Sand and Gravel Mining in the Brazos River: An Assessment of Erosion Potential and Economic Impact

by Thomas C. Gustavson and Graeme R. Bullen

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Bureau of Economic Geology
Noel Tyler, Director
The University of Texas at Austin
Austin, Texas 78713-8924

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ABSTRACT

This work was undertaken at the request of the Texas Parks and Wildlife Department to assess the potential for increased erosion in the Brazos River channel caused by sand and gravel mining as well as to evaluate the economic importance of sand and gravel mining.

The potential for increased erosion was assessed by examining the history of channel meandering for river segments upstream, within, and downstream of the area of sand and gravel mining. Point and channel bars were mapped and sampled in river segments that are upstream, within, and downstream of the area of sand and gravel mining. Natural levee and floodplain sediments were cored and sampled for segments upstream, within, and downstream of the area of sand and gravel mining. The size and number of meanders as well as the amount of lateral movement of meanders over time decreases downstream through the study area. This indicates that sand and gravel mining has not resulted in recognizable increases in regional erosion. Grain-size analyses of sediment samples from river bars show little change in the texture of these sediments, indicating that sand and gravel mining has had no recognizable effect on grain-size distribution of the sediments that make up river bars.

The objective of the economic assessment was to determine the economic importance of sand and gravel dredging operations in Texas's lower Brazos River, from Hempstead on the northwest to near the Foard-Brazoria county line on the south. Data were collected from various state agencies and organizations, the operators, personal correspondence, and reference literature.

Analysis of this data indicates that between 1979 and 1995 sand and gravel operators produced 10,067,848 cubic yards from the Brazos River. Over the same period the State of Texas received $2,170,153 in royalties from these operations. These operators produce between 2 and 3 percent of statewide sand and gravel production and form a critical component of supply for Houston and the surrounding area's construction industry. Along with floods, the Brazos River sand and gravel production is heavily influenced by the construction of roads and highways and

the amount of residential and nonresidential building construction in the area. Substitutes and alternate sources of supply for sand and gravel do exist; however, they are not necessarily economically feasible or readily available. Transportation costs are a critical element in the feasibility of alternate sources of supply and substitutes and in some cases may double the price of sand and gravel to the consumer. The restitution value of the aquatic wildlife in the lower Brazos River is estimated to be around $200,000.

INTRODUCTION

The work described in this report was undertaken to evaluate the potential for channel erosion in the Brazos River as the result of a reduced sediment budget due to sand and gravel mining and to assess the economic impact of mining operations.

Forshage and Carter (1973) demonstrated that sand and gravel mining can have a significant impact on river fauna, water chemistry, and channel morphology in the immediate vicinity of an in-channel mining operation and for a few miles downstream. Clearly, the removal of many tens of thousands of cubic yards of sand and gravel from a localized site over a relatively short period of time will severely alter the local environment as well as channel morphology. This report examines topographic and sedimentologic data to provide a regional assessment of the potential for increased channel erosion due to sand and gravel mining in the Brazos River over the last several decades.

The scope of this work required collection of new data as well as the analysis of available data. For example, available vintages of topographic maps and aerial photography were examined to determine historical changes in the Brazos River and adjacent floodplain for selected river segments above, below, and within the river segment containing both current and past sand and gravel mining operations. New sedimentological data from river bars, exposures of river banks, and cores of natural levees and terraces were collected to characterize river alluvium and floodplain sediments. Flow velocity and bathymetric data and sediment samples from the river bottom were also to be collected as part of the characterization of sediment transport processes. However, this part of the study has been delayed because extremely low water levels in the Brazos River prevented use of equipment necessary to acquire bathymetric and flow velocity data and sediment samples. Flow velocity data were also to be collected at selected river bars. Because of the low discharge of the Brazos River throughout the duration of this study river bars were never flooded, and hence, flow velocity could not be collected.

Sand and gravel have been mined from the Brazos River channel for many years in the region west of Houston. More than 10,000,000 cubic yards of these materials have been produced since 1979. Royalties paid by mining companies to the State during the same time period exceeded $2,000,000.

This report also provides an assessment of the potential economic importance of sand and gravel mining operations in the Brazos River channel. Important questions that will be addressed include the following. What industries in the State depend on these specific operators for supply of sand and gravel? Are there alternate sources of supply? What direct and indirect benefits are provided to the State economy as a result of these operations? What is the restitution value of the aquatic wildlife resources in this area?

To answer these questions data were gathered from various sources. The Texas Parks and Wildlife revenue reports were used to determine yearly production of sand and gravel from the Brazos River and revenue paid to the State. Statewide sand and gravel production data were gathered using the Bureau of Mines Minerals Yearbooks. Information concerning major users and substitutes for sand and gravel was also obtained using the Bureau of Mines Minerals Yearbooks. A questionnaire was sent to two principal operators in the specific area of study, David Kurz of Sand Supply and Roy Beken of Brazos Sand Supply. This was followed up by a plant visit to Sand Supply, Inc. The City of Houston provided data concerning residential and commercial building permits. The Texas Department of Transportation provided information regarding road and highway construction in the area. The Texas Parks and Wildlife's Restitution Schedule was used to determine the restitution value of the aquatic wildlife in the specific area of study. The data for the Restitution Schedule were obtained from studies performed by the Texas Parks and Wildlife Inland Fisheries Department.

The tasks that have been completed by the Bureau of Economic Geology and that are described in this report include (1) determination of historical changes in the Brazos River channel near sand and gravel operations, (2) sedimentology of Brazos River bars, (3) sedimentology of Brazos River banks and natural levees, and (4) an assessment of the potential economic importance of sand and gravel mining (dredging) operations in the Brazos River channel.

Methods

The Brazos River between Washington-on-the-Brazos State Historical Park and Brazos Bend State Park was examined on a reconnaissance level to determine historical changes in channel position using available aerial photographs, USGS topographic maps, and a series of field visits. Aerial photographs are available in a variety of vintages that are as old as 1941. Various editions of topographic maps are based on vintages of aerial photography as old as 1946. Typically the topographic maps have been revised using aerial photography flown in the late 1970's and 1980's to show both cultural and drainage changes since the initial mapping. Revised topographic maps provide as much as a 30-year record of channel change. For selected areas where significant amounts of channel migration have occurred topographic map data were augmented with additional aerial photographic data. Using a Bausch and Lomb Zoom Transfer Scope the outlines of Brazos River channels depicted on aerial photographs were transferred to topographic maps. Augmenting topographic map data with selected 1995 USGS aerial photographic data yields a 44- to 37-year record of channel change for selected segments of the Brazos River.

The distribution and texture of sediments that make up selected bars on the Brazos River were examined by first mapping the bar and its distinguishing morphologic characteristics and then collecting sediment samples from selected sites. Pace and compass maps of selected bars were constructed to illustrate the distribution of bar bed forms such as rippled and flat-bedded surfaces and dunes, the distribution of sediments with different textures such as mud, sand, and gravel, the distribution of current indicators such as tree trunks and imbricated clasts, as well as the outlines of the bar and of the adjacent channel bank. A sample grid was designed to examine downstream sediment textural changes and to approximate the average texture of near-surface bar sediments. The sampling grid also was used to examine textural changes from the lower parts of the bar near the water's edge to higher parts of the bar near where the bar is attached to the river bank. It should be noted here that the mapping of river bars was completed during an extremely low flow stage of the Brazos River and that during normal flow stages the lower parts of these bars would be submerged.

The surface layer of bar sediments can be a grossly inaccurate representation of bar sediments beneath. This happens because in some areas a coarse gravel lag is created by deflation of finer sediments or because finer sediments have been washed downstream or washed deeper into the bar. In other areas the surface of the bar may become covered by a thin veneer of eolian sediments. For these reasons the surface sediment layer was always removed before sampling.

The grain-size distribution of sediment samples from the bar surface was analyzed by sieving to determine the weight percent of each textural class from pebble or coarser gravel to silt and clay. These data were both tabulated and illustrated graphically. The sedimentology of river banks, natural levees, and adjacent floodplains was examined both in outcrop and in cores. Cores were collected from both Washington-on-the-Brazos State Historical Park and Stephen F. Austin State Historical Park using a Central Mine Equipment 175 drilling rig (2.25 inches in diameter core) and from the Brazos Bend State Park using a Giddings Soil Probe (1.25 inch in diameter core). The Giddings Soil Probe was used at the Brazos Bend State Park because bridges on roads leading to the sites to be cored were not capable of supporting the Central Mining Equipment 175 drill rig. Cores were collected with the intention of comparing the downstream changes in channel sediment texture of older sediments to modern channel sediments. Unfortunately, undisturbed core of deeply buried channel sediments at the Washington-on-the-Brazos State Historical Park could not be obtained because these uncemented sediments, which are present below the ground-water table, flowed into the borehole and into the core tube with ground water. The Giddings Soil Probe utilizes a hydraulic ram to take core and cores were taken from the surface to the maximum depth of penetration at each site. Buried channel sediments were not cored at the Brazos Bend State Park because they were below the maximum depth of penetration of the Giddings Soil Probe. Collected cores were examined and logged at the Bureau of Economic Geology Core Research Laboratory for grain-size distribution, soil and sedimentary structures, and color. Good exposures of bank sediments adjacent to the bars that were mapped and sampled were limited to sections of bank at the Stephen F. Austin State Historical Park. In this case grain-size distribution, soil and sedimentary structures, and color were described and recorded in the field. These regional data were compared to determine if significant changes in sediment texture occurred with distance downstream within the study area and if sand and gravel mining operations had affected the distribution of sediment texture in point bars and channel bars in the study area.

The economic assessment of the importance of mining sand and gravel from the Brazos River was based largely on interviews of mining company owners or operators and on the review of sand and gravel production data and royalty data provided by the Texas Parks and Wildlife Department.

EROSION ASSESSMENT

Historical Changes in Brazos River Channel

Lateral migration of stream channels, or meandering, is a natural phenomenon in rivers, and meandering is typically best developed where rivers flow across broad flat low-sloping floodplains. As part of this effort to evaluate the potential for increased erosion by the Brazos River resulting from a reduced sediment budget caused by sand and gravel mining, historical changes in the Brazos River channel near sand and gravel operations were documented. A segment of the Brazos River extending from Washington-on-the-Brazos State Historical Park on the north to Brazos Bend State Park on the south was examined for evidence of channel changes (fig. 1). In addition, river slope and river bank height were plotted from the Gulf of Mexico to north of the Washington-on-the-Brazos State Historical Park. Using these data, comparisons were made of channel changes among areas upstream of, within, and downstream of the sand and gravel mining operations.

Brazos River Slope and Incision Depth

The slope of the Brazos River between Washington-on-the-Brazos Historical Park and Brazos Bend State Park is approximately 0.7 ft/mi (fig. 2). There are no known dams or obstructions to flow downstream of the Washington-on-the-Brazos State Historical Park. Hidalgo Falls and a broken dam, however, are present approximately 5 mi upstream from the park and may account for a steeper river slope at about river mile 235 (fig. 2).

The depth of incision or cutbank height was plotted versus river miles upstream from the Gulf of Mexico (fig. 3). The average incision depth varies along the river from approximately 35 ft for the segment underlain by the Beaumont Formation, to approximately 27 ft for the middle segment underlain by the Lissie, Weches, and Fleming Formations, to approximately 33 ft for the segment underlain by the Oakville, Catahoula, Whitsett, Manning, Wellbourn, Caddell, and Yegua Formations. The depth of incision apparently varies with the lithology of sediments that underlie the Brazos River such that the deepest incisions occur in areas underlain by Beaumont clays, the shallowest incisions occur in areas underlain by sand and gravel of the Lissie, Willis, and Fleming Formations, and the remaining section is incised to an intermediate depth in areas underlain by mixed sands and clays. The cause of this relationship is not clear. Perhaps incision depth is in part a function of relative ease of erodibility of these sediments or of bank stability.

Channel Migration

The maximum lateral shift of meanders upstream of, within, and below the river reach where sand and gravel mining operations have been carried out was measured from topographic maps to determine the relative volumes of sediment lost by bank erosion. The maximum lateral erosion of the river into the cutbank (outside bank of the meander loop) was measured to the nearest 50 ft, and the approximate length of the affected meander loop was measured to the nearest 1,000 ft (tables 1 and 2). About twice as many meanders were measured in the river segment above the area of sand and gravel production as in the area of production. This is mostly due to a stretch of river near Fulshear, Texas, which lies within the region of sand and gravel production, where the river appears to be constrained from significantly eroding its banks by bedrock. Downstream of the area of sand and gravel production the river showed evidence of recent channel shifting only in the Thompson, Texas, quadrangle.

The Brazos River is a dynamic stream that has locally eroded substantial segments of its banks within the study area. Typically erosion occurs on the outside of meander loops (cutbanks), resulting in a broad thin crescent-shaped or lens-shaped area of land loss leading to both a lateral and a downstream shift in the meander loop (figs. 4-6). At the same time that the outside bank of the meander loop is being eroded, sediment is being deposited along the inside of the meander loop, resulting in a lateral shift of the river and its channel. Under normal or low-flow conditions riverbanks may remain relatively stable for long periods of time and show little or no evidence of deposition or erosion. During flood stage, however, significant erosion and deposition may occur with the channel being shifted laterally many tens of feet. In extreme cases a meander loop may be cut off as the river excavates a new shorter steeper channel across the base of the loop.

The topographic maps and aerial photographs that were used to generate figures 4, 5, and 6 represent three or four points in time separated by many years. The duration of individual erosion events, however, is measured in a few days or at most a few weeks. Because most erosion occurs during flood events it is not possible to determine actual short-term erosion rates from aerial photographs and topographic maps. Nor is it reasonable to calculate an annualized erosion rate.

Comparison of the data from different reaches of the Brazos River shows that local channel migrations of as much as 1,000 ft have occurred upstream of, within, and downstream of the sand and gravel mining areas over periods of approximately 20 years (tables 1 and 2). Further comparison of meander migration from above the area of sand gravel mining to the area where mining was active shows that average lateral migration was less in areas of mining (495 ft) than in the areas upstream, where average migration was 750 ft. The average length of a meander loop affected by lateral migration in areas of mining (3,200 ft) was also less than in areas upstream, where the average loop length affected by mining was 3,900 ft.

The effects of channel migration were also examined in detail along stream segments adjacent to the Washington-on-the-Brazos, Stephen F. Austin, and Brazos Bend State Parks (figs 4-6). These areas were chosen for study because they have easy access to the river, because they are State property, and because actively migrating meanders occur along the river boundaries of each park. At Washington-on-the-Brazos and Stephen F. Austin State Historical Parks there is a 37-year record of channel changes; at Brazos Bend State Park there is a 41-year record. These sites have been subject to substantial areas of both land loss and land gain due to the downstream or lateral migration of meanders. More than 600 ft of land loss has occurred along the northern boundary of Washington-on-the-Brazos State Historical Park (fig. 4). However, this loss has been offset in part by 1,000 ft of land gain along the eastern boundary of the park. Stephen F. Austin State Historical Park has lost as much as 1,850 ft of land because of meander migration in the northeastern quadrant of the park (fig. 5). In other areas of the park bounded by the Brazos River as much as 750 ft of land has been gained. The Brazos Bend State Park has lost only a few tens of feet of land over the last 41 years, and locally at its northeastern corner it has gained nearly 1,000 ft of land (fig. 6).

The processes that drive migration of Brazos River meanders will continue to operate in the future much as they have in the past. Land on the concave or outside bank of the meander loop will continue to be eroded as new material is deposited on the inside or convex bank of the meander loop. In meandering rivers at high discharge stages water flows in a helical pattern downstream. Flow velocity is greatest adjacent to the concave banks of meanders, and sediment moving into the stream by bank caving is caught and carried by a transverse component of flow toward the middle of the channel near the bed. Downstream near where the meander curve begins to reverse, some of this sediment is carried toward the convex part of the same bank from which it was derived. In this fashion crosscurrent flow near the river bed contributes large volumes of sediment to point-bar building on convex banks.

Interpretation

The wavelength and amplitude of meander bends on the Brazos River decrease from Washington-on-the-Brazos State Historical Park on the north to Brazos Bend State Park on the south. The lateral migration of meander bends also decreases downstream through the study area. This may be related to the fact that the Brazos River is more deeply incised in this section and that the higher banks are more stable and may serve to slow the development of or lateral shifting of meanders. However, there appears to have been no increase or decrease in the general morphology of individual meander loops over time, and therefore, sand and gravel mining has had no apparent effect on meander loop morphology in the Brazos River. In other words there is no evidence of increased bank erosion due to sand and gravel mining.

Sedimentology of Brazos River Bars

Three Brazos River bars were examined in detail. These included point bars in the river reaches adjacent to Washington-on-the-Brazos State Historical Park in the upstream part of the study area and adjacent to Brazos Bend State Park in the downstream end of the study area and a river side bar in the middle of the study area in a river reach adjacent to Stephen F. Austin State Historical Park. Point bars are broadly U-shaped accumulations of sediment that occur on the inside of a meander loop. Side bars are generally nearly straight and occur adjacent to and parallel to the sides of straight stretches of rivers.

Washington-on-the-Brazos Point Bar

Since 1958 point bar and associated floodplain deposition along the west bank of the Brazos River and erosion of the cutbank on the opposite side of the river have accompanied the eastward migration of the river at the Washington-on-the-Brazos State Historical Park. As a result the channel of the Brazos River has migrated eastward approximately 825 ft (fig. 4). Recent deposition has resulted in a 2,150-ft-long point bar that ranges up to 210 ft in width (fig. 7).

The distribution of surface sediments of the bar was mapped, and 24 near-surface sediment samples were taken in order to characterize sediment textural distribution (fig. 8; table 3). Sediments fine from cobble gravel and sand near the upstream end of the bar to pebble gravel throughout the middle part of the bar to sand near the downstream end of the bar. Those parts of the bar that are adjacent to the Brazos River are typically covered with a thin veneer of sand or sandy mud. Muddy sediments derived from an unnamed tributary to the Brazos River overlie bar sediments near the downstream end of the bar.

Segments of the bar that are underlain by mixtures of sand and gravel have a flat surface and preserve flat bedding within the sand and gravel strata. In the downstream sections of the bar that are characterized by sandy sediments dunes and ripples are common recognized bar surface structures whose internal bedding is preserved as various scales of cross-stratification.

Sediment samples taken from the bar surface vary considerable in texture and range from as much as 40 percent gravel to 100 percent sand, silt, and clay. Silt and clay, however, are typically less than 15 percent. Sediment texture distribution is also typically bimodal with a dominate fine to medium sand fraction and a secondary pebble- and granule-sized fraction. Bar sediments also become finer downstream. Figure 9 illustrates that the sample series WB12, WB24, WB 26, WB19, WB21, WB22, WB25, which were taken from the Washington-on-the-Brazos point bar at progressively farther downstream sites, fines downstream. As the percentage of gravel and coarser sand fractions decreases the percentage of medium, fine, and very fine sand increases.

Stephen F. Austin Channel Bar

Point-bar migration of the Brazos River in the vicinity of the Stephen F. Austin State Historical Park has resulted both in substantial land loss and in creation of substantial new land (fig. 5). Locally the river channel has shifted as much as 1,600 ft. In the vicinity of the Stephen F. Austin channel bar the Brazos River has shifted approximately 850 ft since 1958. Recent deposition has resulted in a 2,000-ft-long bar that is as much as 200 ft wide.

Surface sediment distribution on the bar was mapped, and 28 near-surface sediment samples were collected and analyzed to describe sediment textural distribution (fig. 10). Sediments fine from cobble and pebble gravels near the upstream end of the bar to sand at the downstream end. A long shallow partly flooded trough separates the bar from the river bank. Muds occupy the floor of the trough.

