Analysis of Instream Flows for the Lower Brazos River - Hydrology, Hydraulics, and Fish Habitat Utilization

Final Report

Volume I – Main Report

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Executive Summary

This report addresses the impact of the proposed Allens Creek Reservoir project on the hydrology and aquatic habitat in the lower Brazos River, and on the migration of saline water in the Brazos River estuary. Regional characteristics of the lower Brazos River basin are presented along with historical stream flow records that are analyzed for changes in flow regime over time. A preliminary investigation of the impact of the Allens Creek project on sediment transport is also included.

Recent and historical studies of the fisheries of the lower Brazos River are reviewed and discussed. Three different analyses are presented that investigate the distribution of fish species within aquatic habitats in the Brazos River near the Allens Creek project site. Each analysis uses the same fish collection data set. Two analyses are based on visually classified mesohabitats, and one of those two analyses further analyzes the dataset based upon shallow and deep habitats. The third analysis is based upon hydraulically defined mesohabitat and spatially defined specialized habitats. The results obtained from the three methods were different: two indicated fish communities were made up of habitat generalists, and one analysis indicated some degree of habitat specialization. Additional field sampling and analysis is recommended prior to utilizing these results for permitting decisions.

A spatial habitat model capable of mapping hydraulic mesohabitats and specialized habitats was developed. A two-dimensional hydraulic model was used to describe hydraulic variation within a 6.9 km study reach of the Brazos River located near the Allens Creek project. The habitat model was applied to depth and velocity data generated by the hydraulic model in order to quantify the area and volume of available habitat for flow rates ranging from 19.82 cms (700 cfs) to 116.1 cms (4,200 cfs). The modeled flow rates represent a range between the 8^{th} percentile and 60^{th} percentile flows occurring in the historical stream flow record.

A three-dimensional hydrodynamic model was developed and calibrated to determine patterns of saline water migration in the Brazos River estuary. Four theoretical case studies were executed; the case studies showed that under natural conditions saline waters intrude upstream from the Gulf of Mexico as far as the town of Brazoria, TX. The calibrated model can be used for future studies.

This report describes preliminary and necessary steps required to complete a full instream flow study. Conclusions based on the Brazos River studies are discussed and recommendations are provided for design and implementation of future studies that will establish flow regime recommendations for maintenance of instream flows. Legislative directives in Senate Bill 2 and financial support from the Corps of Engineers were both instrumental in bringing the three natural resource agencies together to agree on a scientifically defendable methodology for this and future studies.

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1. Introduction

The Allens Creek reservoir project is proposed to help the Houston, Texas, area and adjacent coastal basin areas to meet long-term water usage demands projected by the Region H Water Planning Group. The project is an off-channel reservoir that will impound Allens Creek, a small Brazos River tributary and is one of three reservoirs recommended by Region H in the 2002 State Water Plan, including the Bedias and the Little River Reservoirs. This report addresses potential impacts of the proposed Allens Creek reservoir on instream aquatic habitat in the Brazos River downstream of the project and on estuarine salinity migration in the Brazos River estuary.

The Allens Creek project is located near the town of Simonton, Texas, approximately 40 miles west of the center of Houston and 60 miles northwest of the Gulf Coast near Freeport, Texas. On January 16, 2002, the Texas Commission on Environmental Quality (TCEQ) granted Permit No. 2925A specifying a water right priority date of September 1, 1999 (see Appendix A). The permittees are the Texas Water Development Board, the City of Houston, TX, and the Brazos River Authority. The permit specifies that the volume of the authorized impoundment is not to exceed a storage volume of 179.5 million cubic meters (145,533 acre-feet) at normal operating capacity, at a maximum water surface elevation of 36.88 meters (121.0 feet) above mean sea level, resulting in a firm yield of 122.9 million cubic meters (99,650 acre-feet) per year. Construction of the dam is required to commence no later than September 1, 2018 and be completed within three years thereafter.

The Allens Creek watershed area draining directly to the proposed impoundment is small, requiring that storage volume be principally derived by diverting (pumping) water out of the Brazos River. Diversions from the Brazos River are restricted in order to guarantee flow levels for downstream senior water rights, for instream uses, for water quality and for aquatic habitat. The flow restrictions vary monthly and are based upon the river flow measured at the Brazos River Richmond USGS gauge before deducting diversions taken by the project. The maximum combined diversion rate permitted from the Brazos River is 62.3 cubic meters per second (cms) (2,200 cubic feet per second; cfs) and in no event shall diversions be allowed to reduce the Brazos River flow below the Water Quality Protection Flow level of 20.8 cms (734 cfs). The total annual diversion volume is restricted by the permit not to exceed 249.2 million cubic meters (202,000 acre-feet).

Additionally, one of the Special Conditions included in the permit reads as follows:

> *"The owners, in cooperation with the Executive Director [TCEQ], and TPWD [Texas Parks and Wildlife Department], shall undertake a site specific study of instream flow requirements of the Brazos River below the authorized points of diversion. Following completion of the study, either the Permittees, TPWD, or the Executive Director may file an application to amend this amended permit to implement streamflow diversion restrictions based upon the results of the study. Modification of*

streamflow diversion restrictions in that amendment ***may not increase or decrease the firm yield of the project authorized under this permit in paragraph 2(a) by more than 6.4%****."*

The firm yield of this reservoir can be altered by a number of changes, including a change in the permitted maximum rate of diversion from the Brazos River and a change in the timing of diversions. Changes to either of these aspects have the potential to affect fish and aquatic communities; however, the degree of impact is not well known. An additional concern for downstream water rights holders is the impact this project will have on salt water migration in the Brazos River estuary that extends from the Gulf of Mexico, near Freeport, Texas, upstream nearly 42 river kilometers (26 miles) to Brazoria, Texas.

This study, partially funded by the US Army Corps of Engineers, Fort Worth District, (USACE), evaluates the instream fish habitat utilization aspect of aquatic habitat for areas located downstream of the proposed diversion point. This study also evaluates saltwater migration in the Brazos River estuary. The data, modeling, methodology and analysis presented in this report are intended to serve as tools for future assessments of the impact of the Allens Creek project, as well as to aid in the design of upcoming studies that will make specific flow recommendations affecting the permitted firm yield of the project.

A healthy aquatic system includes far more features of biological interest than fish; however, because of the complexity of riverine ecology and the data collection effort that would be required, very few instream flow studies have considered all biological aspects of a river. Fish community health is a good indicator of overall ecosystem health because fish communities integrate properties of the entire watershed (see Appendix N). Fish are relatively long-lived, widespread and easy to identify; they live in a variety of habitats and occupy a range of trophic levels (Perry and Vanderklein, 1996). The study performed and described within this report uses fish habitat utilization as basis for aquatic habitat evaluation.

To evaluate utilization of instream (in-channel) habitats, Texas A&M University (TAMU) was commissioned to perform a one-year fish collection study to characterize the fish communities and their utilization of available habitat on a representative reach of the Brazos River downstream of the Allens Creek project. The collection periods targeted median, 30th percentile and 15th percentile flow events occurring both in the summer and winter seasons. Environmental and hydraulic parameters were collected with each fish collection sample.

Three separate analyses have been performed on the fisheries dataset collected during this study. Gelwick and Li (2002) analyzed fish habitat utilization on the basis of visually delineated mesohabitats (Appendix P). Raymond Li (Li 2003) using a subset of the Gelwick and Li (2002) dataset, similarly analyzed fish habitat utilization on the basis of visually delineated habitats, but separated shallow and deep habitat samples to show the statistical significance of environmental conditions and fish assemblage structure (Appendix Q). Using the Li (2003) data set the Texas Water Development Board (TWDB) presents in this report a third analysis that characterizes fish habitat utilization on the basis of (1) hydraulic mesohabitats and (2) specialized habitats. The results of the three different analyses are compared and strategies for future sampling and analysis are recommended.

To augment the TWDB fish habitat utilization analysis, a spatial GIS model was used to determine areas of hydraulic mesohabitat and specialized habitat available for a series of flow conditions between the 60th percentile and the 10th percentile. A depth-averaged, two-dimensional, hydrodynamic model executed with field-verified, steady state, boundary conditions was used to generate high-spatial-resolution velocity and depth data. New tools to aid in the identification of submerged large woody debris (LWD) were developed for this study in cooperation with University of Texas Center for Research in Water Resources (UT-CRWR) and are described in White et al. (2004). New tools were also developed by both TWDB and UT-CRWR to improve spatial interpolation techniques (Osting 2004, Merwade and Maidment 2003) and by UT-CRWR to integrate observed mesohabitats into a spatially quantitative GIS environment more efficiently (Merwade et al. 2004, Merwade and Maidment 2001).

To determine the extent of salinity migration from the Gulf of Mexico upstream through the Brazos River estuary, additional hydrodynamic modeling was performed. A three-dimensional hydrodynamic model calibrated to field-verified conditions was employed to simulate the distance the salt wedge travels under the influence of tidal forces for a series of river inflow cases.

The CD-ROM provided with this report contains all of the report data including: fish collection data, hydraulic model output, spatial GIS model output and supporting reports, as well as theses and journal articles describing research that has been conducted in support of this study. Most of the data is currently available online and accessible from TWDB's Instream Flow webpage at http:/www.twdb.state.tx.us/InstreamFlows/. The remainder of the data will be made available online.

In the three years since initiation of this Allens Creek Reservoir study, two major developments have occurred to influence the scope and direction of the study. A Memorandum of Agreement between the Allens Creek permittees and TPWD was signed to promote the cooperation of all parties, including TCEQ, involved in the instream flow evaluation for the Allens Creek project and subsequent permit amendment process. In addition, the passage of Texas legislation, Senate Bill 2 (SB2), in 2001 required formal cooperation of the three Texas water agencies, TCEQ, TPWD, and TWDB, on all future instream flow evaluations statewide, including the Allens Creek project. SB2 and the resulting inter-agency agreements led to a consensus approach for conducting studies. Additional descriptive information is provided in the following sections.

The consequence of these recent agreements and legislation will be future performance of an integrated, regional instream flow study of the lower Brazos River that allows consideration of all proposed project scenarios, including the Allens Creek project. The data, methods and analyses presented in this report will be used as a basis for future studies in this region that are anticipated to include specific recommendations for maintenance of instream habitat, as well as considerations for riparian and estuarine needs. The specific makeup of the future study is partially dependant upon the National Academy of Science's (NAS) review of the proposed inter-agency instream flow methodology. The NAS review and recommendations are due for publication in October 2004.

1.1 Memorandum of Agreement for Allens Creek project

A Memorandum of Agreement (MOA), dated November 14, 2001,between the Brazos River Authority (BRA), the City of Houston, the TWDB, and the TPWD exists "*for the purpose of developing a habitat assessment and mitigation plan and an Instream Flow study for the Allens Creek Reservoir project*". A copy of this MOA is attached to this report and labeled as Appendix B. The overall goal of the project as described by the MOA is to effectively determine the instream flows necessary to maintain the health of the aquatic system in both the Brazos River and Allens Creek. An additional goal of the MOA is to provide recommendations that mitigate adverse impacts of the Allens Creek project to terrestrial, wetland and aquatic habitats.

This report is a part of the study required by the MOA that provides tools to assist planners to determine the instream flow requirements of the Brazos River downstream of Allens Creek. The instream habitat of Allens Creek is not considered in this report because very little of the creek located downstream of the project will remain un-inundated. A separate study will be conducted to address impacts of the project on upstream areas of the creek and to address alternatives for mitigation of inundated natural areas.

The riparian aspect of aquatic ecosystem health is being addressed by Texas A&M University, which has been contracted by TWDB to conduct research to determine the importance of oxbow lakes to the health of the aquatic ecosystem in the Brazos River. The TWDB is providing additional engineering support by conducting topographic surveys to determine flood stage required for river-oxbow connectivity and by conducting isotope analysis to determine sources of water to the oxbows (e.g., runoff, river, hyporheic, etc.). This field data will be used to determine frequency and duration of events that provide connection between the river and flood plain areas. While this research is not complete or further discussed in this report, it is anticipated to give valuable information on the interaction of riparian and riverine ecosystems.

Pursuant to the MOA, a committee has been formed to oversee this project. Members are: Doyle Mosier (TCEQ), Kevin Mayes (TPWD), Barbara Nickerson (Freese and Nichols, Inc. – representing the City of Houston and the BRA) and Barney Austin (TWDB). The intent of the committee is to develop a working relationship between the three state agencies and the primary stakeholders in this project.

1.2 Texas Senate Bill 2

The passage of Texas Senate Bill 2 (SB2) during the 77th regular legislative session in 2001, mandated formal cooperation of the three Texas water agencies, TCEQ, TPWD, and TWDB, on all instream flow evaluations. Senate Bill 2 also required the three agencies to develop a plan to study the ecological needs of all river basins statewide and to identify priority basins for which studies would be completed by the end of 2010.

These legislative requirements resulted in a formal inter-agency Memorandum of Agreement (Appendix I) which had several ramifications. The MOA enabled the dissemination and distribution of instream flow knowledge between agency personnel, promoted cooperation and coordination of instream flow studies (like this Allens Creek study) between agencies and resulted in development of a draft statewide methodology to perform instream flow studies (see Appendix N). A Programmatic Workplan was developed and approved by all three agencies that outlines the general scope of planned instream flow studies as well as the schedule of completion for studies of priority basins (see Appendix J).

The National Academy of Science (NAS) is currently reviewing the draft methodology to perform instream flow studies. The NAS review will accomplish several important objectives. The first is to evaluate the scientific and engineering methods described by the Programmatic Workplan and Draft Techincal Overview documents. In addition, the NAS will review and provide advice on appropriate spatial scales, use of habitat-flow relationships, use of landscape ecology metrics, range of biophysical model parameters used in Texas TMDL program, and applicability of water quality models used in Texas TMDL program. Finally, the NAS will evaluate findings for consistency with the requirements of Texas law. The findings and recommendations of the NAS are anticipated to be published in October of 2004.

2. Regional description

Two sites were selected for the study described in this report. **Site 1** is a 6.9 km (4.3 mile) reach of the Brazos River located near Simonton, TX, adjacent to the proposed Allens Creek Reservoir site (Figure 2.1). **Site 2** is a 42 river km (26 mile) stretch of the Brazos River encompassing the Brazos River estuary that extends from West Columbia, TX, to the river mouth at the Gulf of Mexico (Figure 2.1).

The following sections describe regional-scale characteristics of the Brazos River drainage basin. Figure 2.1 illustrates points of interest on the Brazos River watershed including: the Brazos River and its drainage basin within Texas, Site 1, Site 2, representative weather stations and the US Geological Survey (USGS) Richmond gauging station that was used for this study's hydrologic analysis. Figure 2.1 also illustrates the proposed Allens Creek reservoir location as well as the location and completion date of existing reservoirs in the Brazos River Basin whose original storage capacity is greater than 61.7 million cubic meters (50,000 ac-ft).

2.1 Brazos River

The Brazos River is the largest river basin in the State of Texas with a drainage area in excess of 116,500 square kilometers (45,000 square miles). The Brazos River originates in New Mexico near the Texas border and flows southeast across state of Texas, discharging into the Gulf of Mexico near Freeport, Texas.

Flood control and water supply reservoirs are numerous in Brazos River basin, with three major on-channel dams and several large dams located on major tributaries. Water use and regulation has the potential to alter the flow regime and sediment transport within the river system; however, the flow regime in the lower Brazos River basin has remained similar to the historic flow regime primarily because the nearest on-channel reservoir, Lake Whitney, is located several hundred kilometers upstream (see Hydrology section of this report for further discussion of the effects of development in the Brazos River basin).

In the lower Brazos River basin in the vicinity of the proposed Allens Creek Reservoir, the Brazos River is deeply incised with frequent sand flats dominated by Black willow (*Salix nigra*). The meandering nature of the lower Brazos River has created numerous oxbow lakes that support an abundance of riparian habitat used by a variety of wildlife including numerous waterfowl species. In some localized areas, riparian areas have been altered to provide for channel stability using rock rip-rap or gabions.

The importance of the oxbow lakes to the resident fishery has been examined in the middle and lower basin (Winemiller et al. 2000) and is also the subject of an ongoing study conducted jointly by the TWDB, TAMU, Texas State University (formally Southwest Texas State University SWTSU), with assistance from TPWD and TCEQ. Oxbow lakes, particularly those that are hydrologically connected to the river with sufficient frequency to be utilized as part of the reproductive cycle, may be beneficial to the animal community.

Land resources and geology maps for the Brazos River in Texas are shown in Figures 2.2 and 2.3. The Allens Creek Reservoir project and study Site 1 are located on the Gulf Coastal Plain near the interface between sandy soils located upstream and alluvial, expansive clay soils located downstream. Land use types for the area of the Brazos River around the Allens Creek project is shown in Figure 2.4. Primary land use in the area of the site is agricultural. Site 2 is located near the gulf coast where the Brazos River flows through surface formations of expansive clay and wind blown sands (Figure 2.2). Land cover/land use is mixed with forested areas making up the primary cover in the upper half of the study reach and a mix of range and wetland making up the use near the lower half of Site 2.

Designated instream uses of the Brazos River in the vicinity of the proposed Allens Creek Reservoir and downstream to the Gulf of Mexico include contact recreation, aquatic life, general use, fish consumption, and public water supply. The river has a high turbidity level because of its meandering nature through highly erodeable alluvial soils in the watershed. There are no state parks or wildlife management areas located in the vicinity of the proposed reservoir and steep banks limit access for recreational boating. Brazos Bend State Park, in Fort Bend County is located approximately 80 km (50 miles) downstream of Allens Creek, near Rosharon, TX.

Under certain circumstances (e.g., drought and high tides), saline water from the Gulf of Mexico intrudes more than 42 river kilometers (26 miles) up the Brazos River. This can have a negative impact on industrial users who require diversion water that meets a certain salinity standard. This report includes sections that describe the impact of water diversions at the Allens Creek site on the movement and concentration of salt in the Brazos River estuary (Site 2).

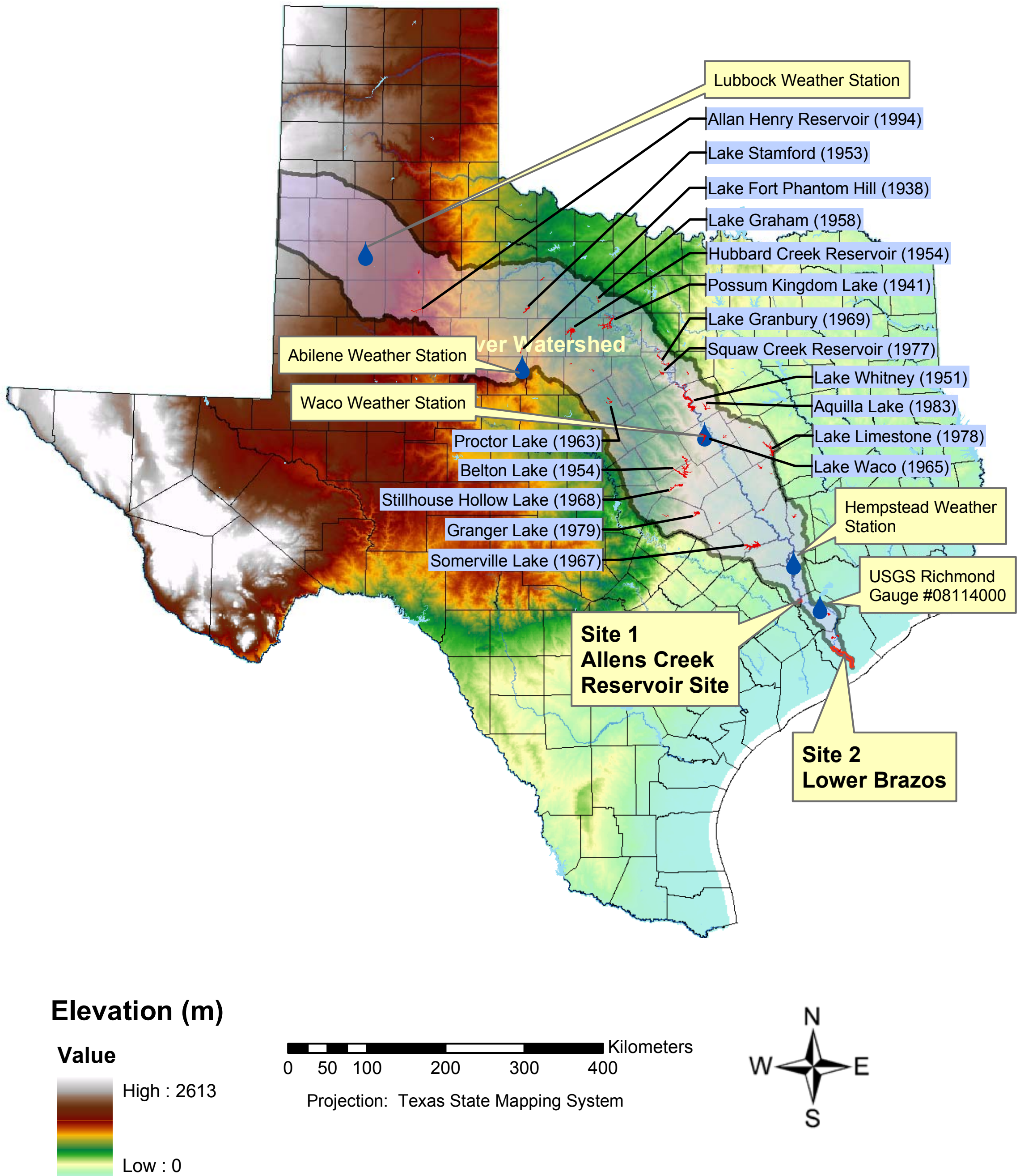

Figure 2.1 - Points of interest on the Brazos River watershed, including all existing reservoirs with storage capacity greater than 61.67 million cubic meters (50,000 ac-ft)

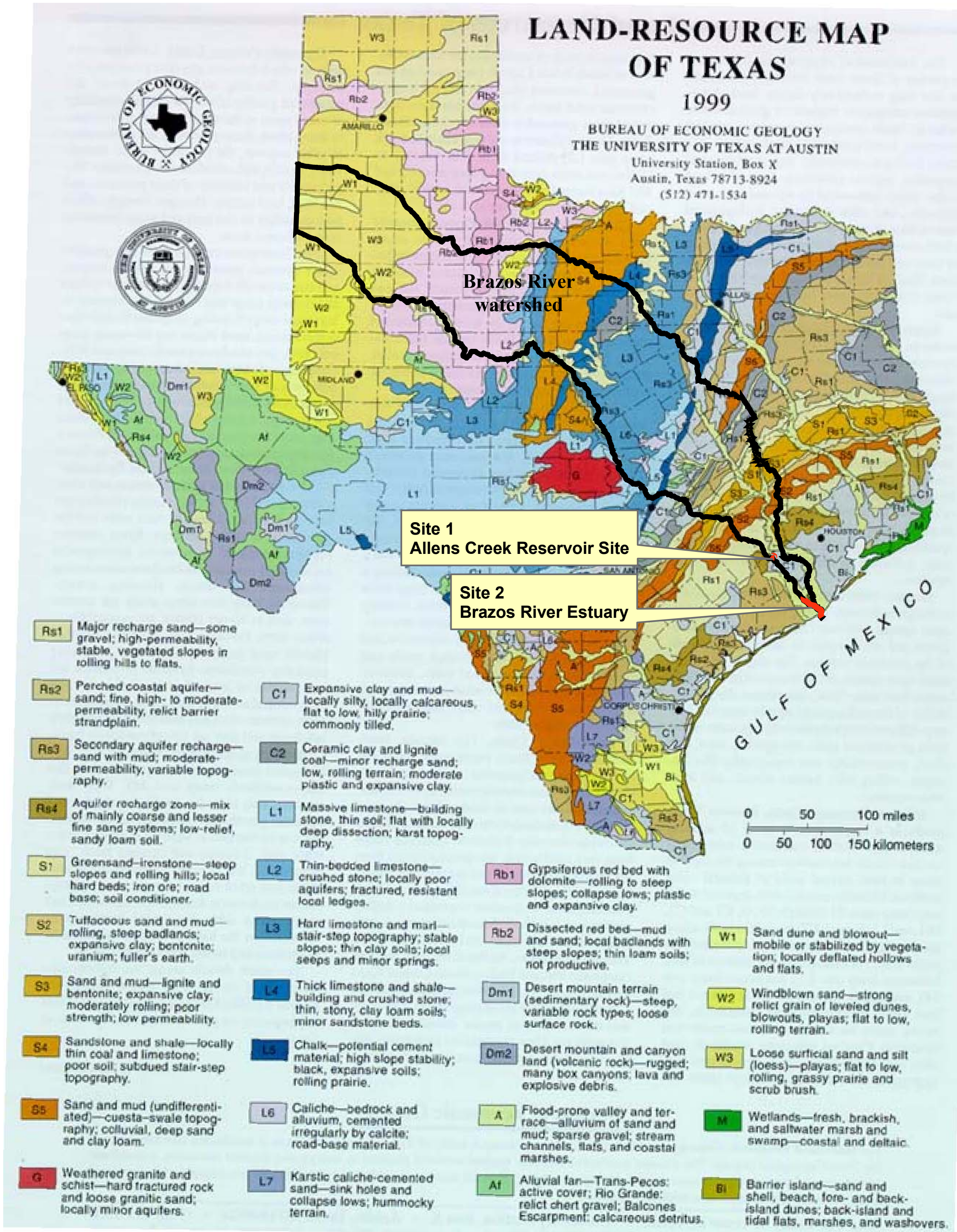

Figure 2.2 – Land resource map of Texas and the Brazos River watershed

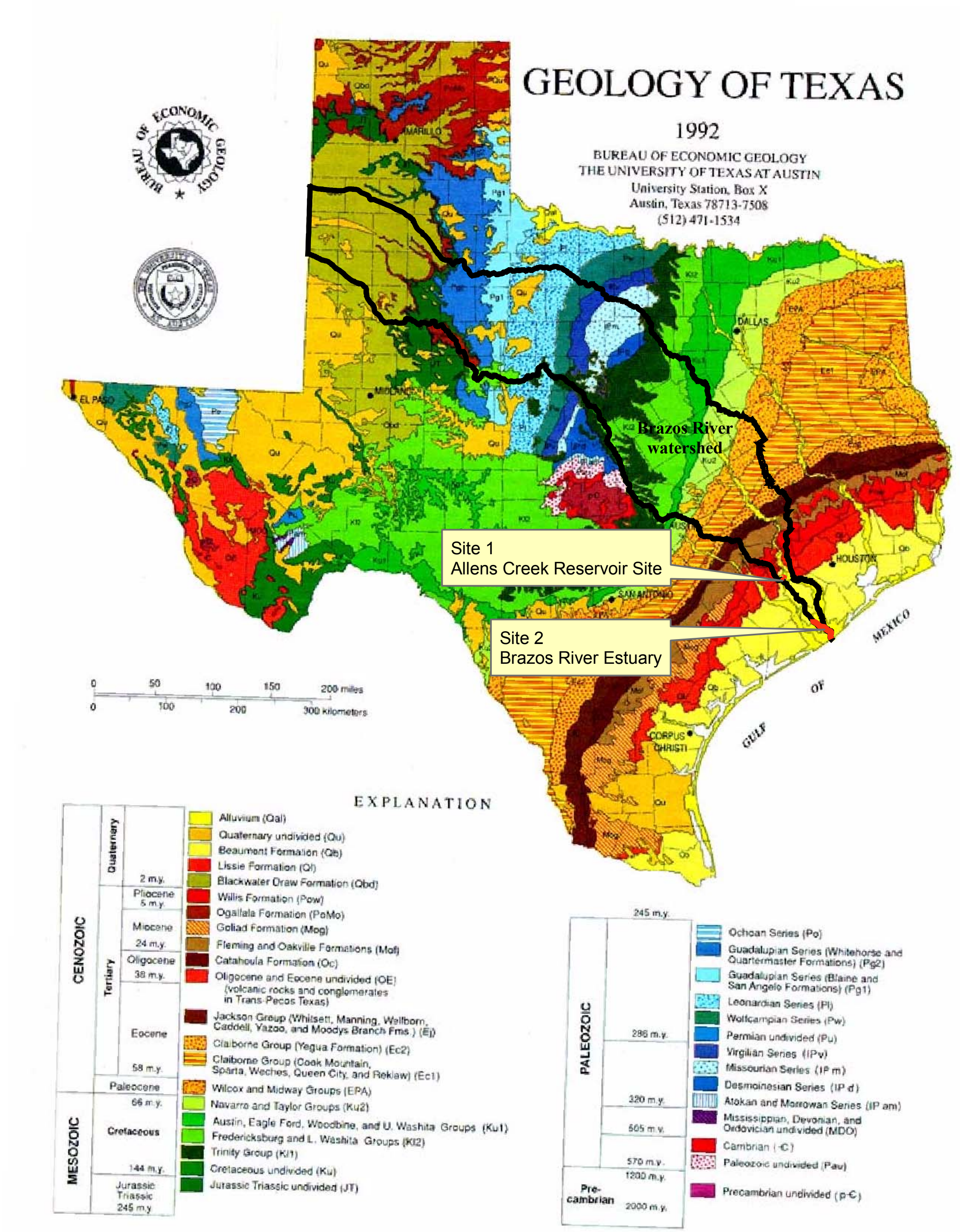

Figure 2.3 – Geological map for Texas and the Brazos River watershed

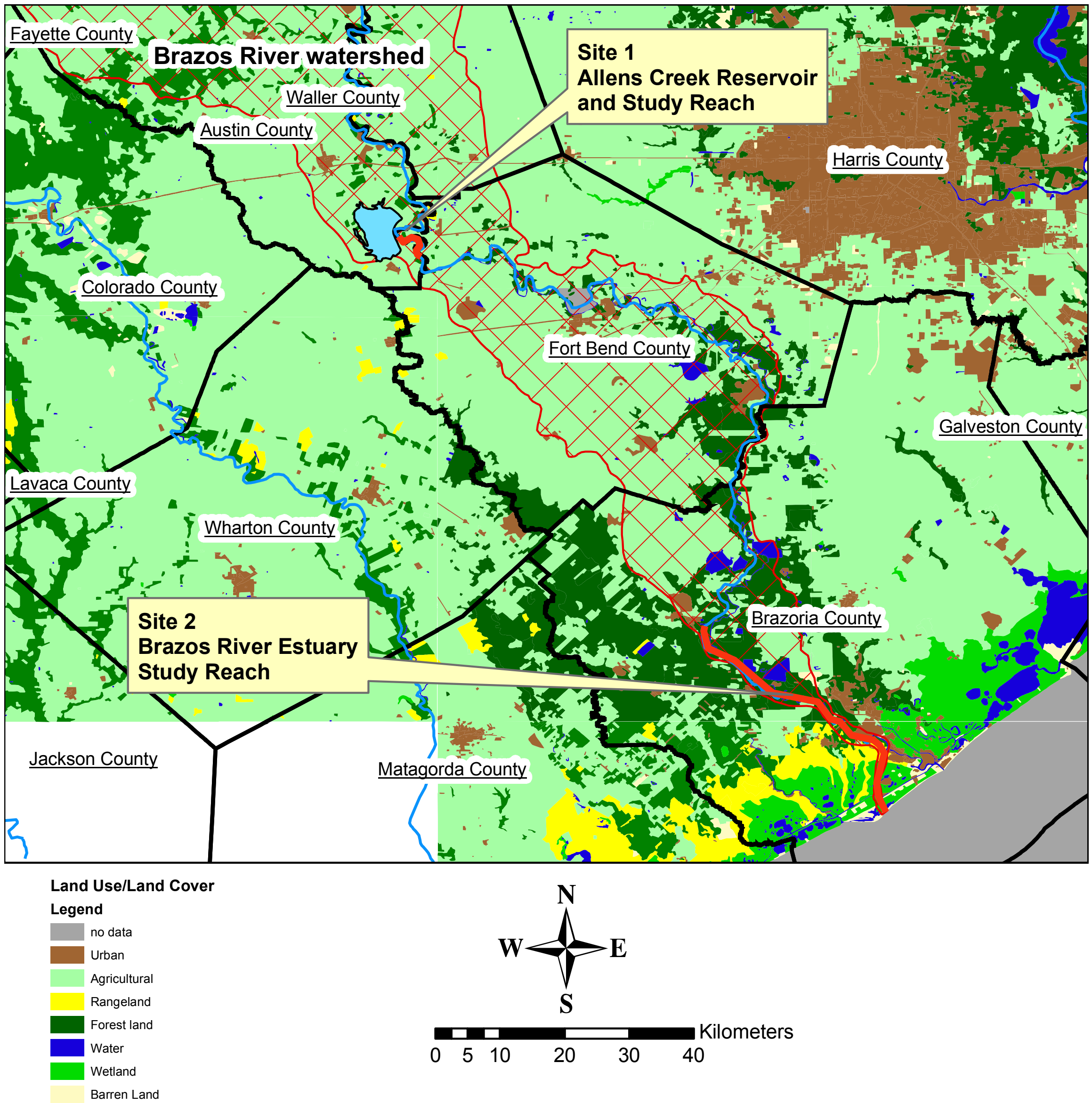

Figure 2.4 – Land use in the lower Brazos River watershed

2.2 Allens Creek

Allens Creek is a third order ungaged tributary of the Brazos River that arises near Sealy, Texas, and flows southeast approximately 29 km (18 miles) to its confluence with the Brazos River in the vicinity of Simonton, Texas. Seasonal flow on Allens Creek is highly variable and is often intermittent during the summer months. Sewage effluent from the City of Wallis' wastewater treatment plant enhances the base flow for Allens Creek. A dense bottomland hardwood forest shades the riparian habitat and an adjacent wetland, Alligator Hole, likely provides nutrient enrichment to Allens Creek during flood flows. The primary land use in the watershed is agricultural and some nutrient enrichment in Allens Creek has been observed as a result of cattle grazing and fertilizers applied for farming. During low flow conditions in the summer, low dissolved oxygen concentrations diminish water quality (Linam 1994, Freese & Nichols 2000). The low dissolved oxygen likely results from a combination of low summer flow and increased biological oxygen demand by organisms growing in nutrient enriched conditions. Dames & Moore (1975) found that the wastewater treatment plant did not significantly contribute to the nutrient loading of Allens Creek, however, the current nutrient contribution from the plant has not been studied. Figure 2.5 shows the proposed extent of Allens Creek reservoir in context of the Allens Creek watershed and the Brazos River.

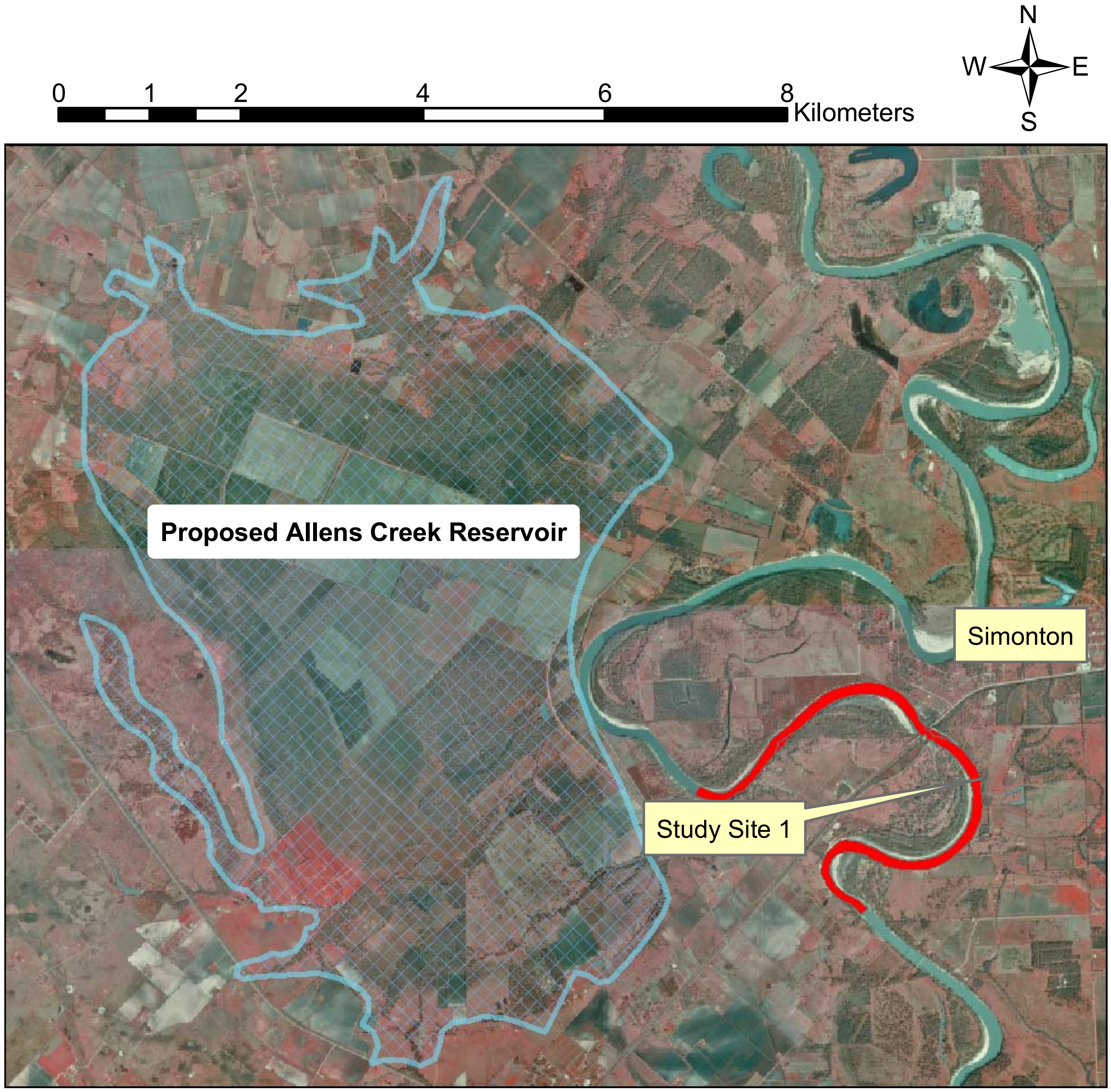

Figure 2.5 – Extent of the proposed Allens Creek Reservoir.

2.3 Climate

Because the Brazos River has such a large watershed, there is a notable range in the seasonal distribution of precipitation and annual average precipitation totals. Data collected at four National Weather Service (NWS) cooperative weather stations illustrate this point: Hempstead (COOP ID #414080), Waco (#419419), Abilene (#410016) and Lubbock (#415411). Annual average rainfall for each of these stations is 103.8 cm (40.9"), 82.9 cm (32.6"), 59.7 cm (23.5") and 46.7 cm (18.4"), respectively. Average rainfall by month for each of these stations is shown in Figure 2.6.

A time-series chart depicting average rainfall by year for the entire period of record for each station is shown in Figure 2.7. No discernible increasing or decreasing trend is observed for these stations.

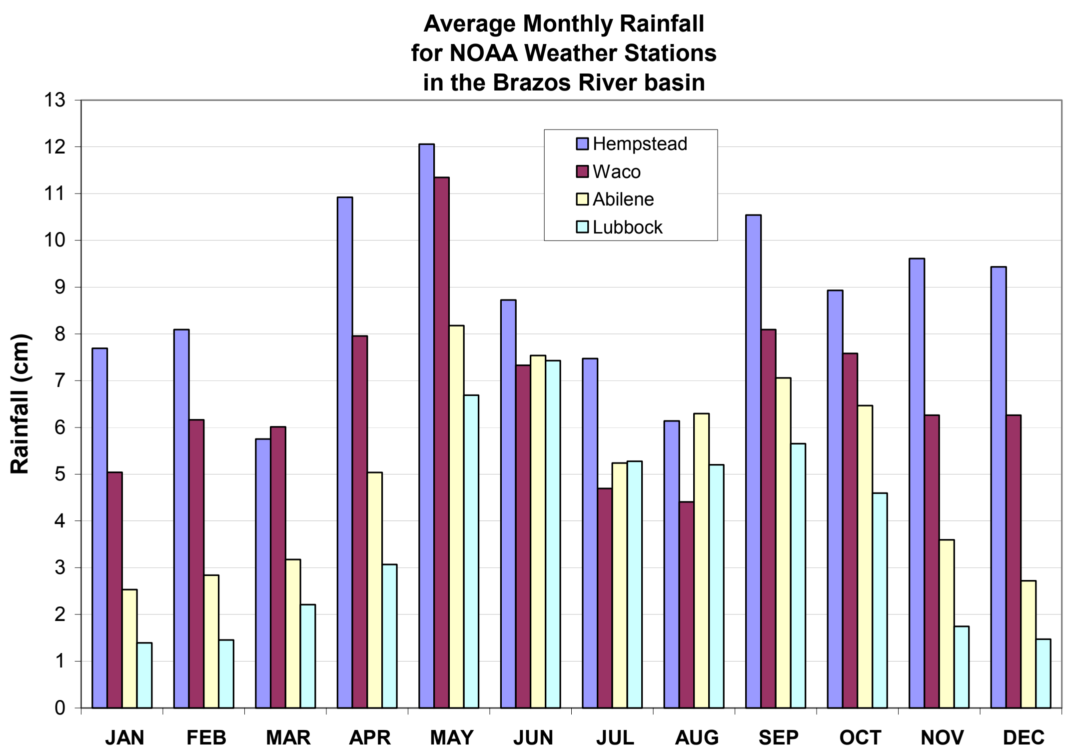

Figure 2.6 – Average rainfall by month for 4 stations in the Brazos River basin.

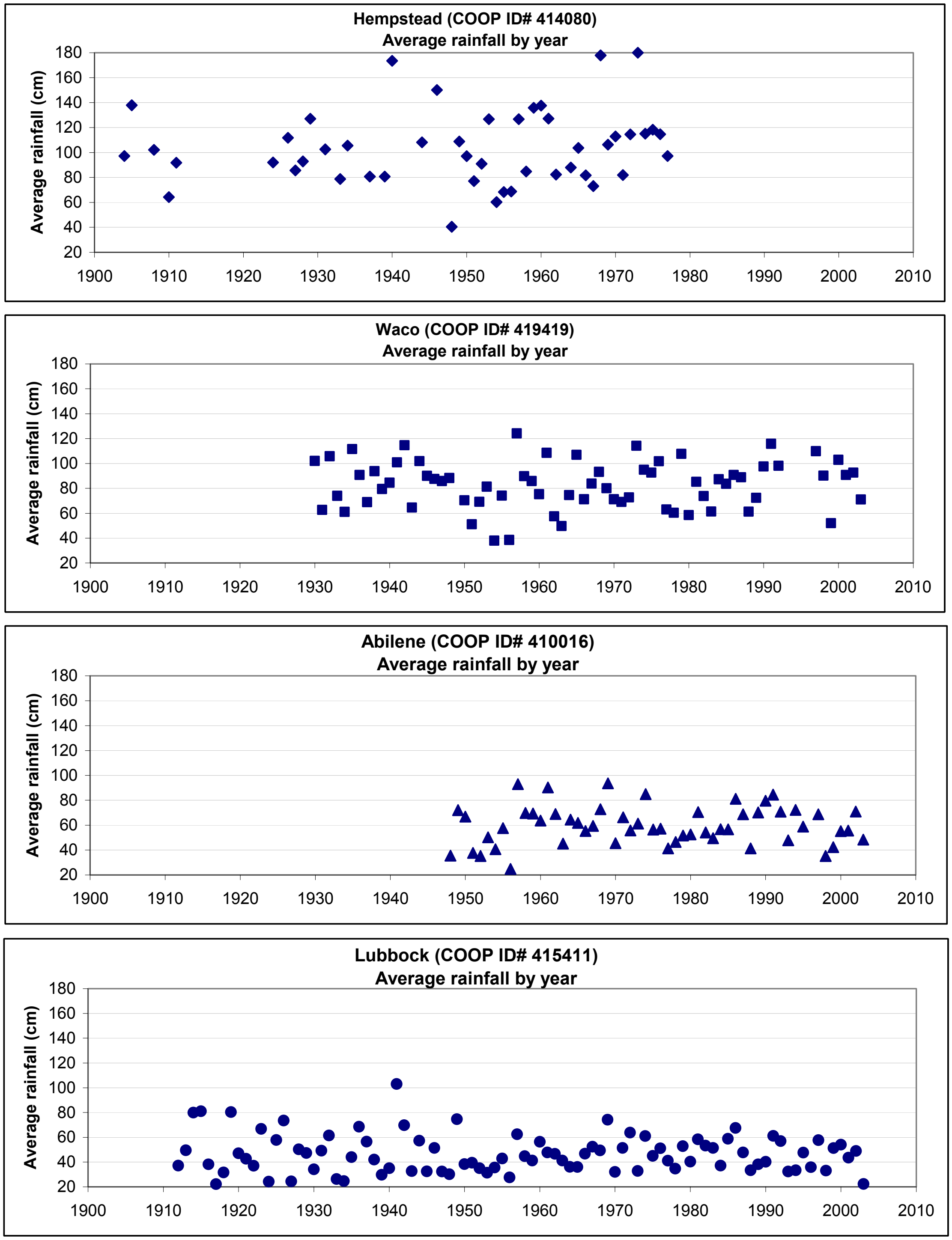

Figure 2.7 – Average rainfall by year for entire historical period of record at each NOAA weather station.

While the humidity is somewhat variable across the basin, with higher humidities near the coast, average temperature by month at each of the four stations is similar (Figure 2.8).

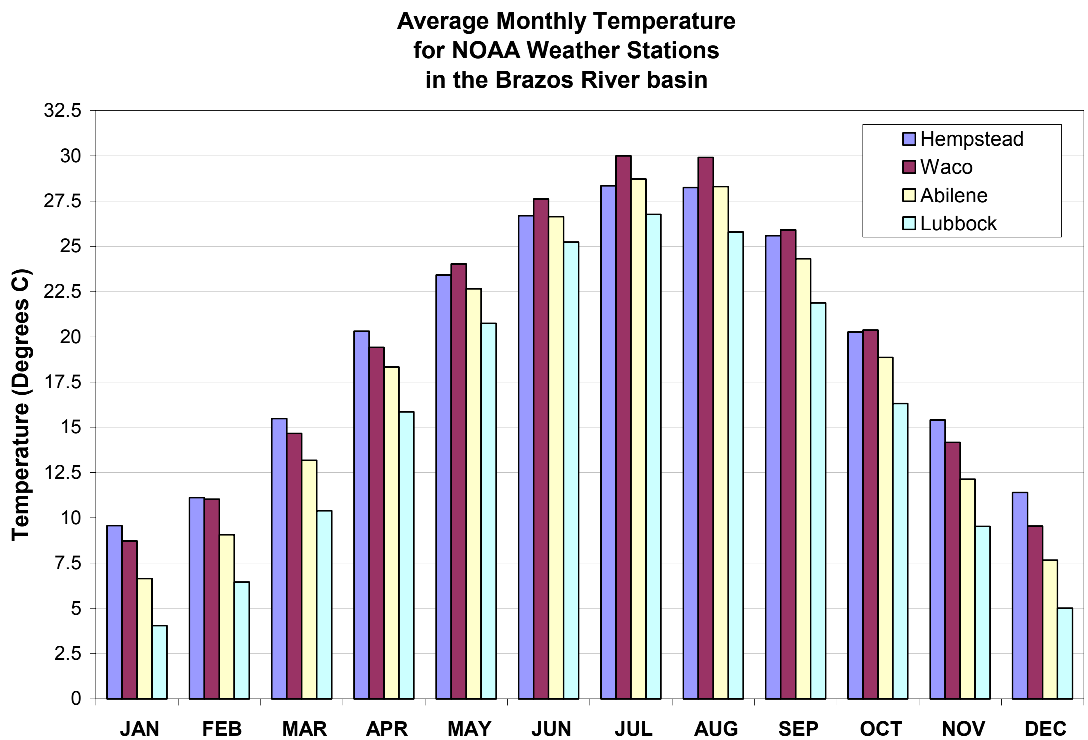

Figure 2.8 – Average temperature by month for 4 stations in the Brazos River basin.

2.4 Hydrology

The Brazos River watershed comprises in excess of 116,500 square kilometers (45,000 square miles) of land. The drainage area above the Richmond gage (USGS ID 8114000, Brazos River at Richmond, Latitude 29°34'56", Longitude 95°45'27" NAD27) is 116,825 square kilometers (45,107 square miles), of which 78% of the area is contributing (USGS Richmond gauge data sheet). All flow frequency statistics discussed in this section were computed using data recorded at the Richmond gage. Data measured at the Rosharon gauge (USGS ID 81146650, Brazos River at Rosharon, Latitude 29°20'58", Longitude 95°34'56" NAD27) was used for inflow data input into the estuarine model. The watershed in the lower reaches of the Brazos River basin is narrow, resulting in less than 1% difference in the contributing drainage area between the Rosharon and Richmond gages. Details of these two gages can be found in Appendix E.

Based on all of the available data from January 1, 1903, to June 8, 2004, the median daily-averaged flow reported at the USGS Richmond gage is 83 cubic meters per second (cms) (2,930 cubic feet per second, cfs). Data for July 1, 1906, to September 30, 1922, was not available. The mean daily-averaged flow is 211 cms (7,451 cfs). The lowest month-long average flow, 5.75 cms (203 cfs), occurred in October 1952; the highest month-long average flow, 2,186 cms (77,198 cfs), occurred in May 1957.

Peak flow events for each year of record are shown in Figure 2.9. A 1,700 cms (60,000 cfs) or higher peak flow event has been measured for half of the years reported. The three highest peak flow events recorded are near 3,398 cms (120,000 cfs) for 1929, 1931 and 1957. Not included in the gauge record is one additional flood event that peaked at approximately 8,495 cms (300,000 cfs) near the Richmond gauge in 1913 (Dames and Moore 1975b). The 100-year discharge at the Richmond gauge was reported as 5,918 cms (209,000 cfs) (Dames and Moore 1975b) but was inconsistently reported as 5,125 cms (181,000 cfs) near the City of Simonton and the Allens Creek Reservoir site (Claunch and Miller 1996, FEMA 2001).

Analysis of the daily-averaged flow for the entire period of record indicates that the 7Q2 flow at the Richmond gauge is 20.3 cms (717 cfs) and the 7Q10 flow is 8.0 cms (281 cfs). The 7Q2 flow is defined as the lowest seven-day daily-averaged flow recurring every two years. Similarly, the 7Q10 is the lowest seven-day daily-average flow recurring every ten years. The water quality protection flow that is stated in the water right permit is 20.78 cms (734 cfs) (Appendix A).

