Multivariate Methodology Assessment of Two Tidal Streams within the San Antonio-Nueces Coastal Basin: Final Report on the Mission and Aransas Rivers

Prepared for
Texas Commission on Environmental Quality
In fulfillment of
Contract 582-8-80180

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March 2011

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LIST OF ACRONYMS

ADCP	Acoustic Doppler Current Profiler
ADV	Acoustic Doppler Velocimeter
ALU	Aquatic Life Use
ANOSIM	Analysis of Similarity
AWRL	Ambient Water Reporting Limit
CFR	Code of Federal Regulations
CLU	Common Land Unit
COC	Chain Of Custody
CPUE	Catch Per Unit Effort
CRP	Clean Rivers Program
CWA	Clean Water Act
DO	Dissolved Oxygen
EMAP	Environmental Monitoring and Assessment Program
ENU	East North Up
EPA	Environmental Protection Agency
ESD	Ecological Site Descriptions
ESRI	Environmental System Research Institute, Inc
FSA	Farm Service Agency
GPS	Global Positioning System
HUC	Hydrologic Unit Codes
LCRA	Lower Colorado River Authority
LCS	Laboratory Control Standard
LCSD	Laboratory Control Standard Duplicate
LIMS	Laboratory Information Management System
MDL	Method Detection Limit

MDs	Multidimensional Scaling
MDM&A	Monitoring Data Management and Analysis
MPN	Most Probable Number
OPRR	Office of Permitting, Remediation, and Registration
NRCS	Natural Resource Conservation Service
PSU	Practical Salinity Units
PVC	Polyvinyl Chloride
QA/QC	Quality Assurance/Quality Control
QAM	Quality Assurance Manual
QAO	Quality Assurance Officer
QAPP	Quality Assurance Project Plan
QAS	Quality Assurance Specialist
QMP	Quality Management Plan
RPD	Relative Percent Deviation
RWA	Receiving Water Assessment
SOP	Standard Operating Procedure
SSURGO	Soil Survey Geographic
SWQM	Surface Water Quality Monitoring
SWQMP	Surface Water Quality Monitoring Procedures
TAMU-CC	Texas A & M University Corpus Christi
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
TCEQ	Texas Commission on Environmental Quality, formerly the Texas Natural Resource Conservation Commission
TOC	Total Organic Carbon
TPWD	Texas Parks and Wildlife Department
TRACS	Texas Regulatory and Compliance System
TSS	Total Suspended Solids

TSWQS	Texas Surface Water Quality Standards
TWDB	Texas Water Development Board
UAA	Use Attainability Analyses
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VSS	Volatile Suspended Solids

ACKNOWLEDGEMENTS

Numerous staff of Texas Parks and Wildlife Department's (TPWD) Science and Policy and Water Resources branches in the Coastal Fisheries Division have contributed to and/or participated in the fieldwork for this project. TPWD's GIS lab had a major role in the formulation of the Land Cover classification. We would like to thank Duane German for his quality work in completing that task as well as interpreting the results and writing the landcover discussion. Nathan Kuhn conducted the instream and riparian habitat sampling. Nathan Kuhn interpreted the results and wrote the habitat discussion. Special thanks go to Alex Nunez, Chad Norris, Paul Silva, Meridith Byrd, Jackie Robison, Todd Neahr and the Coastal Fisheries Division, who were significant participants in data collection efforts. Margaret Scarborough and Amy Ringstaff both provided much needed administrative and purchasing support.

Additional support for the project has been contributed by the Lower Colorado River Authority Environmental Laboratory, whose role in the project has been to analyze water and sediment samples. Special thanks go to Gary Franklin the project manager. The Texas Water Development Board assisted with design of the flow data collection system, collected the River Surveyor data and analyzed flow data. Special thanks go to project manager Dharhas Pothina. The analysis of the flow data for that report was done by Solomon Negusse. Texas A&M Corpus Christi has contributed analysis of benthic invertebrate and aquatic insect samples. Special thanks go to Kim Withers.

TCEQ Project Manager Jason Leifester went above and beyond on all requests and needs throughout the study. His professionalism and attention to detail as well as his ability to adapt made the entire project run smoothly.

EXECUTIVE SUMMARY

The importance of estuaries as nursery grounds for a variety of marine organisms has been well documented, and the habitats within these estuaries provide protection from larger piscivores for the early life history stages of fishes and many other marine organisms. The high primary productivity found within estuaries is generally associated with nutrient loadings via freshwater inputs, and overall productivity is maintained by complexes of emergent vegetation, benthic algae, and phytoplankton, which can all efficiently utilize these nutrients. Nearly all marine fishes are obligately dispersed in the plankton during early life history stages (egg, pre- and post-flexion, and pelagic juvenile), with the majority of estuarine-dependent organisms spawning offshore and their planktonic stages face the challenge of locating and settling into suitable estuarine habitat. The success of these early stages can subsequently affect the community structure of adult populations, many of which are recreationally and/or commercially important.

Tidal streams are highly productive transitional areas between the freshwater of the rivers and the increased salinities found in the estuary. These tidal streams also serve as important nursery areas for many fish and shellfish species, including many of the same recreationally or commercially important species found in the estuary. Routine monitoring of several tidally influenced segments throughout the State of Texas have revealed that water quality standards are not being met, as dissolved oxygen measurements in the tidal segments are routinely lower than the established criteria. These excursions of low dissolved oxygen could have a detrimental effect on the early life history stages of finfish and shellfish utilizing these nursery areas. Water quality management of these areas has been difficult because currently there are no state-wide criteria for assessing tidally influenced waterbodies, and these systems are naturally quite variable over time and space.

The purpose of this study was to further the development of a standardized methodology for assessing ecosystem health and assigning site-specific uses and criteria within tidally influenced portions of streams. This new methodology, which relies heavily on multivariate ordination techniques, has successfully been used to recommend aquatic life uses on three tidal segments identified as not meeting dissolved oxygen criteria, Cow Bayou Tidal (Orange County), Tres Palacios River Tidal (Matagorda County), and Garcitas Creek Tidal (Jackson and Victoria Counties); as well as comparing those streams to reference streams which were meeting the dissolved oxygen criteria, Lost River (Jefferson County) and West Carancahua Creek (Jackson County). For the present study, the tidal portions of the Mission and Aransas Rivers (San Patricio and Refugio Counties) were assessed with this same multivariate methodology, with the Mission River serving as the presumptive reference condition.

Mission River Tidal (Segment 2001) begins at a point 4.6 miles downstream of US 77 in Refugio County, is 19 miles in length, and flows into Mission Bay an inlet to Copano Bay. Aransas River Tidal (Segment 2003) begins at a point one mile upstream of US 77 in Refugio/San Patricio County, is 6 miles in length, and flows into Copano Bay. Both tidal systems are within the San Antonio-Nueces Coastal Basin, and are part of the Copano-Aransas Bay estuary complex.

The two streams were sampled for two years twice seasonally during the spring, summer and fall for chemical (water quality parameters including physiochemical profiles; short term 24 hour datasonde deployments; long term physiochemical profiles; and water and sediment samples); physical (instream flow; landcover/land use analysis; and instream and riparian habitat classification); and biological (nekton sampled with bag seines and trawls; sediment and benthic macroinvertebrate/infaunal) components of ecosystem health. The landcover/land use and instream and riparian habitat classification were conducted once each during the study. All other parameters were sampled multiple times on the seasonal schedule outlined. Multiple sampling stations on each stream encompassed the transitional character of the entire tidally influenced ecosystem, from the freshwater of the river to the saltwater of the bay.

Both streams appear to have not experienced much if any channelization or dredging, and both showed a decrease in their respective maximum depths in their downstream reaches relative to their upper reach. Both streams were characterized as glides at all their sampling reaches. These streams pass through very flat coastal landscapes, so there are no instances where water flows down any significant gradient such as a riffle or rapid. Thus the low stream gradients and relatively flat watersheds associated with them resulted in only calm flowing stream habitat types in the reaches sampled. The sediments in both streams were primarily composed of sand, with increasing clay and silt in their downstream-most sites. Gravel and or cobble were not found along the bottoms of these streams.

Vegetation followed a similar pattern in both streams, with woody materials, especially large trees, being dominant in the upper reaches and herbaceous species and low growing woody shrubs dominating the lower reaches. The sampling transects on the lower portions of the streams did not extend downstream far enough to pick up the full transition of the landscape into bay delta habitats, however, the edges of both streams do eventually transition from a riparian forest wetland community in their upper reaches to a salt marsh type of wetland community as they intersect with their receiving bay. The Mission River had more in-channel fish cover in its upper reach than in its lower ones, while the Aransas showed the opposite pattern having the most fish cover in its lowest reach. Indicators of human influence in these two streams appear to be dominated mainly by agriculture. Human influences attributable to direct human habitation were low, likely because this area is relatively less populated than other parts of the Texas coast.

The two years when the tidal stream study was conducted were drought years with extremely low flows except for flood events during the three last months in 2009 in the Mission River. Flow direction in the river Mission River was either upstream or there was no net flow in all the deployments. The flow pattern in the Aransas River exhibited some seasonality in that the maximum flow velocities which were upstream were reached in the summer in both study years. This was most likely due to the strong winds during the summer months that steadily blow toward the northwest coupled with lower flows. Minimum flow velocities occurred during the spring. In the Mission River however, no seasonal pattern in the stream flow was evident despite similar inflow, meteorological and tidal conditions existing in both streams. Flow in the middle reach of the Mission and Aransas rivers was tidally driven during the study period and residual flows were only small fraction (7 – 42%) of the tidal flow. The residual flow in both streams was upstream in most of the deployments owing to the coupled effect of very low inflow from the feeding watersheds and south-easterly winds that prevail during most of the year.

In the absence of riverine inflows, the effects of wind-driven salinity intrusion had a dramatic effect on transitory water quality readings. Vertical depth profiles failed to find any appreciable stratification of the water column with salinity generally increasing and dissolved oxygen decreasing with depth. Surface waters were more saturated than were either the mid- or bottom-water measurements, with hypoxic and at times anoxic conditions encountered in the bottom waters on each study stream. Low dissolved oxygen conditions were noted most often from the upper station on the Aransas River, although bottom water measurements showed average dissolved oxygen readings were very close to the standard of 4 mg/L. Low dissolved oxygen conditions were not as prevalent at the lower stations on either stream, which may be a reflection of the prominence of wind-driven mixing as outlined in the section on instream flow characterizations.

While dissolved oxygen was one of the primary focuses of the datasonde deployments, as sampling water quality parameters over a full tidal cycles allows for a better understanding of temporal variability. Similar to the transitory water quality readings, the longer term datasonde collections detected only salinity-mediated differences in synoptic water quality between the study streams, with the upper and middle station on the Aransas River (fresher in general, from surface to bottom) being different from all other stations.

Analysis of the water chemistry data by similar techniques also revealed that proxies for inflow (e.g., chloride, total dissolved solids, total phosphorus, and orthophosphorus) were most important in defining differences between the two study streams. This overriding role of inflows, especially the extreme lack of inflows as recorded by the hypersaline conditions on the Mission River, added a large amount of both temporal and spatial variability to the data.

The physical composition of the sediments ranged from mostly sands to high degrees of silts and clays within the same locations over the two years of this study. Across-stream comparisons showed that, unlike the orderly arrangement of stations based on water column parameters (either synoptic or transitory measures), sediment compositions were far more variable and did not reflect any consistent spatial arrangement.

The nekton communities at all stations were comprised of a mixture of highly euryhaline/marine taxa (Clupeidae, Engraulidae, Sciaenidae, Penaeidae, Paleomonidae, Portunidae) that numerically dominated the collections, and these same taxa are numerically abundant in estuaries all along the Gulf of Mexico and Atlantic coasts. Many of the estuarine forms that used the tidal habitats within the study streams were collected at post-larval and juvenile stages, suggesting that each of the streams is serving important nursery functions for the fisheries of Copano and Aransas Bays. For a number of common taxa, differences in nekton abundance were far more affected by salinity than any other physical or chemical parameter measured, irrespective of the season of collection. Seasonality was a very important factor for a number of other taxa, and the strength of this seasonality factor was gear-dependent, as the bag seines recorded the most distinct seasonal communities, while the trawls catches were less distinct across seasons. Many marine forms (e.g., sand trout, red drum, Atlantic croaker, brown shrimp, white shrimp, and spot) were far more abundant in very specific, and in some cases, very limited, seasons, and their abundance did not appear to be negatively affected by the extreme salinities that took place during the drought periods that characterized this study.

Hypoxic events, or low dissolved oxygen conditions, were routinely encountered, although these conditions did not appear to be a major factor in structuring overall community composition. The dissolved oxygen regimes within both study streams were heavily influenced by the interaction of temperature, (a general lack of) precipitation, nutrient-loading, and salinity stratification, as the most negative correlations between low dissolved oxygen and elevated bottom water salinities were found on the Aransas River. Despite these large spatial extents of hypoxic bottom waters, there was little to no relationship between dissolved oxygen measurements and community structure.