Preserved primary structures also change downstream and from higher to lower bar elevations. Bedding in the pebble- and cobble-gravel areas is flat or approximately parallel to the bar surface. Flat-bedded sand and gravel occurs in the upstream areas and higher elevations of the bar. In the downstream end of the bar large bed forms called subaqueous dunes are preserved. Sediments that were deposited as dunes commonly are preserved as crossbedding that formed as the dune slip face migrated downstream.

The texture of near-surface samples varies substantially and ranges from as much as 55 percent gravel to no gravel and 100 percent sand and finer sediment (fig. 11; table 4). Sediment grain-size distribution is bimodal for sand and gravel samples with a primary coarse sand, medium sand, and fine sand fraction peak and a secondary granule and pebble gravel peak. Sand samples are normally distributed about a medium sand peak. Sandy sediments of the bar also fine downstream. A series of samples, SFA 30, SFA 28, and SFA 23, which were taken from progressively farther downstream sites, fines downstream from primarily coarse and medium sand to medium and fine sand to fine sand (fig. 12).

Brazos Bend Point Bar

The Brazos River point bar near the northeast corner of the Brazos Bend State Park has migrated approximately 1.5 km downstream from a position that was mostly north of the park to a position that is mostly within the park (fig. 6). Locally the river channel has shifted as much as 1 km since 1951. Recent deposition on the inside of the meander loop has resulted in a point bar that is approximately 2,300 ft long and as much as 200 ft wide.

Surface sediment distribution on the bar was mapped, and 22 near-surface sediment samples were collected and analyzed for grain-size distribution. Sediments generally fine from cobble gravel and sand near the upstream end of the bar to pebble gravel and sand and eventually sand toward the downstream end of the bar (fig. 13). Muddy sediments typically occupy the lowest elevation parts of the bar near river levels.

Preserved bedforms and primary sedimentary structures also change downstream. Sand and gravel units typically are present in upstream and higher elevation areas of the bar and preserve flat-bedded sediments. Areas that consist primarily of sand typically occur in the downstream areas of the bar or in lower elevations and preserve ripples and dunes on the bar surface as well as associated crossbedding. Surface sediments of the Brazos Bend point bar vary from samples that contain as much as 45 percent gravel by weight to samples that are primarily sand and silt with no gravel (fig. 14; table 5). The grain-size distribution on this bar is partly bimodal with the fine fraction consisting primarily of medium and fine sand and the secondary coarser fraction consisting primarily of gravel- and granule-sized material. In addition there is a small group of six samples that contain 75 to 95 percent fine sand. Sandy sediments of the bar also fine downstream. A series of samples, which were taken from progressively further downstream sites, fines downstream from primarily coarse and medium sand to medium and fine sand to fine sand (fig. 15).

Interpretation

There is significant similarity among Brazos River bars that were examined at Washington-on-the-Brazos, Stephen F. Austin, and Brazos Bend State Parks. Surface sediments fine downstream from coarse sand with cobbles and pebbles in the upstream parts of the bars to primarily sand in the downstream parts of these bars. Primary sedimentary structures are typically flat beds in the upstream gravelly sediments and cross-stratified sand preserved beneath ripples and dunes in downstream areas.

Comparison of composites of grain-size distribution graphs from Washington-on-the-Brazos Historical Park and Brazos Bend State Park shows similar distribution characteristics with primary peaks in the medium and fine sand-size range and a secondary peak in the gravel- and granule-size range. However, for the Washington-on-the-Brazos data there is a distinct secondary peak in the medium sand range, and for Brazos Bend data there seems to be only a shoulder in the medium sand range appended to the fine sand peak. These data suggest that although both the range and distribution of grain size within these two bars are similar, sediments of the Washington-on-the-Brazos point bar are slightly coarser. Grain-size data from the side bar at Stephen F. Austin State Historical Park indicate that the sediments that make up this bar are slightly coarser than sediments in the other bar in that medium and coarse sand make up a significant proportion of this bar and gravel ranges up to 55 percent.

The similarity in grain-size distribution in sediments that make up the point bar that lies upstream of gravel mining operations and the point bar that lies downstream of the gravel mining operations in the Brazos River suggests that mining operations have had little or no effect on grain-size distribution in point bars.

Floodplain and Natural Levee Stratigraphy

The stratigraphy of the Brazos River floodplain and natural levees was assessed by collecting and describing core from a series of boreholes at the Washington-on-the-Brazos, Stephen F. Austin, and Brazos Bend State Parks. Cores 2.25 inches in diameter were collected from three boreholes at both the Washington-on-the-Brazos Historical Park and Stephen F. Austin State Historical Park using a hollow-stem auger. A core of 1.25 inch was collected from three boreholes at the Brazos Bend State Park using a Giddings Soil Probe. The Giddings Soil Probe was used at Brazos Bend State Park because the CME 175 drill rig was too heavy to safely cross load zoned bridges on roads leading to the areas that were to be sampled. Cores were described in terms of sediment or soil texture, sedimentary and soil structures, evidence of bioturbation, and color. Boreholes were sited at progressively greater distances from the river in order to test progressively older material. In addition a composite of several exposures of river bank sediments was described at Stephen F. Austin State Historical Park.

An attempt was made to correlate surface soils in these cores to soils mapped in the parks. The upper 2 m of core collected from the Washington-on-the-Brazos Historical Park and from the Stephen F. Austin State Historical Park did not conform to soils described and mapped for these areas in the soil surveys for Washington and Austin and Waller Counties (Chervenka and others, 1981; Greenwalde, 1984). The upper 2 m of cores from the Brazos Bend State Park, on the other hand, are similar to the Miller soil series, which is mapped throughout much of the park (Mowery and others, 1960).

Washington-on-the-Brazos State Historical Park

The three cores collected at Washington-on-the-Brazos Historical Park contain laminated very fine sand, silt, and clay sequences and a few laminated or cross-stratified fine to very fine sand sequences (figs. 16, 18, and 19). Laminations are typically a few millimeters thick and rarely a few centimeters thick. With the exception of the surface horizon (3 to 4 ft) these sediments have not been strongly altered by pedogenesis. Typically the entire sequence is calcareous, root tubules are common throughout, and roots are present in the surface horizon. Filled burrows are present locally. Clay beds or horizons typically contain evidence of initiation of vertic soil development in the form of former desiccation cracks filled with sediment and fractures with slickensides. These structures develop as a result of multiple episodes of expansion and contraction as a result of wetting and drying.

Finely laminated sediments consisting mostly of very fine sand, silt, and clay with a few thicker clay or sand beds are typical of floodplain sedimentation where sediments are supplied as both suspended and traction load. Clay beds that have been modified by vertic pedogenesis processes probably identify buried soils that began to form because these sediments were exposed to multiple episodes of wetting and drying at the surface.

Stephen F. Austin State Historical Park

A composite section was described from a series of exposures along the western bank of the Brazos River at Stephen F. Austin State Historical Park. Flat-bedded and crossbedded pebbly sands are exposed in the lowest meter of the section (fig. 20). The upper 18 ft of the section, however, consists of a series of upward-fining sediment sequences. Each upward-fining sequence typically consists of a lower 4-inches- to 5-ft-thick ripple cross-stratified to laminated very fine sand unit that fines upward to silt. In turn these sediments are overlain by 4-inches- to 8-inches-thick laminated to massive clay or mud in which individual laminae may consist of thin upward-fining silt-clay sequences. Roots and root tubules are common throughout these sediments. Desiccation cracks are present in some muddy or clayey beds. There is no evidence of pedogenic alteration of these sediments.

These sediments are exposed beneath a natural levee developed along the west side of the Brazos River. The sedimentary structures are typical rapid sedimentation that occurs when the velocity of highly sediment loaded flood waters decreases rapidly as these waters leave areas of unobstructed flow in the river channel and flow across the vegetated margins of the river bank. The series of large-scale upward-fining sediment sequences exposed in the bank resulted from a series of flood events. These sediments accumulated since 1958 because in 1958 the Brazos River occupied the site where these sediments accumulated. The apparent youthfulness of these sediments is consistent with the lack of soil development. In addition, the pebble gravels exposed near the base of this section were probably deposited by the Brazos River approximately 40 years ago.

Cores that were collected from three boreholes at Stephen F. Austin State Historical Park contain primarily clay to medium sand in the upper 13 to 18 ft (figs. 21-23). Primary sedimentary structures have been destroyed in most of these sections, although laminae are preserved in upper parts of the core from the Stephen F. Austin No. 2 borehole (fig. 22). Surface horizons are typically brown (7.5YR 3/4 to 5/6) loams to sandy loams. Other evidence of pedogenesis includes clay or clay loam argillic horizons, sediment-filled desiccation cracks, and the presence of common $CaCO_3$ nodules and slickensides on fracture surfaces in the thick clay sequence in core from the Stephen F. Austin No. 1 borehole (fig. 21). Evidence of bioturbation is preserved as common roots and root tubules and sediment-filled burrows.

These sediments, which were collected from the floodplain of the Brazos River, are typical of floodplain deposits in that they are predominately fine grained, are laminated where primary sedimentary structures are preserved, and show evidence of incipient soil development. These sediments resulted from multiple episodes of overbank sedimentation followed by long episodes of exposure. A possible exception is the 12-ft-thick clay sequence in core from Stephen F. Austin borehole No. 1 (fig. 21). Clay is preserved between depths of 5 and 16 ft. The lack of sedimentary structures and the presence of preserved desiccation cracks, slickensides on fractures, and common $CaCO_3$ nodules all indicate slow episodic sedimentation and pedogenesis in a closed basin such as a segment of an abandoned channel.

The lower sections of core from Stephen F. Austin State Historical Park contain medium to coarse sand and granule to pebble gravel. These sediments are typically calcareous, uncemented, and flat bedded with a few planar crossbedded units. These coarse-grained sediments were deposited in a Brazos River paleochannel; however, there is insufficient core to determine if these sediments were deposited as part of a channel bar or as part of a point bar.

Brazos Bend State Park

Sediments contained in core from three boreholes in the Brazos Bend State Park range from dark-reddish-brown (5YR 3/3) clay loam and clay to black (5YR 2.5/1) clay (figs. 24-26). A few thin sequences of laminated very fine sand, silt, and clay are preserved locally, but typically the clay and clay loam do not preserve primary sedimentary structures. Soil structures indicative of expansive clay are common and include slickensides on fracture faces and shiny pressure faces on peds. Pedogenic $CaCO_3$ nodules are also common. Biogenic structures include common roots and root tubules and few burrows. The clay and clay loam sediments that comprise the surface soil horizons in these cores are similar to soils of the Miller soil series that have been extensively mapped in the Brazos Bend State Park.

The clays and clay loams recovered in these cores were deposited on a floodplain in areas where the coarser traction load sediments were not a significant part of the total sediment load. These sediments were deposited almost entirely from suspension and indicate that these areas were occupied by very slow moving or standing water.

Results

Cores of the Brazos River fine-grained floodplain sediments indicate that these sediments range from 30 to 42 ft thick at Washington-on-the-Brazos State Historical Park to more than 18 ft at Stephen F. Austin State Historical Park, to more than 14 ft at Brazos Bend State Park. These sediments are the result of deposition of traction and suspension loads by flood waters of the Brazos River that overtopped the river channel banks. Fine sands and silts are transported along the floodplain surface by slow-moving currents, and the fine silts and clay are carried in suspension. At the Stephen F. Austin State Historical Park cores penetrated medium to coarse flatbedded to crossbedded sand and pebble gravel. These coarser sediments are in channel deposits that probably accumulated as a point bar or channel bar, and are similar in texture to the texture of point-bar and channel-bar sediments described above.

These cores were taken in anticipation of being able to compare the texture of premining channel sediments, which are buried by fine floodplain or overbank deposits, to the texture of modern channel sediments. The great thicknesses of the fine-grained overbank deposits at Washington-on-the-Brazos Historical Park, which overlie the buried channel deposits, were not known prior to taking core, and it was not anticipated that floodplain sediments would be as much as 42 ft thick. Because of the depth of these sediments, it was not anticipated that buried channel sediments would be mostly below the water table where it is impossible to retrieve undisturbed core. Because undisturbed cores of buried channel sediments could not be collected at Washington-on-the-Brazos a comparison of the texture of modern channel sediments to that of buried channel sediments was not possible.

ECONOMIC ASSESSMENT

Brazos River Sand and Gravel Production

The Brazos River is an important source of sand and gravel for Houston and the surrounding counties. The area supplied by the operators in the Brazos River is approximately 2,000 mi^2. Sand is defined as "naturally occurring unconsolidated or poorly consolidated rock particles that pass through a No. 4 mesh (0.187-inch) U.S. Standard sieve and are retained on a No. 200 mesh (0.0029-inch) U.S. Standard sieve" (U.S. Bureau of Mines, Mineral Facts and Problems, 1985).

Gravel is "naturally occurring unconsolidated or poorly consolidated rock particles that pass through a sieve with 3-inch square openings and are retained on a No. 4 mesh U.S. Standard sieve. Sand and gravel is made up of varying amounts of different rock types and is therefore of varying chemical composition" (U.S. Bureau of Mines, Mineral Facts and Problems, 1985). Figures 25, 26, and 27 indicate the Brazos River sand production, gravel production, and combined sand and gravel production, respectively.

According to David Kurz of Sand Supply, Inc., the low production numbers of 1980, 1982, 1986, and 1992 can be directly attributed to floods that occurred in those years. Floods have a severe effect on production and can cause shortages of supply. This is because production is severely restricted and in some cases completely shut down (D. Kurz, personal correspondence, July 24, 1996).

As can be seen in Figure 28, the Brazos River sand and gravel operators make up a small percentage of statewide sand and gravel production. The contribution of the Brazos sand and gravel operators ranges between 2 and 3 percent of yearly statewide production. It would be easy to assume that this sand and gravel production is therefore "irrelevant" in terms of state-wide production; however, it is a critically important element of the local economy and local sand and gravel supply. Without this supply, sand and gravel would have to be brought in over much greater distances and the transportation costs would raise the price of the delivered sand and gravel substantially.

Industries Dependent on Brazos River Sand and Gravel

The largest use of sand and gravel is as an aggregate for the production of concrete, a construction material used in nearly all residential, commercial, and industrial buildings and in most public works projects such as dams, bridges, sewer systems, road surfaces, runways, sidewalks, etc. The second largest use is as a base material in the construction and repair of highways, railways, and runways. Figure 29 shows the major use categories of Texas sand and gravel.

Sand and gravel from the Brazos River is sold to builders, contractors, road material companies, Texas Department of Corrections, and individuals. It is also sold to concrete redi-mix companies. These companies in turn furnish concrete for residential and commercial construction. The sand is mixed with cement or limestone to make stabilizing materials. This material is used in covering underground utilities, installing culverts, bulkheading overpass and road approaches, installing anchors, etc. The Brazos River also supplies masonry sand, which forms a part of most of the buildings on the western and southern portions of Houston as well as almost all of the buildings in the towns surrounding this area.

The production rate of sand and gravel is linked to the amount of construction activity in the area. This supply and demand pattern can be clearly seen in figures 30 and 31. Except for the flood years of 1980, 1982, 1986 and 1992, the production of sand and gravel from the Brazos River is closely related to the value of building permits (an indicator of building activity) issued for the Houston area. These building permits include permits for residential buildings, nonresidential buildings, building signs, and any additions and alterations. Over the period 1980-1995, the City of Houston issued $24 billion worth of building permits (City of Houston, Building Permits for years 1980-1995).

"The Brazos River operators furnish asphalt sand for road material. About 14% of all asphalt road material is fine-washed sand. All road work in this area uses Brazos River Fine Washed Sand to mix with asphalt and limestone. The operators also furnish a 'river-run' gravel mixture that rural residential homeowners use as driveway material. This is also used as base material for many roads. They also supply sand used in different filtration operations. The Texas Department of Corrections uses this in several of its operations" (Roy Beken, personal correspondence, June 24, 1996).

Similarly the production of sand and gravel from the Brazos River can be correlated with the construction of roads and related works in the area. Figure 32 shows that besides the flood years of 1980, 1982, 1986 and 1992, production of sand and gravel from the Brazos River is related to and influenced by the construction of roads and highways. The projects let by the Texas Department of Transportation include those for road construction, repair, and all related work. Over the period 1985-1995 a total of 1,086 projects were let by the Texas Department of Transportation for Houston and the surrounding counties with a value of $4.7 billion (J. Scnelski, personal correspondence, July 31, 1996).

Substitutes and Alternate Sources of Supply

The primary substitute for sand and gravel is crushed stone. Limestone is most common, but sandstone, granite, and traprock are also used. The angular nature of crushed stone provides more mechanical stability than sand and gravel, especially in road bases and in asphaltic concrete. Slag, bottom ash, and fly ash are also used as substitutes. However, these substitutes may not be economically or technically feasible in the local area.

Crushed stone is not mined in the local area around Houston. Crushed stone used in the vicinity of Houston is imported from the Austin-San Marcos area (60 percent) or from Mexico (40 percent) (D. Kurz, personal correspondence, August 1, 1996). In addition, most of the sand that is used with this crushed stone to make concrete is found in the Brazos River. There are other sources of sand and gravel supply for the area; however, the cost of this sand and gravel is significantly higher.

The lower Colorado River, which lies approximately 30 to 40 mi west of the Brazos River, is also a source of sand and gravel. The material costs about the same to produce. However, hauling costs from the lower Colorado River area double the price of the materials to the users. Hauling costs about $2.50 per mile for a 25-ton load. Hauling from the Colorado River Bottom Area adds about 40 mi for an average user, or about $100 per load. Concrete (with about 40 percent sand) costs about $2.00 more per yard, so an average 60-yard home would cost about $120 more (R. Beken, personal correspondence, June 24, 1996).

Transportation is a major factor in the delivered price of sand and gravel. The cost of moving sand and gravel from the plant to the market may exceed the cost of the aggregate at the plant. Because of the high cost of transportation, sand and gravel continue to be marketed and consumed locally. Wear and tear on highways is an additional unidentified cost.

Direct and Indirect Benefits to the State Economy

The direct benefits provided to the State economy as a result of sand and gravel mining in the Brazos River can be measured by the royalty revenue, employment, and tax revenue these operations generate. The Texas Parks and Wildlife Commission shall manage, control, and protect sand and gravel of commercial value within the tidewater limits of the state, and on islands within those limits, and within the freshwater areas of the state not embraced by a survey of private land, and on islands within those areas. "The Texas Parks and Wildlife Commission, with the approval of the governor, establishes a minimum royalty or a percent royalty of $0.20 ton for sand, gravel, and marl. The permittee shall pay the minimum royalty or a percent royalty of 6.25% on the average selling price per ton sold calculated on a monthly basis, whichever is higher. The percent royalty shall increase to 8.0% on September 1, 1996" (Title 31, Texas Administrative Code, Section 57.101).

Additionally, a yearly permit application fee was implemented in January 1994. This means that applications for permits to take or disturb marl, sand, gravel, or mudshell must be accompanied by the following nonrefundable application fees: (1) $500 for applications to take marl, sand, gravel, or mudshell for purposes of sale; and (2) $200 for all other applications.

Since the inception of this application fee, Texas Parks and Wildlife has received $6,200 in application fees from operators and individuals interested in removing sand and gravel from the Brazos River. The royalties paid to the State of Texas by the Brazos River sand and gravel operators over the period 1979-1995 are shown in figure 32. There is **no** royalty fee earned by the Texas Department of Parks and Wildlife from the lower Colorado River area because all the materials in this area are mined in open pit mines on private property. The same applies to the crushed stone producers.

Of the commercial operators in the Brazos River area of study, Brazos Sand employs about 15 people and Sand Supply about 33 people. The total payroll from these operators is about $1 to 1.5 million per year. According to Roy Beken of Brazos Sand Supply there are five to ten local small contractors who partially depend on the material produced by Brazos Sand Supply to supply their customers. Local driveway builders, septic system installers, concrete finishers, and brick layers all keep their costs down by using these local products. All of these employees and customers are paying State sales taxes (R. Beken and D. Kurz, personal correspondence, June 24, 1996).

