AN ANALYSIS OF CHANGES IN TEXAS WILD-RICE

DISTRIBUTION FOLLOWING THE 1998 FLOOD

OF THE SAN MARCOS RIVER, TEXAS

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CHAPTER I

INTRODUCTION

The San Marcos River is a small, spring-fed river located in Central Texas. It is dominated by flow from springs emanating from the Edwards Aquifer. Because the river is fed by spring water, there is an almost constant water chemistry and temperature throughout the river year-round in the upper reach of the river. The unique environment of the San Marcos Springs provides a home to a wide variety of flora and fauna and five species of federal threatened and endangered species endemic to the upper San Marcos River, including an endangered aquatic grass, Texas wild-rice (*Zizania texana)* (U.S. Fish and Wildlife Service 1996).

Species in the San Marcos River are endangered not only by their small populations, but by the increased possibility of a loss of spring flow. Increased pumpage of the Edwards has lowered aquifer levels, endangering spring flow, and in times of drought spring flow may diminish or cease. It has been projected that if pumping increases at its current rate, the springs will be dry by the year 2020 (Klemt et al. 1979 cited in Rothermel and Ogden 1987).

Throughout the period of record (1915-present), San Marcos springs have not ceased to flow. A drought during the 1950's reduced San Marcos springs to their lowest discharge level of 48 cfs (1.3 m^3/s), and this is considered the drought of record for the region. The long-term flow regime of the river is punctuated by the occurrence of storm events, and both the species and the channel morphology are adjusted to a flashy flow regime with periodic large storms. On October 17 – 18th, 1998, a very heavy rain event occurred over the San Marcos River watershed creating a flood with a peak daily discharge 30 times the 10-year average daily flow. Flows from this storm exceeded bankfull conditions and had the ability to effect geomorphic change in the channel. The peak streamflow on October 17th, 1998 was 21,500 cfs (608 m^3/s) and the gage hight was 21.29 feet (6.5 meters).

Over the last fifty years, Texas wild-rice has declined on the upper San Marcos River in central Texas. The decline in Texas wild-rice can be attributed to disturbance of the plant and to alterations in wild-rice habitat (Poole and Bowles 1999). This study will seek to determine if the 1998 flood event is responsible for changes in the fluvial geomorphology of the Texas wild-rice habitat in the upper San Marcos River.

LITERATURE REVIEW

Texas Wild-rice

Zizania texana Hitchcock (Texas wild-rice) is a large perennial aquatic grass that has thin, flat, elongated leaves that are immersed in swift flowing river currents and form dense stands rooted in the limestone sand and gravel substrate near the middle of the river. Texas wild-rice is adapted to swiftly flowing water of high quality and thermally constant waters (Powers 1996; U.S. Fish and Wildlife Service 1996; Vaughan 1986).

G.C. Neally first collected the plants in August 1892 from the San Marcos River. When first described in 1933, Texas wild-rice was abundant in Spring Lake and irrigation waterways, where it became necessary to control the population through removal (Kimmel 2006; Silveus 1933). By 1976, the population of Texas wild-rice had been reduced in size to only 1,131 square meters (12,173 square feet) in the upper 2.4 kilometers (1.5 miles) of the river and no plants in Spring Lake (Emery 1977). Texas wild-rice became the first federally and state listed endangered plant in Texas.

Habitat Characterization

At present, there have been few ecological studies of *Zizania texana* and only one field study examining habitat parameters of Texas wild-rice (Poole and Bowles 1999). Terrell et al. (1978) provided descriptive observations on the ecology of Texas wild-rice, and Powers and Fonteyn (1995) investigated seed germination and seedling growth in fine and coarse sediments. Vaughan (1986) conducted a study that investigated the factors responsible for the decline of the Texas wild-rice. Vaughan grew Texas wild-rice in the raceways at Texas State University, at varying depths in Spring Lake, and in various soil types and water velocities. Growth rates were higher in the raceways than the San Marcos River, probably due to increased light and temperature. Plants grown at different depths in Spring Lake showed effects of irradiance and depth, with decreased growth rates occurring at the greatest depths. The study found that water depth influenced biomass production and that Texas wild-rice has an optimum level of irradiance and water inundation for growth and survivability. Additionally, the total population of Texas wild-rice in 1986 covered an area of 454 square meters (4886.8 square feet), a loss of 676.5 square meters (7,271 square feet) from 1976, a total percent decline of 59.8 % (Vaughan 1986). In 1992 Rose and Powers reported that Texas wild-rice total population covered an area of 1612.7 square meters (17,358.4 square feet). Texas Parks and Wildlife Department began yearly estimates of Texas wild-rice coverage in the San Marcos system in 1989 (Poole and Bowles 1999; US Fish and Wildlife Service, 2005). These surveys show increasing Texas wild-rice coverage until 1998, when the total areal coverage was estimated at 1,949 square meters (20,979 square feet). Between the 1998 and 1999 surveys, the total coverage dropped by 304 m^2 to 1,645 m^2 (17,707 ft^2). Since that time, the total coverage has expanded each year, and has more than tripled in total area since 1989.

Powers and Fonteyn (1995) concluded from laboratory studies of Texas wild-rice that low oxygen levels in anaerobic soils trigger germination and that clay-based sediments were best suited to wild-rice. However this study did not address the natural conditions of the San Marcos River, where a broad range of nutrients are available in the sediments and organic matter content in sandy and clay soils are the same (Poole and Bowles 1999). Powers (1996) quantified and compared the growth response of Texas wild-rice to different flow regimes and sediment compositions by planting Texas wild-rice in coarse and fine sediments and placing the samples in three areas with different current velocities. The results showed a positive relationship between flow, stem density, and above ground biomass. Research showed that Texas wild-rice preferred faster flowing water and that at lower current velocities, Texas wild-rice might become carbon dioxide stressed. Also, the study showed that plants demonstrated greater above ground biomass and stem density when grown on sandy clay in faster velocity water and a negative growth response when grown in gravel.

Poole and Bowles (1999) expanded upon the research by Powers and Fontyen (1995, 1996) by examining habitat characteristics in the field for areas where Texas wild-rice was growing and areas where Texas wild-rice was absent. Poole and Bowles' research contrasted Powers and Fonteyn (1995) by showing that differences in substrate particle size were highly significant and Texas wild-rice tended to occupy sites with moderately coarse sandy loams to coarse, loamy sands. Texas wild-rice was also found predominantly in shallow areas at a depth of less than one meter. Texas wild-rice was present in areas with higher velocities. Velocities in areas with Texas wild-rice were greater than 0.46 meters per second (1.51 feet per second) and areas without Texas wild-rice had velocities of less than 0.22 meters per second (0.722 feet per second). The results of these studies have allowed for the determination of reliable and accurate identification of the remaining habitat of Texas wild-rice in the San Marcos River.

Fluvial Geomorphology

Fluvial geomorphology is the study of water-shaped landforms and the trends associated with the adjustment of channel form (Knighton 1984). Stream channels exhibit regular downstream changes in depth, width, velocity, sediment load, and stream biology. Streams are considered dynamic "open systems" because they experience a continuous inflow and outflow of energy and matter over a range of time scales (Gordon, McMahon, and Finlayson 1992). Streams are a continuously changing system: river levels change, floods scour and deposit sediment, banks erode, and channel bars form to change the shape of the channel bed.

In different streams, the effects of geology and hydrology are different. In bedrock streams, channels erode due to mass failures of large slabs of rock and the slow eroding of the channel bed by stream transported debris (Knighton 1984). In alluvial streams, the streamflow moves across glacial or riverine deposited material and entrains weak materials that break down easily. In the headwaters of streams, bed materials are usually quite large and exceed the competence of the streamflow. Large, angular rocks disintegrate into the channel and substrate material size decreases downstream as sediments are abraded and smaller sediments are sorted out (Gordon, McMahon, and Finlayson 1992). Local flow conditions also affect substrate sediments. Coarse materials may line riffles, while finer sediments are found where flows decrease and allow deposition: in large pools, in channel bends, at confluences, or in areas of high vegetation (Gordon, McMahon, and Finlayson 1992). The patterns of substrate size and deposition may only change at high flows, especially in streams with coarse, heterogeneous materials, producing substrate that is more closely related to previous flood events than the typical lower flow patterns (Gordon, McMahon, and Finlayson 1992).

Floods

A flood can be simply defined as a flow which overtops the banks of a stream. An ecological definition of a flood is a discharge which scours substrates and disrupts the biota. Floods affect the ecology of a stream by scouring away aquatic and riparian plants and fertilizing a stream ecosystem with nutrients from eroded soils (Gordon, McMahon, and Finlayson 1992; Longley 1975).

At low flow, a stream may follow a winding path between rocks and around bends and bars. As flows increase during a flood event, the path of travel is shortened as the flow "shortcuts" across the meanders. This allows more efficient travel of water. As the floodwaters rise, susceptible portions of the beds and banks of a stream begin to erode and bank vegetation may be uprooted and added to the debris load of the floodwater. After the floodwaters begin to recede, sediment deposits on the channel floor, filling in scour areas.

Significance of the Study

Streamflow and springflow produce a unique suite of biota in the upper San Marcos River. During low flows, temperature and salinity levels may rise and the plant population within the channel may change, with an increase in growth of those species that thrive during low-flow periods, and a loss of species for which low flows are a stress (Gordon, McMahon, and Finlayson 1992). Decreases in streamflow in the San Marcos River will trigger physical changes in Texas wild-rice habitat. The natural flows of the San Marcos have been altered by flood control dams. In addition, much of the channel banks of the upper San Marcos River have been artificially enhanced, creating a constant width channel. Therefore, any reduction in discharge from the springs will lead to decreases in flow velocity and/or depth. Many species, including Texas wild-rice have an inherent need for high water velocities, relying on them to provide nutrients and assist in the dispersal of the species (Gordon, McMahon, and Finlayson 1992; Poole and Bowles 1999). Velocity in the San Marcos River decreases with the reduction in flows due to over-pumping of the Edwards Aquifer, drought, and sedimentation in the upper San Marcos River (Powers 1996; Wood 1996). With slower flow velocities, less material is eroded and re-deposited downstream and bedload material, such as gravel, cannot be entrained (Earl and Wood 2002; Gordon, McMahon, and Finlayson 1992). Decreased flow velocities have also been attributed to lower growth rates in Texas wild-rice in the San Marcos River (Poole and Bowles 1999; Powers 1996) and can cause the Texas wild-rice to become carbon dioxide stressed (Powers 1996).

Aquatic communities, particularly aquatic macrophytes, are established by nutrient levels and streamflows that are ruled by fluxes in the flow regimes occurring in these ecosystems. Flood disturbances act in the dynamics of such ecosystems. Studies have shown that aquatic macrophytes are able to delineate the intensity and frequency of flood disturbances and these disturbances depend mainly on the geomorphic pattern of the river and the pattern of aggradation and erosion that occurs with floods, thus macrophytes are able to act as an indicator of the size and power associated with the flood (Bornette et al. 1998). The geomorphology of the channel bed can affect the flow velocity and intensity of scouring effects of floods (Bornette et al. 1998).

Floods affect the ecosystem of a river by restructuring the riverbed habitats and scouring away aquatic vegetation (Hastie et al. 2001). The historic flood cycle on the San Marcos River removes sediments and provides nutrients to the river from bank erosion (Longley 1975; Powers 1996). Flooding has been a natural occurrence in the San Marcos River and aids in removal of silt through flushing flows, maintaining habitats through removal of vegetation from banks, creating openings in shoreline vegetation, providing nutrients, and by reducing numbers of nonnative fishes and plants (U.S. Fish and Wildlife 1996). However, human modifications, such as bank stabilization, flood control dams, and run of the river dams, have severely altered the natural fluvial regime and drainage pattern in the San Marcos system. These alterations have changed the historical magnitude and occurrence of flood disturbances (Earl 2002, Longley 1975; Powers 1996; U.S. Fish and Wildlife Service 1996).

