Evolution of Oxbow Lakes along the Brazos River

FINAL REPORT
May 2012

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Submitted to the Texas Water Development Board
Contract No. 0904830969

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Project Summary

This work investigated the relationship between oxbow lake geometry and sedimentation for numerous oxbows along the middle and lower reaches of the Brazos River. Specific attributes investigated include: A) the angle of diversion; B) cutoff ratio; C) main channel-lake connections, and D) flood-connections. As is common in geomorphic systems at this scale, (i.e., channel scale) there is non-linearity in the various characteristics of oxbows.

As described in the scope of work, there were four tasks for this project:

- Quantify rates of planform oxbow development;
- Quantify rates of sediment deposition and meander cutoff in-filling for selected localities along the Brazos River;
- Categorize oxbows and meander scrolls based on their morphologic and hydrologic properties;
- Develop a chronology of development of an oxbow lake, as it progresses from meandering bend to remnant oxbow lake.

Introduction

The focus of this work was to determine the processes and rates of oxbow formation in the Brazos River floodplain. Oxbow lakes and similar cutoff channels are ubiquitous features in alluvial rivers in lowlands and represent one end-member of channel activity (Gagliano and Howard, 1984; Lesack and Marsh, 2010).

The following questions are important to understanding development of oxbows in the Brazos River watershed. First, how do sediment plugs fill-in the ends of channels of an oxbow once cutoff occurs? Second, at what stage in the process of deposition does the lake become hydrologically disconnected from the main river channel? Third, what are the spatial and temporal rates for the sedimentation of oxbow lakes? Last, can recent versus historic oxbows in the Brazos floodplain be defined?

Physical Setting

The oxbow lakes in the study area are concentrated in the middle and lower reaches of the Brazos River (Figure 1). Discharge and sediment are received from the Edwards Plateau and the Texas coastal plain, which comprises the largest part of the middle and lower Brazos watershed. Seasonal discharge pulses dominate floodplain lake hydrology with lake drainage processes and surface evaporation becoming important to lake water levels after lowering of the discharge pulse.

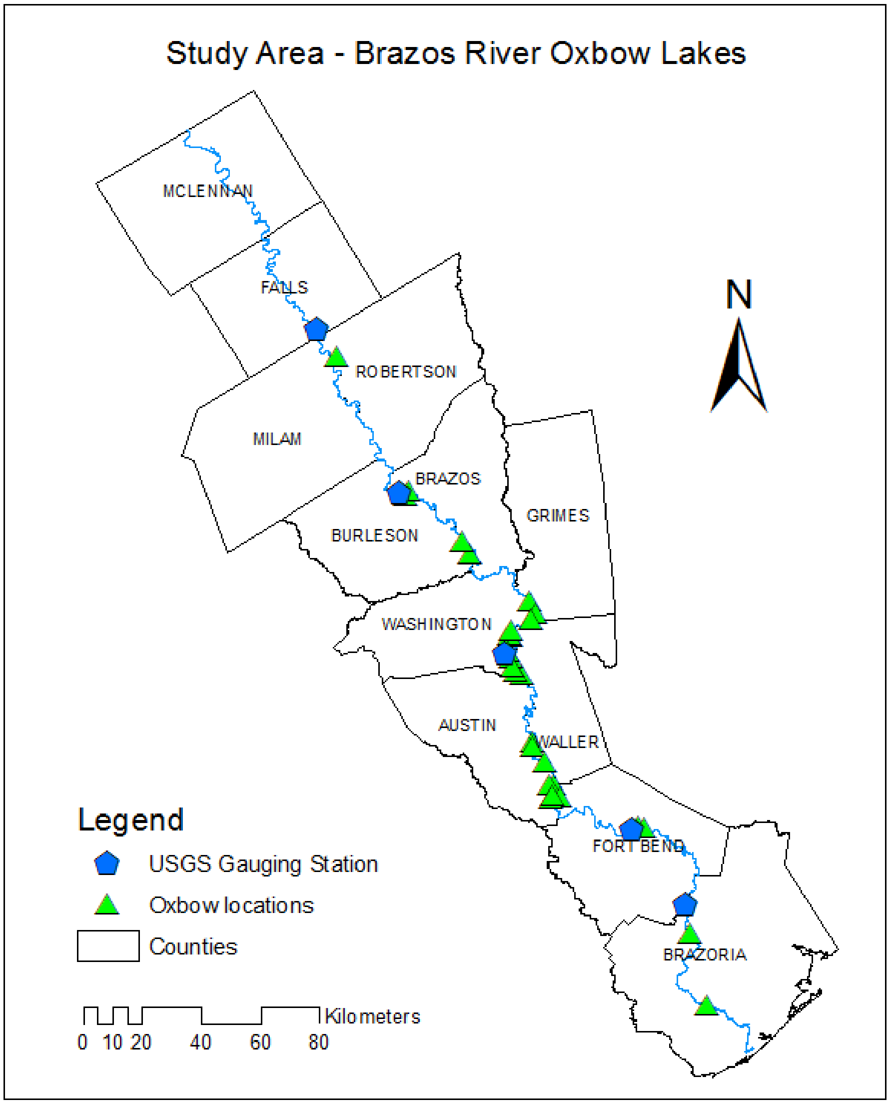

Figure 1. Lower Brazos River including locations of oxbow lakes studied and locations of USGS gauging stations.

The oxbows studied for this report are located on the Texas coastal plain, which exhibits a subtle yet complex and heterogeneous landscape along with varied land-use histories. The drainage of the Brazos River begins outside the coastal plain in an extra-basinal watershed. Considerable drainage from the High Plains of northwest Texas and Edwards Plateau enters the Brazos drainage. The coastal plain is comprised of basin-fringe and intrabasinal drainage systems (Hudson, 2010). The river watershed is divided by abandoned Holocene meander belts that occur as raised ridges within the floodplain.

Methods

A Geographic Information System (GIS) was used to process a model of specific attributes that were collected for each oxbow locality (Table 1) and a spreadsheet program (*Excel®*) integrated the data. The specific attributes collected include: 1) the cutoff ratio (C_R); 2) diversion angle (D_A); 3) cutoff date and 4) rate of sedimentation (S_R).

The cutoff ratio (equation 1) is derived from the length of the abandoned channel divided by the length of the main active channel:

$$C_R = O_L / M_L \quad (1)$$

where, C_R is the cutoff ratio, O_L is the length (m) of the oxbow, and M_L is the length (m) of the main channel, between the upstream and downstream oxbow channel ends (Fig. 2).

Similar, the diversion angle is measured between the upstream portion of the abandoned channel and main channel in the downstream direction (Fig. 2). Both characteristics are collected from the most recent aerial photographs of the cutoff of the abandoned channel. The date of cutoff is calculated from the midpoint between the aerial photographs immediately before and after the cutoff of the main channel (Constantine, 2010). Typically the areal coverage was 20-40 years after dating of the cutoff.

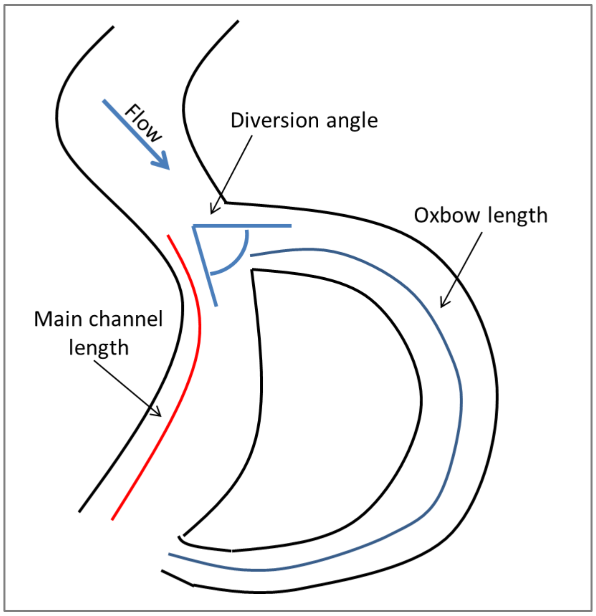

Figure 2. Measuring the cutoff ratio and diversion angle along oxbow lakes. The cutoff ratio is calculated by the oxbow length divided by the main channel length. The diversion angle is between the upstream entrance of the cutoff and the main channel.