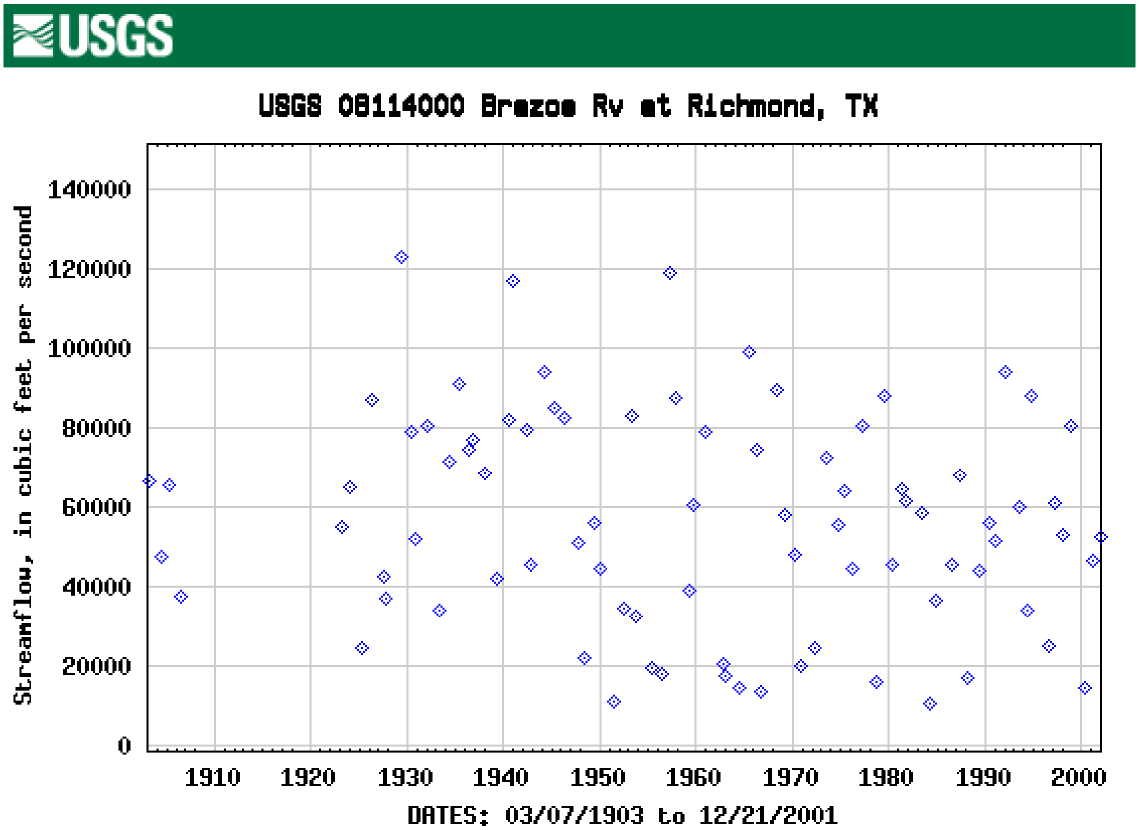

Figure 2.9 – Historical peak stream flow events recorded at the USGS Brazos River gauge at Richmond, TX (source: USGS NWISWeb)

Daily-averaged flows for each month for 50th, 30th and 15th percentile periods of occurrence are presented in Figure 2.10 and Table 2.1. A flow with a 50th percentile recurrence interval is equivalent to the median flow and a 30th percentile flow is equivalent to a flow that is exceeded 70% of the time. Flow notably varies by month, with the January through June period exhibiting considerably higher median flows than the July through December period. During the months of August through November, flows lower than 7Q2 flow were observed for 15% of the days in those months over the historical record.

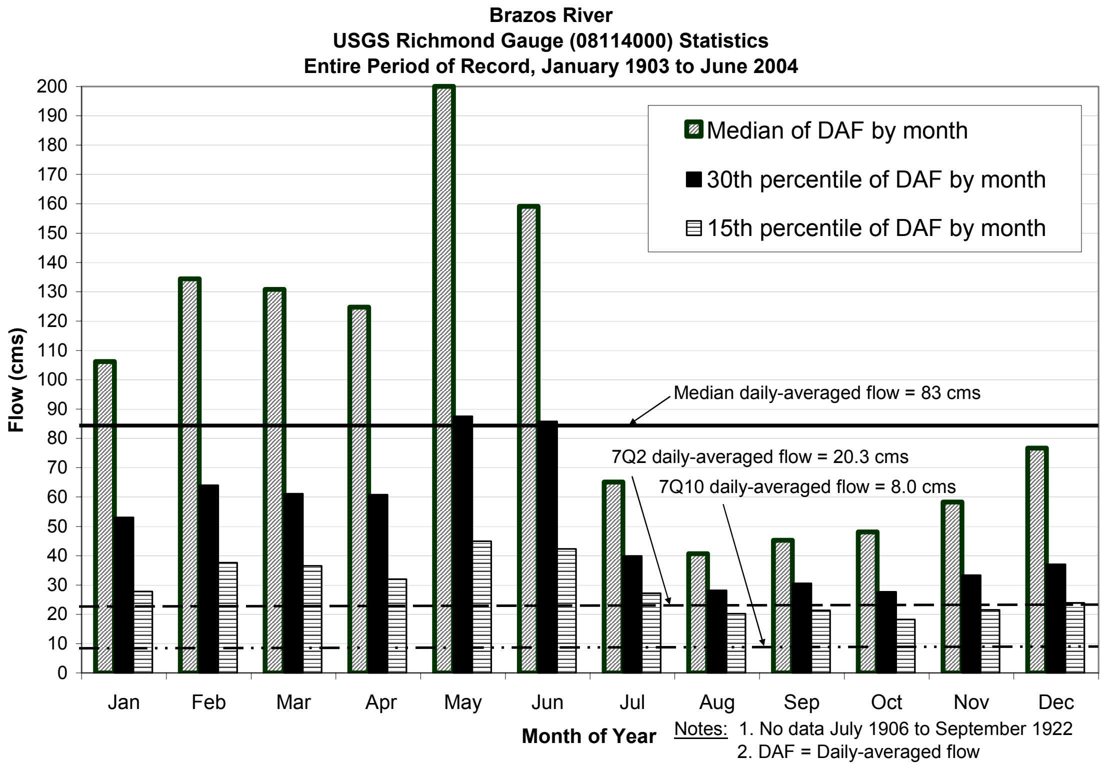

Figure 2.10 – Frequency analysis by month of historical daily-averaged flows at the USGS Richmond gage.

To investigate the effect of water use and development within the Brazos River basin, the Richmond gauge data was analyzed for two time eras representing pre- and post-development conditions. An early era using the earliest gauge data from 1903 to the end of 1940 was used to analyze gauge data prior to installation of the first major dam in 1941, Possum Kingdom. In the years between 1941 and 1970, most of the major dams in the Brazos River basin were constructed, including Lake Whitney and Lake Granbury which impound the Brazos River (Figure 2.1). Statistics for this era of construction are not presented. Because fewer major projects were constructed between 1970 and 2004 than during the 1941 to 1970 era, the flow record between 1970 and 2004 was used to show the effects of water development on the post-development era. Several large projects shown in Figure 2.1 were constructed during the recent era; however, a time era of comparable length to the early era was used for better statistical comparison.

Changes in precipitation patterns or changes in land use throughout the watershed could also be factors contributing to observed changes in flow regime. While changes in land use were not addressed in this report, average precipitation by year at the four weather stations located in the Brazos River basin has remained constant for the period on record (Figure 2.7). Table 2.1 shows flow frequency statistics for the entire data record and for the early pre-development era and the recent post-development era.

Table 2.1 – Frequency analysis of historical daily-averaged flows at the USGS Richmond gage for the entire period of record; probability of exceedance and percentile rank of all historical flows is shown. The era 1903 to 1941 represents the era preceding construction of the first major reservoir (Possum Kingdom) in the basin; 1970 to 2004 represents the era succeeding major water development in the basin.

		Entire period of record 1903 - 2004		**Pre-development 1903-1941**	**Post-development 1970-2004**
Exceedance	**Percentile**	Flow (cms)	*Flow (cfs)*	Flow (cms)	Flow (cms)
0.3%	99.7%	2246	*79,332*	2377	2020
1%	99%	1775	*62,700*	1885	1569
5%	95%	845	*29,835*	855	833
10%	90%	532	*18,800*	527	547
15%	85%	388	*13,700*	368	413
20%	80%	300	*10,600*	283	326
25%	75%	235	*8,310*	221	257
30%	70%	188	*6,630*	177	209
35%	65%	151	*5,340*	146	167
40%	60%	124	*4,390*	120	139
45%	55%	102	*3,590*	100	114
50%	50%	83	*2,930*	83	92
55%	45%	69	*2,430*	68	75
60%	40%	57	*2,030*	57	63
65%	35%	49	*1,720*	48	53
70%	30%	42	*1,490*	41	46
75%	25%	36	*1,280*	34	40
80%	20%	31	*1,080*	28	34
85%	15%	26	*910*	23	30
90%	10%	21	*745*	19	24
95%	5%	16	*565*	15	19
97%	3%	13	*475*	13	16
99%	1%	10	*337*	9	12

Flows lower than approximately 550 cms (20,000 cfs) occurred more frequently in the recent era when compared to the early era. High flow events, greater than 550 cms (20,000 cfs), occurred with significantly less frequency in the recent period than the early era. As shown in Figure 2.9, peak flow events higher than 1,982 cms (70,000 cfs) decreased in frequency and magnitude for the recent era in comparison to the peak flow events reported prior to 1970.

To compare the intra-annual distribution of flow for the two eras, data was combined from January through June into a wet season and July through December into a dry season. Figures 11 and 12 illustrate the difference in probability of exceedance of flows observed in both the wet and dry seasons, for the pre- and post-developmental periods. For the high-flow flood events (0.3% and 1% exceedance), significant reductions from the pre- to post-developmental periods were observed for both the wet and dry seasons. Dry season flows with exceedance probabilties greater than 10% were higher in the recent era than in the early era. Similarly, wet season flows with exceedance probability between 5% and 60% were higher in the recent era than in the early era. Thus, a decrease in high-range flows and an increase in mid-range flows were observed in the recent eras for both the wet and dry seasons. This finding is consistent with the non-seasonal analysis for each era.

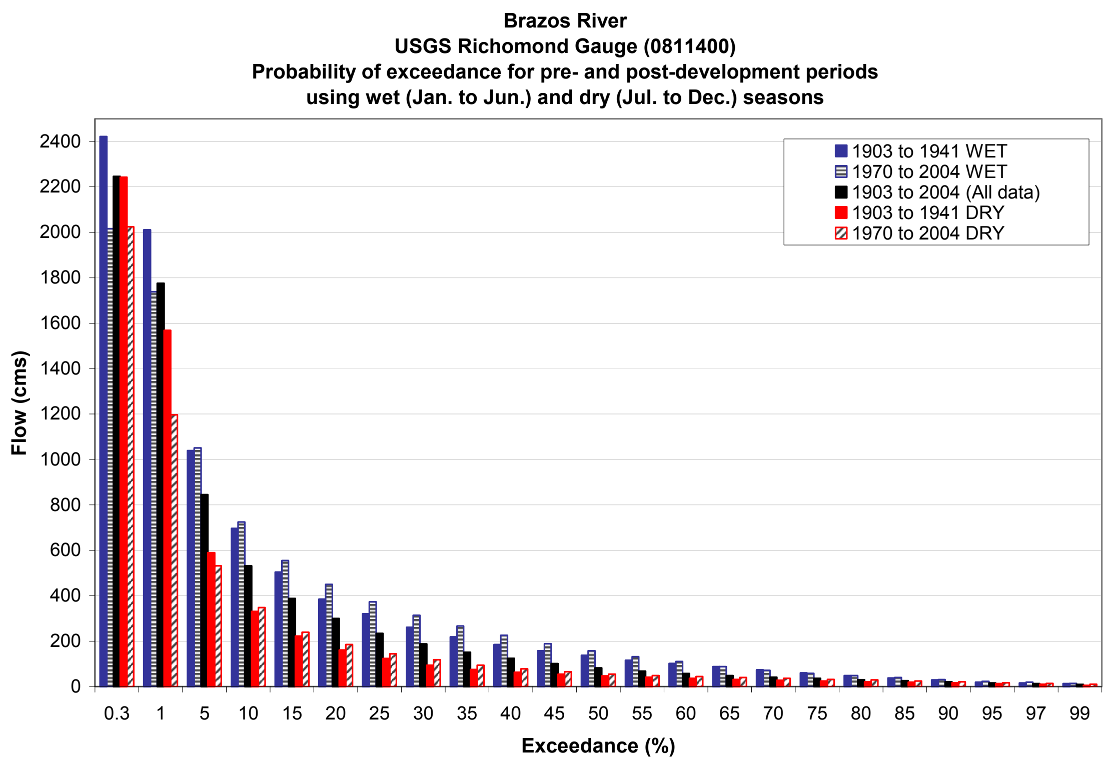

Figure 2.11 – Probability of exceedance for pre- and post-development eras in the Brazos River basin for dry and wet seasons.

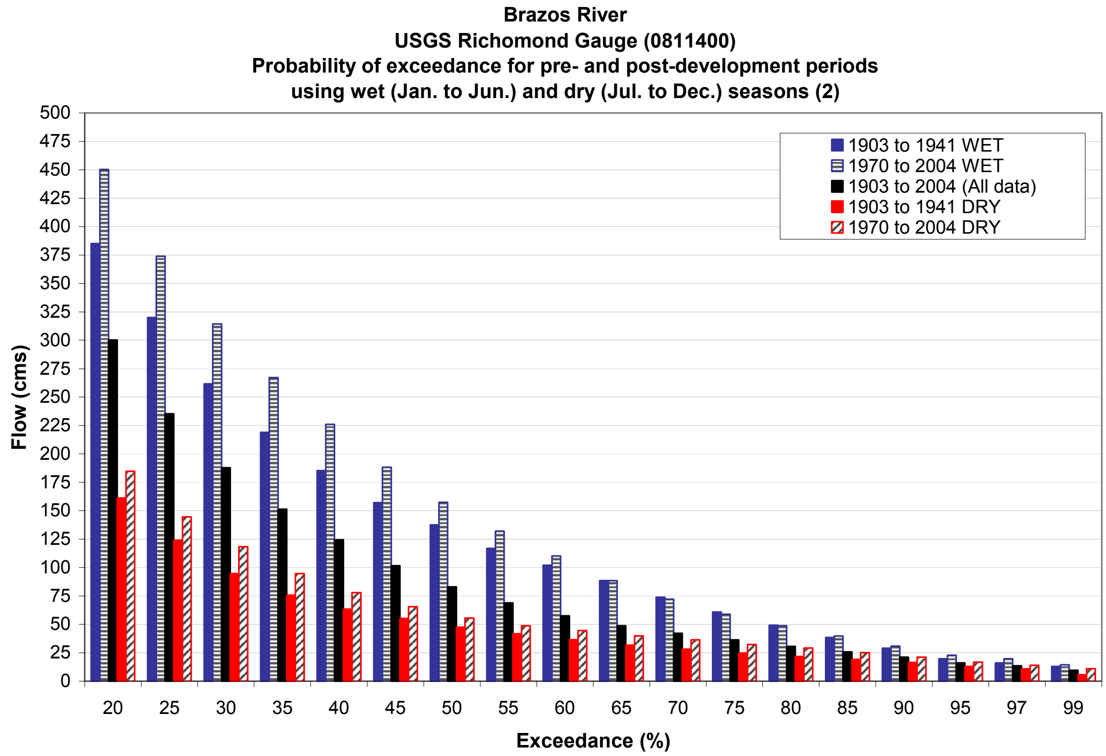

Figure 2.12 – Probability of exceedance for pre- and post-development eras in the Brazos River basin for dry and wet seasons shown for higher exceedance flows.

For comparison, a similar seasonal analysis was performed using seasons hypothesized by Clark Hubbs (Professor Emeritus of fisheries biology at The University of Texas at Austin, personal communication 2003) to be relevant to fisheries life cycles. Winter was defined as November to March and summer was defined as April to October. Figures 2.13 and 2.14 reflect the same decrease in high flow occurrence and increase in low-flow occurrence between the early and recent periods as the analysis based upon wet and dry seasons. However, data analysis using the Hubbs' seasons indicates a more minor difference in flows between pre and post-development eras for the summer months and a more marked difference between the two eras for the winter months than what is indicated by the wet/dry season analysis.

Further analysis of flow exceedance statistics by month (rather than by season, as presented herein) for each of the eras is recommended for future studies. Investigation of additional analysis using the Indicators of Hydrologic Analysis and/or Range of Variation approach proposed by Richter et al. (1996) and Richter et al. (1997) is also recommended.

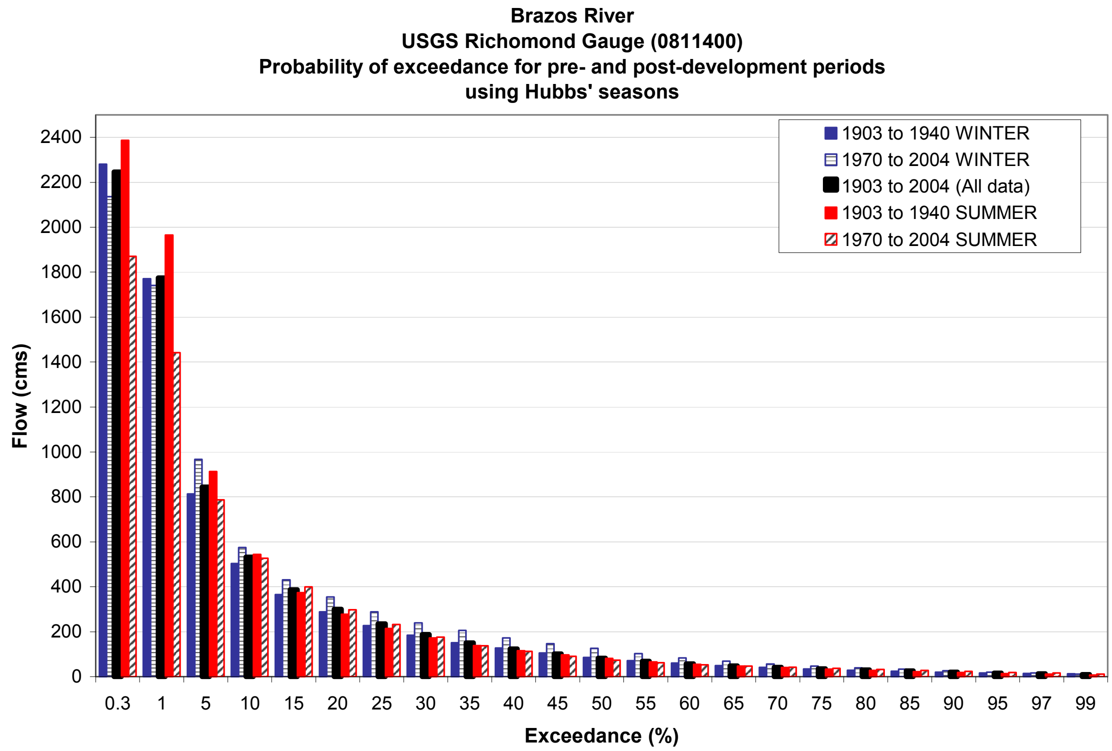

Figure 2.13 – Probability of exceedance for pre- and post-development eras in the Brazos River basin for Hubbs' winter and summer seasons.

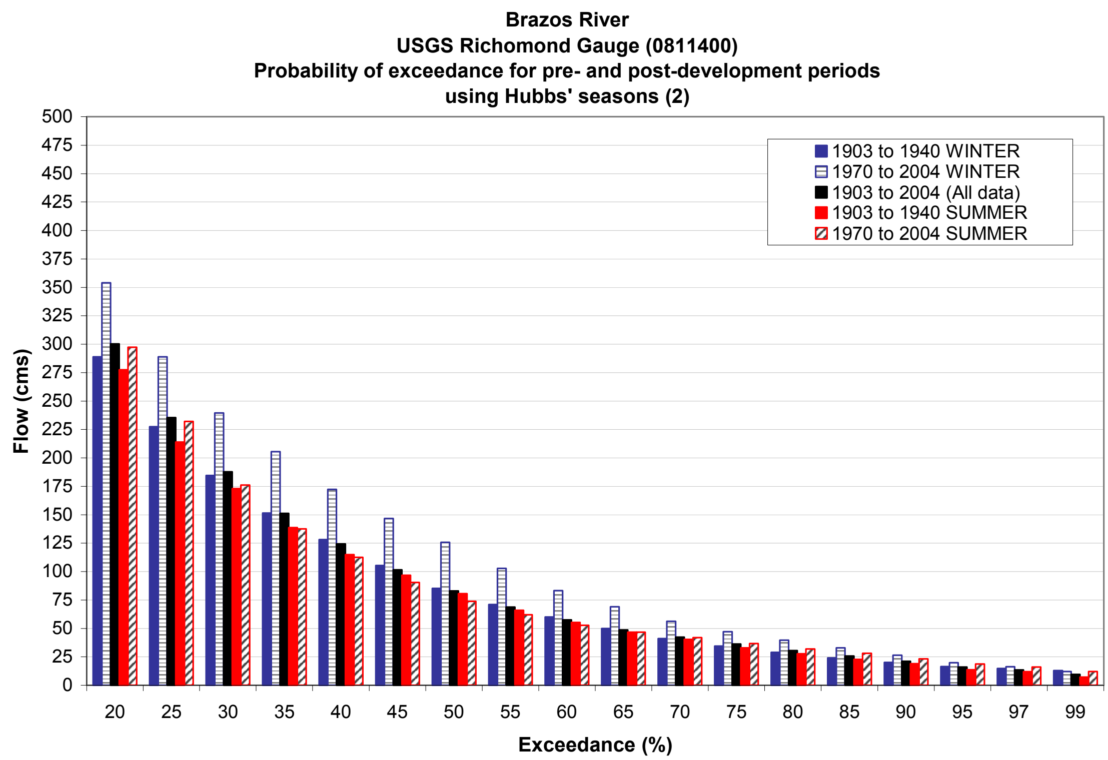

Figure 2.14 – Probability of exceedance for pre- and post-development eras in the Brazos River basin for Hubbs' winter and summer seasons; shown for higher exceedance flows.

2.5 Geomorphology

This section presents a cursory examination and discussion of the physical processes acting on the river in the vicinity of Allens Creek project.

The lower Brazos River, extending from approximately Hempstead, Texas, downstream to the Gulf of Mexico, can be characterized as an incised, sand-bed channel that meanders through both Holocene and Pleistocene alluvial deposits of the Gulf Coastal Plain. Typical of a meandering alluvial channel, high steep banks cut cohesive alluvial deposits on the concave side of each bend, while sandy and silty materials are deposited as bars on the convex side of each bend. The river exhibits high turbidity for the range of observed flows.

Sinuosity, the degree of curvature of a river with respect to the river valley, generally ranges from 1.2 to 1.4 on the lower Brazos River but near project Site 1 sinuosity is significantly higher at 1.99. Variation in sinuosity on the Brazos River is caused by the restriction of the natural meander patterns of the river because of the presence of a valley wall. This wall was formed during the Pleistocene by a river system acting under the influence of a higher sea level.

2.5.1 Slope and cross-section

Field measurements collected between the upstream and downstream boundaries of Site 1 indicated that within Site 1 the water surface elevation slope was 0.176 m/km (0.950 ft/mile) for below median flows. A plan view of Site 1 is shown in Figure 2.15, with color contours that indicate the channel bed elevation, and a thalweg profile of Site 1 is shown in Figure 2.16. The measured mean channel bed slope within the boundaries of Site 1 was 0.222 m/km (1.17 ft/mile). The water surface slope between Site 1 and the Richmond gage was 0.180 m/km (10.70 m drop over 59.5 km) with stable flow conditions at 62.1 cms (0.95 ft/mile at 2,300 cfs). The water surface slope between Site 1 and the Rosharon gage during the same stable flow period was 0.180 m/km (20.40 m drop over 113.29 km). The water surface slope measured between Site 1 and the bridge crossing of State Highway 35 near East Columbia was 0.149 m/km (22.10 m drop over 149.23 km; 0.787 ft/mile). Table 2.2 summarizes the regional slope calculations included in this analysis.

Table 2.2 – Slope measurements in the lower Brazos River (data source reported in parenthesis)

RIVER SEGMENT	Distance (km)	Slope (m/km)	Slope (ft/mi)
Bed slope			
Lower 482 km (300 miles) (Dunn & Raines 2001/USGS)	482	0.132	0.697
Site 1 upstream to Site 1 downstream (TWDB)	6.9	0.222	1.17
Water surface slope			
Site 1 upstream to Site 1 downstream (TWDB/USGS)	6.9	0.176	0.929
Site 1 and USGS Richmond gauging station (TWDB/USGS)	59.5	0.180	0.950
Site 1 to USGS Rosharon gauging station (TWDB/USGS)	113.29	0.180	0.950
Site 1 to SH35 nr East Columbia (TWDB)	149.23	0.149	0.787

The water surface elevation at the State Highway 35 location is tidally influenced, so the average elevation over the corresponding tidal cycle was used to calculate the slope. The water surface fluctuation caused by the tide, which was measured during the same stable flow period as the measurements above, was 19.5 cm. Based on gauging station data, Dunn and Raines (2001) report that channel slope in the lower 482 km (300 miles) of the Brazos River is approximately 0.132 m/km (0.7 ft/mi). TWDB surveyors, however, measured a 3.8 m (12.5’) discrepancy between reported gauge elevation datum at the Bryan gauge and field measured elevation; critical slope calculations based upon gauging station elevation data should be field verified prior to use. The channel slope calculated using the data measured on-site is only valid for this short river segment. Additional data needs to be collected over a longer reach and reported USGS gauging station datum elevations need to be verified in the field to verify the Dunn and Raines slope calculation.

Sample cross sections located within the study reach Site 1 are shown in Figure 2.17; each cross-section is located on the plan view shown in Figure 2.15. Cross-sections 1, 3, and 4 were characteristic pools formed on tight meander bends; nearly vertical walls of cohesive material form the outer, concave bank, while moderately sloped point bars form the inside, convex bank. Cross-section 2 was a riffle area with substrate composed largely of coarse sand, gravel and cobbles. At flows below 25 percentile (75% probability of exceedance), much of this riffle cross-section was dry and all flow was transmitted along the left bank.

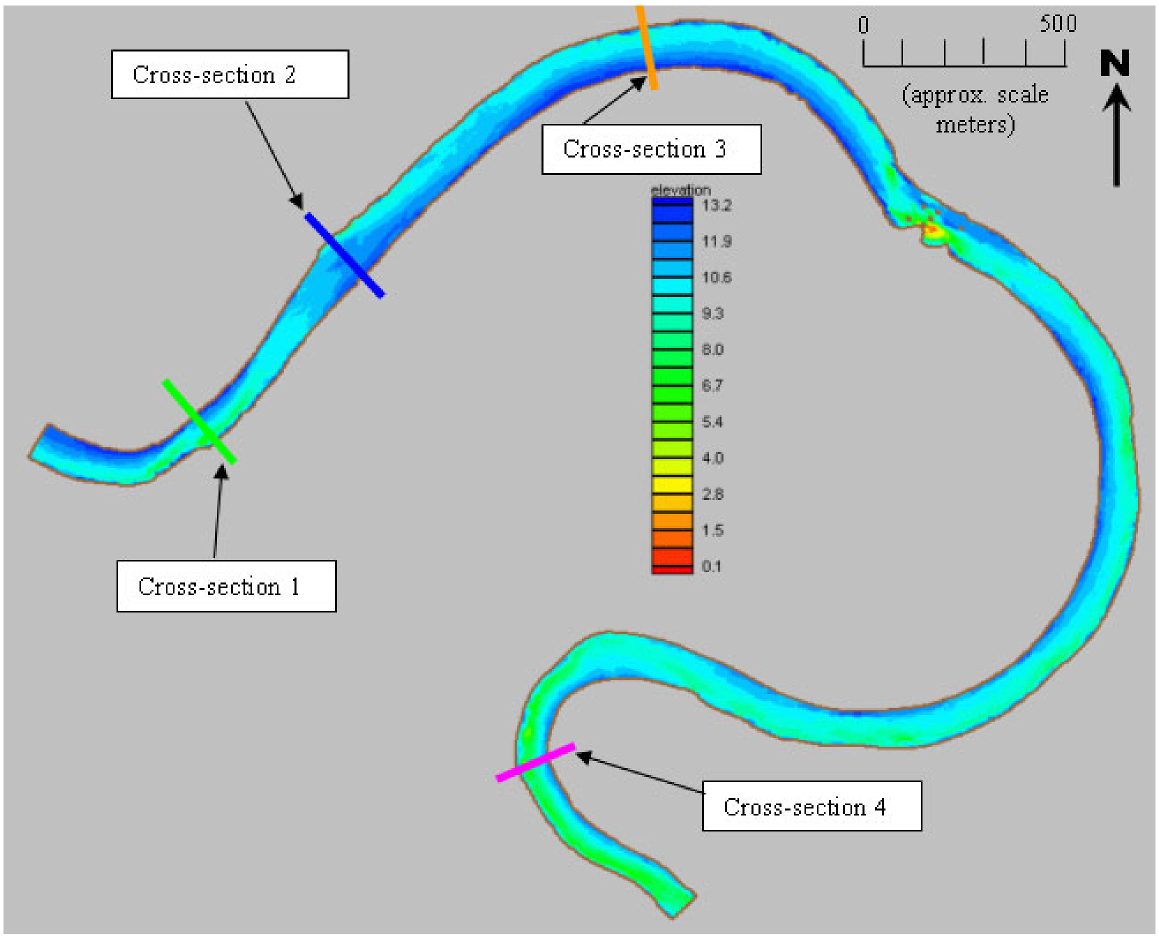

Figure 2.15. Plan view and cross-section locations. Flow from northwest to southeast. Contour fill is channel bed elevation in meters above assumed datum.

2.5.2 Sediment transport

According to Dunn and Raines (2001), at least three potential causes of change in sediment transport exist for the lower Brazos River system: reservoir construction, changes in land use, and instream sand and gravel mining. While changes in land use may have affected changes in sediment load, Dunn and Raines (2001) state that accurate quantification of change in transport arising as a result of changes in land use was not possible. Similarly, quantification of change in transport caused by sand and gravel mining was not possible on the river segment scale since annual sand and gravel removal amounted to less than 25% of total annual transported sediment and the mining operations were spatially dispersed along the river (Dunn and Raines, 2001).

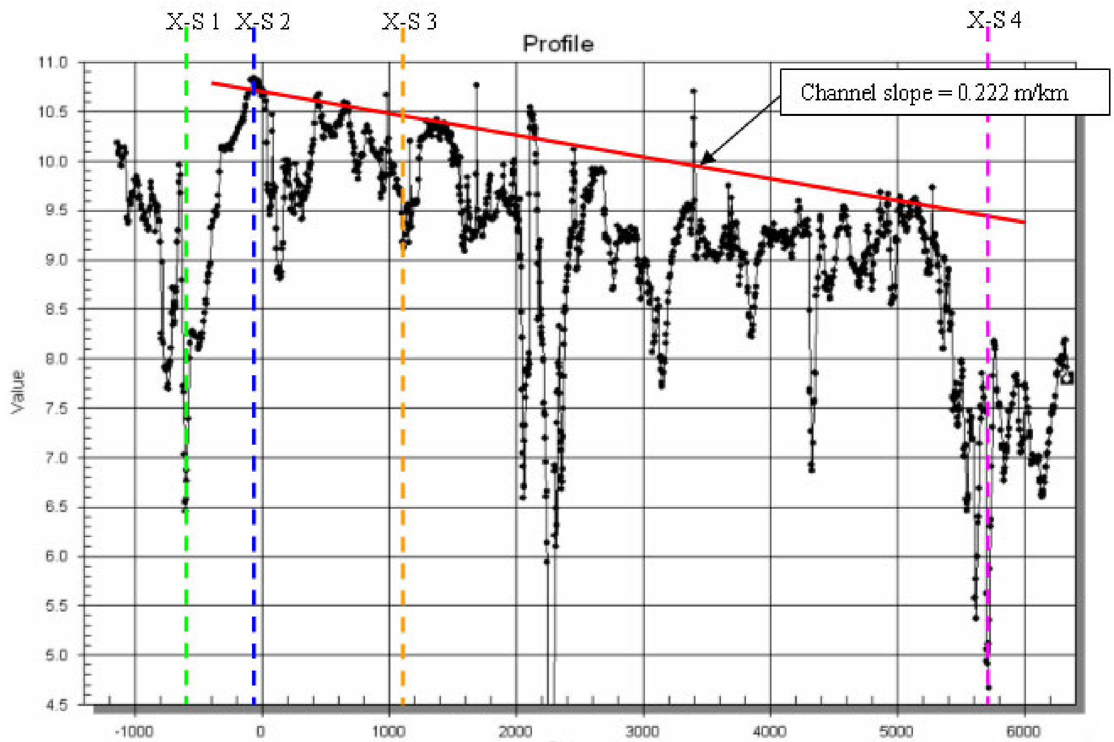

Figure 2.16 - Thalweg Profile line. “Value” is elevation (meters) above assumed datum. “Distance” is in meters along the thalweg line. “X-S 1” represents the location of cross-section one along the profile.

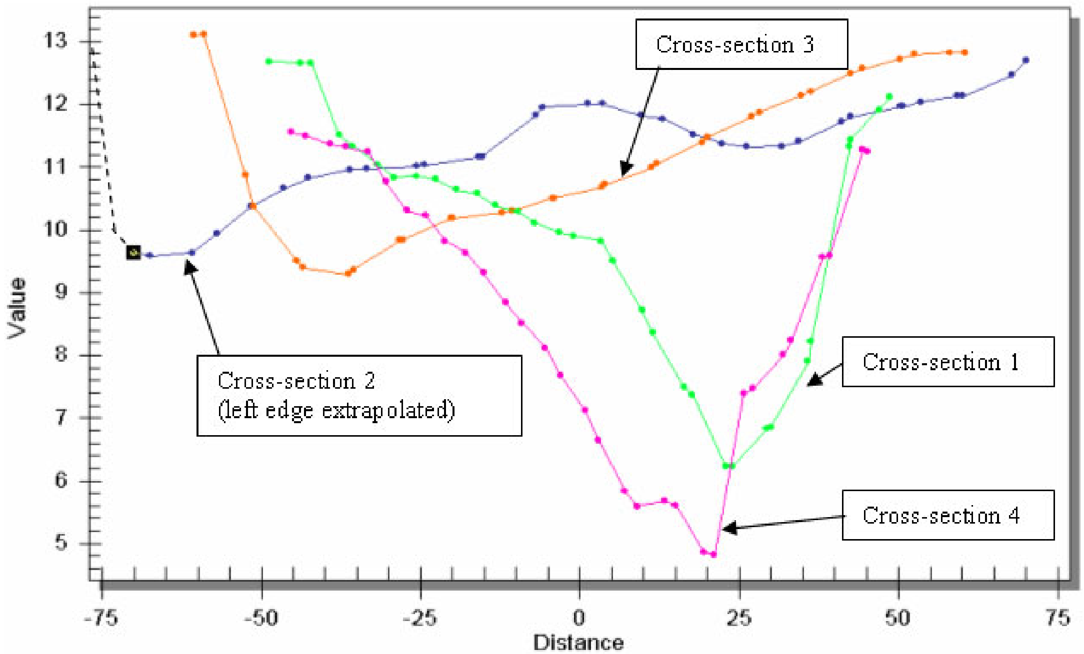

Figure 2.17. Cross-sections, looking downstream. “Value” is elevation (meters) above assumed datum. “Distance” is in meters along from an assumed centerline.

Using USGS suspended sediment data collected between 1966 and 1986, Hudson and Mossa (1997) showed that 90% of the cumulative suspended sediment load in the Brazos River near the Richmond gauge was transported during 21% of the time for the period of record that was analyzed. Hudson and Mossa (1997) found an increase in total suspended sediment mass transported for flows above 300 cms (10,500 cfs), and an even greater increase in total mass transported at 700 cms (24,700 cfs). Maximum mass of suspended sediment transported occurs for flows between 1,500 and 2,000 cms (53,000 and 70,600 cfs), with a sharp decrease in sediment transport occurring for higher flows (Hudson and Mossa 1997). Thus, the effective discharge for most efficient transport of suspended sediment is near or just above 1,500 cms (53,000 cfs). This flow rate corresponds to a peak flow that has been observed approximately once every two years in the historical record at the USGS Richmond gauge (Figure 2.9). This flow rate also corresponds nicely to the theorized, rule-of-thumb recurrence interval for a bankfull flow that discharges the maximum amount of sediment and recurs roughly every 2 years (Leopold 1997).

The pre- and post-development flow exceedance statistics in Table 2.1 indicate that a flow of 300 cms, signifying increased suspended sediment transport, was exceeded 5% more frequently in the post-development era than in the era preceding construction of the first major Brazos River basin reservoir. Conversely, the effective discharge, 1500 cms, was exceeded approximately 5% less frequently in the post-development era. Noting that rainfall data across the basin has not exhibited any major trend of increase or decrease (Figure 2.7), water use or land use trends are the most attributable causes of the change in frequency of these flows.

The number of in-channel impoundments on the Brazos River could result in decreased amounts of sediment transported as a result of sediment trapped behind the impoundment (Figure 2.1); however, post-impoundment sediment transport has not varied considerably from pre-impoundment transport (Dunn and Raines 2001). Sediment levels were potentially sustained by tributary sedimentary inputs and increased local bank erosion which may have occurred because of the increased frequency of flows near the 300 cms threshold. Balancing the increased transport at lower flows, the volume of transported sediment caused by higher flows has decreased, potentially as a result of the decreased frequency of more effective flows near 1,500 cms.

While no specific cause was attributed, two aspects of change in sediment transport have been identified and discussed by Dunn and Raines (2001). Based upon gauging station data, the water surface elevation between Hempstead, TX, and the Gulf of Mexico declined at a rate of ½” to ¾” per year for the historical record (1925 to present). No link between degradation and sediment load could be made directly from the available data, but changes in sediment load were theorized to be attributable to this change. Near the mouth of the Brazos River at the Gulf of Mexico, Sargent Beach eroded at a significant rate; depleted supplies of sand-sized particles that were previously supplied by the Brazos River was theorized to be attributable to this change (Dunn and Raines 2001).

Data from the USGS Richmond gage #08114000 indicated that annual sediment load ranged from a minimum of 900,800 tonnes (993,000 tons) per year in 1979 to a high of 88,275,000 tonnes (97,306,510 tons) per year in 1941. The average annual sediment load for the period between 1924 and 1979 was 20,933,690 tonnes (23,074,376 tons) per year. Water flow volumes for the corresponding periods are reported as 1,691 million cubic meters (1,370,795 ac-ft) for 1979, 19,884 million cubic meters (16,120,000 ac-ft) for 1941, and an average flow over the period of 1924 to 1979 of 6,534 million cubic meters (5,296,820 ac-ft) per year (Quincy 1988). The Allens Creek project is permitted to divert up to 249 million cubic meters (202,000 ac-ft) per year, 3.8% of the total, average, annual flow volume.

Local morphology changes near Allens Creek confluence can be expected given the proposed change in flow regime of the Allens Creek tributary. A small decrease in sediment transport (caused indirectly by the reduction in flow volume) may also occur; however, without further study, neither effect is quantifiable with respect to the Allens Creek project. Further analysis of sediment transport in the lower Brazos River should include studies that quantify bed load sediment transport for a range of flows, long-term monitoring of suspended sediment transport, and accurate quantification of elevations for all measurements throughout the region.

2.6 Water quality

Water quality data are available from the TCEQ for the Brazos River designated Segment 1201 the Brazos River Tidal segment, and Segment 1202, the segment of the Brazos River downstream of the Navasota River. Allens Creek, whose confluence lies within Segment 1202, is reported separately as unclassified Segment 1202H. Water quality data for these segments are summarized in the TCEQ's Draft 2002 State Water Quality Inventory and 303(d) List that is prepared on a bi-annual basis. The Brazos River Tidal Segment (1201) has designated uses for contact recreation, aquatic life, general use, fish consumption, and public water supply. In the 2000 Water Quality Inventory, elevated fecal coliform densities in the lowermost seven miles of the segment prompted only partial support of the contact recreation use in the segment. Other concerns for this segment were elevated nitrogen levels and sediment levels of selenium and hexachlorobenzene (TNRCC 2000). The current draft inventory (TCEQ 2002) reports no concerns and fully supports all uses except fish consumption, which was not assessed.

Designated uses in Segment 1202 are contact recreation, aquatic life, general use, fish consumption, and public water supply; all uses are supported except fish consumption which was not assessed. In the 2000 Water Quality Inventory, elevated fecal coliform densities caused nonsupport of the contact recreation use in the segment. Another concern for this segment was elevated total phosphorous concentrations from agricultural uses in the watershed. There were no fish consumption advisories or closures for the segment (TNRCC 2000). The 2002 Water Quality Inventory notes use concerns for contact recreation use in the upper and middle portions of this segment because of fecal coliform. Concern about excessive algal growth was also noted for the upper portion of the segment. One fish kill totalling 50,671 fish was reported on 1/16/1997 "from SH 36 upstream to two miles above plant B." Temperature was the suspected cause (TCEQ 2002).

Allens Creek is Segment 1202H, an unclassified water body whose uses are reported as aquatic life, contact recreation, and fish consumption. In 2002 Water Quality Inventory aquatic life use was supported and fish consumption use was not assessed (TCEQ 2002). Contact recreation use was not supported in this entire water body because of elevated fecal coliform bacteria levels. An additional concern for Allens Creek is nutrient enrichment by phosphorus. Segment 1202H is identified as category 5c, rank D, on the 303(d) list with concern for fecal coliform bacteria (TCEQ 2002).

Water quality data and statistics for the lower Brazos River are attached in Appendix C. These measurements were taken by various entities and prepared by the TNRCC not specifically for this project.

2.7 Threatened and endangered species

The proposed Allens Creek reservoir site in Austin County, Texas, is within the range of several threatened and endangered species; however, no federal endangered or threatened species or their critical habitats are known to occur within the proposed reservoir site. A list of threatened and endangered species for Ecoregion 4 (Gulf Coast Prairies and Marshes) is presented in Appendix O. Some candidate species and state listed threatened or endangered species have been observed on the site (Freese & Nichols 2000). The species potentially present on the proposed reservoir site include the bald eagle, greater Attwater's prairie chicken, whooping crane, interior least tern, Houston toad, wood stork, white-faced ibis, American swallow-tailed kite, white-tailed hawk, Texas horned lizard, timber rattlesnake, and blue sucker. The only fish species potentially present, the blue sucker, has not been collected in this area of the Brazos River. It does occur in fast currents and deep chutes of medium to large rivers, such as that in the lower Colorado River, Texas, and there is a possibility that blue sucker habitat exists on the lower Brazos River in similar habitats. One potential area characterized as a mid-stream rock outcrop was observed just upstream of the GCWA pump station (upstream of Richmond, TX), however this site has not yet been surveyed or sampled (see following sections of this report for more information and photos).

The construction and operation of the reservoir will impact the remnant prairie community and bluff forest community in the proposed reservoir project area. Thus, the migratory, threatened and endangered species will lose habitat within their range; however, their usage of the area is probably minimal. The bald eagle may benefit by the proposed reservoir, because it will have increased lake habitat available for feeding.

2.8 Bay and estuary inflow considerations

The Brazos River estuary is a minor estuary approximately 113 km (70 miles) downstream of its confluence with Allens Creek and makes only a minimal contribution to coastal fisheries production because of its relatively small size when compared to the major bays and estuaries of Texas. There is some crabbing activity, and commercial activities are limited to some shrimping in the adjacent waters of the Gulf Intracoastal Waterway (GIWW).

The mouth of the Brazos River is a naturally meandering system along the central Texas coast, and forms the Brazos Estuary. However, channel stabilization was provided in order to develop the Gulf Coast Intracoastal Waterway (GIWW) and infrastructure. There has been no more meandering since that time.

TWDB will coordinate with partners to determine freshwater inflow needs of the Brazos River Estuary by conducting sediment, nutrient, salinity, biological productivity and fisheries analyses to optimize inflows for a range of feasible solutions. A comprehensive state-sponsored inflow study of this minor estuary is scheduled for completion in 2006.

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3. Site selection, hydraulic analysis and salinity modeling

For the purposes of investigating the impact of the proposed Allens Creek diversion on aquatic habitat, a study reach deemed representative of Brazos River downstream of the Allens Creek project was selected for site analysis and was designated Site 1. Scientists and engineers from TPWD, TCEQ, TAMU, USACE and the TWBD participated in the reconnaissance and selection process. Fish sampling was conducted within the boundaries of Site 1 to characterize the fish communities that inhabit typical riverine habitats and a steady-state two-dimensional hydraulic model was developed. Site 2 was selected to determine the impact of the Allens Creek diversion on salinity migration in the Brazos River estuary. Site 2 is a 42km (26 mile) segment that extends from East Columbia, Texas, to its downstream boundary at the Gulf of Mexico.

3.1 Selection of Site 1 for aquatic habitat analysis

A 10 km study reach in the lower Brazos River near the vicinity of Allens Creek was identified during a site reconnaissance field trip conducted during the summer of 2001 and attended by representatives of the TWDB, TPWD, TCEQ, U.S. Army Corps of Engineers-Fort Worth District (USACE), and Texas A&M University (TAMU). The Brazos River upstream of the diversion point is not affected by the Allens Creek project, so reconnaissance was carried out by boat over a 16 km (10 mi) segment downstream of the confluence of Allens Creek with the Brazos River.

The upstream boundary of Site 1 is located directly above the confluence of Allens Creek with the Brazos River and extends to a point approximately 6.9 km (4.3 miles) downstream (Figures 3.1 and 3.2). The site was chosen based on parameters such as current velocity, water depth, river morphology, presence of large woody debris and dominant substrate type. Site 1 encompasses features such as velocity shelters, backwaters, sand bars, small islands, scour holes and obstructions created by bridge supports. To obtain a cursory idea of the fish communities present, fish were sampled at a number of habitats using a seine. All parties that participated in the fieldtrip agreed that Site 1 was generally representative of the Brazos River segment investigated during the trip.

Figure 3.1 – Allens Creek entering the Brazos River. Flow ≈ 4,000cfs.

Figure 3.2 – Close-up view of the Allens Creek confluence. Flow ≈ 2,500 cfs.

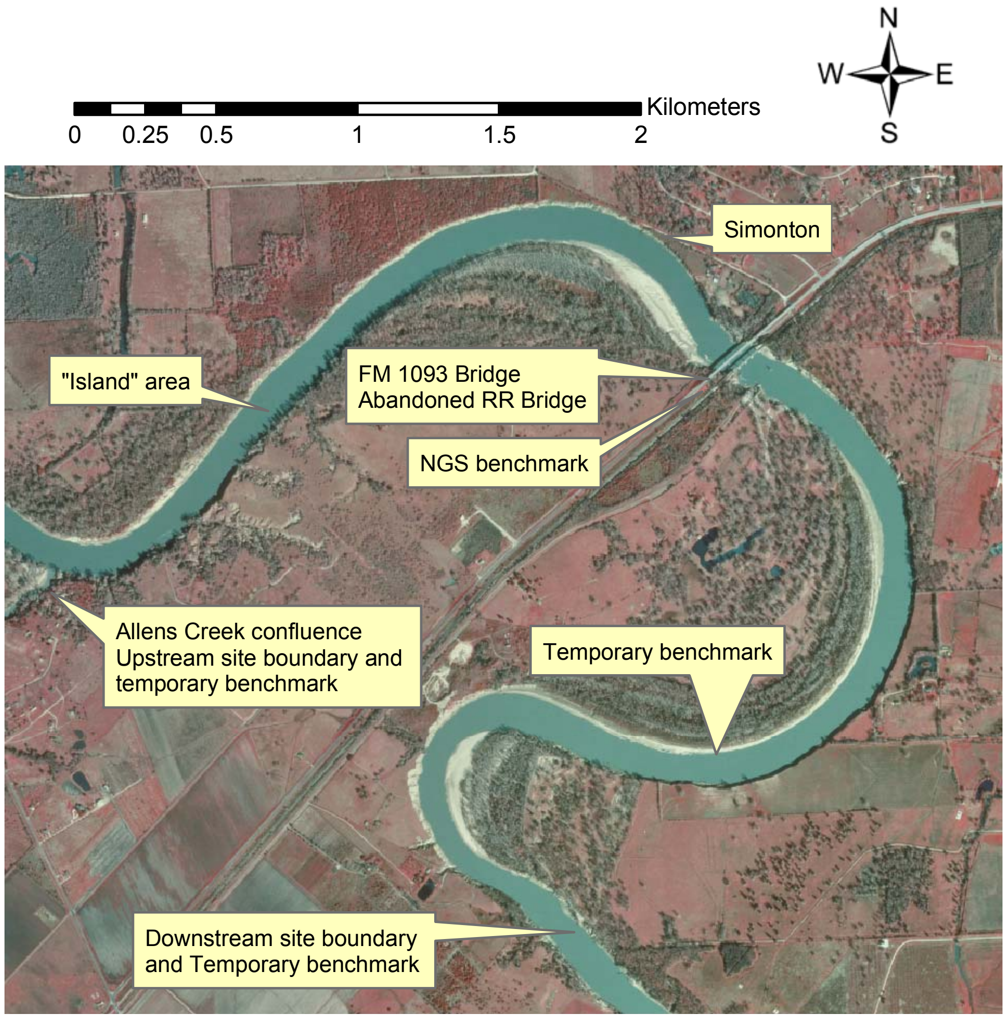

Figure 3.3 –Brazos River, Site 1 DOQQ.

Three adjacent bridge crossings, FM1093, an existing railroad bridge and a washed-out railroad trestle, for which in-channel structures remain, created a unique aquatic habitat in their immediate vicinities (Figures 3.3 and 3.4). One backwater habitat, two embayments and one deep scour hole have formed as a result of deposition and erosion near the in-channel bridge supports and embankments. While these areas are not representative of a significant portion of lower Brazos River habitats, they did provide an opportunity to study unique habitats that may impact fish utilization.

Another such unique habitat was a riffle area located downstream of the Allens Creek confluence (Figure 3.3 see “island” area and Figure 3.5). When flow rates were near and below approximately 42.5 cms (1,500 cfs), roughly the 25 percentile flow, water level in the Site 1 area was low enough to expose a lateral gravel bar with a large backwater area with coarse sediment. Under such low water level conditions, flow was concentrated along the left bank, which created a shallow, fast-flowing riffle habitat.

Figure 3.4 – Highway and railroad bridges at Site 1. Flow ≈ 4,000cfs.

