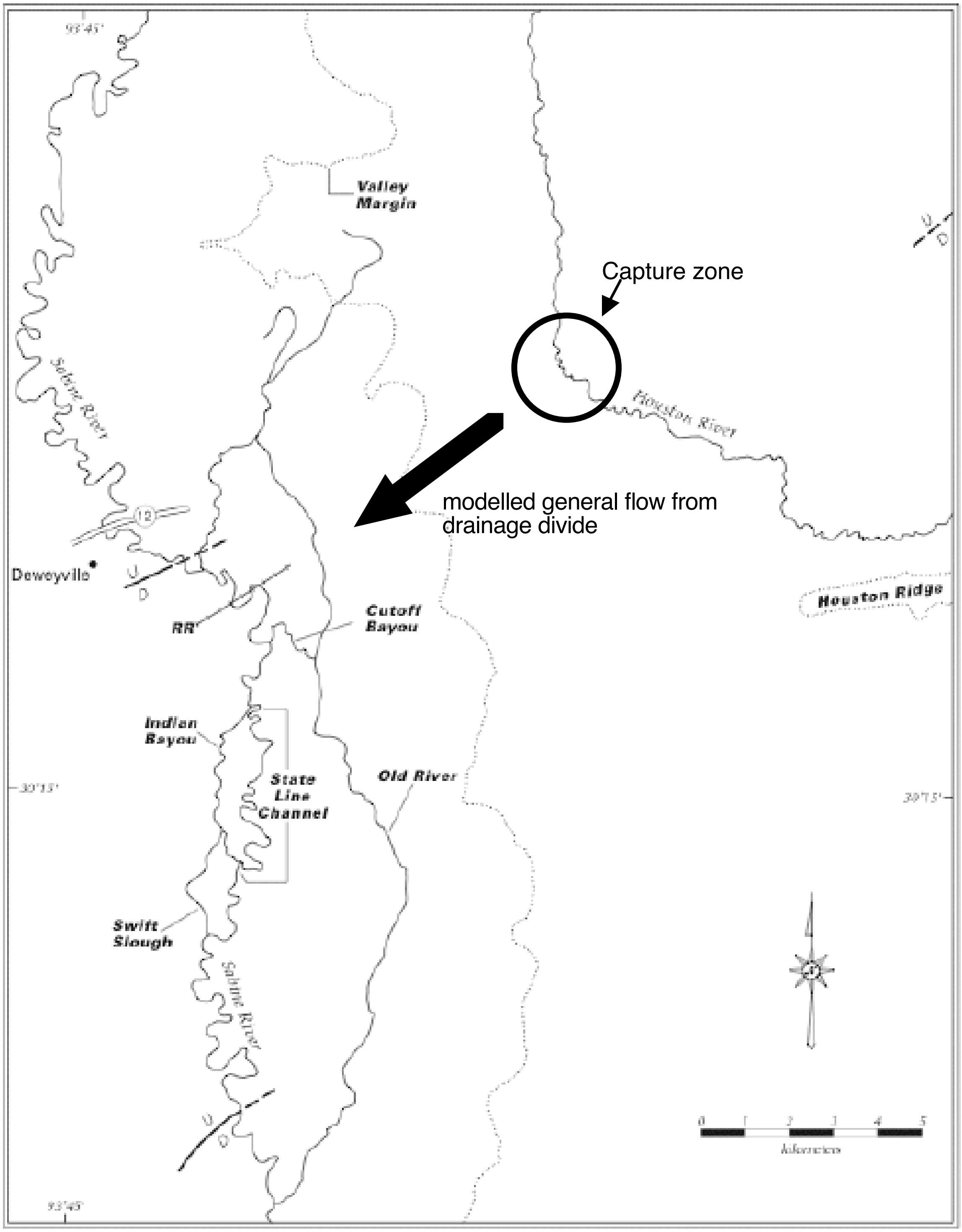


Figure 7. Geomorphic features in the area shown in Fig. 6. Flow paths on the west edge of the current Sabine/Houston River drainage divide are based on modern topography.

This scenario is speculative, and will be explored further in future work. However, both this and the major alternative scenario—that the Old River channel represents the former inlet through the Pleistocene Barrier—have two things in common. Both imply development of the modern geography during the Pleistocene, and both are linked to coastal sedimentation during higher sea level stands. This is obvious in the case of the paleobarrier explanation, and also applies to the stream capture explanation, as reactivation of the DeQuincy and other deep-seated Tertiary faults in southwest Louisiana is due to sedimentary loading on the coastal plain (Heinrich, 1997).