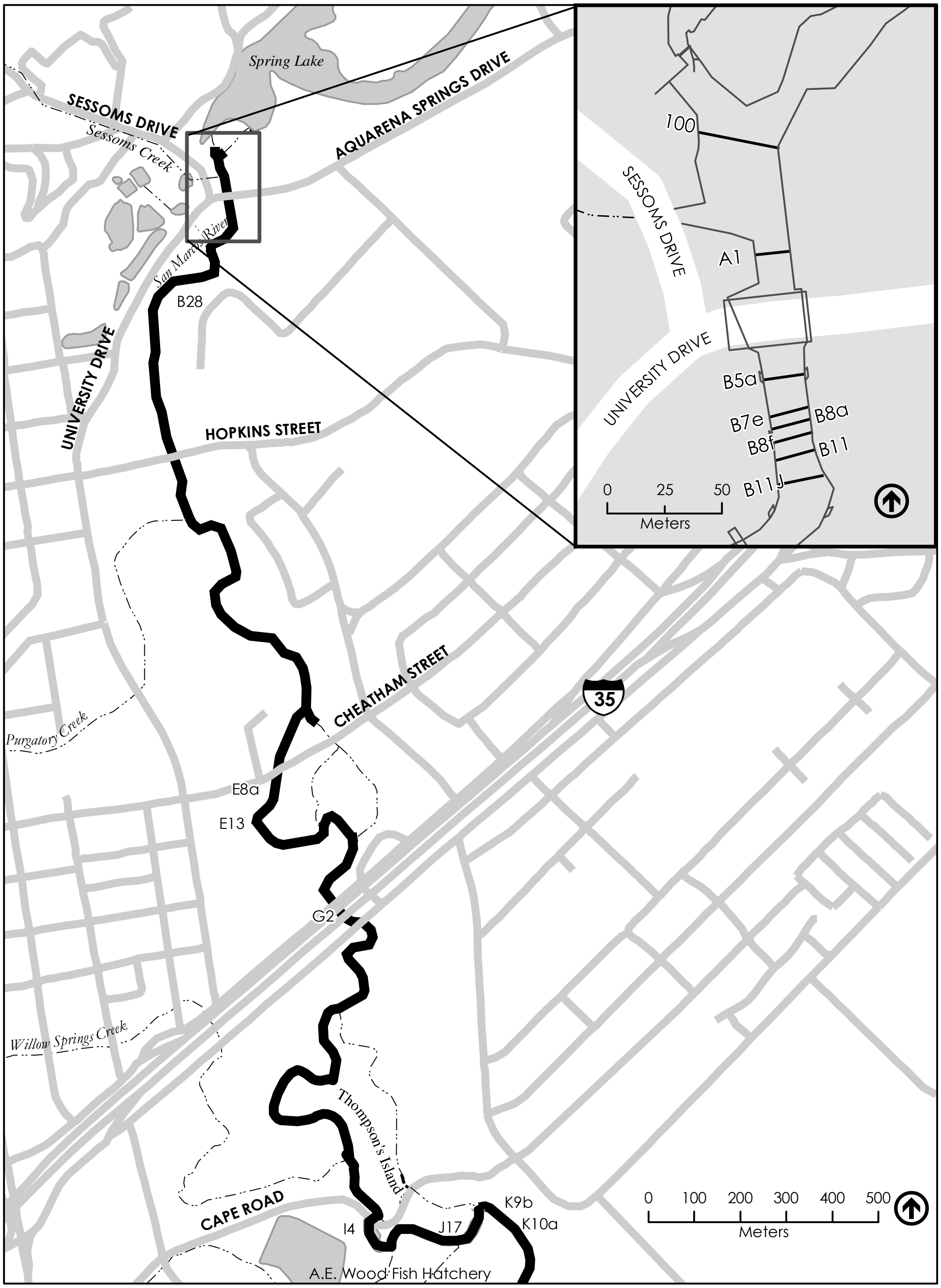
Five flood detention dams have been built on tributary creeks draining into the San Marcos River in order to decrease the severity of flooding in the watershed and to increase the recharge into the Edwards Aquifer. However, as the U.S. Fish and Wildlife Service (1996) points out, the effects of these structures on flushing flows and silt accumulation is uncertain. Flooding still occurs and may flush silt and other materials into the river, but the floodwaters may not be of great enough magnitude to physical remove excess silt from the river bottom and to maintain the natural habitat (Earl and Wood 2002; Longley 1975; Saunders, et al. 2001;). Anthropomorphic factors have not only affected flood magnitude and frequency, but also directly influenced the fluvial geomorphology of the San Marcos River. For example, a large gravel bar has developed below the confluence of Sessoms Creek and the San Marcos River due to construction occurring in the watershed (Earl and Wood 2002).

Study Area

The San Marcos River has its headwaters in Hays County along the San Marcos Fault. The majority of the flow originates from the Edwards Aquifer through a series of major and numerous minor springs, known as the San Marcos Springs. These springs form the second largest system in Texas. The 15 large springs average 3.7 m^3/s (135.7 3.7 ft^3/s) discharge (Ogden, Spinelli, and Horton 1985). Average discharge from the springs for the period of 1928 to 1989 was 8.4 m^3/s (284 ft^3/s) and maximum daily spring flow was 18.9 m^3/s (666 ft^3/s) on December 22, 1991 (U.S. Fish and Wildlife Service 1996). The San Marcos Springs historically have shown the greatest flow reliability and environmental stability of any spring system in the southwest United States, with records indicating that the San Marcos Springs have never ceased flowing, although the flow fluctuates with its source, the Edwards Aquifer springs (Puente 1976).

At the headwaters, a dam impounds the spring flow to create an eighteen-hectare lake named Spring Lake (Figure 2). From the headwaters located in the town of San Marcos, the river is joined by the Blanco River, approximately 2.4 kilometers (4.5 miles) downstream, and then flows 120 kilometers (75 miles) to its confluence with the Guadalupe River near Gonzales, Texas (Vaughan 1986, 1).

Figure 1. San Marcos River Map.



The study area for this research is the upper San Marcos River above the confluence with the Blanco River. This 2.4 kilometer (1.5 mile) section of the San Marcos River has rapidly flowing and remarkably clear water; running primarily from spring-fed waters, and varies from five to fifteen meters wide (49 feet) and up to four meters deep (13 feet). The river bottom in the upper reach is composed of gravel and sand/gravel with many shallow riffles alternating with deep pools. Silt is the dominant substrate in areas near the banks where erosion has occurred, in areas with low flow and near stormwater drainage outlets (Crowe 1994).

The San Marcos River has clear waters of temperatures that rarely vary more than a few degrees from the yearly average of 22 degrees Celsius (71 degrees Fahrenheit). The thermally constant water from the San Marcos Springs provides an environment that supports a wide variety of flora and fauna, including five species of federal threatened and endangered species endemic to the upper San Marcos River. As well, the San Marcos River provides habitat for other unique species such as four endemic species of caddis flies, the Giant River Shrimp, and thirty-one species aquatic plants, and supports a multitude of introduced and exotic species of plants and animals (U.S. Fish and Wildlife Service 1996).

CHAPTER II

METHODOLOGY

Objectives

This study seeks to answer the following questions: (1) did the 1998 flood event change the fluvial geomorphology of the Texas wild-rice habitat within the upper San Marcos River? (2) did the flood enhance or degrade the Texas wild-rice habitat?

To answer these questions, data have been gathered from existing sources as well as from new field work. Analysis and comparison of the geomorphologic character of the river where Texas wild-rice was located prior to the flood with the current channel conditions address these questions.

Existing Data

Data pertaining to Texas wild-rice habitat and species numbers were obtained from the Texas Parks and Wildlife Department (TPWD). TPWD began yearly surveys in the summer of 1989 to determine areal extent of wild-rice stands (U.S. Fish and Wildlife Service 1996, 44). These annual assessments of Texas wild-rice provide records of the location and extent of Texas wild-rice in the San Marcos River. This thesis study uses 1994 and 2003 Texas wild-rice assessment data.

Additional research by TPWD of Texas wild-rice habitat includes transects taken from the San Marcos River above the confluence of the Blanco River as part of a 1995 – 1996 Texas wild-rice habitat characterization study (Poole and Bowles 1999). The Poole and Bowles study methodology used 30 transects, distinguished as those having Texas wild-rice and those without Texas wild-rice. The Poole and Bowles habitat characterization research provided static physical and biological conditions (turbidity analysis, depth or water surface elevation, flow velocity, substrate samples, and aquatic plant composition measurements) and chemical conditions (pH, temperature, dissolved oxygen concentration, and conductivity). Physical conditions utilized from the habitat characterization research for this study include depth and substrate particle size. The transects used in this thesis study were the 15 transects with Texas wild-rice.

FIELD DATA

Substrate and depth data were collected in the fall of 2004 to facilitate the assessment of the impacts of the 1998 flood on the Texas wild-rice habitat. Substrate data were collected along the same transects as those used by Poole and Bowles in the 1995 habitat characterization. The transects chosen for the analysis included the 14 rice transects and one non-rice transect. Sediment samples were taken from three locations at each transect (mid-, left-, and right-bank) using a Wildco hand operated, five centimeter (1.97 inch) benthic core sampler. Where Texas wild-rice was present at the location of the sample, cores were taken adjacent to the rooted zone of the plant to get a representative sample of the substrate but not damage the plant. For each sample, the sediment corer was placed into the substrate until it could not penetrate any further downward. Samples were placed in clean, dry containers, labeled, and taken to the laboratory where they were dried, sieved, and weighed for sediment size analysis. Depth was measured at one meter intervals across the entire width of the river channel at each transect starting at river left and finishing at river right using a stadia rod. The 1995 survey did not tie the cross-sections to an established datum. In order to ensure comparability of the 1995 to the 2004 depth data, the cross-section depth measurements were taken when the flow in the channel was within 20 cfs of the flow during the 1995 survey. In 1995 the flow was 200 cfs and in 2004 the flow was 180 cfs.

METHODS

The two primary research questions were addressed in separate methods. The first method consisted of determining if the 15 sample transects had maintained Texas wild-rice stands in the same general placement after the 1998 flood. This was accomplished through mapping the 15 sample transect locations with the 1994 and 2003 Texas wild-rice location data. This allowed a determination of whether the Texas wild-rice stands had survived the 1998 flood, whether the stands had maintained their placement in the river channel, if stand position had migrated, and if the Texas wild-rice stand changed in size.

The second method used cross-sectional profiles that were developed from the 1994-1995 habitat characterization depth data (Poole and Bowles 1999) and the 2004 fieldwork depth data. The transect depth data for both time periods were plotted on cross-sectional profiles which enabled a comparison of how channel shape and channel depth changed after the 1998 flood. The 1995 and the 2004 substrate data were then added to the cross-sections which allowed for determination of substrate change after the 1998 flood and a comparison of both spatial and temporal change in channel depth and substrate The locations and the areal extents of wild-rice stands were then plotted on the transect cross-sections and mapped. From the maps and the transect cross-sections, the 1994 location and extent of wild-rice were compared to the location and extent of wild-rice stands in 2003. The maps and cross-sections together allowed for analysis of how Texas wild-rice responded to the changes in channel depth and substrate along the transects.

Data Analysis

Transect 100

Transect 100 is located at the headwaters of the San Marcos River, just below the two dams of Spring Lake and the confluence of Sessoms Creek. There has been an overall decrease in channel depth at this transect between 1995 and 2004. The mean depth was 2.2 meters in 1995, and dropped to 0.94 meters by

2004, with channel aggradation occurring more on the left side of the channel. The decrease in channel depth is due to sedimentation across the channel. In addition to the overall aggradation, the variability of flow depth across the channel was reduced. In 1995, the channel depth varied by two meters and by 2004 that was reduced to 1.5 meters. Concurrent with river sedimentation and depth reduction is the growth of new stands of Texas wild-rice. Wild-rice was not found on or near Transect 100 in 1995. By 2004, two stands of wild-rice had grown along the transect width. Additional stands are observed on the left side of channel over the length from the dam to the bridge. There has been no change in the composition of the bed substrate over this time period. The sand content of the bed sediments increased 28.8 %, and the silt fraction decreased 13.5 percent.

Figure 2. Map of Transects 100 - B11J Wild-rice.