Figure 3.5 – Island area looking downstream. Flow ≈ 1,500 cfs.

Further reconnaissance conducted with staff from each of the state agencies and with Barbara Nickerson, representing both the Brazos River Authority and City of Houston, was conducted by helicopter on January 23, 2002 over the entire segment of the river between Allens Creek and the Brazos River estuary. Flow rate on the day of the flight was approximately 113.3 cms (4,000 cfs) as measured at the Richmond gauge. The river morphology was observed as a generally homogenous repetition of meander pools and point bars, with two notable exceptions that warrant further investigation.

The area near the Gulf Coast Water Authority (GCWA) diversion pump station, upstream of Rosenberg, TX, contained a number of mid-stream boulders and rock outcrops that had accumulated large woody debris (Figures 3.6 and 3.7). Whether or not the area near the GCWA pump station contains critical habitat for fish species was not determined but scientists from TCEQ and TPWD have postulated that this area might provide habitat for the endangered blue sucker. TAMU visited the site when river flow rate was approximately 70.8 cms (2,500 cfs), and a future site visit is recommended for further assessment of the area.

Figure 3.6 – Looking South at the GCWA pump station. Flow ≈ 70.8 cm = 2,500 cfs (TAMU photo).

Figure 3.7 – Rock outcroppings near the GCWA pump station.
Flow ≈ 70.8 cms = 2,500 cfs (TAMU photo).

The second noteworthy feature observed during the helicopter reconnaissance was an oxbow lake that is forming near the Harris Reservoir, approximately 9.6 km (6 miles) south of FM 1462 at Rosharon and 12.9 km (8 miles) northeast of SH35 at East Columbia. A Digital Orthophoto Quarter Quadrangle (DOQQ) obtained before the flight and dated January 23, 1996, depicts a sharp bend in the river (Figure 3.8). Since the DOQQ was taken, water has eroded the dividing bank and the river no longer flows continuously through the bend. This forming oxbow is expected to provide both shelter and breeding ground for a variety of fish species. Figure 3.9 shows what the forming oxbow looked like in January 2002, exactly 7 years after the DOQQ was photographed. A topographical survey project is currently in progress to measure the frequency of connection of this and other oxbows with the Brazos River, and to determine the fish communities that utilize these frequently isolated riparian aquatic habitats.

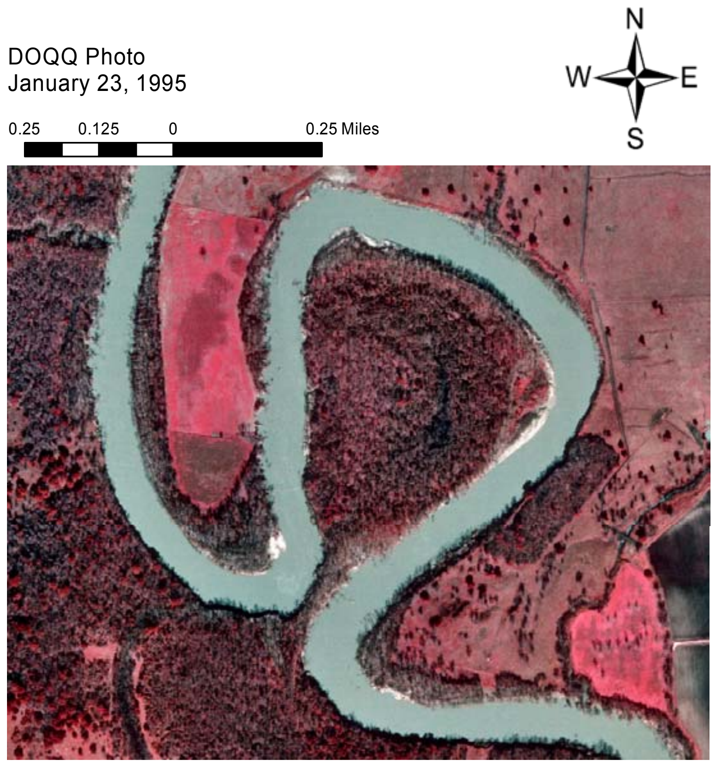

Figure 3.8 – DOQQ of a forming oxbow, January 23, 1996.

Figure 3.9 – Brazos River oxbow, as seen by helicopter on January 23, 2002.
Flow ≈ 113.3 cms = 4,000 cfs.

Based on the on-water reconnaissance performed during the summer 2001 and the airborne reconnaissance performed in winter 2002, Site 1 was determined to be qualitatively representative of the lower Brazos River. An additional study is recommended to determine the frequency and distribution of habitats within Site 1. The results from this study would provide the necessary framework to compare the frequency and distribution of habitats occurring in Site 1 to similar habitats throughout the lower Brazos River basin, enabling a more quantitative determination of the representative character of Site 1. In addition, as part of the characterization of habitats, the boulder area located outside the boundaries of Site 1 should be investigated to determine if further study is warranted.

3.2 Hydraulic modeling on Site 1

To characterize both lateral and longitudinal velocity variations, a two-dimensional hydrodynamic model was developed for study Site 1. The model generated depth and velocity data at points spaced roughly 7 meters (23 feet) apart throughout the entire study site, and the model was executed for a variety of steady-state flow rates ranging from 19.82 cms (700 cfs) to 116.1 cms (4,100 cfs). This section describes the hydraulic modeling exercise; subsequent chapters discuss use of the model output for habitat characterization.

3.2.1 RMA-2

As discussed by Wentzel (2001, PhD thesis), and others (e.g., Leclerc et al. 1995; Moyle 1998; Railsback 1999; Crowder and Diplas 2000), the results of one-dimensional (1-D) hydrodynamic modeling for instream flow assessment are often dependant upon the location of the modeled river transects. Bates (1997) reported that when using PHABSIM, a common 1-D model used for instream flow analysis, transects should be selected to avoid areas of severe contraction and expansion of flow, transverse flow and across-channel variation in water surface elevations. If any of these conditions occur in the segment, then 1-D modeling may not be suitable (USACE 1993).

Two-dimensional hydrodynamic models are designed to resolve such conditions, and a number of features of 2-D finite element modeling contribute to increased hydrodynamic accuracy in river systems with complex morphologies. Depth-averaged 2-D modeling of stream hydrodynamics assumes that water column properties do not change in the vertical direction. This assumption is valid if the effects of the benthic and surface boundary layers are not important for the purposes of the modeling, if the river is not tidally influenced and if the velocity fields near structures (e.g., banks and large woody debris) are not required at an extremely high resolution. A lengthy discussion of the utility of 2-D models is provided in Appendix N in the Draft Texas Instream Flow Studies Technical Overview document (see Chapter 4, Hydrology and Hydraulics).

RMA-2 was used in this study to generate in-channel depth and velocity fields for use in a spatial fish habitat model. It is a two-dimensional, depth-averaged, finite element, hydrodynamic, numerical model. Water surface elevations and horizontal velocity flow fields were calculated from the Reynolds-averaged form of the Navier-Stokes equations for fluid flows. Bottom friction was determined from the Manning's or Chezy equation and eddy viscosity coefficients were used to define turbulence characteristics. The code was originally developed in 1973 for the US Army Corps of Engineers (USACE) with subsequent enhancements made by Resource Management Associates (RMA) and the USACE Waterways Experiment Station (WES). The current version of RMA-2 is supported by the Surface Water Modeling System (SMS) and TABS-MD. SMS was used by TWDB for this study and control of nearly all parameters, boundary conditions and file management options required to run RMA-2 were accessible from inside SMS. Post-processing and visualization of model results was also performed using SMS.

In practical execution of the model, the inflow velocity profile was assumed to be distributed based on depth; bottom roughness and eddy viscosity were used as calibration parameters. SMS and RMA-2 allow the latter two variables to be adjusted in space. RMA-2 allows an adjustment to Manning's N based on depth, and Wentzel (2001) reported that this option is very effective in obtaining a well-calibrated model. Roughness coefficients used for this study were derived from Arcement and Schneider (1983), and eddy viscosity was determined based upon Peclet number (after Donnell et al. 2001). More information regarding both the application of RMA-2 to this project and verification of RMA-2 output with field data is provided in Appendix K.

3.2.2 Data collection at Site 1

To develop and execute the RMA-2 model, three key environmental forcing variables needed to be determined. Very high spatial resolution bathymetric data was collected using a Global Positioning System (GPS) and a depth sounder mounted on a boat. To adjust for the slope of the river surface the bathymetric data was referenced to local temporary benchmarks and reference points that were established adjacent to the study site. In addition, to account for the effects of changes in river stage during the bathymetry data collection period, a combination of staff gauges and pressure transducers were set up at strategic locations along the river to monitor short and long-term changes in the water surface level. The elevation of each pressure transducer and staff gauge was measured using high vertical-resolution surveying techniques so that the relative elevation difference between all equipment sites was determined. The gauges and pressure transducers were used to measure the water surface elevation difference between the upstream and downstream boundaries of the finite element mesh, another requirement for the RMA-2 model calibration. Flow rate was determined by actual field measurement since there was not an established stream gauge located adjacent to the site. However, because of Site 1's close proximity to the USGS Richmond gauge, which is located 60 km (37 miles) downstream, and the relatively small additional drainage area between the two locations, historical readings from the Richmond gauge were used for statistical analyses of flow frequency at Site 1. To account for the time delay between flow conditions at Site 1 and at the Richmond gauge an Acoustic Doppler Current Profiler (ADCP) and a portable acoustic velocity meter (AVM) were used at Site 1 to determine the flows at crucial times during the hydrologic sampling events. The RD Instruments ADCP was used in this study to measure flow rate in water deeper than approximately 3 feet. When use of the ADCP was not possible, the portable AVM unit manufactured by Sontek to record a series of point velocity measurements along the cross-section, which were integrated to calculate flow rate.

Further detail on the data collection methodology can be found in Appendix F and in Appendix N.

3.2.3 Mesh generation for Site 1

In addition to its use in the execution of RMA-2, the Surface Water Modeling System (SMS) developed by Brigham Young University was used to develop the finite element mesh for modeling conducted at both Site 1 and Site 2. The bathymetry point file for Site 1 was imported into SMS, as well as DOQQs for the site. The mesh boundary was established by viewing the extent of the bathymetry point file, simultaneously with the DOQQs. To more clearly define the mesh boundaries, the water's edge was measured with a laser range-finder, but only in limited areas for some flow rates.

After the mesh boundary was established, a high-resolution mesh was generated. Within the guidelines discussed below, mesh resolution was determined by engineering judgment and experience; areas with complex hydraulics (steep longitudinal bathymetry, bridge areas, island areas, flow restrictions, flow obstructions, etc.) were afforded more elements than simple areas with relatively uniform bathymetry. The mesh was generated as fine as possible to maximize the resolution of depth and velocity points that were later utilized for the fish habitat Geographic Information System (GIS) analysis. A hydraulic mesh with a resolution similar to the GIS grid ensures adequate resolution of velocity fields on a scale comparable to that for which hydraulic data will be utilized. The GIS grid cell size used for the fish habitat analysis for Site 1, presented later in this report, was 2.5 meters. The finite element mesh generated for Site 1 consisted of nodes spaced roughly 7 m apart laterally (across the channel) and 12 m apart longitudinally (in the direction of flow). The discrepancy between the GIS grid cell resolution (2.5 m) and the hydraulic model resolution (7 m x 12 m) exists as a result of limitations in the resolution of the bathymetric data used to assign elevation within the hydraulic model and as a result of the limitations of hydraulic modeling assumptions. Generally, the hydraulic mesh should not be generated at a scale finer than the average distance between bathymetric measurements since bathymetry significantly affects model output. The hydraulic model mesh remained coarse to reflect the most accurate bathymetry data collected and to avoid resolving velocity fields over a bed form that may not truly be present. Similarly, minimum mesh size was limited by the assumptions of the specific model being used. Typical model formulations (including RMA-2) utilizing the depth-averaged, hydrostatic, shallow-water assumptions should not be used to resolve horizontal flow perturbations smaller than 1 times the depth, and extra caution should be exercised when resolving perturbations smaller than 5 times depth. It can be noted, however, that reasonable model results have been reported with meshes that were far finer than resolvable by the theoretical model. While they were far outside the suggested sizes given above, Crowder and Diplas (2000) went so far as to report exceptional calibrated results modeling flow obstructions with RMA-2 using an 8cm by 8cm grid in water of 2-meter depth. Increasing resolution often improves model convergence and will be investigated for future use; however, model accuracy is not improved by increased resolution when using RMA-2 at such small scale.

The spatial distribution of nodes and elements for the mesh was carefully controlled since their shape affects the accuracy of model results. The users manual for RMA2 (Donnel et al. 2001) states that elements should be planar (no concave or convex elements), should not have interior angles less than 10 degrees, and should not differ in area by more than 50% from their adjacent elements.

To determine the elevation of the nodes in the finite element mesh, it was necessary to interpolate elevation from the bathymetry data. In practice, this proves somewhat complicated because the traditional interpolation techniques such as Inverse Distance Weighted (IDW), Thiessen Polygon and Cubic Spline do not take into account the known general shape of a river channel (eg., the high vertical gradient near the banks and the relatively low gradient along the length of the channel). While a curvilinear Kriging approach will be investigated in the future, a modified Inverse Distance Weighted technique was instead developed (Osting 2003). This new IDW algorithm, written as a FORTRAN program, uses rectangular search areas in selecting the interpolant data points, with the larger rectangle dimension location parallel to the river thalwag. By placing greater influence on points upstream or downstream of the point to be interpolated this technique increased interpolation accuracy because river bathymetry variations are greatest in the lateral direction. This technique performed remarkably well and was used for interpolating the node bathymetries in this and other recent projects. More information on this technique is provided in Appendix G and in Osting (2003).

An additional caveat considered when assigning bathymetric elevations to mesh nodes was the presence of steep bed gradients oriented in the direction of flow. Most 2-D models use the shallow-water equations with the hydrostatic assumption that are not capable of resolving vertical pressure gradients. Steep bed gradients (slopes greater than 20%) in the direction of flow, however, cause real world vertical pressure gradients and possible flow separations to occur. In some areas where the mesh slope exceeded 20% and model convergence problems occurred, the mesh bathymetry values were manually adjusted to reduce the bed slope.

A limit of 30,000 nodes and 10,000 elements exists in the widely distributed version of RMA-2. Computing effort becomes high with increasing number of nodes (run time approximately squares with a doubling of the number of nodes) so therefore every attempt was made to keep the model coarse enough to adequately model the flow and yet fine enough to pick out the detail of small areas of fish habitat. In the end it was necessary to obtain a recompiled version of RMA-2 that supported the use of 165,000 nodes and 55,000 elements. This made for longer run time, but allowed great resolution of the mesh.

The extent of the Site 1 mesh is shown in Figure 3.10. Computationally, and in terms of the fluid mechanics, the three areas that were the most challenging to model was the area near the bridges, the confluence with Allens Creek and the island area. Photographs of these three locations are shown in Figures 2.13, 2.14, 2.15, and 2.16. Depictions of the mesh resolution in the area around the bridge and the mesh resolution in the island area downstream of Allens Creek are shown in Figures 3.2 and 3.3, respectively.

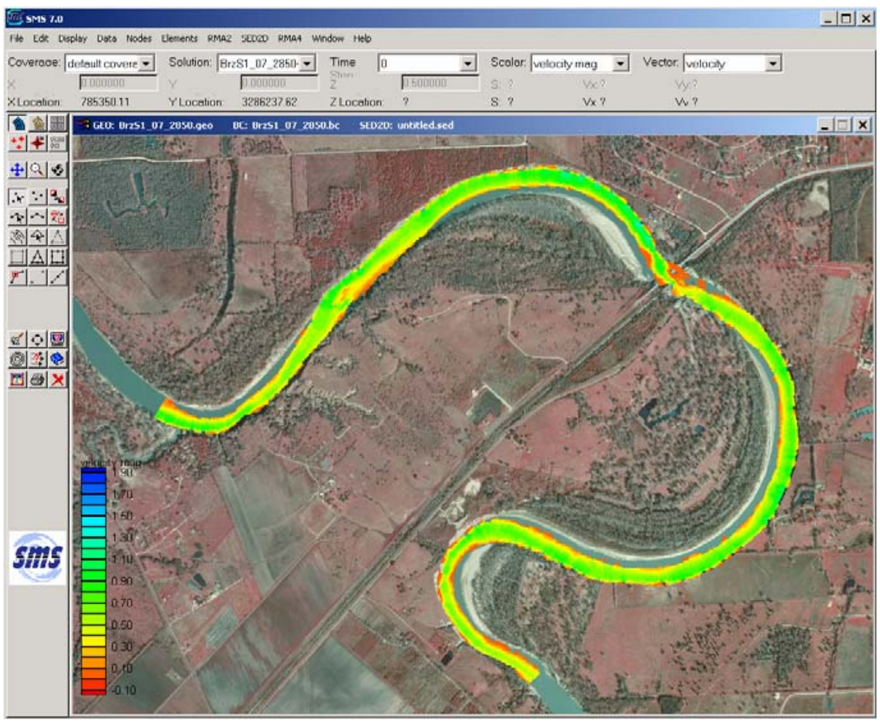

Figure 3.10 – Extent of the finite element mesh. Site 1 of the Brazos River. Flow=2,850cfs. Color contours represent velocity magnitude.

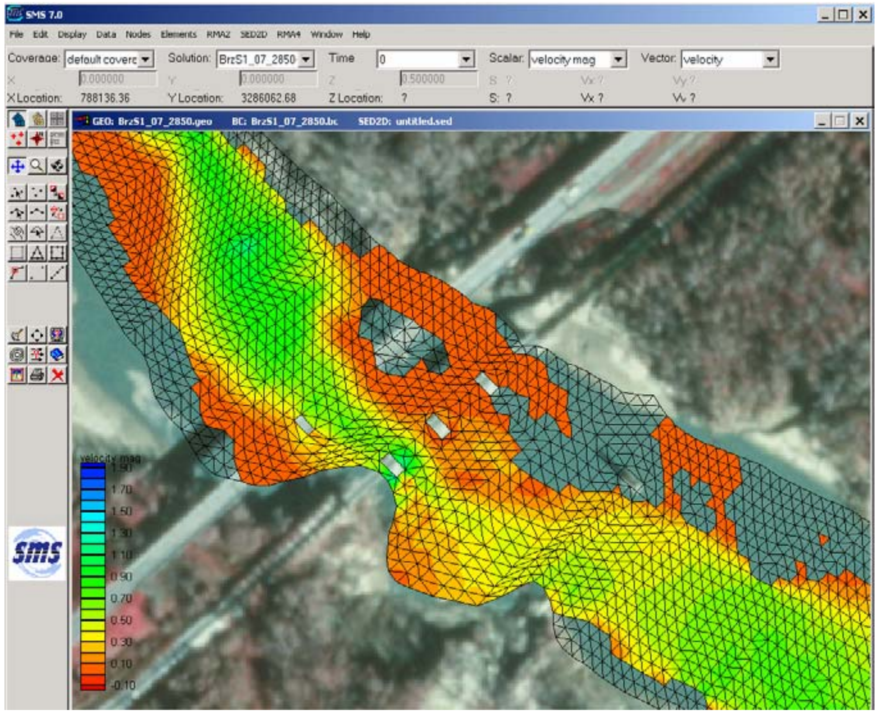

Figure 3.11 – Mesh resolution around the railroad and highway bridges. Flow = 2,850 cfs. Color code represents velocity magnitude.

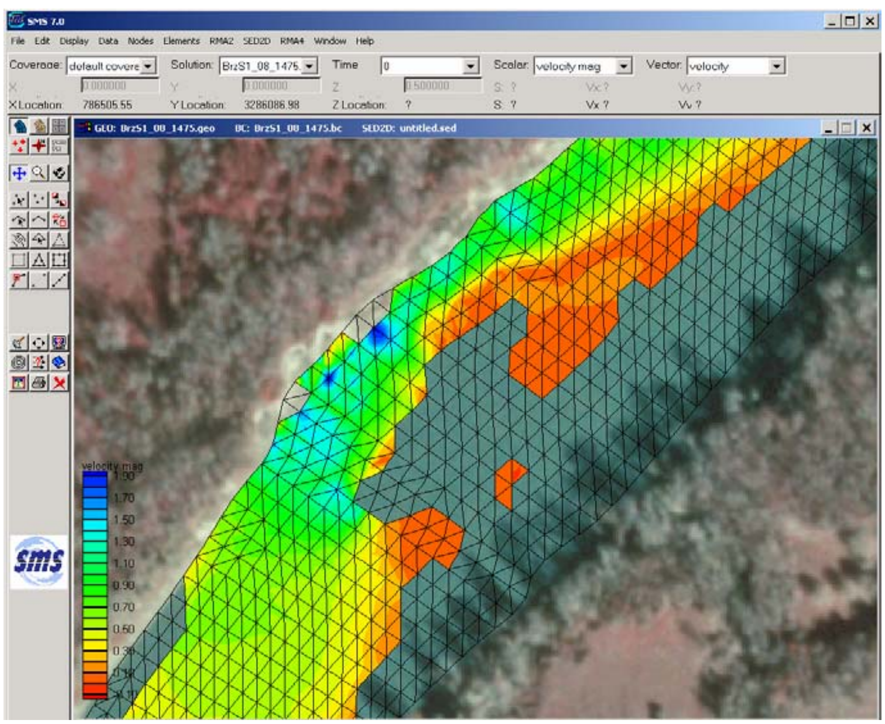

Figure 3.12 – Mesh around the island downstream of Allens Creek. Flow = 1475 cfs. Color code represents velocity magnitude.

3.2.4 Modeled flow rates at Site 1

Thirteen flow rates were modeled for steady-state conditions and are presented in this report (Table 3.1) along with their percentile rank with respect to the entire period of record at the USGS Richmond gauge. Detailed field measurements were recorded at 41.22 cms (1,456 cfs), 94.86 cms (3,350 cfs), and 221.44 cms (7,820 cfs), and these measurements were used to calibrate the model. Flow rates of 25.48, 41.22, 62.29, 73.62, and 116.09 cms (900, 1456, 2200, 2600, and 4100 cfs, respectively) were modeled to correspond to flows that occurred on biological sampling dates. Field measurements are presented in Figure 3.13 in a graph depicting flow versus water surface elevation. Hydaulic model verification data, included in Appendix K, corresponds well to the measured field data.

Median daily-averaged flow for the period of record between July 1903 and June 2004 at the Richmond gauging station is 83 cms (2,930 cfs). A flow of 80.70 cms (2,850 cfs) was modeled to approximate hydraulic and habitat conditions at the median flow at the study site. The lowest flow modeled was 19.82 cms (700 cfs) because, as currently permitted, the Allens Creek project will not draw water from Brazos River when flow is less than the water quality protection flow of 20.78 cms (734 cfs; see Appendix A). Lower flow rates are recommended for future analysis since there is a possibility that the minimum flow criteria will be lowered to increase the firm yield of the Allens Creek project. Considering the negligible flow rate of Allens Creek when compared to the Brazos River even at low flows, no flow contribution from Allens Creek is incorporated into the model.

Table 3.1 – List of steady-state flow rates analyzed at Site 1.

	USGS Richmond gauge #08114000				
Significance of flow rate	Flow (cms)	Flow (cfs)	Percentile Rank of historical flows Winter	Summer	Annual
Hydraulic verification	221.44	7820	71.1%	75.4%	73.9%
Fish sampling	116.10	4100	54.1%	60.9%	58.5%
Hydraulic verification	94.86	3350	49.30%	56.10%	53.80%
Median flow	80.70	2850	45.10%	51.80%	49.50%
Fish sampling	73.62	2600	42.70%	49.60%	47.20%
	67.96	2400	40.20%	47.50%	45.00%
Fish sampling	62.30	2200	38.00%	45.10%	42.70%
	50.97	1800	32.30%	38.80%	36.60%
Hydraulic verification and fish sampling	41.23	1456	26.30%	31.30%	29.60%
	36.81	1300	22.70%	27.20%	25.70%
	31.15	1100	18.40%	21.50%	20.60%
Fish sampling	25.49	900	13.20%	15.40%	14.80%
Water quality protection flow (not modeled)	20.78	734	8.90%	10.10%	9.90%
Low flow	19.82	700	7.90%	9.00%	8.80%

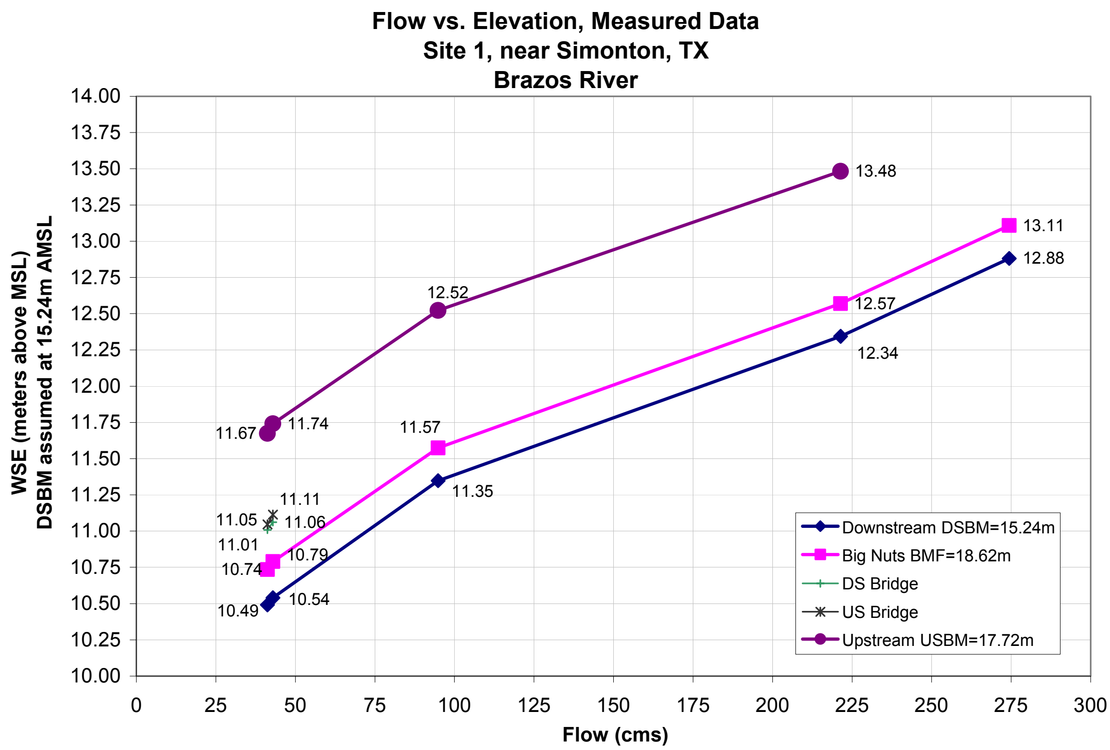

Figure 3.13 – Water Surface Elevation vs. Flow for measurements at Brazos River Site 1.

3.3 Hydrodynamic and salinity modeling at Site 2

To understand how the Allens Creek project might affect the movement of saline water up the river from the coast, a second study segment was chosen. Site 2 encompasses a portion of the Gulf of Mexico, a short stretch of the Gulf Intracoastal Waterway (GIWW) and extends some 42 river km (26 miles) upstream, well beyond the Dow Chemicals pumping station in Brazoria (see Figure 3.14) and beyond the extent of any historically measured salt-water range. The geographic extent of the model was made sufficiently large to properly handle the mass balance equations for transport of salt. Acknowledgement and thanks are hereby extended from the authors to Dr. Junji Matsumoto who performed the numerical modeling of the Brazos River estuary.

3.3.1 TxBLEND3D

For modeling hydrodynamics in coastal and tidal regions where salinity and density gradients exist and where velocity and mixing in the vertical direction is important, it is necessary to employ a three-dimensional (3-D) model. 3-D models have been used extensively at the TWDB for determining freshwater inflow needs of Texas bays and estuaries. TxBLEND3D was used for this study.

The original two-dimensional TxBLEND2D code was designed specifically to simulate water circulation and salinity conditions in estuaries, and has been used in other studies to determine migration of saline water in the Brazos River estuary. The model is finite element based, using triangular elements. To simulate movements in two dimensions, the code solves the shallow water equations (continuity and momentum equations) and determines salinity by solving the mass transport and convective-diffusion equation (Matsumoto 1999). TxBLEND2D is an updated and adapted version of the FLEET and BLEND codes developed by William Gray of Notre Dame University. Additional input routines to handle tides, river inflows, winds and evaporation were added by TWDB engineer Dr. Junji Matsumoto.

TxBLEND3D was developed by TWDB in order to handle bay systems with man-made structures such as ship channels, jetties and dikes, which each add complexity in both the vertical and horizontal dimensions. TxBLEND3D models the horizontal dimension using linear triangular elements and the vertical dimension by non-uniform layers (or levels), so that the open bay portion of a typical system may be modeled by three or four levels while the channel portion may be modeled by five or six levels. The two principal innovations of the TxBLEND 3D code are the use of non-uniform layers and the Cartesian coordinate system (or z-coordinate) in the vertical dimension. The abrupt changes in depth near the ship channels make the z-coordinate system more suitable than the σ-coordinate system commonly used in oceanographic modeling (e.q. Mellor 2003). The TxBLEND3D model has been used on a number of projects, including the Corpus Christi Ship Channel Improvement Project, which was evaluated and approved by the USACE Waterways Experiment Station.

3.3.2 Data collection for Site 2

Use of the TxBLEND3D model required the collection of time-series data for river inflows, river stage variation, tidal elevation variation, multi-layer salinity concentration variation and bathymetric data. Time-series river inflow data observed at the USGS Rosharon gauging station (#81146650) was used for inflows and input into the transient model. Time-series river stage and tide elevation data was collected by TWDB using pressure transducers where indicated in Figure 3.14. The Conrad Bluecher Institute (CBI) tide gauge located near Freeport, TX, in the Gulf was used for off-shore time-series tidal elevations. A number of Hydrolab water quality instruments were installed at various locations along the reach for monitoring salinity variation.

The US Geological Survey (USGS) was contracted to install Sontek Acoustic Doppler Profiler (ADP) devices that measure velocity and monitor flow in the area near the GIWW intersection. This was necessary to account for flows that pass in and out of the locks located on the GIWW. In addition, an ADP was installed by TWDB near the SH36 bridge to measure velocity and provide verification of modeled velocities. A 48-hour inflow study was performed by TWDB and the USGS to generate rating curves for each of the velocity installations. At each ADP installation site, flow rate was measured using ADCPs.

To establish a regional elevation datum for all of the water level measurements, a number of National Geodetic Survey (NGS) benchmarks were chosen and referenced to each pressure transducer site using high-vertical-resolution, post-processed differential GPS equipment (PPDGPS). A conventional three-wire level loop was performed from each of the NGS benchmarks down to the water surface where pressure transducers were installed. Published NGS benchmark elevations were verified using the PPDGPS equipment.

Bathymetric data for Site 2 was collected using the same methodology as that described for Site 1, however a high resolution bathymetry was not required or obtained for Site 2. The movement of salt in the Brazos River was primarily related to freshwater inflow, the amplitude of the tide and the slope of the riverbed; bathymetric resolution of small geomorphologic formations was not required.

Further detail on the data collection methodology can be found in Appendix F.

3.3.3 Mesh generation for Site 2

The mesh for Site 2 was developed using the UNIX version of the SMS software package. Boundaries were determined from the GPS points in the bathymetry files and from the river edge located using existing DOQQs. As is the convention for a model of a tidal or estuarine region, the finite element mesh extended well out into the Gulf of Mexico. This was necessary in order to correctly model the movement of salt away from the river mouth during flood tides and back into the river during the ebb tides. For the purposes of the modeling exercise, the boundary of the mesh was also extended further up the river than the area where bathymetric data was collected. The full extent of the mesh used for this project is shown in Figure 3.15. Mesh resolution near the GIWW intersection was increased since significant mixing occurs in this region that is located near the mouth of the Brazos River (Figure 3.16). Bathymetry for the entire site is shown in Figure 3.17. To render the mesh three dimensional, 6 vertical levels with Cartesian z-coordinates were added. Figure 3.18 shows a vertical view of the mesh (Note that the vertical scale is distorted).

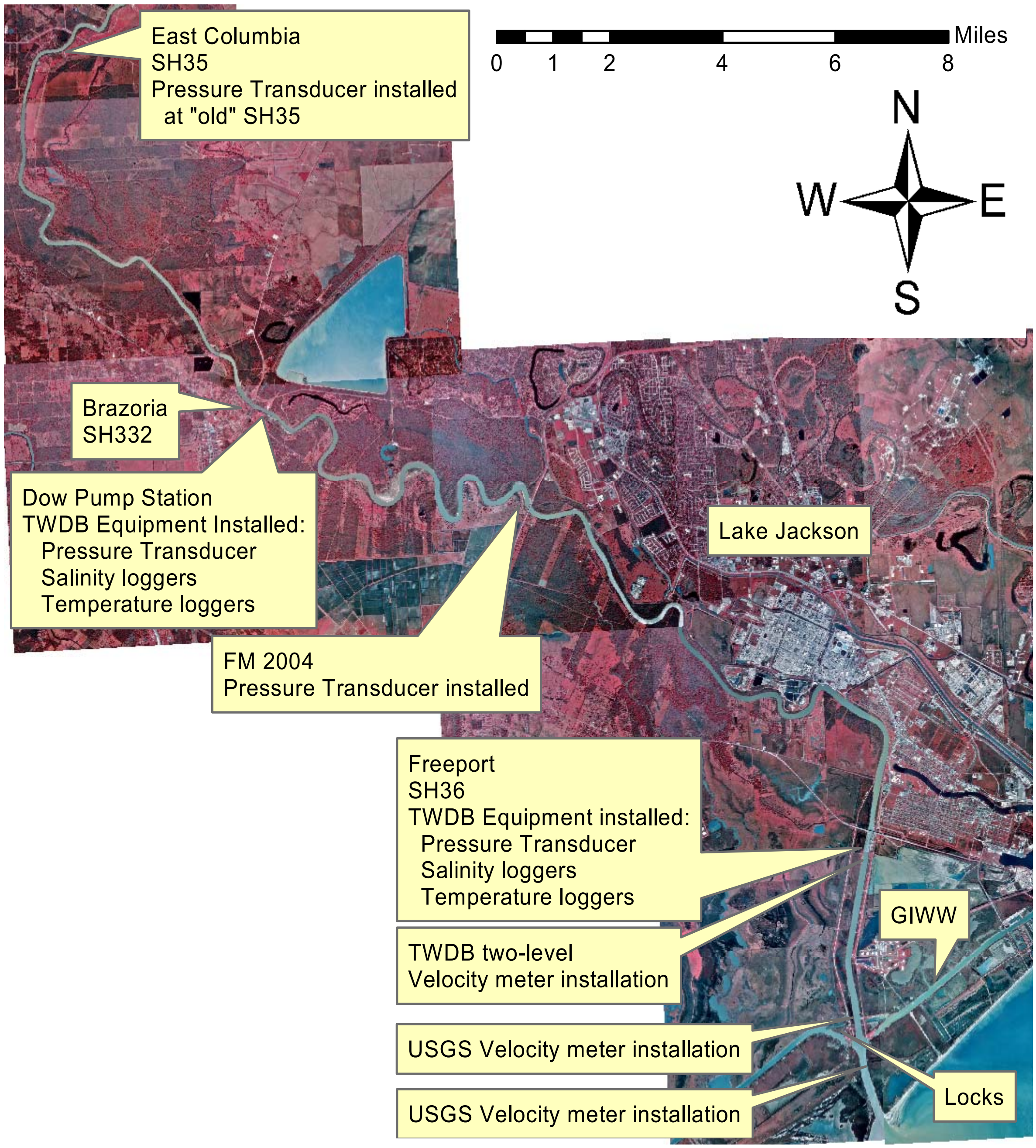

Figure 3.14 – DOQQ of Site 2 of the Brazos River.

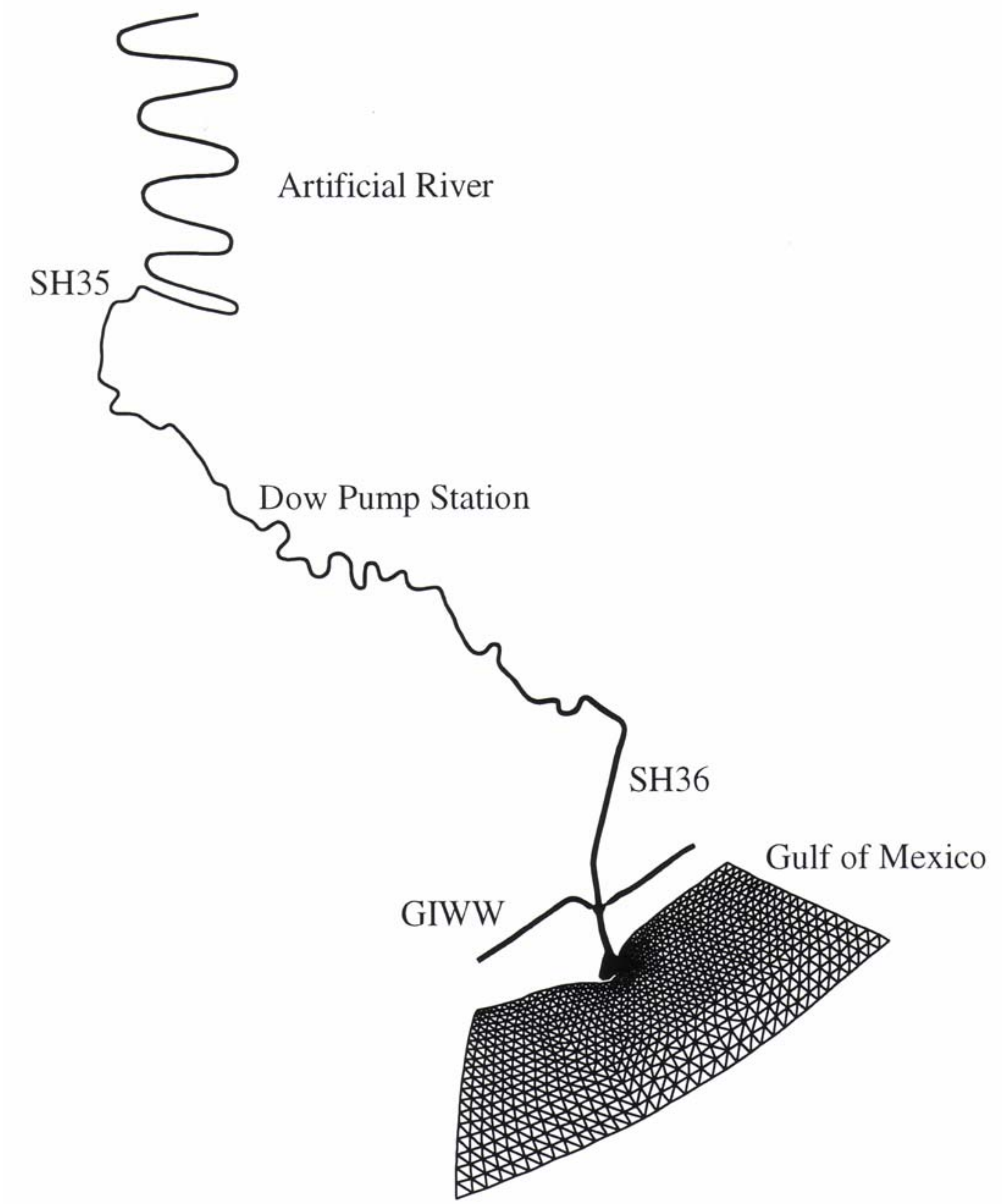

Figure 3.15 – Computational grid for the Site 2 Brazos River Model.

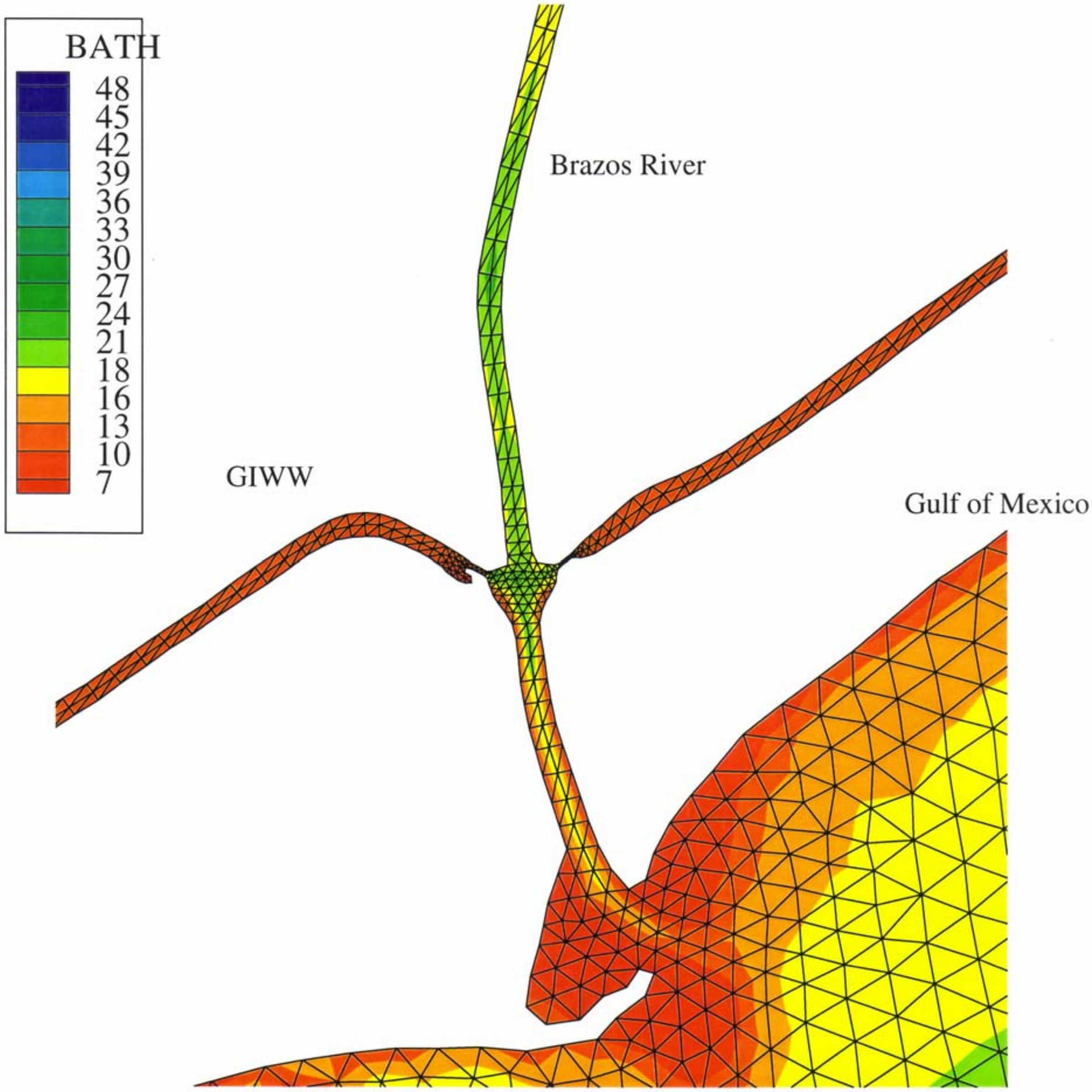

Figure 3.16 – Close-up of the mesh in the Brazos River mouth area.

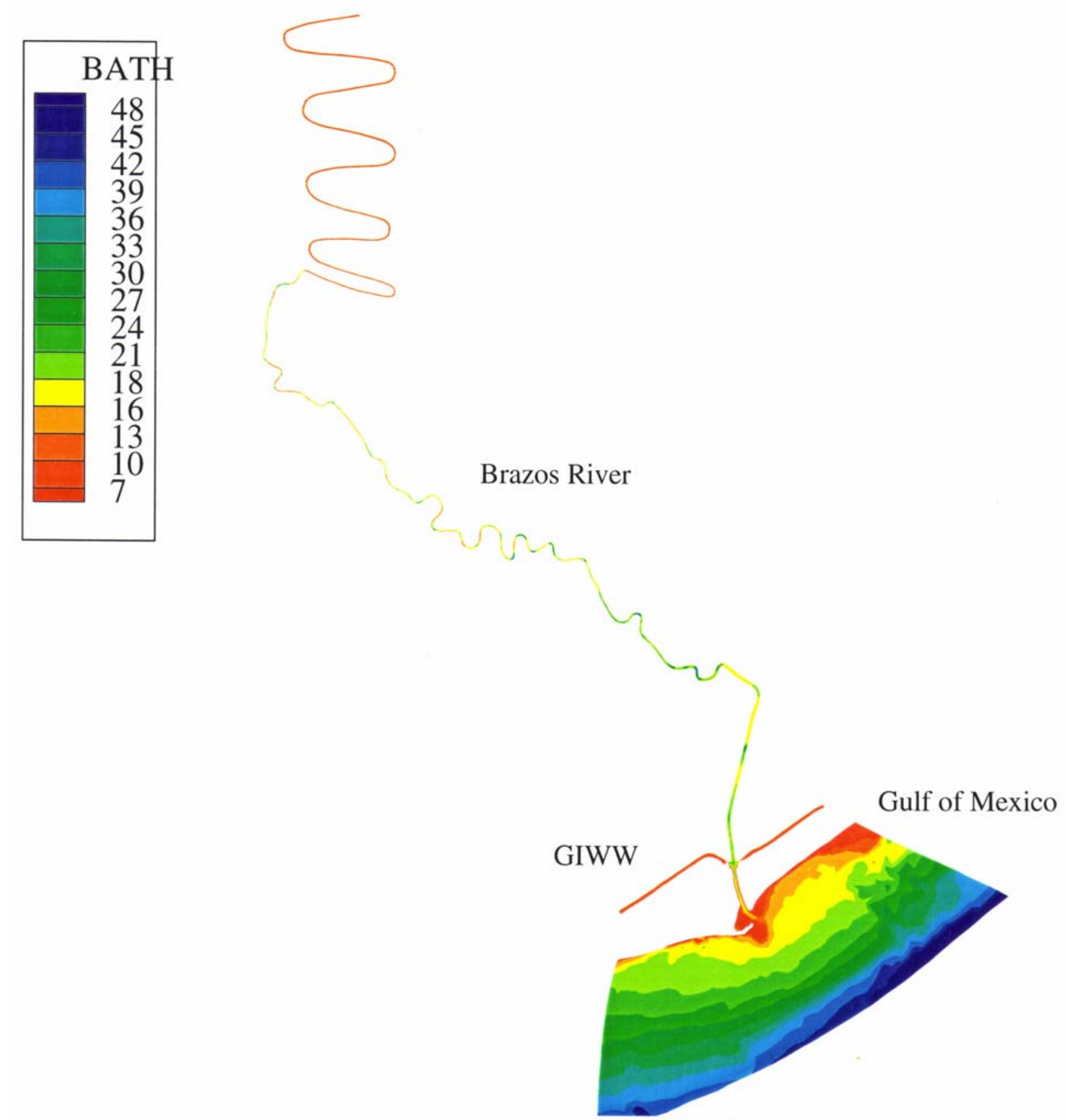

Figure 3.17 – Bathymetry of the Brazos River Model (in feet).

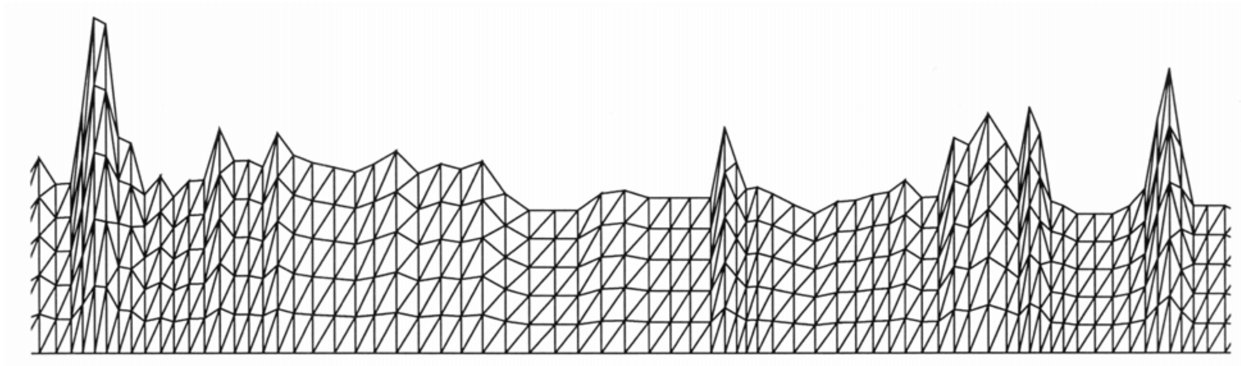

Figure 3.18 – Vertical computational grid for a typical section of the Site 2 Brazos River model.

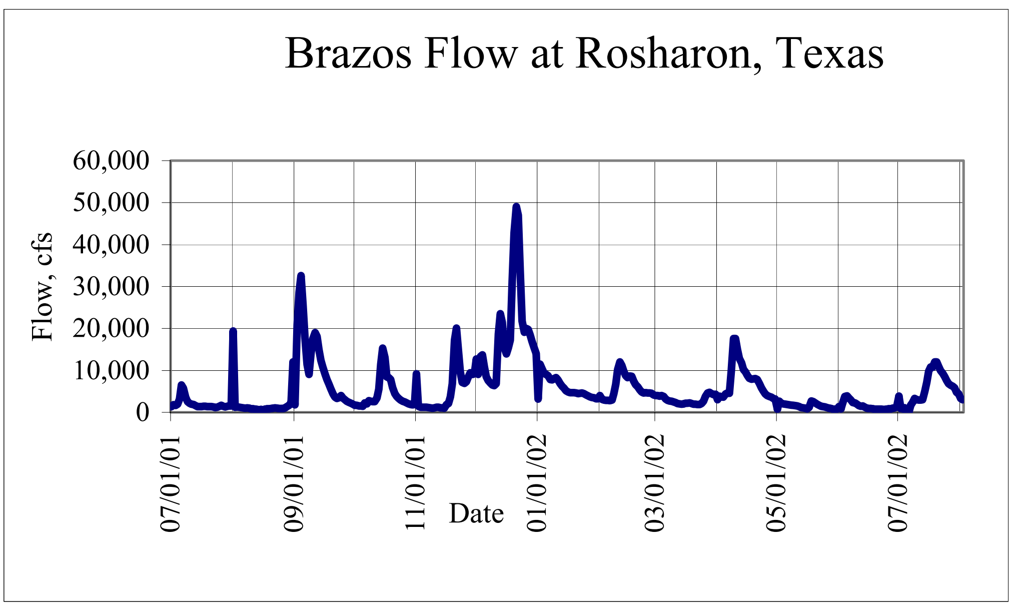

Figure 3.19 – Flow at Rosharon for the period of TxBLEND calibration.