The indirect benefits are harder to determine precisely. Because of the high volume and low unit value of sand and gravel, operations need to be close to the market locations. If the Brazos River operators did not supply Houston and the surrounding area it would have a profound effect on the local economy. Higher costs and undue delays would affect the movement of sand and gravel into this marketplace. The same will apply if stringent controls by the local government keep preventing permits from being issued to operators. These conditions can make it difficult to assess the timing and even the possibility of plants going on-stream and can therefore affect the supply of sand and gravel to the marketplace.

Restitution Value of Aquatic Wildlife Resources

In order to obtain the restitution value of the aquatic wildlife resources in the area of study, data were gathered from the Texas Parks and Wildlife Inland Fisheries Division and used in conjunction with the Texas Parks and Wildlife's Restitution Schedule. This restitution value represents the replacement value of the species and the economic impact to the community were the species to be lost or destroyed.

A preliminary estimate of the restitution value of the aquatic wildlife resources in the lower Brazos River is around $200,000 (J. Ralph and M. Webb, personal correspondence, August 9, 1996) (table 6). Seining and electrofishing were the sampling methods employed to gather data on the species, size groups, and total number per size group. The restitution value is a function of the hatchery price of the various species as determined by the American Fisheries Society (American Fisheries Society, 1992), and the recreational value of some of the species as determined by Texas Parks and Wildlife.

Caveat: Because of the limitations of sampling, this restitution value represents the total sampled species counts multiplied by an expansion factor of 250.6 for seining and 80.5 for electrofishing. This assumes uniform distribution of the species and also uniformity of habitat. This was done in order to obtain a representative value for the lower 347 mi of the Brazos River as the original intent of this sampling was not for the purposes of this report.

In the lower Brazos River area there is no commercial fishing or shrimping or any known commercial use or sale of any aquatic wildlife from this area. There is very little recreational fishing in this area. This may be due to the fact that public access in the lower Brazos River is limited by shallow water depth and private ownership of land adjacent to the river. Most access is located at highway crossings or near municipalities (Sellers, 1994). So although aquatic wildlife reside in these waters, the quantity and quality of the aquatic wildlife may not be able to sustain a commercial fishing or shrimping entity.

It was beyond the scope of this report to determine the effects of these specific dredging operations on the local fish populations. Previous studies have been performed to assess these effects (Foshage, A., and N. Carter, 1973). Figure 33 provides a summary of the fish species found from the sampling efforts in the lower Brazos River and their estimated total value.

CONCLUSIONS

There is no evidence in terms of historical channel changes or in terms of changes in the sedimentology of river bars to suggest that in-channel mining of sand and gravel from the Brazos River has had a recognizable effect on the stability of the Brazos River channel. An examination of the sizes and of the historical changes in the position of meanders in the river channel shows that meander loop size decreases downstream as does the rate of channel migration. The apparent increase in channel stability is not completely understood, but it may be related to the depth of incision of the channel in the lower reaches of the study area.

The results of the economic assessment show that over the period from 1979 to 1995, 8,554,560 cubic yards of sand and 1,512,918 cubic yards of gravel were produced from the

Brazos River between Hempstead on the northwest to near Foard-Brazoria county line on the south. The operators in the specific area of study make up between 2 to 3 percent of total statewide sand and gravel production. Because of the high volume low unit value of sand and gravel, the production from the Brazos River is very important to the local economy. The Brazos River sand and gravel are used in most construction activity in the area. Production from the river is heavily influenced by the construction of roads and highways, residential and nonresidential housing, and all related building activities in the local area.

Alternate sources of sand and gravel supply do exist; however, these are available only at a higher cost. The additional transportation costs make some of these sources an uneconomical alternative. Substitutes, such as crushed stone, are not readily available in the surrounding area and have to be transported over long distances to reach the local marketplace. Benefits from sand and gravel operations in the Brazos River accrue to the State of Texas in the form of royalty payments, employment, and taxes. Over the period 1979-1995, the State of Texas received $2,170,153 in royalty payments from the operators in the Brazos River. The restitution value of the aquatic wildlife resources in this specific area of study is estimated to be about $200,000. This represents the replacement value of the species and the economic impact to the community were the species to be lost or destroyed.

The dredging operations in the Brazos River are an important part of the local Houston economy and community. With dredging locally, all construction in the area is cheaper. Impeding or even closing down these operations through over-zealous controls and regulations would effectively eliminate the remaining reserves from the local area's sand and gravel resource base. Consequently, the Brazos River sand and gravel operations need to be encouraged with reasonable environmental regulations, permit requirements and royalties. As a result, the local economy will be healthier and continue to compete favorably with the nation.

As the Brazos River area sand and gravel are depleted or deprived because of continued urbanization and production, construction costs will continue to increase unless an effort is made to conserve these sand and gravel resources. Perhaps an effort to pool or gather sand and gravel resource information of this area is in order so as to determine the extent and quality of the remaining sand and gravel resources. This resource information would help land planners, operators, State and local officials, and all interested parties make informed decisions concerning urban growth and development and sand and gravel dredging operation's regulations and restrictions throughout this region.

ACKNOWLEDGMENTS

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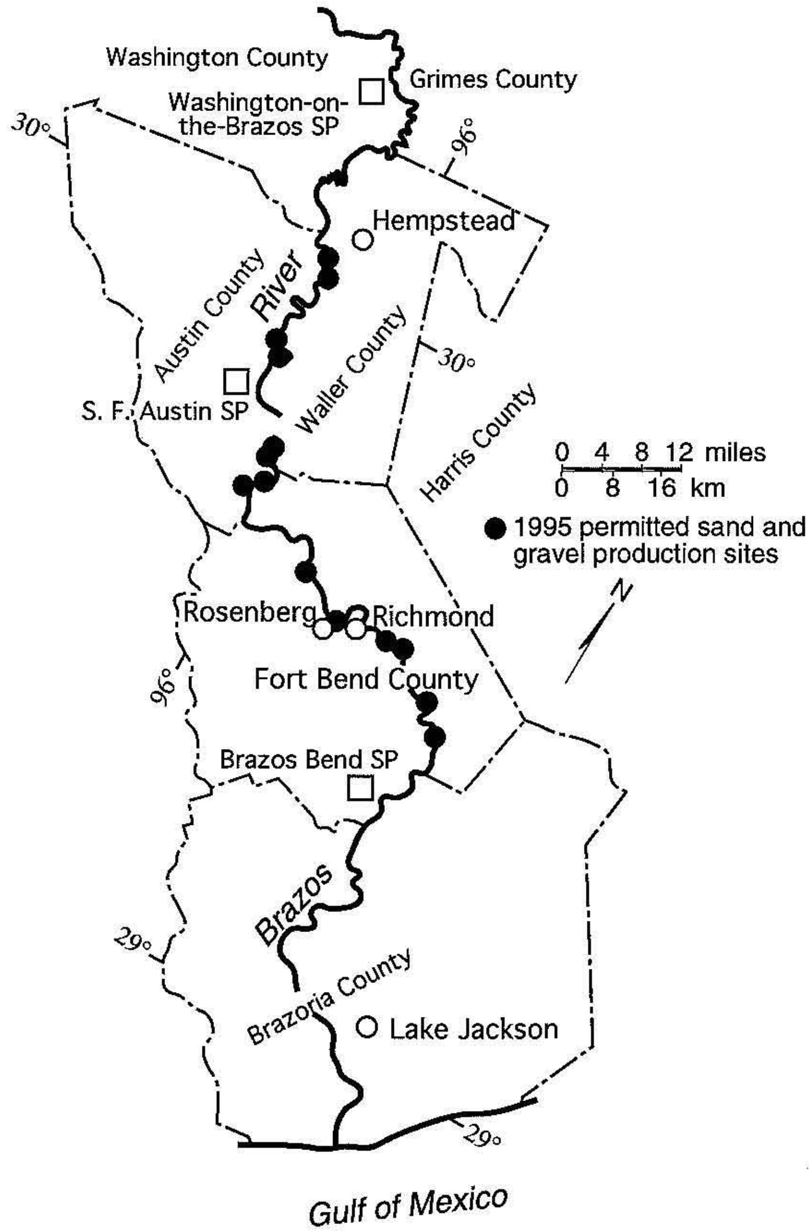


Figure 1. Location of permitted sand and gravel production sites in the Brazos River from near Hempstead on the north to near the Fort Bend-Brazoria county line on the south. This river segment is approximately 185 km (115 mi) long and has been the source of more than 8,400,000 cubic meters (11,000,000 cubic yards) of sand and gravel since 1979.

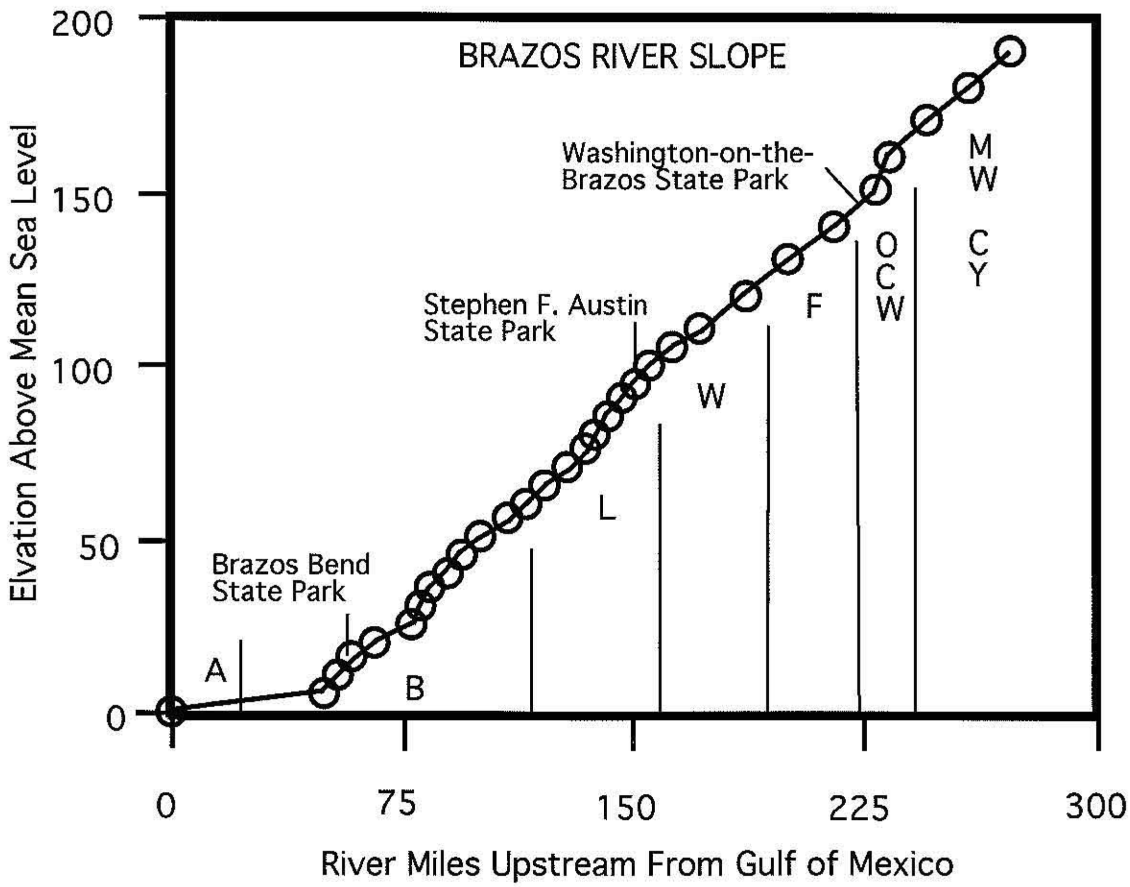


Figure 2. Slope of the Brazos River is about 0.7 ft/mi between Washington-on-the-Brazos State Historical Park and Brazos Bend State Park. The sedimentary formations that the channel is incised into are indicated by the letter: A for alluvium; B for Beaumont; L for Lissie; W for Willis; F for Fleming; OCW for Oakville, Catahoula, Whitsett; and MWCY for Manning,Wellborn, Caddell, Yegua.

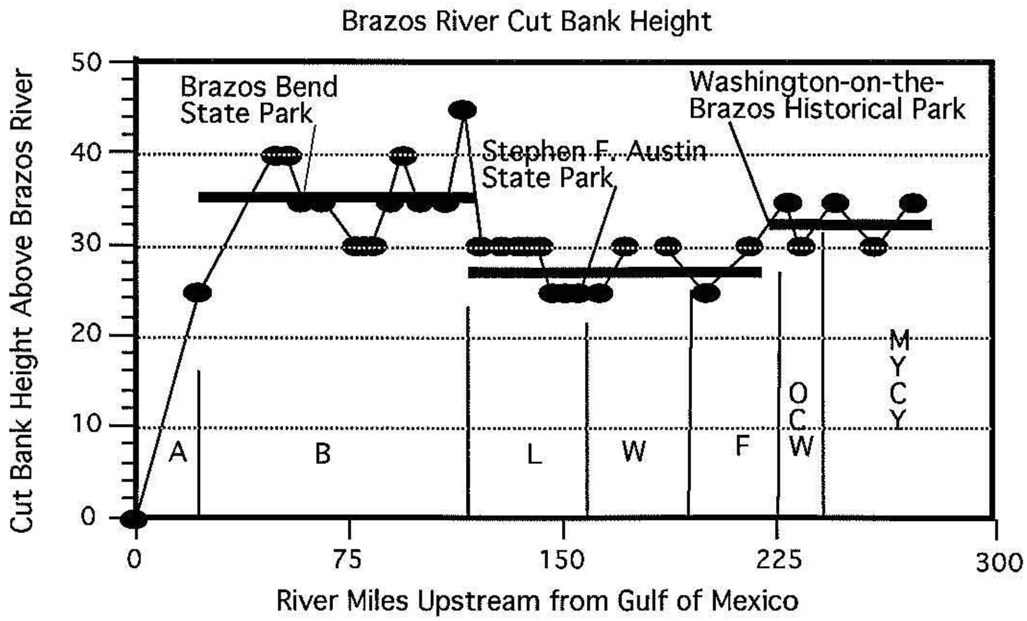


Figure 3. Bank height or depth of incision of the Brazos River from north of the Washington-on-the-Brazos State Historical Park to the Gulf of Mexico. The sedimentary formations that the channel is incised into are indicated by the letter: A for alluvium; B for Beaumont; L for Lissie; W for Willis; F for Fleming; OCW for Oakville, Catahoula, Whitsett; and MWCY for Manning, Wellborn, Caddell, Yegua.

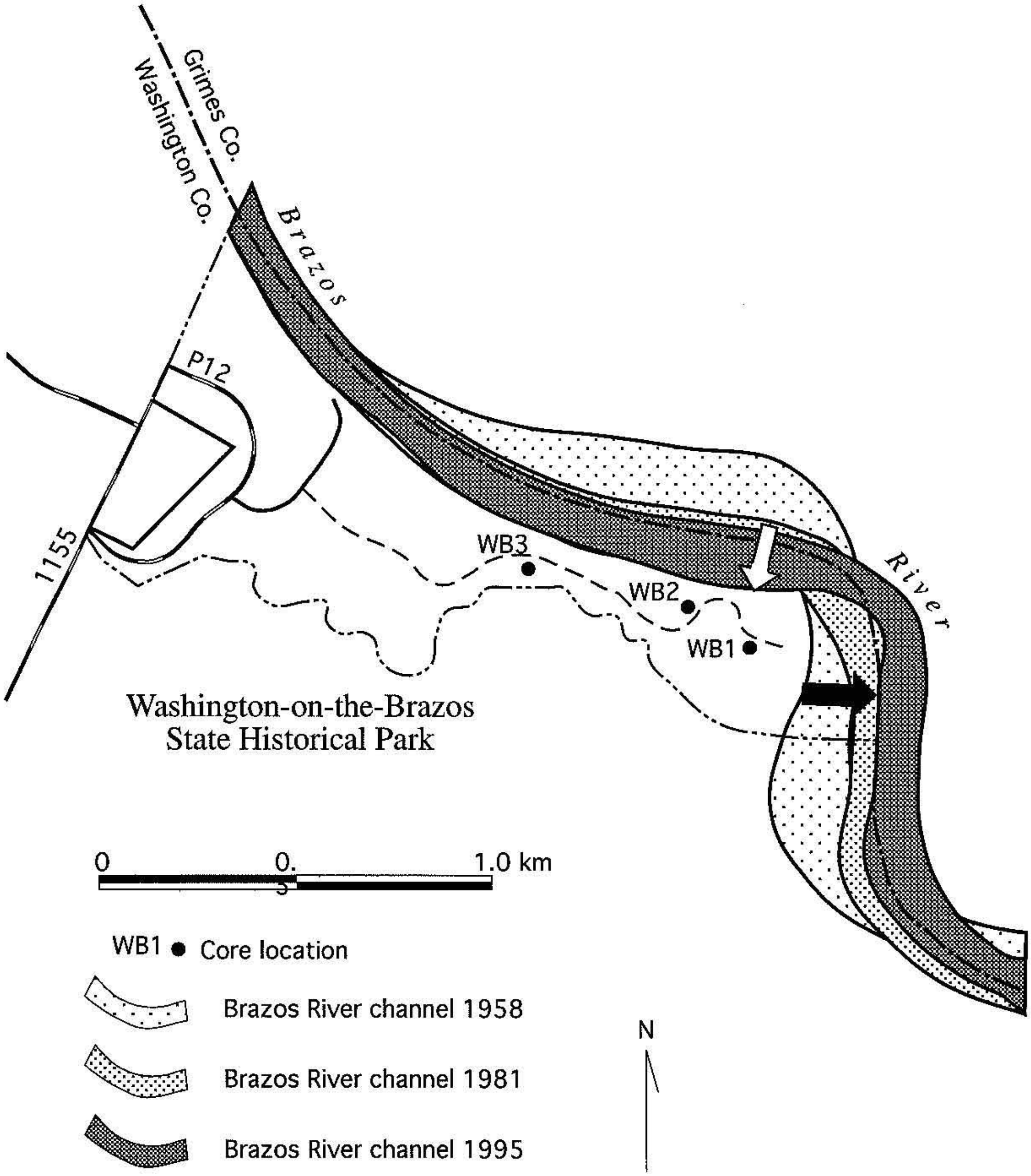


Figure 4. Map illustrating the meander path of the Brazos River at Washington-on-the-Brazos State Park in 1958, 1981, and 1995. Open arrow shows area of land loss. Filled arrow shows area of land gain. Arrows point in direction of channel migration.