Cutoff Bayou's generally northeasterly course away from the Sabine is toward a flat-floored, low-relief topographic depression that corresponds with an extensive area mapped as the Fredonia (youngest Deweyville) alloformation on the geologic map (Heinrich et al. 2002); the only delineation of the Fredonia in the vicinity. A congruent delineation of clay loam soils is evident in the Calcasieu Parish soil survey (Roy and Midkiff, 1988). These are the Una series, a fine, mixed, active, acid, thermic Typic Epiaquept (U.S. Soil Taxonomy). According to the U.S. Soil Series Descriptions database, Una soils are deep, poorly, drained floodplain soils which form in acid clayey alluvium. This description is generally consistent with field observations, with the exception that sandy surface layers and a somewhat higher sand content in the subsoil was found.

Numerous tributaries or high-flow distributaries of the Sabine River and Old River flow into this depression, and could very well occupy Sabine paleochannels. This is interpreted as sediments accumulated after the hypothesized Houston River capture, as the upper Old River paleochannel was being abandoned.

The river and valley from Cutoff Bayou to Sabine Lake can be subdivided based on boundaries shown in Fig. 5, reflecting the downstream increases in the affects of tides and coastal backwater effects, and of progressive Holocene inundation.

Lower Shoats Creek

Shoats Creek is a Louisiana tributary, which in addition to its mouth (lower Shoats Creek), is connected to the Sabine by a tie channel. From Shoats Creek lower (79 km) to Cutoff Bayou a number of boundaries occur. At Shoats Creek, boundaries associated with valley confinement, slope and paleomeanders occur, with additional boundaries defined by geology, network characteristics, point bar characteristics, and slope occurring within the next 10 km downstream. At Big Cypress Creek (58 km), geologic and slope boundaries occur. Also within this reach is the point at which the channel is cut to below sea level.

Shoats Creek lower is the downstream boundary at which any sort of valley confinement occurs, and also marks a significant increase in sinuousity from 1.35 to 1.68; sinuousity is significantly higher in the lower 79 km than upstream. Here also begins a 21 km reach with the lowest channel and valley slopes in the entire study area. Upstream of Shoats Creek, three sets of meander scars are exposed, but downstream two or fewer are evident. This may indicate the upstream limit of burial of some paleomeanders under Holocene sediment. Shoats Creek lower is interpreted to be the approximate upstream limit of the effects of Holocene sea level rise.

This boundary is controlled by the Pleistocene paleogeography of the Louisiana/Texas Coastal Plain, local neotectonic activity, and associated drainage reorganizations. The

Shoats Creek area (and the Devil's Pocket, a Pleistocene meander scar, on the Texas side) correspond generally with the irregular boundary of the Beaumont/Prairie and Lissie formations, and thus the approximate position of a paleoshoreline.

Big Cow Creek

Big Cow Creek is the largest lower Sabine tributary on the Texas side of the river (and second largest overall, after Anacoco Bayou). This confluence (103 km) corresponds to boundaries associated with point bars and slope, and is also the approximate upstream limit of the occurrence of gravels derived from Deweyville deposits on point bars. Downstream flow in the Sabine can also be highly sensitive to inputs from Big Cow Creek. During a major flood in October, 2006, for example, during the peak at Deweyville Big Cow Creek was contributing more discharge than the upstream Sabine gaging station at Bon Wier (see section 1).

Other things being equal, any slope change downstream of this junction would be expected to be negative, given the increased discharge. The slope increase may be related to a geological boundary. Big Cow Creek is in the geological zone associated with a minor valley constriction by the Lissie formation. The Louisiana geological map (Snead et al., 2002) shows a fault zone, with the downthrown side to the south. The Tectonic Map of Texas (Ewing et al., 1991) also shows Tertiary faults with the downthrown side to the south. Neotectonic activity in this area has not been investigated, but topographic evidence in the form of anomalous topographic lineations exists within the valley to support this interpretation (Fig 8).