In a linear geomorphic system, a greater cutoff ratio in abandoned channels of equal depth and width results in lower sedimentation rates as flows connecting to the oxbow during flood deposit sediment across a larger surface area. A larger diversion angle results in an abandoned channel entrance further away from parallel flow with the main channel, which reduces sedimentation rates.

Cutoff ratios and diversion angles are important geometric characteristics controlling the infilling and rates of sedimentation in oxbows lakes (Piégay, 2002; Constantine, 2010). The thickness of sediment deposition was obtained by first obtaining the difference between the elevation of the highest point along the upstream arm of the oxbow and the elevation of the main channel immediately adjacent to the oxbow (Fig.3). The length of cutoff time was calculated by subtracting the cutoff year from the date of the DEM. The sediment thickness was then divided by the number of years since cutoff from the main channel to determine the rate of sedimentation per year, which is expressed in meters per year. Therefore, the rate of sedimentation (eq. 2) is expressed as:

$$S_R = (O_E - M_E) / O_A \tag{2}$$

where, S_R represents the rate of sedimentation (m/yr), O_E is the elevation of the upstream oxbow surface, M_E is the elevation of the main channel, and O_A is the age of the oxbow in years.

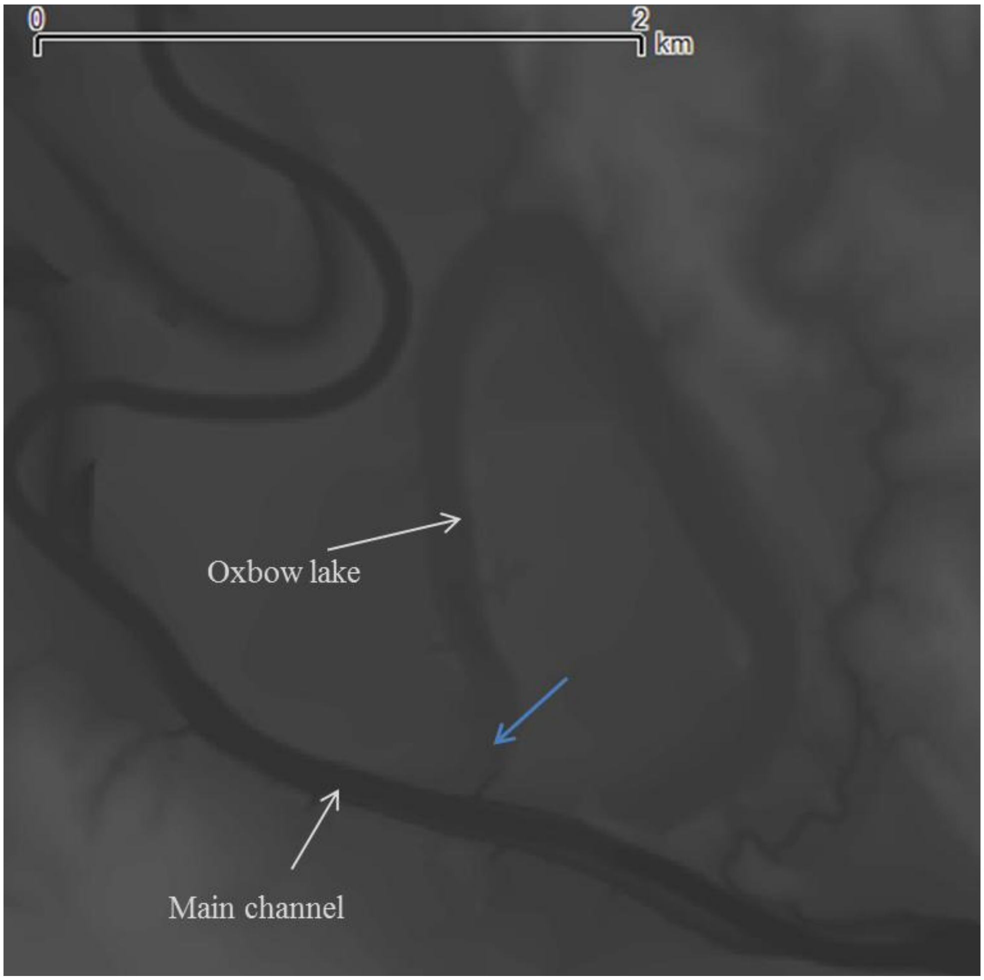

Figure 3. Digital elevation model (DEM) of a typical oxbow lake and the main channel. The oxbow lake is the dark black "horsehoe" form in the center of the image, and the main channel flows along the lower portion of the image. The thin, blue arrow points to highest elevation used in calculation of sedimentation rates, which is the upstream component of the oxbow lake. Main channel flow is from left to right.

Lowland rivers similar to the Brazos exhibit rates of sedimentation that decrease as the cutoff channel fills over time (Hooke, 1995), which is a result of the oxbow surface bottom elevation rising as sediments are deposited. To calculate extensive changes in the rates of sedimentation over time requires substantial sedimentologic and chronologic data. Using the extensive aerial photographs and planimetric maps, an important assumption was made for the sedimentation rates over the time frame of oxbow cutoff in this study. For the purposes of this work it is assumed the oxbow lakes occurring in the Brazos River watershed are in a 'steady-state' condition, whereby sedimentation rates are assumed constant over time. In reality, older oxbows are more stable as fewer connections decrease the amount of sediment infill, while younger oxbows connect more frequently with the main channel.

Field data, specifically the number of connections to main channel ($C_{\#}$) and the flood-flow [F_F, (eq. 4)] required for connection, for five oxbows from Osting (2004) was the basis for the modeling approach we used to build models (Fig. 4 & 5) with sedimentation rates to calculate number of lake to main channel connections and flood flows for the remaining twenty-three oxbows.

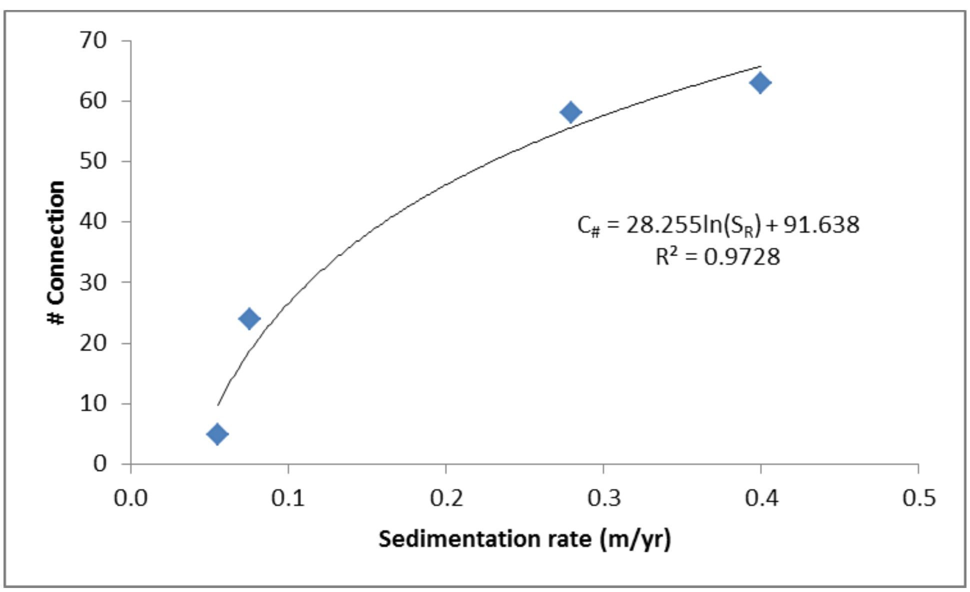

Figure 4. Relationship between the number of connections between the oxbow and main channel, and sedimentation rate. Though sedimentation rates are controlled by the number of connections, this graph shows the excellent relationship between the two variables.