3.3.4 Model calibration for Site 2

Tide and stream gauge data was available for a long historical record; however, most instrumentation installed for this study only recorded between the middle of summer 2001 and early 2003. Therefore the period used for calibrating the hydrodynamic and salinity model was from the middle of summer 2001 to the middle of summer 2002. Flow recorded at the Rosharon gauge for this period of time was used for model input and is shown in Figure 3.19.

Figures 3.20 through 3.24 compare the simulated and observed water surface elevations for the calibration period for the points where pressure transducers were deployed. The modeled results closely matched the observed tide-river flow interaction at all of these sites for both dry and flood periods.

Figures 3.25 and 3.26 show the observed and simulated salinity at the Highway 36 bridge near Freeport for the bottom and surface water layer, respectively. Again, a very close fit between the modeled and observed salinity was obtained for the period of record. A salinity difference of about 5 ppt between the surface and bottom layers at the State Highway 36 Bridge suggests slight salinity stratification even under dry conditions.

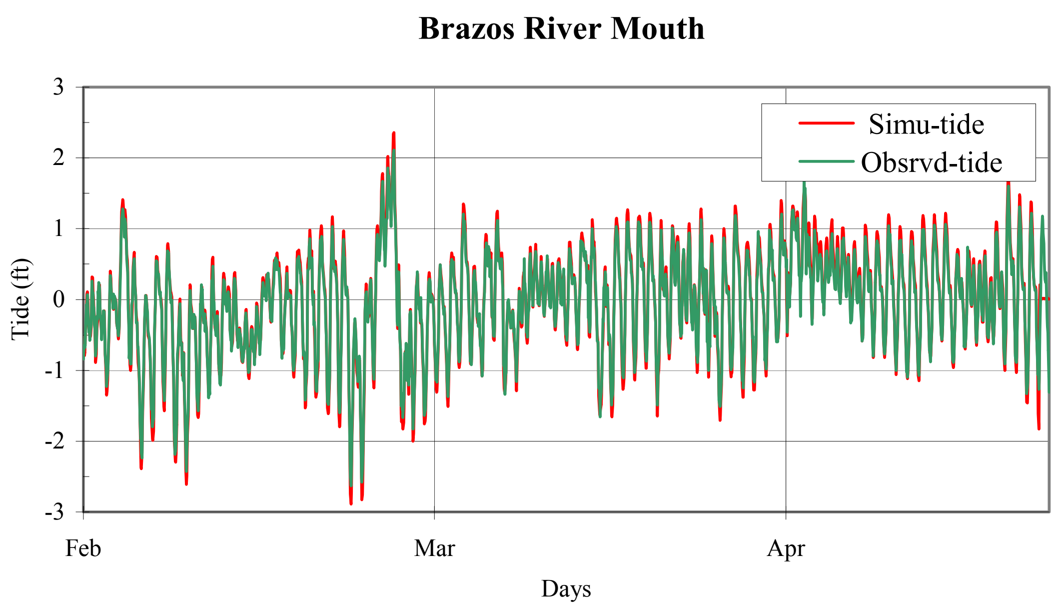

Figure 3.20 - Simulated and observed water surface elevation at the Brazos River mouth.

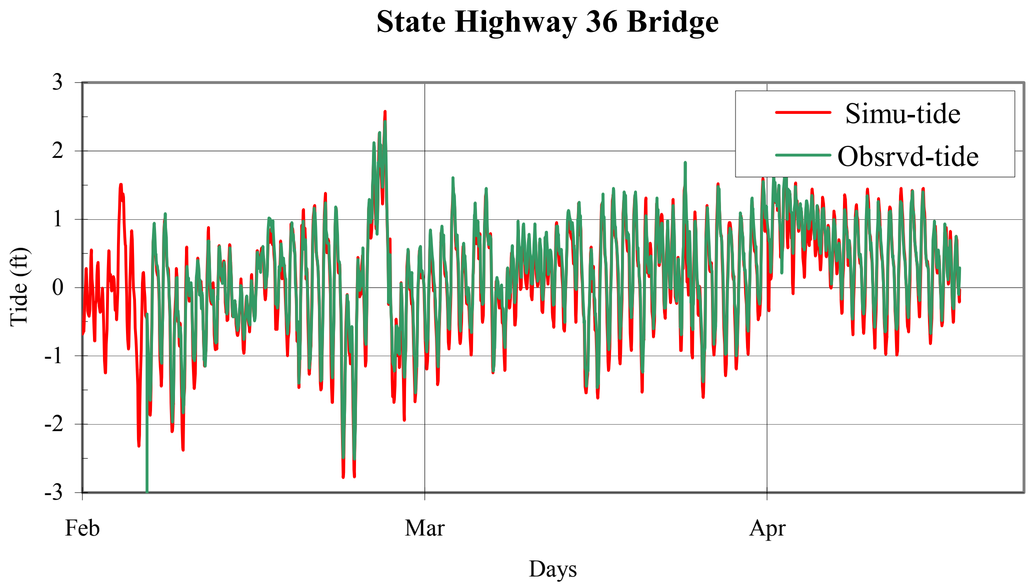

Figure 3.21 - Simulated and observed water surface elevation at the State Highway 36 Bridge.

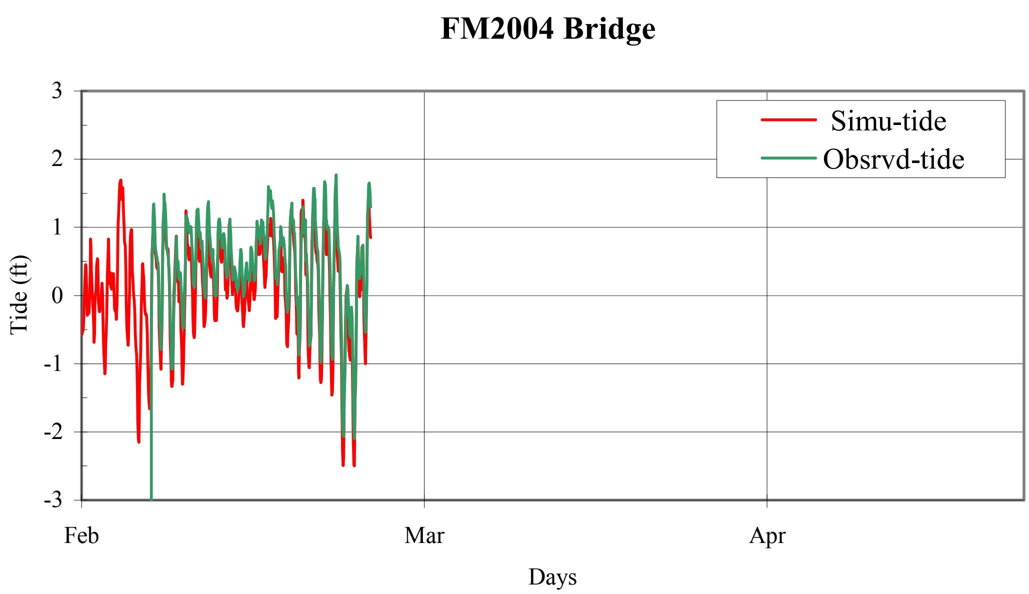

Figure 3.22 - Simulated and observed water surface elevation at the FM2004 Bridge.

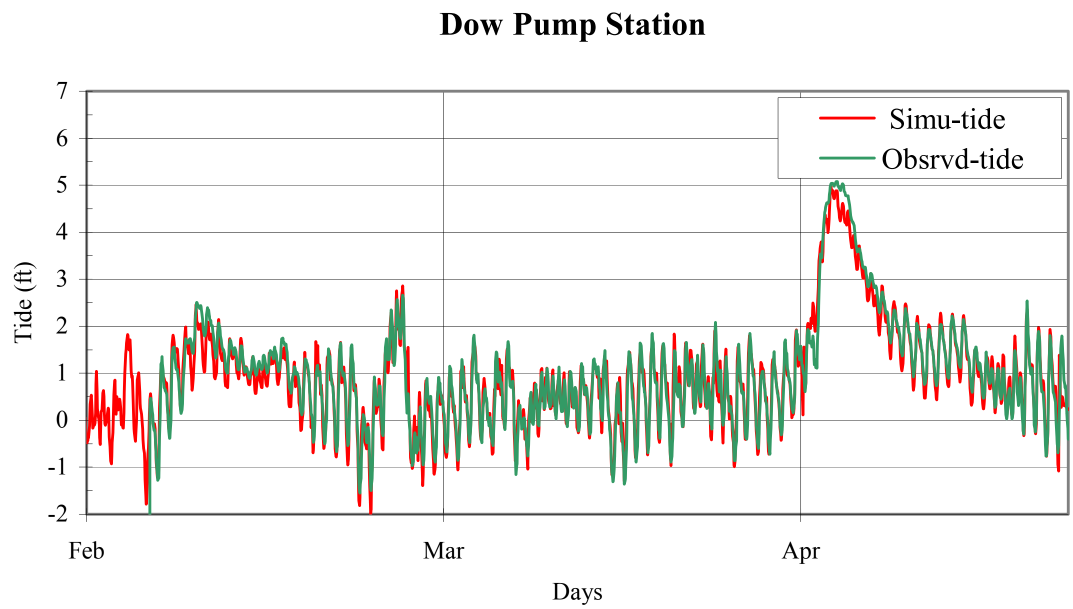

Figure 3.23 - Simulated and observed water surface elevation at the Dow Chemical pump station.

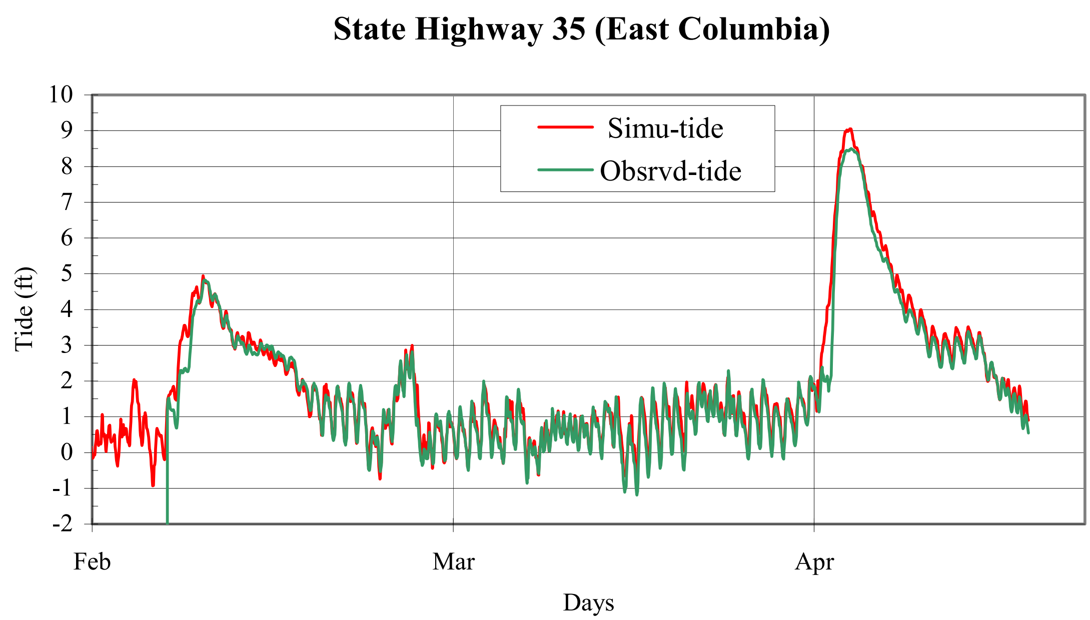

Figure 3.24 - Simulated and observed water surface elevation at the State Highway 35 Bridge.

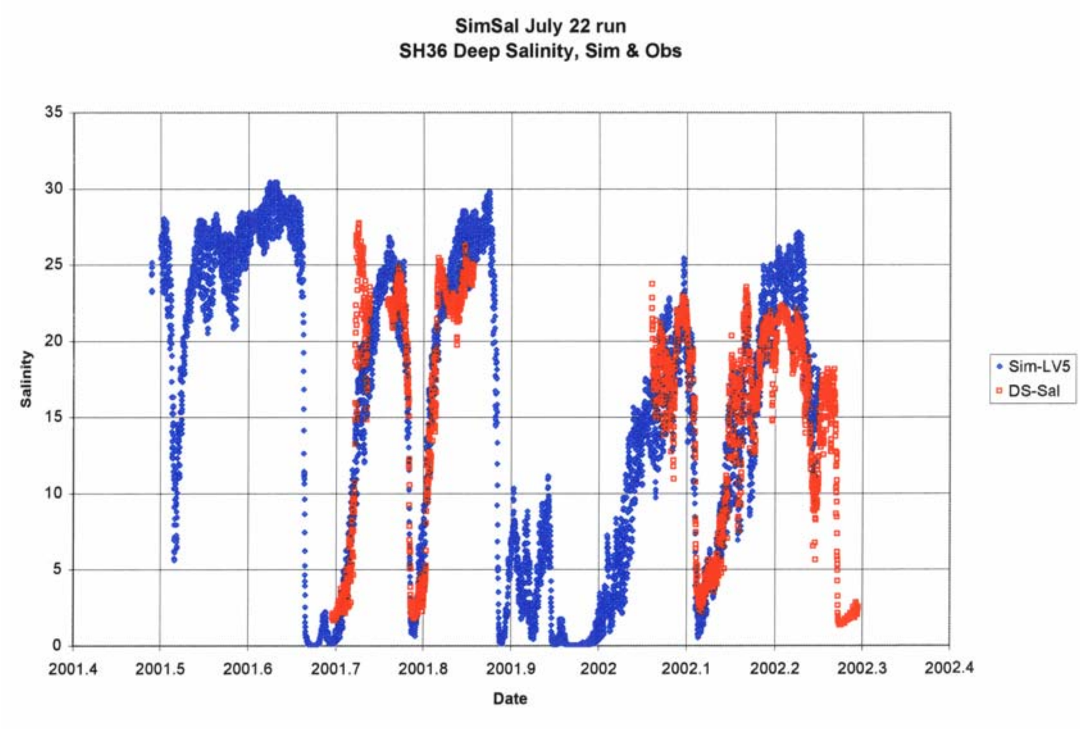

Figure 3.25 – Simulated and observed salinity near the bottom at the Highway 36 Bridge.

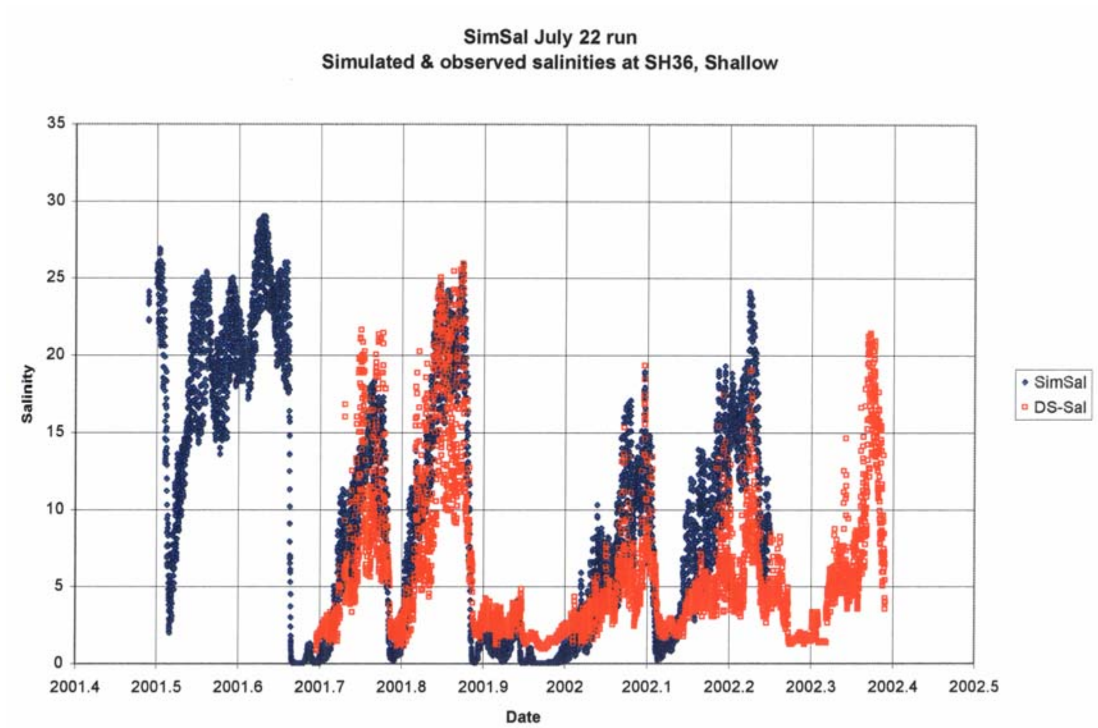

Figure 3.26 – Simulated and observed salinity near the surface at the Highway 36 Bridge.

Figures 3.27 and 3.28 show simulated and observed salinity at the Dow Chemical Brazoria pump station at mid-depth over a particularly dry period in summer 2001. The salinity at the pump station site is much lower than both surface and bottom salinity at the Highway 36 Bridge, over the same time period. Although high salinity ocean water has to travel nearly 20 river km upstream to influence salinity at the pump station, salinity in this location is strongly influenced by the tide. Flows at the Rosharon gauge for the corresponding time period are shown in Figure 3.29. Note that on August 14, 2001, flows dropped as low as 623 cfs. At these low flows, both simulated and observed salinities reach 5 to 9 ppt. Under exceptional conditions of low flow and large tidal amplitude, even higher salinities at this location are expected.

While a comparison of the observed and simulated velocities was not a primary interest for this report, salinity migration in the model is influenced by the mass transport equations that rely on modeled velocity. Therefore, inspection of velocity outputs provided a clue to model performance. During the summer of 2001, two Sontek ADPs were installed near the Highway 36 Bridge. One was placed near the bottom of the river channel to measure low-level velocity, while the other ADP was placed near the water surface. Figures 3.30 and 3.31 show simulated and observed velocities near the bottom and near the surface of the river immediately downstream of the Highway 36 Bridge. Modeled and observed surface water velocities matched one another quite closely. Modeled bottom velocities, however, did not match the observed velocities and a reason for this discrepancy was not determined. One would expect, as was observed in the simulations, that the velocity near the surface would be greater, but this was not observed from the data. It proved to be difficult to anchor the instruments on wooden platform in the mud, and a likely explanation for the velocity discrepancy is that one or both of the ADPs shifted slightly on its platform and was not positioned perpendicular to the flow in the channel. In addition, this was a high traffic area and a vessel may have come into contact with the wooden structure effectively twisting the mounting poles. Additional investigation into this matter is recommended.

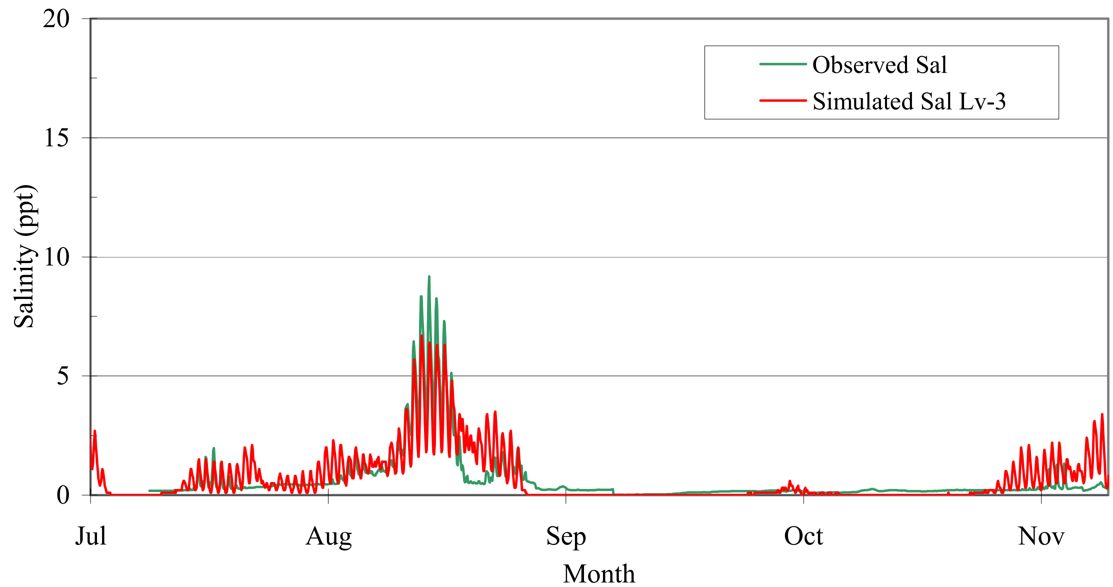

Figure 3.27 – Salinity at mid-depth at the Dow Chemical pump station near Brazoria during the months of July to November 2001.

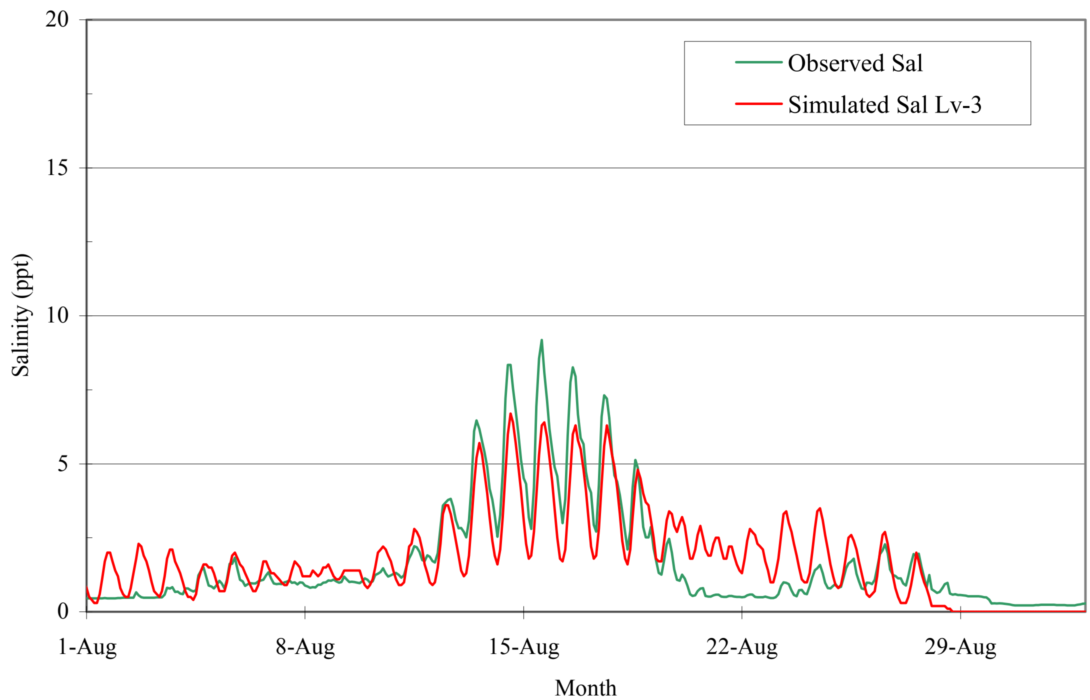

Figure 3.28 - Salinity at mid-depth at the Dow Chemical pump station near Brazoria from August 1, 2001 to August 29, 2001.

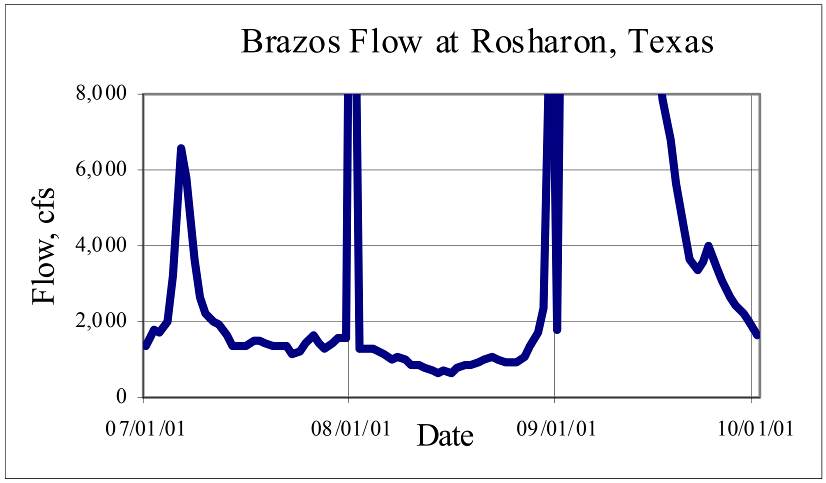

Figure 3.29– Brazos River flows at Rosharon during dry period simulated by TxBLEND3D.

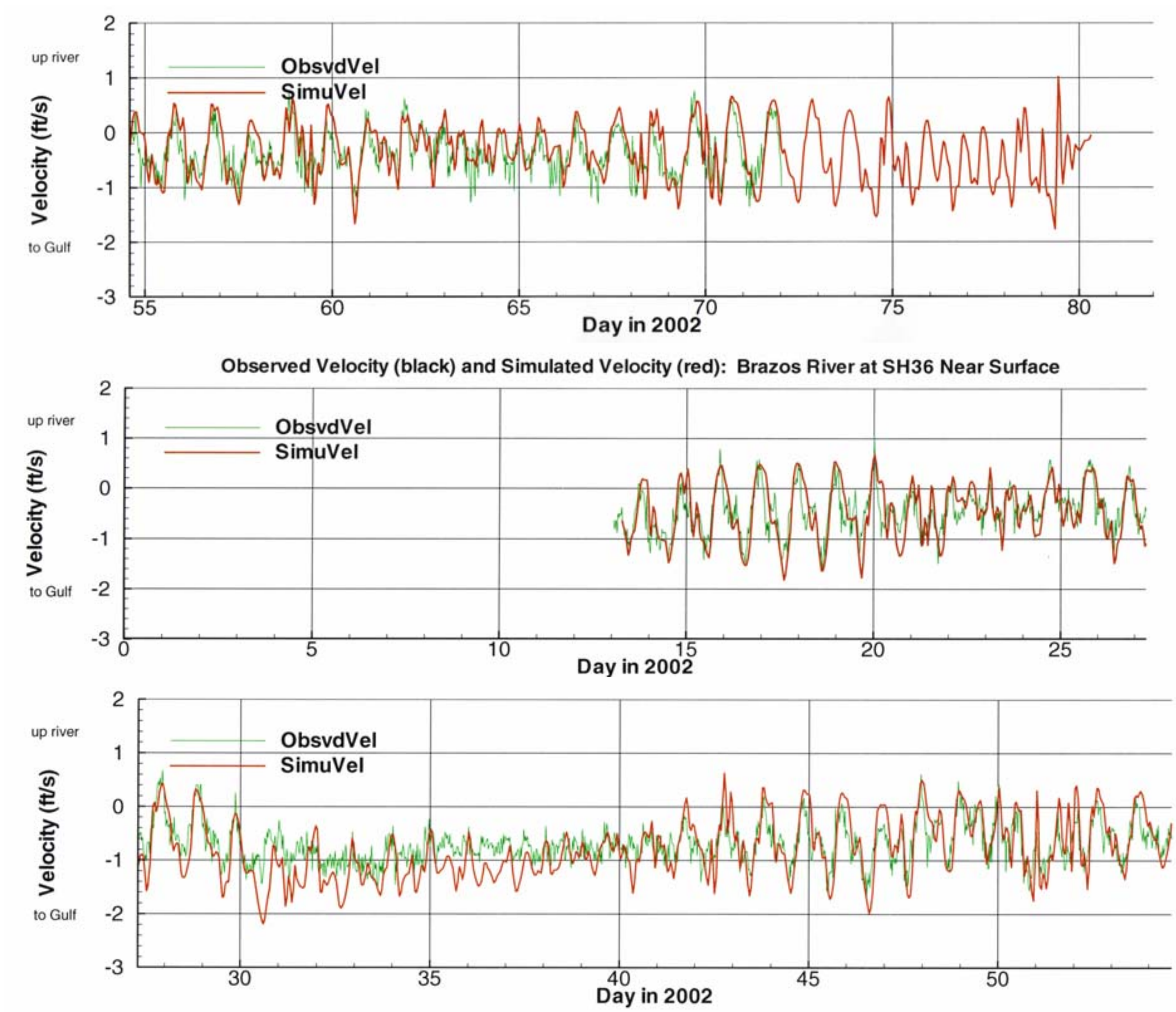

Figure 3.30 – Modeled and observed velocity near the surface at the Highway 36 Bridge.

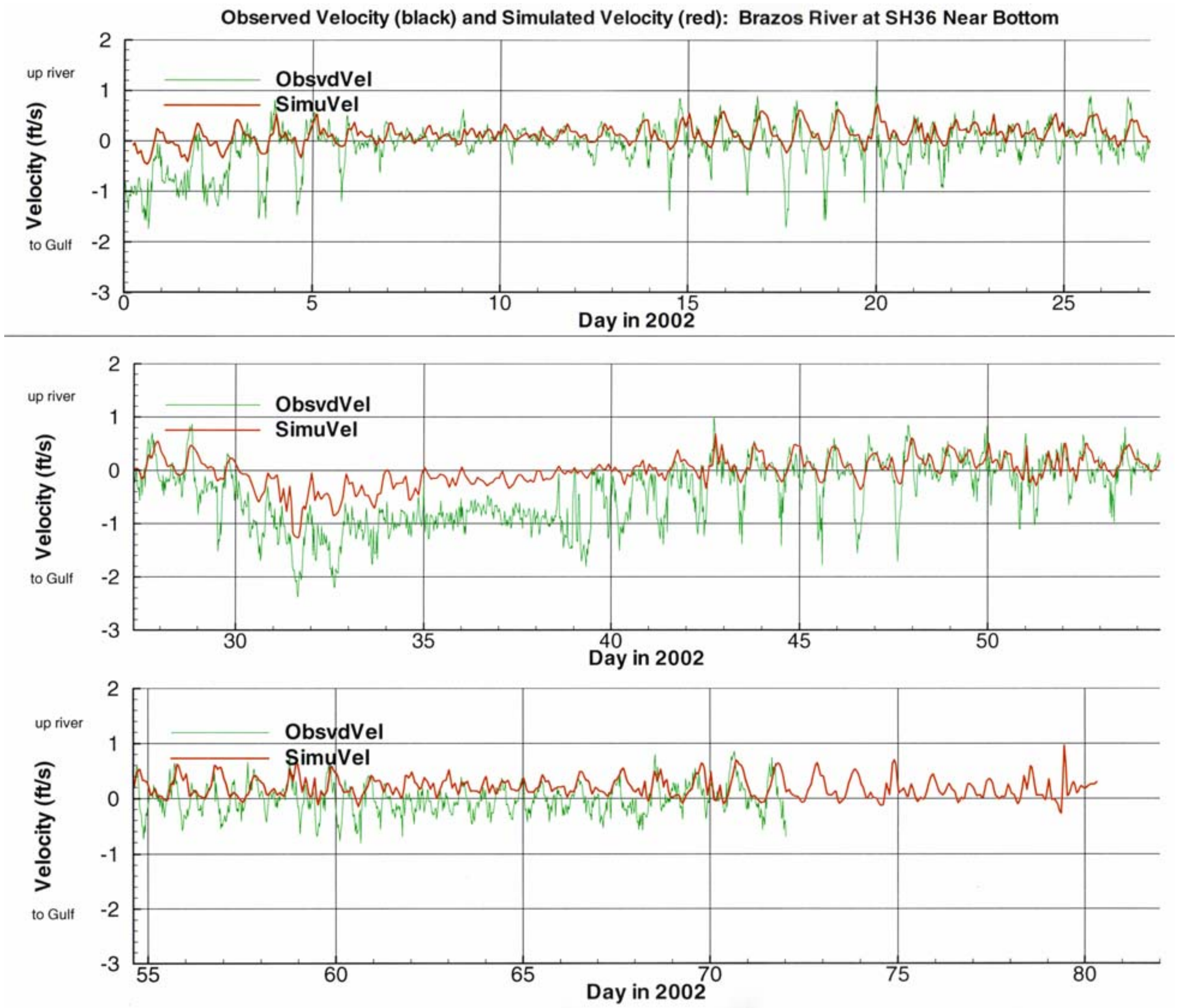

Figure 3.31 – Modeled and observed velocity near the bottom at the Highway 36 Bridge.

3.3.5 Case studies of salinity migration at Site 2

To determine the impact of the proposed Allens Creek Reservoir diversions on the tidally influenced reach of the Brazos River, conservative flow estimates generated by TCEQ's Water Availability Model (WAM) Run 3 were used as input into the calibrated hydrodynamic model. An overview of the WAM project is presented in Appendix L. WAM Run 3 uses naturalized monthly flows as input and removes current permitted diversions from the fully authorized amount. It also assumes 100% re-use of this diverted water and no return flows. Simulated flows for the period 1940 to 1997 are shown in Appendix M. The driest year in the series was 1956, the wettest year was 1992 and the median year, in terms of total annual volume of flow, was 1994. These three years represent a wide range of flows and were chosen to determine a plausible maximum variation of salinity at various points on the tidal portion of the Brazos River.

The calibrated TxBLEND3D model was executed for the three flow cases, dry, wet and median. A constant daily flow for each month of the simulation was obtained by dividing the number of days into the monthly flow volume. For the purposes of the simulation, one additional month (December of the previous year) was used for model "spin-up" for each one-year, one-case model. One additional scenario was tested, using a constant flow of 734 cfs for the entire year. Salinity boundary conditions were kept at 34 ppt at the Gulf and 0 ppt at the river inflow point (upstream boundary of model). Daily tidal data used for all simulation input was the Freeport station data for the year of 2001. There was no expectation that the simulations match actual salinities or tides for the years chosen, only that salinity would be determined at each point of interest for the four flow cases.

Modeling results indicated high salinity in the driest year and very low salinity in the wet year, as was anticipated. Figure 3.32 depicts mid-depth, mid-channel salinity at the Dow Chemical diversion point for the four cases. Notice that even in the wet year, salinity reached 6 or 7 ppt towards the end of the summer during a short dry spell. In the dry year, salinity at the Dow Chemical diversion point remained high throughout the whole year, exceeding 25 ppt nearly every day for most of the mid to late summer period. The constant flow case showed that a constant flow of 734 cfs was sufficient to hold the salinity in the range of 2 to 11 ppt, even during higher amplitude tides.

3.3.6 Salinity migration summary for Site 2

The calibrated model developed for this study can now be used as a tool to determine the impact of various reservoir operating rules and hydrologic conditions on the migration of saline waters in the Brazos River estuary. Salinity levels at all locations modeled were shown to depend on the inflow from the river (fresh water coming downstream) and on tidal amplitude (saline water traveling up from the Gulf). Four cases show that saline Gulf water extended up to and beyond the Dow Chemical pump station near Brazoria, TX, under dry conditions, and during dry periods occurring in an otherwise wet year. The case where flow was held at a constant 734 cfs indicated that salinity levels did not exceed 11 ppt near Brazoria.

Flow in the Brazos at the pumping station does drop below 734 cfs for extended periods, as witnessed in the historical gauge record at Rosharon. The Water Quality Protection Flow in combination with the diversion restrictions also specified in the Allens Creek permit, appears sufficient to protect the Brazoria site from being negatively impacted by an increased occurrence of salt water intrusion. Whether or not the Allens Creek project can have a negative impact on other downstream senior water rights holders depends on the exact location of those diversion points and on the water quality standards they require. Staff at the TWDB look forward to testing any scenarios presented and expect to work closely with TCEQ in this effort.

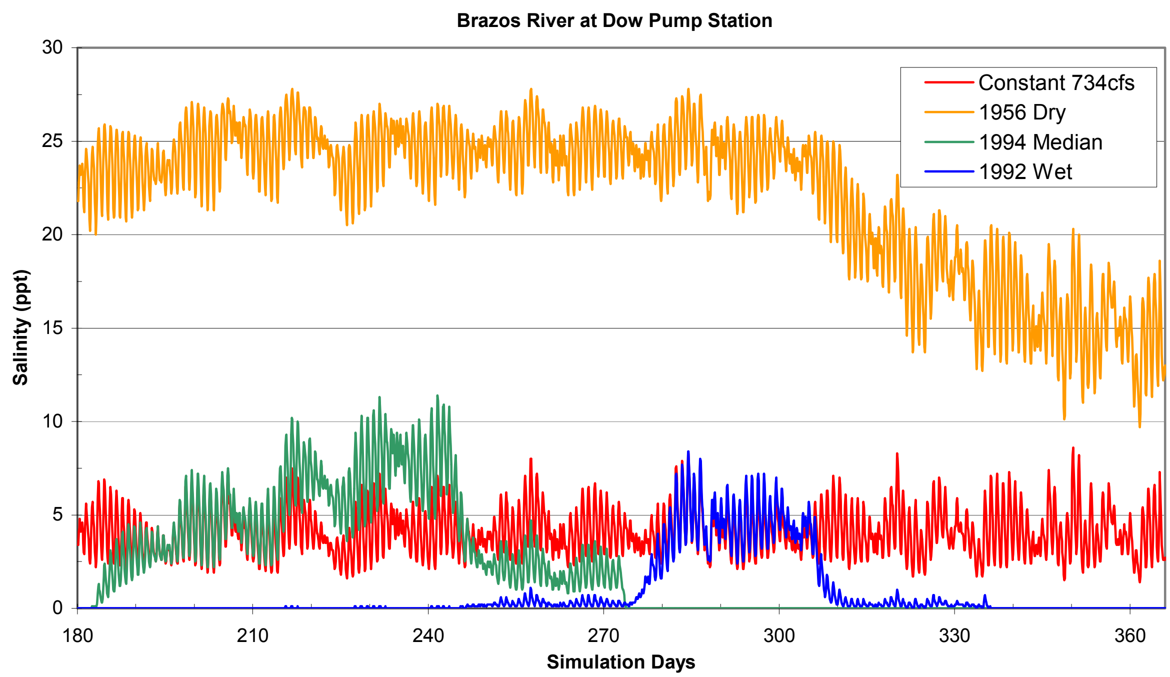

Figure 3.32 – Mid-depth, mid-channel salinity at the Dow Chemical diversion point using four different river flow scenarios.

4. Fisheries overview: historical and recent studies

The warm water fisheries of Texas streams and rivers have a biogeographic characteristic, part of which is related to species richness. The diversity of habitat types and fish partitioning among habitats in warm water rivers requires more complex analytical tools for understanding the relationship between flowing water, habitat and fish habitat utilization. Warm water streams are characterized by warm climatic conditions, spawning seasons over the entire year, shallow river basin gradients, fine substrates, large woody debris, an abundance of backwaters and undercut banks, and a variety of inter and intra-specific competition and niche diversity among fishes using these habitats.

This chapter describes and summarizes fisheries studies conducted in the vicinity of the Allens Creek project. Dames & Moore, Inc. (1975) have studied the fisheries of the Brazos River in the vicinity of the proposed reservoir for a previously proposed nuclear power plant project, which would have utilized a cooling lake formed by the impoundment of Allens Creek. Texas Parks & Wildlife Department (1994) conducted a fish inventory of the site for the TWDB. Texas A&M University, Department of Wildlife and Fishery Science conducted an interagency contract study (TWDB Contract No. 2001-483-376) of the fishery of the lower Brazos River in the vicinity of the proposed Allens Creek Reservoir site (Gelwick and Li 2002, Li 2003) to determine mesohabitat use and community structure of lower Brazos River fishes. Excerpts of both the Gelwick and Li 2002 report and the Li 2003 thesis are included in this chapter, and the reports in their entirety are included on CDROM respectively as Appendix P and Appendix Q.

4.1 Fish inventory and assessment

In the Dames and Moore studies conducted in 1973-74, 41 species representing 13 families of fish were collected from the Brazos River and Allens Creek (Dames & Moore 1975). A list of these fish species can be found in Appendix D. Fish were collected seasonally using seines, electroshockers, gill and fyke nets. Seining was considered the most effective collection device. The authors concluded that many of the fish species collected in Allens Creek were habitual small stream dwellers and complete their life cycle within the creek. Breeding condition gizzard shad, river carpsucker, common carp, channel and blue catfish were collected at the confluence site, and they believed that some species may enter the tributary for spawning, such as the channel catfish. The Texas Parks & Wildlife Department (TPWD) study was not conducted at the same sampling sites, but many of the same species were collected for a total of 44 species (Linam et al. 1994). The TPWD study provides an inventory of fishery resources in Allens Creek and the Brazos River near the confluence. The TAMU study (Gelwick and Li 2002) is the only fishery habitat investigation in the vicinity that provides information about fishery uses of habitat at different flow conditions for instream flow assessment.

The Dames and Moore (1975) fisheries inventory of Allens Creek included collections of nine species that were not collected in 1993, while the 1993 survey found 14 species not collected in the earlier survey. Sunfish and shiner species accounted for most of the species collected in the more recent survey that were not in the Dames and Moore survey.

The western mosquito fish (*Gambusia affinis*) was the most abundant fish species collected in Allens Creek during both the Dames and Moore (1975) and Linam et al. (1994) studies. However, red shiners (*Cyprinella lutrensis*) dominated the study site downstream of the confluence of Allens Creek on the Brazos River in 1993. Although abundant in Allens Creek in 1973-74, this species was not collected at all in the Brazos River at that time. The bullhead minnow (*Pimephales vigilax*) was much more abundant during the earlier study in Allens Creek, than in 1993. However, that species was more abundant in the Brazos River in 1993. The blacktail shiner (*Cyprinella venusta*) was most abundant in the upper Allens Creek area during both surveys, although not one cyprinid species dominated the entire stream. Linam et al (1994) suggested that the shift in cyprinid minnow abundance in the lower Allens Creek area might be due to increases in conductivity, turbidity, and siltation in the lower drainage. Red shiners and bullhead minnows appear better suited than many freshwater fishes (including blacktail shiners) to such physicochemical conditions according to Linam et al. (1994), providing them an advantage over other cyprinids in the lower reach of Allens Creek and the Brazos River.

Other studies conducted for the proposed Allens Creek Reservoir site include: (1) Allens Creek dam and reservoir on Allens Creek, Brazos River Basin, Austin County, Texas by URS/Forrest and Cotton (1977), Inc. for Houston Lighting & Power Company's proposed cooling water lake in support of their proposed nuclear generating station. (2) Supplemental study of Allens Creek Reservoir, prepared for the Sabine River Authority, by Freese and Nichols (1994), and included an "Environmental Report". (3) Status of Environmental Issues for Allens Creek Reservoir, Memorandum Report of the Trans-Texas Water Program, Southeast Area, by Sabine River Authority et al. (1997).

The first study included a fishery and benthic macroinvertebrate inventory and assessment; however, collection data were not available for comparison to current studies. The report stated that nineteen species of fish, representing eight families, were collected. Numerically, the cyprinids were dominant in the samples, representing more than 50 % of total number of fish collected. That finding is consistent with data presented in our study. The second and third most abundant fish families found in the 1977 study were the poeciliids (21%) and centrarchids (20%). Eight species in five families made up the remaining 18%. Based on a standing crop biomass study of the Allens Creek fishery, the authors of the second study concluded that the stream was of moderately low to low productivity in the lower stream reach. None of the species collected were rare, endangered or considered ecologically important, however, given the small size of the stream, the diversity of fish life was high. The third study (Sabine River Authority 1997) stated that the blue sucker, *Cycleptus elongates*, listed statewide as threatened by the TPWD, potentially ranged in the area, but TWDB contract fisheries surveys by Linam et al. (1994) and Gelwick and Li (2002) did not include any collections of that species. The project impacts of greatest concern in the Trans-Texas report were those to the 496 acres of bottomland hardwoods identified in the project area, and the wildlife habitat and wetland site known as Alligator Hole that the forest community supports. According to the Trans-Texas report by the Sabine River Authority et al. (1997) some Brazos River fish may enter Allens Creek during periods of high flow and remain after flows subside. If these fish utilize Allens Creek for a spawning or nursery area during the spring months, the importance of Allens Creek to the aquatic system of the Brazos River could increase. The study also included conversations with TPWD biologists and local fisherman of the Brazos River near the confluence with Allens Creek. Based on these discussions, the authors concluded that there were 13 species of fish known from previous studies near the site, 23 species known to occur in the river, and an additional 12 species likely to occur.

Very little recreational fishing has been observed during sampling trips and by TPWD creel assessments. The most sought after fish in the area are the channel catfish (*Ictalurus punctatus*), blue catfish (*Ictalurus furcatus*), and flathead catfish (*Pylodictis olivaris*). The Brazos River at Simonton had the greatest catch per unit effort (CPUE) of channel catfish, second greatest CPUE of flathead catfish, and third greatest CPUE of blue catfish of the 19 stations sampled during the 1994 inventory conducted by Sellers (1996).

4.1.1 Index of Biotic Integrity

Aquatic life use designations provided by the state environmental regulatory agency, the Texas Commission for Environmental Quality (TCEQ) determines the level of protection streams receive in accordance with the surface water quality standards. Rivers and streams can be assigned one of four aquatic life use categories (exceptional, high, intermediate, or limited). A statewide Index of Biotic Integrity (IBI) has been applied historically to rivers and streams in Texas in conjunction with water quality, benthic macroinvertebrates, habitat data, and fish assemblages to set aquatic life uses in streams. However, the diversity of streams and rivers in Texas required a regionalized approach to this assessment.. Linam et al. (2002) conducted study to regionalize the IBI for Texas' wadeable streams. Fish were collected from 62 relatively undisturbed reference streams located within 11 of the 12 aquatic ecoregions described for the state. An array of metrics was screened to determine which ones were most suited for Texas. Scoring criteria were developed for each of the respective metrics. Metrics suited for all regions of the state include: total number of species, number of native cyprinid species, number of sunfish species, percentage of individuals as omnivores, percentage of individuals as insectivores, number of individuals per unit effort, percentage of individuals as nonnative species, and percentage of individuals with disease or other anomaly. Linam et al. (2002) also used additional metrics applicable to the various ecoregions of the state including: number of benthic invertivore species; number of benthic species; number of intolerant species; percentage of individuals as tolerant species (excluding western mosquitofish *Gambusia affinis*); and percentage of individuals as piscivores. When applied to the reference streams sampled in their study, the statewide IBI produced lower overall scores and aquatic life uses. Scores from the statewide IBI demonstrated a geographical trend, declining from east to west Texas, and did not result in a single exceptional aquatic life use designations even though the streams were selected through a screening process and were among the least disturbed in their respective regions.

Regional criteria were considered by Linam et al. (2002) to be an improvement over the statewide index because the regional criteria accounted for the natural differences between ecoregions and consequently the regional IBI approach provides a better representation of the integrity of the fish assemblage. The IBI region that applies to Allens Creek and reaches of the Brazos River downstream of the confluence are Ecoregions 33 and 35. These Ecoregions include south central and southern humid, mixed land use areas occupying east Texas and extending southwest to the Southern Texas Plains. An array of metrics was screened for each region to determine which ones were most suited for the geographical trends and aquatic life uses within each region. Integrity classes for fish communities in the middle sections of Allens Creek rated from fair to excellent. The fish community in the Brazos River stations rated from fair to good. The river carpsucker (*Carpiodes carpio*) was collected at all but one of the study sites, and was the most abundant of the three sucker species collected in 1993. This species seems to prefer turbid waters and is one of two sucker species listed as tolerant for purposes of IBI in Texas (Linam et al. 1994).

Gelwick and Li (2002) calculated an IBI for the lower Brazos River in the vicinity of Allens Creek using metrics developed by Winemiller and Gelwick (1999) for the Brazos-Navasota River watershed. The regionalized IBI scoring criteria developed by Linam et al. (2002) was not available at the time Gelwick and Li were conducting their TWDB contract study. Gelwick and Li (2002) reported that IBI metrics of seined collections from their study reach rated good (score: 63) for September 2001 and excellent (score: 69) across all six collections over a range of flows. Their study reach also scored consistently higher than the scores for seine and electrofishing collections calculated by Winemiller and Gelwick (1999) for the Brazos River. Gelwick and Li (2002) attributed these differences as possibly because of differences in total area sampled. Winemiller and Gelwick (1999) sampled between 25-200 m of river length per site, whereas Gelwick and Li's (2002) site encompassed over 4950 m of the lower Brazos River study site, thereby increasing the likelihood of capturing species of low densities or abundances.

4.1.2 Macroinvertebrates

Rapid Bioassessment (RBA) protocol III for stream macroinvertebrates following U.S. EPA guidelines was used to evaluate environmental conditions on Allens Creek (Plafkin et al., 1989). Mill Creek, a tributary of the Brazos River in Austin County, Texas was used as the unimpaired reference site (Bayer et al., 1992). Basic water quality parameters, including dissolved oxygen and temperature, were monitored to determine the impairment level at the sites used in the RBA (Wood et al., 1994). Water level and substrate are not used as metrics in the RBA, however, they do influence the benthic macroinvertebrate composition.

Allens Creek and the Brazos River in Austin County, Texas are relatively high stress environments for macroinvertebrates, as reported by Wood et al (1994) in a TWDB contract study with Southwest Texas State University. They found that rapid fluctuations in water level, temperature and substrate can make the environment unsuitable for the most tolerant invertebrate species. Results from the Rapid Bioassessment (RBA) that Wood et al. (1994) conducted for the macroinvertebrate community indicate a slightly impaired to moderately impaired system for Allens Creek and Brazos River in Austin County. They suggest that this indicates some impact is occurring from the wastewater effluents from the cities of Sealy and Wallis, as well as from agricultural and ranching activity in the watershed. A total of six sites were used in the RBA analysis, including four sites in Allens Creek, one at the confluence of Allens Creek with the Brazos River, and another downstream of the confluence. The upstream reference site for Allens Creek was located 1.2 km east of Mixville Road and State Highway 36 intersection at the first bridge that crosses Allens Creek.

4.2 Field sampling protocol for fish habitat utilization study

Assessment of the impact of the proposed Allens Creek Reservoir project on aquatic habitat in the Brazos River is the primary objective of this report. To assess the habitat utilization of fish in this area, the TWDB contracted TAMU to perform fish sampling for a range of flow rates and seasons. The results of the TAMU collections are described in Gelwick and Li 2002 (included on CDROM as Appendix P) and also excerpted later in this chapter. Over the course of this fish collection study, a new fish sampling protocol was developed with the assistance of TAMU and staff from the other state natural resource agencies. The new protocol is described in the following section.