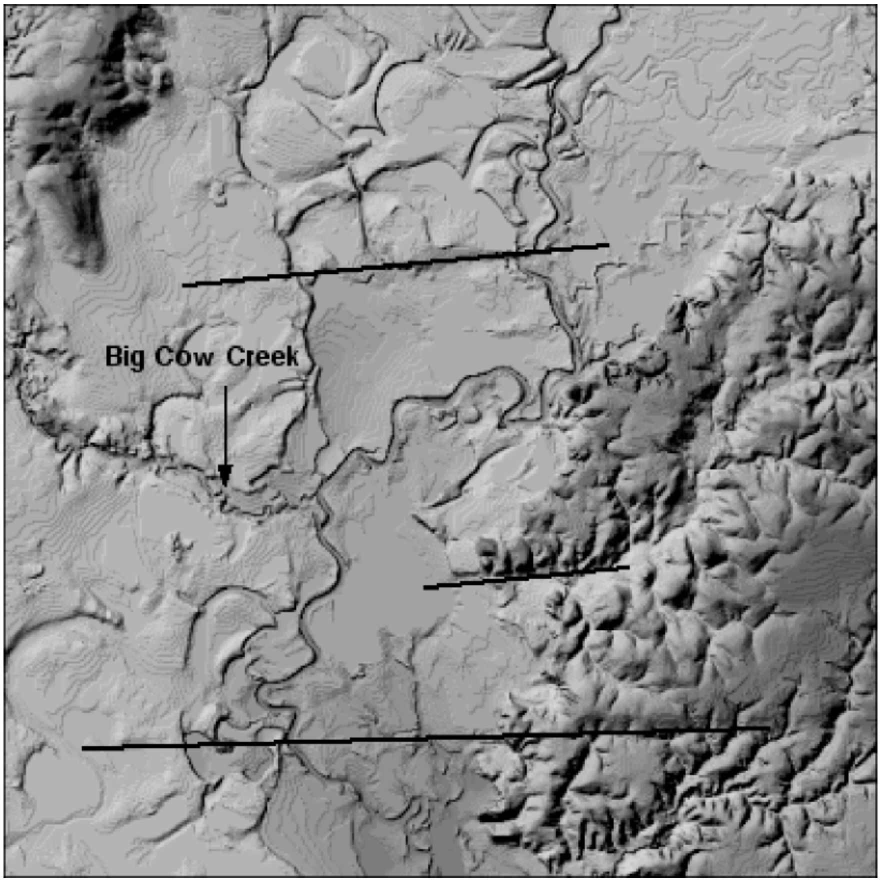


Figure 8. Apparent topographic lineations near the Big Cow Creek confluence with the Sabine River. The relief map has a vertical exaggeration of 10X.

Bon Wier

Several boundaries occur in the vicinity of the US highway 90 crossing near Bon Wier, TX (131 km). An increase in slope occurs at this point, and this is the upper end of the zone of the maximum number of paleomeander sets (three).

About 3 km downstream of Bon Wier, at the Old River confluence near Merryville, the network geometry changes. A number of high flow distributaries and former river channels or yazoo tributaries still hydraulically connected to the Sabine become evident at this point. While still a convergent network at normal flows, at high flows in this vicinity backwater flooding of tributaries occurs, and diversion of flow into floodplain subchannels. These boundaries also occur about 25 km upstream of a geological boundary. Note that "Old River" is a common name in the region for apparent former river channels, and that the Old River near Merryville is not the same channel as the Old River further downstream.

The geometry of Sand Lake, a tributary slough about 3 km upstream of Bon Wier, and of Old River, suggests that this may have been the site of an avulsion. Unfortunately, modifications of the valley associated with the highway and a nearby railway crossing have obscured any topographic evidence of a former connection between Sand Lake and Old River. The changes in slope, network geometry, and number of paleomeander sets are consistent with a major avulsion, however.

Burr Ferry

Burr Ferry (the SH 63 crossing between Burkeville, TX and Burr Ferry, LA) is the site of boundaries at 192 km associated with slope and paleomeanders. Jones Creek at 196 km is associated with a point bar boundary. While this reach is not associated with a boundary between the major geological zones (Table 2), a localized valley constriction associated with Runyon Hills on the Texas side lies between Jones Creek and Burr Ferry.

Point bars are relatively rare and small upstream of Jones Creek, becoming larger and more common downstream, with large active sandy point bars on every bend by 183 km (Red Bank Creek). A significant decrease in slope occurs at Burr Ferry, and an increase from one to two sets of paleomeander scars.

Phillips (2003) previously determined this site to be the approximate downstream limit of the scour zone attributable to Toledo Bend dam, which is consistent with the changes in point bar size and frequency. While there is no major change in width of the modern floodplain here, valley width increases significantly downstream of Runyon Hills, accounting for the presence of two sets of paleomeander scars.

DISCUSSION

Based on the analyses above, the lower Sabine River can be subdivided into several major reaches, as summarized in Table 10 and discussed below.

From Toledo Bend Dam to Burr Ferry, 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, 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 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.

Table 10. Major reaches 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*
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
Burr Ferry to Bon Wier	192-131 *131-91*	Active lateral migration, ubiquitous large point bars, wider valley, larger sediment load	Valley width; avulsion
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
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
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
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

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 the Houston River capture, and flow diversions between channels have been influenced by both natural and human activity.