The organisms that dominated the benthics in these tidal systems can best be described as ubiquitous. Polychaetes (especially *Streblospio benedicti*), oligochaetes, and chironomids were common across the salinity gradient-based station design, and these organisms all have wide ranging distributions. Despite their ubiquitous nature in estuarine systems along the Texas coast, these organisms, and especially their dominance patterns, are sometimes used as indicators of pollution. Many polycheate species are tolerant to elevated levels of sediment organics, and these organisms typically dominate the community of “impacted” or “disturbed” areas. Oligochaetes have also been used as an indicator of pollution, because of their tolerance to organic enrichment. In enriched or oxygen-deficient areas, there are typically high densities of oligochaetes.

This study has shown that no clear differences could be found between the two streams, both which appear to be currently supporting a High Aquatic Life Use classification. The greatest degree of difference among the integrated indicators of ecosystem health seemed to occur in response to seasonal changes that were recorded in water temperature, coupled with and the overarching effect of the drought as measured by salinity and the various chemical constituents that serve as a proxy for salinity. This calendar year variability, which was a direct response to the drought, cut across the many different levels of ecological integrity that were measured for this study. Based on these results, dissolved oxygen concentration does not appear to be one of the major structuring factors in the physical, chemical, or biological components of ecosystem health. The general overlap of ecological conditions within these two streams shows that ultimately, the Mission River is inherently similar to the Aransas River, even during the ecologically challenging periods of an extended drought.

INTRODUCTION

Tidal streams are highly productive transition areas between freshwater and saltwater of the bays. Tidal streams serve as nurseries for many fish and shellfish, including important commercial and sport species. Estuarine dependant fish constitute more than 95 percent of the commercial fishery harvests from the Gulf of Mexico, and many important recreational fishery species depend on estuaries during some part of their life cycle (USEPA 1999).

Routine monitoring of several tidal streams have revealed dissolved oxygen measurements which are not meeting state water quality standards. Water quality management of these streams has been difficult because there are not currently any statewide criteria for assessing tidally influenced waterbodies, and these systems are naturally quite variable over space and time. The purpose of the previous Tidal stream Use Attainability analysis (UAA) study was to collect data in support of the development of a standardized methodology for assessing ecosystem health and assigning site-specific uses and criteria within tidally influenced portions of streams.

Based on the results of the UAA studies from the upper and middle Texas coast (Contreras and Whisenant, 2007; Tolan et al., 2007), dissolved oxygen concentration did not appear to be one of the major structuring factors in the physical, chemical, or biological components of ecosystem health. The greatest degree of difference in indicators of ecosystem health all involved upstream – downstream gradients that appear to be driven by salinity structure (the upper and middle stations were similar but significantly different from the lower station). These salinity-driven gradient conditions cut across all levels of ecological integrity that were measured for this study.

The analysis techniques applied to the salinity-mediated differences found in this study were equivocal; all the measures of ecosystem health on the study streams were very similar to the reference stream. As such, no biocriteria for tidal streams could be developed that would have applicability over large spatial scales.

The UAA study introduced a new assessment methodology to integrate the physical, chemical, and biological components of ecosystem health. During this study Texas Parks and Wildlife Department (TPWD) applied this methodology to the Mission River Tidal and the Aransas River Tidal to further develop the methodology for assessing the health of tidal streams.

The work was performed by Texas Parks and Wildlife Department (TPWD) under contract with the Texas Commission on Environmental Quality (TCEQ). Funding for the contract is from the United States Environmental Protection Agency (USEPA). Under the contract, TPWD Coastal Fisheries Division staff, led by the

Science and Policy Branch, collected data on two tidal streams.

Water Quality Standards

Water quality standards include designated uses for a water body, specific numerical criteria for certain water quality parameters, and narrative criteria (Table 1). The Texas Surface Water Quality Standards (TSWQS) are set by the TCEQ and approved by the USEPA. The TCEQ has established aquatic life uses and associated criteria for all waters of the state. The numeric criterion for dissolved oxygen is a surrogate or indirect measure of whether the aquatic life use is being maintained.

The ability of a water body to support a desired use is an integral consideration in the state and federal water quality standards review and revision process. When a water body is not capable of attaining all the uses included in Section 101(a)(2) of the Clean Water Act (CWA) or where the level of protection necessary to achieve those uses is not being or cannot be met, 40 CFR Part 131 provides a scientific procedure to select and apply segment-specific use criteria. The procedure, known as a use attainability analysis, is consistent with the intent of Sections 26.023 and 26.026 of the Texas Water Code. The regulation specifies that one or more of the following six conditions may be used for determining if a designated use is unattainable:

1. Naturally occurring pollutant concentrations prevent the attainment of the use; or
2. Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of a sufficient volume of effluent without violating State water conservation requirements to enable uses to be met; or
3. Human caused conditions or sources of pollution prevent the attaining of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place; or
4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use; or
5. Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and other factors, unrelated to water quality, preclude attainment of aquatic life protection uses; or
6. Controls more stringent than the technology-based requirements established by Section 301(b) and 306 of the Act would result in substantial and widespread economic and social impact. [40 CFR 131.10(g)].

Table 1. Aquatic Life Use subcategories, and the descriptive measures currently used to assess ecosystem health.

Aquatic Life Use Subcategory	Dissolved Oxygen Criteria, mg/L for Saltwater mean/minimum	Habitat Characteristics	Species Assemblage	Sensitive Species	Diversity	Species Richness	Trophic Structure
Exceptional	5.0/4.0	Outstanding natural variability	Exceptional or Unusual	Abundant	Exceptionally high	Exceptionally high	Balanced
High	4.0/3.0	Highly diverse	Usual association of regionally expected species	Present	High	High	Balanced to slightly imbalanced
Intermediate	3.0/2.0	Moderately diverse	Some expected species	Very low in abundance	Moderate	Moderate	Moderately imbalanced
Limited	<2.0	Uniform	Most regionally expected species absent	Absent	Low	Low	Severely imbalanced

The state of Texas currently has several tidal streams on the list of impaired waterbodies (Draft Texas 303(d) list). The CWA requires that the state conduct Total Maximum Daily Load (TMDL) projects for these streams.

Mission River Tidal Segment 2001 and Aransas River Tidal Segment 2003 are both listed as having high aquatic life use (TCEQ 2006). The dissolved oxygen criteria for a tidal water body with a high aquatic life use are: daily average 4 mg/l, and daily minimum 3 mg/l. The dissolved oxygen criteria only apply in the "mixed surface layer," which in tidally-influenced water bodies is defined as "the portion of the water column from the surface to the depth at which the specific conductance is 6,000 umhos/cm greater than the specific conductance at the surface" (TCEQ 2006).

According to the 2010 *Texas Water Quality Inventory and 303(d) List*, Copano Bay (Segment 2472) is impaired for bacteria in oyster waters (category 5a) in the area along the southern shore including Port Bay and the area near Bayside. Similarly, the entire waterbodies of both the Mission River Tidal (Segment 2001) and the Aransas River Tidal (Segment 2003) are listed for bacteria impairment (contact recreation, category 5a). The Aransas River above Tidal (Segment 2004A) is also listed for bacteria concerns, although Segment 2004A is listed as category 5c.

Study Area

Aransas River Tidal

Aransas River above Tidal (Segment 2004) begins at the confluence of Poesta and Aransas Creeks in Bee County and is 35 miles in length (Figure 1). Aransas River Tidal (Segment 2003) begins at a point one mile upstream of US 77 in Refugio/San Patricio County, is 6 miles in length, and flows into Copano Bay.

The river traverses flat rolling terrain with clay loam and sandy loam soils that support water-tolerant hardwoods, such as elms and oaks, and grasses. The sub-tropical humid climate features mild winters and warm summers. The average rainfall is 36 inches. Leading industries included agribusiness, tourism, oil and gas extraction, and fish packing. In 1990, approximately 33 percent of the land in Aransas County was in farms and ranches, and 14 percent of the farmland was under cultivation. Principal crops included sorghum, fruits, and nuts; the primary livestock products were from cattle (Handbook of Texas Online 2006b).

Buccaneer Cove preserve is located at the mouth of the Aransas River and contains 856 acres of wetlands such as estuarine tidal flats and brackish marshes. This area is owned and managed by the Coastal Bend Land Trust whose primary goal are preserving and enhancing native wildlife habitat in the

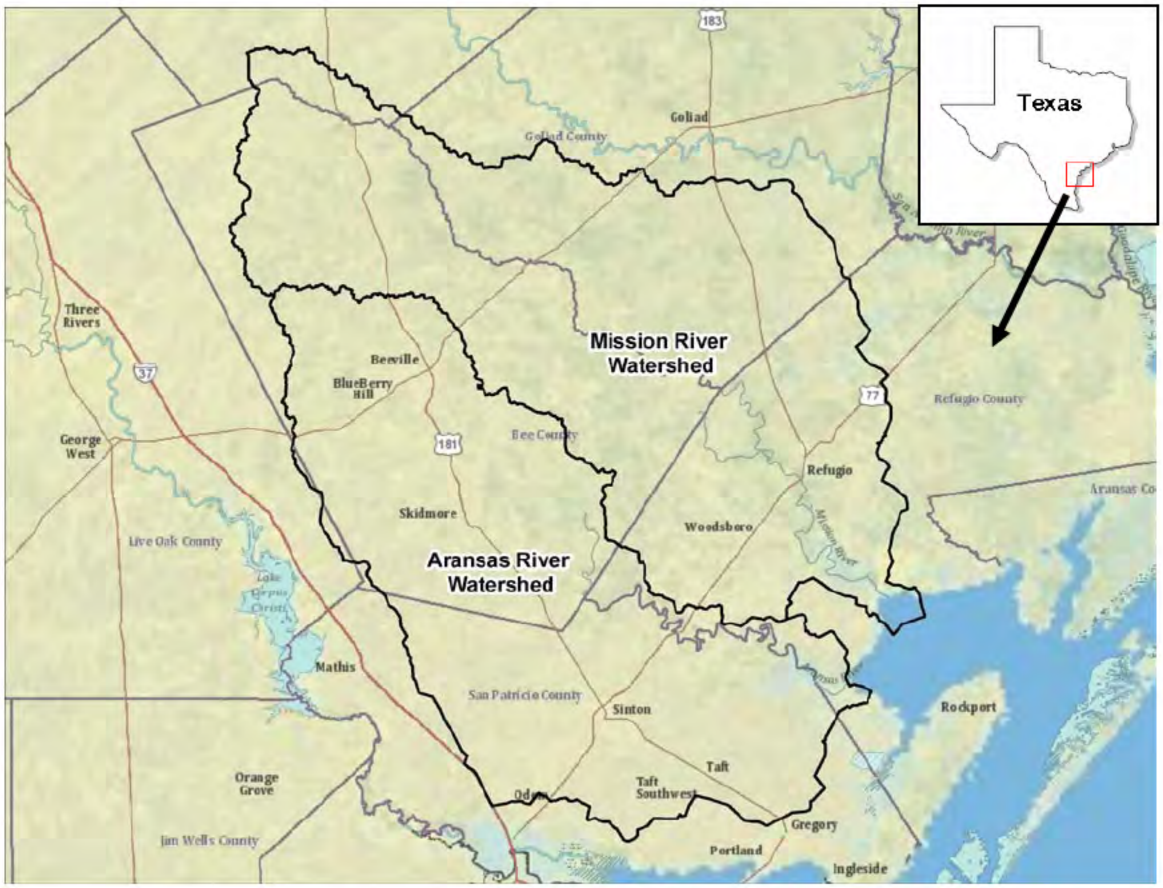


Figure 1. Map of Aransas River watershed and Mission River watershed.

Coastal Bend (NOAA 2006). Welder Wildlife Refuge is located on the Aransas River riparian corridor. Wetlands that exist on the refuge are lower coast riparian –hardwood corridor, prairie pothole and marsh-marsh fringing ponds and lakes (Moulton and Jacob 2001).

Mission River Tidal

Mission River above Tidal (Segment 2002) begins at the confluence of Blanco and Medio Creeks in Refugio County and is 9 miles in length (Figure 1). Mission River Tidal (Segment 2001) begins at a point 4.6 miles downstream of US 77 in Refugio County, is 19 miles in length, and flows into Mission Bay an inlet to Copano Bay.

It traverses gently undulating coastal prairies surfaced by clay and loam and spotted by groves of hardwoods and pines. It is home to a myriad of waterfowl and native slough grasses. Refugio County covers 771 square miles of generally flat land covered with tall prairie grasses and spotted in some areas with mesquite, live oak, prickly pear, and huisache. In 1982, 91 percent of the land in Refugio County was being used for farms and ranches; about 18 percent of the farmland was under cultivation. About 54 percent of the area's agricultural income that year derived from livestock, particularly cattle and hogs; crops included sorghum, cotton, corn, wheat and hay. Watermelons and pecans are also grown in the area. Natural resources include petroleum, natural gas, and industrial sand. In 1982, 56,470,457,000 cubic feet of gas-well gas, 39,920 barrels of condensate, 23,483,771 barrels of crude oil, and 50,934,814,000 cubic feet of casing-head gas were produced in the county (Handbook of Texas Online 2006b).

The Fennessey Ranch is privately owned and consists of 4,000 acres of abundant wetlands, meadows, natural lakes, riparian woods and brush land bordered on three sides by the Mission River (Fennessey web site). The current economic base incorporates hunting, wildlife tours, photography, and cattle enterprises (Smith and Dilworth 1999).