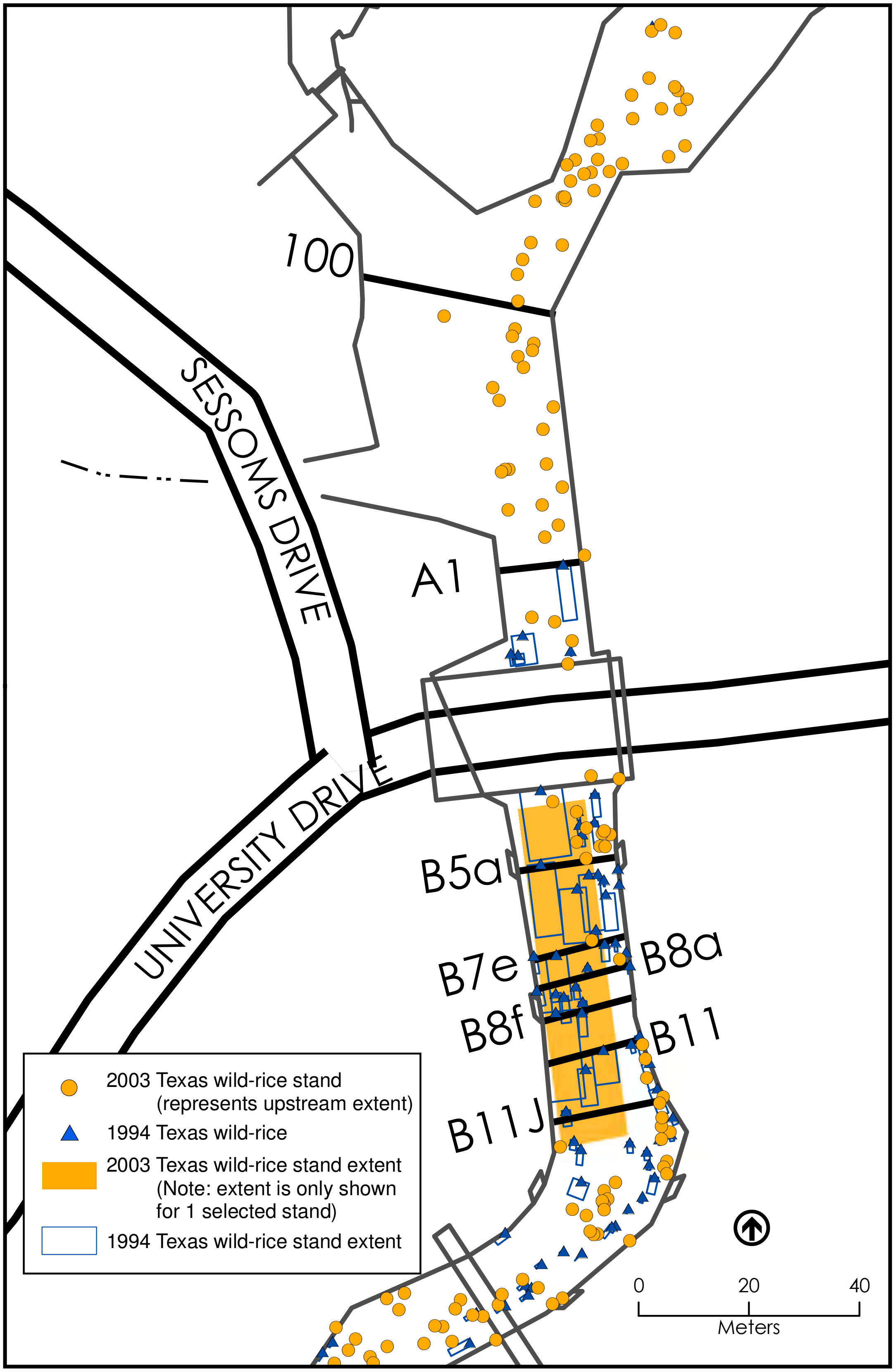
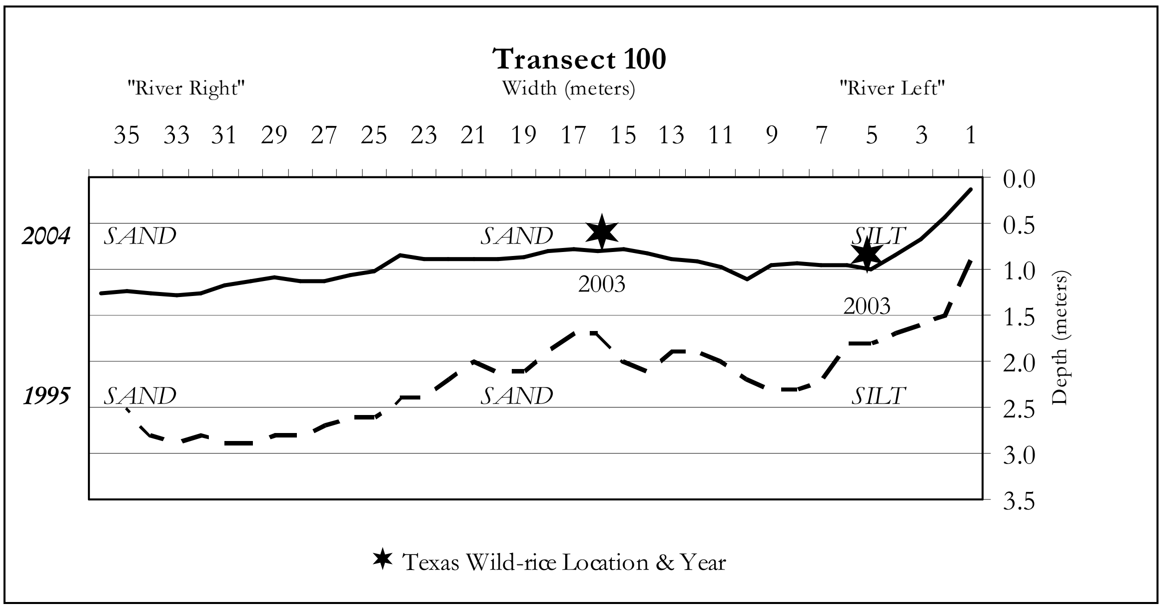


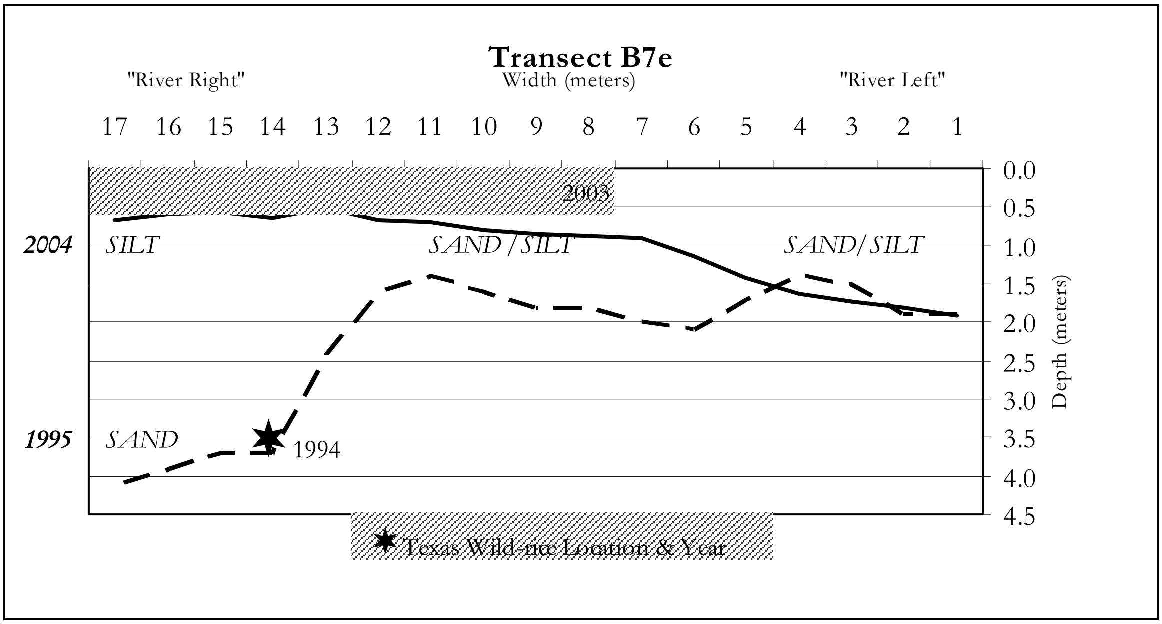
Figure 3. Transect 100.



Transect B7e

Transect B7e is located in Sewell Park below Spring Lake and the confluence of Sessoms Creek. There has been an overall decrease in channel depth at this transect between 1995 and 2004. The mean depth was 2.26 meters in 1995, and dropped to 1.03 meters in 2004, with the area from the right side of the river to the middle showing the largest amount of aggradation. The decrease in channel depth is due to sedimentation across the channel. In addition to the overall aggradation, the variability of flow depth across the channel was reduced. The right side of the river changed approximately three meters in depth from 1995 to 2004 as sedimentation occurred. Concurrent with river sedimentation, the composition of the bed substrate changed from sand in 1995 to silt and sand/silt in 2004. The sand content of the bed sediments decreased by 4.2 percent, and the silt fraction increased by 18.2 percent. Simultaneous with these modifications in Transect B7e is the expansion of stands of Texas wild-rice into the newly shallow areas filled with sand and silt. In 1994, a stand of Texas wild-rice was found on the transect and several other small stands of wild-rice were in the general area. In 1994, several small stands of wild-rice were evident on river left. In 2003, the stands of wild-rice have increased in size and number from the middle of the channel to river right. The stands have combined and are treated as one contiguous stand. In 2003, the stands on river left were no longer present due to being scoured out of the river.

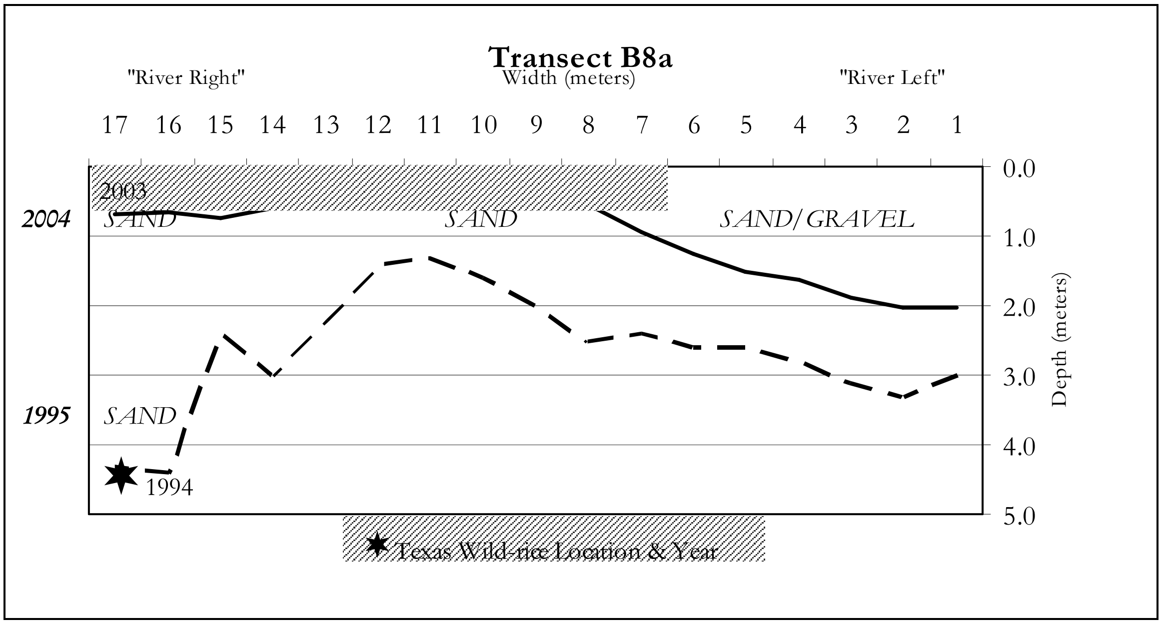
Figure 4. Transect B7e.



Transect B8a

Transect B8a is located in Sewell Park below Spring Lake and the confluence of Sessoms Creek. There has been an overall decrease in channel depth at this transect between 1995 and 2004. The mean depth was 2.64 meters in 1995 and dropped to 0.99 meters in 2004. The right side of the river changed in depth by approximately three meters. The decrease in channel depth is due to deposition of material on right side of the river. The composition of the bed substrate on the right side remained sand between 1995 and 2004. The mid-channel substrate composition in 2004 was sand and the left side was a mixture of sand and gravel. The sand content of the bed sediments increased by 4.5 percent, and the silt fraction increased by 12.5 percent. Simultaneous with these modifications in B8a is the expansion of stands of Texas wild-rice into newly shallow areas filled with sand and silt. In 1994, a separate stand of wild-rice was located on river right near the shore and river left near the shore. In 2003, the stands of wild-rice had increased in size and number, as observed with transect B7e, and had combined together from the middle of the channel to river right. The stand of wild-rice on river left was not present in 2003, due to being scoured out of the river.