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REFERENCES

Alford, J.J., Holmes, J.C., 1985. Meander scars as evidence of major climate change in southwest Louisiana. Annals of the Association of American Geographers 75, 395-403

Blum, M.D., Morton, R.A., Durbin, J.M., 1995. "Deweyville" terraces and deposits of the Texas Gulf coastal plain. Gulf Coast Association of Geological Societies Transactions 45, 53-60.

Brierly, G.J., Fryirs, K., 2005. Geomorphology and River Management. Applications of the River Styles Framework. Oxford, Blackwell.

Brinson, M.M., 1993. A Hydrogeomorphic Classification for Wetlands. Vicksburg, MS: U.S. Army Corps of Engineers Waterways Experiment Station, Tech. Rept. WRP-DE-4.

Ewing, T.E., Budnik, R.T., Ames, J.T., Ridner, D.M., Dillon, R.L., 1991. Tectonic Map of Texas. Austin: Texas Bureau of Economic Geology.

Gumbricht, T.T., McCarthy, J., McCarthy, T.S., 2004. Channels, wetlands and islands in the Okavango Delta, Botswana, and their relation to hydrological and sedimentological processes. Earth Surface Processes and Landforms 29, 15-29.

Heinrich, P.V. 1997. Pleistocene fault-line scarps and neotectonics in Southwest Louisiana. Abstracts with Program, Geological Society of America 29, 23.

Heinrich, P.V., Snead, J., McCulloh, R.P. 2002. Lake Charles 30 X 60 Minute Geologic Map. Baton Rouge: Louisianan Geological Survey.

Hupp, C.R., Osterkamp, W.R., 1996. Riparian vegetation and fluvial geomorphic processes. Geomorphology 14, 277-295.

Johnson, J.B., 2005. Hydrogeomorphic Wetland Profiling: An Approach to Landscape and Cumulative Impacts Analysis. Corvallis, OR: U.S. Environmental Protection Agency National Health and Environmental Effects Research Laboratory rept. EPA/620/R-05/001.

Johnston, C.A., Bridgham, S.D., Schurbauer-Berigan, J.P., 2001. Nutrient dynamics in relation to geomorphology of riverine wetlands. Soil Science Society of America Journal 65, 557-577.

Montgomery, D.R., 1999. Process domains and the river continuum. Journal of the American Water Resources Association 35, 397-410.

Moret, S.L., Langford, W.T., Margineantu, D.D., 2006. Learning to predict channel stability using biogeomorphic features. Ecological Modelling 191, 47-57.

Morton, R.A., Blum, M.D., White, W.A. 1996. Valley fills of incised coastal plain rivers, southeastern Texas. Transactions of the Gulf Coast Association of Geological Societies 46, 321-331.

Newson, M.D., Newson, C.L., 2000. Geomorphology, ecology, and river channel habitat: mesoscale approaches to basin-scale challenges. Progress in Physical Geography 24, 195-217.

Otvos EG. 2005. Numerical chronology of Pleistocene coastal plain and valley development; extensive aggradation during glacial low sea-levels. Quaternary International 135: 91-113.

Phillips, J.D. 2003. Toledo Bend Reservoir and geomorphic response in the lower Sabine River. *River Research and Applications* 19: 137-159.

Phillips, J.D., Musselman, Z.A. 2003. The effect of dams on fluvial sediment delivery to the Texas coast. *Coastal Sediments '03.* Proceedings of the 5th International Symposium on Coastal Engineering and Science of Coastal Sediment Processes, Clearwater Beach, Florida, p. 1-14.

Phillips, J.D., Slattery, M.C. 2006. Sediment storage, sea level, and sediment delivery to the ocean by coastal plain rivers. *Progress in Physical Geography* 30, 513-530.

Phillips, J.D., Slattery, M.C., 2007. Downstream trends in discharge, slope, and stream power in a coastal plain river. *Journal of Hydrology* 334, 290-303.

Phillips, J.D., Slattery, M.C., Musselman, Z.A. 2005. Channel adjustments of the lower Trinity River, Texas, downstream of Livingston Dam. *Earth Surface Processes and Landforms* 30: 1419-1439.

Robertson, K.M., Augspurger, C.K., 1999. Geomorphic processes and spatial patterns of primary forest succession on the Bogue Chitto River, USA. Journal of Ecology 87, 1052-1063.

Rodriguez, A.B., Anderson, J.B., Simms, A.R., 2005. Terrace inundation as an autocyclic mechanism for parasequence formation: Galveston estuary, Texas, U.S.A. Journal of Sedimentary Research 75, 608-620.