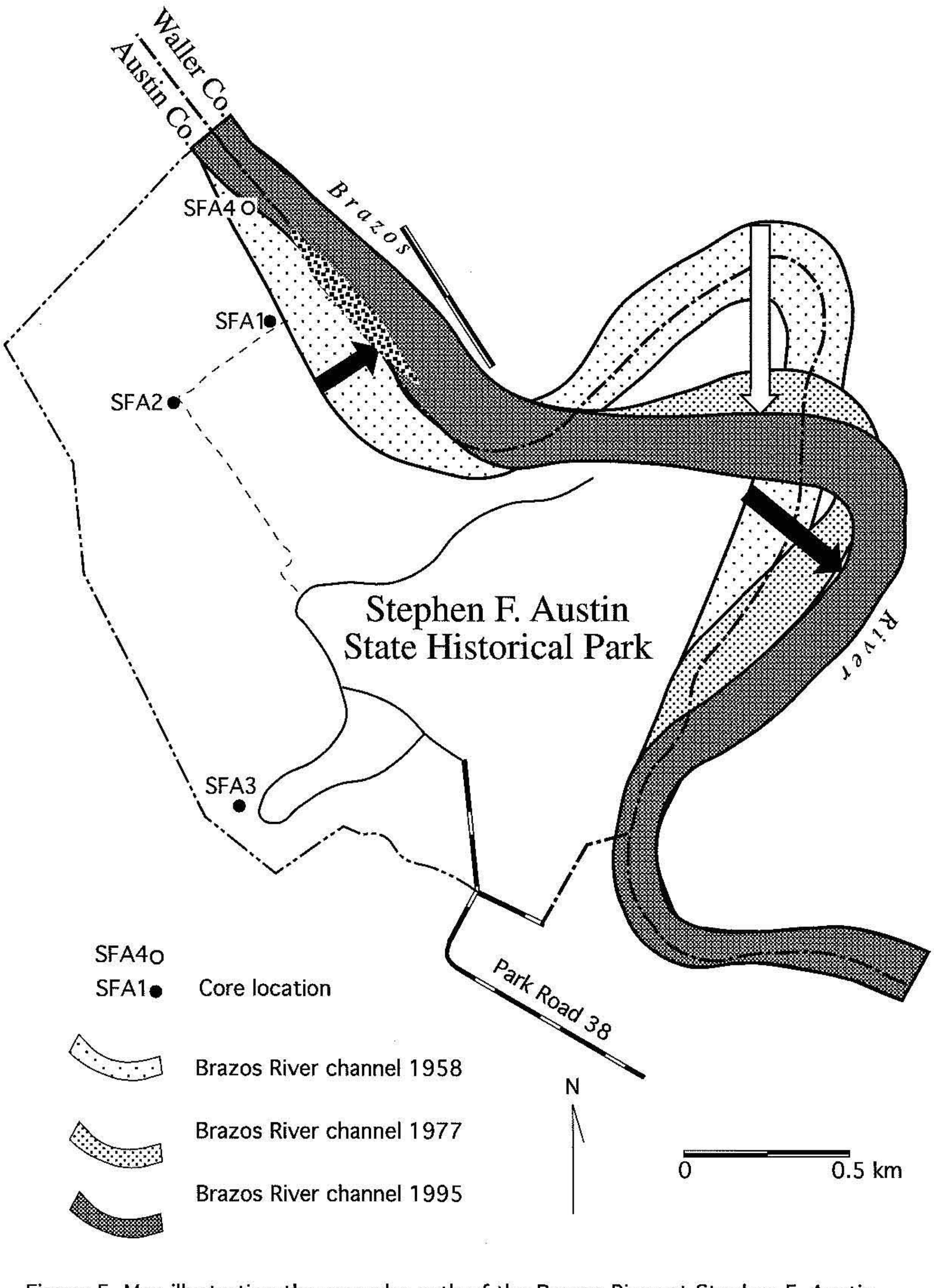


Figure 5. Map illustrating the meander path of the Brazos River at Stephen F. Austin State Historical Park in 1958, 1977, and 1995. Open Arrow shows area of land loss. Filled arrows show areas of land gain. Arrows point in direction of channel migration.

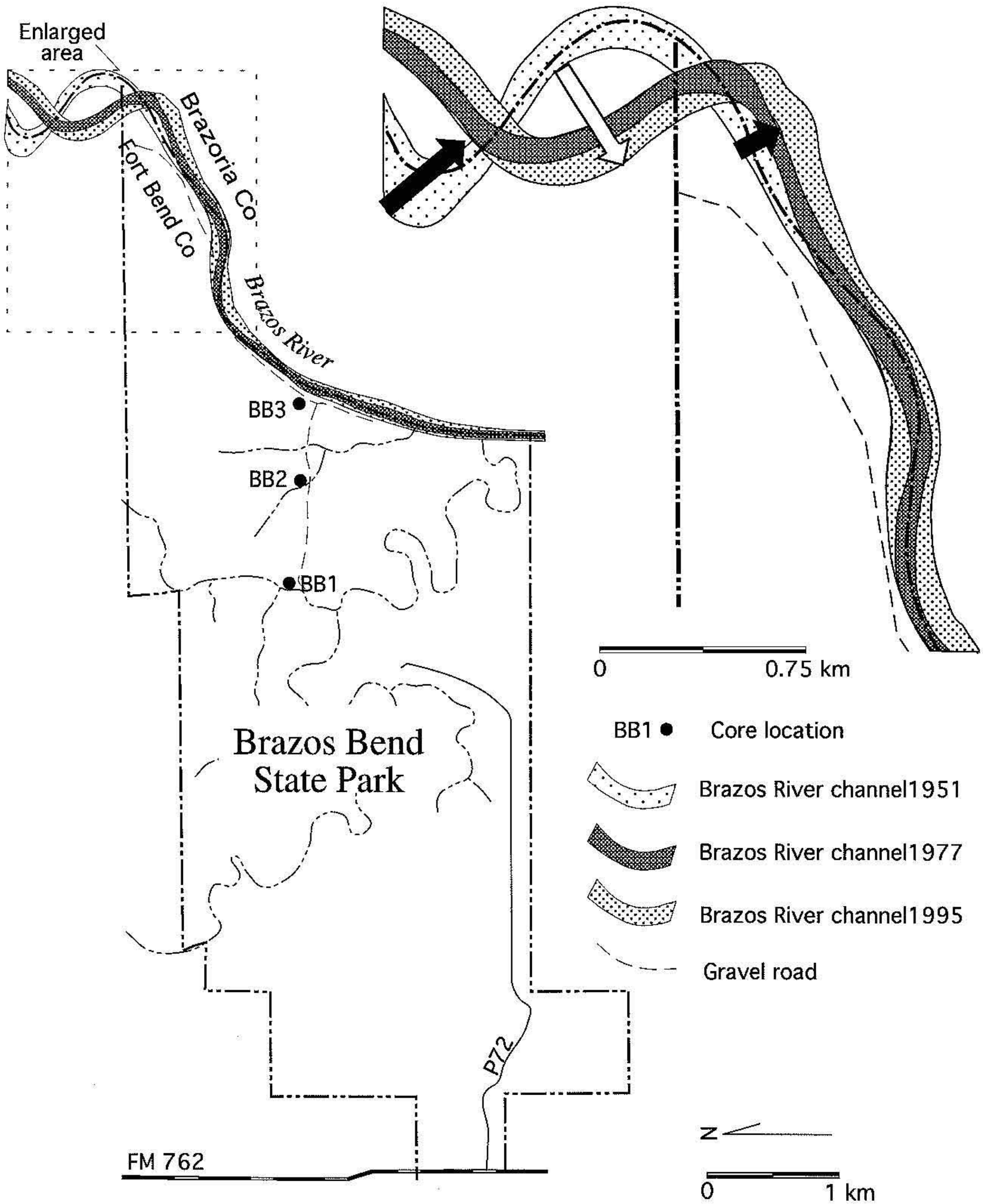


Figure 6. Map illustrating the meander path of the Brazos River at the Brazos Bend State Park in 1951, 1977, and 1995. Open arrow shows areas of land loss. Filled arrows show ares of land gain. Arrows point in direction of channel migration.

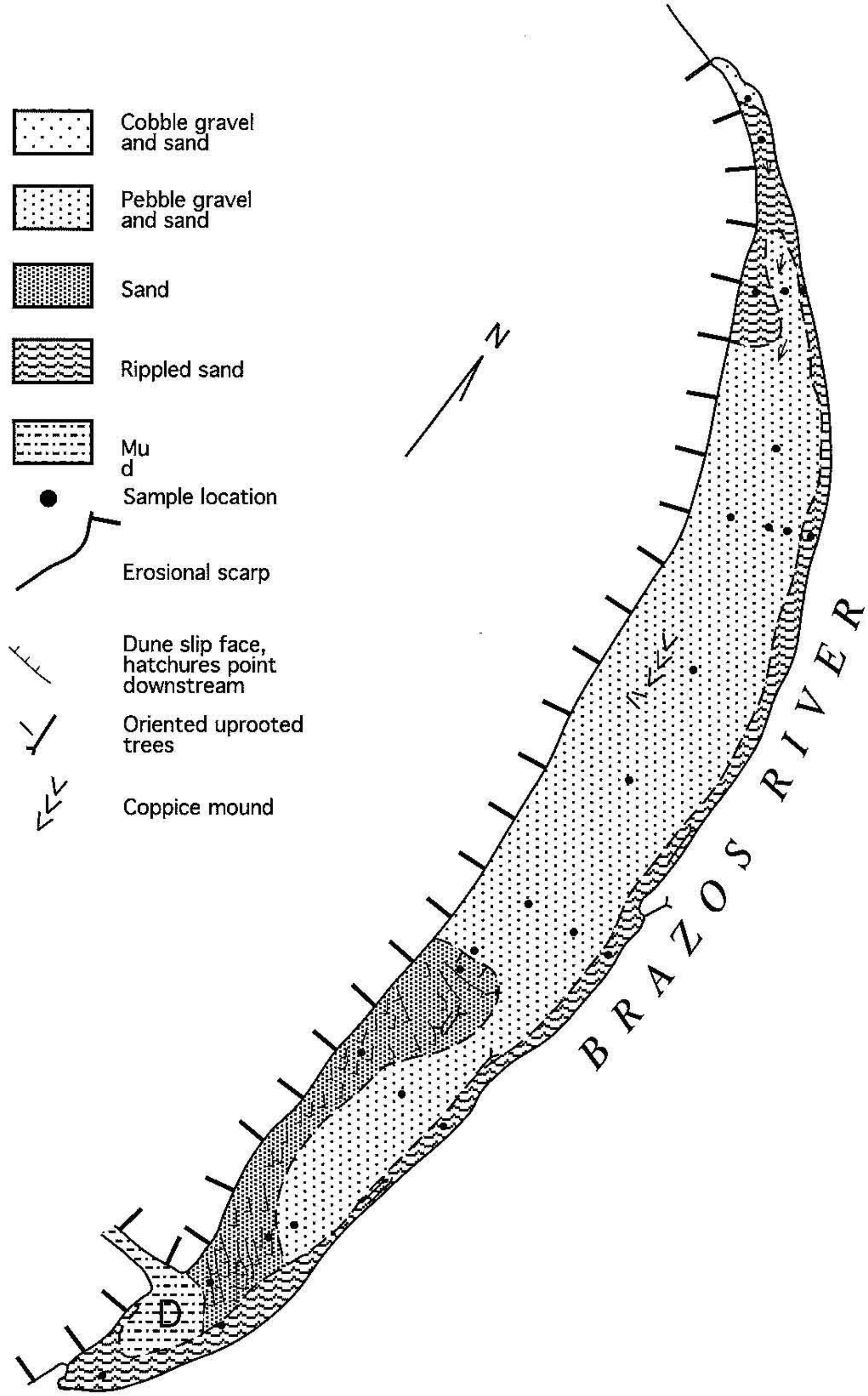


Figure 7. Map of surface sediment distribution and sample location of a Brazos River point bar adjacent to the Washington-on-the-Brazos State Historical Park. See figure 4 for location.

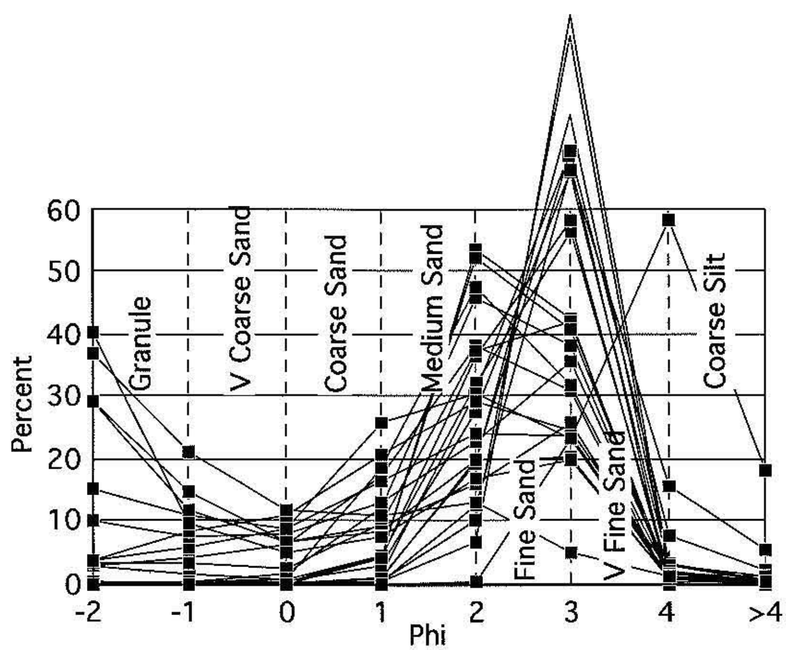


Figure 8. Composite of 24 sediment texture graphs from Brazos River point bar adjacent to the Washington-on-the-Brazos State Historical Park.

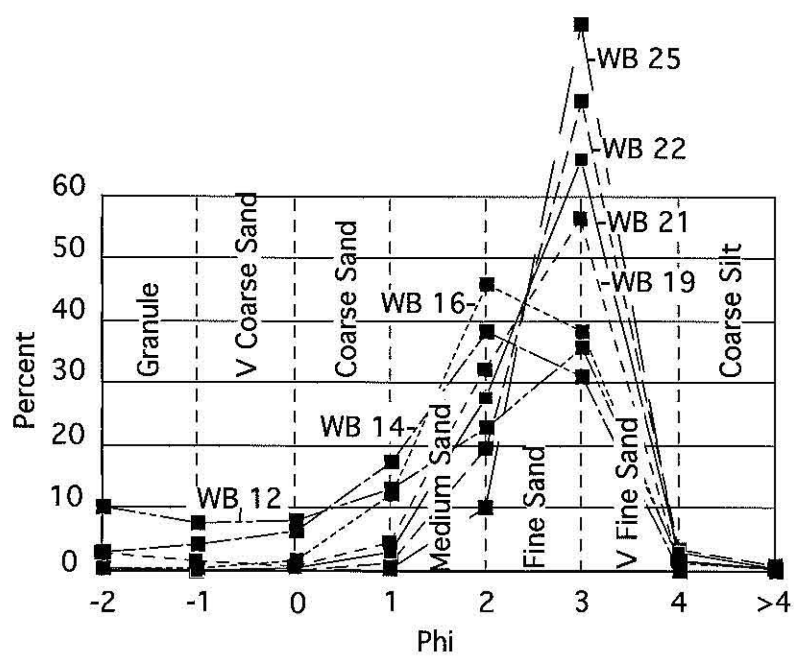


Figure 9. Selected sediment texture curves illustrating that bar sediments fine downstream.

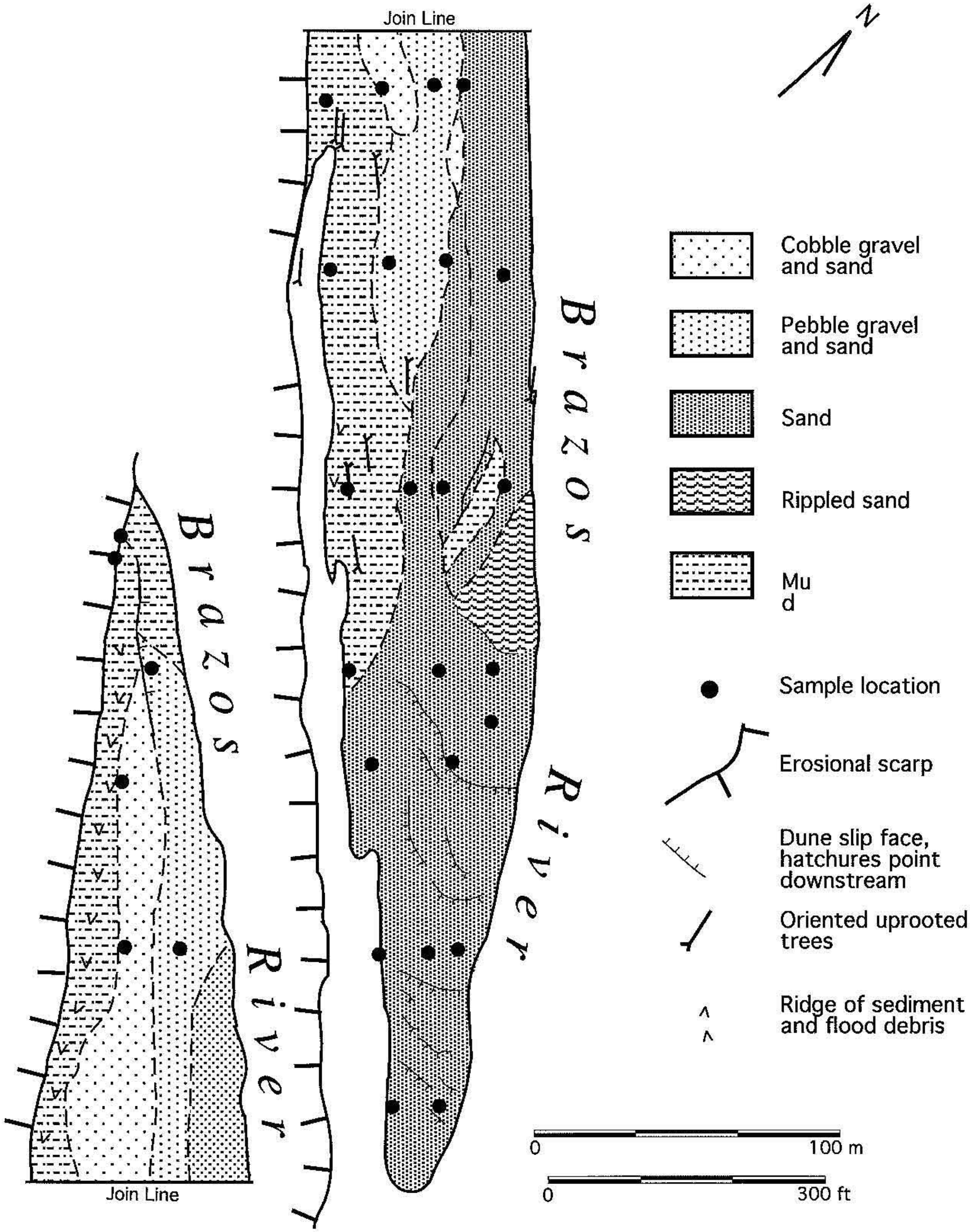


Figure 10. Map of surface sediment distribution and sample location of a Brazos River side bar adjacent to the Stephen F. Austin State Historical Park. See figure 5 for location.

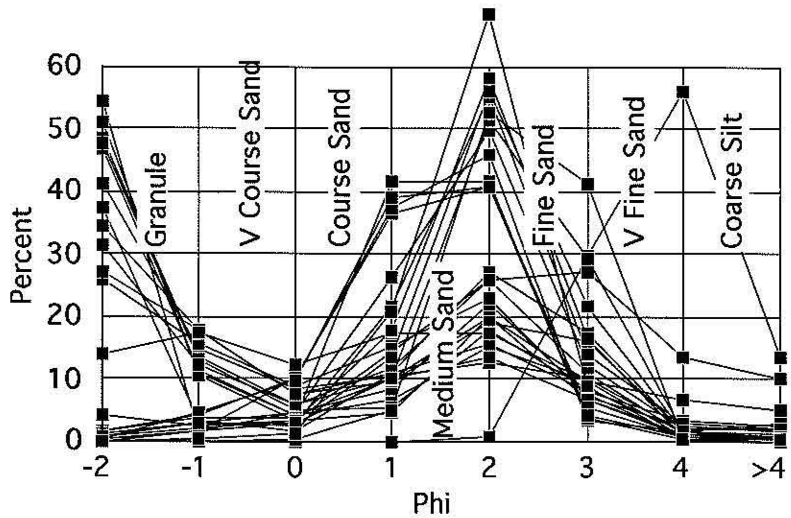


Figure. 11 Composite of 28 sediment texture graphs from Brazos River channel bar adjacent to the Stephen F. Austin State Historical Park.