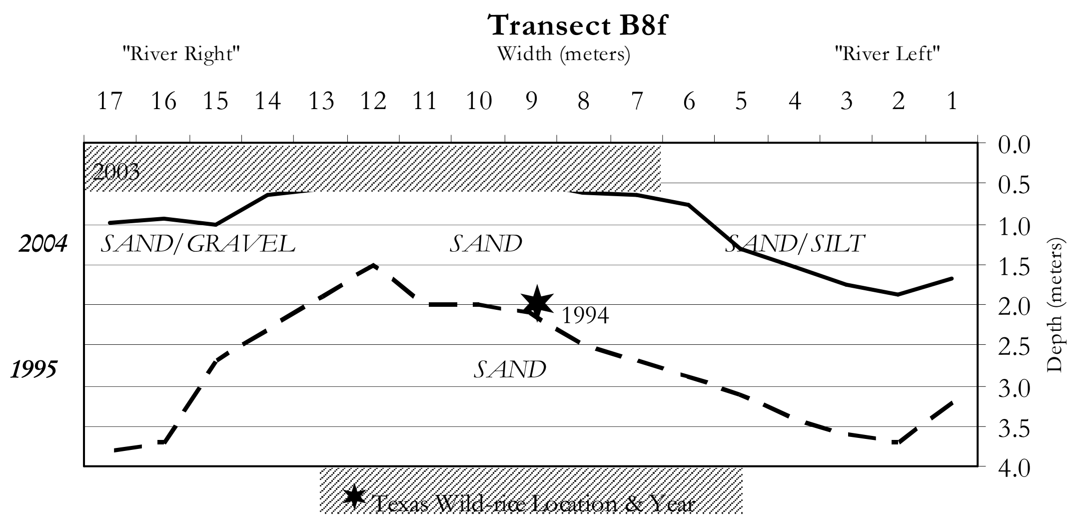
Figure 5 . Transect B8a.



Transect B8f

Transect B8f is located in Sewell Park below Spring Lake and the confluence of Sessoms Creek. There has been an overall decrease in channel depth at this transect between 1995 and 2004. The mean depth was 2.77 meters in 1995 and dropped to 0.95 in 2004. The right side of the river changed in depth approximately 2.5 meters from 1995 to 2004. The decrease in channel depth is due to sedimentation. The composition of the bed substrate in the mid-channel remained sand between 1995 and 2004. In 2004, the right side of the river was composed sand and gravel, and the left side was sand and silt. The sand content of the bed sediments decreased by 0.7 percent, and the silt fraction increased by 18.7 percent. In 1994, a stand of wild-rice was located on transect B8f at the middle of the channel. A large stand of wild-rice was located just upstream of B8f as well and extended from the right bank to the middle of the channel. In 2003, the stands of wild-rice had increased in size and number and combined together from the middle of the channel to river right to form a contiguous stand of wild-rice.

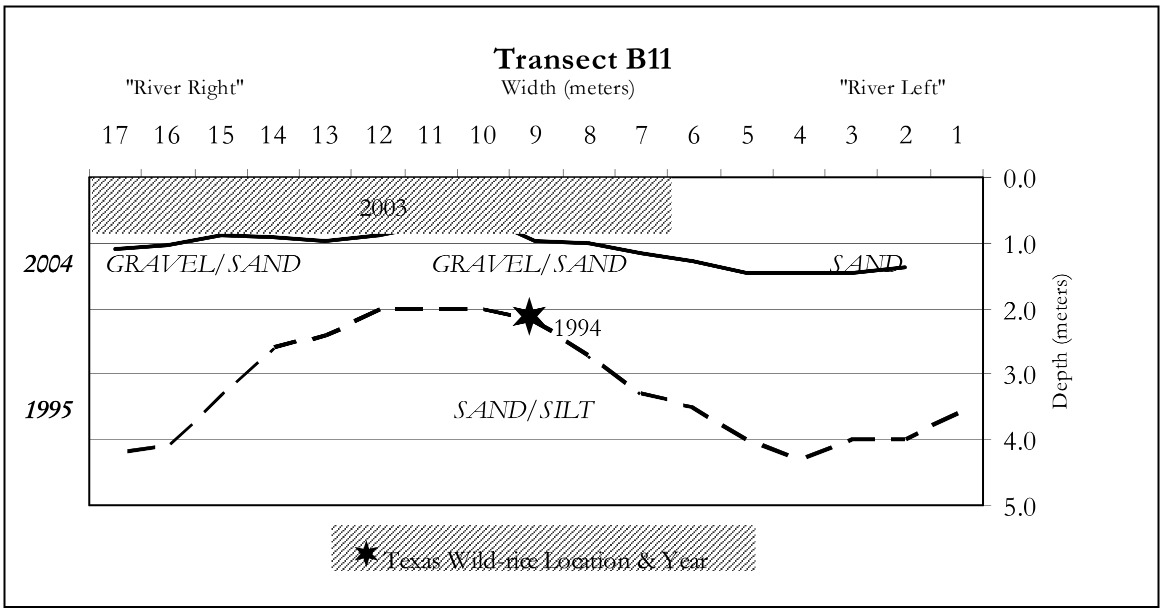
Figure 6. Transect B8f.



Transect B11

Transect B11 is located in Sewell Park below Spring Lake and the confluence of Sessoms Creek. There has been an overall decrease in channel depth at this transect between 1995 and 2004. The mean depth was 3.19 meters in 1995 and dropped to 1.08 in 2004. The right side of the river aggraded approximately 3 meters and the left side approximately 2 meters. The decrease in channel depth is due to sedimentation. Concurrent with river sedimentation, the composition of the bed substrate changed from 1995 to 2004. In 1995, the composition of substrate in the mid-channel near the wild-rice stand was sand and silt, and in 2004, the substrate was gravel and sand. In 2004, the substrate composition on the right side of the river was gravel and sand while the left side was sand. The sand content of the bed sediments increased by 22.4 percent, and the silt fraction increased by 1.6 percent. Simultaneous with these modifications in Transect B11 is the expansion of stands of Texas wild-rice into the newly shallow areas filled with sand and gravel. In 1994, a stand of wild-rice was located on transect B11 at the middle of the channel. Several small stands of wild-rice were located at river left. In 2003, the stands of wild-rice had increased in size and number and combined together from the middle of the channel to river right forming a contiguous stand of wild-rice. The stand of wild-rice at river left in 2004 is in the same area but has moved downstream slightly since 1994.

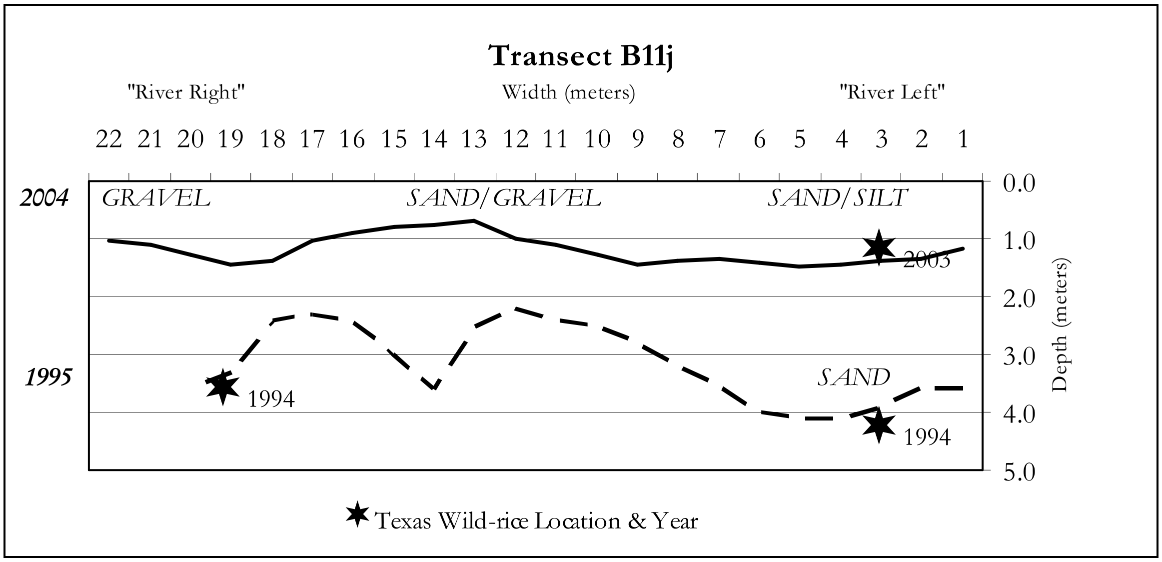
Figure 7. Transect B11.



Transect B11j

Transect B11j is located downstream of Sewell Park below Spring Lake and the confluence of Sessoms Creek. There has been an overall decrease in channel depth at this transect between 1995 and 2004. The mean depth was 3.15 meters in 1995 and aggraded to 1.09 meters in 2004. Both the left and right sides of the river changed approximately 2.5 meters. The decrease in the channel depth is due to sedimentation. Concurrent with the sedimentation, the composition of the bed substrate changed from 1995 to 2004. In 1995, the composition of substrate on the left side of the river near a wild-rice stand was sand, and in 2005, the substrate was sand and silt on the left, mid-channel was sand and the right side was gravel. The sand content of the bed sediments decreased by 19.2 percent, and the silt fraction increased by 31.2 percent. Simultaneous with these modifications in Transect B11j is the change in the size and distribution of wild-rice stands. In 1994, a Texas wild-rice stand was located on the right side of the river and by 2004, the stand of wild-rice had been removed. Additionally, in 1994, the wild-rice stand on the left side of the river was approximately 1.9 meters in width and 6.3 meters in length and in 2004 the wild-rice stand was 1.6 meters in width and 1.6 meters in length. Transect B11J is the furthest upstream transect to show a decrease in wild-rice.

Figure 8 Transect B11J.

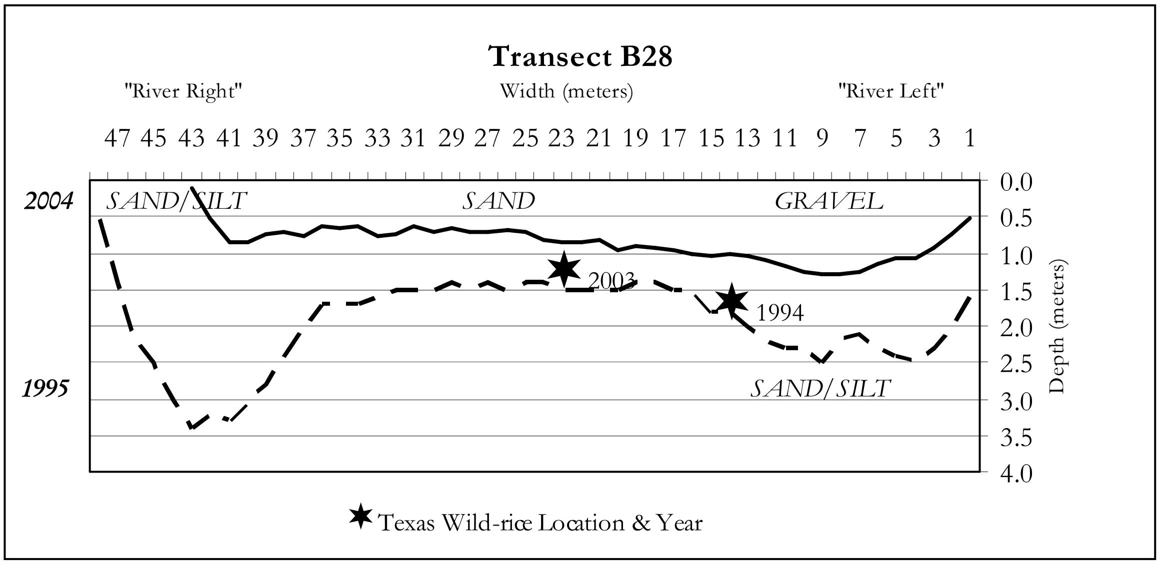


Transect B28

Transect B28 is located in the northern section of City Park in the San Marcos River. There has been an overall decrease in channel depth at this transect between 1995 and 2004. The mean depth was 1.95 meters in 1995 and dropped to 0.86 meters in 2004. The right side of the river changed approximately 2 meters and the left side changed approximately 1.5 meters. The decrease in the channel depth is due to sedimentation. Concurrent with the sedimentation, the composition of the bed substrate changed from 1995 to 2004. In 1995 the composition of the substrate on the left side of the river near a wild-rice stand was sand and silt and in 2004, the substrate was gravel and sand on the left, mid-channel was gravel, and the right side was gravel. The sand content of the bed sediments increased by 15.2 percent, and the silt fraction increased by 12.8 percent. Simultaneous with these modifications in Transect B28 is the increase in the number and the expansion of Texas wild-rice stands into the newly shallow areas filled with sand and gravel. In 1994, a stand of wild rice was located on transect B28 at the middle of the channel. Several small stands were located on the left side of the river. In 2003, four new stands of wild-rice had become established near transect B28.