Review of Water Quality Data

According to the TCEQ 2008 water quality inventory, the Aransas River Tidal was fully supporting for Dissolved Oxygen (DO). Of 26 samples, all met screening criteria levels for the Aquatic Life Use (ALU). General use categories for pH, ammonia, and water temperature were also fully supporting in 28 samples collected. Recreational use categories of bacteria, both geomean and bacteria single sample *Enterococcus*, were non-supporting with exceedance in the geomean of 23 samples for bacteria as well as 11 of the 23 samples for bacteria single sample *Enterococcus*. In the 2006 TCEQ water quality inventory, the segment was non-supporting for *Enterococcus.* It was also listed as screening level concern for nitrate and orthophosphorus. In the 2004 TCEQ water quality inventory the segment was listed for *Enterococcus* non-supporting and concern for Orthophosphorus.

According to the TCEQ 2008 water quality inventory, the Mission River Tidal was fully supporting for DO grab minimum and no concern for DO grab screening level. General use categories for pH, ammonia and water temperature were also fully supporting in 28 samples collected. Recreational use categories of bacteria geomean and bacteria single sample *Enterococcus* were non-supporting for the geomean of 28 samples for bacteria and ten exceedances in the 28 samples for bacteria single sample. In the 2006 TCEQ water quality inventory the segment was non-supporting for *Enterococcus.* In the 2004 TCEQ water quality inventory the segment was listed for *Enterococcus* non-supporting.

Wastewater Outfalls

There are no wastewater outfalls in the Aransas River Tidal segment, although five wastewater permits individually drain into an unnamed tributary of Chiltipin Creek and these enter Segment 2003. The Above Tidal Segment has four wastewater permits that currently drain into the Aransas River (City of Beeville: 3,000,000 gpd with provisions for irrigation of the grass and landscaping of the plant site: to Poesta Creek to the Aransas River Above Tidal; City of Beeville, Chase Field: 2,500,000 gpd; Skidmore WSC: 131,000 gpd; Tynan WSC: 45,000 gpd: Papalote Creek to the Aransas River).

The town of Woodsboro is the only wastewater discharge currently permitted in the Mission River Tidal Segment (Basin Highlight Report, 2007). The Above Tidal Segment has two wastewater discharges currently permitted (Town of Refugio; and Pettus MUD into Medio Creek to Mission River Above Tidal; see Figure 2).

Summary of TCEQ Historical Data

A raw data report of all SWQM data on Segments 2001 and 2003 were obtained for the period of record ending November 28, 2007. Dissolved oxygen measurements have been collected at two stations on the Aransas River (Station 12947 – boat ramp on FM 629 south of Bonnie View and Station 12948 - at US 77) and a single station on the Mission River (Station 12943 – at FM 2678).

In the mixed surface layer DO measurements were all found to be within acceptable water quality standard limits (Nelson and Tolan 2008). In the vertical profiles no profile measurements were collected from Segment 2001. Data from eight sampling events are available to evaluate vertical profiles of dissolved oxygen and specific conductivity on Segment 2003. In each instance, profile

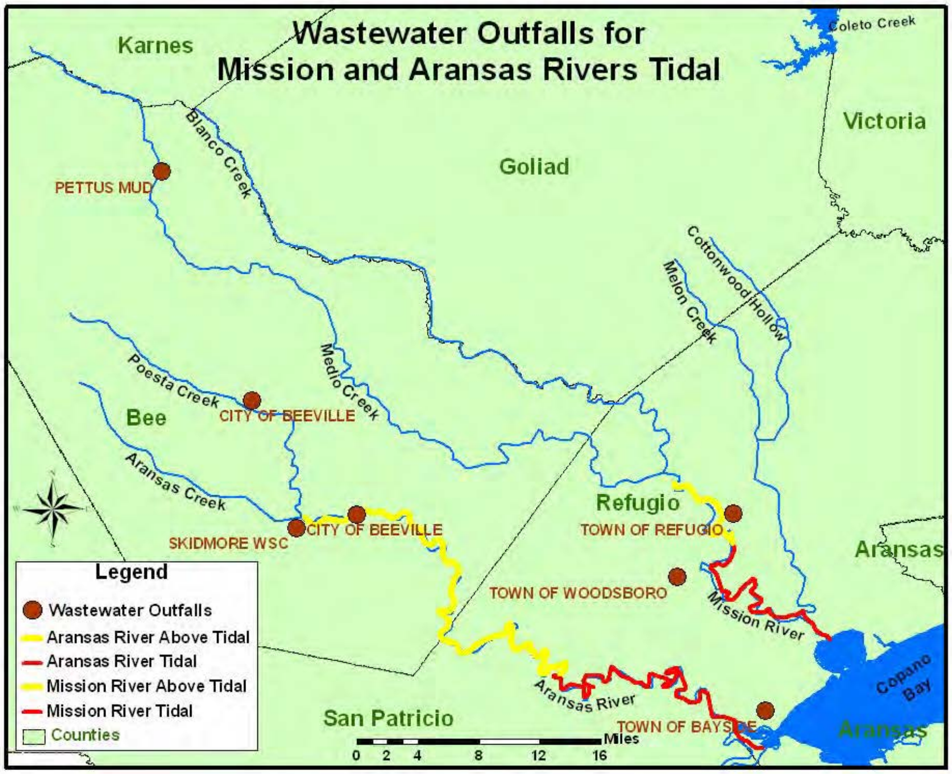


Figure 2. Map of wastewater outfalls for the Mission and Aransas Rivers Tidal.

measurements revealed that the water column was well-mixed with respect to the amount of DO present. Only a single occasion (1/23/2007) revealed a salt wedge present in the water column (a difference between the surface and bottom specific conductance readings > 6000 umhos/cm). Even under these conditions, DO measurements from both the surface and bottom layers were nearly identical and revealed a well-mixed water column.

The trends of routine parameters collected over time revealed that no samples exceeded the screening criteria for tidal waters for the parameters of temperature, DO, or pH (Nelson and Tolan 2008).

A more complete record of both routine and conventional parameters were taken from Station 12948, with nearly monthly sampling from September 1968 until December 1974, then quarterly sampling from January 1975 through July 2004. Only a single event exceeded the temperature screening value of 35 ^{o}C, whereas six total events recorded DO lower than the recommended criteria value of 4 mg/l. The standards for pH were nearly always satisfied, with only a single observation above (9.1) and one below (6.0) the screening value. The time series for specific conductance reveals that the influence of saltwater intrusion is minimal at this upriver station, with only a few records above a salinity value of 5 Practical Salinity Units (PSU) (approximately 10,000 umhos/cm). Conventional parameters at Station 12948, a middle station, also reflect lower saline conditions (Nelson and Tolan 2008).

Monthly sampling was conducted at Station 12943 on the Mission River from 1972 until 1974, with quarterly sampling comprising the remainder of the records from May 1969 to November 2007. The only screening criteria to be exceeded was DO, with a total of five low DO events. Saltwater intrusion is far more evident on this tidal segment, with salinities ranging from fresh to 27.6 PSU (specific conductance values range from 192 to nearly 60,000). There is no discernable trend in these salinity intrusion events. Conventional parameters at the station on Segment 2003 are markedly higher than on Segment 2001. These can be linked directly to the influence of the saltwater intrusion events (Nelson and Tolan 2008).

METHODOLOGIES

Site Selection Criteria

Three fixed sampling stations were selected in each stream; one station characteristic of the upper tidal reach, one characteristic of the middle, and one characteristic of the lower tidal reach. Sampling sites were selected from a landscape perspective. TPWD personnel trained in landscape ecology, estuarine ecology and estuarine biology visited the two streams. Sample sites were selected according to vegetation types present. The lower tidal reach station (Station 3) had *Spartina alterniflora* present and the landscape was noticeably flatter. At the middle station (Station 2), the vegetation was dominated by species that are far more brackish-water tolerant. In the upper station (Station 1), vegetation more tolerant of freshwater was present. For example, oak and elm trees were present at Station 1, and the banks of the creek are usually steeper with a much deeper channel than in the middle or lower stations. Locations of sampling sites on the Aransas and Mission Rivers are shown in Figures 3 and 4.

Sampling Methods

Sampling occurred for physicochemical, water chemistry, nekton, benthos, sediment and flow in Aransas River Tidal and Mission River Tidal six times annually for two consecutive years. Replicate seasonal sampling took place twice each in the spring, summer, and fall of 2008. The entire sampling protocol was repeated in 2009, resulting in a total of 12 sampling efforts. Instream and riparian habitat classification and land cover/land use analysis was conducted once during the study.

With few exceptions, biological, flow and physiochemical data were collected concurrently at the same stations within the same calendar week. Stream characteristics dictated minor modifications of the sampling methods for each site.

Documentation of Field Sampling Activities

Field sampling activities are documented on field data sheets. Flow data sheets and multi-probe calibration records are part of the field data record. For all visits, station ID, location, sampling time, sampling date, sampling depth, preservatives added to samples and sample collector's name/signature are recorded. Values for all measured field parameters are also recorded. Detailed observational data are recorded including water appearance, weather, biological activity, stream uses, watershed or instream activities, unusual odors, specific sample information, missing parameters (items that were to have been sampled that day, but weren't), and a qualitative description of flow severity.

Recording Data

All field and laboratory personnel followed the basic rules for recording information as documented below:

1. Legible writing in indelible, waterproof ink with no modifications, write-overs or cross-outs,
2. Correction of errors with a single line followed by an initial and date;
3. Close-outs on incomplete pages with an initialed and dated diagonal line.

Chocolate Swale
Farm-to-Market Road 629
Farm-to-Market Road 1360
Boenig
Rooke
Toland
Levien
Staindorf
Beck
Langridge
Aransas River
Site: 1
28.123012
-97.327268
Site: 2
28.12076
-97.309471
Site: 3
28.101258
-97.285536
Chiltipin Creek
Vega
County Road 90A
County Road 90
County Road 81
County Road 92
County Road 83
County Road 85
County Road 87
N
W
E
S
Refugio
Aransas
San Patricio
Calhoun
Bee
Nueces
0 0.25 0.5 1 1.5 2
Miles
1 inch = 3,000 feet
Legend
Sample Site
Interstate Highway
Roads
County Roads
Other Roads
State Highways
Farm to Market Roads
Private Roads
United States Highways

Figure 4. Fixed sampling locations on the Mission River Tidal.

Landcover Classification

Texas Parks and Wildlife Department is mapping vegetation communities using the classification system developed by Comer et al. (2003) and NatureServe based on Ecological Systems. Ecological systems represent sets of geographically juxtaposed communities that share similar ecological processes, substrates, and/or environmental gradients. Ecological systems may occur at a variety of scales. Ecological systems must be stable for 50 years or more. These non-hierarchical, associations may occur in multiple systems. TPWD is extending the Ecological Systems by creating "Mapping Systems" (Appendix 1), which explicitly recognize variation within the system based on physiognomic variation in the component vegetation, i.e. Post Oak Savannah Live Oak Woodland vs. Post Oak Savannah Post Oak Woodland. Appendix 1 contains detailed descriptions of the Ecological Systems and Mapping Subsystems associated with each Ecological System. Human caused and maintained systems are also described. This document draws from the work of David Diamond and Lee Elliot (2009) and also NatureServe Explorer (2009). The primary advantage for analysis of watersheds is the greater thematic resolution allowing better ecological interpretation of differences in watersheds and the effects on water quality. The Ecological systems Database was created using remote sensing and ecological modeling techniques.

Remote Sensing

TPWD personnel developed a project study area that consisted of those polygons that defined the Aransas and Mission River Watersheds in the United States Geological Survey (USGS) 12 digit Hydrologic Unit Codes (HUC) dataset. Additional HUC's were selected to form a buffer around the watersheds of interest (Figure 5).

TPWD personnel selected multiple date, temporally appropriate LandSat 5 TM images (Table 2). The impervious cover layer developed by the USGS / Multi-resolution Land Cover Consortium for the 2001 National Landcover Dataset (http://www.mrlc.gov/index.php) was acquired. A layer stack was created using Erdas Imagine 9.3 from these data.