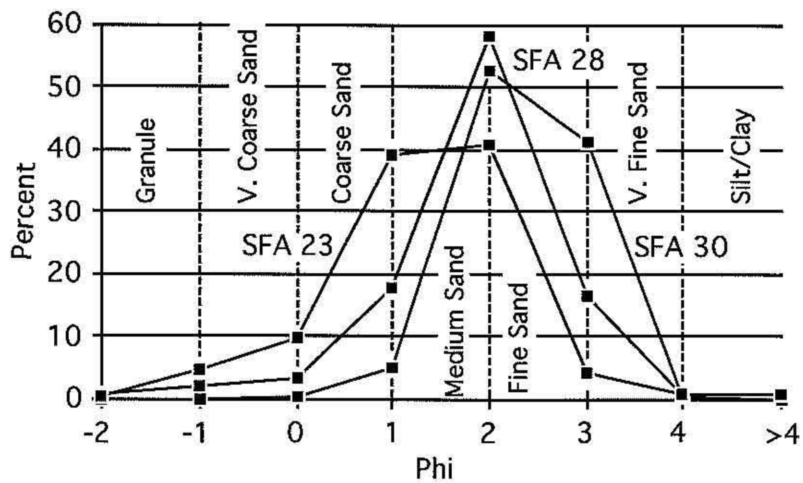


Figure 12. Mean sand size decreases downstream from medium sand (SFA 23) to fine sand (SFA 30) on the Brazos River channel bar at Stephen F. Austin State Historical Park .

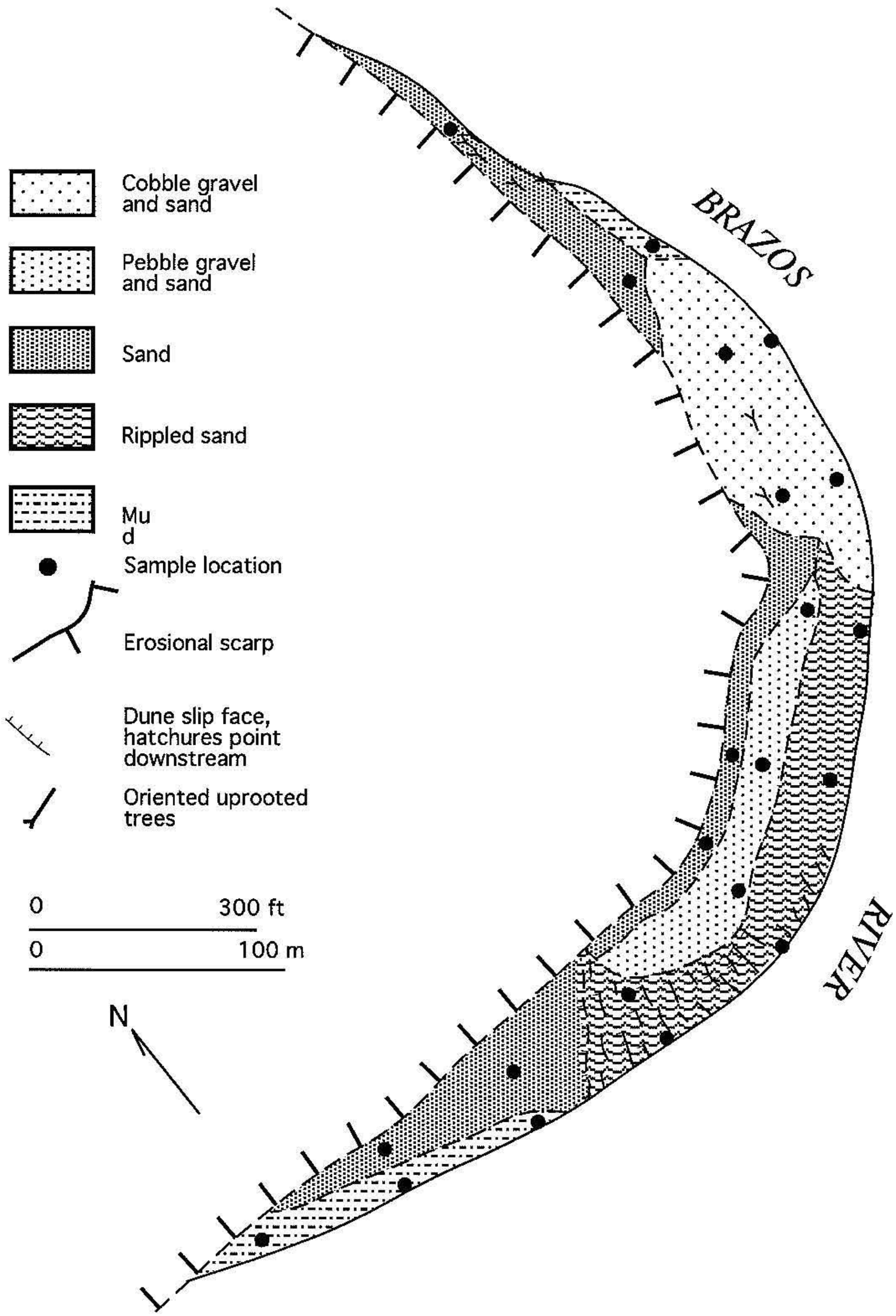


Figure 13. Map of surface sediment distribution and sample location of a Brazos River point bar adjacent to the Brazos Bend State Park. See figure 6 for location.

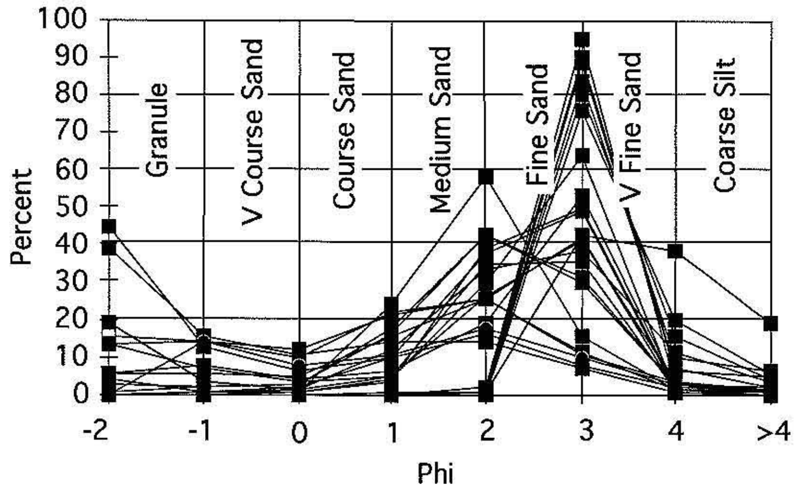


Figure 14. Composite of 23 sediment texture graphs from Brazos River point bar adjacent to the Brazos Bend State Park.

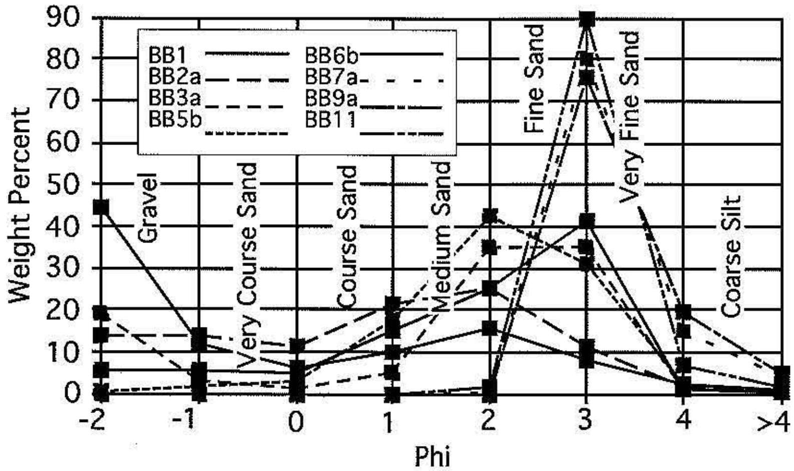


Figure 15. Samples BB1, BB2a, BB3a, BB5b, BB6b, BB7a, BB9a, and BB11 were sample sites distributed from near the upstream end to near the downstream end of the Brazos River point bar adjacent to Brazos River State Park, and illustrate the progressive downstream fining of bar surface sediments.

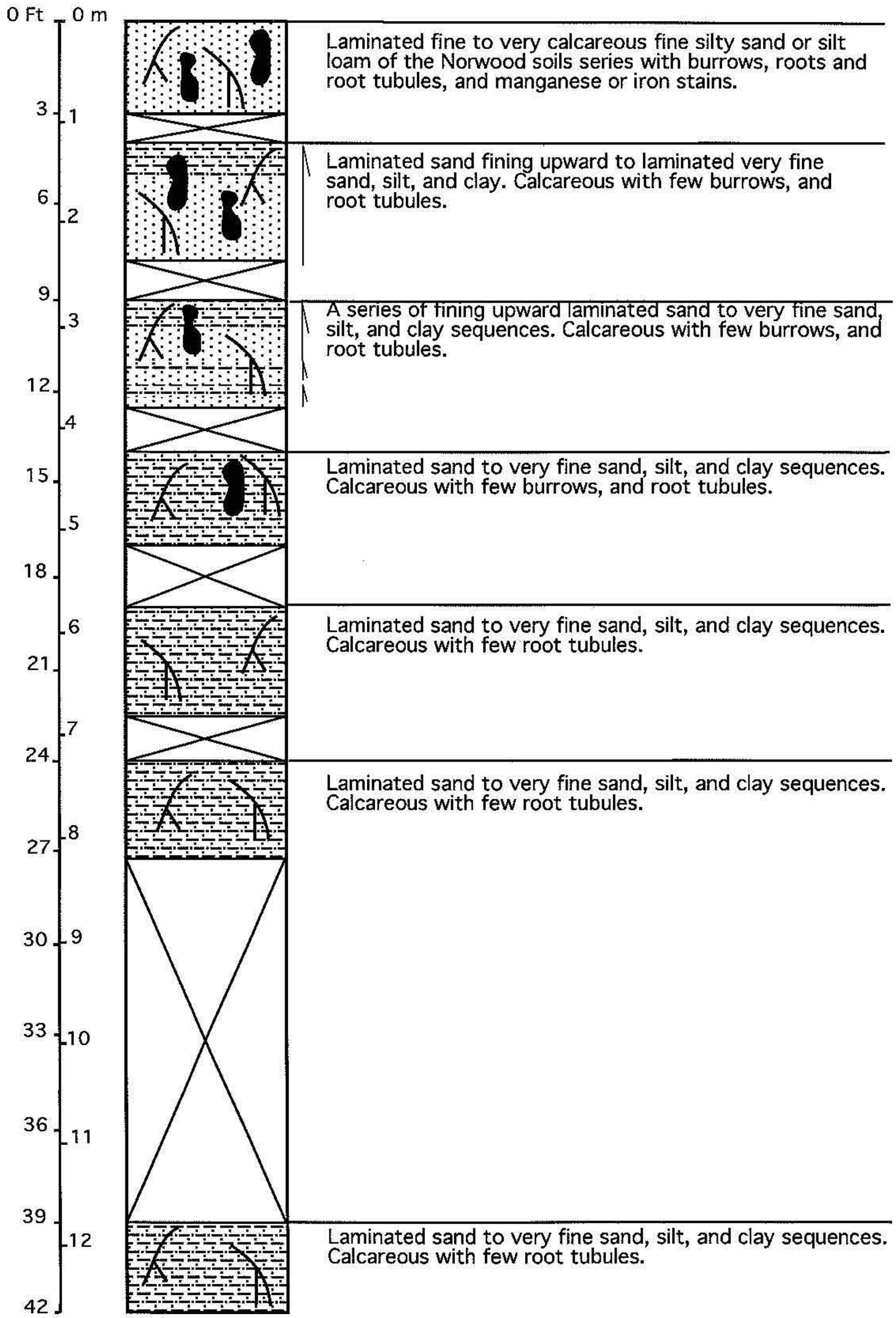


Figure 16. Core from Washington-on-the-Brazos No. 1 bore hole at the Washington-on-the-Brazos State Historical Park. See figure 4 for bore hole location and figure 17 for explanation of symbols.

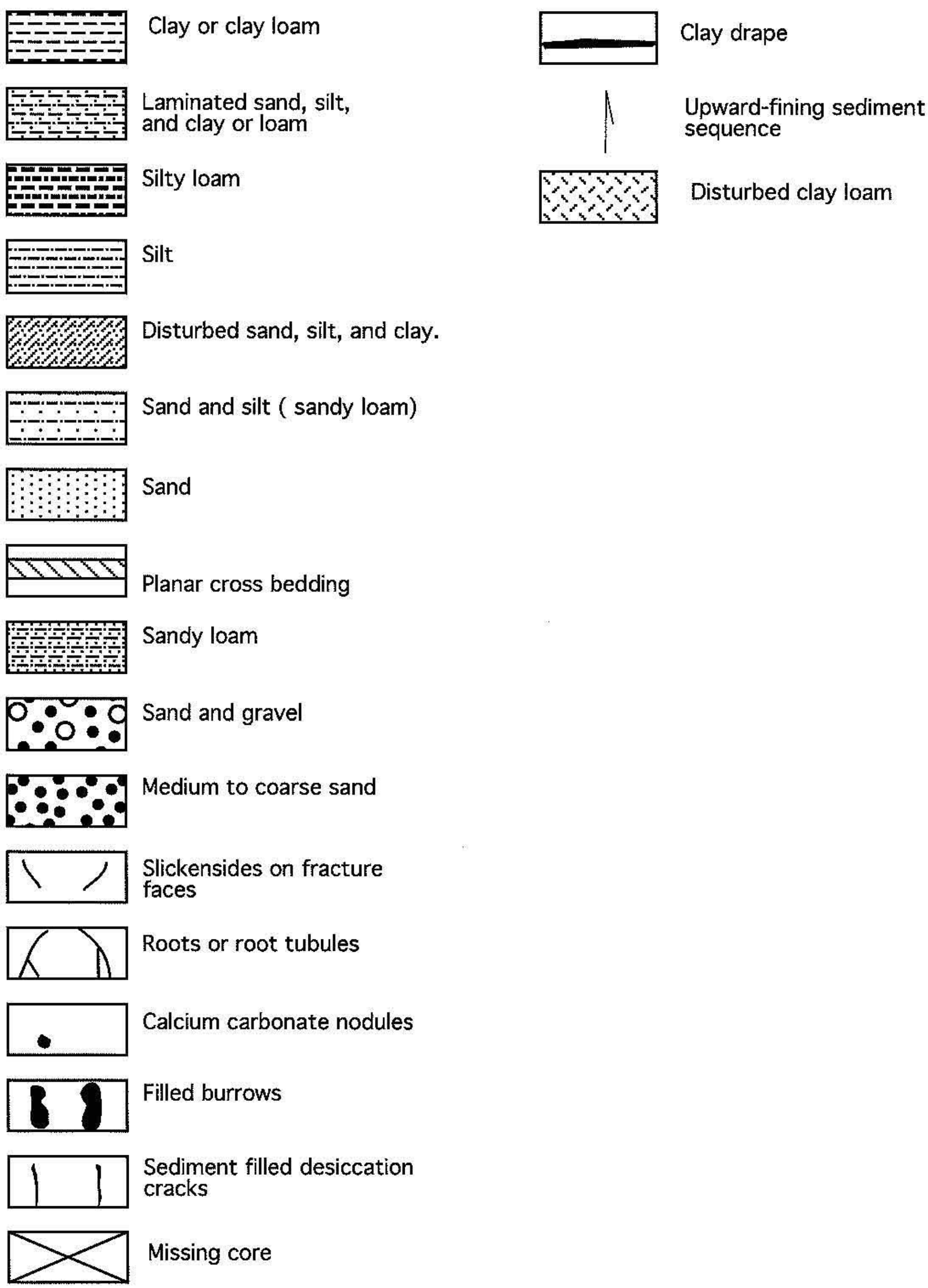


Figure 17. Explanation of symbols used in figures 16 and 18 through 26.

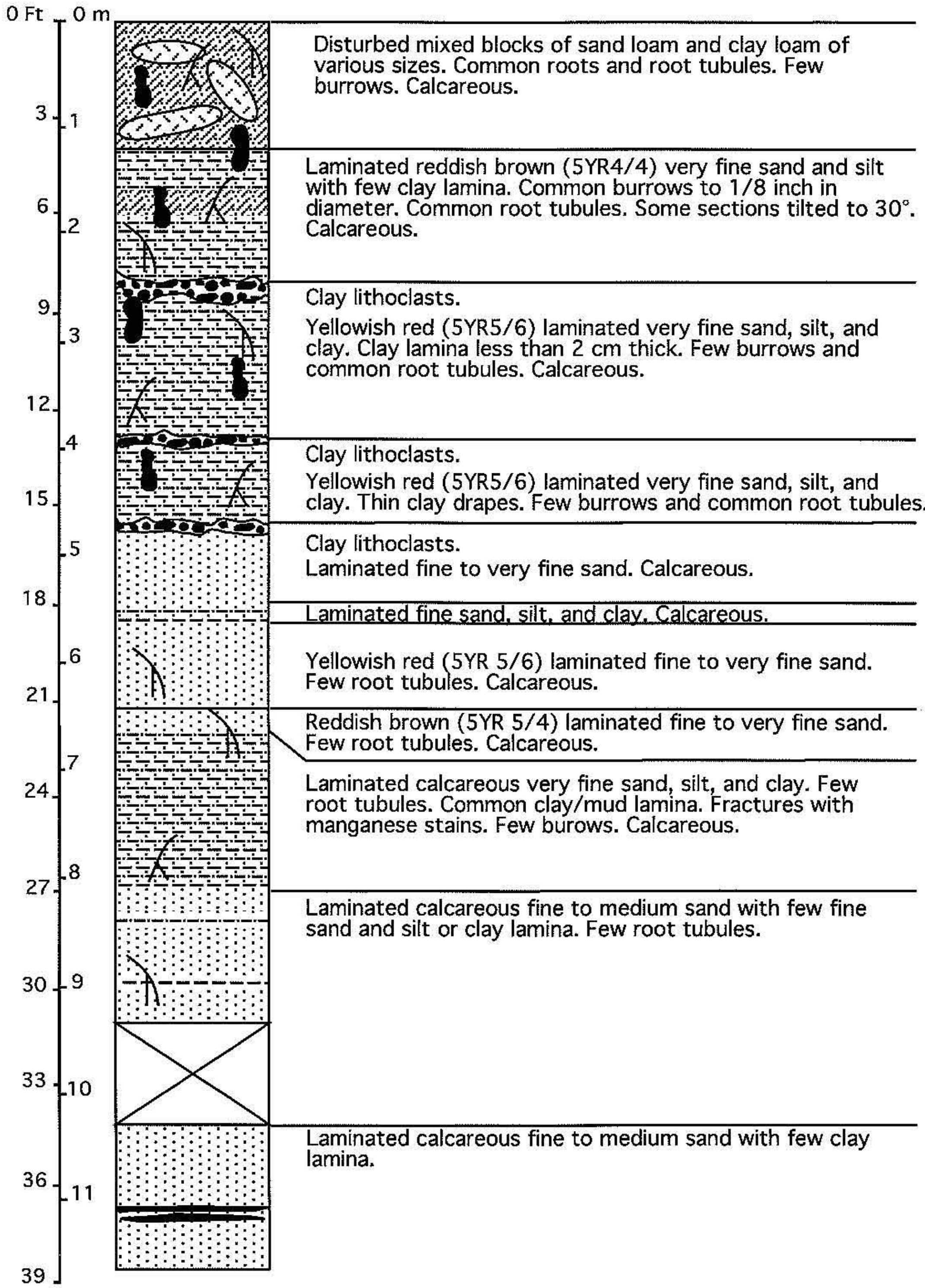


Figure 18. Core from Washington-on-the-Brazos No. 2 bore hole at the Washington-on-the-Brazos State Historical Park. See figure 4 for bore hole location and figure 17 for explanation of symbols.