Figure 9. Map of Transect B28 Wild-rice.

Figure 10. Transect B28.

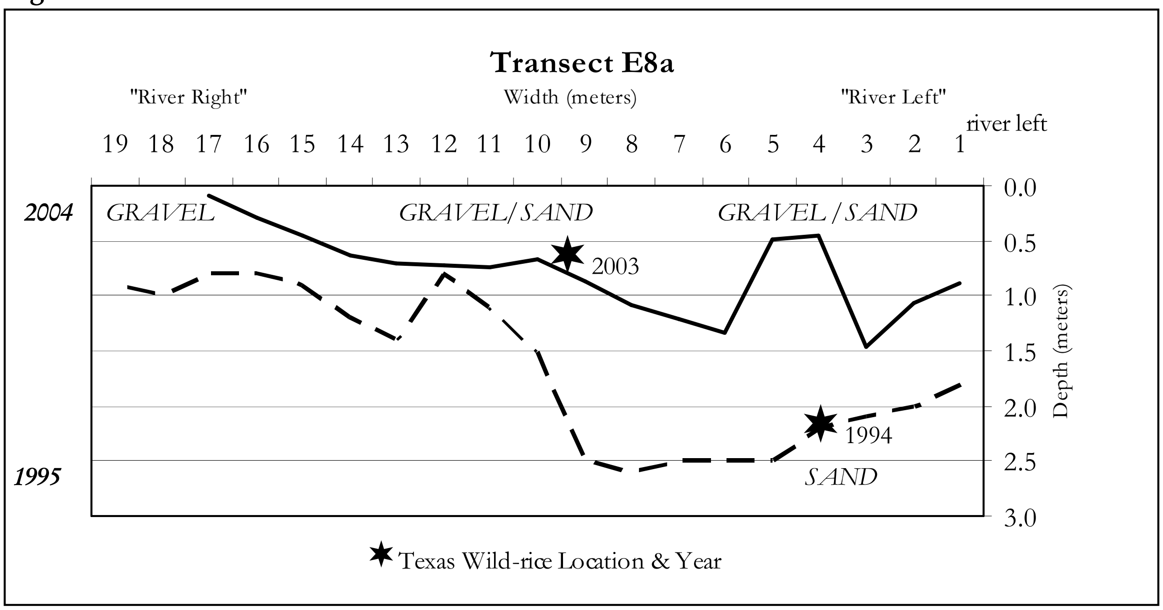


Transect E8a

Transect E8a is located in the San Marcos River below Rio Vista Dam and the Cheatham Street Bridge. There has been an overall decrease in channel depth at this location between 1995 and 2004. The mean depth was 1.64 meters in 1995 and dropped to 0.77 meters in 2004. The right side of the river changed approximately 1 meter and the left side of the river changed approximately 0.5 meters. The decrease in the channel depth is due to sedimentation. Concurrent with the sedimentation, the composition of the bed substrate changed from 1995 to 2004. In 1995 the composition of the substrate on the left side of the river near a wild-rice stand was sand and in 2004, the substrate was gravel and sand, mid channel was gravel, and the left side of the river was gravel. The sand content of the bed sediments decreased by 0.1 percent, and the silt fraction increased by 17.1 percent. Simultaneous with the modifications in Transect E8a is the increase in number of Texas wild-rice stands into the newly shallow areas filled with sand and gravel. One stand of wild-rice on the left side of the river which was present in 1994 was not present in 2003 and four new stands of wild-rice had become established near the middle of the river in 2003.

Figure 11. Map of Transect E8a Wild-rice.

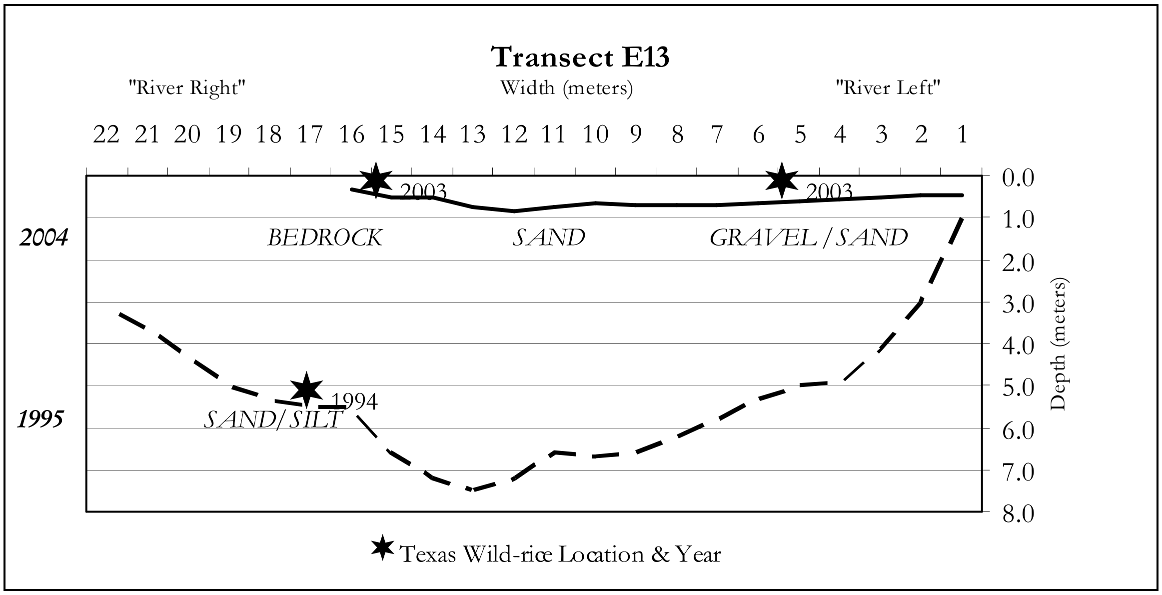
Figure 12. Transect E8a.



Transect E13

Transect E13 is located in the San Marcos River at Crook Park. Because of drastic changes in the stream around E13, data in this study was not taken for E13 but rather for E14, which does not translate to data taken in 1995. The plant stand at transect E13 was washed out in the 1998 flood. This resulted in an error in the fieldwork when the plant stand of E14 was misidentified as E13. This error was not realized until the depth transects were compared after fieldwork was completed. Neither depth nor sediment data were taken at E14; thus a comparison of data cannot be made. Of worthwhile note however is that the transect taken at E14 in 2004 showed the average depth was 0.61 meters and the composition of the substrate was gravel and sand on the left side of the river, sand substrate at the middle of the river, and bedrock at the right side of the river. The area where transect E13 was located was bedrock on the right side of the river whereas in 1995 the composition of substrate was sand and silt.

Figure 13. Transect E13.



Transect G2

Transect G2 is located in the San Marcos River directly below the Interstate 35 bridges. There has been an overall decrease in channel depth at this location between 1995 and 2004. The mean depth was 3.33 meters in 1995 and dropped to 0.94 meters in 2004. The decrease in the channel depth is due to sedimentation. Concurrent with the sedimentation, the composition of the bed substrate changed from 1994 to 2004. In 1995 the composition of the substrate on the right side and in the middle of the river was sand and in 2004, the substrate on the right side and in mid-channel was gravel, and the left side was sand. The sand content of the bed sediments decreased by 2.3 percent, and the silt fraction increased by 14.3 percent. Simultaneous with the modifications in Transect G2 is the removal of a stand of wild-rice in the middle of the river as the newly shallow areas filled in with gravel.

Figure 14. Map of Transect G2 Wild-rice.

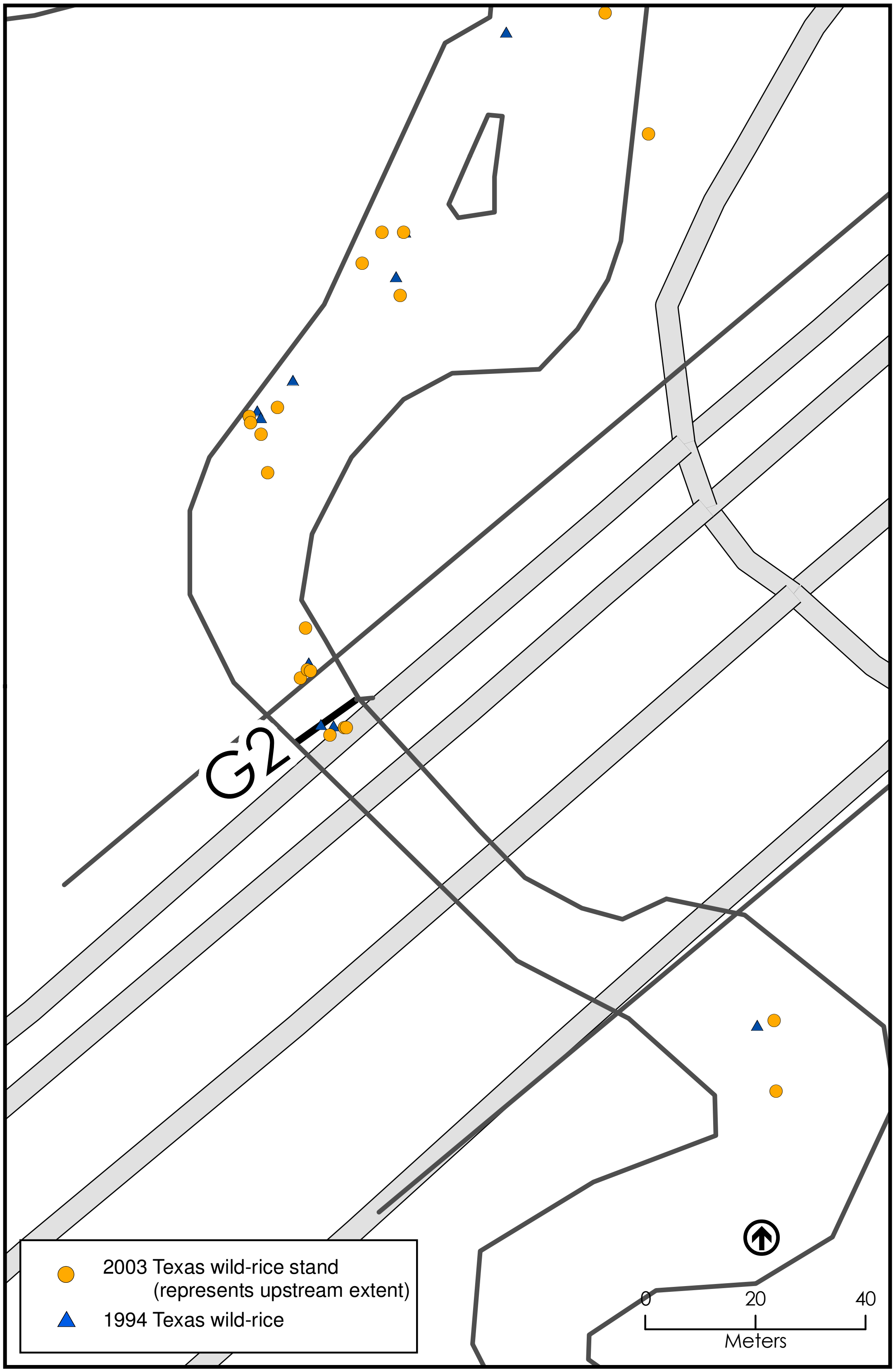
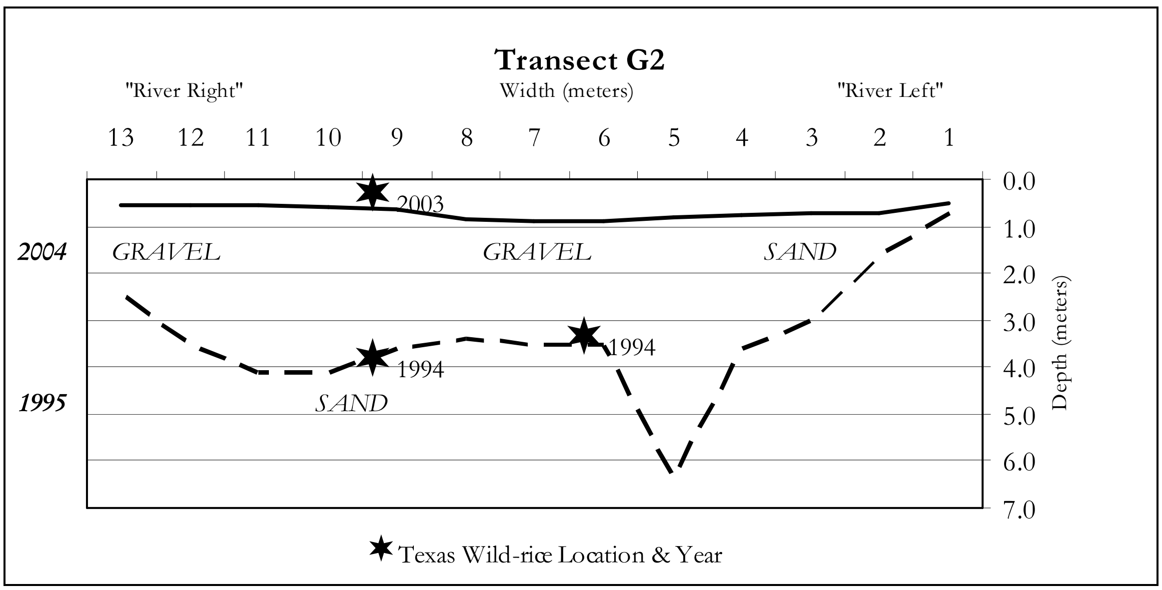


Figure 15. Transect G2.