Table 2. LandSat Data

LandSat TM Path 26 Row 40 Scene Acquisition Date
January 28, 2007
March 19, 2008
May 17, 2006

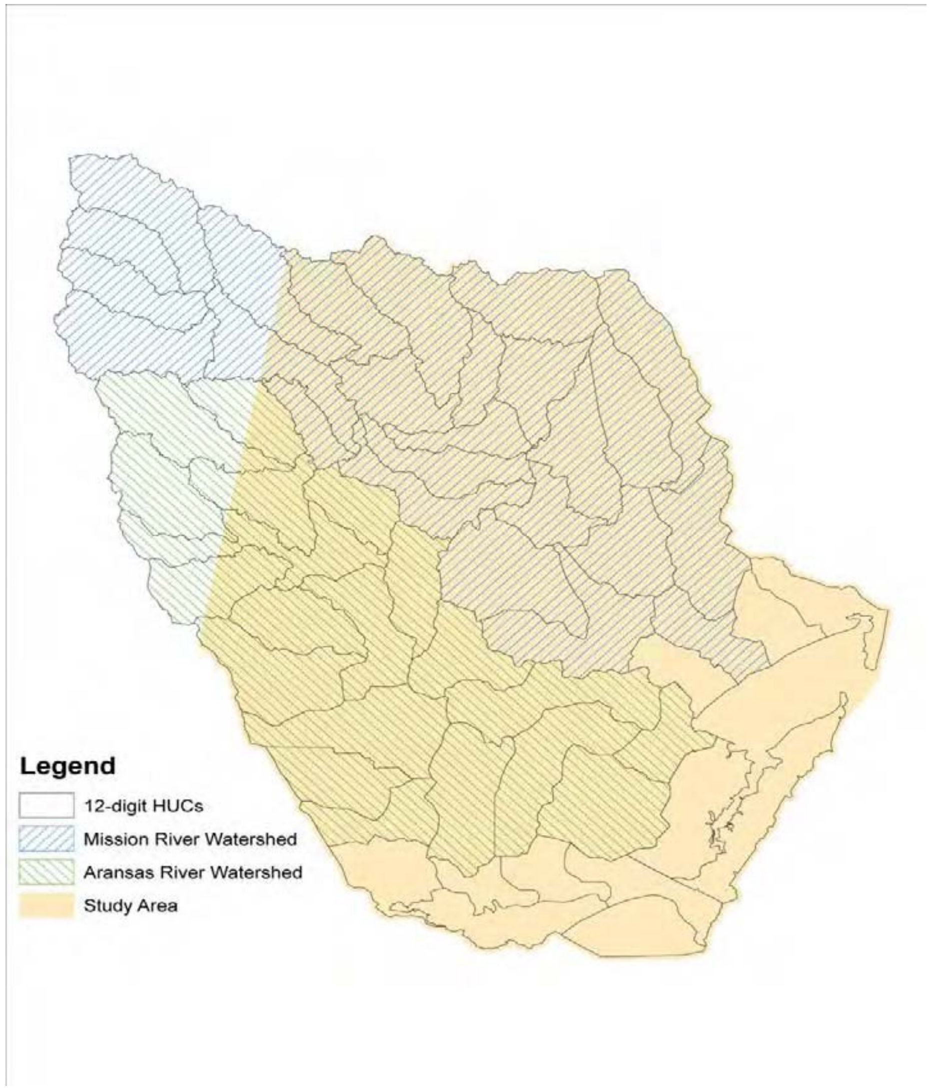


Figure 5. Study area for the Mission and Aransas Tidal Stream Study.

The LandSat TM layer stack was clipped to the study area boundary using the Mask command in Erdas Imagine. National Agricultural Imagery Program 2008 county mosaics were acquired for San Patricio, Aransas, Bee, Goliad, and Refugio Counties. These images were mosaiced to create a seamless high resolution dataset. The 1st principal component was created using the Principal Components command in Erdas Imagine. This data was degraded to 5 meter pixels using the Imagine Degrade command. This high resolution panchromatic layer was then clipped to the study area using the Imagine Mask command. The layer stack and the high resolution panchromatic layer were then merged using the Imagine HPF Resolution Merge command.

Training data was then developed from ground collected samples and photo derived samples for all land cover classes (Table 3). This training data was then used with the Imagine Supervised Classification command to create a landcover data set for the study area (Figure 6).

Ecological Modeling

The landcover data was then used as an input to the modeling process to develop the Mapping Systems Database. Natural Resource Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database was used for the study area. The Ecological Site Descriptions (ESD) developed by NRCS scientists was used along with the landcover data to model the mapping systems. Each Landcover / ESD combination was assigned to a particular Ecological System. USGS National Hydrologic Database 1:24000 data was acquired for the study area. The streams that are not contained within SSURGO floodplain ESD's were selected and buffered to 30 meters width. Each landcover class that intersected this layer was assigned to a riparian Ecological System.

Texas LIDAR elevation data sets for the study area were acquired from the Texas Natural Resources Information System. This data was used to refine the Tidal Marsh Ecological Systems and Saline Prairie Ecological System.

The Common Land Unit (CLU) data from the Farm Service Agency (FSA) was acquired and was used to refine agriculture and tame grass areas. Those lands define as Agricultural lands by the FSA were extracted from the general dataset and were used to develop zonal majority information by use of the Imagine Zonal Attributes command. The majority landcover and percent of pixels that were that value, for each CLU polygon, was calculated.

Table 3. Landcover types used for Habitat descriptors.

Landcover Name	**Description**
Grassland	Gramminoid and other herbaceous vegetation dominated community. Less than 25% woody vegetation canopy coverage.
Saline Prairie	Gramminoid dominated community. Dominated by salt tolerant species such as *Spartina spartina.* Less than 25% woody vegetation canopy coverage.
Grass Farm	Irrigated and fertilized agricultural grassland. Usually dominated by Bermuda grass or St. Augustine turf grasses.
EG Shrubland	Evergreen woody stem vegetation less than 15 feet in height. Usually multi-trunked but may be single trunked. Canopy coverage should be greater than 25% and total % coverage of evergreen species should exceed 75%.
CD Shrubland	Cold deciduous woody stem vegetation less than 15 feet in height. Usually multi-trunked but may be single trunked. Canopy coverage should be greater than 25% and total % coverage of cold-deciduous species should exceed 75%.
Mixed Shrubland	Mix of Evergreen and Cold deciduous woody stem vegetation less than 15 feet in height. Usually multi-trunked but may be single trunked. Canopy coverage should be greater than 25% and total % coverage of either type species should not exceed 75 %.
CD Forest and Woodland	Cold-deciduous tree dominated community with heights in excess of 15 feet. Canopy coverage greater than 25% and total percent coverage of cold-deciduous species greater than 75%.
CEG Forest and Woodland	Coniferous evergreen tree dominated community with heights greater than 15 feet. Canopy coverage greater than 25% and total % coverage of CEG species greater than 75%.
BLEG Forest and Woodland	Broad leaf evergreen tree dominated community with heights greater than 15 feet. Canopy coverage greater than 25% and total % coverage of BLEG (usually live oak) species greater than 75%.
Mixed Forest and Woodland	Mixed tree dominated community with heights greater than 15 feet. Canopy coverage greater than 25% and total % coverage of no species type greater than 75%.

Landcover Name	Description
Regularly Flooded Tidal Marsh	Inter-tidal marsh, semi-permanently or regularly flooded. Salt tolerant species usually predominant. (ex., *Spartina alternaflora* or *Shenoplectus maritimus*)
Irregularly Flooded Tidal Marsh	Inter-tidal marsh, flooded on flood tides only.
Fresh Marsh	Non-tidal marsh community dominated by mostly salt intolerant species.
Shrub Wetland	Tidal or non-tidal wetland communities dominated by woody stemmed species less than 15 feet tall. (ex. Buttonbush or sea-ox-eye daisy)
Swamp	Tidal or non-tidal forest or woodland wetland community. Usually characterized by semi-permanent flooding. (Ex. Bald cypress)
Agriculture	Row crop agricultural fields, to include small grains
Barren	Natural areas of little or no vegetation.
Urban	Urban areas, usually with less than 60% impervious cover. Characterized by suburban residential communities or low density commercial development.
High Intensity Urban	Urban areas, usually with greater than 60% impervious cover. City centers and high density commercial development is common.

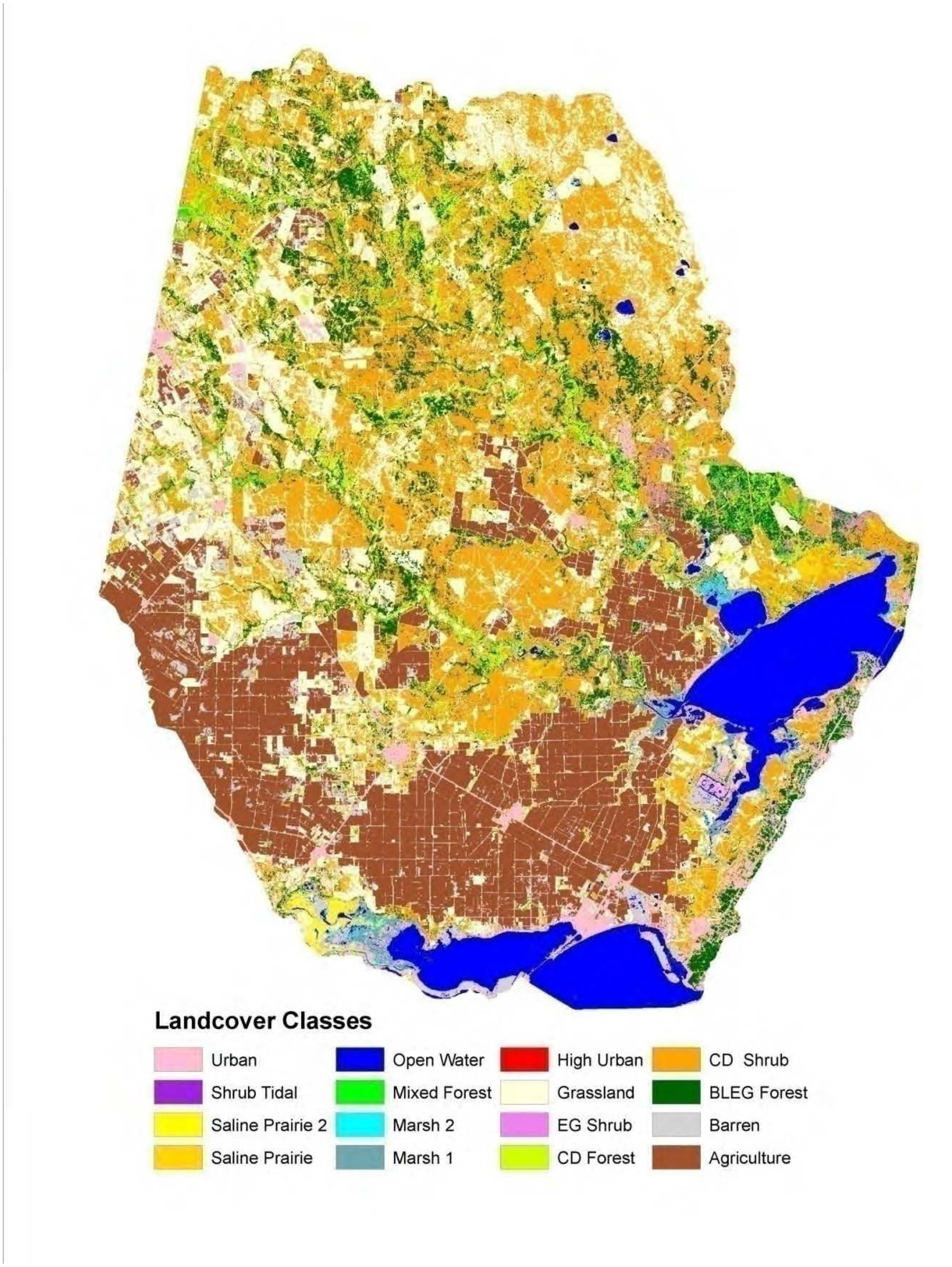


Figure 6. Landcover data within the Mission and Aransas River watersheds.

Ground Data Collection

TPWD personnel collected ground data on land cover, composition, ecological system, and mapped vegetation type using a legend developed via an expert committee. The starting point for the legend was NatureServe's Ecological Systems classification, but this was supplemented with an eye toward mapping all land cover types (see Table 3) within each Ecological System (see Appendix 1) if those cover types existed. In addition, agricultural and other human-related types were included in the legend.

The general data collection procedure included:

1. Sample plots were located either near a road or on accessible public lands. Locations were precise, based on use of a GPS (usually Trimble 232 with +/- 3 meter accuracy) linked to ESRI GIS software on a computer in the field vehicle. Samples were spread across the entire Phase 1 region.
2. Samples along roads were collected at one-mile intervals, often on both sides of the same road, starting from a random location. In addition, samples were collected at most stream/road crossings. Samples on public lands were more accessible and were examined directly on the ground.
3. For data collected along roads, we were limited to views from the right-of-way, aerial photography, and other environmental data layers loaded on the laptop, including county SSURGO soils and the Geological Atlas of Texas. Where trees obscured the view away from the road, we relied primarily on aerial photos and road-side observation to select a sample plot of relatively homogeneous vegetation. All sample plots were located at least 30 meters from the road within a square with sides of at least 50 meters, to reduce possible edge effects on the 30 meter square satellite data.
4. We collected a standardized suite of data using a computerized feature data form (Table 4) with drop-down windows to reduce mistakes, and we took a picture at most site locations.

Table 4. Field Collection Database Schema.