As described in Chapter 3 of this report, a representative study reach was selected by the reconnaissance team in the lower Brazos River within the vicinity of Allens Creek. Fish sampling sites were identified based on current velocity, water depth, river morphology, presence of large wood debris, and dominant substrate type. Six fishery collections were completed over a range of river discharges within selected mesohabitats at targeted flows representing the 15th, 30th, and 50th percentile discharges based on the 60-year gage record compiled by TWDB staff for the USGS gage at Richmond, Texas (#08114000). Seasonal sampling was conducted at each flow regime for summer (April-October) and winter (November-March), based on seasonal changes of fish habitat utilization in Texas reported by Clark Hubbs (personal communication, Professor Emeritus of Fisheries Biology, The University of Texas at Austin, 2001). Actual sampling dates, the flow rate recorded at the Richmond gauge on those dates and the percentile rank of the flow (considering the entire historical gauge record) are shown in Table 4.1. Summer sampling corresponded to targets; winter sampling field trips were higher than targets because of a particularly wet winter season in 2002.

Table 4.1 – Fish sampling targets, dates, flow (Gelwick and Li 2002) and percentile rank.

Reported season and flow targets	Sampling date	USGS Richmond gauge #08114000 Flow (cms)	Flow (cfs)	Percentile Rank of historical flows Winter	Summer	Annual
Summer 50	Sept 20-23, 2001	114.48	4043	53.8%	**60.6%**	58.2%
Summer 30	Aug 27-30, 2002	41.82	1477	26.7%	**31.7%**	30.0%
Summer 15	May 13-16, 2002	25.09	886	13.0%	**15.2%**	14.6%
Winter 50	Mar 29 - Apr 1, 2002	118.51	4185	**54.6%**	61.5%	59.1%
Winter 30	Feb 2-5, 2002	74.28	2623	**43.0%**	49.8%	47.5%
Winter 15	Mar 8-11, 2002	63.09	2228	**38.4%**	45.5%	43.0%

Eleven sites were identified inside the study reach based upon visual characterization of mesohabitat by biologists from TAMU and the state agencies. Five runs, four pools, one riffle, and a tributary confluence were selected during reconnaissance and subsequently sampled during the study. The presence of pool, run, or riffle mesohabitats did not vary across the six collection discharges, which ranged from 886-4185 cfs, although the location and extent of these habitats did change with flow, which influenced the available habitat for fish utilization.

The lower reaches of Allens Creek were hydrologically connected to waters of the Brazos River during all targeted flows with the exception of the low flow event. Gelwick and Li (2002) reported that during low flow periods (e.g., such as during their 15^{th} percentile flow collections) fish movement between the Brazos River and Allens Creek was likely impeded by the combined effects of a low river stage and high sediment aggregation (i.e., sediment dam) across the mouth of Allens Creek. In addition, a large woody debris habitat at the FM 1093 bridge crossing was rendered unavailable for fish utilization at low flows (e.g. such as during the summer 15^{th} percentile discharge) due to its elevation above the water level on a sediment bar.

Gelwick and Li (2002) used seines and gillnets as their primary methods to collect fishes in these habitats. Nearshore shallow-water areas within each mesohabitat were sampled with a 5 x 1.25 x 1.25 m bag seine of 5 mm bar mesh. Midpoint along each mesohabitat, seines were hauled along at least three contiguous 15 m longitudinal transects until no additional species were collected in two consecutive hauls. Transects selected were representative of the shallow water habitats in each delineated mesohabitat. The total number of seine hauls was recorded to standardize abundance per m^2.

Experimental monofilament gillnets measuring 38.1 m long by 1.8 m deep and consisting of five equal sized panels with graduated mesh (2.5, 3.8, 5.1, 6.3 and 7.6 cm mesh) were used to collect fishes in deep-water habitats. Three to five gillnets were set overnight for a total of 9 to 15 gillnet collections per collection period. This saturation sampling methodology of these mesohabitat areas was believed to be effective in collecting fish species utilizing these habitats. According to Stalnaker et al. (1989), backwater areas are important mesohabitats in rivers, and were also sampled using gillnets. Gillnet captures were standardized as abundance per net area in m^2.

Experimental monofilament gillnets were set overnight in deep water habitats, and typically caught longnose gar (*Lepisosteus osseus*), spotted gar (*Lepisosteus oculatus*), blue catfish (*Ictalurus furcatus*), channel catfish (*Ictalurus punctatus*) flathead catfish (*Pylodictus olivaris*) and smallmouth buffalo (*Ictiobus bubalus*). Since it is rare to collect fish in gillnets set in higher velocity waters, gillnets were usually deployed in pools, runs, backwaters, and eddies. A gillnet was also set across the confluence of Allens Creek and the Brazos River at least once per collection trip. Gillnets were deployed to ensure that each mesohabitat (as delineated by TWDB, TPWD, TCEQ and TAMU during the summer of 2001) was sampled.

Deep-water areas, large aggregations of woody debris, and mesohabitat sites dominated by large woody debris were sampled with a boat-mounted electofisher. Gelwick and Li (2002) used a Coffelt model VVP-2C electrofisher powered by a 5,000 watt Honda generator mounted onto a 4.3-m aluminum jon boat. Fishes were collected only in areas of large aggregations of woody debris and mesohabitat sites dominated by large woody debris during the winter 30th and summer 15th percentile discharge collections. Electrofishing catch was standardized as abundance per m^2 sampled. Due to technical difficulties with the electrofishing equipment, samples were not collected in the woody debris field near the downstream end of the study reach during the winter 30th percentile collections. In addition, the deeper pools were too deep to effectively shock and the shallow (but faster) runs and riffles were too fast to shock. However, gill netting, baited funnel-type minnow traps, hoop nets and minnow traps replaced the electrofishing collections during periods of technical difficulty, and these techniques were considered effective in collecting fishes utilizing these habitats.

The baited funnel-type minnow traps used were 7.62 mm mesh with 2.54 cm funnel openings, and were used to collect fishes during the winter 50th, 30th, 15th and summer 15th percentile discharge rates. Minnow traps were deployed in large aggregations of woody debris for approximately 72 hours. The hoop nets were set for 72-hour periods during the summer 15th and 30th percentile discharge collections. There were two 61 cm in diameter hoop nets, and two 91.44 cm hoop nets of 2.54 cm mesh.

At each area sampled, depth, velocity, DO, conductivity, salinity, and water temperature information was collected. Depth and velocity were measured in the center of each sampling area with a YSI-85 (Yellow Springs Instrument) multimeter at three equidistant points along a diagonal transect that bisected the seined or electrofished area. Single values for depth and current velocity of gillnet, hoop net, or minnow trap sites were measured in the center of the sampled area. Water depths less than 150 cm were measured using a graduated wading rod. Depths greater than 150 cm were measured using a Speedtech® sonar depth meter. Flow was measured at 0.6 x depth using a Marsh-McBirney Flowmate 2000 electromagnetic flow meter. At large woody debris habitats, flows were measured several feet upstream of the structure. Substrate type was recorded for each mesohabitat, however sediment distributions were very homogenous throughout the sampling areas, consisting primarily of sand and silt. The only habitat that had some coarser sediments (gravel and sand) was the riffle area.

4.2.1 Sampling bias

The Brazos River has a diversity of habitat types including deep pools, backwaters, shallow and steep margins, some riffles and large woody debris, and tributary confluences. These habitat types required different types of sampling gear to collect fish for the assessment of habitat utilization. Deep-water areas, large aggregations of woody debris, and mesohabitat sites dominated by LWD were sampled with a boat-mounted electrofisher. Seines and gillnets were the primary effective methods used to capture fishes (Gelwick and Li 2002). Three baited funnel-type minnow traps were used to collect fishes in areas difficult to sample with gillnets, seines, or electrofishing gear. Baited hoopnets were used to sample deep pools where electrofishing was not effective. The application of all these gear types was considered an effective method of documenting the fish habitat utilization of the lower Brazos River (Gelwick and Li 2002).

Electrofishing was inadequate in deep habitats because of water depth, current velocity, and the extent of open water. The later is important because the fish inhabitants have ample area to utilize for escape, whereas fishes electrofished near shallow banks are “trapped” against the shallows, making their capture more effective. Gelwich and Li (2002) found that electrofishing in shallow areas consistently caught more fishes than in deep areas. The fishes caught by electrofishing in the shallow areas were mostly small. Seining generally captures small fish more effectively than electrofishing (Gelwick and Li 2002). Because small fishes were collected, which are actually more difficult to capture with electrofishing gear than are larger fishes, it is probable that if a certain species of fish were present they would have been collected (Fran Gelwick, pers. comm. 2003).

Another potential sampling bias was related to setting and checking gillnets. Gillnets were set overnight since most of the fish collected during the fish habitat study by Gelwick and Li (2002) were more active at night. The river can be very hazardous at night, and removing fish from gillnets under artificial lights at night is less effective. Therefore, sampling was conducted overnight and fish were removed the next day for safety reasons. Night-time habitat utilization was not separated from day-time habitat utilization.

Experimental gillnets with different mesh sizes across the five panels increase the range of sizes of fish vulnerable to the gear, although it does reduce the area sampled for each size. One of the greatest biases is that gillnets are passive gears, so fish must be moving to be collected, and then must be entangled sufficiently to remain in the net until they can be retrieved and before the nets are damaged by predators and scavengers. In contrast, most of the other sampling gears used in this study were active and used across a sampling area (Fran Gelwick, pers. comm. 2003).

4.2.2 Fish density sampling issues

There is some question about the most effective means of representing the number of fish utilizing fish habitats. Some believe that relative abundance should be used for each sampling gear, while others believe that absolute abundance is better when several different non-comparable sample types are used in the collection of fishes. When calculating the number of fish per area, gill nets can only be assumed to collect fish across the area of the net, but the catch per unit effort is measured in number per hour. Baited minnow traps are also set over a period of time and, like gillnets, do not provide a fish density per unit area. Electrofishing is applied over a specific area, but catch per unit effort is generally calculated as catch per unit effort for the amount of time shocked. It should be noted that efficiency of sampling around LWD may not be the same as in an open habitat since repositioning is required. Seines were found to be more effective for collecting smaller fishes per unit area of near-shore habitats (Gelwick and Li 2002).

Fish collections may be standardized for different types of sampling gears by estimating the area or volume of habitat sampled by each gear and then standardizing fish collections to that volume as an indication of effort. For instance, the number of fish collected per unit area of gill net per hour fished can be compared to the area or volume of seined habitat. However, such standardizations would be difficult for multiple gear types, such as for the baited minnow traps and hoop nets that were used in this study. Electroshocking can also be standardized,but electrofishing was not effective for the Brazos River.

Considering the difficulty of standardizing across gear types, the absolute abundance of fishes utilizing each habitat was initially considered the best means by which to model fish habitat utilization for this study. However, after further consultation with Drs. Fran Gelwick (TAMU) and Tim Bonner (Texas State University), a different approach that standardized by gear type was established to provide a meaningful density assessment. By using seine data exclusively for the shallow water analyses, and gill net data exclusively for the deep-water analyses we were able to avoid multiple gear type standardization errors. These gears were the most effective for the depths they sampled. Therefore, all shallow-water habitats can be compared on an equal effort basis from standardized seine samples, as could deep-water habitats for standardized gillnet samples. We believe this provided a robust and accurate data set for our analyses.

4.3 Analysis using visually classified mesohabitats

As described in section 4.2, a contract report was submitted by TAMU to describe and analyze findings (Gelwick and Li 2002). Raymond Li performed additional analysis in his Masters' thesis based upon a subset of the same Gelwick and Li dataset. The mesohabitats reported and utilized in both of these reports were those same consensus-approved mesohabitats that were characterized by visual observation in the field during the reconnaissance field trip. Excerpts from those reports are included in the following two sections. Where applicable, comments from the authors of this report were included and shown in bold type. Such comments were included for clarification or for continuity where some text was removed from the source document.

4.3.1 Excerpts from Gelwick and Li 2002

This section contains text excerpted directly from Gelwick and Li (2002). The full text is included as Appendix P on the CDROM that accompanies this report.

Introduction

This project was designed to provide information concerning Brazos River fish communities. Previous studies documenting fishes occurring near our study reach can be found in Linam et al. (1994) and Winemiller et al. (2000). Studies reporting fish communities of tidal portions and upper reaches of the Brazos River can be found in Johnson (1977), Wilde and Ostrand (1999), Winemiller and Gelwick (1999), and Ostrand and Wilde (2002). McEachran and Fechhelm (1998) lists documented species occurrences in the Brazos River watershed.

The objectives of this project were to: (1) delineate and photodocument riffle, run, and pool mesohabitats within our study reach; (2) characterize and quantify the fishes occurring in identified mesohabitats; (3) determine indicator species of mesohabitats based on fish distributions; and (4) calculate an Index of Biotic Integrity for the reach.

Allens Creek

Allens Creek is important as a spawning area for fishes migrating into it from the Brazos River. While a comprehensive migration study was not performed, the following species likely migrate into Allens Creek from the Brazos River for food, shelter and spawning habitat: pirate perch, longear sunfish, red shiner, bullhead minnow, blacktail shiner, spotted gar, flathead catfish, and largemouth bass. Some of these species likely use Allens Creek for protection from flood flow events, migrating back into the Brazos River during low flow periods.

Fish Collections

Captured individuals that were rare, threatened, or endangered and large common fishes were identified and immediately returned to the river. All other fishes were euthanized in tricane (MS-222), fixed in 10% formalin, and returned to the lab for enumeration. With the exception of bowfin (*Amia calva*) and spotted gar (*Lepidosteus oculatus)*, several individuals of each species captured was catalogued as voucher specimen into the Texas Cooperative Wildlife Collections located on the campus of Texas A&M University.

Indicator Species Analysis

We performed an indicator species analysis (Dufrêne and Legendre 1997) based on percent abundances in collections and percent occurrence among collections to test the probability that species were indicators of pool, run, riffle, and tributary confluence mesohabitats. We calculated species abundance per m^2 sampled in each mesohabitat-type for each of our six collection periods. Two separate analyses were performed with PC-ORD (McCune and Mefford 1997): (1) using only those species exceeding 1% of total collections; and (2) including all species regardless of abundance.

Results and Conclusions

Mesohabitat-Site Delineation

Eleven sites were identified based upon mesohabitat delineations **(Figure 4.1)**.

Physicochemical Parameters

Mean daily discharge ranged from 1,792 to 17,300 cfs (from 82 years of record), compared to a range of 886 to 4,185 cfs during our collection periods. Averaged across all sites, water temperature ranged from 13.8 to 31.4°C, conductivity ranged 467.5 to 1059.0 µS/cm, dissolved oxygen concentration from 6.72 to 13.67 and saturation from 76.2 to 117.5% for each collection period (Table 6).

Water depths and current velocities of each sampling location are reported. Mean depth and current velocity measurements of mesohabitat within each collection period are reported. Because gillnets were generally deployed in deep backwaters and not areas representative of their respective mesohabitat-site, we did not include gillnet depths and velocities in our overall calculations of the mean. Mean current velocities were related to mesohabitat types. Pool mesohabitat-sites were generally characterized by minimal velocities (mean 14.2; range 7.7 to 20.7 cm/s). Runs were characterized by moderate velocities (21.3; 15.4 to 27.9 cm/s) and riffles by the highest velocities (34.1; 20.0 to 66.0 cm/s). Velocities of the Allens Creek confluence site were negligible due to a backwater effect by riverflow of the Brazos River. Mean water depths of areas seined were 38.6, 50.6, 50.8, and 38.6 cm in pool, run, riffle and tributary confluence mesohabitats, respectively.

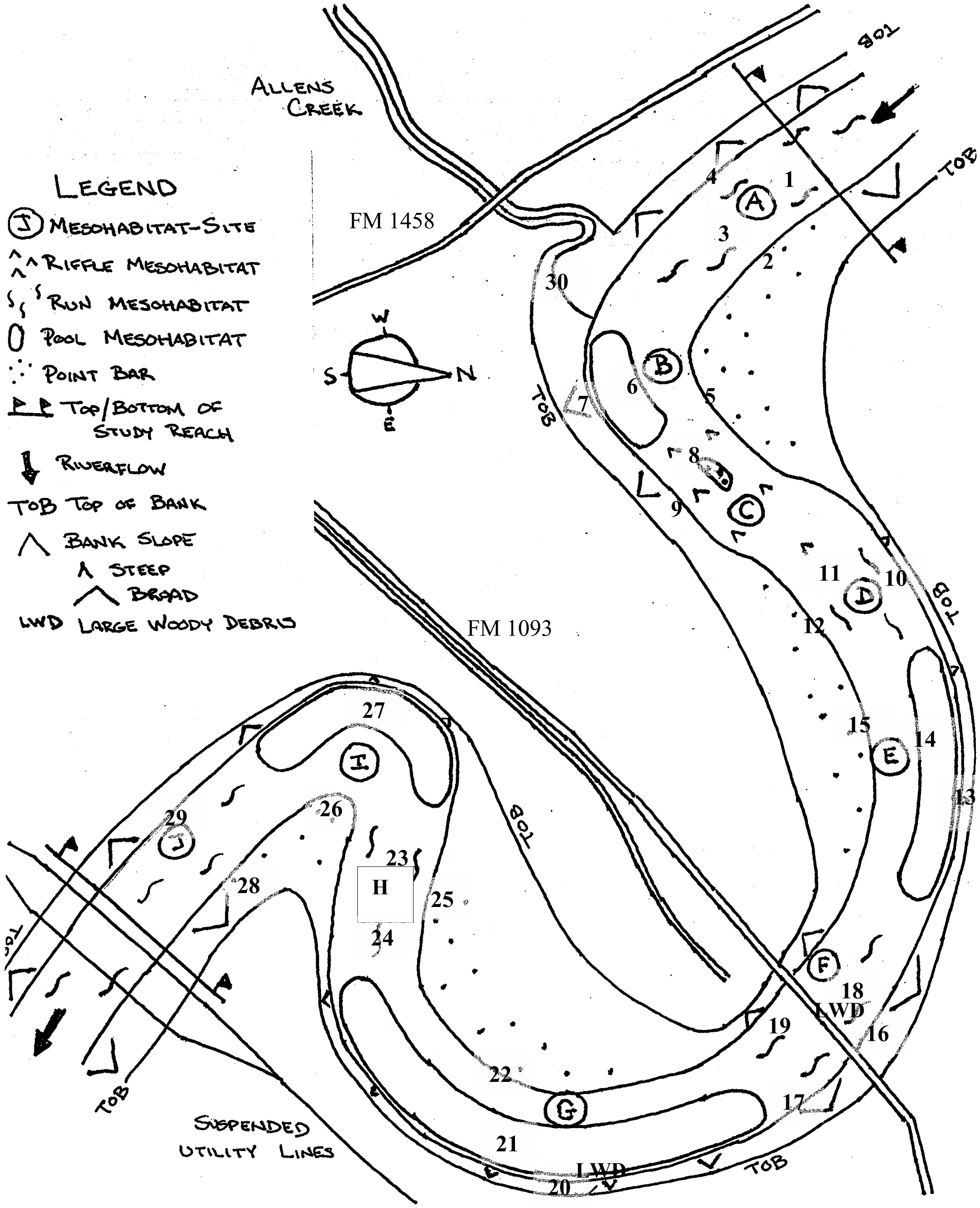

Figure 4.1 - Sketch map of Brazos River study reach with mesohabitat-sites indicated by a letter code and sampling locations by a numeric code.

Fish Species and Mesohabitat Use

A total of 44,122 individuals representing 43 species from 14 families were collected across our 6 collection periods. Red shiners (*Cyprinella lutrensis*) and bullhead minnows (*Pimephales vigilax*) accounted for 67.4% and 16.9% of our collections, respectively. Other common species (abundances exceeding 1% of overall collections) were ghost shiner (*Notropis buchanani*), silverband shiner (*N. shumardi*), striped mullet (*Mugil cephalus*), and mosquitofish (G*ambusia affinis*). Three individuals of sharpnose shiner (*Notropis oxyrhynchus*) were collected in the confluence of Allens Creek (mesohabitat-site AC) during our summer 50th percentile discharge collections. The sharpnose shiner was recently proposed as a candidate species for federal listing by the U.S. Fish and Wildlife Service (2002).

Fish Species Indicators

Of the common species, bullhead minnow had the highest indicator value of pools but was not-significant ($P > 0.05$; Table 16). Red shiner and striped mullet had the highest values for runs, but were also not significant. Riffles were poorly differentiated by fishes of any species. Ghost shiner, silverband shiner, and mosquitofish had the highest indicator values of the tributary confluence habitat, with mosquitofish being the only significant indicator species.

4.3.2 Excerpts from Li 2003

This section contains text excerpted directly from Raymond Li's thesis (Li 2003). The full text is included as Appendix Q on the CDROM that accompanies this report. **Additional text was added to this section by the authors for clarification and that text is shown in bold.**

The fish habitat data used in this thesis is a sub-set of the dataset collected by Gelwick and Li (2002) that omits irregular samples as well as all hoop net, electrofishing, and minnow trap samples. By way of a brief summary, Raymond Li found some differences in habitat utilization among fish species after separating standard shallow (collected using seine gear) and standard deep (collected using gillnet gear) samples. Any reference to mesohabitats is based upon the visually classified habitats reported by Gelwick and Li (2002).

Abstract

Large floodplain rivers are spatially heterogeneous and temporally dynamic ecosystems. However, few studies have quantified the variation and species-environment relationships of fish assemblages in the main-river channel of large rivers. Fishes were collected along a 10-km reach of the lower Brazos River, a large floodplain river in Texas. Collections targeted the 15th, 30th, and 50th

percentile discharge rates of summer and winter season, **according to procedures established by previous TWDB studies (Mathews and Bao 1991; Bao and Mathews 1991). Mr. Li's objectives were:** (1) to compare fish assemblage structure in shallow river-margins versus deepwater habitats, (2) to identify species-environment relationships that likely structure fish assemblages in these two habitats, (3) to quantify the relative variation in assemblage structure of these two habitats and for each the relative variation related to spatial versus seasonal sources, and (4) compare results to predictions of various theoretical models.

During the TWDB contract study, forty-one species and 28,469 individual fishes were collected in the main-river channel. Assemblages were less variable than levels typically reported for streams, and had weak species-environment relationships. Within the shallow river-margin fish assemblage, temporal variation was primarily the result of either juvenile recruitment, displacement of individuals following spates, or seasonal immigration by one estuarine species. Among the deepwater assemblages, increased movement associated with reproductive activities increased temporal variation. Spatial variation was detected only among deepwater assemblages and was related to velocity. Eighteen commonly collected species were evaluated for relationships with environmental variables and season. Shallow river-margin assemblages were dominated by habitat-generalists and were most strongly differentiated by season, discharge and conductivity. Deepwater samples were dominated by longnose and spotted gar and were most strongly differentiated by current velocity. For shallow river-margin and deepwater assemblages, environmental variables uniquely explained more of the total variation than season. Biotic factors are probably responsible for a large proportion of the unexplained variation.

Drawing from prevailing models (Schlosser 1987, Matthews et al. 1988), **Mr. Li expected environmental conditions** of the lower Brazos River to be less variable and more predictable than conditions of headwater systems, but less predictable than those characterizing tropical lowland rivers. **Accordingly, he hypothesized Brazos River fish assemblages** would show moderate temporal variation in fish assemblage structure that would be largely related to physicochemical and hydrologic conditions. Moreover, because the reach was located 195 km from coastal waters, **he expected the abundance** of estuarine species to increase during springtime migrations and reproductive periods. **He** hypothesized that spatial variation of current velocities among mesohabitats would be correlated with the structure of fish assemblages **(Ray Mathews, TWDB fisheries biologist and contract manager for the study, agrees with this hypothesis)**. Geomorphic mesohabitats form a gradient of depth and flow conditions, along which the greatest differences are between more lotic conditions in riffles and lentic conditions in backwaters and pools. **Therefore, Mr. Li hypothesized** that limnophilic taxa would be associated with more lentic backwaters, tributary confluences, and pools whereas rheophilic taxa would be associated with more lotic riffles and runs (Aadland 1993). **Moreover, he expected assemblage**

structure to be related to spatial variability in physicochemical conditions associated with specific mesohabitat types.

Study Reach

The lower Brazos River is a warm water, meandering (Sinuosity Index of 2.16 calculated from USGS 1:20,000 topographic maps), floodplain river. Several flood control dams and water supply reservoirs are located along the upper reaches of the watershed, but the lower Brazos River remains one of few large-river systems in Texas and the U.S.A. that has a relatively unregulated flow regime **(see Hydrology section of this report)**. The study reach was located within the Western Gulf Coastal Plain physiographic province between Sealy and Simonton, Texas (29º40'N and 96º01'W) draining approximately 72,000 km2 (Figure 2). The reach began 600 m above the river confluence with Allens Creek and ended 10-km downriver. Lateral point bars dominated the shoreline.

This river segment **shown in Figure 4.2** was selected because it contained representative habitats of the lower Brazos River and also was the site for concurrent hydrologic studies by the Texas Water Development Board (TWDB) for a proposed municipal water supply reservoir on Allens Creek. **The representative study reach and habitats were selected by biologists of the three natural resource agencies: Ray Mathews (TWDB representative and contract manager), Kevin Mayes (TPWD), and Doyle Mosier (TCEQ).**

Species-environment Relationships

In shallow river-margin samples, most of these species were collected across a wide range of conditions, thus most were weakly associated with the measured environmental variables. **Based upon canonical correspondence analysis plots,** gizzard shad and inland silversides were strongly associated with silt substrates, higher temperatures, and the tributary confluence site. Threadfin shad and western mosquitofish were also associated with higher temperatures. Striped mullet were associated with higher discharge rates and winter samples. Although a large range of values was measured for dissolved oxygen, current velocity, and conductivity, these environmental variables were not strongly associated with distribution of species' abundances. With summer and winter included as covariables, the 16 environmental variables uniquely explained 32.8% of the variation in species' distributions across shallow river-margin samples. By contrast, summer and winter uniquely explained only 6.7% of the variation in species' distributions.

Discussion

According the flood-pulse concept (Junk et al. 1989), the main channel of floodplain rivers is of limited value as fish habitat. Therefore, studies evaluating the spatial and temporal dynamics of large-river fish assemblages have traditionally emphasized those fishes occupying aquatic floodplain habitats (e.g. Kwak 1988, Saint-Paul et al. 2000, Slavik & Bartos 2000). However, recent studies suggest that the main channel of large rivers contain a speciose and abundant resident-fish assemblage (Dettmers et al. 2001, Stewart et al. 2002). Over 28,000 individuals from 41 species and 13 families were captured in this study, which is consistent with results for samples from the middle to lower Brazos River (Winemiller & Gelwick, Texas A&M University, unpublished report) and the adjacent floodplain lakes (Winemiller et al. 2000).

Strong patterns of habitat partitioning by fishes between shallow river-margin and deepwater habitats were observed in this study. Shallow river-margins were dominated by small-bodied species and juveniles of larger fishes, whereas deepwaters contained mostly large-bodied fishes. Although size selectivity of sampling gears contributed to these patterns, other samples using a less habitat-biased method (electrofishing) indicated that fish distribution between shallow river-margin and deepwater assemblages followed a similar pattern of habitat partitioning related to body size (Gelwick & Li, Texas A&M University, unpublished report **[Gelwick and Li (2002)]).** Characterized by shallow water depths and slow current velocities, shallow river-margins provide small-bodied fishes with refuge from strong river currents and large piscivorous fishes (Bain et al. 1988, Schlosser 1985). By contrast, large-bodied fishes are restricted to deepwater habitats as these areas provide protection from terrestrial and avian predators (Angermeier & Karr 1983, Power et al. 1989, Harvey and Stewart 1991). Such habitat partitioning suggests that these assemblages are structured by different environmental variables and therefore should exhibit differences in their spatial and temporal variation. **During Raymond Li's study,** temporal variations were strongly correlated with seasonal population fluctuations. By contrast, spatial variation was low and probably related to the short study reach (Fuselier & Edds 1996), despite it containing habitats representative of those along a much greater reach of the river. Spatial variation was detected only for deepwater assemblages, for which current velocity was the variable most strongly related to the presence or absence of fish. **Author note: The low spatial variation may also be an artifact of visual classification of mesohabitats; further analysis showed overlap of velocity and depth measurements occurring within "run" and "pool" habitats.**

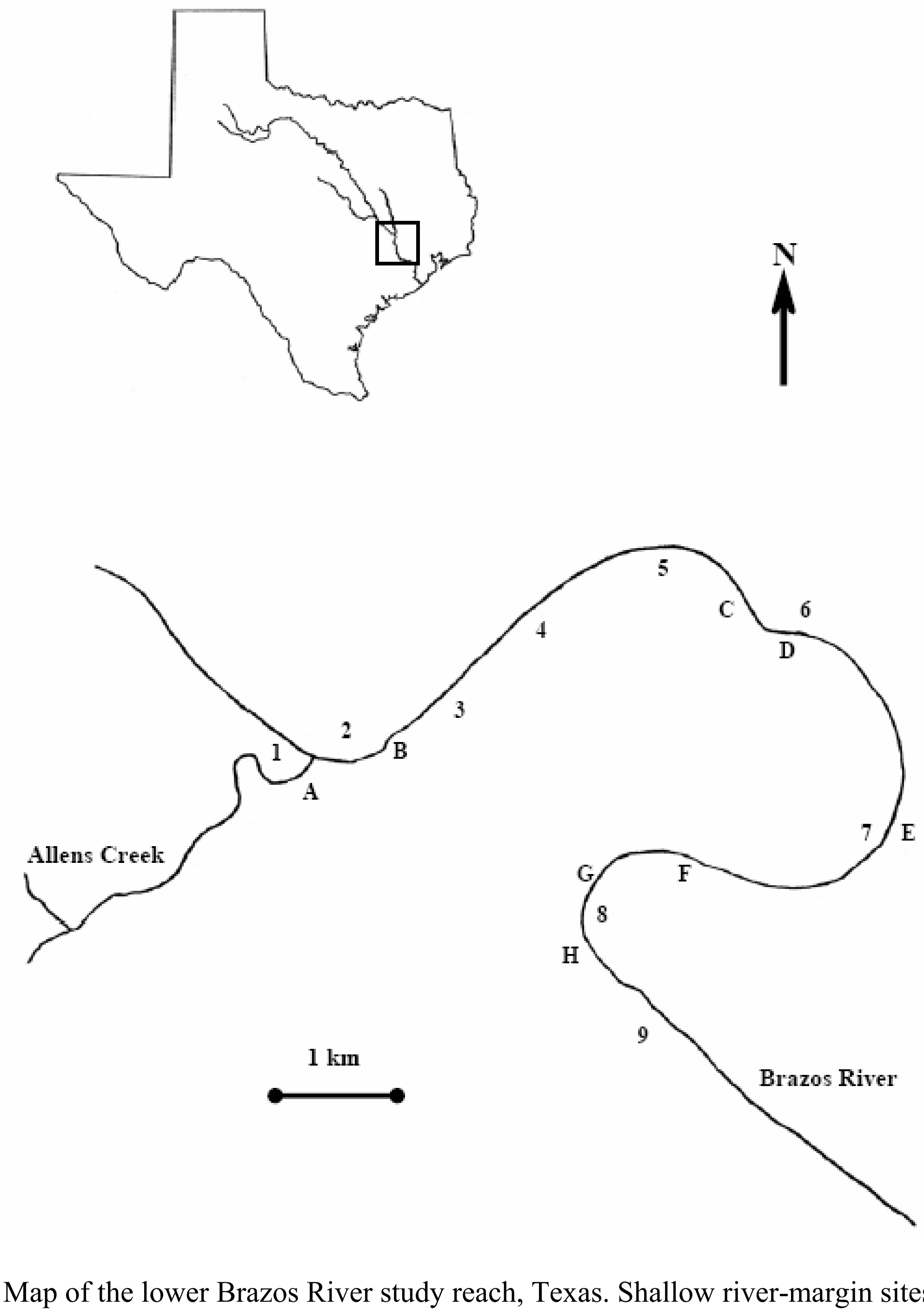

Figure 4.2. Map of the lower Brazos River study reach, Texas. Shallow river-margin sites are designated by numbers and deepwater sites are designated by letters in ascending order from upstream to downstream.

Shallow River-margin Assemblages

Author Note: In order to avoid confusion, a difference in terminology is hereby pointed out. Raymond Li's use of "river-margin" assemblages is based on classifying all samples collected by a seine as margin assemblages. This terminology is not consistent with TWDB's partitioning (in succeeding sections of this report) of the river margin into four specialized habitats: lentic and lotic river margins; lentic and lotic embayments (see Chapter 5).

Temporal variability of the shallow river-margin fish assemblage was strongly correlated with natural population fluctuations due to juvenile recruitment, seasonal migrations, and displacement or mortality of individuals following spate. The influence of spring recruitment on temporal variability of fish assemblages has been well documented in headwater streams and wadeable rivers (Turner et al. 1994, Taylor et al. 1996). Fish abundances are typically highest during the spring recruitment period and gradually reduce over the remainder of the year **(Raymond Li's personal observation)**. A similar temporal pattern was observed in the lower Brazos River during the contract study. Fish abundances were highest in samples during the winter 15th and 50th percentile collections, which coincided with spring reproduction of most fishes in the region (Robison & Buchanan 1988). Although lengths of individuals were not measured, young-of-the-year fishes were abundant during the winter 15th and 50th percentile collections **(Raymond Li's personal observation)** and probably increased temporally variability of the assemblage. Fish assemblage composition is rarely stable and movement by fishes across large distances can strongly influence temporal variability of assemblage structure within a single reach. Particularly in streams and rivers where environmental conditions within habitats continually change, individuals must continually shift between less hospitable and more preferable habitat conditions (Angermeier & Schlosser 1989). Similarly, seasonal migration can also contribute to temporal variability of fish assemblages.

Previous studies have documented strong spatial separation of stream-fish assemblages among riffle, run, and pool mesohabitats (Gorman & Karr 1978, Schlosser 1987, Taylor 2000). In the headwaters of the Brazos River, the spatial variation fish assemblages is related to current velocity and water depth conditions (Ostrand & Wilde 2002). By contrast, shallow river-margin fish assemblages in this contract study were similar among sites. Such contradictions might be related to several factors. Perceptions of variability depend on the spatial scale for evaluation. For example, studies across broad regions (e.g., Rahel & Hulbert 1991, Waite & Carpenter 2000) include a wide range of environmental conditions and therefore greater spatial variation among assemblages (Taylor et al 1996). By contrast, these study sites were contiguous along a 10-km reach of the lower Brazos River, and environmental conditions were largely consistent across sampling sites within each collection period. Despite spatial consistency of their environmental conditions, shallow river-margin habitats are extremely sensitive to river-stage fluctuations (Bain et al. 1988). Because river discharge rates are rarely stable, river-margin fishes must relocate in response to fluctuating water levels to maintain themselves at appropriate water depths. Consequently, fishes must shift laterally to avoid strong current velocities and piscivorous fishes associated with deeper waters, while also avoiding stranding in shallow water (Schlosser 1985, Bain et al. 1988). In such variable environments, habitat-generalist species typically dominate the assemblage composition (Poff & Allan 1995, Jepsen 1997), and likely contributed to the spatial homogeneity of shallow river-margin assemblages in the lower Brazos River. **For example, red shiners accounted for two-thirds of Li's catch in shallow river-margins.** Tolerant of a wide range of environmental conditions and physical habitat types, red shiners are generalist species capable of exploiting a broad range of habitats (Marsh-Matthews & Matthews 2000).

Higher values for species richness and numerical abundances in the tributary confluence site were probably related to upstream movements by river fishes and downstream movements by stream fishes (Whiteside & McNatt 1972, Osborne & Wiley 1992). **For instance, the capture of three species—green sunfish, largemouth bass and slough darter—was largely restricted to Allens Creek during both Raymond Li's TWDB contract study, and a previous TWDB contract study with the Texas Parks & Wildlife Department (Linam et al. 1994).** Species richness and catch abundances were much lower in riffle samples. With the exception of speckled chub, most species captured within the Allens Creek confluence avoid faster current velocities observed in riffles, thus contributing to lower species richness and catch abundances in river samples.

Deepwater Assemblages

In contrast to assemblages of the shallow river-margin, deepwater fish assemblages showed considerable spatial and temporal variation. Analogous to the separation between riffle and pool fishes typical of most streams (Taylor 2000), deepwater fish assemblages of the lower Brazos River were spatially segregated between lentic and lotic habitat types. Like streams, large rivers are comprised of lotic and lentic habitat types along a gradient of depth and current velocity. The faster current velocities and shallower water depths make lotic habitats generally less inhabitable by large-bodied stream fishes (Matthews et al. 1994). Because of larger habitat volume, greater depth, and higher thermal inertia of water in pools, they are somewhat buffered from extremes in environmental conditions (Aadland 1993).

In the lower Brazos River, stronger associations of less frequently captured species (freshwater drum, smallmouth buffalo, channel catfish, and common carp) with deeper pools alongside shallow runs might have indicated fish movement between these habitats under changing conditions, especially across discharge rates. Adventitious tributaries are headwater streams that flow directly into large rivers, and the stability of their fish assemblages are greatly influenced by seasonal upstream-migration by river-fishes (Gorman 1986).

Species-environment Relationships

Species distributions in the lower Brazos River were only weakly related to measured in-stream variables. Shallow river-margin assemblages were dominated by cyprinids, all of which showed low associations with measured environmental variables. With the exception of ghost shiner and silverband shiner, these species are habitat generalists that can tolerate a broad range of conditions (Bayer et al., Texas Parks and Wildlife Department, unpublished report). Although considered intolerant species, ghost shiner and silverband shiner are schooling species and generally restricted to large rivers with turbid water (Robison & Buchanan 1988, Ross 2001), such as the lower Brazos River. Weak species-environment relationships also were probably related to the low spatial variation of environmental conditions in my short study reach. **The study reach was 6.9 km long, which in the opinion of TWDB staff is actually a very long study reach when compared to most other instream flow studies.** Since flood frequency of the lower Brazos River is low and collections were conducted during baseflow discharge conditions, fish assemblages during this study showed low levels of change, comparable to those expected of assemblages having more deterministic—as compared to stochastic—organizational patterns. **Based on historical data recorded at the nearest gage station, USGS Richmond gauge (# 08114000), flood flows occur frequently in the spring and summer and the probability of exceedance of each flow during fish collections is provided in Table 4.1**

Conclusions

Since most large floodplain rivers have been extensively modified, their fish assemblages have experienced drastic declines. Contrary to earlier theories and prevailing perceptions about large rivers, the main river channel of the lower Brazos River contained a speciose and abundant resident-fish assemblage. Across three summer and three winter collections during baseflow conditions, 28,468 individuals representing 41 species and 13 families were captured across both shallow river-margin and deepwater habitats within a 10-km reach. Despite the spatial heterogeneity and temporal dynamics of the environmental variables in the lower Brazos River, fishes exhibited distributions that were less variable than typically reported for headwater streams and wadeable rivers. Moreover, fish species revealed weak environmental relationships. Temporal variation in the fish assemblage appeared to be primarily related to juvenile recruitment, displacement of individuals following spates, or seasonal immigration by one estuarine species (striped mullet). Low spatial variability seemed to be associated with fairly constant environmental conditions across the study reach.

Geographic, regional, and local scale environmental variables were each consistent across sites during each collection period. Therefore, species-environment relationships were largely related to temporal variation in physicochemical conditions. Spatial variation in species assemblage structure was most influenced by current velocity, which was strongly related to the presence or absence of large-bodied fish. Future studies should incorporate broader spatial-scales that include greater variations in environmental conditions when assessing variation and species-environment relationships of fish assemblages in main-channel habitats of large rivers.

A 142,892 acre-feet municipal water supply reservoir is planned for Allens Creek. With water diversions proposed from the Brazos River mainstem to the reservoir, potential impacts to the river-fish assemblage will undoubtedly depend on the timing, frequency, and duration of those diversions. **In this study, the spatial and temporal variation of fish assemblages in the lower Brazos River were documented, and species-environment relationships that were responsible for assemblage variation over an annual cycle of typical discharge rates were identified.** This information provides a baseline for the fish habitat utilization analysis of the instream flows assessment conducted in this document, for future monitoring that could help detect and mitigate impacts associated with water diversions, and to discriminate between effects of anthropogenic disturbances versus those due to natural assemblage fluctuations.

4.4 Discussion and analysis of visually classified mesohabitats

As previously mentioned, the TAMU studies classified river mesohabitats based upon visual observation. A consensus was reached by all members of the reconnaissance team regarding the visual classifications of the sampling sites and those classifications were used for both the Gelwick and Li (2002) and Li (2003) analyses. Depth and velocity measurements were collected for each sample at three locations arranged on a diagonal line connecting two opposite corners of each sampling location. In some instances all three measurements were reported for analysis, but in other instances only the average of the three measurements was reported.

Using the available depth and velocity measurements (Gelwick and Li 2002), further investigation was performed by TWDB staff to characterize the hydraulic conditions observed and measured within each mesohabitat. The measurements were found to overlap across all mesohabitats, rendering the mesohabitats, particularly the run and pool mesohabitats, indistinguishable from each other based upon hydraulic conditions. Figure 4.3 illustrates overlap of depth-velocity pairs; each point represents one measurement and the symbol represents the visually classified mesohabitat that was reported.

Pool, run and Allens Creek confluence mesohabitat hydraulic measurements are shown to be indistinguishably overlapping. Six backwater samples were classified and exhibited generally slower (less than 5 cm/s) and shallower (less than 100 cm) hydraulic conditions than the other habitats; however, samples of both pool and run habitat were recorded in even slower and shallower locations. Similarly, riffle mesohabitat was recorded for generally shallower locations (less than 50 cm), but a number of each of the other habitats (including backwater habitat) were recorded with similar hydraulic conditions. Mesohabitat labeled as LWD was considered run habitat, but was reported separately and is shown in Figure 4.3 labeled as LWD.

The significant overlap of hydraulic conditions may explain the results of the Gelwick and Li (2002) and Li (2003) studies which found that no significant fish habitat utilization variation could be explained by visually-classified mesohabitat and that the fish communities were habitat generalists. Based upon the findings exhibited in Figure 4.3, a reanalysis using the same statistical techniques to test for significance of variation caused by velocity and depth may be warranted.

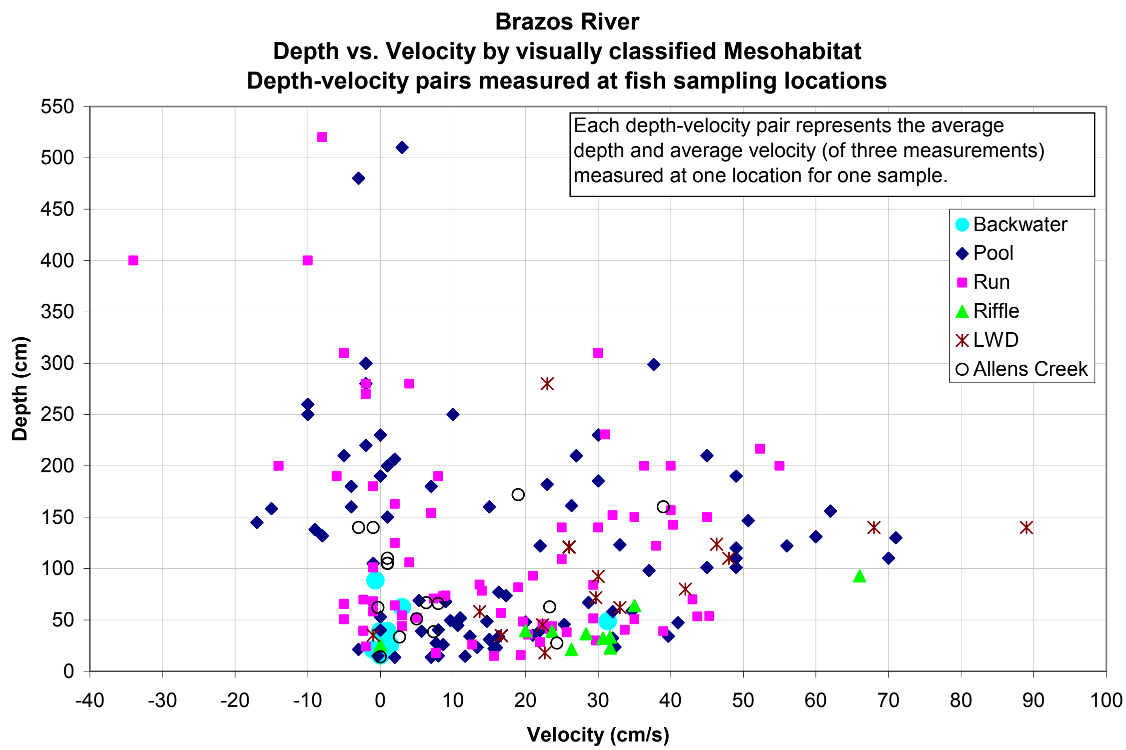

Figure 4.3 – Depth and velocity pairs for each visually classified mesohabitat (Gelwick and Li 2002).

5. TWDB fisheries analysis

Using the same dataset, three methods for analyzing fish habitat utilization in the lower Brazos River are presented in this report. Gelwick and Li (2002) and Li (2003) examined fish habitat utilization on the basis of visually classified mesohabitats. Li (2003) additionally examined fish habitat utilization on the basis of shallow and deep water habitats. Both of those studies are excerpted in Chapter 4 of this report.

The distribution of fish was further analyzed by the TWDB to characterize fish distribution based on depth and velocity. New habitat classifications were defined for all samples. To provide an equal comparison, the TWDB analysis used that same data set as Li (2003), which was a subset of the original Gelwick and Li (2002) data set. This chapter describes the development of the new habitat classifications using field data, the application of habitat criteria to a spatial (GIS) model, analysis of the availability of habitat for varying flow conditions and a simple standardized analysis of the observed fish utilization within the new habitats.

5.1 Development of spatial habitat model

Using the Li (2003) dataset, depth and velocity measurements collected for each fish sample were investigated to identify trends among the samples. Figure 5.1 shows the cumulative fraction of samples collected versus three variables: depth, velocity and Froude number. The Froude number is an indicator of water-column disturbance in gravity driven flows (e.g., open river channels) that incorporates both the depth and velocity measurements; use of the Froude number for fish habitat utilization was found useful by Vadas and Orth (1998) and by Yu and Peters (1997).

In this initial investigation of hydraulic conditions, each sample counted equally and individual fish abundance was not considered. In keeping with the Li (2003) analysis, the shallow water seine data set was evaluated separately from the deep water gillnet data set since the fish abundance data would be treated separately in the ensuing analysis.

All but two of the shallow water samples were collected in water less than 80 cm (2.62 feet) and greater than 15 centimeters (cm) (0.5 feet). Conversely, only 10% of the deep water samples were collected in water shallower than 80 cm. Ninety percent of the deep water samples were collected in water shallower than 300 cm (9.84 feet), with one sample collected in water just over 500 cm deep. Based upon the charts in Figure 5.1, an even distribution of samples appears to have been collected between 15 cm and 300 cm.

A roughly even distribution of samples were also collected for shallow water samples among velocities between -5 cm/s (-0.16 ft/s) and 35 cm/s (1.15 ft/s), and 50% of the samples occurred with velocity less than 10 cm/s (0.33 ft/s). A discontinuity existed for the velocity distribution of deep-water samples between 10 cm/s (0.33 ft/s) and 20 cm/s

(0.66 ft/s), and almost 45% of the samples were recorded with current velocity in the direction opposite to the river flow direction (negative velocity).

Similar to the distribution of depth and velocity among shallow samples, the distribution of Froude number calculated using the depth-velocity pairs for shallow water samples was even over the range between 0.0 and 0.20. Froude number calculated for deep-water depth-velocity pairs exhibited a discontinuity, 60% of the samples were collected between Froude numbers of 0.0 and 0.05.

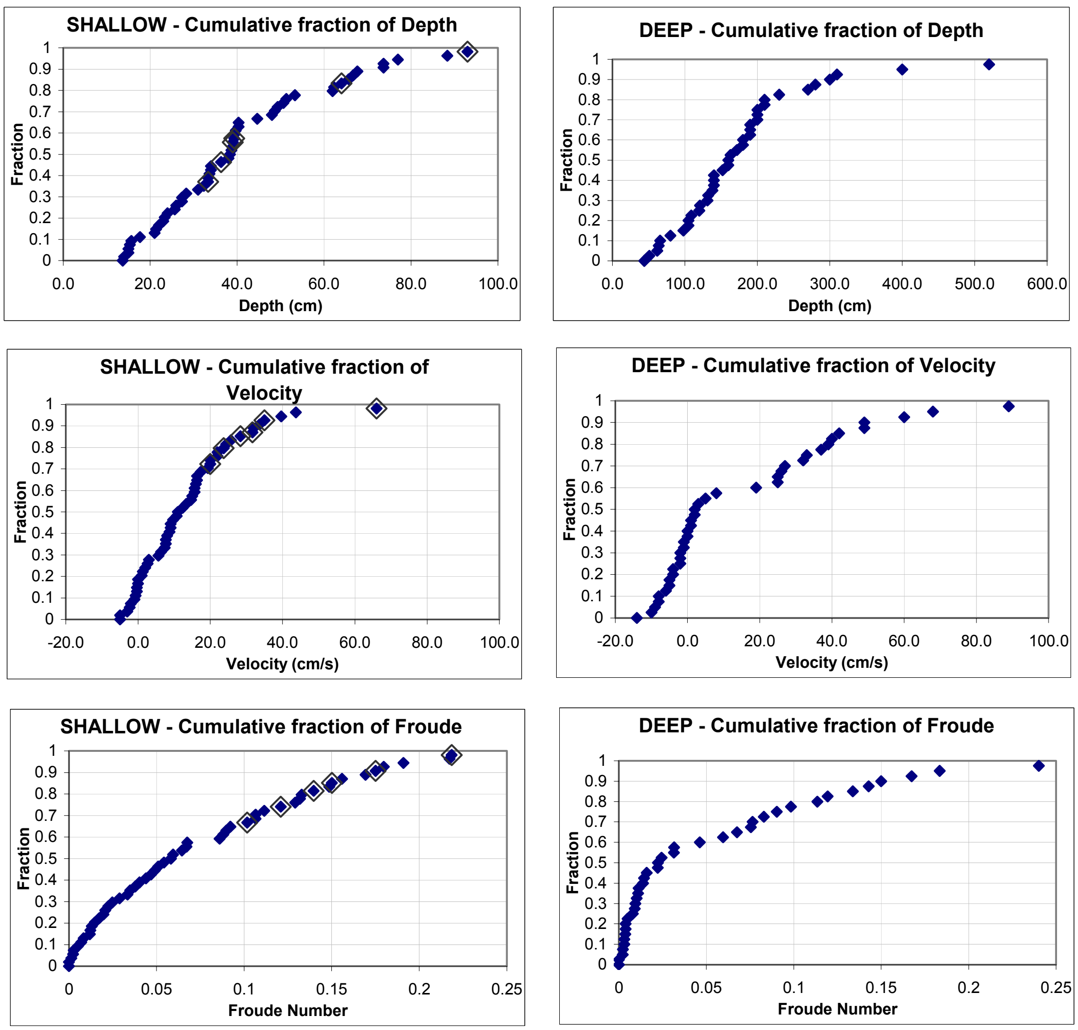

Figure 5.1 – Cumulative fraction of samples by depth, velocity and Froude number, for shallow (left) and deep (right) collections. Samples outlined were visually classified by Gelwick and Li (2002) as riffles.