The following equation (3) is used to calculate the number of connections for all dated oxbows using the rate of sedimentation:

$$C_{\#} = 28.255*\ln(S_R) + 91.638 \quad (3)$$

Where, $C_{\#}$ is the number of connections between the main channel and oxbow and S_R is the rate of sedimentation. Figure 5 is similar in that it calculates the flood flow required to connect with the abandoned channel.

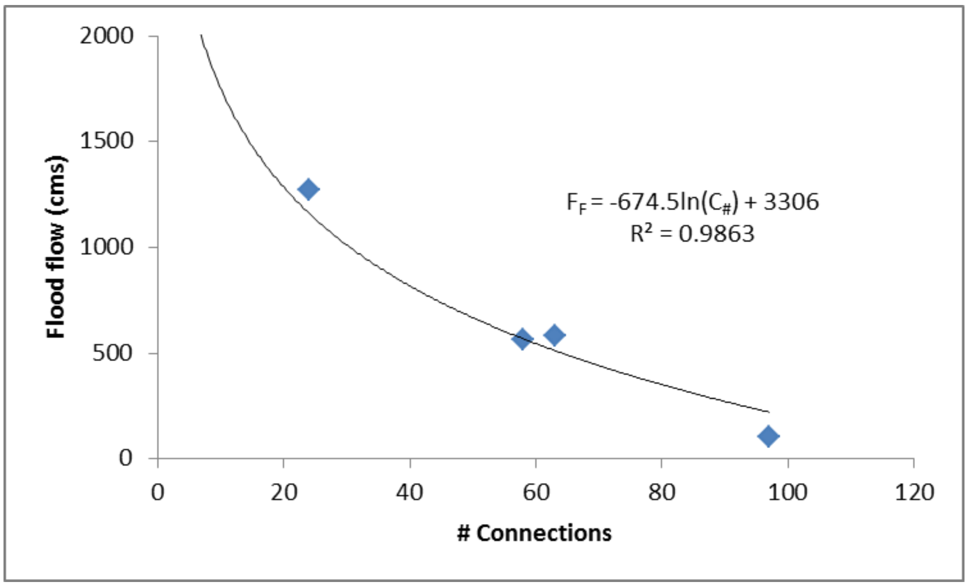

Figure 5. Relationship between flood flows and the number of connections for oxbows from Osting (2004).

The following equation (4) is used to calculate the flow required to maintain connection between the oxbow lake and the main channel:

$$F_F = -674.5*\ln(C_{\#}) + 3306 \quad (4)$$

Where, F_F is the flood-flow required to connect the main channel to the oxbow lake and $C_{\#}$ is the number of connections between the main channel and the oxbow.

To better understand the dynamic characteristics of oxbows in what's often considered a homogenous environment, it would be useful to categorize the main channel into distinct reaches. Phillips (2006) segments the main channel into a series of river style reaches, which are geomorphically distinct from one another. Variables from Phillips (2006) used in conjecture with the data collected include the slope of the reach, channel sinuosity, channel/flow patterns, and the channel-floodplain connectivity.

Hydrologic records for five US stream gauging stations (Fig. 1 & Table 1) were compiled to connection flood flows determined by Osting (2004). The daily mean flows were collected for the entire time of record.

Table 1. Gauge stations for the middle and lower Brazos River.

Gauge #	Gauge name	Year	Location (UTM)
8098290	Highbank	1965	E707398, N3446477
8108700	Bryan - SH 21	1993	E735419, N3390800
8111500	Hempstead	1938	E770962, N3336407
8114000	Richmond	1903	E232885, N3275668
8116650	Rosharon	1967	E249298, N3249472

A model (Fig. 5) was created comparing the number of connections and the flood flow required to make that connection from Osting (2004). This model was then applied to those dated oxbows that had cutoff since gauge records began for gauge stations directly upstream of the particular oxbows. The number of days containing a flow that equaled or exceeded the modeled flow was obtained for each oxbow to determine the relationship between flood flows and number of connections.

Results and Interpretation

Several analyses are presented below (Table 2). Sedimentation rates are examined in relation to cutoff ratio, diversion angles, sinuosity class, slope class, channel/flow pattern class, and channel/floodplain connectivity class. The numbers of connections, both field and modeled, are analyzed against several attributes to determine the planform development and sediment dynamics of 28 dated oxbow lakes.

Table 2. Oxbow lakes examined in this study. Oxbows were numbered starting from the furthest upstream lake, therefore lake O28 is closest to the entrance into the Gulf of Mexico.

Oxbow lake	UTM latitude (m)	UTM longitude (m)	Cut-off ratio	Diversion angle	Distance to channel (m)*	Lake area (km^2)**	Cutoff date	Sedimentation rate (m/yr)
O1	713892	3436836	6.10	39.3	-	-	1933	0.030
O3	738505	3391194	2.52	105.1	-	-	1974	0.080
O4	756635	3374278	14.41	77.5	159	0.153	1974	0.280
O5	759306	3370459	22.67	129.5	400	0.140	1920	0.101
O6	779341	3353993	8.71	50.7	405	0.034	1896	0.078
O7	781151	3349800	2.54	56.2	218	0.041	1938	0.066
O8	780014	3347769	8.95	133.2	13	0.064	1938	0.033
O9	773125	3344514	1.84	109.5	235	0.072	1961	0.211
O10	772444	3342875	18.85	98.1	1021	0.110	1913	0.047
O11	772825	3342048	11.64	110.9	125	0.204	1946	0.094
O12	772114	3337184	11.56	102.5	74	0.144	1913	0.093
O13	772956	3334809	12.07	89.8	516	0.088	1913	0.093
O14	773721	3331775	5.00	67.2	-	-	1960	0.256
O15	774847	3330334	11.22	48.3	337	0.190	1974	0.400
O16	776814	3329440	8.29	63.1	59	0.141	1950	0.143
O17	780408	3306523	5.11	55.3	774	0.062	1960	0.051
O18	780315	3304998	2.98	64.6	113	0.195	1917	0.049
O19	784236	3299863	6.85	62.0	-	-	1962	0.027
O20	786154	3292235	4.95	128.0	393	0.155	1948	0.196
O20	737297	3389811	9.98	89.0	-	-	1920	0.076
O21	787796	3292221	4.46	84.1	-	-	1948	0.196
O22	789703	3287926	5.82	66.4	334	0.104	1947	0.231
O23	787218	3288256	2.46	132.6	156	0.095	1947	0.192
O24	786581	3287503	1.82	99.5	-	-	1947	0.154
O25	234842	3276629	7.10	142.8	210	0.225	1919	0.075
O26	236974	3276175	3.40	141.7	151	0.290	1919	0.113
O27	250403	3239758	25.50	128.8	-	-	1996	0.218
O28	254881	3215198	5.90	143.7	334	0.094	1920	0.055

***Values obtained from Hudson (2010). Dashes indicate lake distances not calculated in Hudson (2010).**
****Values obtained from Hudson (2010).**

To compare the accuracy of the sedimentation rates collected using the Digital Elevation Model, the control points from the Osting (2004) report were compared to elevations from the DEM (Table 3). The percent error is low (mean = 4.09%), indicating DEM elevations are comparable to field surveyed points. The major outlier is Cutoff Lake (O28) with a 63.34% error. This is most likely attributable to the difficulty in establishing an elevation control point from Osting (2004).