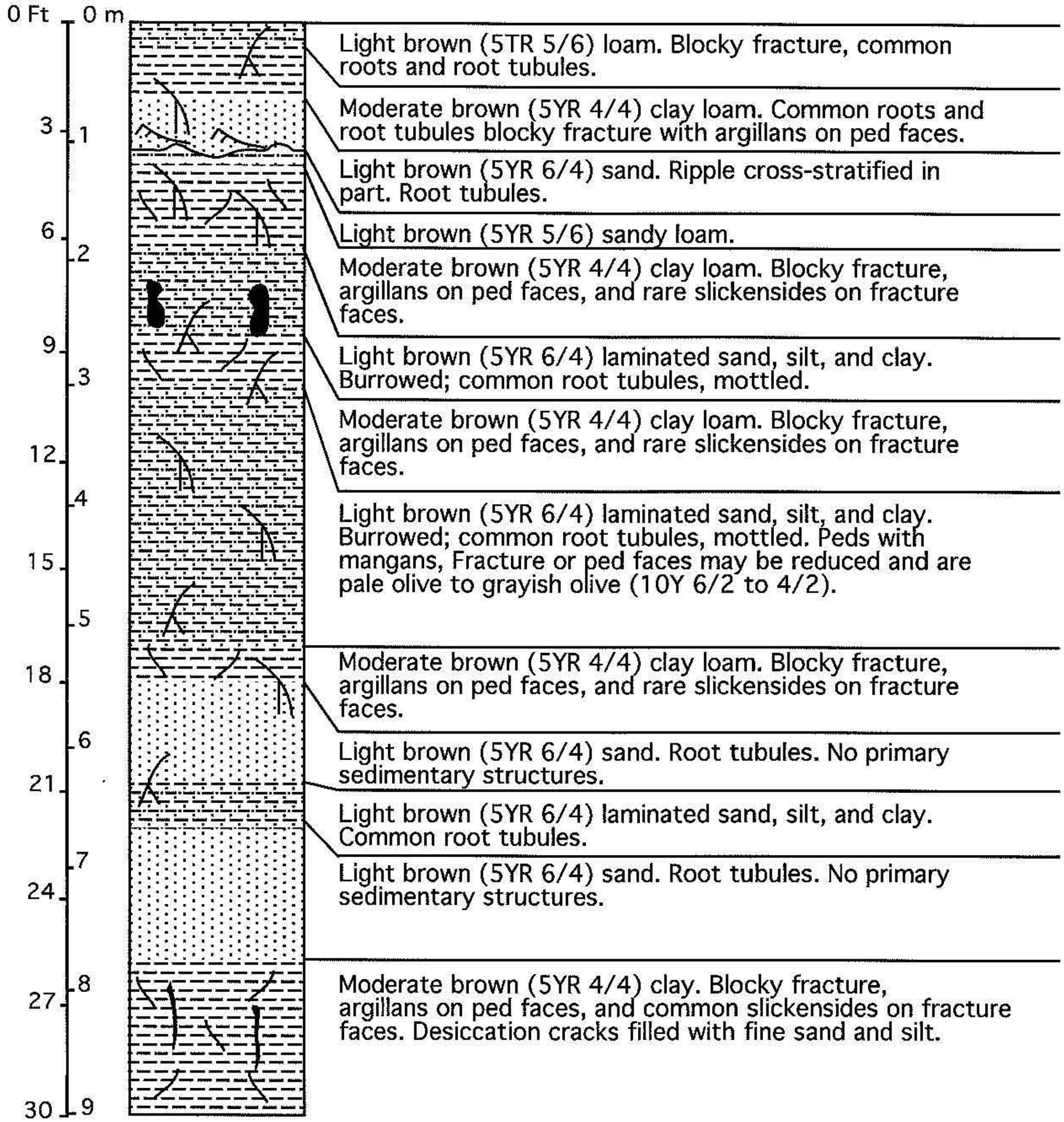


Figure 19. Core from Washington-on-the-Brazos No. 3 bore hole at the Washington-on-the-Brazos State Historical Park. See figure 4 for bore hole location and figure 17 for explanation of symbols.

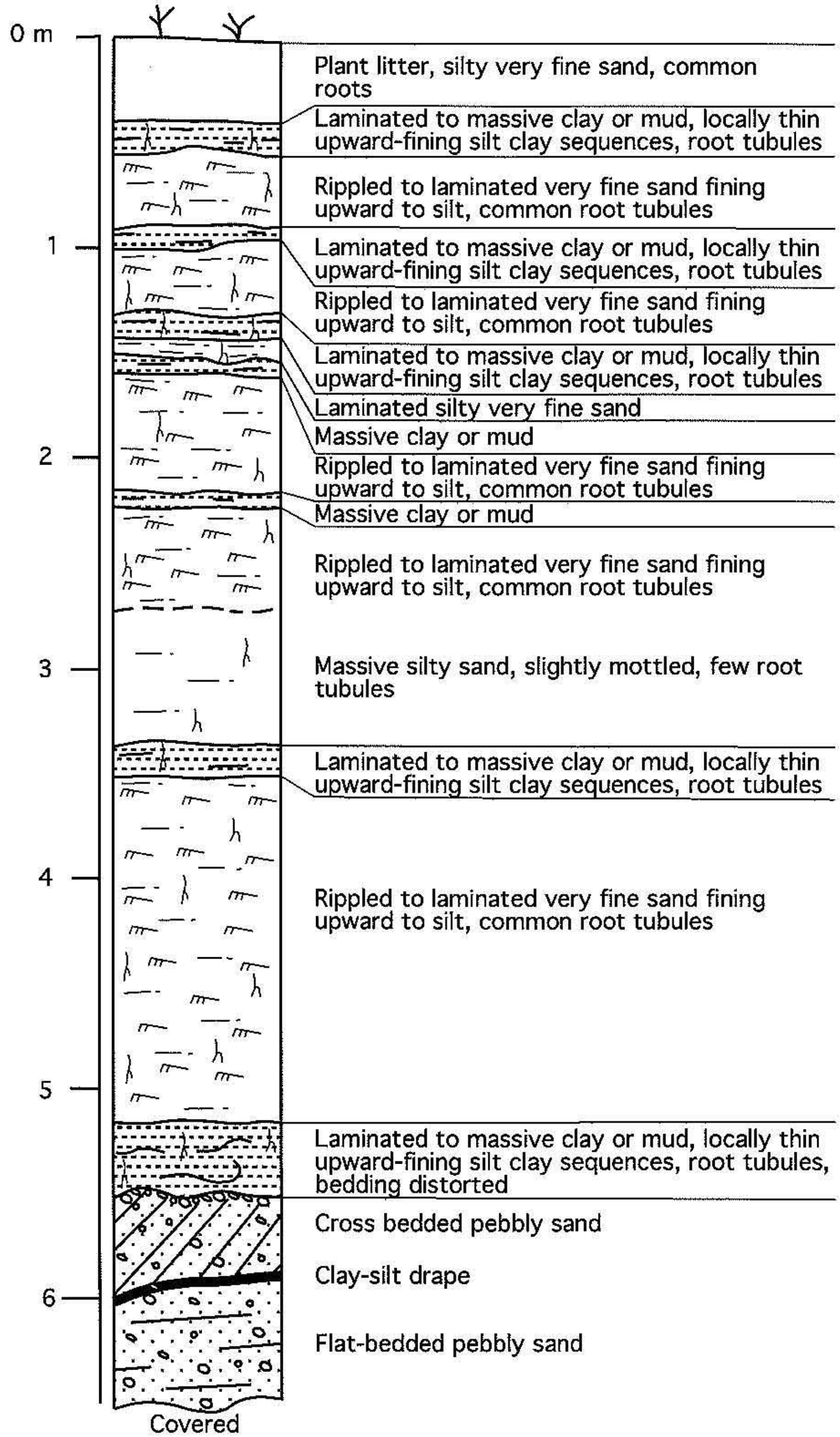
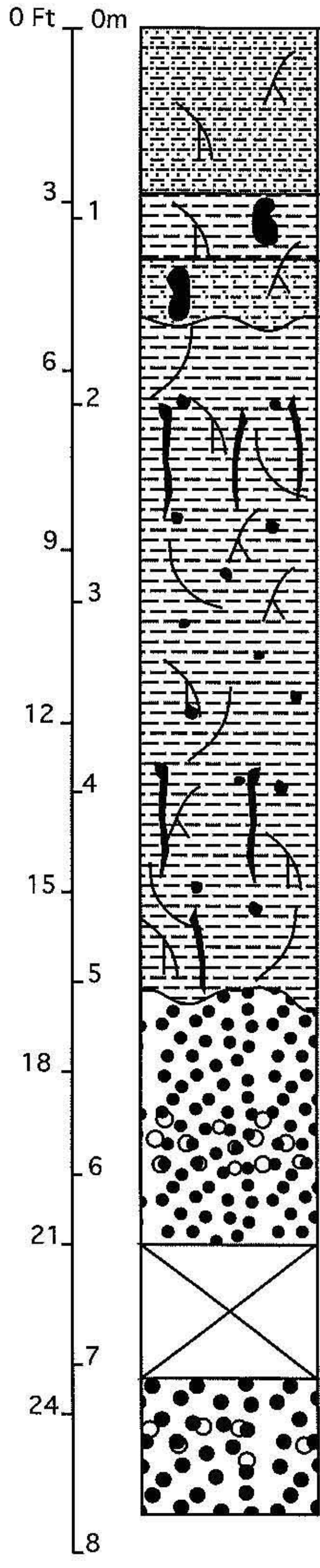


Figure 20. Stratigraphic section from the cut bank at Stephen F. Austin State Historical Park. See figure 5 for section location and figure 17 for explanation of symbols.

Steven F Austin No. 1



Brown (7.5 YR 4/3 to 7.5 YR 5/6) sandy loam, calcareous, many roots, friable, no preserved primary sedimentary structures.

Brown (7.5YR 4/3) clay loam, common fine roots, few burrows, calcareous, No preserved primary sedimentary structures.

Brown (7.5YR 4/3) sandy loam, many fine root tubules, burrows, calcareous

Dark reddish gray (5YR 4/2) clay, subangular blocky, calcareous, common root tubules, no primary sedimentary structures.

Very dark gray (5YR 3/1) clay, calcareous, common $CaCO_3$ nodules, common root tubules, shiny pressure faces on peds, slickensides on fracture faces, filled fractures, no primary sedimentary structures.

Gray (10YR 6/1) clay, calcareous, common $CaCO_3$ nodules, common root tubules, shiny pressure faces on peds, slickensides on fracture faces, filled fractures, no primary sedimentary structures.

White (10YR 8/1) medium to coarse sand and granule to pebble gravel, calcareous, flat-bedded, loose.

Yellow (10YR 8/6) medium to coarse sand, calcareous, flat-bedded, loose.

Yellow (10YR 8/6) medium to coarse sand and granule to pebble gravel, calcareous, flat-bedded, loose.

Figure 21. Core from the Stephen F. Austin No. 1 bore hole at the Stephen F. Austin State Historical Park. See figure 5 for bore hole location and figure 17 for explanation of symbols.

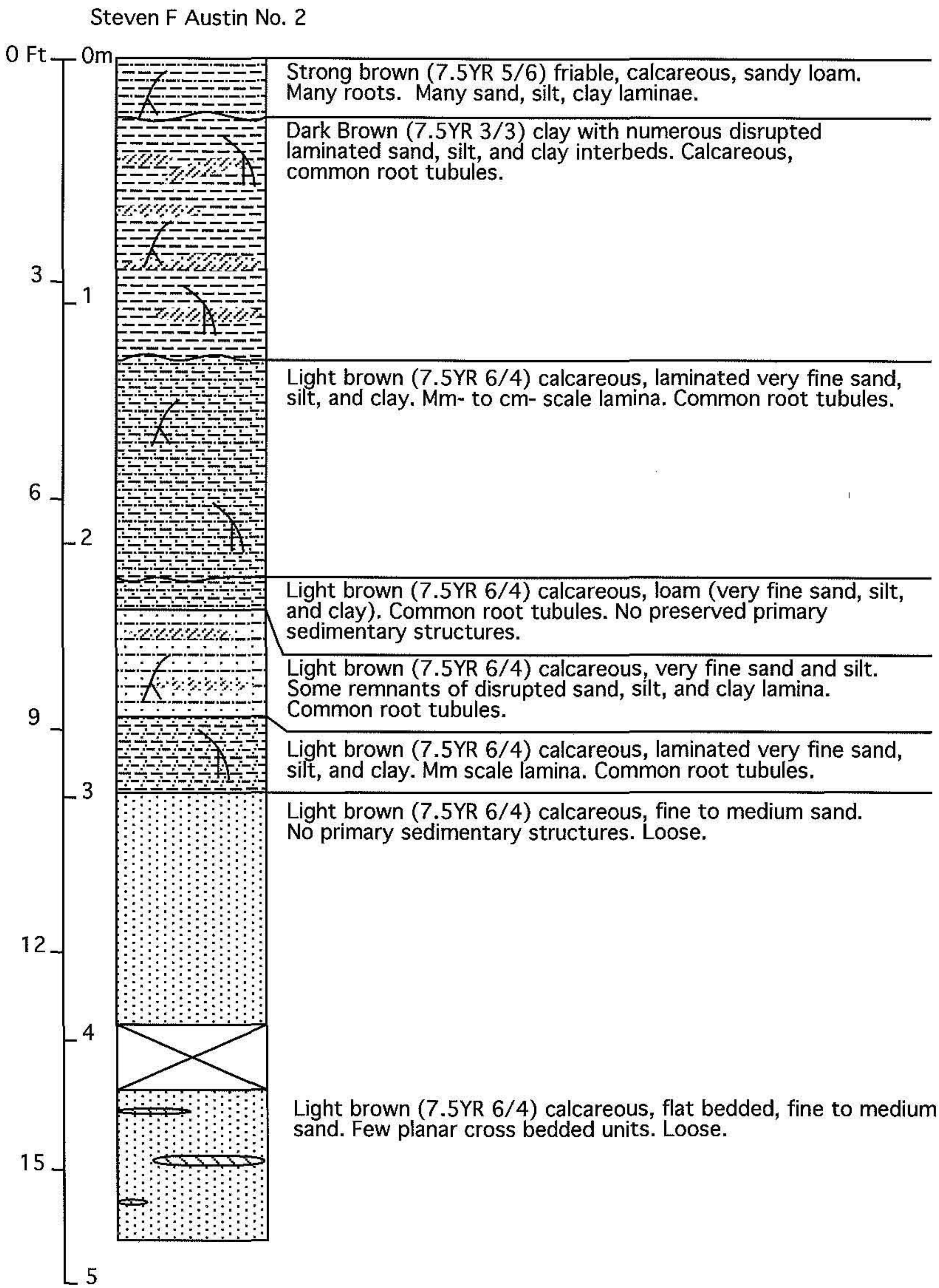


Figure 22. Core from the Stephen F. Austin No. 2 bore hole at the Stephen F. Austin State Historical Park. See figure 5 for bore hole location and figure 17 for explanation of symbols.

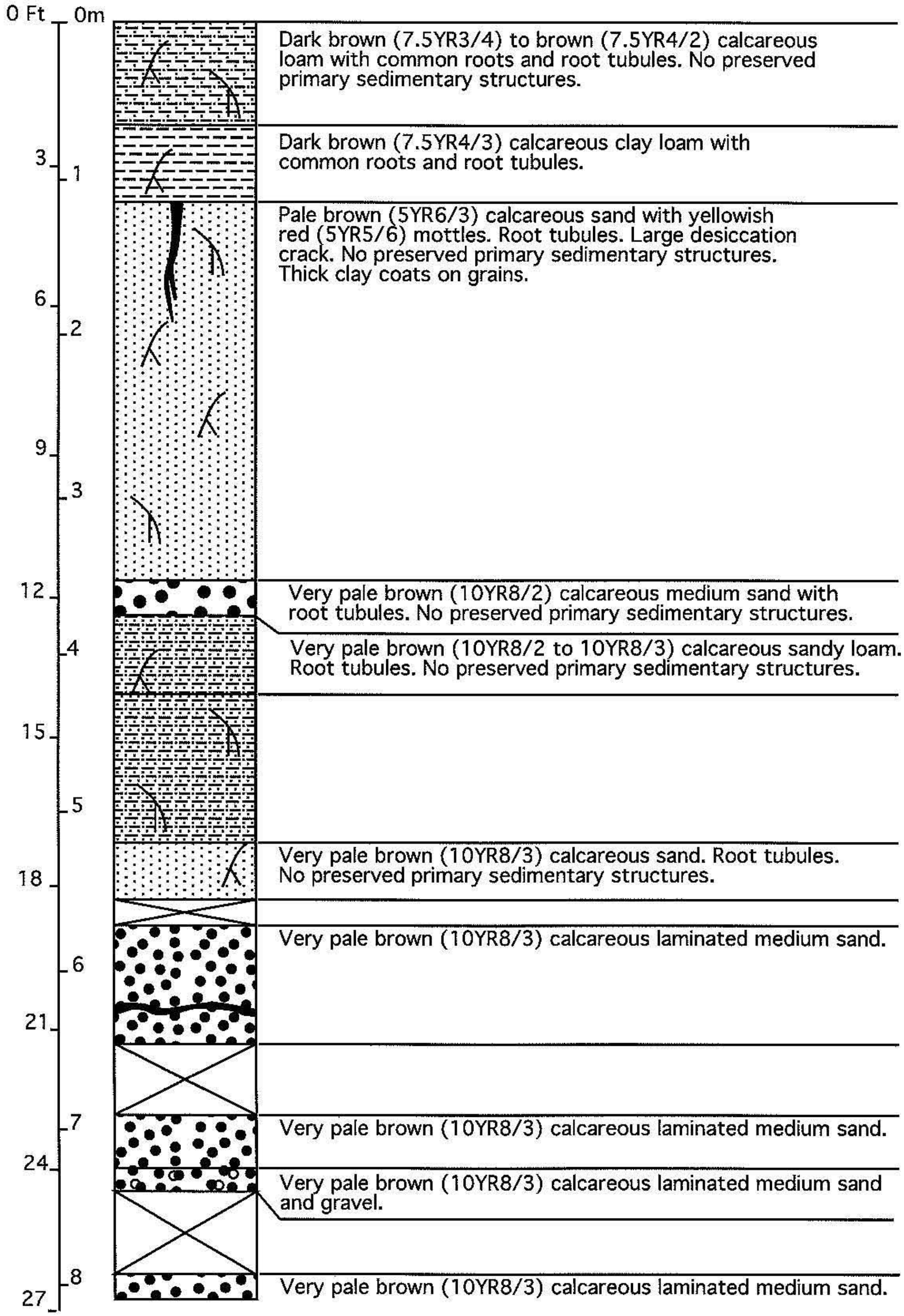


Figure 23. Core from the Stephen F. Austin No. 3 bore hole at the Stephen F. Austin State Historical Park. See figure 5 for bore hole location and figure 17 for explanation of symbols.