Based upon the observations noted above, four hydraulic mesohabitats were classified based upon the distribution of depth and velocity that was observed across all samples. Hydraulic habitat was divided into shallow mesohabitat, where depths were less than 80 cm (2.62 feet), and deep mesohabitat, where depths were greater than or equal to 80 cm. Samples exhibiting velocity less than 10 cm/s (0.33 ft/s) were classified as lentic (low velocity) areas and samples exhibiting velocity greater than 10 cm/s were classified as lotic (moving velocity) areas. Figure 5.2 graphically illustrates the depth and velocity criteria and Table 5.1 lists the depth and velocity criteria.

Table 5.1 – Criteria for hydraulic mesohabitat (lengths in cm, velocity in cm/s)

	Depth		Velocity	
	low	**high**	**low**	**high**
Shallow Lentic	0	0.8	< 10	10
Shallow Lotic	0	0.8		> 10
Deep Lentic		> 0.8	< 10	10
Deep Lotic		> 0.8		> 10

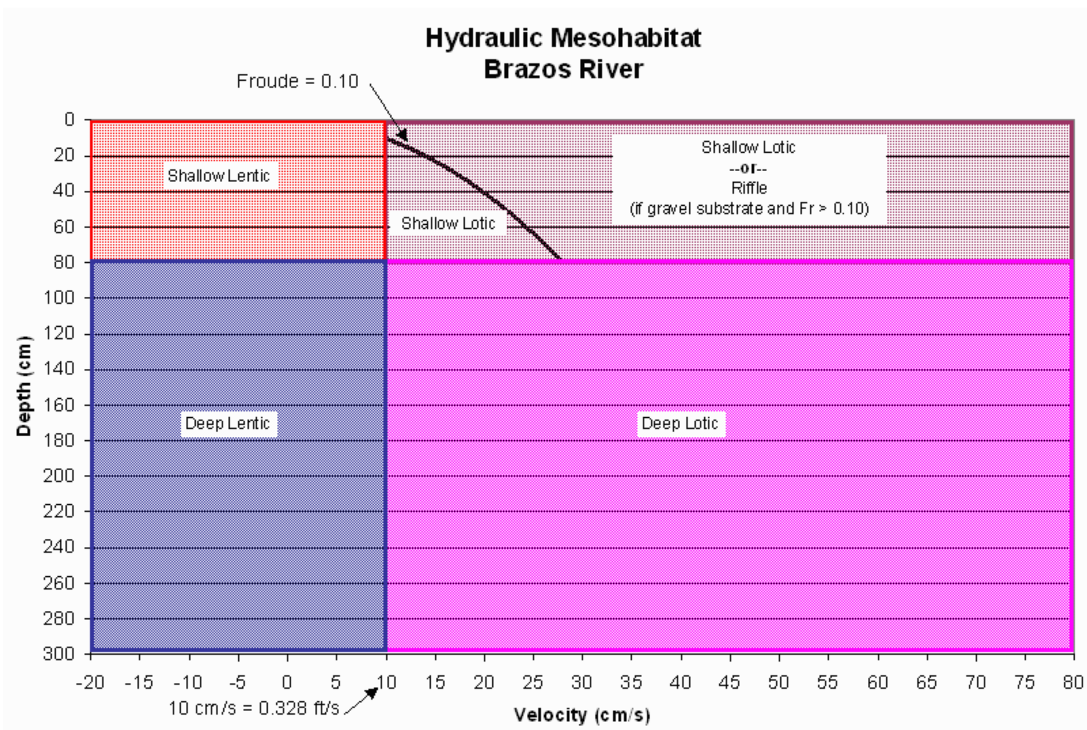

Figure 5.2 – Hydraulic mesohabitat chart

Four additional specialized habitats were identified based upon substrate and location within the river channel (Table 5.2). Deep margin specialized habitat was defined as deep mesohabitat that was located less than or equal to 1.5 meters (4.92 feet) from shore. The significance of this habitat with respect to fish collection data could not be investigated since deep margin data was not collected; however, the significance of this specialized habitat is discussed in following sections. Six locations were sampled and classified visually by Gelwick and Li (2002) as riffle habitat in areas where that habitat coincided with coarse substrate (Gelwick and Li 2002). All of these riffle samples were also a part of the Li (2003) dataset. As shown on Figure 5.1, riffles occurred for a range of depths (including the deepest shallow water sample), occurred only in the highest 20% of samples with respect to velocity and occurred in the highest 35% of samples with respect to Froude number. Since all riffles sampled occurred with a Froude number greater than 0.10, the riffle mesohabitat was identified for locations with coarse substrate and Froude number greater than or equal to 0.10. A substrate grid was developed to mark areas with coarse substrate suitable for riffle habitat and is shown in Figure 5.3. Another specialized habitat, backwater, was identified by Gelwick and Li (2002), and located near the bridge area in the center of the study reach. The backwater area is also shown in Figure 5.3. Shallow margin specialized habitat was defined as shallow habitat with depth less than 50 cm (1.64 feet). Shallow water samples collected in water less than 50 cm represented almost 75% of all shallow water samples, and, as discussed in later sections, less than 50% of the individual fish on the basis of absolute abundance occurred in this depth category.

The significance of each of these hydraulic mesohabitats and specialized habitats is discussed in the following section. Based upon the criteria developed in this section, the habitat for all samples in Li (2003) dataset were reclassified using the measured depth, velocity and location data. Using the habitat criteria presented in this section (Tables 5.1 and 5.2), a spatial analysis was performed using a Geographic Information System (GIS) to delineate the habitats. The criteria were applied to depth and velocity grids that were generated by the hydraulic model described in earlier sections of this report. The criteria were applied separately to each flow rate modeled, and both the area and volume of each hydraulic mesohabitat and specialized habitat were calculated. The results of the GIS model are summarized in following sections.

Regarding the applicability of the habitats described in this section, the habitat criteria were developed based on differences in fish sampling methodology and also partially on discontinuities present in the datasets. These reclassified habitats should be considered representative of the area to which the fish data from the Gelwick and Li (2002) study is applicable rather than completely representative of the aquatic habitats present of the lower Brazos River. Additional unique and important habitats may exist outside of the range of habitats sampled and further study is recommended.

Table 5.2 – Criteria for specialized habitat areas (length in meters)

	Hydrauilc Mesohabitat	Substrate	Backwater	Froude	Depth low	Depth high	Distance from water edge
Riffle	Shallow Lotic	coarse	-	> 0.10	-	-	-
Shallow * Margin	any Shallow	-	-	-	0	0.5	-
Deep * Margin	any Deep	-	-	-	-	-	<= 1.5
Backwater	Shallow Lentic	-	yes	-	-	-	-

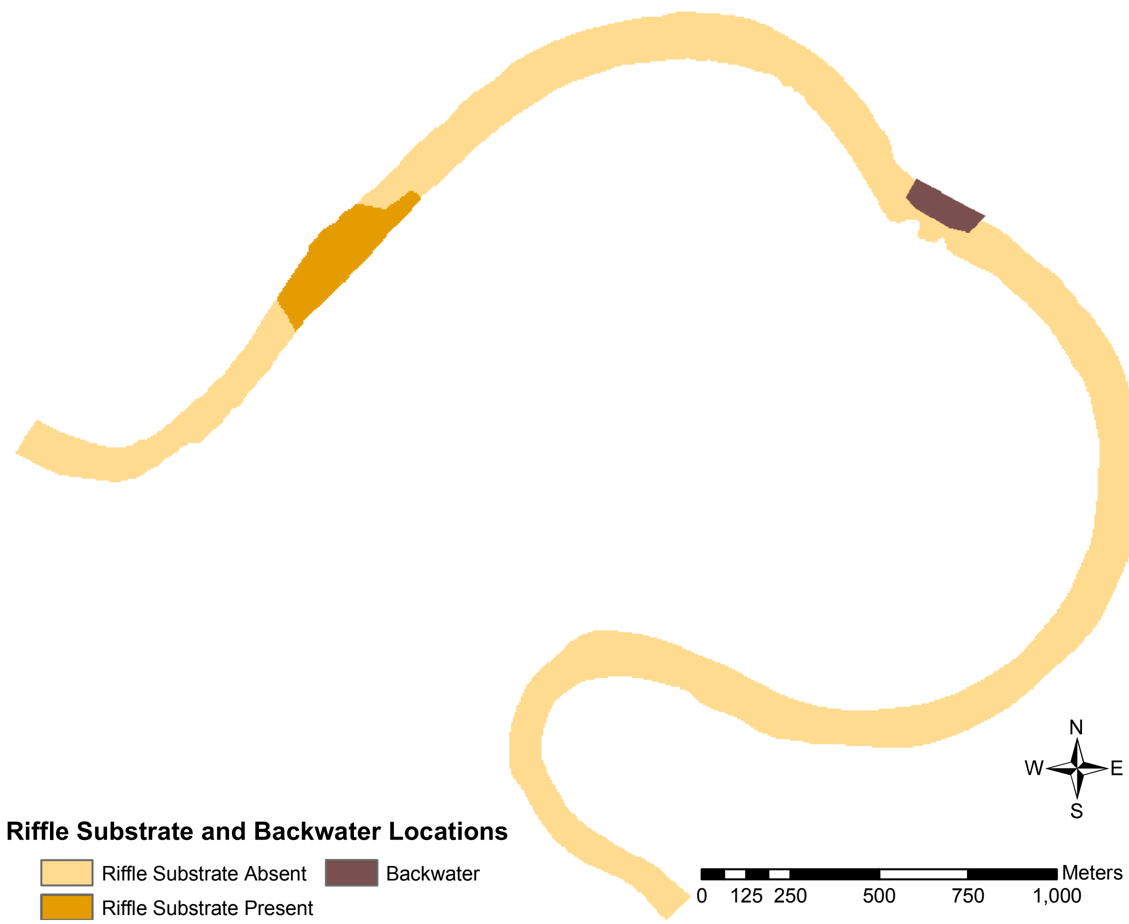

Figure 5.3 – Substrate and backwater grids used in mesohabitat analysis.

5.2 Species distribution within hydraulic mesohabitats and specialized habitats

The evaluation of the fishery of the lower Brazos River was examined by partitioning the fluvial dynamics of the river into categories of habitat that could be understood and analyzed for their community structure, their function and their flow sensitivity. Following the method presented in Li (2003), partitioning was partially done by sampling methodology, and partially by examining the hydraulic and fishery collection data. Gelwick and Li (2002) sampled shallow areas by seines and the deep areas with gillnets. As described in Chapter 4, other sampling methods were used to collect fish within the study reach but these samples were not considered. Electrofishing was not effective and was discontinued early in the sampling effort, and hoop nets and baited fish trap collections were not very productive as applied to deep habitats. It was determined in consultation with Dr. Fran Gelwick (TAMU – Department of Wildlife and Fisheries Science) and Dr. Tim Bonner (Texas State University @ San Marcos – TSU – Aquatic Biology Program) that to best compare the relative abundance of fishes within each habitat area, only seine data would be used to analyze the shallow fish community structure, and only gillnet data would be used to analyze the deep fishery.

5.2.1 Mesohabitats and fundamental habitat groups

As described in section 5.1, four hydraulic mesohabitats were delineated on the basis of fish distributions within the depth-velocity structure of the lower Brazos River (Figure 5.2). Consistent with the Li (2003) analysis, sampling technique was used as the criteria to separate the shallow and deep water habitats. Shallow waters were sampled by seining (≤ 80 cm), and deep waters by gillnets (> 80 cm). As a preliminary investigation into the distribution of fish collected amongst all samples, the relative non-standardized abundance was calculated for each species across all samples and was inspected on a cumulative, non-species-specific basis. This allowed a rough investigation of the distribution of fish with respect to depth, velocity and Froude number upon which a more detailed investigation would proceed. The cumulative relative fractions of fish by depth, velocity and Froude number are shown in Figure 5.4, separated by shallow and deep collections.

A comparison of Figures 5.1 and 5.4 indicates that, for shallow water samples, 80% of all fish were collected below 10 cm/s (Figure 5.4) while only 50% of the samples were collected under conditions with velocity less than 10 cm/s (Figure 5.1). In other words, 80% of the fish collected in water moving less than 10 cm/s were obtained from only 50% of the sites sampled. Similar inspection of the deep-water samples revealed that 85% of the fish were collected below 10 cm/s (Figure 5.4) while only 60% of the samples were collected with velocity less than 10 cm/s (Figure 5.1). This skewness of fish abundance distribution with respect to distribution of sampled velocities contributed to the designation of the lentic velocity criteria of less than 10 cm/s and lotic velocity criteria of greater than 10 cm/s.

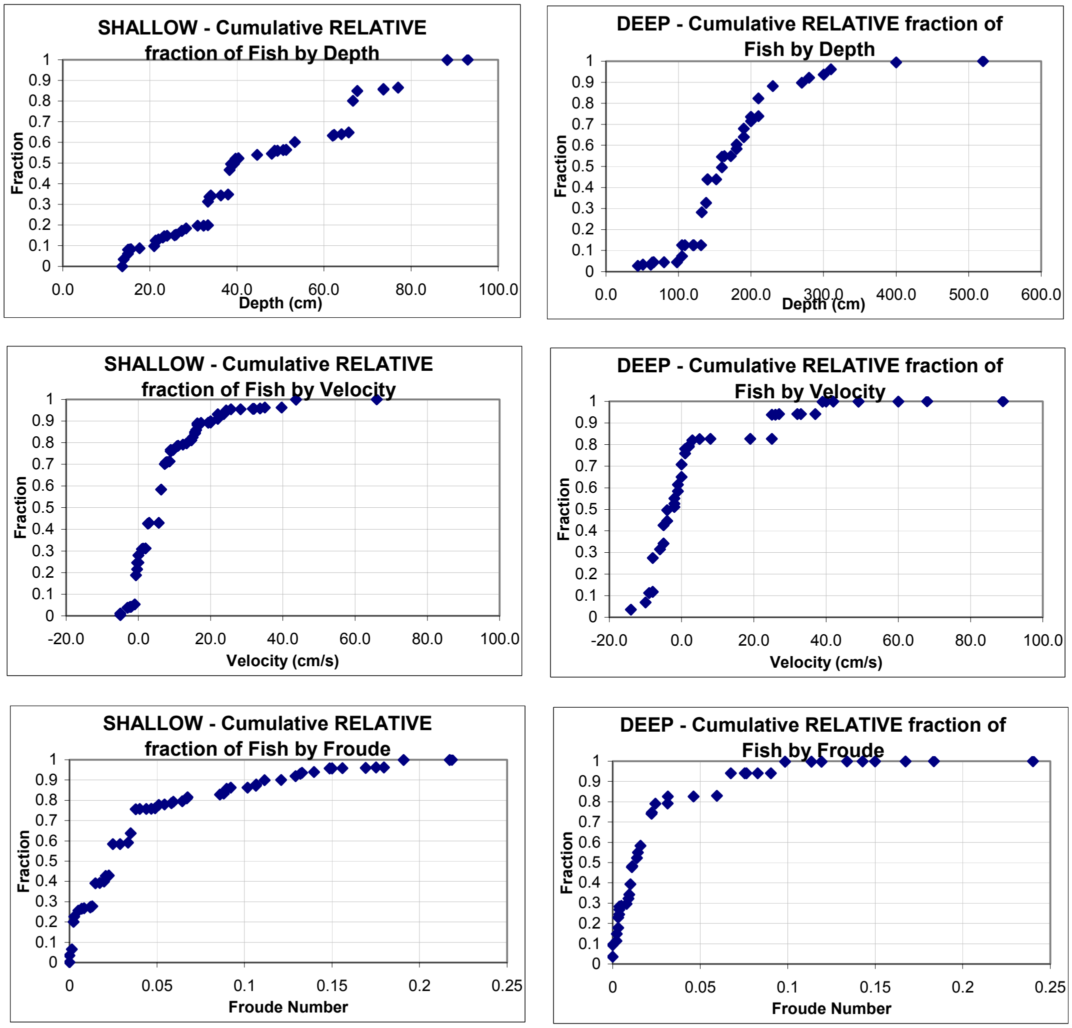

Figure 5.4 – Cumulative fraction of relative abundance (not standardized) for depth, velocity and Froude number, for both shallow and deep partitions.

There were a total of 40 deep water gillnet samples and 54 shallow seine samples, and some habitats were sampled more than others. In order to correct for this problem, the fish collection data was standardized so that the abundance of species within each of the habitats could be compared on an equal basis, i.e., as if each habitat had been sampled on an equal basis. Since, among samples of each gear type, the sampling effort for each sample was equivalent by design (Li 2003), sampling effort could be standardized as the number of samples collected.

Using velocity distribution analysis as an example of the standardization procedure, Table 5.4 presents fish abundance based upon the lentic and lotic categories. Using inland silversides as an example where the total standardized abundance was 62.2 individuals collected, the relative standardized abundance designates that 96.9% of the 62.2 individuals occurred in the lentic category. The intent of the standardization was not to calculate the density of fish (zero abundance samples do not count toward the standardization); rather, the intent was to understand where a species was most frequently found among those habitats (or seasons) in which it was collected. Inspection of Table 5.3, which tabulates absolute abundance within the velocity habitats, reveals that 29 individuals of inland silverside occurred in 6 of 26 samples collected in shallow lentic habitats.

The absolute abundance of fish within hydraulic mesohabitats was analyzed by velocity distribution (Table 5.3), and partitioned at 10 cm/s due to the broad changes in fish species composition above and below that velocity. Velocity less than 10 cm/s was considered lentic habitat and velocity greater than or equal to 10 cm/s was considered lotic habitat. The relative standardized abundance in that data set (Table 5.4) showed a clearer abundance pattern among those species that represented more than 10% of the collection in the lentic zone. Small-bodied fish, such as the inland silverside, shad species, mosquitofish, ghost shiner and bullhead minnow dominated the shallow lentic habitat, while larger-bodied fish, such as the skipjack herring, smallmouth buffalo, and river carpsucker dominated the deep lentic habitat. Shallow higher velocity waters were dominated by the speckled and sliver chubs. Only one species dominated the faster flowing deep waters of the river, and that was the striped mullet. The shallow and deep hydraulic habitats were then partitioned on the basis of velocity (i.e., into lentic and lotic zones), as demonstrated in Figure 5.2 and Table 5.5.

Table 5.3 – Absolute abundance by hydraulic mesohabitat partitioned on the basis of velocity into fluvial categories.

Species			**Hydraulic Mesohabitat**			
Species with abundance greater than 0.1% across all collections			**Lentic**		**Lotic**	
Scientific Name	**Common Name**	**abundance**	< 10 cm/s		>= 10 cm/s	
Shallow water seine species			abundance	samples	abundance	samples
Menidia beryllina	inland silverside	30	29	6	1	1
Dorosoma cepedianum	gizzard shad	41	38	8	3	2
Dorosoma petenense	threadfin shad	129	113	11	16	5
Cyprinella lutrensis	red shiner	18614	8108	25	10506	28
Macrhybopsis aestivalis	speckled chub	73	19	6	54	11
Machrybopsis storeriana	silver chub	31	4	3	27	5
Notropis buchanani	ghost shiner	768	538	16	230	17
Notropis shumardi	silverband shiner	1741	1069	19	672	21
Pimephales vigilax	bullhead minnow	4626	3113	24	1513	27
Ictalurus punctatus	channel catfish	28	11	5	17	6
Mugil cephalus	striped mullet	619	214	4	405	6
Gambusia affinis	mosquitofish	1395	1296	15	99	11
Total number of samples				26		28
Percent of samples collected in Summer			22.22%		27.78%	
Percent of samples collected in Winter			25.93%		24.07%	
Percent of samples collected in each Habitat			48.15%		51.85%	
Deep water gillnet species			abundance	samples	abundance	samples
Alosa chrysochloris	skipjack herring	2	2	1		
Carpioides carpio	river carpsucker	16	15	9	1	1
Ictiobus bubalus	smallmouth buffalo	10	10	9		
Dorosoma cepedianum	gizzard shad	18	16	8	2	2
Ictalurus furcatus	blue catfish	15	13	10	2	1
Ictalurus punctatus	channel catfish	5	4	4	1	1
Lepisosteus oculatus	spotted gar	30	23	7	7	3
Lepisosteus osseus	longnose gar	154	103	16	51	5
Mugil cephalus	striped mullet	3	1	1	2	2
Aplodinotus grunniens	freshwater drum	5	5	5		
Total number of samples				24		16
Percent of samples collected in Summer			22.50%		17.50%	
Percent of samples collected in Winter			37.50%		22.50%	
Percent of samples collected in each Habitat			60.00%		40.00%	

Table 5.4 – Relative standardized abundance by hydraulic mesohabitat partitioned on the basis of velocity into fluvial categories.

Species			**Hydraulic Mesohabitat**	
Species with abundance greater than 0.1% across all collections			**Lentic**	**Lotic**
Scientific Name	**Common Name**	**abundance**	< 10 cm/s	>= 10 cm/s
		(standardized)		
Shallow water seine species				
Menidia beryllina	inland silverside	62.2	96.90%	3.10%
Dorosoma cepedianum	gizzard shad	84.7	93.17%	6.83%
Dorosoma petenense	threadfin shad	265.5	88.38%	11.62%
Cyprinella lutrensis	red shiner	37101.3	45.39%	54.61%
Macrhybopsis aestivalis	speckled chub	143.6	27.48%	72.52%
Machrybopsis storeriana	silver chub	60.4	13.76%	86.24%
Notropis buchanani	ghost shiner	1561.0	71.58%	28.42%
Notropis shumardi	silverband shiner	3516.2	63.14%	36.86%
Pimephales vigilax	bullhead minnow	9383.4	68.90%	31.10%
Ictalurus punctatus	channel catfish	55.6	41.07%	58.93%
Mugil cephalus	striped mullet	1225.5	36.27%	63.73%
Gambusia affinis	mosquitofish	2882.6	93.38%	6.62%
		Total number of samples	26	28
		Percent of samples collected in Summer	22.22%	27.78%
		Percent of samples collected in Winter	25.93%	24.07%
		Percent of samples collected in each Habitat	48.15%	51.85%
Deep water gillnet species				
Alosa chrysochloris	skipjack herring	3.3	100.00%	
Carpioides carpio	river carpsucker	27.5	90.91%	9.09%
Ictiobus bubalus	smallmouth buffalo	16.7	100.00%	
Dorosoma cepedianum	gizzard shad	31.7	84.21%	15.79%
Ictalurus furcatus	blue catfish	26.7	81.25%	18.75%
Ictalurus punctatus	channel catfish	9.2	72.73%	27.27%
Lepisosteus oculatus	spotted gar	55.8	68.66%	31.34%
Lepisosteus osseus	longnose gar	299.2	57.38%	42.62%
Mugil cephalus	striped mullet	6.7	25.00%	75.00%
Aplodinotus grunniens	freshwater drum	8.3	100.00%	
		Total number of samples	24	16
		Percent of samples collected in Summer	22.50%	17.50%
		Percent of samples collected in Winter	37.50%	22.50%
		Percent of samples collected in each Habitat	60.00%	40.00%

Legend

77.77% Green highlight indicates a relative standardized abundance that is greater than an even distribution (50%) among standardized samples

The use of depth and velocity criteria was instrumental in diagnosing and partitioning the fishery community structure into fundamental habitat groups within each hydraulic mesohabitat (Table 5.5). Consistent with Li's observations (2003) the small-bodied fish primarily utilized the shallow hydraulic habitats, and the large-bodied fish utilized the deep hydraulic. This habitat utilization is consistent with our findings in other large Texas rivers. However, because this fish habitat utilization is based only on seining in shallow waters and only on gill nets in deep waters, there may be some sample bias in size class analysis (i.e., small and large bodied fish community assessment) based on this sampling strategy.

Table 5.5 – Fundamental mesohabitat groups based upon depth and fluvial conditions.

	Shallow Hydraulic Mesohabitat		Deep Hydraulic Mesohabitat	
	Lentic	**Lotic**	**Lentic**	**Lotic**
	< 10 cm/s	>= 10 cm/s	< 10 cm/s	>= 10 cm/s
Number of samples	26	28	24	16
Percent of all samples	48.15%	51.85%	60.00%	40.00%
Percent of summer samples	22.22%	27.78%	22.50%	17.50%
Percent of winter samples	25.93%	24.07%	37.50%	22.50%
Species common name				
Species with abundance greater than 0.1% across all collections, listed in decreasing relative standardized abundance	inland silverside	silver chub	skipjack herring	striped mullet
	mosquitofish	speckled chub	smallmouth buffalo	longnose gar
	gizzard shad	striped mullet	freshwater drum	spotted gar
	threadfin shad	channel catfish	river carpsucker	channel catfish
	ghost shiner	red shiner	gizzard shad	blue catfish
	bullhead minnow	silverband shiner	blue catfish	gizzard shad
	silverband shiner	bullhead minnow	channel catfish	river carpsucker
	red shiner	ghost shiner	spotted gar	skipjack herring
	channel catfish	threadfin shad	longnose gar	smallmouth buffalo
	striped mullet	gizzard shad	striped mullet	freshwater drum
	speckled chub	mosquitofish		
	silver chub	inland silverside		

Notes:

Species occurring in each habitat are shown in order of decreasing relative standardized abundance

species — Species shown with green shading are those whose relative standardized abundance is greater than an even distribution (50%) among standardized samples

The relative abundance of fish within hydraulic mesohabitats partitioned by depth was further analyzed on the basis of distance from shore. In the shallow water habitats, depth was used as a substitute for distance from shore. The dividing line between the two characterizing distances from the shore, margin and channel, was theorized at 50 cm on the basis of estimating the boundary between the near-shore margin habitats and the open channel in the lower Brazos River (Figure 5.5). This definition of margin habitat is different than Li's (2003) partitioning and this TWDB boundary is subject to interpretation. We suggest that further analysis is needed for a better understanding of these habitats. Since there was an uneven distribution of samples between margin and channel habitat (Table 5.6), the fish collection data were standardized by sample as before (Table 5.7).

Silver chub and striped mullet dominated the margin habitat on the basis of standardized collection data, and other small-bodied species were very abundant, including in decreasing order of abundance the mosquitofish, red shiner, silverband shiner, and bullhead minnow. The channel was dominated in decreasing order of abundance by gizzard shad, inland silverside, threadfin shad, channel catfish, and speckled chub. Bullhead minnows and silverband shiners were also highly abundant in channel habitats.

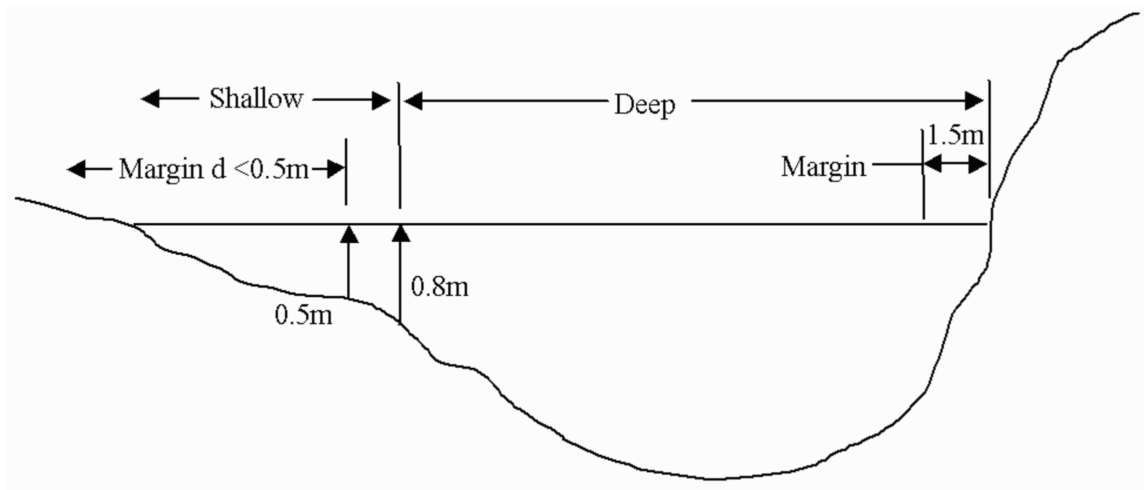

Figure 5.5 – Generalized channel cross-section depicting margin habitats

The seasonal distribution of fishes within the mesohabitats, based on both Clark Hubb's seasons and summer/winter seasons, is shown in Table 5.8 for absolute abundance, and Table 5.9 for relative abundance (see end of chapter for these tables). The broad seasonal analyses based on both the partitioning recommended by Dr. Clark Hubbs and the summer and winter seasons under various flow rates show some definitive temporal trends. For instance, the relative abundance of fishes in the shallow water seine samples was in nearly reverse order for the two broad seasons. There were peaks in shallow-dwelling fish species abundance during March and September, which appears to correspond to major spawning periods. The shifts in seasonal species dominance within deep water habitats was not as abrupt as the shifts in seasonal species dominance within the shallow water habitats, but there were clear changes, especially for gizzard shad, spotted and longnose gar, freshwater drum, and striped mullet. The distributions of fish relative abundance was more evenly distributed within deep waters, although greater abundances among the species were observed in August and February, which may be related to pelagic spawning activity.

Table 5.6 – Absolute abundance by mesohabitat partitioned on the basis of depth for shallow samples.

Species			Hydraulic Mesohabitat			
Species with abundance greater than 0.1% across all collections			Margin		Channel	
Scientific Name	Common Name	abundance	< 50 cm		>= 50 cm	
Shallow water seine species			abundance	samples	abundance	samples
Menidia beryllina	inland silverside	30	9	3	21	4
Dorosoma cepedianum	gizzard shad	41	11	5	30	5
Dorosoma petenense	threadfin shad	129	52	7	77	9
Cyprinella lutrensis	red shiner	18614	15419	39	3195	14
Macrhybopsis aestivalis	speckled chub	73	47	12	26	5
Machrybopsis storeriana	silver chub	31	29	7	2	1
Notropis buchanani	ghost shiner	768	575	25	193	8
Notropis shumardi	silverband shiner	1741	1279	29	462	11
Pimephales vigilax	bullhead minnow	4626	3346	38	1280	13
Ictalurus punctatus	channel catfish	28	15	6	13	5
Mugil cephalus	striped mullet	619	602	8	17	1
Gambusia affinis	mosquitofish	1395	1078	15	317	11
Total number of samples				40		14
Percent of samples collected in Summer			35.19%		14.81%	
Percent of samples collected in Winter			38.89%		11.11%	
Percent of samples collected in each Habitat			74.07%		25.93%	

Table 5.7 – Relative standardized abundance by mesohabitat partitioned on the basis of depth for shallow samples.

Species			Hydraulic Mesohabitat	
Species with abundance greater than 0.1% across all collections			Margin	Channel
Scientific Name	Common Name	abundance	< 50 cm	>= 50 cm
Shallow water seine species		(standardized)		
Menidia beryllina	inland silverside	93.2	13.04%	86.96%
Dorosoma cepedianum	gizzard shad	130.6	11.37%	88.63%
Dorosoma petenense	threadfin shad	367.2	19.12%	80.88%
Cyprinella lutrensis	red shiner	33139.2	62.81%	37.19%
Macrhybopsis aestivalis	speckled chub	163.7	38.75%	61.25%
Machrybopsis storeriana	silver chub	46.9	83.54%	16.46%
Notropis buchanani	ghost shiner	1520.7	51.05%	48.95%
Notropis shumardi	silverband shiner	3508.7	49.21%	50.79%
Pimephales vigilax	bullhead minnow	9454.2	47.78%	52.22%
Ictalurus punctatus	channel catfish	70.4	28.77%	71.23%
Mugil cephalus	striped mullet	878.3	92.53%	7.47%
Gambusia affinis	mosquitofish	2678.0	54.34%	45.66%
Total number of samples			40	14
Percent of samples collected in Summer			35.19%	14.81%
Percent of samples collected in Winter			38.89%	11.11%
Percent of samples collected in each Habitat			74.07%	25.93%

Legend

77.77% Green highlight indicates a relative standardized abundance that is greater than an even distribution (50%) among standardized samples

5.2.2 Specialized Habitats and Communities

The community structure of certain areas within each of the hydraulic mesohabitats described above greatly varied, so the mesohabitats were partitioned further into ten mutually exclusive specialized habitats. The ten specialized habitats included the following: 1) backwater, 2) lentic channel, 3) lentic margin, 4) lentic embayment, 5) lotic channel 6) lotic margin, 7) lotic embayment, 8) riffle, 9) lentic confluence, and 10) lotic confluence (see Tables 5.10, 5.11, 5.12 and 5.13 at the end of this chapter). The species composition and special habitat conditions within each of these specialized habitats are discussed in section 5.4 that focuses on the distribution of fish species related to spawning habitats, migrations, mesohabitat utilization, and environmental variables. As before, these specialized habitats were partitioned into shallow water seine collected species and deep water gillnet collected species. Only the species with abundances greater than 0.1% of the collections within each habitat were reported in Table 5.11, in order to better determine trends in species dominance patterns or guilds within each of the ten specialized habitats.

As is apparent in Table 5.11, lentic embayments were the most frequently sampled (47.5 %) of all specialized habitats, followed by lotic channels (32.5 %), lotic margins (31.5 %), lentic margins (20.4 %), and riffles and backwaters (both 11.1 %). For all habitats, depth and velocity had a strong influence on species composition, to the extent that separate guilds were functioning within each major hydraulic mesohabitat (see Fundamental Mesohabitat Groups, Table 5.1), and the fishery composition partitioned on this basis for each of the specialized habitats led to some important findings (Table 5.11 and 5.4). The green highlighted abundances in Table 5.11 indicate that a fish species showed a greater relative standardized abundance in a particular specialized habitat than would be expected if that fish was evenly distributed throughout the ten habitats. For each fish species, the abundance shown in bold type indicates the specialized habitat where the largest relative standardized abundance was found for that species. Table 5.11 clearly shows that there were numerous species that were most abundant in the shallow lentic confluence habitat than the other specialized habitats. Similarly, numerous species were more abundant in the deep lotic embayment habitat than in other specialized habitats; however, only one sample was collected in the deep lotic embayment habitat and the small sample size (one sample standardized to 40 samples) likely skewed the results of this analysis. Seasonal abundances changed the most in deep lentic embayments and deep lotic channels, with winter actually having greater abundances. Perhaps the deeper habitats provide more stable conditions during the winter for the guilds that are found in those habitats. More sampling is recommended to determine if this utilization of habitat is a relic of the standardization method or if it is significant in the field.

The specialized habitat communities or guilds are displayed in Table 5.12 for shallow water seine sampled areas, and Table 5.13 for deep water gillnet sampled areas. The tables show the community structure of species within each habitat in order of decreasing relative standardized abundance. The highlighted fish species in each of the ten specialized habitats indicate which fishes were more abundant in a particular habitat than the expected abundance if the fishes were evenly distributed across each of the ten habitats. The species in bold represent the specialized habitat in which each species is observed to have the highest abundance across all of the habitats in which it occurs. Therefore, the shallow lentic confluence habitat was utilized by the most species that most frequently occurred in that habitat when compared to other habitats within which they also occurred. Inland silverside, mosquitofish, and silverband shiners topped the list and showed greater utilization of that habitat. Channel catfish and speckled chub most frequently utilized the lotic channel and were the most abundant species in that habitat; however, as mentioned above, only one sampling event occurred in this habitat.

Among the deep specialized habitat communities, embayments had the greatest diversity and number of dominant fish species. The deep lotic embayment habitat had seven highly abundant fish species, five of which were more abundant in that habitat type than any of the others; however, the fact that only one sample was collected in this habitat should be considered when reviewing this data. The channel and blue catfish, striped mullet, and river carpsucker were among those that were most abundant in the deep lotic embayment habitat. It is important to keep in mind that striped mullet are a migratory species that swim upstream in large coastal rivers, and they only occurred for a short time in the lower Brazos River from March-April at high flows (50 percentile). Thus, there is an important temporal consideration in the community structure. Most fish species are not migratory to the extent of the striped mullet, and were resident within the reported specialized habitats over a greater range of seasons and flows. Each specialized habitat is characterized by a very different guild structure, which is probably a function of differences in how species forage, seek protection, use spawning habitat, respond to environmental variables, and interact with other species.

5.3 Relationship of habitat areas to flow rate

The evaluation of fish habitat distributions within the lower Brazos River was performed using GIS mapping of the various habitats at different flows. One of the goals of this study was to determine the changes in habitat availability over a range of flows. The changes in the surface area of each of the specialized habitats over a range of flows were summarized in Table 5.14 and Figures 5.6 and 5.7, as well as shown in map form in Appendix H.

Edwards (1997), in a TWDB contract study on the ecological profiles of selected stream-dwelling Texas Freshwater Fishes, concluded that density-dependent interactions become greater among and within species as water volumes are decreased. He reported that decreased water volumes temporarily puts a larger number of individuals per volume of water together competing for fewer overall resources. This "concentrating effect" he refers to can cause increased mortalities of all life stages by limiting food resources and available spawning habitat. Because the concentrating effect is better expressed on a volume basis, these analyses were also conducted for a range of flows and summarized in

Table 5.15 and Figures 5.8, 5.9 and 5.10. The relationship between flow and the availability of specialized habitats is not linear, and therefore the "concentrating effect" is not linear either. That is an important concept in attempting to determine the impact of reduced flow on the lower Brazos River, and the instream flow needs of the fishery.

Table 5.14 – Area (x 10^3 m^2) of available habitat for each modeled flow rate.

	Flow rate (m^3/s)											
Habitat	**19.82**	**25.48**	**31.14**	**36.81**	**41.22**	**50.97**	**62.29**	**67.96**	**73.62**	**80.7**	**94.86**	**116.09**
Dry	244.9	217.9	201.4	184.8	176.5	142.8	108.9	98	90.9	77	54.8	38.6
Backwater	1.8	1.8	1.7	1.6	1.62	3.7	6.8	6.9	7	7.4	8.4	4.4
Shallow Lentic	8.5	6.6	6.5	6.1	6.98	6.7	5.4	4.5	4	4.7	6.05	3.4
Shallow Lentic Margin	131	127.8	123.6	119.1	119.6	111.4	106.8	103.1	105.2	88.3	96.2	58.6
Shallow Lotic	91.1	85.8	80.4	73.8	68.9	66.7	65.3	62.7	57.2	51.4	45	48.4
Shallow Lotic Margin	59.3	60.1	59.5	59.3	53.9	49.4	41.3	39.7	34.7	40.9	21.1	30.3
Riffle	3.3	2.9	2.6	2.2	2	1.8	2.8	2.8	2.7	2.5	1.4	0.8
Deep Lentic	15.5	12	11	9.5	9.7	9.7	8.6	8.3	8.2	8.8	8.9	8.1
Deep Lentic Margin	0.3	0.45	0.5	0.5	0.6	0.8	1	1	1.1	1.1	1.2	1.3
Deep Lotic	228.9	268.7	296.2	325.9	342.7	388.4	433.8	451.7	468.1	496	533.4	578.7
Deep Lotic Margin	2.1	2.7	3.2	3.8	4.2	5.3	6.6	7.3	7.6	8.7	10.4	14

Table 5.15 – Volume (x 10^3 m^3) of available habitat for each modeled flow rate.

	Flow rate (m^3/s)											
Habitat	**19.82**	**25.48**	**31.14**	**36.81**	**41.22**	**50.97**	**62.29**	**67.96**	**73.62**	**80.7**	**94.86**	**116.09**
Total volume (10^3 m^3)	482.2	537	579	624.6	654.1	752.2	859.7	903.9	945.8	1028.1	1158.7	1331.1
Backwater	0.4	0.4	0.4	0.4	0.3	0.6	1.1	1.2	1.3	1.5	1.7	1.7
Shallow Lentic	5.4	4.2	4.1	3.9	4.4	4.2	3.4	2.8	2.5	3	3.8	2.2
Shallow Lentic Margin	12.5	11.6	11.7	11.1	11.4	11.5	10.1	9.8	9.7	9.4	10.2	6.1
Shallow Lotic	59.5	56.8	53.3	48.7	45.3	43.6	42.9	41.2	37.9	34	29.4	31.9
Shallow Lotic Margin	20.1	20.6	20.3	20.4	19	17.5	14.5	13.9	12.5	14.1	8.1	11.3
Riffle	1.6	1.6	1.4	1.2	1.2	0.8	1	1.1	1.2	1	0.8	0.5
Deep Lentic	39.7	33.2	27.4	22.7	20.9	20	18.2	17.7	17.5	18.7	19.5	17.5
Deep Lentic Margin	0.5	0.6	0.7	0.8	0.7	1	1.3	1.4	1.5	1.5	1.8	2
Deep Lotic	339	403.7	454.5	509.7	544.3	644.7	756.9	803.3	849.4	930.8	1065.8	1234.4
Deep Lotic Margin	3.5	4.2	5.1	5.8	6.5	8.2	10.4	11.5	12.3	14.2	17.7	23.6

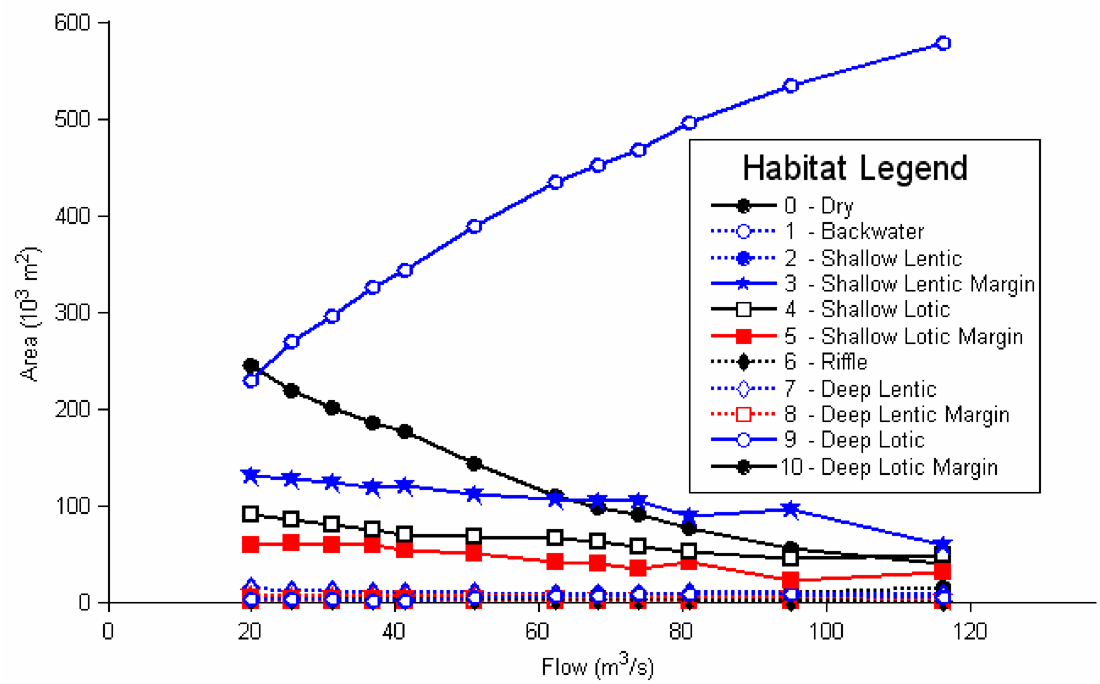

Figure 5.6 – Habitat Area vs. Flow

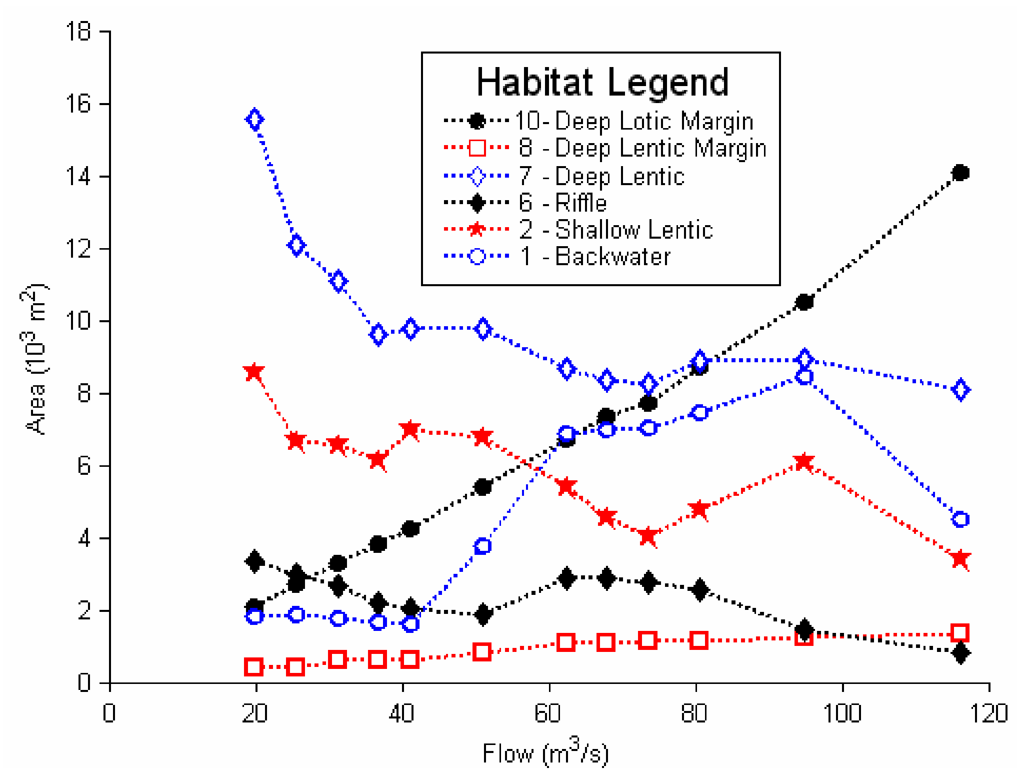

Figure 5.7 – Habitat Area vs. Flow – Less Abundant Habitats

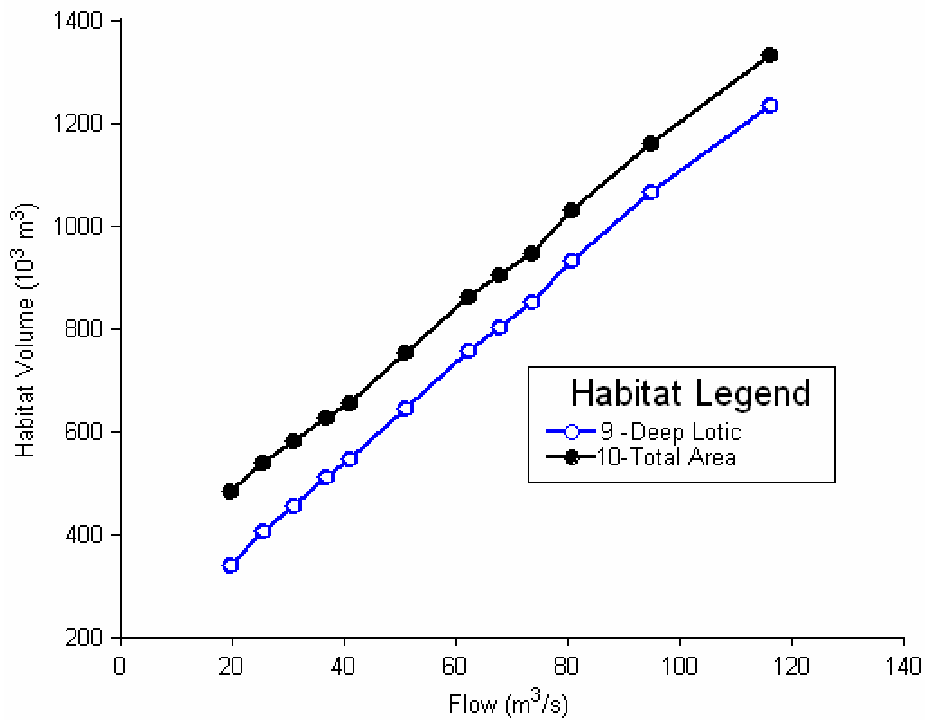

Figure 5.8 – Habitat Volume vs. Flow – Plot #1

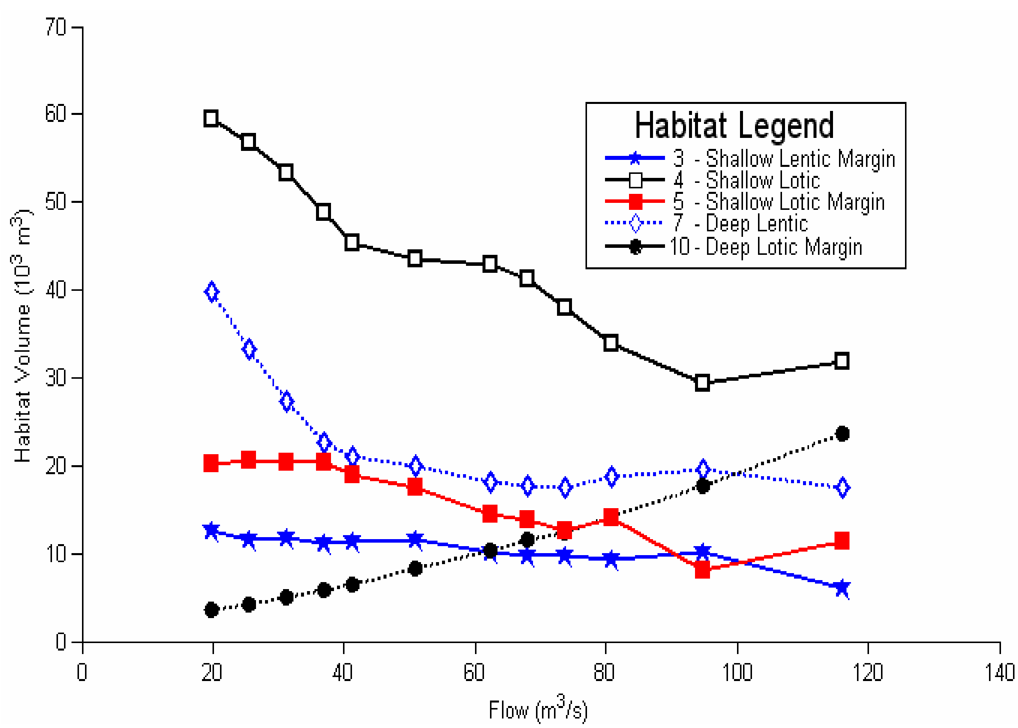

Figure 5.9 – Habitat Volume vs. Flow – Plot #2

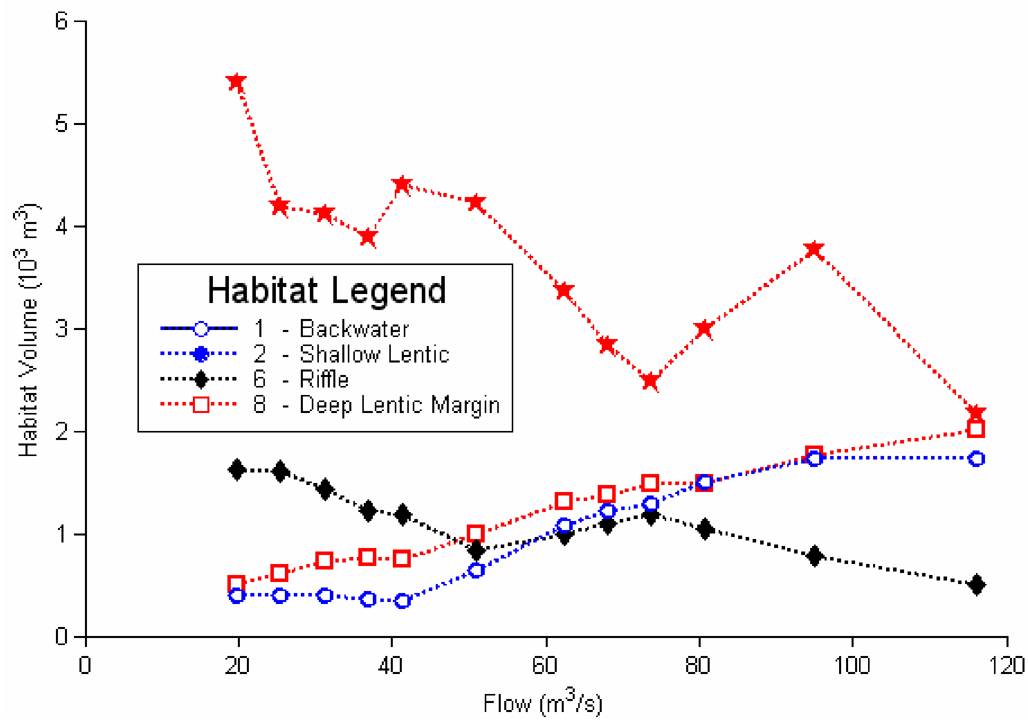

Figure 5.10 – Habitat Volume vs. Flow – Plot #3

The relationship between the area and volume of specialized habitats and flow was variable, with some habitats losing area and others gaining area with changes in flow. Most of the shallow habitats lost surface area and volume with increasing flow (Figures 5.6 and 5.7), while most of the deep habitats gained surface area and volume (Figure and 5.8). Deep lotic channel and deep lotic margin habitats increased substantially with increasing flows, while deep lentic habitats only made slight gains with increasing flows. Deep lentic margin habitat actually decreased over a range of increasing flows, but the rate of loss was rapid from 60-125 cms and then gradual thereafter. Shallow lotic channel and margin habitats had a gradual loss of area with increasing flows, while backwaters and riffles were variable over the range of flows. Therefore, determining the "concentrating effect" that Edwards (1997) referred to is not a linear assessment, but rather variable and complex. Riffle habitat and deep lentic habitats appear to be the habitats that are most limited over the range of flows. Riffles are very limited in the lower Brazos River, so their importance is difficult to evaluate. Speckled and silver chub and red shiner utilized riffles, although these species were more abundant in other habitats. Smallmouth buffalo, gizzard shad, and river carpsucker utilized deep lentic habitats most often, and these habitats lost area as flows increased. Thus, the concentrating effect could be said to increase for the habitat that these species' utilize as the flow increased. However, fish collection data shows a low abundance of these species within this mesohabitat, and changes in their abundance was inconclusive over a range of flows. The longnose gar was actually much more abundant in this mesohabitat at lower flows, possibly as a result of concentrating prey that could increase their foraging efficiency.