Field Name	Data Type	Example Value(s)	Description
SampleDate	Date	9/21/2007	Date sample taken.
TeamLeader	Text	Duane German	Name of data collection team leader.
SiteID	Integer	291	Unique identifier for sample site.
PictureID	Integer	421	Unique identifier for each sample site photo.
EcoSysName	Text	Edwards Plateau Floodplain Terrace	Name of Ecological System from the map legend (see Appendix 1).
EcoSysConf	Text	High	A categorical value expressing team leader's confidence in correctness of Ecological System identification. Values: High, Good, Medium, Low.
CoverClass	Text	Grassland	Name of the landcover class (see Table 2)
TotWood_PC	Text	0-5	Total percent cover of all woody vegetation – categorical data 0-5, 6-25, 26-50, 51-75, 76-100
BLEG_PC	Text	26-50	Total percent cover of all Broad-leafed Evergreen trees – categorical data 0-5, 6-25, 26-50, 51-75, 76-100 – must be less than or equal to TotWood_PC
NLEG_PC	Text	76-100	Total percent cover of all Needle-leafed Evergreen trees – categorical data 0-5, 6-25, 26-50, 51-75, 76-100 – must be less than or equal to TotWood_PC
Tree_PC	Text	26-50	Total percent cover of all trees – categorical data 0-5, 6-25, 26-50, 51-75, 76-100 – must be less than or equal to TotWood_PC
Shrub_PC	Text	6-25	Total percent cover of all shrubs – categorical data 0-5, 6-25, 26-50, 51-75, 76-100 – must be less than or equal to TotWood_PC
Herb_PC	Text	0-5	Total percent cover of all herbaceous plants – categorical data 0-5, 6-25, 26-50, 51-75, 76-100
Tree1	Text	*Ulmus crassifolia*	Scientific name of **most** visually dominant over-story tree species in plot area. This is a single-trunked perennial woody plant of greater than 5 meters in height. NA if none present.
Tree2	Text	*Carya illinoinensis*	Scientific name of **second most** visually dominant over-story tree species in plot area. This is a single-trunked perennial woody plant of greater than 5 meters in height. NA if none present.

Field Name	Data Type	Example Value(s)	Description
Tree3	Text	*Quercus fusiformis*	Scientific name of **third most** visually dominant over-story tree species in plot area. This is a single-trunked perennial woody plant of greater than 5 meters in height. NA if none present.
Shrub1	Text	*Juniperus ashei*	Scientific name of **most** visually dominant shrub in plot area. Shrub is defined as woody perennial plant, usually multi-trunk, between .5 meters and 5 meters in height. Will contain NA value if no shrubs present in plot.
Shrub2	Text	*Prosopis glandulosa*	Scientific name of **second most** visually dominant shrub in plot area. Shrub is defined as woody perennial plant, usually multi-trunk, between .5 meters and 5 meters in height. Will contain NA value if no shrubs present in plot.
Shrub3	Text	*Sapindus saponaria*	Scientific name of **third most** visually dominant shrub in plot area. Shrub is defined as woody perennial plant, usually multi-trunk, between .5 meters and 5 meters in height. Will contain NA value if no shrubs present in plot.
Herb1	Text	*Cynodon dactylon*	Scientific name of **most** visually dominant herbaceous plant in plot area (1/4 acre). Include woody vines. Will contain bare ground is no herbaceous plants are present.
Herb2	Text	*Bothriochloa laguroides*	Scientific name of **second most** visually dominant herbaceous plant in plot area (1/4 acre). Include woody vines. Will contain NA if bare or only one species present.
Herb3	Text	*Panicum virgatum*	Scientific name of **third most** visually dominant herbaceous plant in plot area (1/4 acre). Include woody vines. Will contain NA if bare or only one species present.

Watershed Analysis

The 12 digit HUC's, that make up the Mission watershed and Aransas watershed, were extracted. This data was used to clip the Ecological Systems that are in each watershed. Summary statistics were developed for each watershed using ESRI ArcGIS Summary command.

Instream and Riparian Habitat Classification

Habitat data were collected in the spring (April 23-24) of 2008. Habitat characteristics were surveyed according to methods outlined in the U. S. Environmental Protection Agency's Environmental Monitoring and Assessment

Program (EMAP) document entitled, “Field Operations and Methods Manual for Non-Wadeable Streams” (Lazorchak et al. 2000) except where noted. Habitat classification was conducted once for each stream (Mission River Tidal and Aransas River Tidal) at 3 sampling reaches per stream. Each sampling reach was sub-sampled at 11 transects (Lazorchak et al. 2000), and the transect locations were recorded using global positioning system (GPS). For a more detailed description of the methodology used to sample each of the following variables refer to Lazorchak et al. (2000). Variables measured included: 1) a thalweg (i.e., maximum depth) profile along the length of each stream sampling reach that included an estimate of bottom substrate type and channel habitat type; 2) an estimate of littoral (i.e., channel bank) depth and substrate type along the margin of the channel at each transect location; 3) an estimate of the coverage of large woody debris in each channel reach; 4) a measurement of channel physical characteristics which included channel wetted width, presence of bars or islands and their width if present, bankfull width, bankfull height , channel incised height, and bank angle/degree of bank undercutting; 5) an estimate of canopy cover along channel banks using a densiometer; 6) another measure of riparian vegetative structure involving separate visual estimates of canopy, understory and groundcover vegetation; 7) an estimate of fish cover and aquatic vegetation within the channel; and 8) an estimate of the degree of human influence in the immediate sampling area around transects. The portions of the EMAP methodology pertaining to “legacy trees”, invasive/alien plant species, and measurement of channel sinuosity were not included in this study. However, channel sinuosity was estimated using geographical information system analysis. The length of each stream reach was found along the channel of stream “as the fish swims”. Then the straight line distance from start of reach to end of reach was found “as the crow flies”. Then the channel length was divided by the straight length. The larger the number was the more sinuous the stream (Kaufmann et al 1999). Densiometer measurements were taken following the manufacturer’s instructions rather than the method suggested by Lazorchak et al. (2000). Measurements of channel margin depth and substrate type were estimated using a graduated polyvinyl chloride (PVC) pole along banks. Because coastal streams have a very low gradient, channel slope as discussed in Lazorchak et al. (2000) was not measured. The presence of power lines was also added to the portion of the method measuring human influence. All data presented are means and standard deviations.

Instream Flow Characterization

Texas Water Development Board (TWDB) staff assisted in initial site selection collected supporting hydrographic data, and analyzed flow data. TWDB performed basic analysis of this data, including summary discharge and velocity data, as well as results of analyses conducted to separate tidal and non-tidal (residual) components of stream flow velocity. Appendix 2**.**

TPWD collected data at 3 monitoring stations, an upper station, a middle station and a lower station. The monitoring stations are referred to as M1, M2 and M3 for the Mission River and as A1, A2 and A3 for the Aransas River with M1 and A1 being the most upstream sites and M3 and A3 being the most downstream sites for each of the rivers. For the flow analysis however, only the middle stations, M2 and A2, were studied. Figure 6 shows the locations of the TPWD monitoring stations along with other long term flow monitoring stations that were used. SonTek's bottom-mounted up-looking Argonaut XR Acoustic Doppler Velocimeter (ADV) (1500 kHz and 3000 kHz) was deployed at the middle stations (M2 and A2; Figure 7) in each of the two streams to measure flow velocity and direction for at least 24 hours (in order to record flow over an entire tidal cycle) during each sampling trip. The Argonaut XR was deployed on the bottom in the middle of the stream. This instrument averaged and recorded measurements in water velocity, direction and water height over 5-minute intervals.

Following the USGS basic stream flow protocol for collecting flow data with boat-mounted Acoustic Doppler Current Profiler (ADCP) (Norris 2001), TWDB recorded instantaneous measurements of discharge for a total of six sampling events on the two streams for the June 23, 2009 sampling event (Appendix 2). Discharge measurements at stations D-M4 and D-A2 (Figures 8 and 9) were done at/very close to the ADV deployment stations, i.e. M2 and A2, and at the same time of the ADV deployments. These data were used to relate the average velocity data collected by the ADCP to the discharge measurements. Three more discharge measurements were made in Mission River at various locations upstream of D-M4 (Figure 8). Two of these measurements, D-M2 and D-M3 were set up within 20 minutes of each other, directly upstream and downstream of a tributary in order to investigate inflow from/diversion into this tributary. The third transect in Mission River, D-M1, was located 10 river miles upstream of M2 and discharge data from this station was used in this analysis to study changes in the flow regime along the stream. There was one more discharge measurement site in Aransas River, in addition to the transects near A2 (Figure 9). Each of the discharge sampling events lasted for 17 – 22 minutes.

Stream flow data were collected using acoustic Doppler technology, which measures water motion by transmitting sound through the water column at a fixed frequency and then measuring the Doppler-shifted echoes. The echoes are influenced by backscatter from scatterers (plankton and sediment) in the water and are converted to along beam (acoustic) velocity components.

The RiverCat system in addition is equipped with compass/tilt sensor and bottom-tracking circuitry to enable calculation of stream discharge. Documents on appropriate techniques for use and analyses of ADP collected data have been made available from the U.S. Geological Survey (USGS) testing and open file

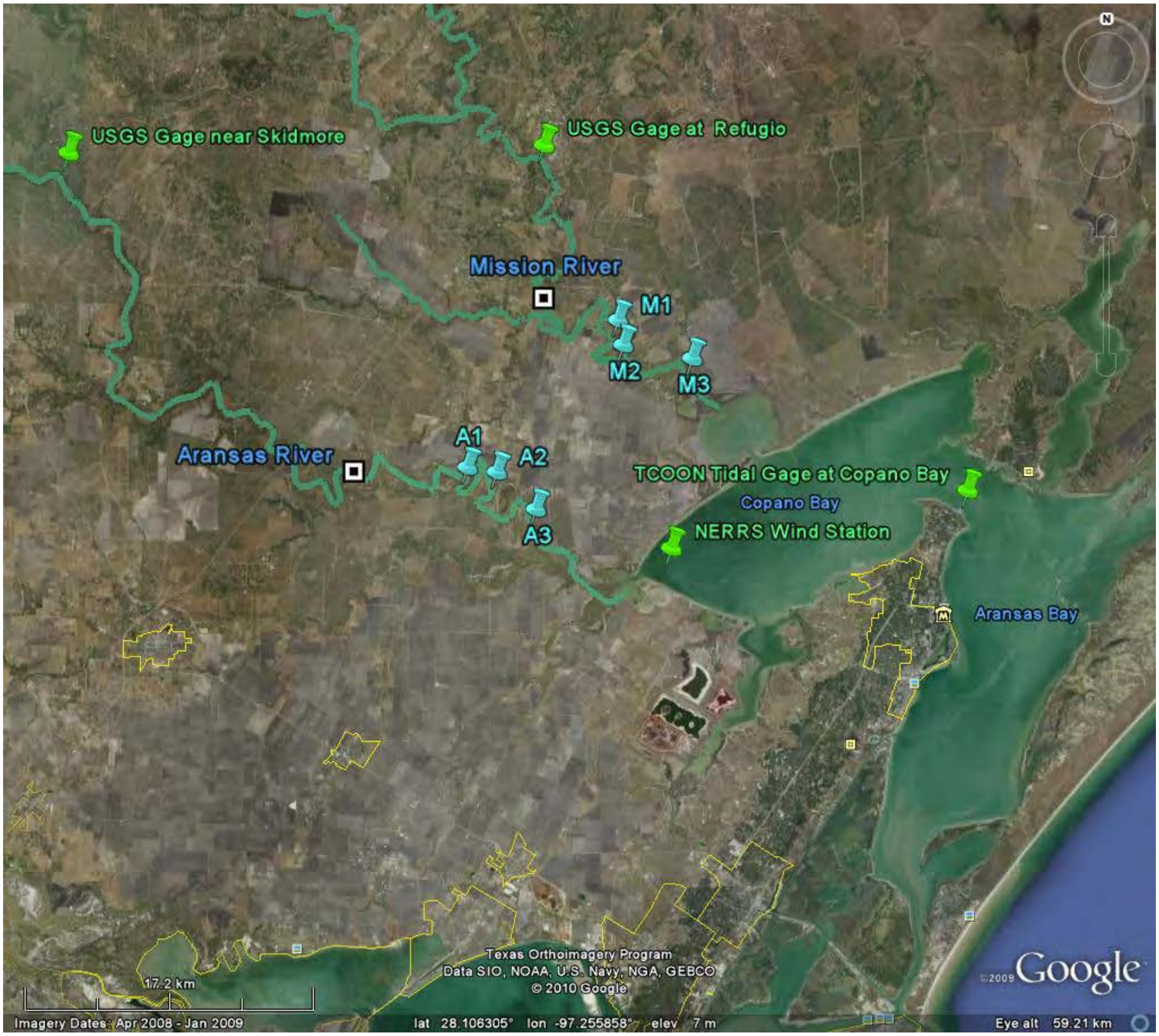


Figure 7. Monitoring Station Locations in the Mission and Aransas River study area..