Table 3. Difference between Osting (2004) elevations and DEM elevations concerning control points.

Lake*	Osting control points (m)	DEM control points (m)	Error (%)
Moehlman Slough (O5)	66.9	67	0.15
Korthauer Bottom (O6)	38.6	40	3.63
Cutoff Lake (O28)	13.91	5.1	63.34**
Big Bend Oxbow (O8)	58.6	60	2.4
Hog Island Lake (O9)	0.88	0.97	10.2

***The lake names are used from Osting (2004), with the label for this work in parenthesis**
**** The error for 'Cutoff Lake' is very high most likely because of the difficulty measuring the control point in the original 2004 field survey**

Figure 6 displays the correlation between rates of sedimentation (m/yr) and the cutoff ratio. A very weak correlation exists between the two variables, with the slope of the linear trend being gently downward with many of the rates of sedimentation occurring between 0.0 and 10.0 (m/yr). As expected, most of the rates of sedimentation larger than 0.1 m/yr occur with oxbows having a cutoff ratio of less than 10.0. As the length of the oxbow increases, relative to the main channel length, the area available for sediment deposition increases, therefore lowering the rate of sedimentation for an oxbow with a high cutoff ratio.

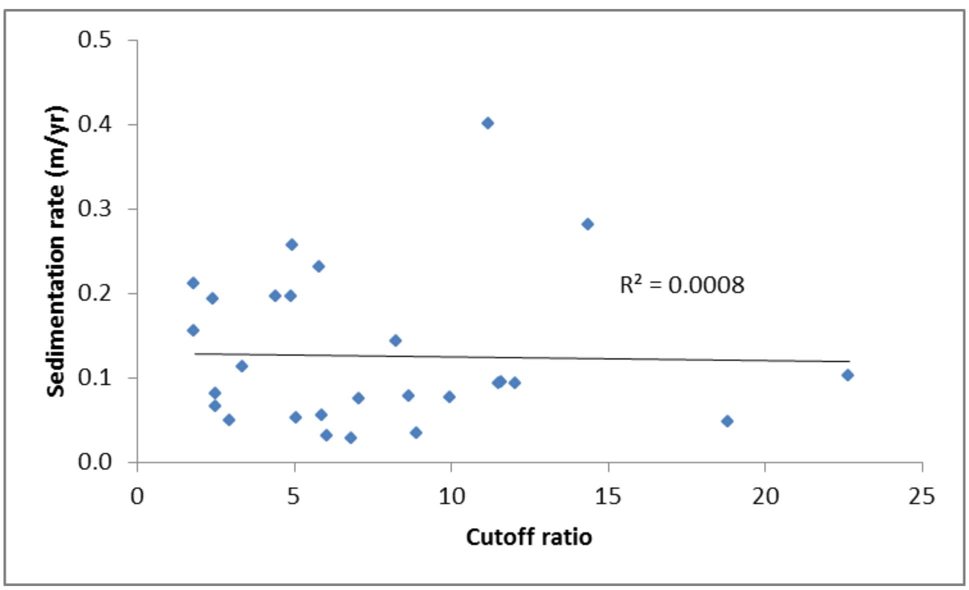

Figure 6. Relationship between sedimentation rates and the cutoff ratio.

Figure 7 displays a strong correlation (R2 = 0.84) between these two variables. As the cutoff ratio increases the number of connections between the main channel and the oxbow increase. A larger cutoff ratio has a larger lake surface area, allowing for sediment transported into the lake to be deposited in a thinner amount throughout the lake area. The flood-flow required to connect is smaller than oxbows with low cutoff ratio, allowing for lower, more frequent discharges to enter the oxbow.

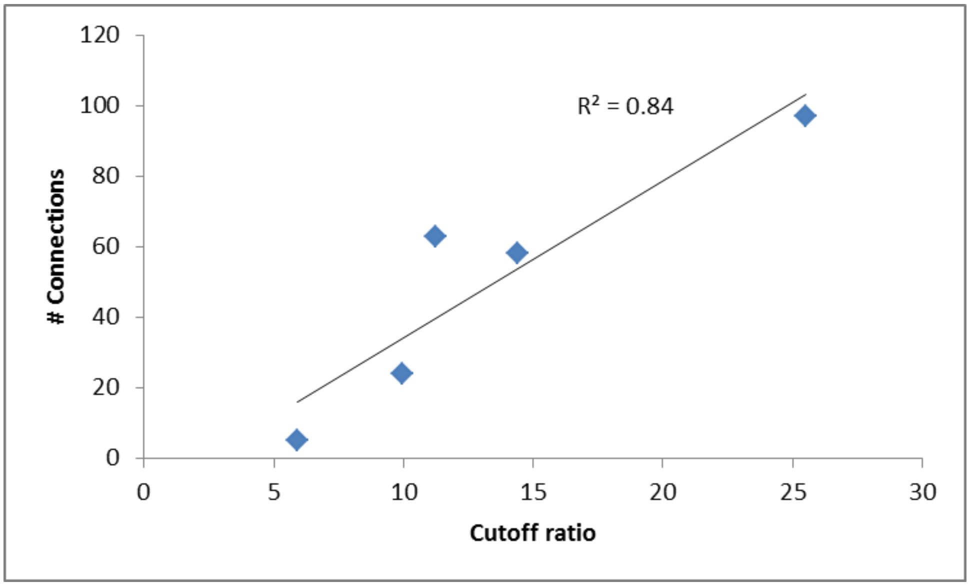

Figure 7. Relationship between cutoff ratio and connections from oxbow lakes studied in Osting (2004).

The relationship between rates of sedimentation and the diversion angle (Fig. 8) displays a gently downward sloping trend as diversion angles increase. With larger diversion angles the upstream entrance to the oxbow lake is at a more perpendicular angle to the main channel, which impedes sediment flowing into the abandoned channel during sufficient connection discharges. Sediment is more easily able to enter oxbow lakes with a lower diversion angle, since the upstream entrance is closer to parallel with the main channel.

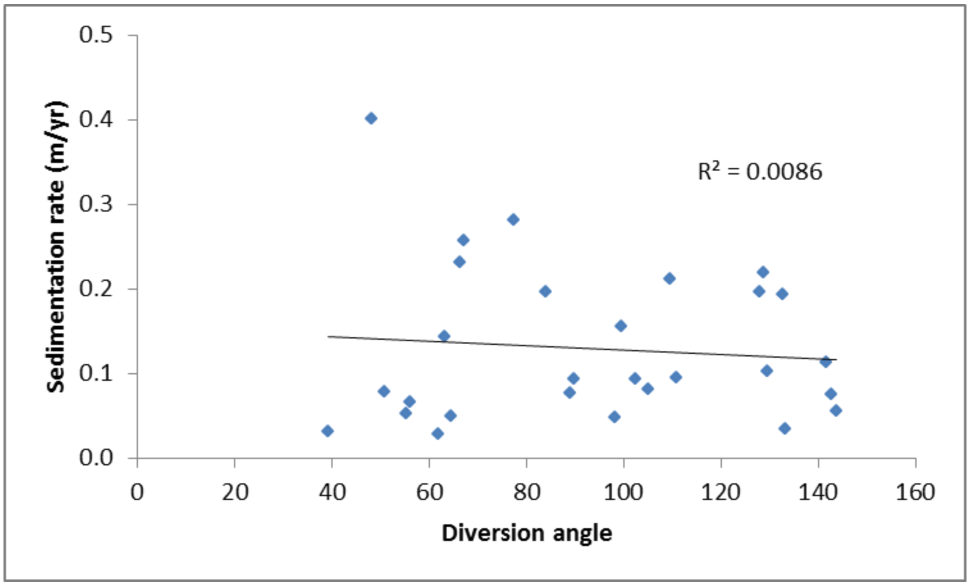

Figure 8. Relationship between sedimentation rates and the diversion angle. Main channel flow enters the oxbow more easily when the diversion angle is lower, with higher maximum rates of sedimentation at diversion angles less than 100.