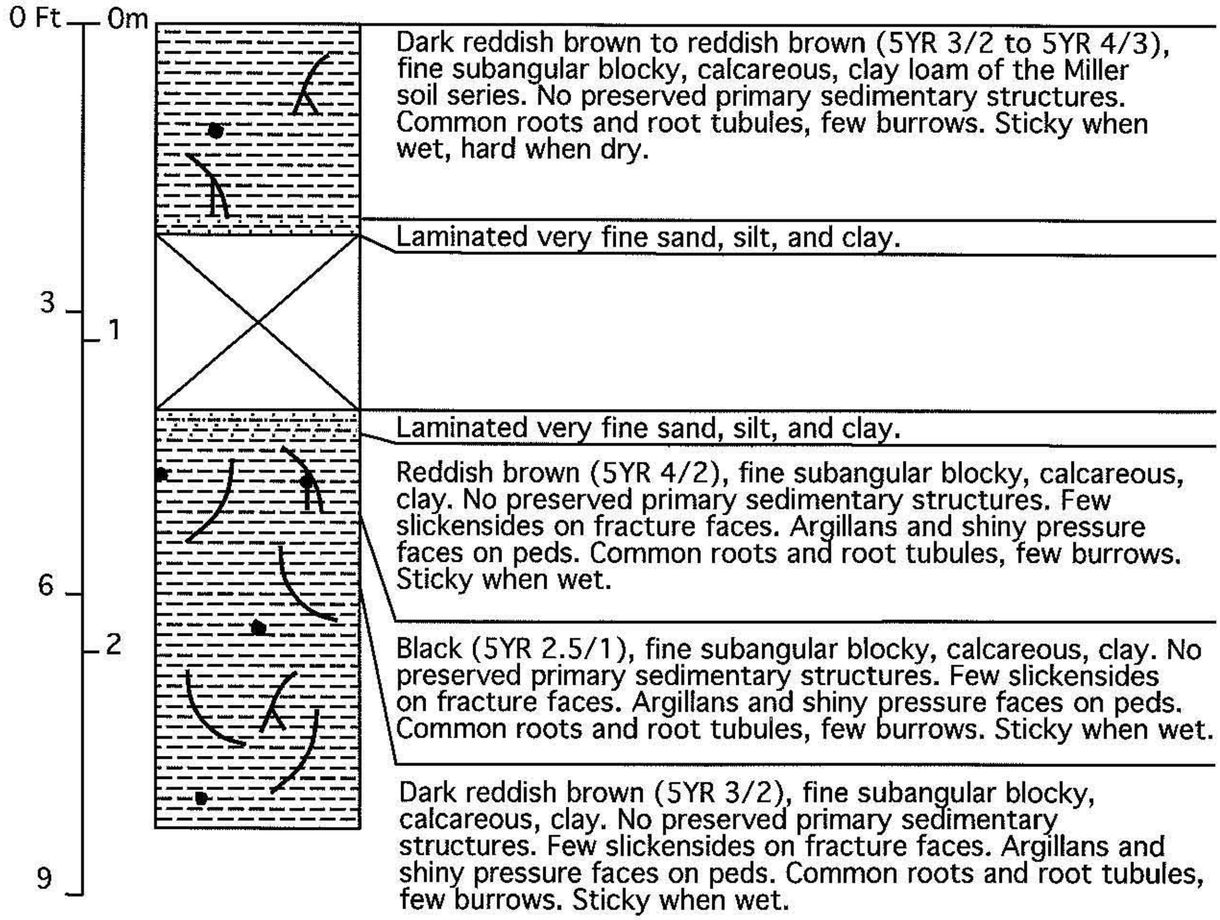


Figure 24. Core from the Brazos Bend No. 1 bore hole at the Brazos Bend State Park. See figure 6 for bore hole location and figure 17 for explanation of symbols.

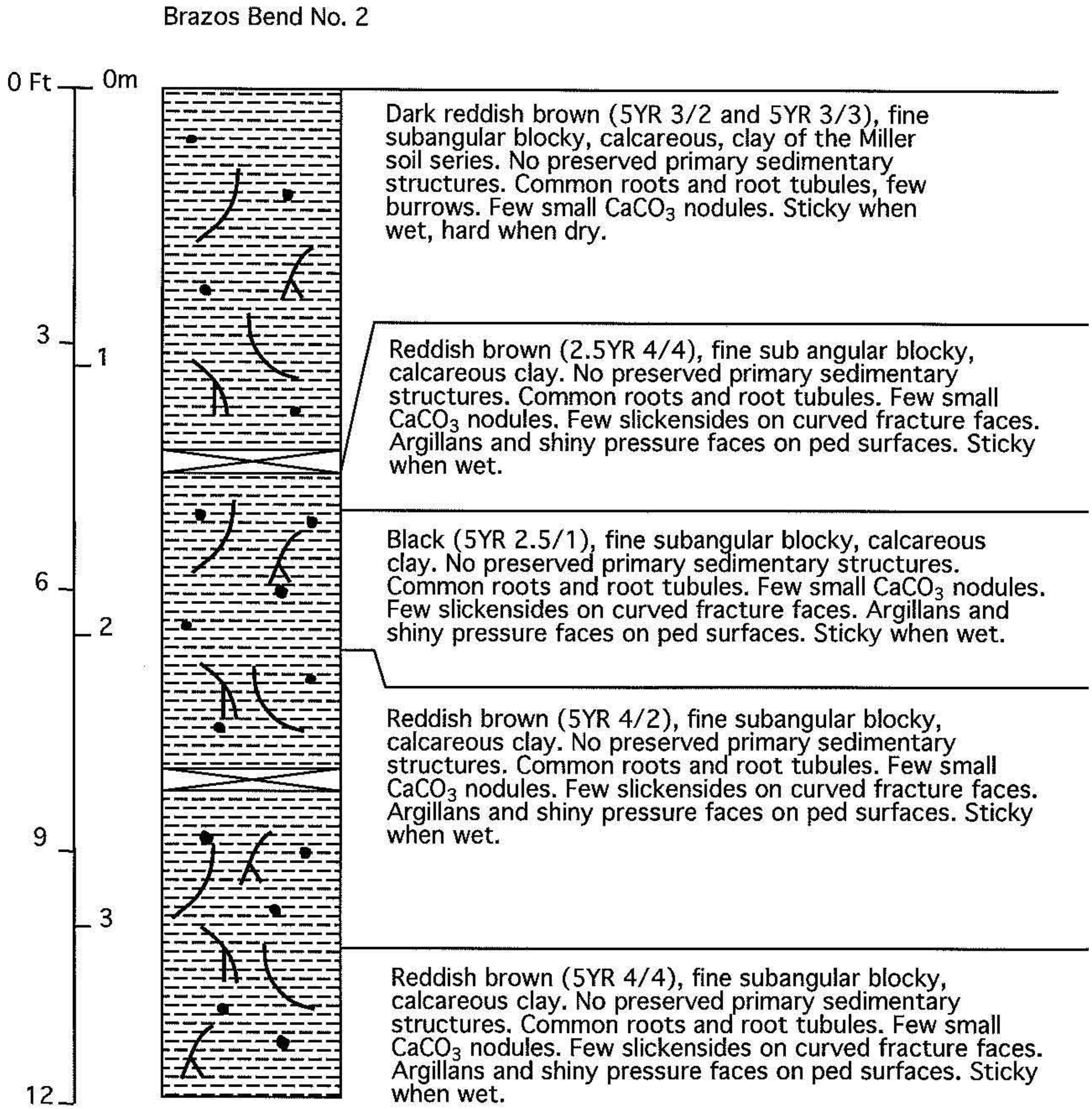
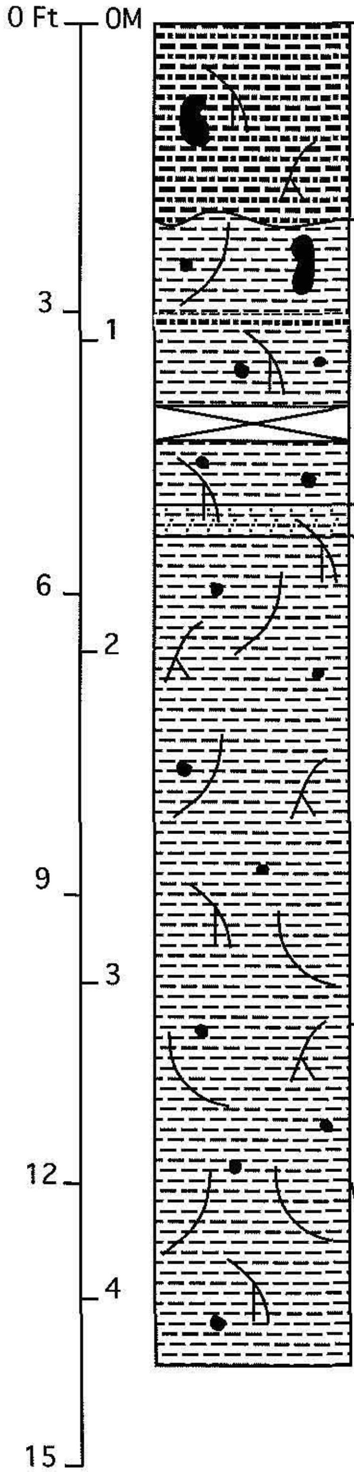


Figure 25. Core from the Brazos Bend No. 2 bore hole at the Brazos Bend State Park. See figure 6 for bore hole location and figure 17 for explanation of symbols.

Brazos Bend No. 3



Dark reddish brown (5YR 3/3), fine subangular blocky, calcareous, clay loam of the Miller soil series. No preserved primary sedimentary structures. Common roots and root tubules, few burrows. Sticky when wet, hard when dry.

Reddish brown (5YR 4/4), fine subangular blocky, calcareous clay. Few silt or very fine sand laminae. Common roots and root tubules, few burrows. Few small $CaCO_3$ nodules. Few slickensides on curved fracture faces. Argillans and shiny pressure faces on ped surfaces. Sticky when wet. Few silt laminae.

Laminated calcareous very fine sand, silt, and clay.

Reddish brown (5YR 4/4), fine sub angular blocky, calcareous clay. No preserved primary sedimentary structures. Common roots and root tubules. Few small $CaCO_3$ nodules. Few slickensides on curved fracture faces. Argillans and shiny pressure faces on ped surfaces. Sticky when wet.

Very dark gray (5YR 3/1), fine subangular blocky, calcareous, clay. No preserved primary sedimentary structures. Common roots and root tubules. Few small $CaCO_3$ nodules. Few slickensides on curved fracture faces. Argillans and shiny pressure faces on ped surfaces. Sticky when wet.

Very dark grayish brown (10YR 3/2), fine subangular blocky, calcareous, clay. No preserved primary sedimentary structures. Common roots and root tubules. Few small $CaCO_3$ nodules. Few slickensides on curved fracture faces. Argillans and shiny pressure faces on ped surfaces. Sticky when wet.

Figure 26. Core from the Brazos Bend No. 3 borehole at the Brazos Bend State Park. See figure 6 for bore hole location and figure 17 for explanation of symbols.

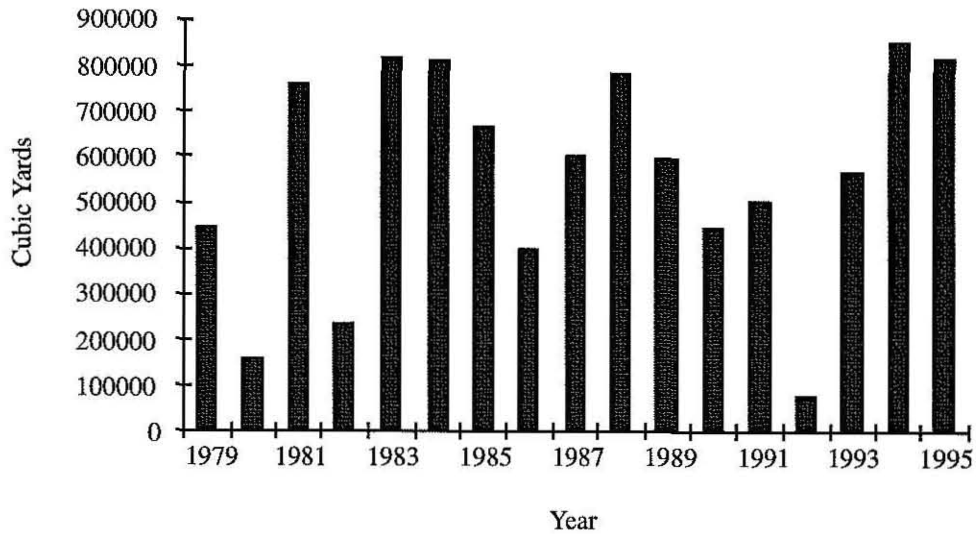


Figure 27: Brazos River Sand Production 1979-1995, Adapted from Texas Parks and Wildlife Revenue Reports 1979-1995: 8,544,860 cubic yards

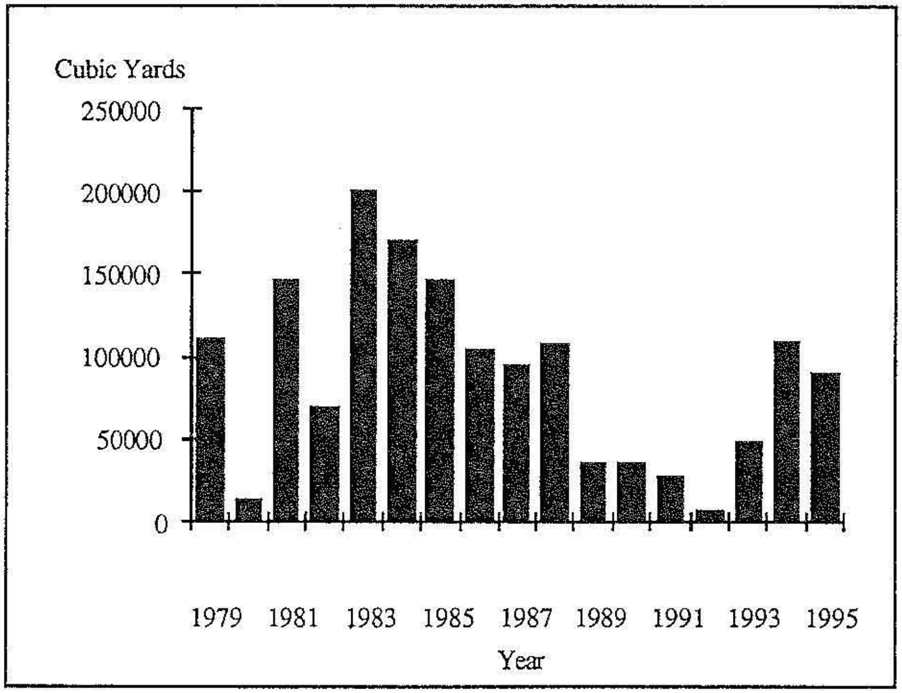


Figure 28. Brazos River Gravel Production 1979-1995, Adapted from Texas Parks and Wildlife Revenue Reports 1979-1995: 1,512,988 cubic yards

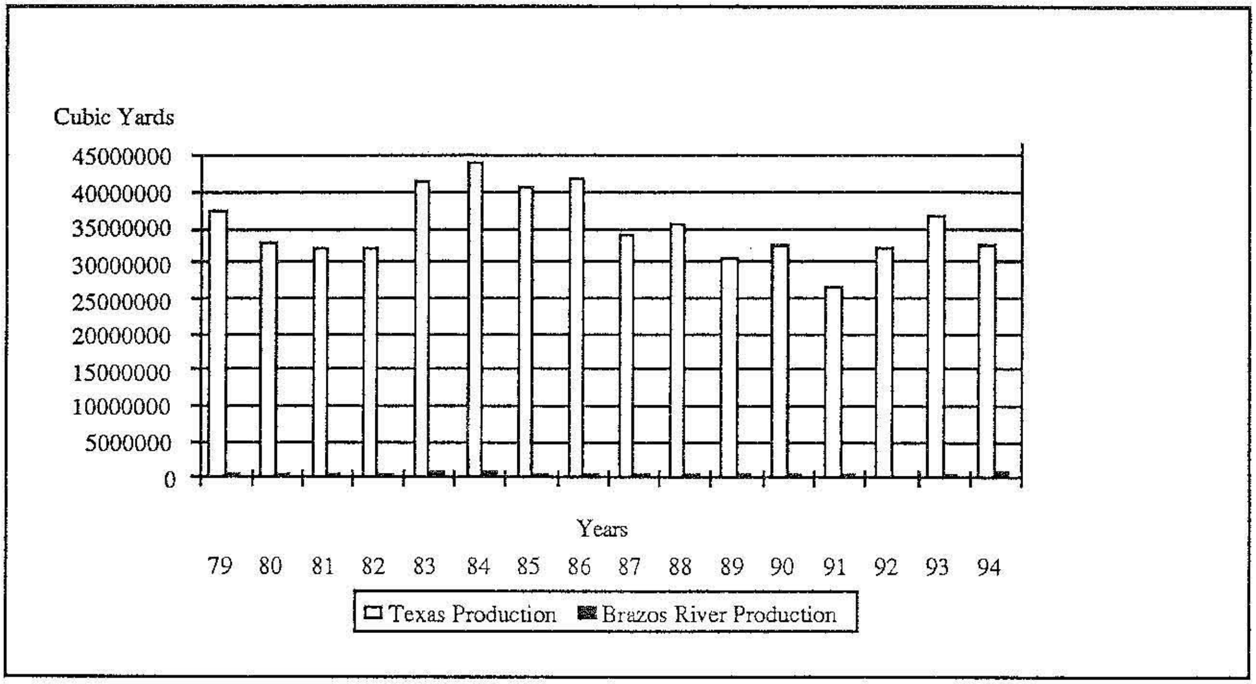


Figure 29. Texas Sand and Gravel Production vs Brazos River Sand and Gravel Production 1979-1994, Adapted from US Bureau of Mines, Minerals Yearbooks, Volume II, 1979-1994, and Texas Parks and Wildlife Revenue Reports, 1979-1994.

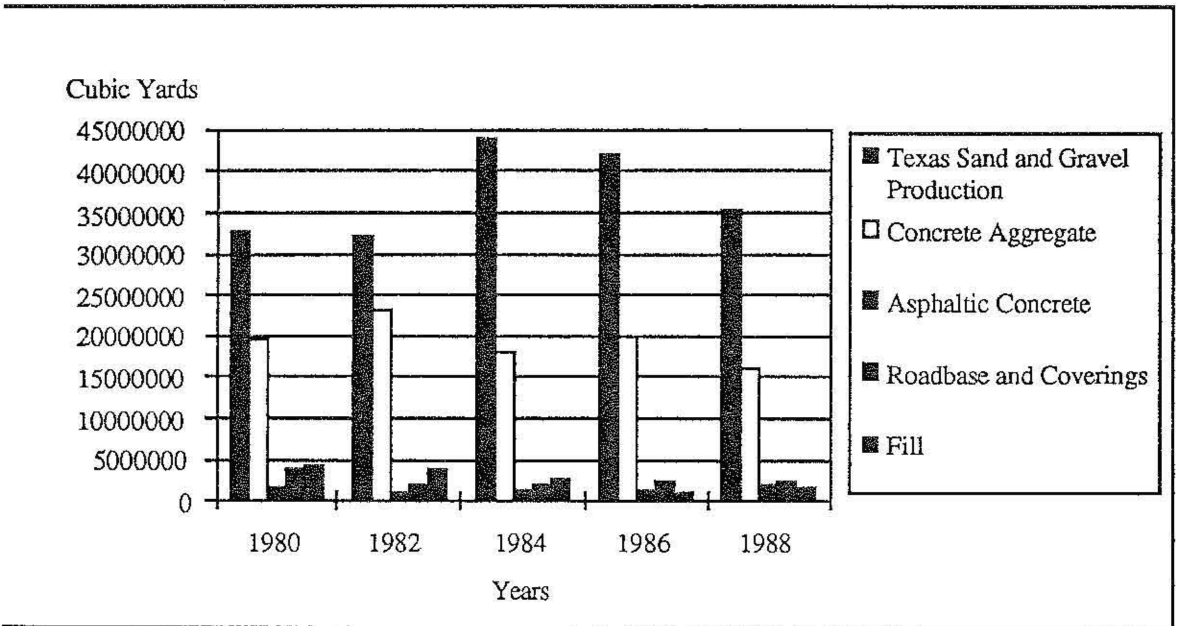


Figure 30. Texas Sand and Gravel Sold or Used, By Major Use Category 1980-1988, Adapted from US Bureau of Mines, Minerals Yearbooks, Volume II, 1980-1988, and Texas Parks and Wildlife Revenue Reports, 1980-1988.