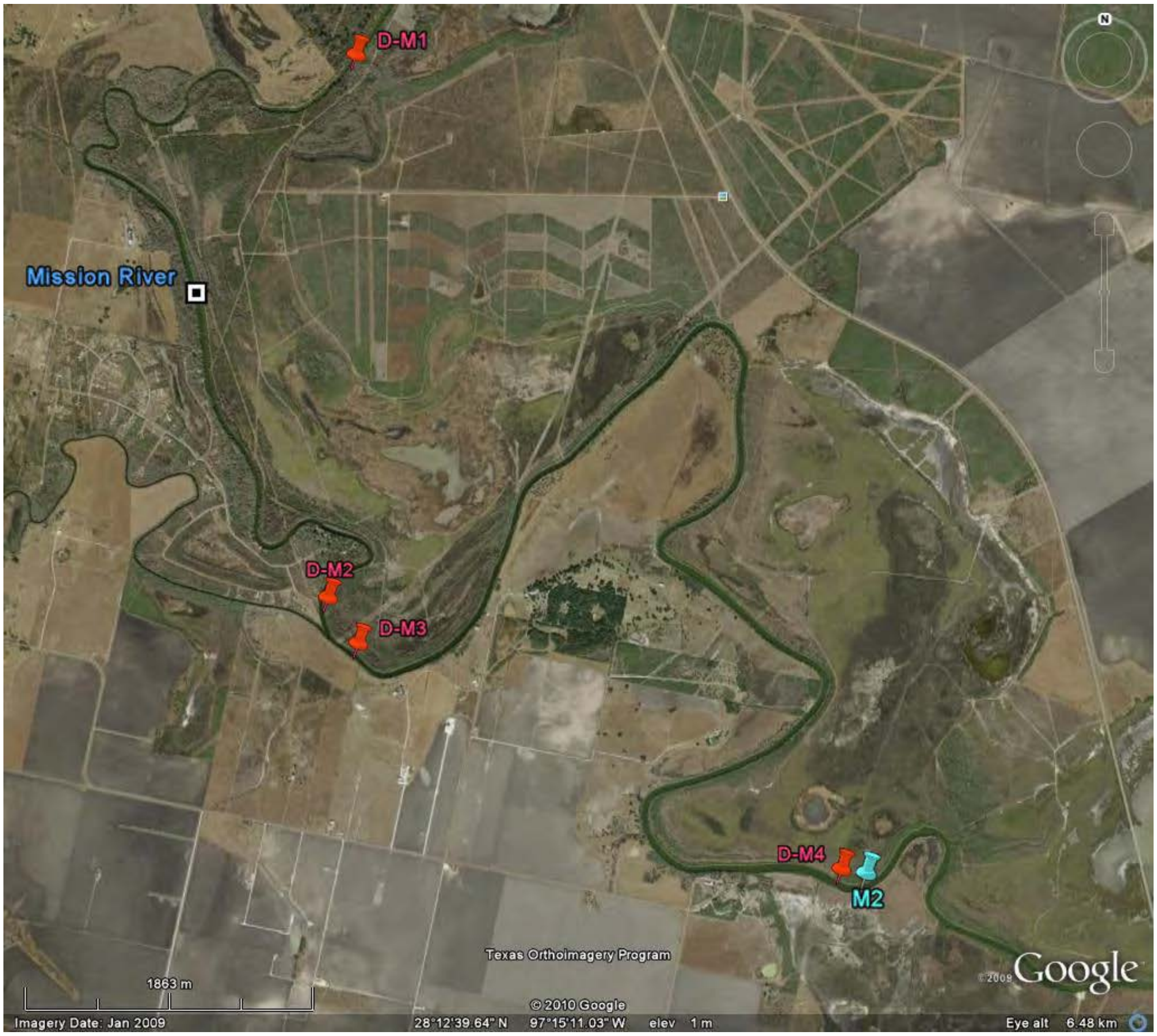


Figure 8. Velocity measurement station (M2) and discharge measurement stations on the Mission River.

Figure 9. Velocity measurement station (A2) and discharge measurement stations on the Aransas River.

reports (e.g., Rantz et al. 1982, Morlock 1996, Norris 2001, Morlock and Fisher 2002). Since different companies have different nomenclature for these instruments and since the same instruments can be used in both roles, we refer to the boat-mounted current profilers as ADCP and the stationary up-looking velocimeters as ADV.

The objectives of the velocity data analysis were the extraction of the tidal and residual components of the current velocity, examination of directionality of flow and the determination of statistical characteristics of the data. The stream discharge data was used to examine spatial variations in flow and also to construct a simple velocity-discharge rating curve for the velocity dataset. Stream discharge and velocity data were collected using acoustic Doppler technology.

Measurement of Stream Discharge

When performing water-current surveys covering large areas, or when monitoring river discharge, it is often convenient to use a boat-mounted system. When operating from a moving platform, an ADCP measures relative currents. As such, it is important to measure independently the speed of the platform so that it can be subtracted from the instrument's measure of raw current. This procedure then establishes residual water currents relative to the fixed Earth. It is generally desirable to perform these calculations in real-time (SonTek 2005a). This usually is done either by the ADCP tracking the river bed (bottom-tracking) or by using differential GPS. Both techniques require driving the platform or boat along transects across an area of interest, during which time, velocities are measured in 'depth bins'. Depth and width of each depth bins are also measured during the transect and instantaneous discharge across the 'measured' cross-section is given as the sum of the calculated discharges in each bin. Hence, this technique can obtain very accurate instantaneous flow discharge measurements over a large area.

The USGS protocol recommends performing four transects in close succession at a site to establish accuracy of the stream discharge measurements. For typical streams under steady-flow conditions, the USGS expects replicate measurements of total discharge to differ by no more than 5% (Norris 2001). Expectations for this kind of agreement are unrealistic for tidal streams. Within a tidal stream segment, there is continual variation in the forces acting on stream waters. This complicates the implicit assumption that the four transects replicate flow. In tidal waters, the USGS therefore suggests reducing the time variant element in estimates of flow by using individual transects as representative measures of discharge (Norris 2001). This is in contrast to their recommendation to conduct more than four transects in turbulent water, but recognizes the difficulty of measuring discharge under rapidly changing conditions. Clearly, there is no standard methodology for tidal streams, but by conducting four or more transects the range of variability can be documented for future use in determining an appropriate methodology. For each site and sampling event, ADCP transects were summarized and compared on the basis of total discharge. Total discharge is a function of the instantaneous discharge measured by the instrument and a volume transport estimated in the cross-sectional areas where the instrument cannot record data.

ADCPs and ADVs cannot measure flow across the entire width of the channel. The acoustic Doppler technology and methods of deployment prevent measuring flow near the surface and bottom layer, as well as any portion of the channel too shallow for boat access such as portions near the banks. These non-measured areas must therefore be estimated. Discharge in the surface and bottom layers is estimated according to a power equation by the ADCP software. Discharge along the stream edges also is estimated according to an equation that the user selects based on the expected angle (steep or shallow) of the bank. In this equation, the distance between the last good measurement and the edge of the bank is necessary to accurately estimate flow along the non-measured edges. In large channels and rivers, the non-measured portion of the channel may be very small. For small streams and shallow bayous, the non-measured portion may be relatively large compared to the area directly measured. For comparison among the streams in this study, this is not likely to be a problem; however, the difference between measured and estimated discharge is documented. The selection of an ADCP with the appropriate frequency of operation is important in minimizing the area in front of the transducer commonly known as the blanking distance, where no measurements can be made. In shallow depth waters, use of high frequency ADCPs(3.0 MHz) gives sufficient depth of measurement (up to 6m) while providing a minimum blanking distance of 0.6m.

Measurement of Stream Velocity

Time-series data is invaluable when investigating flow regimes affected by tidal currents and freshwater inflow, such as in these tidally influenced study streams. ADVs represent flow by averaging velocity across the water column from surface to bottom. They are usually either mounted on river beds looking upward or submerged at one edge of the river looking sideways. These instruments measure a cone-shaped segment of the water column over a user defined start and end distance. The cone is divided into ‘bins’ with each bin representing a velocity measurement at a specific distance from the transducer. These measurements are then averaged to obtain the current velocity. Since ADVs can be installed for extended periods of time, they are useful for obtaining flow history at a site.

The Doppler technology employed by the ADV instruments is reliable for low flow situations, as is found in many coastal streams, because there is no minimum velocity detection level (SonTek 2005b). However as with any technique, there are concerns for establishing the accuracy and reliability of the data. ADVs, being essentially identical to ADCPs, are also prone to the blanking distance drawback. This depth may be a large part of the water depth in shallow streams over which the velocity will not be measured hence reducing the reliability of measurements. Another drawback of these instruments is that based on the river profile and size there may be significant parts of the water column that are not captured by the cone of measurement. Although velocity measurements given by the ADV may be reliable, measures of stream discharge may be inaccurate for this reason, though reliable estimates can be obtained by applying the ADV velocity data to a discharge rating curve generated by ADCP data. Rating curves are determined from measures of stream discharge collected by an ADCP for various flow regimes (section 2.2 has more on rating curve computation). The USGS uses this technique for their stream gage program. Additionally, the USGS has established a considerable body of literature documenting and testing appropriate practices for using ADVs and analyzing associated data (e.g., Lipscomb 1995, Norris 2001). However, much of the literature concerns non-tidally influenced streams and it is not known how well these procedures work in tidal streams.

Velocity Data Analysis

The raw velocity data for each of the ADV deployments were saved in binary files (.arg) for processing using SonTek's ViewArgonaut software. ViewArgonaut's data filtering and screening features were implemented on the files to remove high frequency noises and bad data when deemed necessary. To conduct more extensive statistical and graphical analysis using external scripts, these files were batch-exported as spaced delimited text files from ViewArgonaut. Some of the deployments were set up in XYZ coordinate system where the velocity components along each axis of the instrument's Cartesian coordinate system were measured while in others the East North Up (ENU) coordinate system was used and time series of the velocity components in the true North, East and Up direction are reported in the binary files. To maintain consistency and simplify the velocity computations, all measurements conducted with XYZ coordinates were converted to ENU system within ViewArgonaut before they were exported for processing. This process doesn't change the original files.
To calculate the magnitude of the resultant velocity (speed of flow), the river flow was assumed to have no lateral and vertical components in both study sites since the preliminary investigation of the velocity data showed laminar one-dimensional flow. The river velocity was then computed from the velocities along the true east and north as:

$$X = \pm\sqrt{E^2 + N^2} \qquad \textbf{(eq. 1)}$$

Equation 1. River velocity computation.

The direction of flow (upstream versus downstream) was determined from the sign of the east/north components of the velocity. Since the channels at the sampling stations were oriented in the south east and east direction (Figure 10), negative east velocity indicates upstream flow. Python scripts were developed to do the above velocity computations and other analysis of the velocity data in an efficient manner. To avoid bias in our statistical analysis, velocity data that included full tidal cycles were used in the computations

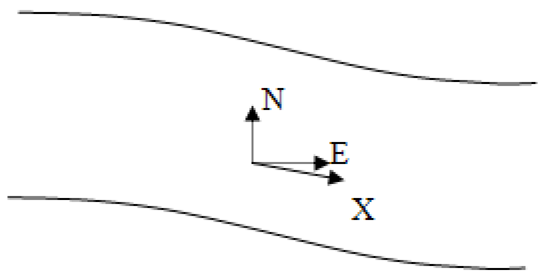


Figure 10. Resultant Velocity Calculation Diagram.

where:

E is the velocity component along true East

N is the velocity component along true North

X is the velocity in the direction of flow.

Upstream flow is negative, downstream flow is positive.

Discharge Analysis

Processing of discharge data collected using ADCPs was done using SonTek's RiverSurveyor software. The RiverSurveyor software has graphical interfaces for displaying color contours of bin velocities for the entire measurement cross-section, depth averaged velocity profile along the transect path, as well as tabular summary of discharge, velocity and cross-sectional areas of flow for multiple transects. This software makes it easy to investigate velocity profiles and presence of bi-directional flows. Moreover, faulty measurements can be identified and diagnosed quickly.

When ADCPs are set up at one location on the channel, they measure the depth averaged velocity for a small portion of the river channel. This may not give an accurate estimation of the river discharge in wide streams due to the velocity variation across the channel. Hence, boat mounted ADCPs are used to measure river discharge across a stream. However this is a costly procedure compared to deploying stationary ADVs. Hence regression equations for estimating discharge from velocity measurements are developed from concurrent velocity and discharge measurements under varying flow conditions. This method is cost-efficient and can give good discharge estimates. In the Mission-Aransas study, 8-11 continuous ADCP transects each lasting approximately 20 minutes were taken in conjunction with the June 23, 2009 ADV deployments at the middle stations in both Mission and Aransas rivers.

The discharge rating curve was based on the total discharge (QTot) which is the sum of the discharge measured by the ADCP (QM) and estimated discharge near the banks (QL and QR for the left and right banks) as well as near the surface and bottom (QT and QB for the near surface and bottom estimates) of the channel where the ADCP doesn't not take measurements (Equation 2).

$$Q_{Tot} = Q_M + (Q_L + Q_R + Q_T + Q_B) \qquad \textbf{(eq. 2)}$$

Equation 2. Discharge rating curve.

The power fit with the default exponent of 1/6 was used for extrapolating the vertical velocity profile in the unmeasured top and bottom portions. The sloped bank option was selected in the software for calculating the discharge volume near the banks. The software computes the discharge volume near the banks as a product of the last velocity measurement near the bank and the cross-section of flow (area of the triangle between the edge of the bank and last velocity profile measurement in the case of sloped banks). Normally, multiple measurements taken during different stream flow conditions are required to develop discharge rating curves. However in this study, due to the presence of only a single discharge sample for each site, a linear regression (Equation 3) with zero intercepts was assumed. Moreover, the performance of this regression equation in predicting discharge could not be evaluated due to the lack of multiple discharge measurements.