Constantine (2010) showed that in coarse-grained fluvial systems with high diversion angle, aggradation rates, or rates of sedimentation, are higher. This relationship of high diversion angle-high rate of sedimentation does not apply to the Brazos River, which is a sand-dominated system (Dunn, 2001). Therefore, changes in the composition of the sediment load, in addition to the planform characteristics of the oxbow, affect the rate of sedimentation in abandoned channels.

Figure 9 displays the relationship between the number of connections, observed from Osting (2004) and the diversion angle for 5 of the 28 oxbows. It should follow that a higher diversion angle results in fewer connections as the abandoned channel, oxbow lake, is more perpendicular to the direction of flow in the main channel.

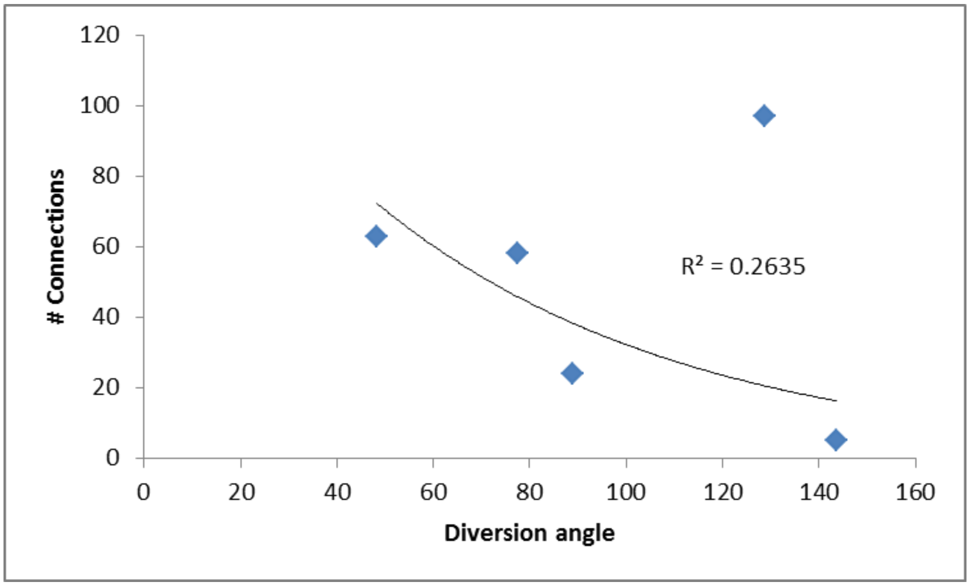

Figure 9. Relationship between diversion angle and the number of connections for oxbow lakes studied in Osting (2004). The outlier is O27, a recent oxbow cutoff in the last decade, though number of connections is listed as connecting back to 1983. The correlation improves to R^2 = 0.9241 when the O27 oxbow is removed.

The outlier in the upper right corner of Fig. 9 deserves special attention. This oxbow is dated to 1996, both from Osting (2004) and the use of temporal aerial photographs by the authors. The oxbow was cutoff in 1996, yet connections between the oxbow and main channel have occurred dating to 1983 from Osting (2004), when the oxbow lake was not yet separated from the main channel. Removing this data point, which though cutoff only since 1996 is nevertheless listed as reconnecting since the 1980s, yields a strong correlation of R^2 = 0.9241, which supports the assertion that oxbow lakes with greater diversion angles reconnect less with the main channel.

Figures 10-13 examine the oxbow lake data in relation to the geomorphically-determined river style classes presented in Phillips (2006). It should be noted that several of the classes across the different characteristics include a low number of data points. Overall, several characteristics of the development of oxbows are presented.

Figure 10 displays boxplots of sedimentation rates according to sinuosity classes from river reach styles. Sinuosity is classified as: low sinuousity, 1.25–1.49; meandering, 1.50-1.99;

strongly meandering, 2.0-3.0, and tortuous, >3.0. The median rate increases as sinuosity of the channel increases. The greatest range in sedimentation occurs with strongly meandering channel segments.

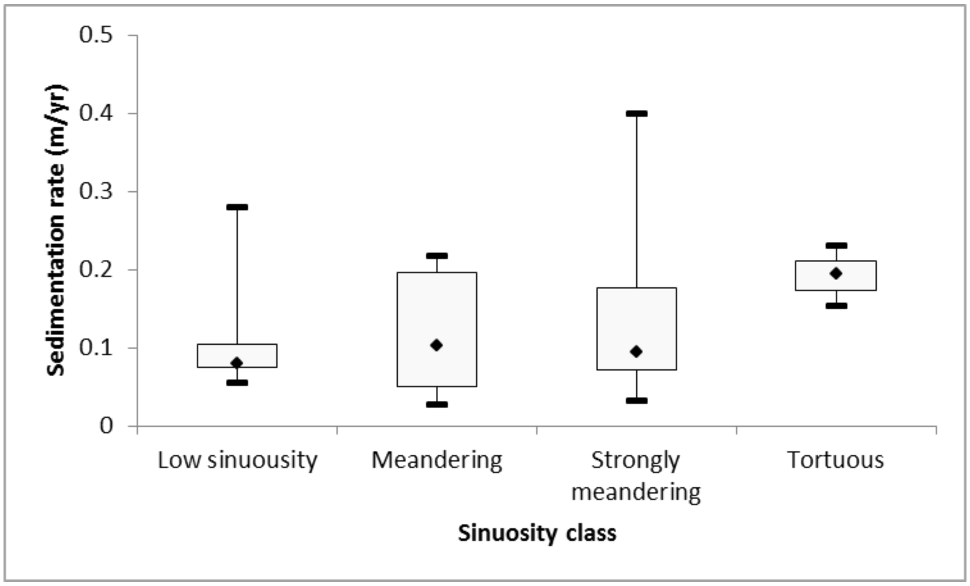

Figure 10. Relationship between sedimentation rates and sinuosity classes presented in Phillips (2006).

Figure 11 displays boxplots for sedimentation rates in six slope gradient classes for the main channel. The largest range occurs in the lower two slope classes. Generally, increasing slope results in greater rates of sedimentation.

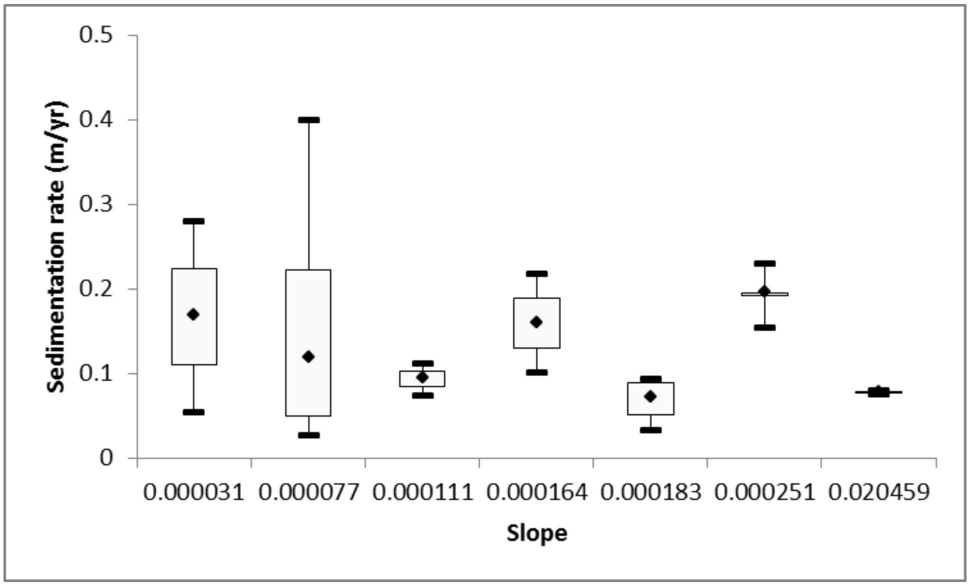

Figure 11. Relationship between sedimentation rates and channel slopes presented in Phillips (2006).