Spotted gar was less abundant at lower flows. In contrast, the deep lotic and deep lotic margin habitats gained area with increasing flow. However, shallow lotic channel, and shallow lotic/lentic margins were reduced in area with increasing flows; and thus it is important to note that increases in flow are not good for all habitats.

Specialized habitat plots show graphic changes in area and volume over a range of flows. The windows A, B and C in the maps shown in Appendix H magnify areas that are considered important for tracking. Window A is where the riffle is located, B has the backwater and C contains abundant large woody debris (LWD) which was found to be important in formation of embayments. While embayments were not separately identified in the GIS habitat model, the fishery utilization of the embayments highlighted their importance, and we recommend further studies of this type of habitat. The reduced area of the riffle with increasing flows is illustrated in Window A. The backwater and deep lentic habitat areas are illustrated in Window B, and under varying flow conditions both of these habitats change not only in surface area, but also spatially. At higher flows, a different spatial portion of the river channel and floodplain were inundated than at low flows. The importance of that is not understood, and is also worthy of further analysis. Window C shows the increasing domination of deep lotic habitat and with increasing flow, as well as shallow lentic and lotic margins with abundant LWD. The availability of LWD appears to be an important factor to the fishery and requires further study.

The specialized habitat plots (Appendix H) are grouped together according to the mesohabitats (Figure 5.2) of which they are a part. Note that this grouping follows color families to facilitate tracking the changes in mesohabitats and specialized habitats over a range of flows, e.g., shallows habitats range from yellow through red, and deep habitats are shades of blue. Those with the closest velocity characteristics within the depth categories are grouped together (e.g., shallow lentic and lentic margins; deep lotic and deep lotic margins are grouped together). With that in mind, note that the shallow lentic habitats (numbered 2-3) and shallow lotic habitats (numbered 4-5) that form two of the major mesohabitat categories shown in Figure 5.2 gradually decline in surface area with increasing flow (Appendix H). Because of the scale change, this effect is more clearly illustrated in Figure 5.11. In contrast to surface area changes, Figure 5.10 shows that the volume of the shallow lentic mesohabitat changes little with increasing flows. Figures 5.2 and 5.11 also show that the deep lotic mesohabitat has the reverse trend, volume and area increases as with increasing flows. The rate of increase in deep lotic mesohabitat area is considerably greater with increasing flows, than the declining area and volume of shallow lentic and lotic mesohabitats over the same range of flows. The deep lentic mesohabitat lost over 25% of its area and volume as flows increased between 20-40 cfs, but the area and volume changed little over the remaining flow range. These fluvial trends in mesohabitat and specialized habitat area and volume are important in evaluating the instream flow needs of the lower Brazos River fishery. They tell us how much habitat is available for utilization by fish at different flows, what concentrating effects may occur, provide us with some insight into how alterations in the flow might effect the fishery, and how we can manage the resource utilizing environmental flow concepts.

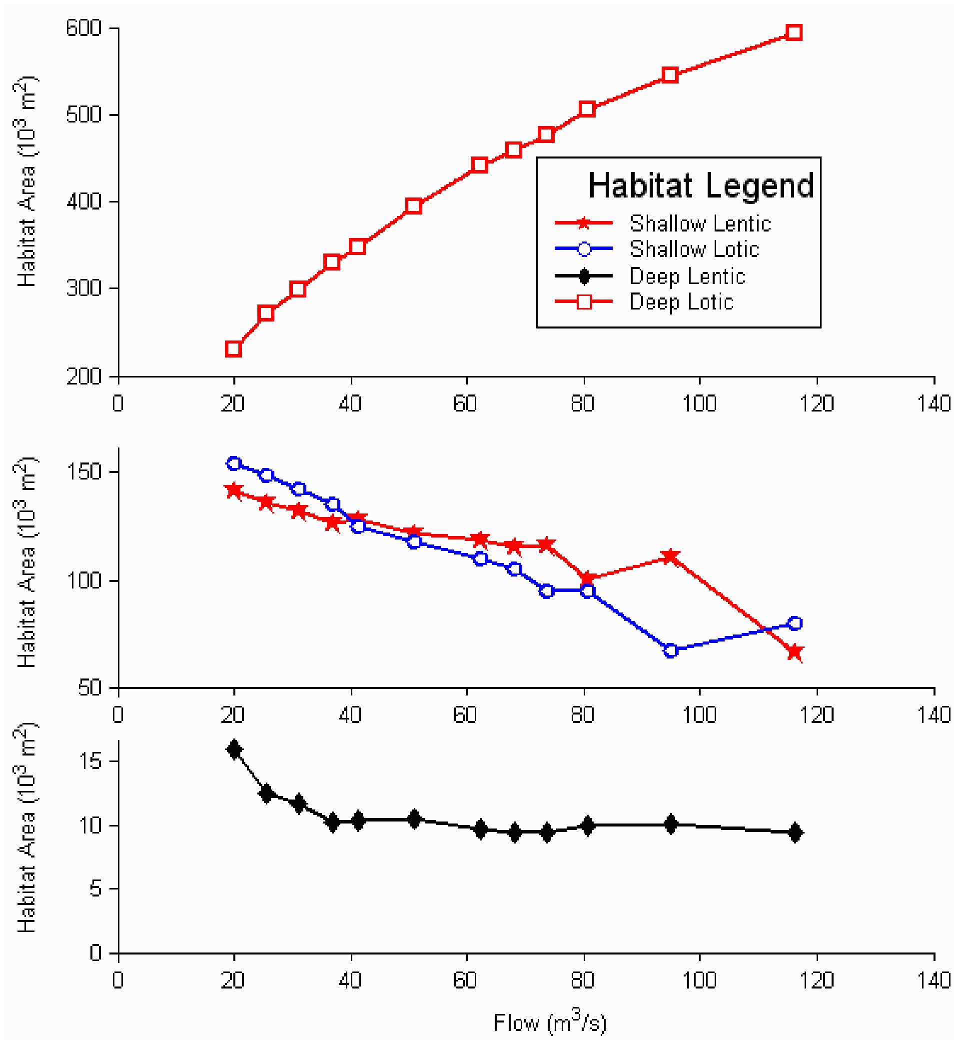

Figure 5.11 – Hydraulic mesohabitat vs. flow

In the style of analysis reported by Austin and Wentzel (2001), habitat-duration charts were developed to show the probability of exceedance for particular areas of habitat. Each of the flow rates modeled and presented in preceding figures were ranked by the occurrence of the flow rate over the entire period of historical record at the USGS Richmond gauging station (Figures 5.12, 5.13 and 5.14). Flow rates that are more frequently exceeded have a higher probability of exceedance and are located to the right of the figure; higher flow rates have lower probability of exceedance and are shown to the left side of each figure. Table 2.1 presents the relationship between historical flows and exceedance, and Table 3.1 presents the relationship between modeled flow rates and probability of exceedance.

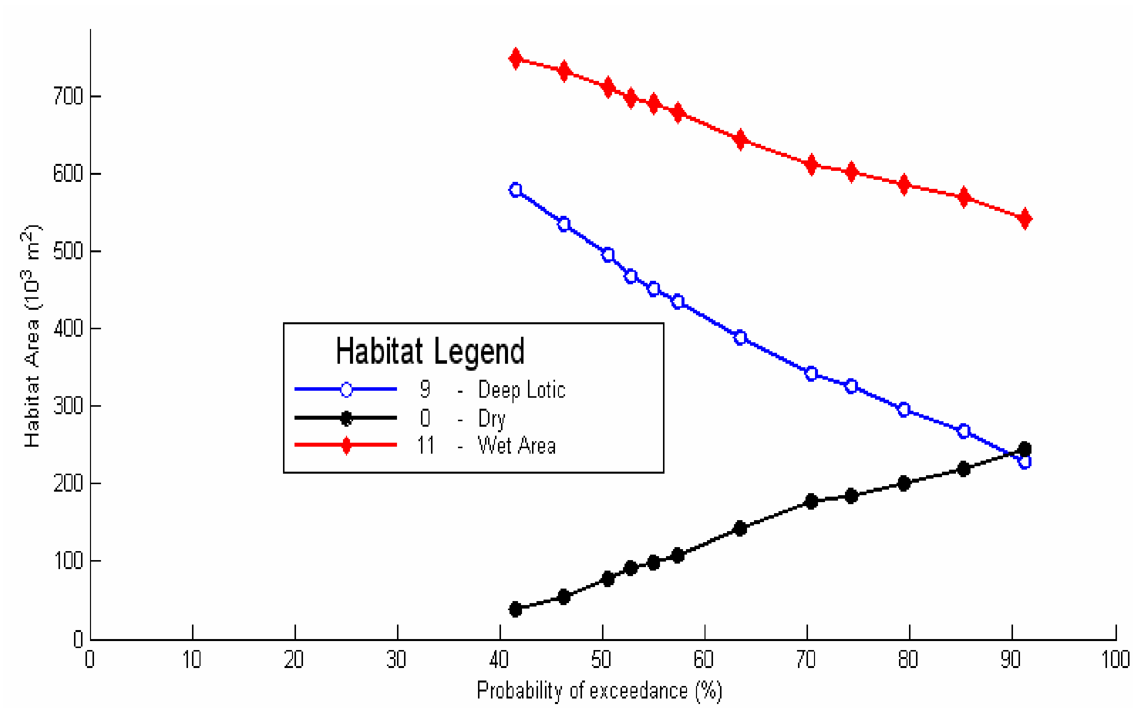

Figure 5.12 – Specialized habitat area vs. probablity of flow exceedance – for the more abundant habitats sampled

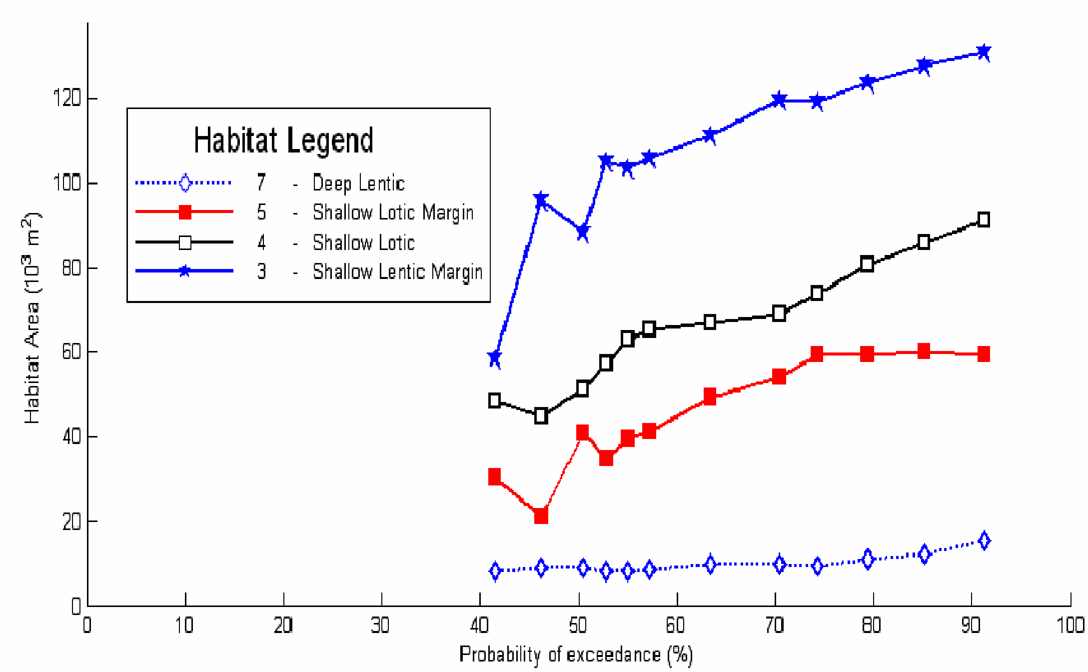

Figure 5.13 – Specialized habitat area vs. probablity of flow exceedance – for the medium-abundant habitats sampled

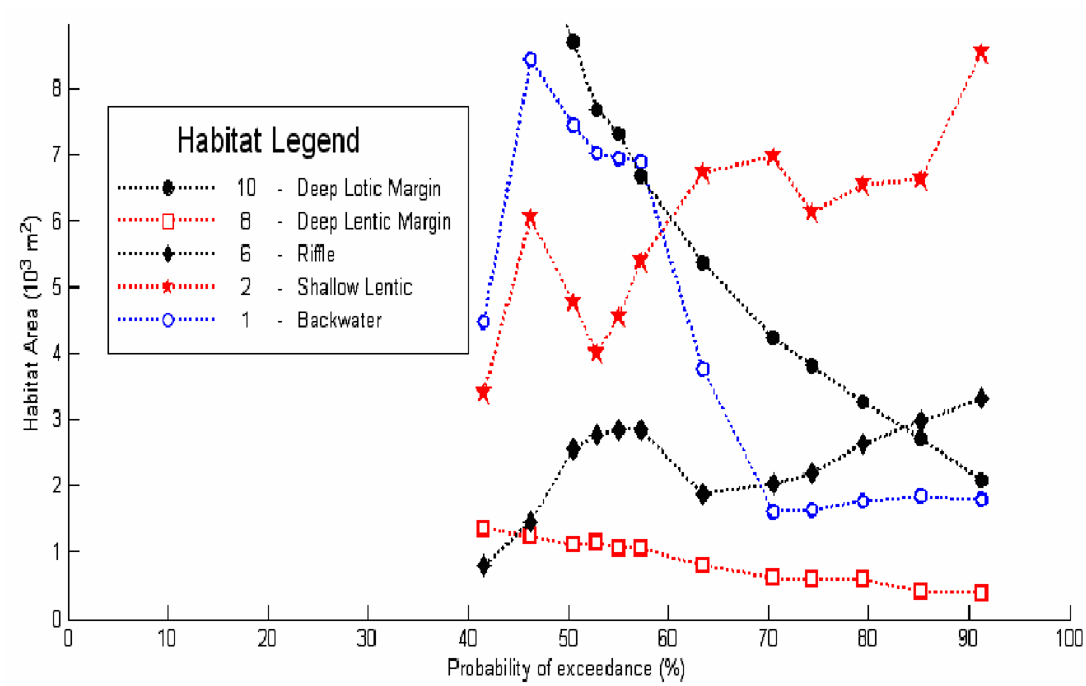

Figure 5.14 – Specialized habitat area vs. probablity of flow exceedance – for the least-abundant habitats sampled

5.4 Additional factors influencing distribution of fish species: spawning habitats, migrations, specialized habitat utilization, environmental variables, and large woody debris

Gelwick and Li (2002) and Li (2003) both reported the fish species making up the Brazos River communities to be habitat generalists. Similarly, TWDB showed a large degree of habitat generalization, but also showed consistent use of habitats by some species. Partitioning mesohabitats into specialized habitats (Table 5.11) did show some strong habitat associations, which may revise our concepts of habitat generalist that many of the species are considered to be.

The distribution of fish species in the lower Brazos River was evaluated on the basis of specialized habitat associations, spawning period, migration habits, mesohabitat utilization, temperature, and flow. Unique habitats, such as the mouth of Allens Creek provided a habitat with varying depths and velocities, woody structure, and the only tributary flow within the study reach. A large percentage of variation was left unexplained by environmental variables in Raymond Li's (2003) thesis study, and season might represent an important influence on biotic processes like reproductive period and migration. The temporal occurrence of species and their distribution within various habitats is considered here on a broad basis. Although fish assemblages in temperate regions in North America are highly influenced by seasonal changes (Jackson et al. 2001), the lower Brazos River is located at a latitude where seasons are less discrete and variable. Seasons in Texas can be generally segregated into two primary time periods according to Clark Hubbs (personal communication), summer (April-September—higher activity, migration, and primary spawning period of fishes) and winter (October-March—reduced activity and movement period). Elevated temperatures and low dissolved oxygen concentrations frequently limit survivorship in small sluggish flowing streams in Texas (Carlander 1977). Based on water quality data provided by Gelwick and Li (2002), this does not appear to be the case in large rivers like the Brazos River with adequate dissolved oxygen levels and a range of habitats with varying temperatures. The average temperature for the lower Brazos River during the Gelwick and Lee (2002) survey ranged between 13.8 (winter low) to 31.4 ºC (summer high), dissolved oxygen concentration ranged from 6.72 (summer low) to 13.67 (winter high), and percent oxygen saturation ranged from 76.2 (summer low) to 117.5 % (winter high). The TCEQ water quality data for the Brazos River designated use segments 1201 and 1202 with a high aquatic life designation (TNRCC 2002, see Chapter 2.3 Water Quality of the Brazos River). The TWDB contract study for assessing the ecological profiles for selected stream-dwelling Texas freshwater fishes (Edwards 1997) provides individual fish responses to changes in flow and habitat availability.

The distribution and temporal variation of fish catch data in the various habitats may be related to seasonal changes in fish behavior and reduced activity associated with cooler water temperatures and reduced food availability (Tables 5.8 and 5.9). During the warmer months of the year, fishes are more active due to reproductive condition and foraging on abundant food items (Gido and Matthews 2000). The importance of certain habitats in the lower Brazos River for fish reproduction is considered a key factor contributing to the higher abundance and diversity of fish species at some sites (e.g., Allens Creek confluence site, backwater habitat). The importance of foraging habitats is also a pivotal factor in fish distributions (e.g., lotic river margins and embayments), as are habitats that provide protection from predators (e.g., riffles and shallow lentic habitats, especially where woody structure is present). As discussed in detail in Section 5.2, depth and velocity (Tables 5.3 and 5.6), are also important factors influencing riverine habitat utilization and function.

The distribution of the fishery within our study reach is discussed below on the basis of fundamental habitat groups, hydraulic mesohabitats, specialized habitats, reproductive biology, foraging habitats, migrations, and environmental conditions. There are four major hydraulic mesohabitats within the lower Brazos River, which were delineated by velocity, depth, and fish species distributions: 1) shallow lotic, 2) shallow lentic, 3) deep lotic, and 4) deep lentic (Figure 5.2). There are five specialized habitats within these hydraulic mesohabitats, for a total of ten including 1) backwaters, 2) lentic embayments, 3) lotic embayments, 4) riffles, 5)lentic margins, 6) lotic margins, 7) lentic channel, 8) lotic channel, 9) lentic confluence, and 10) lotic confluence (Tables 5.12, 5.10, and 5.11). Backwaters and embayments are a subset of the shallow lentic mesohabitats, riffles are a subset of the shallow lotic mesohabitats, and river margins are a subset of shallow lentic and lotic mesohabitats. The Allens Creek tributary confluence created a mixture of shallow lentic to lotic habitats with a variety of structure, which resulted in a diverse habitat assemblage. Embayments, backwaters, and some river margins had woody structure that contributed to the specialized nature of these habitats.

5.4.1 Backwater habitats

There was only one backwater habitat in the study reach, but it appeared to be an important refugia and nursery habitat (Figure 5.15). River-channel backwaters are frequently important reproductive and nursery habitats for fishes in low gradient river systems, such as the Brazos River (Humphries et al. 1999). Fish utilizing these backwater areas are generally small-bodied fishes that are not susceptible to stranding with falling river stages. Frequent flooding of these backwater areas provides alluvial deposits that result in soft nutrient rich substratum with abundant insect populations and algae growth. These areas serve as an important food resource for young fish needing nursery habitats (Terry et al., 1998; Finger and Stewart 1987).

Fishes shown in this study to utilize the specialized backwater habitat community consisted primarily of the highly abundant red shiner, bullhead minnow, striped mullet, silverband shiner, ghost shiner, mosquitofish, longnose gar, and gizzard shad. The gizzard shad is a pelagic spawner, silverband shiners spawn in deep water in strong current, ghost shiners spawn over sluggish riffles, and striped mullet spawn offshore in the Gulf of Mexico (Robison and Buchanan 1988). While these species do not utilize this habitat for spawning, they likely utilize backwater habitats for productive feeding zones and protection from predators. The red shiner, bullhead minnow, and longnose gar may use backwaters for spawning habitat, and their young may benefit from this area as a protected nursery habitat with abundant food resources.

Figure 5.15 – Backwater habitat near bridge (looking upstream)
{Gelwick and Li 2002; Aug 27-30, 2002; 48.8 cms (1,725cfs); D=62.3cm, V=3.0cm/s}

Raymond Li suggested that the “low flow recruitment hypothesis”, described by Humphries et al. (1999) for rivers that lack regular and predicatable flood-pulses, is applicable to the lower Brazos. The lower Brazos River does have frequent and predictable flooding; thus this hypothesis may not be applicable. However, there are few overbanking flows in the lower Brazos River, due to the deeply encised channel. The “low flow recruitment hypothesis” is used to explain why some fish species spawn during the warmest months and lowest flows. There are numerous species that spawn during warm, low flows in the lower Brazos River, consistent with the Humphries hypothesis. The hypothesis postulates that some species of fishes take advantage of the extended low flow period of rivers to spawn, because of the concentration of appropriately-sized prey. These prey items may be of sufficient size and density to allow larvae of the fish species to make the transition from small pools, tributaries, or backwaters to their preferred adult stage habitats in a river system. This may explain the spawning cycles of some species, however, there is little information to support this hypothesis as an overall strategy of the fishery, because the lower Brazos River does not conform with the hydrology Humphries described, and many species appear to spawn during cooler, higher flow periods.

The collection of Longnose gar, in backwater habitat in May at mid-flows was probably associated with the coincidence of spawning temperatures (Robison and Buchanan 1988), that usually takes place in May to mid-June. Longnose gar may access backwaters to spawn during high flows that allow them to swim through normally shallow entrance zones. The newly hatched fry attach themselves vertically to submerged structure by an adhesive organ on their snout (Suttkus 1963). One warmouth was found in the backwater habitat during the late summer (September 20-23) sampling at the 50 percentile flow, when this habitat was most accessible. This species is generally a solitary sunfish that is most commonly found in sluggish backwaters, swamps, bayous, borrow ditches, and oxbow lakes where there are considerable muddy substrates, detritus, and many sources of woody cover (Edwards 1997). Warmouths are among the largest of the sunfishes. Spawning probably occurs from early March through July (Edwards 1997), with males building redds (nesting sites) near stumps or other woody habitat (LWD) and guarding emergent fry for about a week after the fry are free-swimming (Robinson and Buchanan 1988).

5.4.2 Embayments

Embayments are primarily small sloughs that form off of the main river channel and provide lentic habitat similar to backwaters. The difference between embayments and backwaters is that embayments are not off-channel water bodies with restricted entrance zones, but rather, they are open littoral sloughs separated from mainstream flows. Embayments also differ from backwaters in that there are shallow and deep parts of embayments. The river flow entering these habitats creates variable velocities ranging from lentic to lotic conditions that are often measured in the reverse direction of the mainstream flow.

In the lower Brazos River, embayments have primarily formed behind sloughed banks by eddy flows that cut into the bank during high flow events. Eddy flows often originate downstream of a non-erosive zone created by LWD, and erode the sand and silt from the bank behind these structures (Figure 5.16). Embayments are fairly numerous in the lower Brazos River, and warrant further analysis. Embayments do not appear to be as important as spawning or nursery habitats as backwaters, but may function as important foraging zones, especially for the numerous bottom-feeding species that utilize these areas.

Based on relative standardized abundance data, deep lotic embayments were characterized by an abundant resident fishery, consisting primarily of skipjack herring, freshwater drum, channel and blue catfish, longnose and spotted gar, smallmouth buffalo river carpsucker, and gizzard shad. Skipjack herrings were abundant in lentic embayments, and although they are a freshwater fish species they occasionally wander into brackish and estuarine waters on the Gulf coast (Lee et al., 1980). This species is common in large rivers, with open waters and swift to moderate currents, however, it is also occasionally found in backwaters (Beckett and Pennington 1986; Sanders et al. 1985). Skipjack herring is tolerant of turbidity, as are all of the species that occur in the lower Brazos River. These are schooling fish that feed primarily on minnows and other small fishes (Robinson and Buchanan 1988). They are somewhat migratory during spring spawning runs, which occur from May to early July in the Mississippi River (Coker 1930), and early March to late April in Florida (Wolfe 1969). Spawning occurs in flowing water only in the main channel, preferably over coarse sand or gravel substrates (Wolfe 1969). Thus, they are classified as obligate riverine for reproduction.

Figure 5.16 – Embayment downstream of LWD (looking upstream)
{Gelwick and Li 2002; Aug 27-30, 2002; 48.8 cms (1,725cfs); D=230 cm; V=0.0 cm/s}

Based on the relative standardized abundance, blue catfish were generally found in deep lotic embayments. According to Robison and Buchanan (1988) blue catfish are a large heavy-bodied catfish with a wedge-shaped head that inhabit large rivers with swift, deep channels. Blue catfish are bottom feeders that often forage over sand substrates at night in dark waters; their senses of smell and taste are more important than sight in locating prey items (Robison and Buchanan 1988). The parents construct nests in late spring to early summer, and guard their nest until the eggs hatch (Robison and Buchanan 1988). Blue catfish are frequently found in moderate currents and depths over sand substrates, which corresponds to the lower Brazos River collection site.

Shallow embayments were not sampled during this study, and future studies should include these habitats and provide additional sampling of deep lotic embayments. Interestingly, in contrast to backwater habitats, small-bodied fishes did not utilize embayments. However, it is also important to note that deep lotic embayments were only sampled once during summer low flow conditions using gillnets and the results may not indicate typical conditions.

5.4.3 Allens Creek confluence habitat

The Allens Creek confluence is an ecotone between a small stream and the largest river in Texas in terms of drainage area. At low flows in the stream and river, a sediment block forms between these two systems, which temporarily obstructs surface water exchange and fish migration. When flow is sufficient to maintain an open channel at the confluence, the confluence represents a connectivity ecotone between two different habitats (Figure 5.17). Adventitious streams, like Allens Creek, are low stream order tributaries that have a confluence with a large stream order river, differing by three or more stream orders in size. Interface sites between adventitious streams and their mainstreams are often more diverse and variable than either the tributary stream or mainstream alone (Schaefer and Kerfoot, 2004). The Allens Creek confluence habitat represents a specialized and important fishery habitat. The observed patterns in community variability and distribution of some species may be best explained by the interactions between the big river fauna and the stream fauna (Matthews and Robinson 1998). A large change in stream order can result in abrupt community differences at the interface point and an overall break in the river continuum (Vannote et al. 1980), which appears to be the case at the confluence site. The community composition at the confluence is vastly different than at any other mesohabitat or specialized habitat within the lower Brazos River study reach, or at sample sites within Allens Creek (Linam et al., 1994). Tributaries are often used as spawning and nursery areas for riverine species (Matthews 1998), which contributes to greater diversity. The confluence likely represents an important reproductive habitat area and because collections and studies of early life history stages of fishes were not a part of the TWDB contract study (Gelwick and Li 2002) or thesis (Li 2003), further study is warranted.

The diversity of fishes that occur in this area during spawning periods and temperatures supports this hypothesis. For instance, four species of sunfish were collected within the confluence habitat during the late summer spawning period, including the redear, longear, bluegill, and orangespotted sunfishes. The green sunfish also occurred there during March, and white crappie occurred in late August. These species were also collected during a TWDB interagency contract study with the Texas Parks and Wildlife Department conducted by Linam et al. (1994). These species benefit from the low gradient protected habitat with spawning substrates and woody debris that protect free-swimming fry and provide foraging habitat for adults (Zalewski and Lapinska 2003; Siefert 1968; Pflieger 1975). All of these species are nest spawners (Carlander 1977).

Males build and fan nests in the shallow, low gradient, sand, mud, and detritus substrates available at this site and guard the nest until the fry become free-swimming (Robinson and Buchanan 1988). Sunfishes are frequently abundant in streams, and their occurrence here may be a result of migrations to the confluence site where they may access Allens Creek. Longear sunfish in particular require the presence of cover in habitats (Edwards 1997), and most of the other sunfishes probably, to some extent, have similar requirements. LWD was present at this site. The warmouth was the only sunfish that was not collected at the confluence site.

Figure 5.17 – Allens Creek confluence habitat (looking upstream)
{Gelwick and Li 2002; Aug 27-30, 2002; 48.8 cms (1,725cfs); D=38.3 cm; V=7.3 cm/s}

Historically, the slough darter has only been found in this confluence habitat during its March spawning period (Collette 1962) and this was true for this study. Females deposit eggs on woody structure in areas with adequate flow to oxygenate the eggs, since they do not fan them like the sunfishes (Braasch and Smith 1967). The adults prefer sluggish to no flow conditions in backwaters, sloughs, and oxbow lakes (Robison and Buchanan 1988). Western mosquitofish were very abundant during the summer at all flows, and probably provided prey stock for numerous piscivorous predators, including green sunfish, largemouth and spotted basses, white crappie, and longnose gar. Bullhead minnow were abundant in the summer when breeding takes place within cavities excavated by males near structure (usually logs and snags) (Dolloff and Warren 2003; Lee et al. 1980). The male guards and fans the eggs to free them of sediments and aerate them. Blackstripe topminnows were only found in the Allens Creek confluence. They are a slender species found in low gradient rivers with high turbidity. Blackstripe topminnows generally prefer river margins with a moderate current over a variety of bottom types (Robinson and Buchanan 1988). They are surface feeders that prey on both terrestrial and aquatic insects, crustaceans, snails and algae (Shute 1980). Breeding has been observed in late spring and summer; eggs are deposited on algae, aquatic vegetation, or woody detritus and are not guarded (Carranza and Winn 1954).

Two species of silversides were also found almost exclusively at the Allens Creek confluence. The brook silverside was only found in this specialized habitat and only during the summer high flows in late September. It is an extremely elongate, slender, translucent species that is a schooling surface-dweller, and is noted for its unusual behavior of making short jumps out of the water to avoid predation. They reportedly spawn Arkansas rivers in late spring and summer when water temperatures reach 20-22.8 ºC in pools over aquatic vegetation or gravel beds (Robison and Buchanan 1988). Their residence in the confluence site occurred at higher water temperatures than those reported for spawning in Arkansas, 28.5 to 32.8 ºC (Gelwick and Li, 2002). The water temperatures in the spring (March-April) ranged from 20.6 to 20.9 ºC, which is more consistent with the previously reported spawning temperatures. Since the reported spawning habitat does not exist in the lower Brazos River, the brook silverside may alternatively be using the woody structure and submerged brush for spawning habitat found in the confluence site, similar to the reported spawning behavior of the inland silverside. The inland silverside was much more abundant in the confluence site, occurring there primarily during the summer at moderate to high flow regimes. It is a slender, translucent species with a flattened head, long anal fin and two dorsal fins, and occurs in large rivers, oxbow lakes, and impoundments, as well as estuarine and freshwater marshes of the Texas Gulf coast (Robinson and Buchanan 1988). They are commonly found in moderate currents along sandbars and are an important forage species for predatory fish, like bass and gar feeding in surface waters and littoral zones (e.g., river or lake margins) (Echelle and Mense, 1968). According to Hubbs (1976, 1982) spawning is protracted and occurs from late March or April through July. Hubbs et al. (1971) noted that in Lake Texoma spawning condition adults were found in brushy areas, and the eggs were found in algal growth on brush stems, similar to habitat conditions in the confluence area. The breeding season ended when water temperatures exceeded 30 ºC (Hubbs and Bailey 1977).

Spotted gars are another species that was most frequently collected in the lotic confluence habitat, and commonly collected in the lentic confluence habitat (Tables 5.10, 5.11, and 5.13). Spotted gars are an elongate fish with a prominent broad snout, which are generally found in low velocity waters with lots of structure (Suttkus 1963). They apparently are less tolerant of turbidity than other gars (Robison and Buchanan 1988), explaining why the longnose gar is more abundant in the lower Brazos River than the alligator and spotted gar. Fish make up to 90 percent of the diet in adults, with the remainder consisting of freshwater shrimp, crayfish and insects (Redmond 1964). This species spawns in shallow waters in spring, and the adhesive eggs are scattered over substrate (Redmond 1964). Echelle and Riggs (1972) found spawning in Lake Texoma from early April-May over dead vegetation and algae mats in weedy, quiet waters. This type of habitat is similar to that found in the confluence site.

5.4.4 River margin habitats

River margins provide habitat varying from shallow gently sloping gradients to deeply incised margins. The river margin is considered an important habitat because many fish orient spatially on bank features, forage on terrestrial insects that fall into the water from riparian trees and shrubs, and seek protection in the woody habitats and brush that are predominately found along the shore (Dolloff and Warren 2003; Zalewski and Lapinska 2003) (Figure 5.18). Future studies should certainly focus more effort on sampling margin habitats in a quantitative manner. With the assumptions provided on our delineation criteria for river margin habitat (see Section 5.2, Figure 5.5), the following section is a discussion of the fish community that fit into that important habitat.

Deep margin habitats were not sampled in this study, but both lentic and lotic shallow margin habitats were sampled (Tables 5.10, 5.11, 5.12 and 5.13). The lotic margin habitat (Figure 5.19) was characterized by a much more abundant fishery than the lentic margin, and many of those fishes frequenting the lotic river margin habitats were pelagic species, such as the silver and speckled chub, striped mullet, and channel catfish. Littoral species such as the red shiner, silverband shiner, and ghost shiner were abundant in these habitats.

Figure 5.18 – Deep margin habitat (looking upstream)
{Gelwick and Li 2002; Aug 27-30, 2002; 48.8 cms (1,725cfs); D=132 cm; V= -8.0 cm/s}

Red shiners dominated two-thirds of the shallow margin fish collections. Li (2003) similarly reported that the red shiner along with two cyprinids species and the bullhead minnow dominated the shallow river margin assemblage. Red shiners are habitat generalists, capable of exploiting a broad range of habitats (Marsh-Mathews and Mathews 2000). They reach sexual maturity rapidly and have multiple spawning periods in the spring and summer, facilitating rapid recruitment into the population (Gido et al. 1997). Edwards (1997) reported that red shiners have an extended spawning season in Texas, and that he had collected small individuals in all but the coldest winter months. This suggests a spawning season from about mid-late February until mid-November depending upon water temperatures. This species spawns over submerged vegetation and well oxygenated substrates or woody structures, including the nests of a variety of sunfishes (Altenbach 1993, Edwards 1997). The other highly abundant generalist, the western mosquitofish, were less abundant in shallow margin habitats (Table 5.7 and 5.11) than in Allens Creek confluence.

Figure 5.19 – Shallow margin habitat (looking upstream)
{Gelwick and Li 2002; Aug 27-30, 2002; 48.8 cms (1,725cfs); D=32.3 cm; V=32.0 cm/s}

Despite spatial consistency in environmental conditions within the river for temperature, dissolved oxygen, conductivity, and substrate, shallow margins are very sensitive to river-stage fluctuations (Bain et al. 1988). As a result of fluctuations in river stage, river-margin fishes tend to be adapted to lateral shifts to avoid strong current velocities or stranding that may occur with changing river stage and piscivorous fishes associated with adjacent lotic and lentic channel habitats (Schlosser 1985, Bain et al. 1988). Habitat-generalist species, such as the red shiner and bullhead minnow, typically dominate the assemblage composition in highly variable riverine environments, such as the river-margin habitat (Burr and Warren 1986; Lee et al. 1980).

Silverband shiners were also abundant in shallow margin habitats. They are a pale, moderately deep-bodied, slab-sided fish that thrives in the moderate to swift currents of large rivers with sand-gravel bars (Robinson and Buchanan 1988). It is a schooling species that is known to spawn in Missouri in mid-August (Pflieger 1975) and the Mississippi River of Louisiana from June to early August at water temperatures ranging from 26-29 ºC (Suttkus 1980). An analysis of the sizes of specimens taken from Texas in the various museums by Edwards (1997) suggests that a slightly longer breeding season occurs in Texas than that which is reported from Missouri and Louisiana. Individuals in nuptial coloration have been reported in collections from the Red River in late April, which also suggests a late-spring initiation to the spawning season (Robison and Buchanan 1988). This species is tolerant of great turbidities (Gilbert and Bailey 1962).

Some species were frequently found in the fast currents of the shallow lotic margin habitats, including the speckled and silver chub. These chubs are benthic insectivores that have fusiform shaped bodies morphologically adapted to strong currents found in this specialized habitat (Robinson and Buchanan 1988). The speckled chub's depressed body with well-developed barbells and large pectoral fins makes this fish particularly suited for bottom dwelling in swift flowing waters (Robinson and Buchanan 1988). Speckled chubs frequently occur alone or in small schools of 10-20 individuals, and rarely in large schools (Edwards, 1997). They feed in turbid waters using external taste buds located on the head, body, and fins (Starrett 1950). Juveniles tend to be solitary, feeding actively from the bottom, or on items falling within the water column, while adults are more likely to feed exclusively on the bottom and are easily frightened into seeking cover when disturbed (Tomelleri and Eberle 1990, Etnier and Starnes 1993). Trautman (1981) noted their diunal distribution, with a preference for deeper water during the day and shallower water at night. In Oklahoma, spawning occurs in May-August when water temperatures exceed 21.1 ºC (Trautman 1981). Eggs are deposited in deep water with swift current, and are fertilized as they drift, and therefore this species is classified as obligate riverine for reproduction (Bottrell et al. 1964). The silver chub similarly inhabits large, sandy-bottomed rivers in small numbers or solitary. It has a diurnal migration characterized by inhabiting deep water with moderate to swift current during the daytime and shallow near-shore water at dusk to feed on insects and other small invertebrates (Buchanan 1976). The silver chub spawns from April-May in Kansas (Cross 1967).

Blacktail shiners were rare in the lower Brazos River study reach, and their occurrence was almost exclusively in the shallow lotic margin habitats. Blacktail shiners are a large bluish-silvery colored shiner that schools in moderate to large rivers with sand substrates (Robinson and Buchanan 1988). It generally prefers current rather than standing water, and is tolerant of high turbidity. Blacktail shiners are known to spawn from June-August in Missouri, and in Mississippi from April to September in crevices created by submerged structure (Pflieger 1975). Blacktail shiners are frequently sympatric with red shiners, although blacktail shiners are more likely to inhabit larger rivers with faster currents, while red shiners generally inhabit the quieter waters of smaller rivers and streams (Edwards 1997). Hybridization sometimes occurs with red shiners (Pflieger 1975).

5.4.5 Lentic channel habitats

These habitats are primarily the deep pool habitats characterized by sluggish flows that occur within the mid-channel area within the lower Brazos River. Li (2003, thesis) found that lentic habitats (specifically, deep pools alongside shallow runs) were characterized by the occurrence of four low abundance fish species: freshwater drum, smallmouth buffalo, channel catfish, and common carp. Li hypothesized that this position in the river may facilitate movements between pool and run habitats under changing flow rates. These fish may move to the shallow adjacent habitats for more productive food resources within the sediments. However, caution should be exercised when discussing these findings because Gelwick and Li (2002) classified pools and runs visually which led to significant overlap in hydraulic characteristics of those habitats.

Deep lentic habitats were not as diverse as shallow lentic habitats (Tables 5.11 and 5.13). However, there were some seasonal pulses of fishes utilizing deep lentic habitats, including the striped mullet, bullhead minnow, silverband shiner, ghost shiner, speckled chub, river carpsucker, smallmouth buffalo, threadfin and gizzard shad. The smallmouth buffalo was the most frequently occurring fish species in the deep lentic habitats, followed by the gizzard shad and river carpsucker.

Striped mullet migrations into this area occurred only during the March-April sampling period at the 50-percentile flow period (4185 cfs). This species annually migrates offshore during the spring, has a worldwide circumtropical distribution, and often ascends coastal rivers for considerable distances (Lee et al., 1980).

Smallmouth buffalo were found in low abundance during low flows in the lentic channel habitats where this deep-bodied, highly compressed fish is an opportunistic bottom feeder (McComish 1967). Their spawning season is variable, but it is often associated with periods of rising water from April-June over a range of habitats and environmental conditions, including quiet backwaters, riverine habitats and inundated floodplains (Jester, 1973). Jester (1973) reported that smallmouth buffalo eggs are deposited over the bottom or on vegetation and structure at depths ranging from 4-8 feet.

A low abundance of longnose gar occurred during summer low flows in the deep lentic channels. Bullhead minnows were very abundant in lentic channel habitats during March-April sampling at the 50-percentile flow. They are a stout minnow with a large head, tolerant of turbidity and siltation, and thus abundant and widespread in large sluggish rivers with sand, silt, and mud bottoms in the coastal plains (Suttkus 1963). This description is consistent with conditions that we found in the Brazos River. This schooling, omnivorous species feeds near the bottom primarily on insects, algae, and plant material (Starrett 1950). The silverband shiner was also abundant in this habitat, but only during winter 50-percentile flow. This species prefers swift to moderate currents in the main channels of large rivers with sand and gravel substrates (Robison and Buchanan 1988), and is tolerant of extremely turbid water (Gilbert and Bailey 1962), as typifies the lower Brazos River.

The ghost shiner was another shiner species that was well represented in this habitat during the March-April sampling period at the 50 percentile-flow. It is a small, pale, very slab-sided shiner that is a schooling species generally occupying large, warm, sluggish rivers with high turbidities (Robinson and Buchanan 1988). This midwater species, frequents backwaters and pools that are protected from strong currents (Edwards 1997), similar to conditions found in the lentic channel. Spawning in Oklahoma occurs during late spring to August (Miller and Robison 1973) and in Missouri from April to early June over sluggish riffles (Pflieger 1975). The lentic channel is not the ghost shiner's primary breeding habitat, but the ghost shiner's use of this habitat is consistent with its usual ecological niche (Edwards 1997). Based on their occurrence during its spawning period ghost shiners probably did use the shallow lotic channel margins for spawning. Spawning in Texas may be protracted beginning in early February and continuing through September or October (Edwards 1997).

Freshwater drum were found primarily in lentic channels during the April-May and August sampling periods. They are the only freshwater representative of the marine family Scianidae in Texas (Hubbs et al. 1991), and typically inhabit deep pools of medium to large rivers and impoundments (Etnier and Starnes 1993). Freshwater drum are a bottom dwelling species that feeds on mollusks, small fish, chironmids, small crustaceans, and other aquatic invertebrates (Pflieger 1975). Spawning occurs in late spring (April or May) in Arkansas (Robison and Buchanan 1988) and May to July in the Mississippi River drainages within Louisiana, at water temperatures between 18.9-22.2 ºC, which are the periods that this species occurred within the lower Brazos River study reach. Freshwater drum are pelagic spawners that school during spawning behavior at shallow depths within pools and runs. Females release large quantities of floating eggs until they hatch at the surface (Etnier and Starnes 1993). Free swimming fry move to deeper water and finally assume their bottom-dwelling mode of life (Robinson and Buchanan 1988).

River carpsucker, a species collected from deep lentic channels most often during the summer (63%) (Table 5.9), are a large, deep-bodied and compressed silver fish with a high arched back (Robinson and Buchanan 1988). A distinct south-western subspecies, *Carpiodes c. carpio*, occurs in Texas in Gulf coastal drainages (Hubbs and Black 1940). The river carpsucker is a schooling sucker in moderate to large rivers and reservoirs (Pflieger 1975). It prefers low velocity waters in sand and silt-bottomed pools, backwaters, and oxbow lakes of low to moderate gradients (Pflieger 1975); similar to those found in deep lentic channels of the Brazos River. It is more tolerant of turbidity than other carpsuckers and large schools browse extensively on attached filamentous algae (Behmer 1965). They spawn in early June through late July or August in 1-3 feet of water near structure, and their adhesive eggs are broadcast over substrate and structure (Robinson and Buchanan 1988).

Threadfin shad are a relatively small, silvery herringlike fish with a thin, deeply compressed body (Robison and Buchanan 1988). They were abundant in shallow lentic channels, but were not found in deep lentic channels. Threadfin shads primarily inhabit moderate to large rivers, with sluggish currents, but are tolerant of faster currents than the related gizzard shad (Robison and Buchanan 1988). They are a pelagic, schooling fish and are an important species of forage fish (Burgess 1980). They spawn their adhesive eggs over submerged vegetation and structure (Laubou 1965) in the spring when temperatures reach 21.3 ºC and may continue to spawn at intervals for several months into the summer (Pflieger 1975). Gizzard shads are a silvery fish with a deeply compressed, oblong body (Robison and Buchanan 1988). Gizzard shads were abundant in both shallow and deep lentic channel habitats. The gizzard shad is primarily a pelagic species and often swims in large schools in open water. It prefers deep calm water, but is very versatile in a range of habitats (Robison and Buchanan 1988). They spawn from early April through May at the surface, and their adhesive eggs sink to the bottom and attach to substrate or structure, and there is no parental care (Kilambi and Baglin 1969). They are sensitive to rapid temperature changes (Robison and Buchanan 1988). Young shad of both species provide excellent food for most native game fishes, but adult gizzard shad are too large for most predators (Robison and Buchanan 1988).

A single common carp was collected in the lower Brazos River within the mid-channel section of the lentic channel habitat. The carp is native to Asia, and was introduced into European and U.S. waters. This non-native species is generally considered a nuisance species that is detrimental to native fish species, especially centrarchids (sunfishes and basses) and other predators, because of their habit of rooting bottom substrates for food. This activity directly disrupts active nests and potential nesting sites (Becker 1983). It also increases turbidity, which decreases light penetration, lowering productivity of algae and aquatic macroinvertebrates (Becker 1983). In addition, silt from these feeding activities may suffocate eggs of other species (Robison and Buchanan 1988).

5.4.6 Lotic channel habitats

The shallow lotic channel habitat type was most frequently occupied by channel catfish and speckled chub. The red shiner, threadfin shad, and inland silverside were also frequent inhabitants of this habitat in shallow areas (Table 5.11); whereas longnose and spotted gar were found in low abundance in deep lotic channels (Tables 5.10 and 5.13). These were the only two species that were found in this habitat. Thus, this is the most un-utilized specialized habitat within the lower Brazos River. In comparison, the shallow lotic channel was abundantly inhabited by nine species. The reason for the unusually low utilization of the deep lotic channel is not well understood, but may be related to reduced food availability in deep scoured sediments.

5.4.7 Riffle habitats

Riffle habitats were relatively rare, high-energy flowing environments in this study. Riffles occurred where sand-gravel bars and point bars within the channel constricted the flow so that higher velocity currents were formed (Figure 5.20). They were the only habitat where coarse substrates collected within the channel. All other habitats within the river were composed of some composition of sand and silt. Coarse substrates are often important spawning habitat; however, there was no observation during the study that this was occurring. The frequency of this habitat throughout the lower Brazos River is not definitively known, so the importance of riffle habitat to the fish community is difficult to quantify.