Transect I4

Transect I4 is located in the San Marcos River directly above Cape Road near Thompson's Island. There has been an overall decrease in channel depth at this location between 1995 and 2004. The mean depth was 0.98 meters in 1995 and dropped to 0.68 meters in 2004. The decrease in depth was due to sedimentation. Concurrent with the sedimentation, the composition of the bed substrate changed from 1995 to 2004. In 1995 the composition of the substrate in the mid-channel near the wild-rice stand was sand and in 2004, the substrate was gravel and sand on the right side, mid-channel was gravel and sand, and the left side was gravel. The sand content of the bed sediments increased by 20.9 percent, and the silt fraction decreased by 4.9 percent. Simultaneous with these modifications in Transect I4 is the loss of the stand of wild-rice as the area filled in with gravel and sand. In 1994 a stand of wild-rice was located in the mid-channel and by 2004, no stands of wild-rice were in the immediate area of Transect I4.

Figure 16. Map of Transects I4 - K10a Wild-rice.

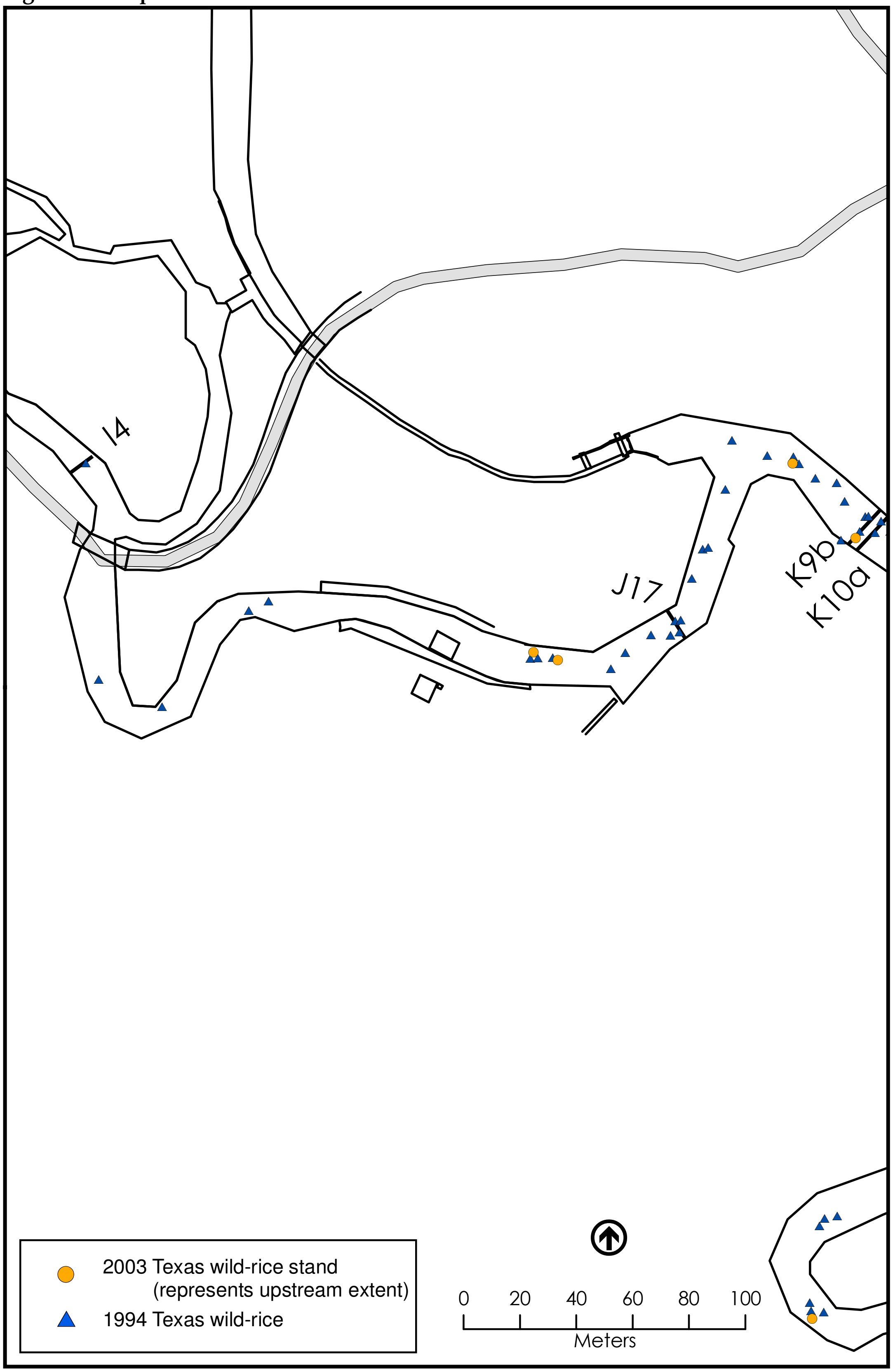
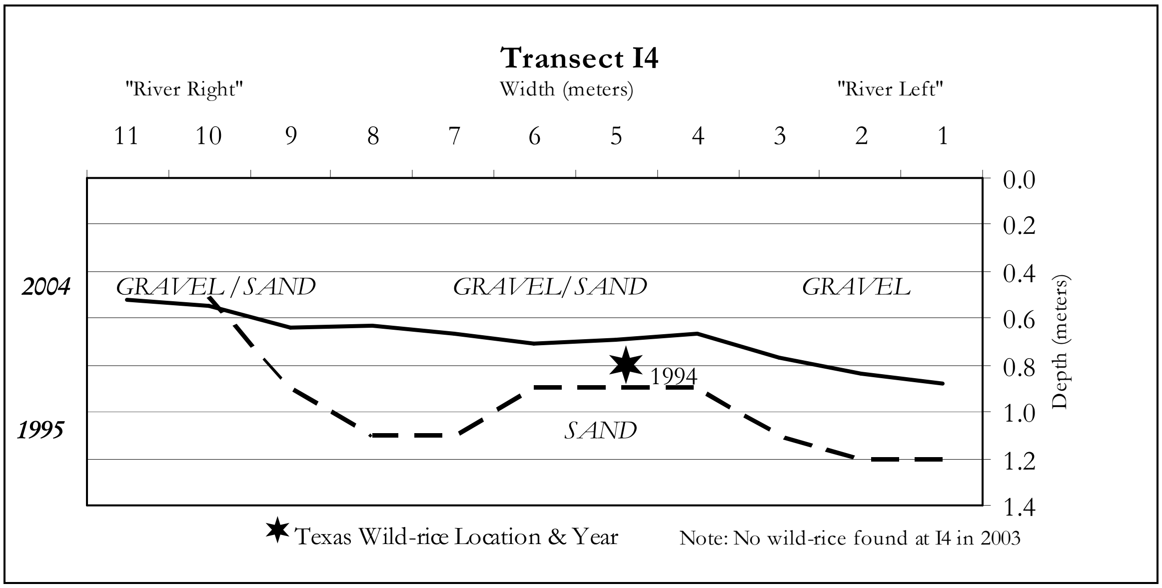


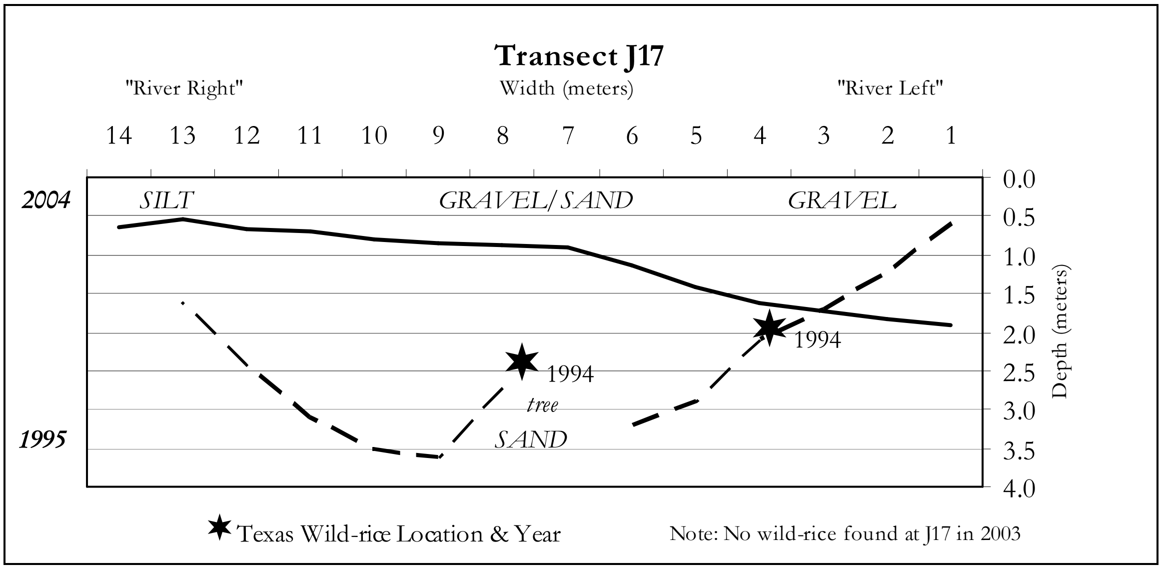
Figure 17. Transect I4.



Transect J17

Transect J17 is located in the San Marcos River adjacent to Thompson's Island below the State Fish Hatchery and above the dam at Thompson's Island. There has been an overall decrease in channel depth at this transect between 1995 and 2004. The mean depth was 2.38 meters in 1995 and dropped to 0.99 meters in 2004. The decrease in the channel depth is due to sedimentation. Concurrent with the sedimentation, the composition of the bed substrate changed from 1995 to 2004. In 1995 the composition of the substrate mid-channel near a wild-rice stand was sand and in 2004, the substrate was silt on the right, mid-channel was gravel and sand, and the left side was gravel. The sand content of the bed sediments decreased by 6 percent, and the silt fraction increased by 16 percent. Simultaneous with these modifications in Transect J17 is the loss of wild-rice stands. In 1994 a stand of wild rice was located in mid-channel and on the left side of the river. In 2003 no wild-rice stands were located on or near this transect.