Figure 12 displays boxplots for the two major channel/flow patterns in the study area. All oxbows dated and observed in the study area fall into a class of either a main single thread channel or a single thread channel with tributaries acting as avulsion channels along the river floodplain. The tributaries flow parallel along the main channel through the floodplain. Sediment rates have a greater range in the single thread channel, with the median and 3rd quartile greater in the second channel/flow class.

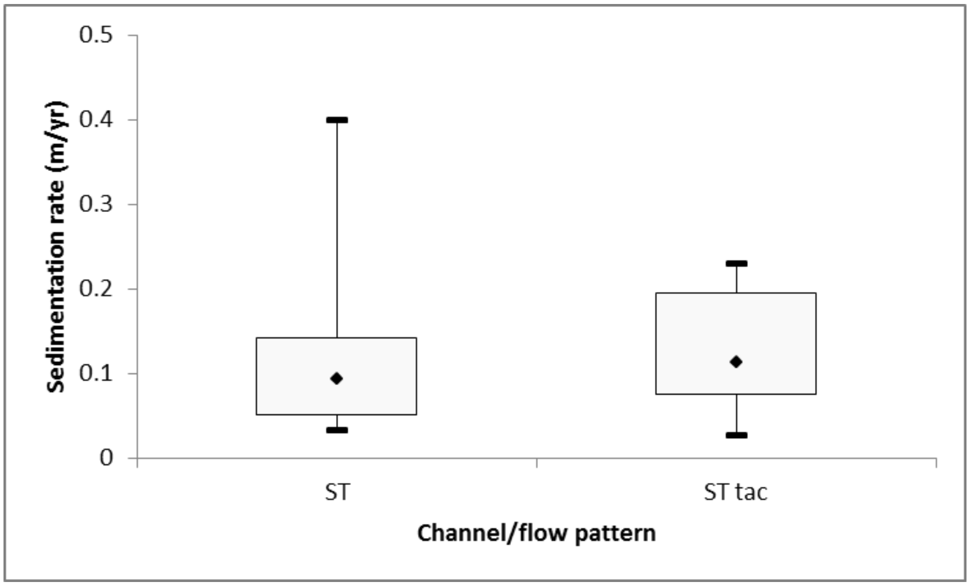

Figure 12. Boxplot of sedimentation rates for single thread and single thread with tributaries occupying avulsion channel & flow pattern. Sedimentation rates between the channel types are approximately equal for the majority of data points. ST = single thread channel, ST tac = tributaries occupying avulsion channels.

Of the four classes presented in Phillip (2006), the channel-floodplain connectivity is perhaps most relevant to the evolution of oxbows in the Brazos River watershed, specifically rates of sedimentation contributing to the infilling of abandoned channels. It was expected that different connectivity classes would have a marked influence on sedimentation rates. The 1st quartile, median, and 3rd quartile sedimentation rates are relatively close in value, ranging from 0.05 m/yr to 0.2 m/yr. The 'low' connectivity class has the greatest range but also contains the most oxbow data points. Overall, maintaining the steady-state nature of the observed sedimentation rates of lower Brazos River oxbows may require flood flows of sufficient magnitude that all oxbows across connectivity classes are flooded.

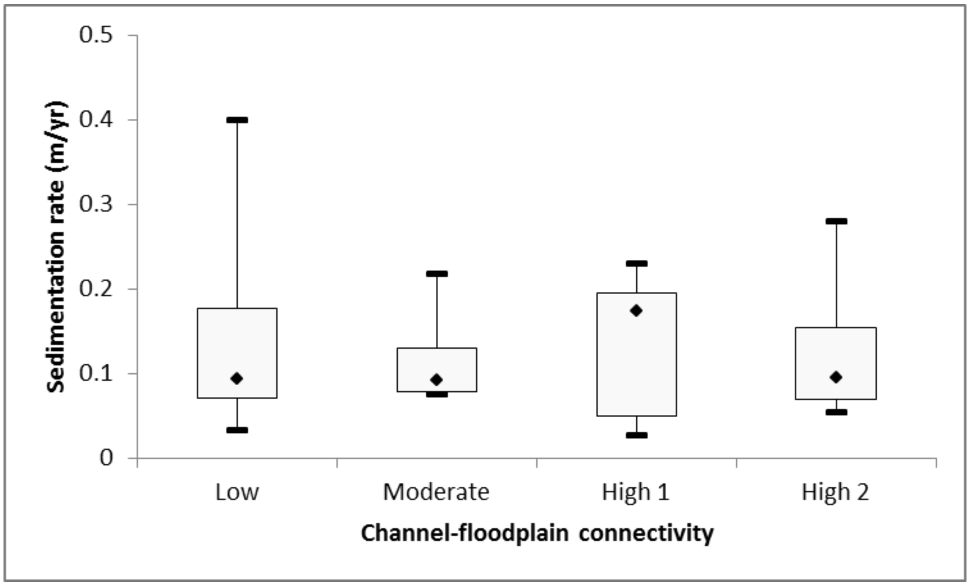

Figure 13. Boxplot of sedimentation rates for channel-floodplain connectivity. High 1 is primarily from flooding of oxbows, sloughs, and flood basins; whereas high 2 is from cross-floodplain flow.

It should be noted that many of the oxbow lakes occur near the boundary between different river reaches presented in Phillips (2006). The upstream or downstream proximity may influence the geomorphology of many of the oxbows presented in this study.

Figure 14 displays the strong correlation $R^2 = 0.9157$ between the number of connections and the age (years since cutoff from main channel) of an oxbow lake. This correlation of decreasing connections with increasing age is expected because as an individual oxbow ages the number of connections decreases as the abandoned channel slowly fills with sediment.

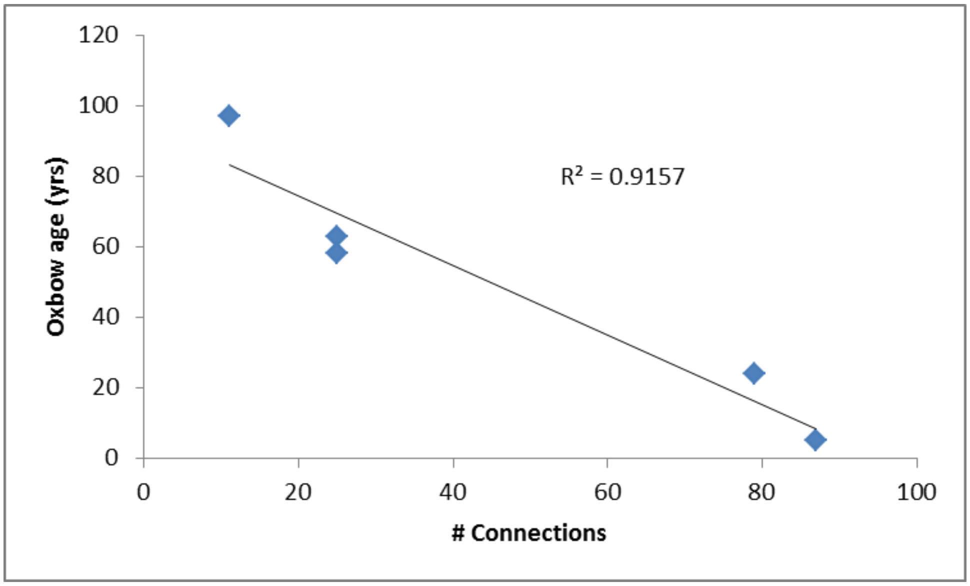

Figure 14. Relationship between the number of connections and the age (years) of the oxbow.