Roy, A.J., Midkiff, C.T., 1988. Soil Survey of Calcasieu Parish, Louisiana. Washington: US Department of Agriculture, Soil Conservation Service.

Scott, M.L., Friedman, J.M., Auble, G.T., 1996. Fluvial process and the establishment of bottomland trees. Geomorphology 14, 327-339.

Thomas MA, Anderson JB. 1994. Sea-level controls on the facies architecture of the Trinity/Sabine incised-valley system, Texas continental schelf. In *Incised-Valley Systems: Origin and Sedimentary Sequences*. Dalrymple RW, Boyd R, Zaitlin BZ (eds.). SEPM (Society for Sedimentary Geology): Tulsa, OK: 63-82.

Snead, J., Heinrich, P., McCulloh, R.P. 2002. De Ridder 30 X 60 Minute Geologic Map. Baton Rouge: Louisianan Geological Survey.

SCOPE OF WORK PLAN

Geomorphic Processes, Controls, and Transition Zones in the Lower Sabine River

Jonathan D. Phillips & Michael C. Slattery

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Overview

This work plan addresses a cooperative research study of the geomorphology of the Lower Sabine River, Texas (and Louisiana). The study will delineate major geomorphic process zones, with an emphasis on stream energetics as indicated by stream power and shear stress; identify major geomorphic controls (including sea level and climate change and antecedent topography); and determine the location and primary controls over key "hinge points" or transition zones.

The specific objectives are to:

(1) Develop a baseline characterization of the ccondition and behavior of the lower Sabine River (downstream of Toledo Bend reservoir).

(2) Examine longitudinal (downstream) changes in flow processes and energetics, channel and valley morphology, and patterns of recent geomorphic change.

(3) Classify the lower Sabine (based on items 1, 2) into geomorphic process zones.

(4) Identify the primary controls—both contemporary and historic—of the geomorphic process zones.

(5) Identify the current location, primary controls over, and potential future changes in critical transition zones.

Deliverables will include a report covering the objectives above, and maps (hardcopy and digital) of the process and key transition zones.

Methods

Baseline Characterization at broad river scales will establish the geomorphic framework of the river in terms of geology, topography, hydrology, soils, and land/water use. The major data sources will be:

- 1:250,000 scale geologic maps from the Texas Bureau of Economic Geology.
- Digital elevation models obtained from the U.S. Geological Survey Data Distribution Center.
- Discharge and stage data from U.S. Geological Survey gaging stations on Sabine River

- •Soil surveys from the Natural Resources Conservation Service in the form of published surveys for counties within the study area, or obtained via the NRCS web soil survey data distribution program.
- •1-m and 2.5-m resolution digital orthophotoquads (DOQQ) from the Texas Natural Resources Information System (TNRIS) and the Lousiana statewide GIS.
- •1:24,000 topographic maps in DLG (digital line graph) form from TNRIS.

Current Geomorphic Condition assessments will be made using the data sources listed above. The current condition assessment will describe the contemporary state of the reach based on factors such as the degradational or aggradational state of the channel, frequency of overbank flooding, lateral migratory stability, typical range of flows, presence or absence of diagnostic geomorphic features (for example knickpoints, cut banks, point bars, tributary-mouth bars or deltas, oxbows, and meander scars), and morphometric properties (for example valley vs. channel width ratio, channel sinuosity, valley slope). Phillips conducted fieldwork on the lower Sabine in 2001 and 2002 (see Phillips 2003; Phillips and Musselman 2003); additional fieldwork will be conducted for this project.

Specific criteria to be assessed based on the digital, archival, and field data include:

•Channel sinuousity, which may reflect upstream limits of effects of Holocene sea lelvel rise, as Phillips et al. (2005) and Phillips and Slattery (2006) found for the Trinity River.

•Channel thalweg elevation relative to sea level.

•Channel and water surface slopes.

•Discharge, stream power, and shear stress at gaging station locations for reference flows (mean daily discharge exceedence probabilities of 1, 10, and 50 percent; bankfull discharge; the flood of record; and selected high flow events).

•Evidence for tidal and coastal backwater influences.

•Transition from convergent to divergent flow network (see Phillips and Slattery, 2006).

•Ratios of valley, modern floodplain and channel widths and width/depth ratios.

•Presence and mobility of sandy point bars.

•Evidence for channel incision/aggradation or widening/narrowing.

•Evidence for active floodplain and valley accretion (or erosion).

•Presence of remnant Quaternary alluvial terrace surfaces identified in previous studies in southeast Texas.

•Presence and size of Quaternary paleomeanders (which reflect previous flow regimes and may influence contemporary geomorphology and hydrology).