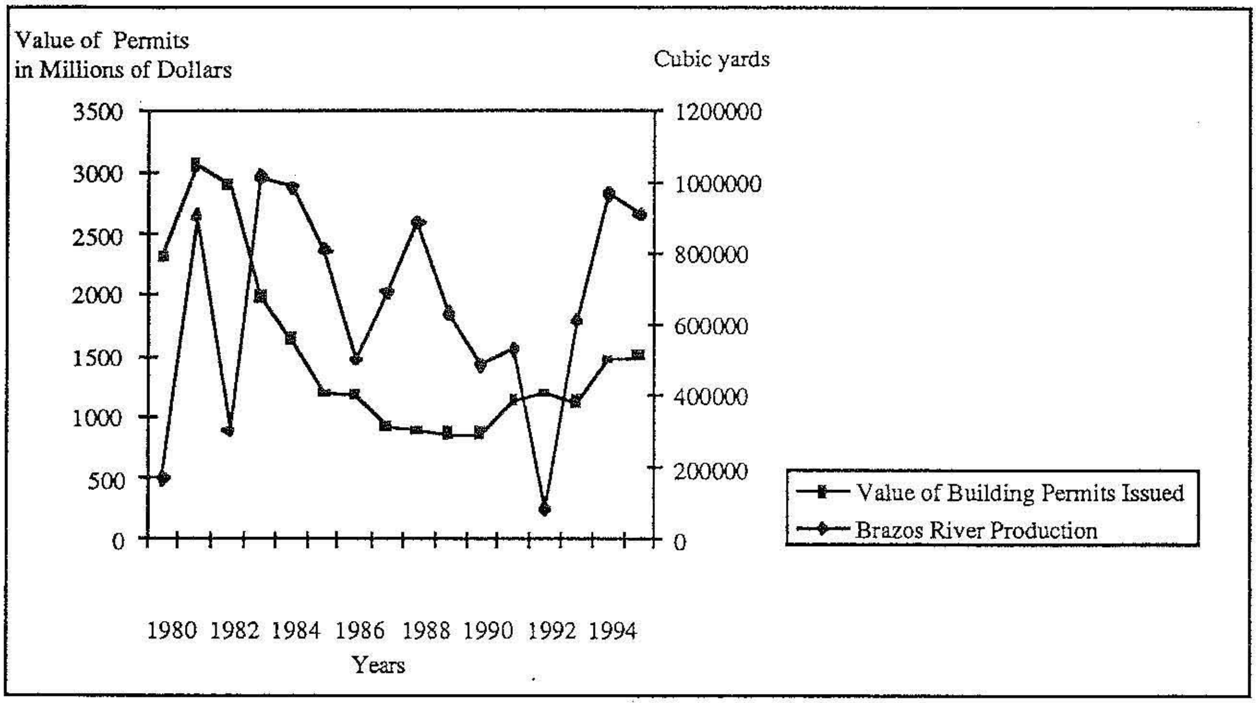


Figure 31. Brazos River Production vs Value of Building Permits Issued, Adapted from the City of Houston, Department of Public Works, Building Permits for 1980-1995, and Texas Parks and Wildlife Revenue Reports 1980-1995.

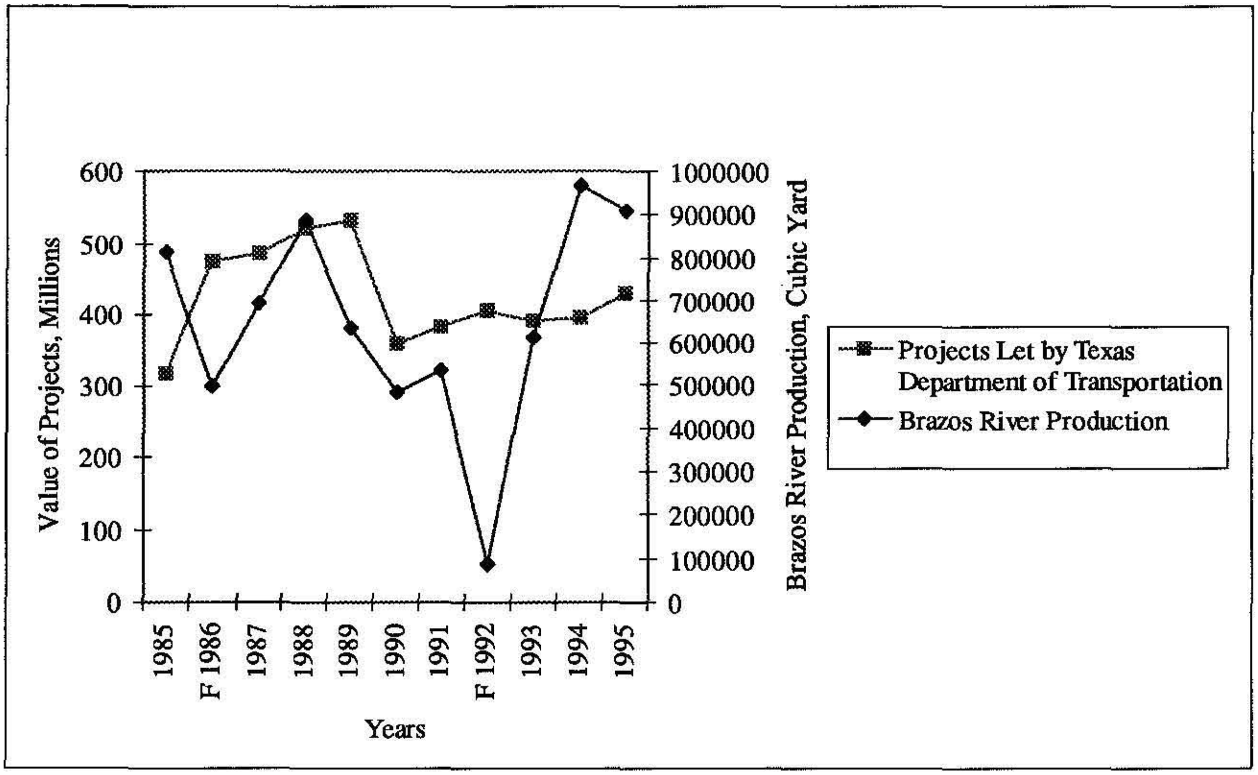


Figure 32: Brazos River Production vs Value of Projects Let By Texas Department of Transportation 1985-1995, Adapted from J. Scnelski, personal correspondence, 07/31/96, and Texas Parks and Wildlife Revenue Reports 1985-1995

F = Flood

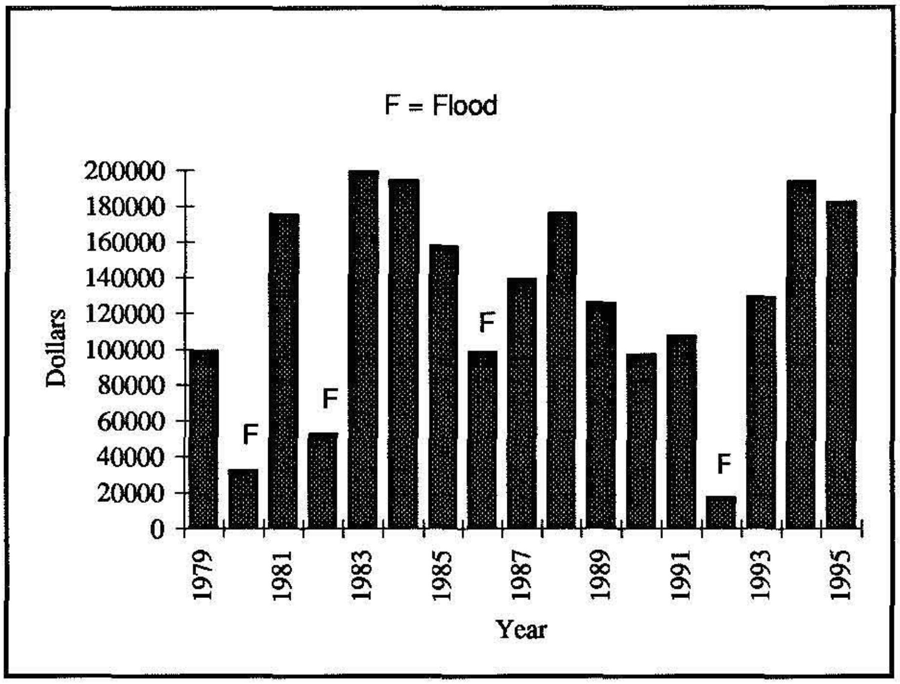


Figure 33: Brazos River Sand and Gravel Revenue 1979-1995, $2,170,153
Adapted from Texas Parks and Wildlife Revenue Reports 1979-1995

Table 1. Changes in meander paths of the Brazos River Washington-on-the-Brazos State Historical Park to the Gulf of Mexico.

Topographic quadrangle map	Approximate maximum erosion of meander cut bank (ft)	Approximate affected meander length (ft)	Number of meanders/ quadrangle	Original map date	Revised map date
Brazos River upstream of sand and gravel mining operations					
Washington	600	6,000	4	1958	1981
	600	3,000			
Courtney	650	5,000	8	1958	1981
	400	4,500			
	600	5,000			
	600	6,000			
	600	6,000			
Howth	500	5,000	4	1960	1977
	600	3,000			
	1,000	4,000			
Daniels	800	2,000	13	1960	1981
	200	2,000			
	600	5,000			
	600	5,000			
	600	4,000			
	800	4,000			
	1,000	3,000			
	1,100	3,000			
	1,000	2,000			
Burleigh	800	4,000	2	1958	1971
Sunnyside	2,000	5,000	11	1958	1977
	600	3,000			
	800	3,000			
	1,000	4,000			
	250	4,000			
	750	4,000			
Mean	1,750	3,903			
Brazos River within the segment subjected to sand and gravel mining					
San Felipe	1,400	4,000	8	1958	1977
	200	2,000			
	900	3,000			
	1,000	3,000			
Wallis	200	4,000	10	1958	1977
	600	4,000			
	100	3,000			
	150	4,000			
	200	3,000			
	200	2,000			
Mean	495	3,200			
Brazos River downstream of the segment subjected to sand and gravel mining					
Thompson	1,000	2,000	8	1970	1980
	1,000	2,000			
	200	1,000			
Mean	733	1,667			

Table 2. Changes in meander paths, Brazos River.

Park	Approximate maximum erosion of meander cut bank (ft)	Approximate affected meander length (ft)	Number of meanders/ quadrangle	Original map date	Revised map date
Washington-on-the-Brazos	825 650	3,000 5,000	2	1958	1995
Stephen F. Austin	750 1,600 900	4,000 4,500 3,650	3	1958	1995
Brazos Bend	1,500 1,500 975	3,000 2,500 2,500	3	1958	1995

Table 3. Textural data from point bar on the Brazos River adjacent to Washington-on-the-Brazos State Historical Park. Sample location shown in figure 6.

Sample Number	Pebble Gravel	Granule Gravel	V.Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	V. Fine Sand	Silt & Clay	Total Weight
WB1	37	21	12	11	13	5	1	0.4	100.4
WB2	40.3	9.5	4.9	7.7	16.9	19.7	0.8	0.1	99.9
WB4	0	0	0.1	3.4	52.2	40.6	1.6	1.1	99
WB5	0	0	0	0.1	0.2	23.3	58.3	18.2	100.1
WB6	29.4	14.6	6.6	8.4	19.9	20.5	0.6	0.1	100.1
WB7	0	0	0.6	18.4	47.4	31.7	1.3	0.6	100
WB8	29.4	11.7	6.7	9.4	16.3	25.7	0.6	0.1	99.9
WB9	3.8	8.3	10.8	20.9	29.3	24.8	1.9	0.3	100.1
WB10	15.1	11	8.8	16.3	23.9	23.5	1.2	0.1	99.9
WB11	3.2	3.5	2.6	9.9	37.4	42.1	1.2	0.2	100.1
WB12	10 .3	7.7	7.9	13.2	23	35.8	1.7	0.4	100
WB13	3.8	6.1	8.8	26	30.7	23.4	0.8	0.4	100
WB14	3	4.3	6.3	17.2	38.4	30.7	0.1	0.1	100.1
WB15	0	0.1	0.6	4.3	36.4	58.1	0.2	0.3	100
WB16	0.3	0.4	1.5	12.3	46	38.1	1.2	0.3	100.1
WB17	0	0.1	0.1	0.9	19.9	69.3	7.7	2.1	100.1
WB18	0	0.1	0.2	4	53.4	42.2	0.1	0.1	100.1
WB19	3	1.6	0.8	4.5	32.1	56.4	1.5	0.2	100.1
WB20	0	0	0	0.4	12.5	66.3	15.5	5.4	100.1
WB21	0.5	0.1	0.1	3	27.4	65.6	2.8	0.5	100
WB22	0.3	0	0.1	0.1	19.4	75	3.5	0.7	99.1
WB23	0	0.02	0.02	0.1	6.3	90.4	2.5	0.6	99.94
WB24	0	0	0	0.7	30.1	68.4	0.6	0.2	100
WB25	0	0	0	0.3	9.9	87.7	1.6	0.5	100

Table 4. Textural data from side bar on the Brazos River adjacent to Stephen F. Austin State Historical Park. Sample location shown in figure 7.

Sample Number	Pebble Gravel	Granule Gravel	V.Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	V. Fine Sand	Silt & Clay	Total Weight
SFSA6	18.8	7.9	9	22.8	25	15.7	0.6	0.2	100
SFA2	37.4	3.4	1.7	11.1	26.9	17.2	1.5	0.8	100
SFA4	41	14.7	8.5	10.4	12.7	10.3	1.7	0.5	99.8
SFA5	50.8	10.8	4	6.9	15.1	9.9	0.6	0.4	98.5
SFA6	54.1	1.7	4.7	8.4	22	7.5	0.7	0.7	99.8
SFA7	48.5	13.4	5.7	10	13.5	6.7	1.4	0.6	99.8
SFA8	46.6	11.2	4.3	10.2	19.9	6.6	0.9	0.4	100.1
SFA9	50.8	10.5	3.2	4.7	19.9	9.8	0.7	0.5	100.1
SFA10	0	0	0	0	0.9	29.8	56	13.4	100.1
SFA11	34.5	17.8	7.5	10.8	15.7	8	3.3	2.5	100.1
SFA12	4.2	2.5	3.4	14.5	25.8	26.9	13.4	10.3	101
SFA13	47.5	13.1	4.9	5.6	17.6	8.5	1.6	1.2	100
SFA15	0.6	2.7	4.6	26.3	49.5	12.3	2	2	100
SFA16	26	15.6	8.99	15	23	7.3	2.3	1.8	99.99
SFA17	31	12	5.7	11.9	26	11	1.4	0.5	99.5
SFA18	11	15.3	12	23.8	30.9	6.4	0.3	0.1	99.8
SFA19	1.8	3.6	3.6	41.4	41.7	3.2	1.7	3	100
SFA20	1.8	4.2	10	36.3	40.7	5.4	0.8	0.7	99.9
SFA21	0	1.8	10.3	37.3	45.6	3.7	0.4	0.9	100
SFA22	27	17.8	7.6	9.9	18.9	16.2	1.8	0.9	100.1
SFA23	0.2	4.5	9.8	38.9	40.8	4.3	0.6	0.8	99.9
SFA24	0	0.5	1.1	20.6	68.2	8.6	0.4	0.5	99.9
SFA25	14.1	17.1	12.1	17.5	17.4	9.9	6.8	5	99.9
SFA26	0.2	1.4	3	21.5	55.1	13.8	2.8	2	99.8
SFA27	1	3	2.5	13.4	56	21.4	1.6	0.9	99.8
SFA28	0.9	2.1	3.2	17.7	58.1	16.4	0.8	0.7	99.9
SFA29	0.9	2.8	2.8	10.2	51.5	29.3	1.6	0.9	100
SFA30	0	0.1	0.5	5.2	52.7	41.3	0.2	0.03	100

Table 5. Textural data from point bar on the Brazos River adjacent to Brazos Bend State Park. Sample location shown in figure 8.

Sample Number	Pebble Gravel	Granule Gravel	V.Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	V. Fine Sand	Silt & Clay	Total Weight
BB1	0	0	0	0.15	2	90	6.6	1.9	100.65
BB2a	0	0	0	0.05	0.09	75.5	19.5	5.2	100.34
BB2b	0	0	0	0.08	0.76	88.5	6	4.7	100.04
BB3a	0	0	0	0.07	0.27	80.2	15.2	4.1	99.84
BB3b	0	0	0	0.5	0.5	83.5	9.6	6.1	100.2
BB4a	0	0	0	0.03	1.9	94.5	2.8	0.7	99.93
BB4b	3	1.9	2.6	16.2	42.6	29.6	3	1.1	100
BB4c	0.2	0.4	0.8	24.1	58.2	15.1	1	0.2	100
BB5a	4.1	0.4	0.3	3.4	38.6	49.4	2.3	1.3	99.8
BB5b	5.4	5.8	5.1	15.4	25.4	41.3	1.4	0.2	100
BB5c	0	0.3	1.9	10.1	37.7	48.4	1.2	0.4	100
BB6a	0	0.9	1.6	11.8	33.2	38.1	11	3.3	99.9
BB6b	0.6	2	2.9	17.9	42.3	31.3	2.6	0.4	100
BB6c	0	0.2	0.8	4.3	29.3	63.7	1.2	0.7	100.2
BB7a	18.8	3.3	1.4	5.1	34.7	35.1	1.1	0.4	99.9
BB7b	13.2	7	3.3	4.9	26.4	40.6	3.5	1.3	100.2
BB8a	15.1	13.8	9.8	21.6	25.1	10.5	3.4	0.9	100.2
BB8b	5.8	7.8	4.1	6.2	19.2	53	2.6	1.5	100.2
BB9a	13.6	13.9	11.6	21.3	25.3	11.4	1.5	1.3	99.9
BB9b	38.8	15.3	10.2	13.8	13.9	7.1	0.8	0	99.9
BB10a	0	0	0	0	0.8	42.1	37.9	18.9	99.7
BB10b	35	14.3	7.8	10.5	17.8	9.7	2.6	2.1	99.8
BB11	44.2	12.3	6.2	10	15.9	7.9	2.2	1.2	99.9

Table 6. Summary of fish species found and their estimated value. Adapted from K. Sellers, 1994; J. Ralph, personal correspondence, August 9, 1994; and M. Webb, personal correspondence, August 9, 1996.

Species	Total Count	Value	Species	Total Count	Value
Spotted Gar	1,533	$16,700.05	Freshwater Drum	485	$363.74
Longnose Gar	656	$5,004.21	Common Carp	242	$426.50
Gizzard Shad	3,708	$862.92	Speckled Chub	4,009	$378.98
Threadfin Shad	126,979	$12,073.54	Warmouth	582	$165.12
Red Shiner	376,027	$35,546.75	Longear Sunfish	13,684	$2,725.18
Sharpnose Shiner	502	$47.46	Spotted Bass	162	$2,214.84
Silverband Shiner	10,524	$994.86	Largemouth Bass	583	$648.54
Chub Shiner	752	$71.09	Minnows (mixed species)	1,754	$165.81
Bullhead Minnow	447,273	$42,281.81	Ghost Shiner	2,756	$260.53
Blue Catfish	14,383	$9,464.48	Green Sunfish	1,048	$299.60
Channel Catfish	24,189	$2,058.36	Weed Shiner	1,002	$94.72
Flathead Catfish	13,776	$49,596.17	Inland Silverside	251	$23.73
Bluegill	1,836	$421.47	White Crappie	332	$171.85
Pallid Shiner	2,255	$213.17	Black Crappie	251	$136.43
River Carpsucker	64,135	$4,632.18	Smallmouth Buffalo	323	$1,513.35
Western Mosquitofish	41,748	$1,397.57	Mississippi Silvery Minnow	16,690	$1,577.75
GRAND TOTAL	1,149,757	$193,631.20			