Equations (3) and (4) calculate the number of connections for each oxbow and the main channel and the flood-flow or discharge required for that connection (Table 4). Because only a small number of sites was field surveyed to observe and record the number of oxbow-main channel connections and required discharge, the values in Table 4 allow one to investigate the number of real-world days, using the stream discharge data from the gauges in Table 1, that the main channel did in fact connect to oxbow lakes.

Table 4. Modeled number of connections and modeled flood-flow (cms) needed to reconnect the main channel to oxbow lakes along the Brazos River. Using the modeled flood flow and discharge records to compare the number of days of a given flood to the modeled number of connections between the main channel and oxbow.

Oxbow lake	Modeled # connections	Modeled flood flow (cms)
O1	7	1952
O3	20	1276
O4	56	595
O5	27	1084
O6	19	1304
O7	15	1495
O8	7	1952
O9	48	700
O10	5	2227
O11	25	1136
O12	25	1147
O13	25	1147
O14	53	625
O15	66	482
O16	37	876
O17	8	1928
O18	6	2064
O19	10	1727
O20	46	729
O20	19	1327
O21	46	729
O22	50	664
O23	45	737
O24	39	839
O25	18	1339
O26	30	1014
O27	49	686
O28	10	1768

Figure 15 displays the relationship between the modeled number of connections, calculated with equation (1), and the age of dated oxbows. Though a weak correlation exists, $R^2 = 0.3278$, nonetheless, the general trend is apparent that younger oxbow cutoffs have greater number of connections with the main channel during high discharge periods.

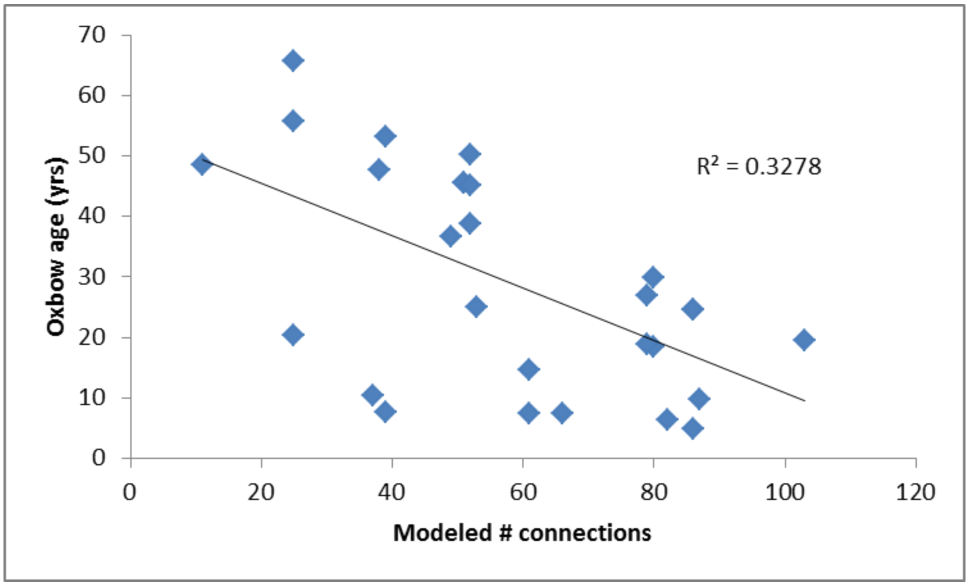

Figure 15. Relationship between modeled connections and oxbow cutoff age for entire dataset.

The correlation shown in Fig. 16, is the modeled number of connections compared to the number of days in which the required flood flow for reconnection occurred, as recorded from nearby USGS gauging stations. Only 13 of the 28 dated oxbows are presented in the relationship between modeled connections because the cutoff dates for these oxbows was within the period of discharge for the gauging station associated with a particular oxbow. Using historic stream discharges and the relationship between connections and rates of sedimentation, one can estimate the number of days a particular discharge will cause connection between the main channel and the abandoned oxbow lake.

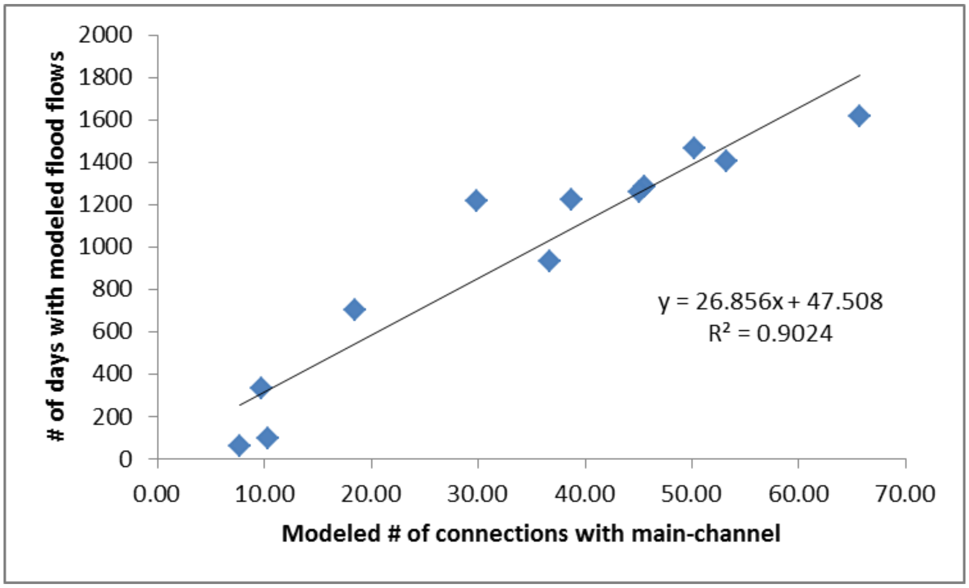

Figure 16. Relationship between the number of days with a modeled flood flow and the modeled number of connections with the main channel.

Using the following equation:

$$y = 28.95x - 4.3218 \qquad (5)$$

Where, y is the number of days in the real-time discharge records that a flood-flow, sufficient to reconnect, occurs, and x is the modeled number of connections between the main-channel and oxbow lake. Using equation (5) it is possible to estimate the number of days an oxbow will connect based on the modeled number of connections with the main channel. With predicted discharge values, it is possible, in combination with the rates of sedimentation, to estimate when oxbows become relatively disconnected to the main channel and at what point they may sufficiently fill with sediment to disconnect.

Task 3 in this report is to categorize the oxbows based in part on their hydrologic properties. In addition to the flood-flow data shown above (Fig. 5 & 16), work by Hudson (2010) presents data on several of the oxbows dated in this work concerning the wetted lake area and the distance to the main channel from the abandoned channel entrance (Fig. 17 & 18). Figure 17 shows that as distance from the main channel decreases the sedimentation rate generally increases in magnitude, with the highest rates in oxbow lakes that are 0.4 km or less from the main channel. It is important to remember that 'distance to main channel' varies over time as the main channel migrates across the floodplain.