The linear regression equation normally used for developing the rating curve for tidal streams (Dunn et al., 1997) is:

$$Q = B_1 + B_2V + B_3S \qquad \textbf{(eq. 3)}$$

Equation 3. Linear regression for developing rating curve.

where Q is the estimated discharge in cubic meters per second, B1, B2, and B3 are the regression coefficients, V is the measured velocity in meters per second, and S is the measured stage in meters above (+) or below (-) the mean stage measured during the hydrographic survey.

The coefficients B1 and B3 are assumed to be zero as more than one coinciding discharge and velocity measurements are required to estimate them. The coefficient B2 is computed as:

$$B2 = Q_{av}/V_{av} \qquad \textbf{(eq. 4)}$$

Equation 4. Computation of coefficient B2.

where Q_{av} is the average of the eight discharge measurements and V_{av} is the time averaged velocity over the 20 minutes when the ADCP transects were made. The procedures for computing the regression coefficients for the two streams are shown in Appendix 2.

Tidal Analysis and Estimation of Residual Velocity and Discharge

The non-tidal flow velocity components associated with freshwater water flow and wind driven currents were extracted using a script that implemented the Doodson X0 low pass filter (Doodson 1928). Because this filter needs at least 39 hours of hourly data, only velocity datasets that were 60+ hours long were filtered using this technique to extract non-tidal (residual) components for at least one tidal cycle (24.8 hrs) and the datasets were averaged to hourly frequency beforehand. Once the residual components were extracted with the filter, the tidal components of flow velocity and the estimated residual discharge used in this analysis were calculated as:

$$V_{Tid} = V_T - V_R \qquad \textbf{(eq. 5)}$$

Equation 5. Tidal components of flow velocity.

$$Q_{est} = A.B2.V_R \qquad \textbf{(eq.6)}$$

Equation 6. Estimated residual discharge.

where VTid and VR are the tidal and non-tidal components of the flow velocity (VT), A is the cross-sectional area of flow, B2 is the regression coefficient calculated in equation 4, and Qest is the estimated residual discharge.

Water Quality

Physiochemical Profiles

Field physiochemical data profiles were measured using instantaneous water quality reading instruments calibrated to the manufacturers' specifications. Data were recorded approximately approximately 0.3 m below the surface and 0.3 m above the bottom at each station. If stations were sufficiently deep, a mid-depth sample was taken halfway between the surface and bottom measurements. Secchi depth was also recorded.

Short-Term 24-hour Deployments

Multiparameter logging sondes were deployed at each sampling station on each study stream. Temperature, dissolved oxygen, salinity, and pH (when sondes were equipped with a pH probe) were logged every half-hour for 24 hours. The sondes were deployed with the sensors approximately 0.3 m below the water surface. Calibration records were retained for each deployment.

Water and Sediment Samples

Water and sediment samples were collected for laboratory analysis of the parameters presented in Table 5. Lower Colorado River Authority (LCRA) provided disposable sample containers that are purchased pre-cleaned for conventional parameters and glass containers for sediment samples that are used for sampling performed by TPWD. Certificates are maintained in a notebook by the LCRA.

Field Sampling Procedures

The Texas Parks & Wildlife Department followed the field sampling procedures documented in the TCEQ *Surface Water Quality Monitoring Procedures Volume 1: Physical and Chemical Monitoring Methods for Water, Sediment and Tissue, 2003 (RG-415)* and *Volume 2: Methods for Collecting and Analyzing Biological Community and Habitat Data, 2005 (RG-416)* unless otherwise noted. Procedures for biological, Land use/ Land cover analysis and habitat sampling are outlined in the work plan and attached documents.

More detailed documentation on sample handling and custody, analytical methods, instrument/equipment testing and inspecting, maintenance, and quality control measures used for the water and sediment samples collected for this project can be found in TPWD (2008).

Biological Sampling

Nekton Collections

Nekton collections were made by bag seines and otter trawls. Catch per unit effort (CPUE) for seining was recorded as the total number of individuals per linear foot seined at each site. CPUE for trawling was the total number of individuals collected per hour of trawling. All nekton collected were identified in the field, enumerated, and measured to the nearest millimeter. Nekton that could not be identified in the field were preserved on ice or in formalin and transported to the laboratory for identification. Voucher specimens of each species were retained in 10% formalin. Voucher specimens too large to fit in a five-gallon bucket were photographed for verification of identification. Vouchers are currently stored at TPWD facilities in Corpus Christi, until a final review of the report for each tidal stream. After completion of each report, all vouchers will be archived in the Natural History Collection of the Texas Memorial Museum in Austin, Texas.

Table 5. Field sampling and handling procedures for water and sediment samples.

Parameter	Matrix	Container	Preservation	Sample Volume	Holding Time
TSS/VSS	Water	high density polyethylene	<6º C, dark	200 mL	7 days
TDS	Water	high density polyethylene	<6º C, dark	100 mL	7 days
Chloride	Water	high density polyethylene	<6º C, dark	100 mL	28 days
Sulfate	Water	high density polyethylene	<6º C, dark	100 mL	28 days
Total Phosphorus	Water	high density polyethylene	<6º C, dark, pH<2 with H_2SO_4	100 mL	28 days
Total Kjeldahl Nitrogen	Water	high density polyethylene	<6º C, dark, pH<2 with H_2SO_4	100 mL	28 days
Nitrite+Nitrate Nitrogen	Water	high density polyethylene	<6º C, dark	200 mL	48 hours
Ammonia-Nitrogen	Water	high density polyethylene	<6º C, dark, pH<2 with H_2SO_4	100 mL	28 days
Ortho-Phosphorus	Water	high density polyethylene	<6º C, dark	100 mL	48 hours
$CBOD_5$	Water	high density polyethylene	<6º C, dark	1000 ml	48 hours
TOC	Sediment	Glass	<6º C,	500 g	14 days
Grain Size	Sediment	Glass	<6º C,	500 g	14 days
Percent Solids	Sediment	Glass	<6º C,	500 g	14 days

Seines

The 30-foot seine was 8 feet deep using a 3/16 inch delta material with double floats and double lead weights. An effective seine haul was one that was not affected by hang-ups or lifting the net off the bottom. Because of a narrow shelf and a steep channel profile on the side of many of the sampling stations, many areas were too deep to wade the deep end of the seine. In that case, one end of the seine was walked or held against the bank and the seine was deployed perpendicular to the shore with the boat then maneuvered back in an arc to shore with the boat. At each sampling location, seine pulls were repeated until a linear distance of 125 feet of shoreline had been covered.

Trawls

For trawl collections, a 10-ft otter trawl was used. Trawling was conducted for three five-minute intervals (not covering the same area) at constant engine speed of 1300 revolutions per minute (RPM) or approximately 3 mph. There were problems with snagging woody debris throughout the study. Flooding conditions frequently created new woody debris snags at stations. If the trawl duration lasted at least three minutes before becoming entangled, it was considered an adequate effort. If trawl sampling duration was less than three minutes and it became snagged, the contents of the trawl were released, no data were recorded, and the trawl was repeated. In rare situations, trawls were snagged repeatedly at a station, and the effort was ended with no data recorded for that station.

Sediment and Benthic Macroinvertebrate/Infaunal Collections

At each station, benthic organisms were collected from the mid-channel area using a Petite Ponar. The Petite Ponar measured 6 inches long by 6 inches wide by 6 inches deep, yielding an approximate sample volume of 216 cubic inches. If the sample was retrieved with the jaws of the Ponar not completely closed or the sampler was not completely full, the sample was discarded and the grab was repeated. Three replicate samples were collected. Each replicate was individually labeled and processed separately. Whole collections were first placed in a 500-micron mesh bag, field-washed to remove the majority of the sediment, and preserved in 10% buffered formalin with Rose Bengal. Benthic infaunal community samples were delivered to the Center for Coastal Studies at Texas A & M University Corpus Christi (TAMU-CC) for identification and enumeration. Sediment samples were collected with the same gear as the benthic infaunal communities and analyzed for grain size, total organic carbon, and percent solids.

Quality Control

Sampling done as part of this study followed quality control (QC) requirements as outlined in the TCEQ Surface Water Quality Monitoring Procedures Manual. See the Quality Assurance Project Plan (TPWD 2008) for details of field and laboratory quality assurance and quality control procedures.

For the water chemistry samples, field splits were collected. One QC sample was obtained every ten water chemistry samples or portions thereof. Precision of duplicate and split results were analyzed. If precision for a parameter was outside of the acceptable range, results for that parameter were flagged for further investigation. Individual sample results were examined for discrepancies to determine if the data should be discarded. No results were discarded based on comparison of duplicates and splits.

Equipment blanks were collected once per trip for each type of equipment (bucket, Niskin bottle, etc.) that was used to collect a water sample. No equipment contamination was observed during the study.

Prior to deployment, multiparameter datasondes were calibrated according to manufacturers' instructions. Diurnal water quality measurements were logged electronically and later downloaded to computers. Instruments were post-calibrated and post-calibration records were checked for each deployment to verify that instruments did not exceed the criteria required by TCEQ (page 9-11 of the TCEQ Surface Water Quality Monitoring Procedures). Data for a given parameter were discarded when post-calibration did not meet acceptable limits for that parameter. Other QA/QC activities included verifying that data were reported in the correct units.

Original field data sheets are maintained in the TPWD Austin office under the supervision of the Project Manager. Copies of the data sheets were provided to the Data Manager, QA Officer and data entry personnel. Laboratory data were provided electronically to the Data Manager and in hard copy to the QA Officer. A Microsoft Access database was created to manage the data. Field data were entered manually and laboratory and datasonde data were uploaded. Electronic files are stored on the TPWD network. All data is backed up on network drives and on compact disk.

Quality checks were made on all data that was keyed into electronic format. Internal checks were run to ensure consistency between TCEQ laboratory data labeling and TPWD sample identification and to verify that data could be retrieved and that units were appropriate. Hard copies of all field data, QA/QC checklists and quarterly reports are kept on file at the TPWD office (Coastal Fisheries Division) at 4200 Smith School Rd, Austin, Texas 78744. All documents will be kept for 5 years as stipulated by the TCEQ.

Analysis Techniques

The major purpose of this study was to collect the information necessary to further the development of an assessment method that can be applied to tidally influenced streams. Assessment methods which have been utilized for inland surface waters as well as estuarine and coastal marine waters have historically been based on establishing biological criteria which measure the ecological health and diversity of the biological communities characteristic of these water bodies. These biological criteria can serve as guidelines or benchmarks adopted by regulatory agencies to evaluate the integrity of surface waters. Coupled with the traditional physical and chemical criteria used by the EPA and TCEQ to establish the beneficial use classifications of surface waters, the integration of the biological assessment provides for a more holistic approach to the protection and management of aquatic ecosystems. Currently, no established methodology exists for assessing the biological integrity of tidally influenced streams in Texas.

Bioassessment, coupled with habitat assessment, helps to identify probable causes of impairment that may not be detected by the more traditional physical and chemical water quality analyses alone. The detection of water resource impairment, accomplished by comparing biological assessment results to the biological criteria, leads to more definitive chemical testing and focused investigations which should reveal the cause of the degradation (Gibson et al. 2000). This in turn should lead to an evaluation of the source of the impacts (either point source or non-point source) and a determination of the effectiveness of any control measures recommended for these sources (i.e., the application of the Total Maximum Daily Load process).

A central principle of a biological assessment is the comparison of a water body to a biological criterion, based in part, on a reference condition (Gibson et al. 2000). Because absolutely pristine tidal river segments do not exist along the coast of Texas, comparisons must be made with the understanding that reference segments exist with some minimal level of acceptable impacts. In their technical guidance document that establishes the protocols for establishing biocriteria, Gibson et al. (2000) recognize that reference conditions need to be established in a variety of ways. They should include information derived from various sources:

> **Historical Data** are usually available that describes biological conditions in the region over some period of time in the past. Careful review and evaluation of these data provide insight about the communities that once existed and/or that may be reestablished. Review of the literature and existing data is an important initial phase in the biocriteria development process. However, if data have not been collected for this specific purpose, they need to be carefully reviewed before being applied,
>
> **Reference Sites** are minimally impaired locations in the same or similar water bodies and habitat types at which data are collected for comparison with test

sites. Reference sites could include sites that are away from point source or concentrated nonpoint loadings; sites occurring along impact gradients (nearfield/farfield); and regional reference sites that may be applied to a variety of test sites in a given area,

Expert Opinion/Consensus A consensus of qualified experts is always needed for establishing the reference condition; and helping develop the biocriteria. This is especially the case in impaired locales where no candidate reference sites are acceptable and models are deemed unreliable. In these cases, expert consensus is a workable alternative used to establish reference “expectations”. Under such circumstances, the reference condition may be defined using a consensus of expert opinion based on sound biological principles acceptable to the region of interest. The procedures for these determinations and decisions should be well documented for the record.

Because each tidal stream station under investigation was characterized with respect to its potential for saltwater intrusion (e.g., upper, middle, and lower stations), site-specific reference conditions were also chosen to represent the upper, middle, and lower reaches, and these were paired with the corresponding test sites for all comparative purposes. For the current Mission-Aransas Tidal Stream study, neither stream was designated *a priori* as the reference stream, but rather, comparisons of the components of ecosystem health between these two streams were investigated for overall statistical differences (see Statistical Tests). Then, in a broader context of spatial applicability of any derived biocriteria, the components of ecosystem health from the Mission and Aransas Rivers were evaluated against other tidal systems where similar physical, chemical, and biological datasets were available.