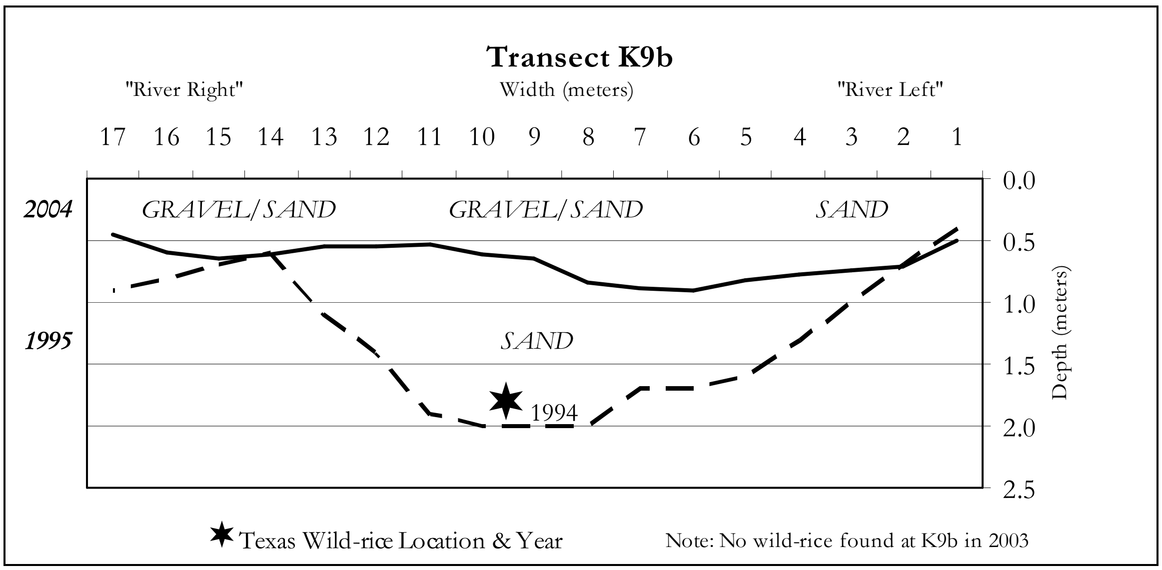
Figure 18. Transect J17.



Transect K9b

Transect K9b is located in the San Marcos River below the State Fish Hatchery and below the dam at Thompson's Island. There has been an overall decrease in channel depth at this transect between 1995 and 2004. The mean depth was 1.28 meters in 1995 and dropped to 0.67 meters in 2004. Mid-channel depth decreased by approximately 1 meter. The decrease in channel depth is due to sedimentation. Concurrent with the sedimentation, the composition of the bed substrate changed from 1995 to 2004. In 1995 the composition of the substrate in mid-channel near a wild-rice stand was sand and in 2004, the substrate was gravel and sand on the right side, mid-channel was gravel and sand, and the left side was sand. The sand content of the bed sediments increased by 0.9 percent, and the silt fraction increased by 11.1 percent. Simultaneous with these modifications in Transect K9b is a change in the location and size of the stand of wild-rice from 1995 to 2004. The stand had moved slightly towards river right by 2004 and the size of the stand had decreased.

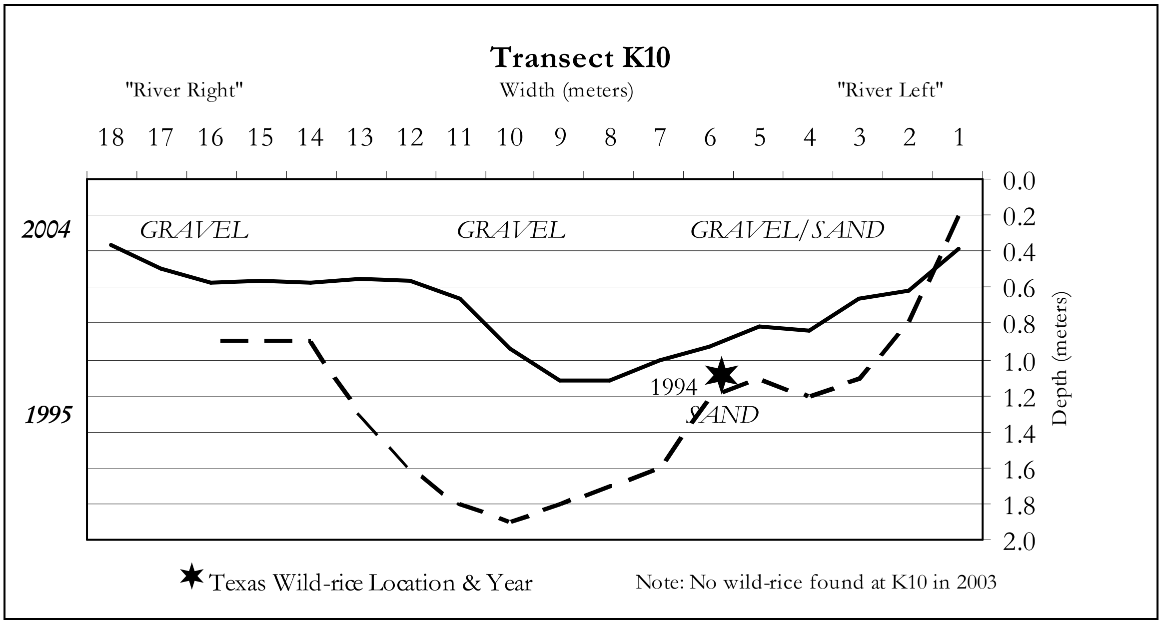
Figure 19. Transect K9b.



<u>Transect K10</u>

Transect K10 is located in the San Marcos River below the State Fish Hatchery and below the dam at Thompson's Island. There has been an overall decrease in channel depth at this transect between 1995 and 2004. The mean depth was 1.25 meters in 1995 and dropped to 0.71 meters in 2004. The mid-channel depth changed approximately 0.5 meters between 1995 and 2004. The decrease in channel depth is due to sedimentation. Concurrent with the sedimentation, the composition of the bed substrate changed from 1995 to 2004. In 1995 the composition of the substrate on the left side was sand and in 2004, the substrate was gravel and sand on the left side, mid-channel was gravel, and the right side was gravel. The sand content of the bed sediments increased by 11.9 percent, and the silt fraction increased by 3.1 percent. Simultaneous with these modifications in Transect K10 is the loss of Texas wild-rice stands. In 1994, two stands of wild-rice were located along Transect K10 and one stand was located immediately downstream of the Transect. In 2004, the stands of wild-rice did not exist due to being removed by scouring.

Figure 20. Transect K10.



Transect L1

Transect L1 is located in the San Marcos River downstream of the State Fish Hatchery and below the dam at Thompson's Island. There has been an overall decrease in channel depth at this transect between 1995 and 2004. The mean depth was 2.53 meters in 1995 and dropped to 1.25 meters in 2004. The right side of the river changed approximately 2.5 meters. The decrease in channel depth is due to sedimentation. Concurrent with the sedimentation, the composition of the bed substrate changed from 1995 to 2004. In 1995 the composition of the substrate in mid-channel near the wild-rice stand was sand, and in 2004, the substrate was gravel and sand on the right side of the river, gravel and sand at the mid-channel, and the left side of the river was gravel and sand. The sand content of the bed sediments increased by 6.5 percent, and the silt fraction increased by 7.5 percent. Simultaneous with these modifications in Transect L1 is the removal of Texas wild-rice stands. In 1994 a stand of wild-rice was located mid-channel and in 2004 no wild-rice stands were located in this area of the river.

Figure 21. Map of Transect L1 Wild-rice.

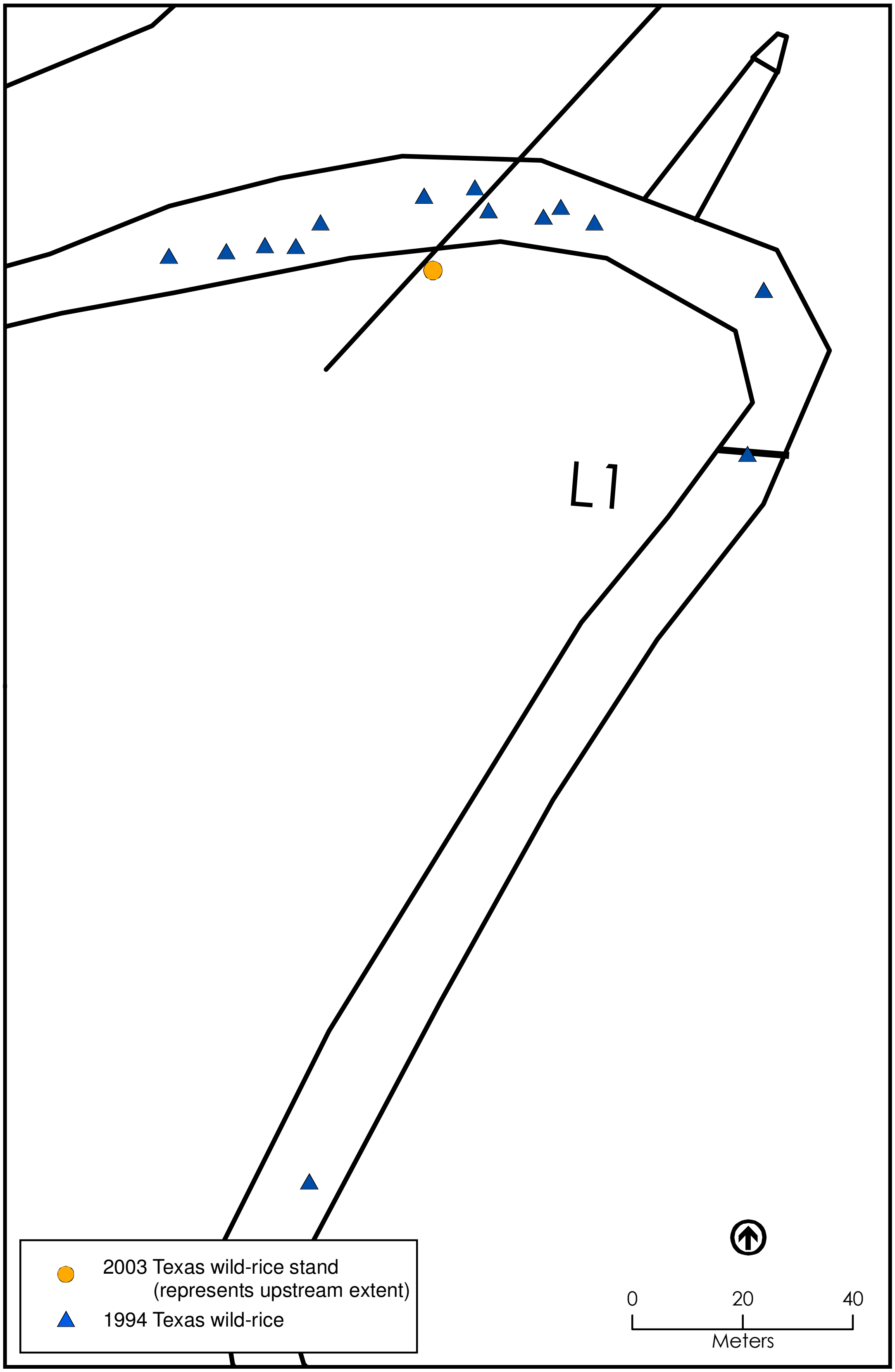
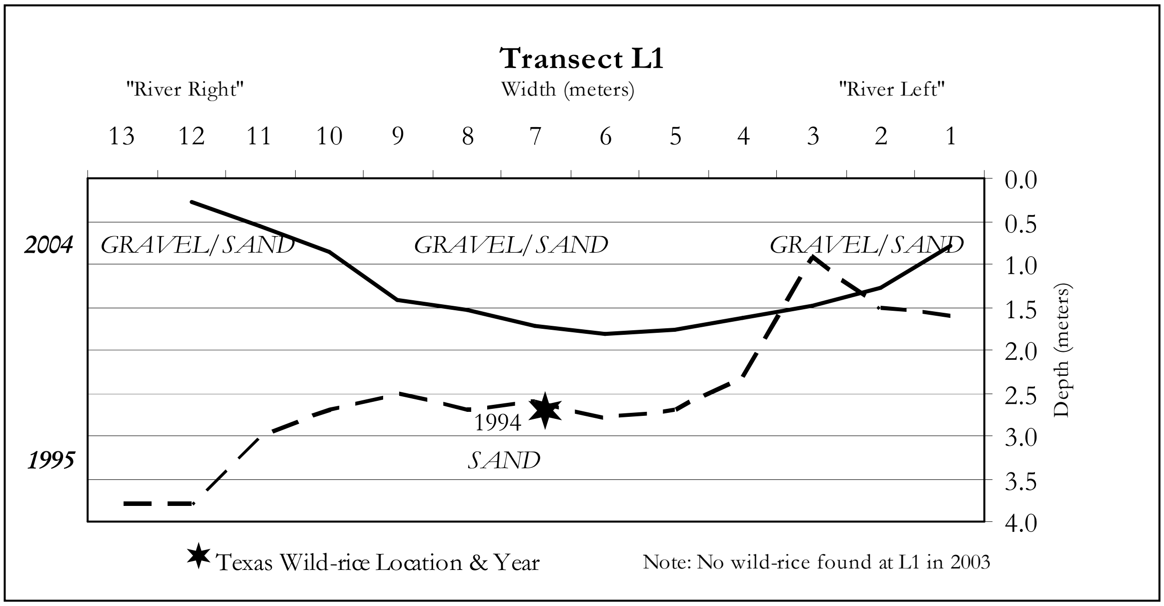


Figure 22. Transect L1.