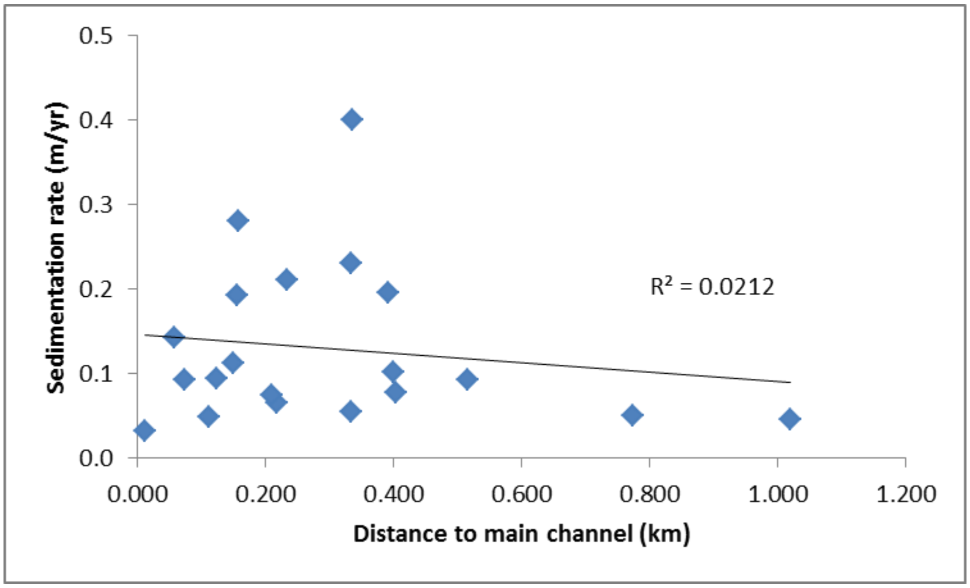

Figure 17. Relationship between sedimentation rates and distance to main channel presented in Hudson (2010).

Figure 18 displays the weak correlation between the wetted-lake area and rates of sedimentation. Though a similar relationship should exist as that between sedimentation rates and cutoff ratios, the opposite is true, with a more pronounced upward trend. As lake area increases the rates of sedimentation also increase. This is opposite of what was shown in Fig. 6 in that as the cutoff ratio increases, the lake lengthens relative to the main channel, the rates of sedimentation decrease. Therefore, changes in the width of the abandoned channel between oxbows may explain why rates of sedimentation increase with larger wetted lake area but decrease with larger cutoff ratios.

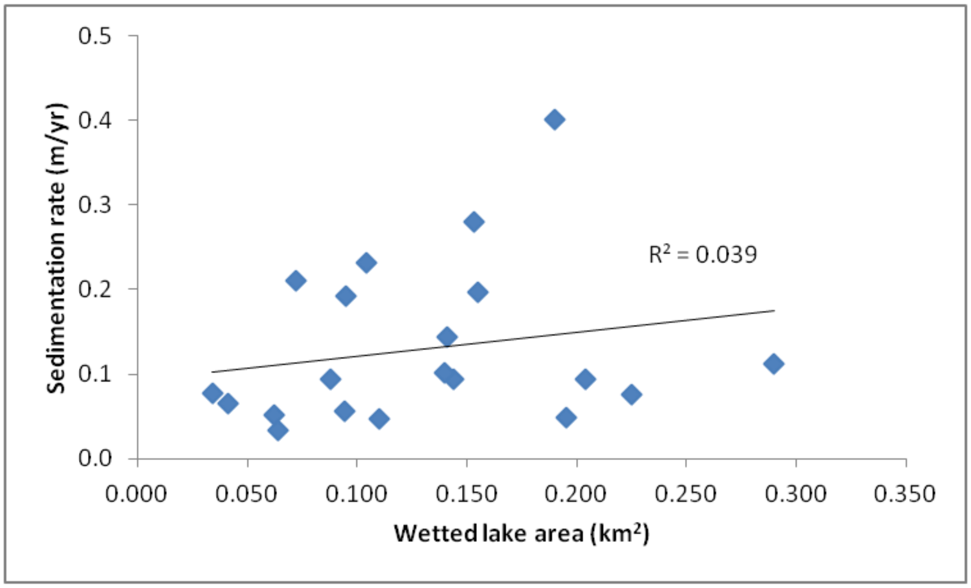

Figure 18. Relationships between sedimentation rates and the wetted lake area presented in Hudson (2010).

The highest sedimentation rates are found in lakes between 0.15 and 0.20 km^2 in area. Several factors may affect lake area, making this analysis tentative. First, groundwater levels in the Brazos River watershed may fluctuate significantly, affecting the surface water expression in different fluvial environments (Chowdhury, 2004). Second, evaporation may also cause lake levels, and therefore area, to change over the course of seasons. Last, it is difficult to determine the origin of water in the lake, whether it is remnant water from separation to the main channel or flood water from recent reconnections.

Summary

This work addresses four components to the evolution of oxbows in the middle and lower Brazos River watershed: 1) quantifying the rate of planform oxbow development, or cutoff; 2) quantifying the rates of sediment deposition; 3) categorizing oxbow lakes based upon their morphologic and hydrologic characteristics; and 4) developing a chronology of development of an oxbow lake as it progresses from meandering bend to remnant oxbow lake.

Concerning the first task, quantifying rates of oxbow development, 28 of the 54 (52%) total oxbow lakes occurring in the middle and lower reaches of the Brazos River are dated as having cutoff on or after 1896, with a cutoff occurring on average every 4.2 years. The oldest cutoff occurred in 1886, while the youngest in 1995.

Concerning the second task, rates of sedimentation in meters per year range from 0.027 to 0.4. The cutoff ratio was found to slightly decrease sediment rates, as expected, while an increase in diversion angle lowers the sedimentation rates, also as expected.

The various river style reaches show that many different characteristics still result in similar rates of sedimentation. The most marked classes are low slopes and tortous sinuosity, both which present higher rates of sedimentation. It should be noted that ongoing channel migration removes the depositional sedimentary units of oxbows. Therefore, oxbow dynamics in the middle and lower Brazos watershed are subject to a number of fairly rapid environmental changes.

Additional analysis should attempt to determine how rates of sedimentation change as a oxbow fills over time. This would negate the steady state assumption made in this work concerning the number of oxbow-main channel connections and flood flows required to make the connection. Both flood flows and sedimentation rates will change over time as an oxbow fills with sediments.

Foundational Findings

- A total of 28 distinct oxbow lakes were dated for their time of cutoff using a combination of historical maps and time series aerial photographs

- Several variables were measured including the cutoff ratio, diversion angle and sedimentation rates. In addition, the number of connections and floods required for connections were used in combination to build several models of oxbow characteristics. Last, the oxbows were categorized according to specific river-style classifications including sinuosity, slope and channel-floodplain connectivity

- As the cutoff ratio increases the sedimentation rates increase for the dataset

- Contrary to the cutoff ratio, as diversion angle increases there is a slight decrease in sedimentation rates

- The number of connections from field observations matches closely (R^2 = 0.9728) to the sedimentation rates for 5 oxbows

- Sedimentation rates decrease as distance to the main channel increases for the dataset

- Sedimentation rates increases as the area of the oxbow lake increases

- A strong correlation (R^2 = 0.9024) exists between the modeled number of connections and the number of days with a flood flow meeting or exceeding the modeled flow needed to connect for 13 of the oxbow lakes

- A strong correlation (R^2 = 0.9469) exists between the flood flow required for connection and the number of connections for 5 oxbows in which higher flood flows have fewer number of connections

- As the number of connections increases for an oxbow lake, the age of the cutoff increases. Therefore, older oxbows have fewer connections in a steady-state environment

- A strong correlation (R^2 = 0.84) exists between an increasing cutoff ratio and increasing number of connections

- A poor correlation (R2 = 0.2635) exists between the diversion angle and number of connections

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