Figure 5.20 – Riffle habitat (looking upstream)
{Gelwick and Li 2002; Aug 27-30, 2002; 48.8 cms (1,725cfs); D=93.0 cm; V=66.0 cm/s}

None of the species in the lower Brazos River are restricted to coarse substrates for spawning purposes, although attachment of adhesive eggs to gravel may benefit some species. Channel catfish, speckled chub, striped mullet, red shiner, bullhead minnows, and silver chub were the most frequently occurring species within this specialized habitat. Channel catfish are a slender, elongate catfish species with a deeply forked caudal fin and free adipose fin (Robison and Buchanan 1988). Channel catfish have a widespread distribution in streams, rivers, reservoirs, and farm ponds, but the species is basically riverine and benefits from flow (Lee et al. 1980). The adults tend to seek out deep pools, submerged logs and overhanging banks in large rivers, and feed in riffles and shallow pools on fish, insects, mollusks, and crayfish (Etnier and Starnes 1993). They spawn from May-July in dark natural cavities or holes cleared by the male, near undercut banks or underneath submerged structure or debris dams (Robison and Buchanan, 1988). At the study site, juvenile channel catfish were observed foraging in tight schooling aggregations within a riffle zone too shallow for large piscivorous fish access during the habitat reconnaissance phase of this study, which were too shallow for large predatory piscivorous fishes access.

Bullhead minnows are sometimes reported in strong currents, although they generally prefer sluggish flowing lentic mesohabitats (Etnier and Starnes 1993; Lee et al., 1980). This benthic omnivore appears to benefit from faster flows during foraging activity over shallow riffles zones (Starrett 1950, Becker 1983). Red shiners are primarily a shallow lentic to lotic species, especially near river margins, but are very widespread in their distribution (Table 5.11). Riffles are not their primary habitat, but they do occur there and they are abundant in schools wherever they occur (Table 5.11). They have an extended breeding season in Oklahoma from April to September (Farringer et al. 1979), and probably do in Texas as well. They are one of the most important forage fish species within the lower Brazos River, providing food for numerous piscivous predatory fishes in the food chain (personal observation; Peters et al. 1989; Yu and Peters 2002).

5.4.8 Effect of large woody debris on fishery composition

Large woody debris makes an important contribution to the structure and function of the fishery and marcroinvertebrate community in many streams (Benke et al. 1984; Jacobi and Benke 1991). Benke et al. (1984) showed that in the coastal blackwater rivers of the southeastern U.S. LWD habitats might only account for 6% of the potential invertebrate habitat spatially; however, macroinvertebrate standing stock biomass, annual production and densities in these habitats are 16-50% greater than adjacent benthic habitats. Benke et al. (1984) in a study of the Setilla River found that invertebrate production in LWD habitats exceeded that of the adjacent benthic habitats by 84%. In a TWDB contract study by Wood et al. (1984), the macroinvertebrate standing stock biomass, secondary production and invertebrate densities in LWD habitats (also referred to as snag habitats) in Allens Creek and the Brazos River exceeded that of benthic habitats by 10% to more than 50%. Wood et al. (1984) concluded that where snag/LWD are present in Allens Creek and the Brazos River, they are important structural components of the habitat (Figure 5.21). LWD provides and harbors organic matter, an abundant aquatic macrophyte population, and an insect population that are essential food resources for many of the fishes utilizing those habitats (Gregory et al. 2003). LWD is important in establishing the trophic structure in Allens Creek, the confluence site, river margins, shallow lentic and lotic channels, backwaters and other shallow habitats in which snags become lodged in the substrates.

Figure 5.21 – Large woody debris (looking upstream)
{Gelwick and Li 2002; Aug 27-30, 2002; 48.8 cms (1,725cfs); D=140 cm; V=89 cm/s}

Woody habitats in Sandies Creek, a tributary of the Guadalupe and Colorado River, were similarly utilized by aquatic organisms for feeding, colonizing, attaching eggs, seeking shelter from predators or high velocities, and other ecological functions within the stream environment (Mathews and Tallent 1997, Mathews and Bao 1991; Bao and Mathews). Based on the distribution of fish species within specialized Brazos River habitats that contained LWD (using the larger Gelwick and Li 2002 dataset), it appears that many of the functions of LWD affected the fishery in the lower Brazos River (Tables 5.16 and 5.17). For instance, during the summer spotted gar only occurred in deep lentic embayment habitats with LWD (Table 5.17). Spotted gars are ambush predators (Mathews and Bao 1991), and woody habitat may be an important camouflage structure for that foraging strategy. Similarly, speckled chub, channel catfish, and longear sunfish only occurred in shallow lotic channel habitats with LWD during the winter; silver chub and ghost shiners only occurred in winter shallow lotic margins with LWD (Table 5.17). All of these species are primarily insectivores, except the channel catfish, which feeds on insects, small fish, and detritus (Lee et al., 1980). All of these species probably benefited from the marcrophytes attached on the LWD. Channel catfish may utilize LWD for

establishing nest sites, which often occur underneath submerged logs or woody debris (Robison and Buchanan 1988).
Several other fish species appeared to benefit from LWD including the bullhead minnow, red shiner, and mosquitofish. These fish species may have used the LWD for protection from predators and as velocity shelters. In addition, several fish species had frequent distributions (≥50% relative abundance) in habitats with LWD, including gizzard shad (winter lentic embayments), river carpsucker and freshwater drum (summer lentic embayments), and longnose gar, smallmouth buffalo, and freshwater drum (spring lentic embayments). Gizzard shad and river carpsucker generally prefer calm pelagic waters, and may have used LWD as velocity shelters during higher flow periods (Mathews and Bao 1991). River carpsuckers browse extensively on attached filamentous algae, which grows abundantly on woody structure (Behmer 1969). Freshwater drum and smallmouth buffalo bottom feed on mollusks, chironmids, small crustaceans, and other aquatic invertebrates that may have been found in the vicinity of LWD (Robison and Buchanan 1988).

The presence of LWD in lotic channels and summer lotic margins had little effect on the distribution of the river fishery. However, lotic channels were more difficult to sample in the vicinity of LWD, and some sampling error may account for this observation. Overall, the occurrence of LWD in lentic habitats had a greater effect on the distribution of the fishery. It is possible that LWD in higher flow (lotic) areas of the river system were less colonized by aquatic insects, and thus were less important as a food source. They may also be less stable in river due to the unstable substrates they are anchored in, resulting in their displacement during flood events.

LWD is important not only for visual orientation, physical cover/camouflage, and velocity shelters, but also for spawning (Mathews and Bao 1991; Marzolf 1978; Mathews and Tallent 1997). Certain fish species, such as the mimic shiner, attach their eggs to LWD, so their presence has many uses to the aquatic community. Benke et al. (1985) reported that snags supported 60% of total invertebrate biomass and 16% or the production in the Satilla River in coastal plains Georgia; 78% of drifting biomass originated from the snags, and four of the eight major fish species obtained at least 60% of their prey biomass from snags, although all fish species utilized snags to some extent. If food is limiting in a river system, sunfish production could easily be reduced by 70% based on food availability alone if snag removal was performed for flood control, according to Benke et al. (1985). Thus, the entire fish composition would shift to a population dependent on benthic fauna, which would favor the suckers and small shiners. In a TWDB funded study conducted by Southwest Texas State University on macroinvertebrate utilization of habitats in Allens Creek and the Brazos River, Wood et al. (1994) showed that the macroinvertebrate standing stock biomass, secondary production and invertebrate densities in LWD habitats exceeded that of benthic habitats by 10% to more than 50%. However, Angermeier and Karr (1984) suggested that the association between fish and woody debris in streams was even more important for the advantage it provided as camouflage than increased food availability. Lobb and Orth (1991) reported that nearshore, structurally complex habitats, such as snags, were important in influencing the assemblage structure of fishes of large low gradient warmwater rivers in West Virginia. Therefore, LWD provides multiple functions to fish, and the management implications for understanding the importance of this habitat in low gradient warmwater streams and rivers is considerable.

LWD can be separated into various types of woody habitat, including bank and channel snags, debris dams, and rootwads (Mathews and Tallent 1991; Mathews and Tallent 1996; RWA, Inc. 1995). The ecological function of these various habitats differs, and the flow dynamics associated with them are also different. For instance, snags do not completely block the flow in the space they occupy, and invertebrate organisms attached to them provide food resources for the fish. The branches also serve as attachment sites for adhesive eggs and egg strands released by spawning fish. The trunk and branches divert and modify flow patterns, creating a challenge for modeling. Debris dams, on the other hand, block the flow in the part of the water column that they occupy because of sediment and organic debris build-up behind these generally large, well-anchored woody structures that are positioned within the depositing portion of the stream channel. Debris dams provide velocity shelters on their downstream side that many fish use to avoid the high-energy flow environments of rivers and streams, as well as for ambush habitat for predaceous fish species (Mathews and Bao 1991, Mathews and Tallent 1991). Rootwads provide habitat for fish along banks, especially where undercut banks exist, and they vary greatly in size from the small root hairs of willows to the large root systems provided by oaks and cypress knees. Rootwads provide cover and shelter for some species of fish, and modify the near-shore flow dynamics (Mathews and Bao 1991, Mathews and Tallent 1991).

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Table 5.8 – Absolute abundance by season and by collection period.

				Clark Hubbs Seasons		Collection periods											
				Summer	Winter	Summer						Winter					
Species			Date	(April to October)	(Nov. to March)	Sept 20-23, 2001		Aug 27-30, 2002		May 13-16, 2002		Mar 29 - Apr 1, 2002		Feb 2-5, 2002		Mar 8-11, 2002	
Species with abundance greater than 0.1% across all collections			Flow (m^3/s)			114.5		41.8		25.1		118.5		74.3		63.1	
Scientific Name	**Common Name**	**abundance**	**Percentile Rank**			58.2%		30.0%		14.6%		59.1%		47.5%		43.0%	
Shallow water seine species						abundance	samples	abundance	samples	abundance	samples	abundance	samples	abundance	samples	abundance	samples
Menidia beryllina	inland silverside	30		28	2	19	2	3	2	6	1	1	1			1	1
Dorosoma cepedianum	gizzard shad	41		37	4	36	6	1	1			3	2			1	1
Dorosoma petenense	threadfin shad	129		116	13	46	6	68	5	2	1	3	1	8	2	2	1
Cyprinella lutrensis	red shiner	18614		5407	13207	1744	8	886	9	2777	9	4720	9	1578	9	6909	9
Macrhybopsis aestivalis	speckled chub	73		19	54	11	4	8	4			33	5	11	1	10	3
Machrybopsis storeriana	silver chub	31		30	1	27	4	1	1	2	2			1	1	0	0
Notropis buchanani	ghost shiner	768		110	658	71	5			39	5	293	8	49	7	316	8
Notropis shumardi	silverband shiner	1741		309	1432	221	7	10	4	78	6	776	8	30	8	626	7
Pimephales vigilax	bullhead minnow	4626		1063	3563	723	8	237	8	103	8	1879	9	166	9	1518	9
Ictalurus punctatus	channel catfish	28		12	16	10	4			2	2	6	2	8	2	2	1
Mugil cephalus	striped mullet	619		6	613					6	2	612	7	1	1		
Gambusia affinis	mosquitofish	1395		1264	131	359	5	173	7	732	7	71	3	21	2	39	2
Total number of samples			54	27	27		9		9		9		9		9		9
% of Lentic samples			48.15%	22.22%	25.93%	11.11%		5.56%		5.56%		5.56%		9.26%		11.11%	
% of Lotic samples			51.85%	27.78%	24.07%	5.56%		11.11%		11.11%		11.11%		7.41%		5.56%	
Deep water gillnet species						no collections		abundance	samples	abundance	samples	abundance	samples	abundance	samples	abundance	samples
Alosa chrysochloris	skipjack herring	2		2		-		2	1								
Carpioides carpio	river carpsucker	16		10	6	-		5	2	5	3	1	1	2	2	3	2
Ictiobus bubalus	smallmouth buffalo	10		5	5	-		2	2	3	3	1	1	3	2	1	1
Dorosoma cepedianum	gizzard shad	18		2	16	-				2	2	6	3	7	3	3	2
Ictalurus furcatus	blue catfish	15		5	10	-		2	2	3	2			6	4	4	3
Ictalurus punctatus	channel catfish	5		3	2	-		1	1	2	2			1	1	1	1
Lepisosteus oculatus	spotted gar	30		7	23	-		5	3	2	2	14	3	1	1	8	1
Lepisosteus osseus	longnose gar	154		96	58	-		2	2	94	4	23	5	8	3	27	7
Mugil cephalus	striped mullet	3		1	2	-				1	1	1	1			1	1
Aplodinotus grunniens	freshwater drum	5		4	1	-		2	2	2	2	1	1				
Total number of samples			40	24	16				8		8		8		8		8
% of Lentic samples			40.00%	22.50%	17.50%	-		10.00%		12.50%		12.50%		12.50%		12.50%	
% of Lotic samples			60.00%	37.50%	22.50%	-		10.00%		7.50%		7.50%		7.50%		7.50%	

Table 5.9 – Relative standardized abundance by season and by collection period.

				Clark Hubbs Seasons		Collection periods					
				Summer	Winter	Summer			Winter		
Species			Date	(April to October)	(Nov. to March)	Sept 20-23, 2001	Aug 27-30, 2002	May 13-16, 2002	Mar 29 - Apr 1, 2002	Feb 2-5, 2002	Mar 8-11, 2002
Species with abundance greater than 0.1% across all collections			Flow (m3/s)			114.5	41.8	25.1	118.5	74.3	63.1
Scientific Name	**Common Name**	**abundance**	**Percentile Rank**			58.2%	30.0%	14.6%	59.1%	47.5%	43.0%
Shallow water seine species											
Menidia beryllina	inland silverside	30		93.33%	6.67%	63.33%	10.00%	20.00%	3.33%		3.33%
Dorosoma cepedianum	gizzard shad	41		90.24%	9.76%	87.80%	2.44%		7.32%		2.44%
Dorosoma petenense	threadfin shad	129		89.92%	10.08%	35.66%	52.71%	1.55%	2.33%	6.20%	1.55%
Cyprinella lutrensis	red shiner	18614		29.05%	70.95%	9.37%	4.76%	14.92%	25.36%	8.48%	37.12%
Macrhybopsis aestivalis	speckled chub	73		26.03%	73.97%	15.07%	10.96%	0.00%	45.21%	15.07%	13.70%
Machrybopsis storeriana	silver chub	31		96.77%	3.23%	87.10%	3.23%	6.45%		3.23%	
Notropis buchanani	ghost shiner	768		14.32%	85.68%	9.24%		5.08%	38.15%	6.38%	41.15%
Notropis shumardi	silverband shiner	1741		17.75%	82.25%	12.69%	0.57%	4.48%	44.57%	1.72%	35.96%
Pimephales vigilax	bullhead minnow	4626		22.98%	77.02%	15.63%	5.12%	2.23%	40.62%	3.59%	32.81%
Ictalurus punctatus	channel catfish	28		42.86%	57.14%	35.71%		7.14%	21.43%	28.57%	7.14%
Mugil cephalus	striped mullet	619		0.97%	99.03%			0.97%	98.87%	0.16%	
Gambusia affinis	mosquitofish	1395		90.61%	9.39%	25.73%	12.40%	52.47%	5.09%	1.51%	2.80%
		Total number of samples	54	27	27	9	9	9	9	9	9
		% of Lentic samples	48.15%	22.22%	25.93%	11.11%	5.56%	5.56%	5.56%	9.26%	11.11%
		% of Lotic samples	51.85%	27.78%	24.07%	5.56%	11.11%	11.11%	11.11%	7.41%	5.56%
Deep water gillnet species											
Alosa chrysochloris	skipjack herring	2		100.00%		-	100.00%				
Carpioides carpio	river carpsucker	16		62.50%	37.50%	-	31.25%	31.25%	6.25%	12.50%	18.75%
Ictiobus bubalus	smallmouth buffalo	10		50.00%	50.00%	-	20.00%	30.00%	10.00%	30.00%	10.00%
Dorosoma cepedianum	gizzard shad	18		11.11%	88.89%	-		11.11%	33.33%	38.89%	16.67%
Ictalurus furcatus	blue catfish	15		33.33%	66.67%	-	13.33%	20.00%		40.00%	26.67%
Ictalurus punctatus	channel catfish	5		60.00%	40.00%	-	20.00%	40.00%		20.00%	20.00%
Lepisosteus oculatus	spotted gar	30		23.33%	76.67%	-	16.67%	6.67%	46.67%	3.33%	26.67%
Lepisosteus osseus	longnose gar	154		62.34%	37.66%	-	1.30%	61.04%	14.94%	5.19%	17.53%
Mugil cephalus	striped mullet	3		33.33%	66.67%	-		33.33%	33.33%		33.33%
Aplodinotus grunniens	freshwater drum	5		80.00%	20.00%	-	40.00%	40.00%	20.00%		
		Total number of samples	40	16	24	no collections	8	8	8	8	8
		% of Lentic samples	40.00%	22.50%	17.50%	-	10.00%	12.50%	12.50%	12.50%	12.50%
		% of Lotic samples	60.00%	37.50%	22.50%	-	10.00%	7.50%	7.50%	7.50%	7.50%

Table 5.10 – Absolute abundance by specialized habitat

Species			Specialized habitat																			
Species with abundance greater than 0.1% across all collections			Backwater		Lentic Channel		Lentic Margin		Lentic Embayment		Lotic Channel		Lotic Margin		Lotic Embayment		Riffle		Confluence Lentic		Confluence Lotic	
Scientific Name	Common Name	abundance																				
Shallow water seine species			a	s	a	s	a	s	a	s	a	s	a	s	a	s	a	s	a	s	a	s
Menidia beryllina	inland silverside	30	2	1							1	1							27	5		
Dorosoma cepedianum	gizzard shad	41	13	1	5	2	7	2					3	2					13	3		
Dorosoma petenense	threadfin shad	129	7	2	36	2	12	2			8	2	7	2			1	1	58	5		
Cyprinella lutrensis	red shiner	18614	2183	6	823	4	2666	10			785	4	8623	17			1040	6	2436	5	58	1
Macrhybopsis aestivalis	speckled chub	73	6	2			10	3			13	2	30	6			11	3	3	1		
Machrybopsis storeriana	silver chub	31			2	1	2	2					26	4			1	1				
Notropis buchanani	ghost shiner	768	41	3	126	2	64	7			14	3	213	11			3	3	307	4		
Notropis shumardi	silverband shiner	1741	83	4	95	3	38	7			34	4	600	11			33	5	853	5	5	1
Pimephales vigilax	bullhead minnow	4626	239	5	909	4	485	10			120	4	1327	16			36	6	1480	5	30	1
Ictalurus punctatus	channel catfish	28	4	2			4	1			8	2	7	2			1	1	3	2	1	1
Mugil cephalus	striped mullet	619	194	2									402	5			3	1	20	2		
Gambusia affinis	mosquitofish	1395	91	4	72	3	198	3			13	3	63	6			3	1	935	5	20	1
Total number of samples				6		4		11				4		17				6		5		1
Percent of samples collected in Summer			5.56%		3.70%		7.41%				3.70%		18.52%				5.56%		5.56%			
Percent of samples collected in Winter			5.56%		3.70%		12.96%				3.70%		12.96%				5.56%		3.70%		1.85%	
Percent of samples collected in each Habitat			11.11%		7.41%		20.37%				7.41%		31.48%				11.11%		9.26%		1.85%	
Deep water gillnet species			a	s	a	s	a	s	a	s	a	s	a	s	a	s	a	s	a	s	a	s
Alosa chrysochloris	skipjack herring	2							2	1												
Carpioides carpio	river carpsucker	16			1	1			14	8					1	1						
Ictiobus bubalus	smallmouth buffalo	10			1	1			8	7									1	1		
Dorosoma cepedianum	gizzard shad	18			2	1			12	5					1	1			2	2	1	1
Ictalurus furcatus	blue catfish	15							12	9					2	1			1	1		
Ictalurus punctatus	channel catfish	5							4	4					1	1						
Lepisosteus oculatus	spotted gar	30			2	1			13	5	1	1			1	1			8	1	5	1
Lepisosteus osseus	longnose gar	154			5	1			93	13	4	3			45	1			5	2	2	1
Mugil cephalus	striped mullet	3							1	1					1	1					1	1
Aplodinotus grunniens	freshwater drum	5							5	5												
Total number of samples						2				19		13				1				3		2
Percent of samples collected in Summer					2.50%				17.50%		12.50%				2.50%				2.50%		2.50%	
Percent of samples collected in Winter					2.50%				30.00%		20.00%								5.00%		2.50%	
Percent of samples collected in each Habitat					5.00%				47.50%		32.50%				2.50%				7.50%		5.00%	

a = absolute abundance, s = number of samples

Table 5.11 – Relative standardized abundance by specialized habitat

Species			Specialized habitat									
Species with abundance greater than 0.1% across all collections			Backwater	Lentic Channel	Lentic Margin	Lentic Embayment	Lotic Channel	Lotic Margin	Lotic Embayment	Riffle	Confluence Lentic	Confluence Lotic
Scientific Name	**Common Name**	**abundance** (standardized)										
Shallow water seine species												
Menidia beryllina	inland silverside	323.1	5.57%				4.18%				**90.25%**	
Dorosoma cepedianum	gizzard shad	368.8	31.73%	18.30%	9.32%			2.58%			**38.07%**	
Dorosoma petenense	threadfin shad	1373.5	4.59%	35.38%	4.29%		7.86%	1.62%		0.66%	**45.60%**	
Cyprinella lutrensis	red shiner	120634.1	16.29%	9.21%	10.85%		8.78%	22.71%		7.76%	**21.81%**	2.60%
Macrhybopsis aestivalis	speckled chub	505.3	10.69%		9.72%		**34.73%**	18.86%		19.59%	6.41%	
Machrybopsis storeriana	silver chub	128.4		21.03%	7.65%			**64.32%**		7.01%		
Notropis buchanani	ghost shiner	6592.4	5.60%	25.80%	4.77%		2.87%	10.26%		0.41%	**50.29%**	
Notropis shumardi	silverband shiner	14360.3	5.20%	8.93%	1.30%		3.20%	13.27%		2.07%	**64.15%**	1.88%
Pimephales vigilax	bullhead minnow	40566.6	5.30%	30.25%	5.87%		3.99%	10.39%		0.80%	**39.40%**	3.99%
Ictalurus punctatus	channel catfish	281.3	12.80%		6.98%		**38.40%**	7.91%		3.20%	11.52%	19.20%
Mugil cephalus	striped mullet	3265.9	**53.46%**					39.10%		0.83%	6.61%	
Gambusia affinis	mosquitofish	14343.6	5.71%	6.78%	6.78%		1.22%	1.40%		0.19%	**70.40%**	7.53%
Total number of samples			6	4	11		4	17		6	**5**	1
Percent of samples collected in Summer			5.56%	3.70%	7.41%		3.70%	18.52%		5.56%	5.56%	
Percent of samples collected in Winter			5.56%	3.70%	12.96%		3.70%	12.96%		5.56%	3.70%	1.85%
Percent of samples collected in each Habitat			11.11%	7.41%	20.37%		7.41%	31.48%		11.11%	9.26%	1.85%
Deep water gillnet species												
Alosa chrysochloris	skipjack herring	4.2				**100.00%**						
Carpioides carpio	river carpsucker	89.5		22.35%		32.94%			**44.71%**			
Ictiobus bubalus	smallmouth buffalo	50.2		**39.86%**		33.57%					26.57%	
Dorosoma cepedianum	gizzard shad	151.9		26.33%		16.63%			**26.33%**		17.55%	13.16%
Ictalurus furcatus	blue catfish	118.6				21.30%			**67.46%**		11.24%	
Ictalurus punctatus	channel catfish	48.4				17.39%			**82.61%**			
Lepisosteus oculatus	spotted gar	317.1		12.61%		8.63%	0.97%		12.61%		33.64%	**31.53%**
Lepisosteus osseus	longnose gar	2214.8		4.52%		8.84%	0.56%		81.27%		3.01%	1.81%
Mugil cephalus	striped mullet	62.1				3.39%			**64.41%**			32.20%
Aplodinotus grunniens	freshwater drum	10.5				**100.00%**						
Total number of samples				2		19	13		1		3	2
Percent of samples collected in Summer				2.50%		17.50%	12.50%		2.50%		2.50%	2.50%
Percent of samples collected in Winter				2.50%		30.00%	20.00%				5.00%	2.50%
Percent of samples collected in each Habitat				5.00%		47.50%	32.50%		2.50%		7.50%	5.00%

Legend

77.77% Green highlight indicates a relative standardized abundance that is greater than an even distribution (12.5% for shallow, 16.7% for deep) among standardized samples

77.77% Bold indicates the largest deviation for each species of the relative standardized abundance from the percentage of sampled mesohabitat

Table 5.12 – Specialized habitat communities for shallow water seine samples.

	Specialized habitat									
	Backwater	**Lentic Channel**	**Lentic Margin**	**Lentic Embayment**	**Lotic Channel**	**Lotic Margin**	**Lotic Embayment**	**Riffle**	**Confluence Lentic**	**Confluence Lotic**
Number of samples (before standardizing)	6	4	11		4	17		6	5	1
Percent of all samples	11.11%	7.41%	20.37%		7.41%	31.48%		11.11%	9.26%	1.85%
Percent of summer samples	5.56%	3.70%	7.41%		3.70%	18.52%		5.56%	5.56%	
Percent of Winter samples	5.56%	3.70%	12.96%		3.70%	12.96%		5.56%	3.70%	1.85%
Species common name										
Species with abundance greater than 0.1% across all collections, listed in decreasing relative standardized abundance	**striped mullet**	threadfin shad	red shiner		**channel catfish**	**silver chub**		speckled chub	**inland silverside**	channel catfish
	gizzard shad	bullhead minnow	speckled chub		**speckled chub**	striped mullet		red shiner	**mosquitofish**	mosquitofish
	red shiner	ghost shiner	gizzard shad		red shiner	red shiner		silver chub	**silverband shiner**	bullhead minnow
	channel catfish	silver chub	silver chub		threadfin shad	speckled chub		channel catfish	**ghost shiner**	red shiner
	speckled chub	gizzard shad	channel catfish		inland silverside	silverband shiner		silverband shiner	**threadfin shad**	silverband shiner
	mosquitofish	red shiner	mosquitofish		bullhead minnow	bullhead minnow		striped mullet	**bullhead minnow**	
	ghost shiner	silverband shiner	bullhead minnow		silverband shiner	ghost shiner		bullhead minnow	**gizzard shad**	
	inland silverside	mosquitofish	ghost shiner		ghost shiner	channel catfish		threadfin shad	**red shiner**	
	bullhead minnow		threadfin shad		mosquitofish	gizzard shad		ghost shiner	channel catfish	
	silverband shiner		silverband shiner			threadfin shad		mosquitofish	striped mullet	
	threadfin shad					mosquitofish			speckled chub	

Notes:

Species occurring in each habitat are shown in order of decreasing relative standardized abundance

species — Species shown with green shading are those whose relative standardized abundance is greater than the distribution of samples among habitats.

species — Bold species indicate the species occurred most frequently (on a standardized basis) in the habitat in which it is shown in bold.

Table 5.13 – Specialized habitat communities for deep water gillnet samples.

	Specialized habitat									
	Backwater	Lentic Channel	Lentic Margin	Lentic Embayment	Lotic Channel	Lotic Margin	Lotic Embayment	Riffle	Confluence Lentic	Confluence Lotic
Number of samples (before standarizing)		2		19	13		1		3	2
Percent of all samples		5.00%		47.50%	32.50%		2.50%		7.50%	5.00%
Percent of summer samples		2.50%		17.50%	12.50%		2.50%		2.50%	2.50%
Percent of winter samples		2.50%		30.00%	20.00%				5.00%	2.50%
Species common name Species with abundance greater than 0.1% across all collections, listed in decreasing relative standardized abundance		**smallmouth buffalo** gizzard shad river carpsucker spotted gar longnose gar		**skipjack herring** **freshwater drum** smallmouth buffalo river carpsucker blue catfish channel catfish gizzard shad longnose gar spotted gar striped mullet	spotted gar longnose gar		**channel catfish** longnose gar **blue catfish** **striped mullet** **river carpsucker** **gizzard shad** spotted gar		spotted gar smallmouth buffalo gizzard shad blue catfish longnose gar	striped mullet **spotted gar** gizzard shad longnose gar

Notes:

Species occurring in each habitat are shown in order of decreasing relative standardized abundance

species — Species shown with green shading are those whose relative standardized abundance is greater than the distribution of samples among habitats.

species — Bold species indicate the species occurred most frequently (on a standardized basis) in the habitat in which it is shown in bold.

Table 5.16 – Absolute abundance by season and by collection period for habitats with LWD

			Collection periods									
			Summer				Winter					
Species			Sept 20-23, 2001	Aug 27-30, 2002	May 13-16, 2002		Mar 29 - Apr 1, 2002	Feb 2-5, 2002		Mar 8-11, 2002		**Date**
Species with abundance greater than 0.1% across all collections			114.5	41.8	25.1		118.5	74.3		63.1		**Flow (m^3/s)**
Scientific Name	**Common Name**	**abundance**	58.2%	30.0%	14.6%		59.1%	47.5%		43.0%		**Percentile Rank**
Shallow water data not a part of Li 2003 data set				25	25		25	25	25	25		**Gelwick & Li 2002 Location**
Shallow water seine species			Lotic	Lotic Margin	Lotic Margin		Lotic	Lotic Margin	Lentic Margin	Lotic		**Hydraulic mesohabitat**
Menidia beryllina	inland silverside											
Dorosoma cepedianum	gizzard shad											
Dorosoma petenense	threadfin shad											
Cyprinella lutrensis	red shiner	2478		202	74		80	2038	1	83		
Macrhybopsis aestivalis	speckled chub	3					3					
Machrybopsis storeriana	silver chub	1						1				
Notropis buchanani	ghost shiner	12						12				
Notropis shumardi	silverband shiner	40			9		4	27				
Pimephales vigilax	bullhead minnow	636		5	3		17	609		2		
Ictalurus punctatus	channel catfish	1					1					
Mugil cephalus	striped mullet											
Gambusia affinis	mosquitofish	124			1			1	122			
Lepomis megalotis*	longear sunfish*	2					2					
	* not included in Li summary											
Deep water data is a part of Li 2003 data set				20	20	24	20	20		20	24	**Gelwick & Li 2002 Location**
Deep water gillnet species			no collections	Lentic Embayment	Lentic Embayment	Lotic	Lentic Embayment	Lentic Embayment		Lentic Embayment	Lotic	**Hydraulic mesohabitat**
Alosa chrysochloris	skipjack herring		-									
Carpioides carpio	river carpsucker	8	-	4	2			1		1		
Ictiobus bubalus	smallmouth buffalo	2	-		1		1					
Dorosoma cepedianum	gizzard shad	3	-		1					2		
Ictalurus furcatus	blue catfish	7	-	1	1			3		2		
Ictalurus punctatus	channel catfish		-									
Lepisosteus oculatus	spotted gar	2	-	2								
Lepisosteus osseus	longnose gar	68	-		46	2	7	5		7	1	
Mugil cephalus	striped mullet		-									
Aplodinotus grunniens	freshwater drum	2	-	1	1							

Table 5.17 – Relative abundance by season and by collection period for habitats with LWD

			Collection periods									
			Summer				Winter					
Species			Sept 20-23, 2001	Aug 27-30, 2002	May 13-16, 2002		Mar 29 - Apr 1, 2002	Feb 2-5, 2002		Mar 8-11, 2002		**Date**
Species with abundance greater than 0.1% across all collections			114.5	41.8	25.1		118.5	74.3		63.1		**Flow (m^3/s)**
Scientific Name	**Common Name**	**abundance**	58.2%	30.0%	14.6%		59.1%	47.5%		43.0%		**Percentile Rank**
Shallow water data not a part of Li 2003 data set				25	25		25	25	25	25		**Gelwick & Li 2002 Location**
Shallow water seine species			Lotic	Lotic Margin	Lotic Margin		Lotic	Lotic Margin	Lentic Margin	Lotic		**Hydraulic mesohabitat**
Menidia beryllina	inland silverside											
Dorosoma cepedianum	gizzard shad											
Dorosoma petenense	threadfin shad											
Cyprinella lutrensis	red shiner	2478		8.15%	2.99%		3.23%	82.24%	0.04%	3.35%		
Machrybopsis aestivalis	speckled chub	3					100.00%					
Machrybopsis storeriana	silver chub	1						100.00%				
Notropis buchanani	ghost shiner	12						100.00%				
Notropis shumardi	silverband shiner	40			22.50%		10.00%	67.50%				
Pimephales vigilax	bullhead minnow	636		0.79%	0.47%		2.67%	95.75%		0.31%		
Ictalurus punctatus	channel catfish	1					100.00%					
Mugil cephalus	striped mullet											
Gambusia affinis	mosquitofish	124			0.81%			0.81%	98.39%			
Lepomis megalotis*	longear sunfish*	2					100.00%					
* not included in Li summary												
Deep water data is a part of Li 2003 data set				20	20	24	20	20		20	24	**Gelwick & Li 2002 Location**
Deep water gillnet species			no collections	Lentic Embayment	Lentic Embayment	Lotic	Lentic Embayment	Lentic Embayment		Lentic Embayment	Lotic	**Hydraulic mesohabitat**
Alosa chrysochloris	skipjack herring		-									
Carpioides carpio	river carpsucker	8	-	50.00%	25.00%			12.50%		12.50%		
Ictiobus bubalus	smallmouth buffalo	2	-		50.00%		50.00%					
Dorosoma cepedianum	gizzard shad	3	-		33.33%					66.67%		
Ictalurus furcatus	blue catfish	7	-	14.29%	14.29%			42.86%		28.57%		
Ictalurus punctatus	channel catfish		-									
Lepisosteus oculatus	spotted gar	2	-	100.00%								
Lepisosteus osseus	longnose gar	68	-		67.65%	2.94%	10.29%	7.35%		10.29%	1.47%	
Mugil cephalus	striped mullet		-									
Aplodinotus grunniens	freshwater drum	2	-	50.00%	50.00%							

6. Conclusions and recommendations

Directed towards the larger goal of identifying potential impacts of the permitted Allens Creek Reservoir project on the Brazos River, this report presents baseline information on the lower Brazos River basin and presents previous work performed in the basin by the TWDB and partners at Texas A&M University. The input from and cooperation with US Army Corps of Engineers, Texas Commission on Environmental Quality and Texas Parks and Wildlife Department was appreciated and enhanced this analysis.

This report also presents new analyses with respect to hydrology, fish habitat and salinity migration in the lower Brazos River. While the work completed to date is considerable, the authors recommend that additional work be performed before flow regime decisions are made that affect present or future water rights permit holders in the lower Brazos River basin. Future studies will include recommendations for maintenance of aquatic habitat and estuary inflows that have the potential to alter the permitted firm yield, reservoir release rules or diversion rates of both the Allens Creek project and future projects on the lower Brazos River.

6.1 Conclusions

This section summarizes findings included in this report with respect to hydrology, aquatic habitat, hydraulic modeling and salinity migration modeling. A discrete study reach, Site 1, located near the Allens Creek project site was determined to be representative of the lower Brazos River. Intensive studies were performed at Site 1 with respect to hydrology, hydraulics and fish habitat utilization. Salinity migration modeling was performed at Site 2 in the Brazos River estuary.

6.1.1 Hydrology

The USGS Brazos River at Richmond, TX, gauge (#0811400) was used to investigate historical stream flow in the lower Brazos River. Flow rate measured at study Site 1 near Simonton, TX, corresponded to flow measured at the Richmond gauge. Less than 1% difference in contributing drainage area at the site when compared to the drainage area of the gauge and no major tributaries contributed flow between the site and the gauge. Even though the Richmond gauge was located 60 river km (37 miles) downstream of the study site, the historical record at the gauge was considered representative of the conditions existing at the study Site 1 because of the narrow watershed and lack of inflow occurring between the study site and the gauge.

Using the entire historical data record, the median flow at Richmond was 83 cms (2,930 cfs) and the 7Q2 flow was 20.3 cms (717 cfs). The 100-year flood flow was reported differently in two reports, 5,918 cms (209,000 cfs) (Dames and Moore 1975) and 5,125 cms (189,000 cfs) (FEMA 2001). Looking at the historical flow record by month, median flow for each month January through June was higher than the overall median calculated using the complete record, and median flow for each month July through December was lower than the overall median (Figure 2.10).

The historical flow record was broken into two eras to compare the flow regime existing before construction of Possum Kingdom Lake (pre-1941 era) to the most recent era (1970 to 2004). Low flow events occurred more frequently in the recent era and high flow events occurred more frequently in the early era (Table 2.1); however, the differences in the frequency of occurrence were both less than 5%. Analysis comparing seasons revealed similar results. The number of peak flow events higher than 1,982 cms (70,000 cfs) was fewer in the recent era (Figure 2.9).

Mass of transported suspended sediment was less significant for flow rates below 300 cms (10,500 cfs) than for flow rates above 300 cms, and the effective discharge, that which transports most sediment, was near 1,500 cms (53,000 cfs) (Hudson and Mossa 1997). The effective discharge of 1,500 cms corresponds to the peak discharge that occurred in half of the years on record, approximately 1,700 cms (60,000 cfs) (Figure 2.9).

6.1.2 Aquatic habitat

Using the same dataset, three methods for analyzing fish habitat utilization in the lower Brazos River were presented in this report. Gelwick and Li (2002) and Li (2003) examined fish habitat utilization on the basis of visually classified mesohabitats. Li (2003) additionally examined fish habitat utilization on the basis of shallow and deep water habitats. The TWDB in this report examined fish habitat utilization on the basis of hydraulically defined mesohabitats and specialized habitats, and also presented a spatial GIS model capable of quantifying the area of those habitats available for a range of flow rates.

Gelwick and Li (2002) and Li (2003) both reported the fish species within the riverine communities to be habitat generalists. Similarly, TWDB showed a large degree of habitat generalization, but also showed consistent use of specialized habitats by some species. Therefore, a hydraulically-based classification of habitat proved effective in better understanding fish relationship to their habitat. Species-specific patterns of habitat association are basic to the concept of an ecological niche and provide information necessary for making decisions concerning instream flow needs.

Trends in habitat partitioning were evident among species for the ten specialized habitats that were delineated on the basis of fluvial zones (lotic and lentic) and channel location (confluence, margin, backwater, riffle). Sampling method bias results in differences in fish collections, although recognizing that small-bodied fishes dominated shallow habitats and large-bodied fishes dominated deep water habitats was helpful in standardizing relative abundance. Large woody debris was shown to make important structural and functional contributions to habitats that fish exploit for feeding, spawning, protection, and camouflage.

Species relationships related to specialized habitat conditions was strong for some species, and fish indicators could be determined. For instance, two species of silversides utilized the Allens Creek confluence site almost exclusively; the deep lotic margins were frequented by silver and speckled chubs, striped mullet and channel catfish, while red shiners were founded most frequently in shallow lotic margins.

Aquatic mesohabitat and specialized habitat was defined based upon depth, velocity and location within the study reach. The area and volume of habitat was quantified by combining within a GIS environment the habitat definitions and hydraulic model output. Additionally, habitat-duration figures were developed to describe the probability of occurrence of habitat area. Density-dependent interactions reportedly become greater among and within species as habitat volume is reduced by changes in flow (Edwards 1997). A concentrating effect can cause increased mortalities of all life stages by limiting food resources and available spawning habitat (Edwards 1997). However, the concentrating effect observed in this study was not linearly related to flow, and in fact some specialized habitats lost volume with increasing flows.

6.1.3 Hydraulic modeling for aquatic habitat

Hydraulic modeling using RMA-2 generated steady-state depth and velocity data throughout Site 1 for use in the GIS habitat model. The resolution of depth and velocity points was the highest resolution deemed possible considering the source bathymetry data, the domain of nearly 50,000 nodes and the assumptions incorporated into the hydrodynamic model. The calibrated model performed well and generated reasonable depth and velocity fields (see verification in Appendix K).

6.1.4 Salinity migration in the estuary

The calibrated hydrodynamic model of the minor Brazos River estuary presented in this report showed concentrations of saline waters to exceed 5 ppt in the vicinity near Brazoria, TX, under theoretically natural conditions. In a historically dry year, concentrations exceeded 10 ppt for the entire year in the same location, and in a historically wet year, concentrations exceeded 5 ppt only during dry summer months during high-tide. During a historically median year, significant periods of the summer were characterized by salinity concentrations in excess of 5 ppt.

For a theoretical case that applied a constant river inflow equivalent to the Water Quality Protection Flow (20.78 cms, 734 cfs) for an entire year, mid-depth salinity did not exceed 10 ppt at peak, and exceeded 5 ppt during roughly half of the daily high tide events modeled.

Under the currently permitted operating rules, the Allens Creek project is not anticipated to have significant effect on salinity migration in the lower Brazos River estuary. Additional scenarios can now be investigated using this calibrated model.

6.2 Recommendations

This section provides recommendations to improve the design for future studies of the lower Brazos River. Also discussed are some issues that were not easily incorporated in other sections but probably warrant further investigation before determining the instream flow requirement of the lower Brazos River. This list of recommendations is based primarily on the work presented in this report and is not intended to be a comprehensive list of tasks for future instream flow studies.

6.2.1 Hydrology

Wherever possible, investigation of historical statistics of intra-annual flow variation is recommended for purposes of comparing pre-development flow conditions to post-development flow conditions.

Field verification is recommended of gauge datum elevations for gauges used in slope and riparian inundation analyses.

A time-series flow and habitat analysis that accounts for the proposed operation of the Allens Creek reservoir project is recommended Thereby enabling an analysis of the probability of exceedance of available habitat area could be compared between the pre- and post-development conditions.

6.2.2 Aquatic habitat

6.2.2.1 Habitat sampling recommendations

The fish sampling strategy utilized for this study was collaboratively discussed and agreed-upon by a number of state agency staff and research personnel.

A significant field sampling effort was performed over the course of this single year, two season study. Future studies that assess the effects of inter-annual flow variation (wet year, dry year, median year) would provide additional insight.

For future fish habitat studies, reporting of each fish sample is recommended to include the following data: date, sampling gear type, begin time, end time, environmental parameters, substrate, depth and velocity at three locations, GPS position (at depth/velocity locations), area sampled, photograph and additional notes as necessary. Collection of accurate sampling location information is important for verification of both a hydraulic model and a GIS habitat model.

Visually classified habitats, classified on the basis of surface disturbance (Li 2003, Vadas and Orth 1998), may not be appropriate in large-river situations where surface waves may result from wind stress rather than river currents. Mesohabitat classification using measured physical parameters is recommended.

Sampling of an even distribution of habitats is recommended. Figure 5.1 illustrates a discontinuity in the sampling of deep-water habitats in the 5 to 20 cm/s velocity range. Additionally, sampling of near-shore edge habitats may be beneficial. Deep-water edge habitats and deep-water mid-channel habitats were not classified in the existing dataset.

Sampling a range of flow conditions and a range of seasons is also recommended. The short duration of this field sampling effort was not sufficiently long for sampling of low-flow winter events. Spawning season was not targeted for fish collections. Future studies should target flow ranges not covered by the existing data set and to target important life-cycle periods.

Fish size is an important consideration and should be recorded when possible. In addition, fish sampling techniques should be limited to those capable of being standardized.

6.2.2.2 Habitat analysis recommendations

Both Gelwick and Li (2002) and Li (2003) included rigorous statistical analysis and interpretation of fish utilization trends using the visually classified mesohabitats. These studies both found that fish species were habitat generalists. TWDB found evidence of habitat specialization for some fish when mesohabitats were further divided by velocity and depth and into specialized microhabitats. The results of TWDB's findings, however, are not easily comparable with the prior studies because the data was not subjected to similar statistical analyses. The TWDB results do suggest that separating mesohabitats into hydraulically distinct microhabitats could provide a viable framework to determine fish habitat utilization. It is recommended that future studies incorporate hydraulically classified habitat analysis with the rigorous statistical testing used by Gelwick and Li (2002) and Li (2003).

Sampling procedures for large rivers need to be standardized for different gear types implemented in different depths. Quantitative ecological assessments and statistical analyses require standardized data.

6.2.2.3 Additional aquatic analyses

For investigation of river and stream biological conditions, an IBI analysis using the standard refined regional protocols developed by the Texas Parks and Wildlife Department is recommended in the Brazos River near Allens Creek. Patterns of community organization related to habitat availability and quality, water quality, environmental conditions, and land use are critical to understanding the responses of fluvial systems to alterations in flow regimes.

Macroinvertebrates are an important structural component of river systems and have been frequently used to evaluate the environmental stresses in streams, evaluate functional feeding group composition, and apply to EPA's Rapid Bioassessment protocols to determine effects of various types of impacts. They showed important differences in secondary production in stream reaches with woody structure, and the relationship between fish and woody structure and the macroinvertebrate community needs further analysis. Our studies and those of our contractors have shown that changes in fish and macroinvertebrate communities along a gradient of increasing habitat heterogeneity and volume are important for environmental flow assessment. Spatiotemporal variation in fish-habitat associations is influenced by both stochastic and deterministic processes, which need further analyses.

6.2.3 Hydraulic modeling for aquatic habitat

6.2.3.1 Field data within the bounds of an intensive analysis site

Increased resolution of bathymetric data would improve hydraulic model mesh and also improve the depth aspect of the GIS habitat model. The resolution of the bathymetry data used for this large-river project was suitable for describing square grid habitats with dimensions of approximately 5 meters x 5 meters (16.4 feet x 16.4 feet). If increased resolution is required, use of navigational aids during data collection is recommended. If extremely high-resolution bathymetry is required, use of a multi-beam echosounding equipment is recommended, but is only feasible in waters greater than 2m (6 feet) deep.

The boundaries for the hydraulic mesh were generated using a combination of the bathymetry field data, GPS water edge data and DOQQ aerial photos. To improve the model mesh and to provide additional model verification data, a significant number of water edge location measurements are recommended for a range of flow rates.

Acoustic flow measurement data was used to determine flow rate on site. Use of the acoustic instrumentation throughout the site is recommended for a range of flow rates. Such data is recommended for verification of the hydraulic models.

Installation of non-vented pressure transducers to continuously measure water level at multiple sites throughout the study site is recommended. Installation of a barometric pressure sensor on site is required to adjust for fluctuation of atmospheric conditions.

Installation of semi-permanent benchmarks located high on the river bank, higher than the stage predicted for a 2-year flood event, is recommended.

Quantitative substrate mapping is recommended to improve habitat descriptions and to better calibrate the effect of bed roughness on hydraulics. Similarly, submerged or partially submerged debris and structure mapping is recommended.

6.2.3.2 Note on ephemeral nature of bed forms

All of the bathymetry for Site 1 was collected in two days by TWDB and TPWD. Two boats with similar acoustic depth sounders and GPS equipment essentially halved the length of time it would have taken to survey the whole river segment. Apart from the obvious timesaving to TWDB staff, an advantage to collecting all the data in a short period of time is that the change in water surface elevation experienced during data collection is likely minimal as are any changes that may have occurred to the geometry of the riverbed. Subtle changes occur to both the composition of the substrate and its shape with changing flow conditions. Of course large flood events cause dramatic changes, and may even change the course of the river.

This analysis is based on the data collected at the time it was collected. It is assumed that at some time in the future, the results will still be representative of the Brazos River downstream of Allens Creek experiencing this flow regime, but Site 1 may look quite different.

Additionally, bathymetry data was collected at a medium-to-high flow near 226 cms (8,000 cfs). Bed forms existing at such flows may be different than those existing at low flow. Since low flow analysis is one primary objective of instream flow studies, an investigation of the relationship of bed forms and/or substrate to flow rate is recommended.

6.2.3.3 Note on hydraulics near large woody debris

Evaluation of habitat in rivers with extensive large woody debris (LWD) is problematic. While the importance of LWD for certain fish species has been clearly demonstrated (Angermeirr and Karr 1984; Benke et al. 1985; Lobb and Orth 1991), the large and small-scale effects of LWD on flow and local velocity are particularly difficult to both measure and model. In terms of the hydrodynamics, there are four major issues (Hodges, pers comm., 2002):

1. The scale of the LWD is generally many times smaller than the resolvable flow scales in a typical hydraulic model for a river.
2. The flow effects of LWD are inherently 3D, while hydraulic models currently used for instream flow studies are either 1D or 2D.
3. Flow effects around LWD vary with depth of submergence.
4. LWD is fundamentally ephemeral, so requires either continuous field surveying, acceptance of a “snapshot” in time, or a model, which predicts the collection/removal as a function of river discharge through time.

The presence of LWD on the lower Brazos River does very little to impede the flow and was not significant at the roughly 5m resolution of our hydraulic model. For the purposes of the hydraulic model executed for this study, LWD was only given minor consideration. The area around the FM 1093 bridge crossing, where a large amount of debris has accumulated, was cut out of the model mesh and treated as an obstruction to flow. Visual inspection of this area confirmed that there was very little flow *through* this mass.

Main-channel reservoirs have the possibility of dramatically changing the presence of woody debris in a river; much more so than off-channel impoundments. There are two reasons for this: a) the dam can physically stop LWD from moving downstream from the upper reaches and b) online reservoirs can contain the major floods that tend to uproot trees from the river banks and result in their entrainment into river channels. Neither of these possibilities was considered in this study.

6.2.3.4 Hydraulic model formulation

The vast majority of commercially available hydraulic codes are based upon the hydrostatic assumption. For characterizing flow fields smaller than those noted above (approximately 5 meters scale on this large river), investigation of non-hydrostatic codes is recommended.

For analyzing sediment movement throughout the study reach, a hydrodynamic code coupled with a sediment transport model is recommended.

Three-dimensional codes may be useful when combined with sediment transport codes, and may also be useful in the event that aquatic habitat utilization could be quantified with respect to an organism’s location within the water column.

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- Texas A&M (principal investigator, Dr. Fran Gelwick): Fisheries studies and biological sampling on the Sulphur and Brazos Rivers. Graduate students Raymond Li and Christine Burgess conducted most of the fieldwork.

- UT CRWR (principal investigator, Dr. David Maidment): Developed the mesohabitat tool in the GIS environment and assisted with investigation of interpolation techniques. TWDB staff worked closely with PhD candidate Venkatesh Merwade.

- Dr. Ben Hodges (Principal investigator and engineering consultant): Peer review of hydraulic model and engineering practices employed throughout this project. With his hydraulics group at UT CRWR, he is currently researching the importance of LWD on riverine hydraulic models.

- Dr. Gary Grossman (University of Georgia): Peer review of fisheries analysis incorporated into draft versions of this study and recommendations for future studies. He is currently working with Dr. Ben Hodges to assess the hydraulic importance of LWD habitat.

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