CHAPTER III

ANALYSIS OF RESULTS

The data gathered along the transects demonstrate changes in channel morphology, location of Texas wild-rice, and the extent of Texas wild-rice. The comparison of data from 1995 and 2004 illustrate changes in the bed sediment thickness, changes in channel shape, and dramatic shifts in both the spatial distribution and total areal coverage of the Texas wild-rice in the San Marcos River. The results are summarized in Table 1.

Transect ID	2004 average depth (m)	1995 average depth (m)	Amount of aggradation (m)	Texas Wild-Rice	Substrate 1995	Substrate 2004	% sand change	% silt change	1994 Texas Wild-Rice Observation	2004 Texas Wild-Rice Observation
100	0.92	2.2	1.279	Increase	sand	sand	28.8	-13.5	none	2 new stands
B11	0.97	3.19	2.224	Increase	sand/silt	gravel/sand	22.4	1.6	2 stands	continuous patch over half of channel
B11j	1.14	3.15	2.01	Decrease	sand	sand/silt	-19.2	31.2	1 stand on right; patch on left was $12m^2$	no stand on right; patch on left now $2.5m^2$
B28	0.84	1.95	1.113	Increase	sand/silt	gravel/sand	15.2	12.8	1 stand at mid-channel	4 new stands in mid-channel
B7e	0.97	2.26	1.289	Increase	sand	sand/silt	-4.2	18.2	2 stands	continuous patch over half of channel
B8a	0.94	2.64	1.703	Increase	sand	sand	4.5	12.5	2 stands	continuous patch over half of channel
B8f	0.90	2.77	1.875	Increase	sand	sand	-0.7	18.7	1 stand at mid-channel; continuous patch over half channel	stands have mergerd and continuous patch expanded
E8a	0.73	1.64	0.908	Increase	sand/silt	gravel/sand	-0.1	17.1	1 stand on left	1 stand removed, 4 new stands at mid-channel
G2	0.94	3.33	2.387	Decrease	sand	gravel	-2.3	14.3	1 stand at mid-channel	no stands
I4	0.63	0.98	0.349	Decrease	sand	gravel/sand	20.9	-4.9	1 stand at mid-channel	no stands
J17	0.92	2.38	1.459	Decrease	sand	gravel/sand	-6	16	1 stand at mid-channel; 1 stand on left	no stands
K10	0.67	1.25	0.577	Decrease	sand	gravel/sand	11.9	3.1	3 stands on right	no stands
K9b	0.63	1.28	0.648	Decrease	sand	gravel/sand	0.9	11.1	1 stand at mid-channel	no stands
L1	1.16	2.53	1.37	Decrease	sand	gravel/sand	6.5	7.5	1 stand at mid-channel	no stands

Table 1. Transect Summary.

A total of seven transects experienced an increase of Texas wild-rice; three of the transects have new stands of wild-rice and four transects show wild-rice stands have increased in areal extent. The other seven transects experienced a loss of wild-rice between 1995 and 2004. However, estimates from Texas Parks and Wildlife Department show an increase from 1,624 square meters to 3,390 square meters (17,480 square feet to 36, 489 square feet) between 1995 and 2004 with the only decrease occurring from 1998 to 1999 (US Fish and Wildlife Service 2005). The spatial distribution of Texas wild-rice has noticeably changed between 1995 and 2004 and the data taken at the transects demonstrate the locations where Texas wild-rice areal coverage has increased. Table 1 displays the increase or decrease in Texas wild-rice at the transects.

In 1995, more individual stands of wild-rice were documented in the channel and Texas wild-rice was found in all transects. Although the number of individual stands present in the channel decreased by 2004, the area covered by Texas wild-rice increased. At four of the cross-sections (B7e, B8a, B11, B8f), stands of wild-rice merged to form continuous wild-rice patches within the channel from which the number of individual stands could not be counted. The increase in channel coverage that accompanied development of a continuous patch of plants is responsible for the overall increase in areal extent measured by Texas Parks and Wildlife Department. The formation of patches further indicates an increase in optimal habitat that is occurring at specific river locations.

Seven transects experienced a decline of Texas wild-rice and in six of these transects the entire areal coverage of wild-rice that was present in 1995 was gone in 2004. These transects are located in the downstream portion of the study reach and almost all are downstream of Sewell Park (Figure 3).

Changes in channel morphology are evident at every transect cross-section. Extensive aggradation is measured all along the river. This aggradation is responsible for a reduction in the diversity of bed morphology, as the cross-sections illustrate a pattern where sediment has filled in any depth features on the channel bed. By 2004, the majority of the cross-sections show a river with a flat bed. Average channel depth decreased by anywhere from 0.35 meters to 2.39 meters (1.15 feet to 7.84 feet). Bed aggradation averaged slightly greater where the areal coverage of Texas wild-rice increased than where it decreased. Accompanying aggradation was a change in bed composition at many of the cross-sections. Data taken in 1995 included information on only the fines fraction of bed sediment. Samples were divided into their clay, silt, and sand fractions and no data were reported on the amount of gravel in the bed. Only the fines fractions from 2004 are, therefore, used for comparison to 1995. Differences are quantified for the percent of total fines that are sand size and silt size, but no conclusions can be made about changes in the overall bed grain-size distribution. Despite these limitations, the data illustrate dramatic shifts in the proportion of the fines fraction that is sand and silt between 1995 and 2004. The percent of sand in the fines fraction increased on average 9.4% for those transects with an increase in Texas wild-rice. The same fraction increased only 1.8% at transects that experienced a decrease in wild-rice. An opposite trend is shown in the percent silt content of the fines. For those transects increasing in Texas wild-rice areal coverage the percent silt increased by 9.6% on average while at transects that lost wild-rice the increase averaged 11.2%. A more dramatic change is measured for the areas within the cross-sections where the wild-rice expanded. There is an increase in percent sand of 23% on average for those areas where new stands or patches of wild-rice were observed. The increase in percent sand occurs as the percents of silt and clay decrease in the same locations.

The fines fraction is only part of the sediment in the river, and gravels are a significant portion of the river substrate. During the 2004 field survey, the percent volume of gravel for each substrate sample was measured at each transect. These measurements document a distinct difference in the substrate where wild-rice is found and where it is absent. Those cross-sections experiencing an increase in wild-rice coverage have a bed substrate that averages 73% gravel. This is contrasted to only 58% gravel substrate composition on average where wild-rice is no longer present. Personal observation of the river substrate since the 1998 flood provides further information on the change in the gravel portion of the substrate. In the upper reaches of the San Marcos River, where the areal coverage of wild-rice has increased, the gravels are predominantly fine to medium size clasts. Further downstream in the river, corresponding to areas now void of wild-rice, the gravels are larger and often cobble size. Not only has the amount of gravel in the bed substrate changed, but also the size distribution of the gravel.

CHAPTER IV

DISCUSSION

Texas wild-rice has experienced a substantial increase in its total areal coverage despite being eradicated from several habitats in the lower portion of the upper San Marcos River, including half the study transects. Where wild-rice was present at transects taken in 1995 in the Sewell Park area, the wild-rice has increased in number and size of stands to form significant contiguous vegetated patches. Wild-rice has established further upstream, into the area downstream Spring Lake. Previous to 1998, very few stands of Texas wild-rice existed in this section of the San Marcos River and no stands of wild-rice were in the proximity of Transect 100. Texas wild-rice has extended habitat where sedimentation has filled in portions of the river that were previously too deep for wild-rice growth. Conversely, wild-rice habitat has only expanded into the recently shallow portions of the river in the upper portion of the study area. This selective increase in wild-rice stand growth corresponds to the region of the river where bed aggradation occurred with an influx sediments of predominately coarse sands and small to medium sized gravels.

The 1998 flood impacted Texas wild-rice habitat throughout the upper San Marcos River. In the lower portion of the Upper San Marcos River below City Park, many of the wild-rice stands were removed by the scouring action of the flood. The wild-rice stand at Transect K9b remained, however the location of the stand moved and decreased in size after the 1998 flood. Transect E8 lost one wild-rice stand on the left side of the channel; however four new stands established in the middle of the channel. Since the 1998 flood, the wild-rice has not re-established at any of the downstream transects where it was previously located. The decrease in average channel depth is not significantly different at these transect cross-sections from that measured for the upper part of the study reach, but the sediment causing channel aggradation has a silt content that is an order of magnitude greater than in the upper study reach. The high proportion of sedimentation by silt has created a substrate where silt dominates the fine sediment content. Those transects where silt has accounted for the majority of channel aggradation are also those where wild-rice has not been able to re-establish. In addition to the increase in silts in the fine sediments, the characterization of the sediment in the downstream part of the study reach has changed from predominately sand in 1995 to a sediment composed of principally gravel or gravel and sand sediments. The inability of wild-rice to re-establish at these locations re-affirms Texas wild-rice's habitat preference for sand and fine gravel substrate. Thus, there exists a potential threat to wild-rice survival from continued siltation of the channel bed if flushing flows do not transport the accumulated silt from the channel. This pattern also indicates a threat to wild-rice by the aggradation of large gravels if future flood flows do not transport the gravels or if additional gravel sediments are introduced to the river from anthropogenic sources.

CHAPTER V

CONCLUSIONS

The extreme magnitude of the 1998 flood led to both scouring of numerous stands of wild-rice and channel bed aggradation. Flood waters are beneficial in the San Marcos River when they remove fines that have built up in the channel, wash dead vegetation from the river, and provide nutrients to the river from erosion of bank sediment (Longley, 1975; Powers, 1996). It is reasonable to assume that overland flows contributed to channel bed aggradation slowly over the years, but this is likely a minor rate of aggradation when compared to the potential contributions associated with the 1998 flood. Mass wasting was observed immediately after the 1998 flood water receded, indicating that the wasting occurred on the falling limb of the flood hydrograph (Personal observation). Observations indicate a large number of sediment slumps along the river banks. Mass wasting of the channel banks is the likely source for the sand in the upper portion of the study reach and the silt in the lower part of the study reach. Mass wasting was diminished in the upper portion of the study reach due to channel stabilization and concreted walls in

Sewell Park. Sediment in the upper study area derives from Sink Creek, Sessoms Creek, and through overland flow. The input of the gravel sediments was from mass wasting, overland flow and anthropogenic sources. The larger sized gravels in the lower portion of the study area are assumed to have originated from construction projects in the upstream watershed of Sessoms Creek. The change in the substrate in the Upper San Marcos River from silt and clays to sandy gravels increased the available habitat for Texas wild-rice as the channel aggraded. However, in the lower portion of the study area, the sand and sand silt substrate shifted to a predominately gravel substrate through channel aggradation after the 1998 flood. The channel aggradation and the associated scour from the flood removed Texas wild-rice plants and diminished the available wild-rice habitat. Determining the origin of the gravel and other sediments input to the San Marcos River is not possible in this study and the need exists for further study to measure sediment inputs from the various sources and to measure the rates of ongoing channel bed aggradation.

Five flood detention dams have been built on tributary creeks draining into the San Marcos River in order to decrease the severity of flooding in the watershed and to increase the recharge into the Edwards Aquifer. These dams have altered the frequency and the magnitude of flood cycles. By reducing the frequency with which higher flows occur in the San Marcos River, the ability of the river to flush out the accumulated bed sediment is reduced. A flushing flow would scour the accumulations of silts and clays from the river and leave behind the larger size sediments, such as sands and gravels. These flushing flows could benefit the lower portion of the study area by removing excess silts and depositing sands in the gravel substrate, thus creating suitable habitat for restoration of Texas wild-rice.

The San Marcos River is unique because of its combination of habitats, which is due in part to the flow regime of the river. A decrease in the frequency of river bed scour from flooding can have a lasting impact on the channel bed substrate and thus the habitats in the system.

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