Owing to a general lack of available historical data, coupled with the absence of any established protocol for determining biological integrity in tidally influenced coastal segments, the initial task before the project team is to determine whether any statistical differences can be found between the reference streams and the study streams. Separate comparisons of the mid-coast and upper-coast impacted vs. reference streams will involve either parametric or non-parametric tests. The null hypothesis in all tests will be whether water quality or any other attainment indicator (e.g., biocriteria) at the study sites is significantly different from the conditions at the reference sites. The following techniques (or any combination that is identified through the Expert Opinion/Consensus criteria) will be used in the development of a Tidal Stream Site-Specific Use and Criteria Methodology:

Statistical Evaluations

Historically, many of the derived parameters (metrics) used in developing specific biocriteria can be classified as non-parametric community measures or indices, drawn from dynamic assessments of the fish, invertebrate, macrophyte, and planktonic assemblages that make up a biological community (Karr et al. 1986;

Engle et al. 1994; Deegan et al. 1997; Allen and Smith 2000). These dimensionless indices are used to summarize a series of diverse community measures into one or more quantitative variables. Indices are used to reveal much of the underlying information inherent in the vast amount of raw data a biological assessment generates. In this realm of data reduction, indices are much akin to the principal components and canonical correlations tests. Indices are most often used to describe measures of community composition such as species abundance, diversity, evenness, richness, and dominance, or conditions such as incidence of disease, malformation, and parasite load, or distribution of year classes and age structure (Table 6).

Principal components is parametric-based test used to reduce number of variables (WQ parameters, habitat variables, physiochemical parameters, etc.) down to a manageable subset that explains the greatest amount of total variation. A limitation posed by the sampling design is the large number of variables relative to the limited number of "replicates" or observations. Ideally, a five-to-one dependent variable-to-independent variable ratio (i.e., dependent variables to observations) is optimal to satisfy the assumptions of many multivariate parametric procedures (Johnson and Wichern 1992).

Increasing levels of environmental stress have historically been considered to decrease overall diversity, decrease species richness, and decrease evenness (or conversely increase the dominance of a few species) (Clarke and Warwick 2001). This oversimplified interpretation of the effects of "stress" may, however, not be observed. Recent theories on the influence of disturbance or stress on diversity have suggested that in situations where disturbance is minimal, species diversity can be reduced due to competitive exclusion (Paine 1966; Connell 1978; Huston 1979; Dial and Roughgarden 1998; Payton et al. 2002). These works show that at slightly increased levels or frequencies of disturbance, competition is relaxed and an overall increase in diversity results. At even higher or more frequent levels of disturbance, species start to become eliminated by stress, so that overall diversity falls off. Thus it is at some intermediate level of disturbance that diversity is highest.

Depending on the starting point of the community under investigation, in relation to any existing stress levels, increasing levels of stress (e.g., induced by pollution), may either result in an increase or a decrease in diversity (Clarke and Warwick 2001). It is therefore difficult, if not impossible, to determine where a particular tidal stream community under investigation may fall along this continuum, or what value of diversity (or any other metric utilized to describe a specific biocriterion) would be expected if the community were not subjected to any anthropogenic stresses. Therefore, changes in diversity can only be assessed by comparisons between stations along a spatial contamination gradient or with historical data (Clarke and Warwick 2001). This conceptual framework was central to the site selection criteria outlined earlier. With a

Table 6. Potential metrics for biological communities that could be considered for tidally influenced streams. Reprinted in part from Gibson et al. (2000); Table 11-1, and modified for this study.

	Richness	**Composition**	**Tolerance**	**Trophic / Habitat**
Benthic Macroinvertebrates	► Dominant taxa ► Taxa Richness ► Shannon-Wiener Diversity Index ► Mean # of species ► Pielou's Evenness Index ► Average taxonomic diversity	► # amphipods per event ► Amphipod biomass ► Mean abundance of bivalves/site ► # of gastropods per event	► % Polychaetes ► Polychaete biomass ► % Oligochaetes ► Oligochaete biomass	► % or biomass epibenthic ► % or biomass deposit feeders ► % or biomass suspension feeders
Fish	► Dominant taxa ► Taxa richness ► Average taxonomic diversity ► # of estuarine spawners ► # anadromous / catadromous spawners ► Total fish exclusive of *Brevoortia* sp.	► Total # of species ► # species in bottom trawl ► # species comprising 90% of individuals ► # of marine species ►# of freshwater species	► #, %, or biomass of *Brevoortia* sp. ► #, %, or biomass of *Anchoa* sp. ► #, %, or biomass of Poeciliidae ► % Incidence of disease, tumors, or anomalies	► Proportion of planktivores ► Proportion of benthic feeders ► Proportion of piscivores ► Sciaenidae composition

general lack of historic data on which to base any meaningful comparisons, it first must be established that significant differences can be detected within each study stream, and secondarily, that these differences deviate significantly from the expectations of the reference condition.

Multivariate ordination techniques form the basis of the biocriteria methodology proposed for tidally influenced streams. The PRIMER v6.0 (Plymouth Routines in Multivariate Ecological Research) software program will be used for all community-based analysis. Multidimensional scaling (MDS), or non-metric ordination of the samples, is a technique that constructs a “map” or a configuration of the samples in a specified number of dimensions that graphically represents the underlying sample patterns. The basis of the MDS is the similarity matrix among all the samples. These can include the biological data, the physiochemical data, or any of the datasets collected for this study. Separate ordinations of the stations can then be related by the rank correlations of the different similarity matrices. MDS is computationally more efficient than parametric-based techniques, and there is no need to limit the “dependent variable” side of the equation to the most abundant species.

Similarities between each pair of samples are calculated using the Bray-Curtis similarity measure (for biological data) or Euclidean Distance (for the environmental and physiochemical data). The Bray-Curtis measure is defined as:

$$S_{jk}(i) = 100 \left\{ 1 - \frac{\Sigma_{i=1}^{p} |y_{ij} - y_{ik}|}{\Sigma_{i=1}^{p} (y_{ij} + y_{ik})} \right\} \qquad \textbf{(Eq. 7)}$$

where y_{ij} is density of the i^{th} species in the j^{th} sample, and y_{ik} is the density of the i^{th} species in the k^{th} sample. In the Bray-Curtis measure, $S = 0$ if the two stations have no species in common, and $S = 1$ if the community composition is identical, because $| y_{ij} – y_{ik} | = 0$ for all i.

Different transformations of the raw data can place additional weight on the rarer species, allowing for a more complete picture of the biological community to emerge. Agreement between the configurations of the different datasets can be measured by weighted Spearman’s rank correlation. This allows for the species configuration (the biological picture) to be confirmed or rejected by the configurations of the “other data” (the physical and chemical pictures) that was collected concurrently. Stated another way, this technique reveals if the patterns in the biology agree with the patterns seen in the physical and chemical constituents reflective of each water body.

Analysis of Similarity (ANOSIM) is analogous to the parametric-based ANOVA, but it is not nearly as limited as an ANOVA because there are no parametric assumptions placed on the data. The multivariate form of the similarity matrix, which is the same foundation of the MDS procedure, is the basis for this test. This test is built on a simple non-parametric permutation procedure, applied to the (rank) similarity matrix underlying the ordination of the samples. The procedure constructs a test statistic (*R*) based on the ranks of the similarities within and between stations. This value is then tested for significant differences against a null distribution constructed from random sampling of all possible permutations of the sample labels (Clarke and Warwick 2001). Values of the R-statistic close to unity show that the community compositions of the samples are very different, whereas those close to zero demonstrate that they are very similar.

The SIMPER (SIMilarity PERcentages – PRIMER v5.0) routine will be used to examine the contribution of individual species (*i*) to the community structure seen at each station (see Equation 1). Values of $S_{jk}(i)$ are averaged over all pairs of samples (*j,k*) between stations to give the average contribution. The ratio of $Savg_{(i)}$ to its standard deviation indicates how consistently a species discriminates among the assemblages. If a species is found at consistent levels (i.e., densities) across all samples at a station, then the standard deviation of its contribution is low, and the ratio is high (Clarke and Warwick 2001). Such a species will contribute more to the intra-group similarity, and can be thought of as typifying that group. Candidate species for “indicator taxa” (those that are either tolerant or intolerant to pollution/water quality degradation/low dissolved oxygen, nutrient loadings, etc.) can be identified with this test.

Average taxonomic diversity and distinctness tests address some of the shortcomings identified with species richness and many of the other diversity indices (Warwick and Clarke 1995). They are based not only on the species abundances (denoted by x_i, the number of individuals of species *i* in the sample), but also on the taxonomic distances (ω_{ij}) through a classification tree between every pair of individuals (Fig. 11).

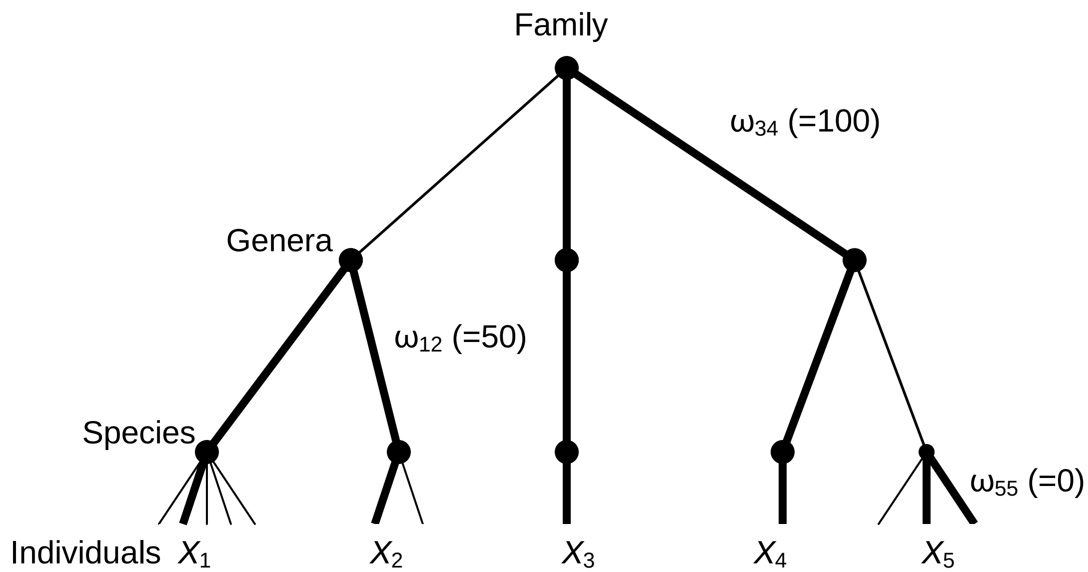


Figure 11. Hypothetical taxonomic tree for a sample consisting of 5 species, scaled such that the largest number of steps in the tree (the two species at the greatest taxonomic distance apart) is set to $\omega = 100$. Redrawn from Clarke and Warwick (2001).

Average taxonomic diversity of a sample is then defined as:

$$\Delta = [\sum\sum_{i<j} \omega_{ij} x_i x_j] / [N(N-1)/2] \qquad \textbf{(Eq. 8)}$$

Where the double summation is over all pairs of species *i* and *j* ($i,j = 1,2,\ldots,S$: $i<j$), and $N = \sum_i x_i$, the total number of individuals in the sample. Δ has a simple interpretation; it is the average 'taxonomic distance apart' of every pair of individuals in the sample, or stated another way, the expected path length between any two individuals drawn at random.

In the hypothetical sample shown in Fig. 10, the distance between individuals in species 1 and 2 (drawn in bold lines) is ω_{12}= 50; between species 3 and 4 is ω_{34}=100; and between two individuals of species 5 is ω_{55}=0 (Clarke and Warwick 2001).When the taxonomic tree reduces to a single level hierarchy (all the species belong to a common genus), then Δ becomes:

$$\Delta^o = [2 \sum\sum_{i<j} p_i p_j] / (1 - N^{-1}), \quad \text{where } p_i = x_i / N$$
$$= (1 - \sum_i p_i^2) / (1 - N^{-1}) \qquad \textbf{(Eq. 9)}$$

Equation 9 is a form of the Simpson diversity index. Δ can therefore be seen as a natural extension of Simpson, from the case where path length between individuals is either 0 (same species) or 100 (different species from different Families) or a more refined scale that captures the intervening relatedness values (0=same species, 20 different species in the same genera, 40=different genera but the same family, etc.; Clarke and Warwick 2001). In order to eliminate the dominating effect of the species abundance distribution $\{x_i\}$, leaving a distinctness measure that is more reflective of the overall taxonomic hierarchy, Warwick and Clarke (1995) recommend dividing Δ by the Simpson index Δ^o, to give average taxonomic distinctness:

$$\Delta+ = [\sum\sum_{i<j} \omega_{ij} x_i x_j] / [\sum\sum_{i<j} x_i x_j] \qquad \textbf{(Eq. 10)}$$

One of the qualities of the taxonomic diversity (Δ) and average taxonomic distinctness ($\Delta+$) is that they are sample-size independent, inheriting this property from the Simpson index from which they are generalized. This fact can be exploited when comparing current data to historical datasets (see Tolan, 2008 for detailed descriptions of the historical datasets under comparison) or for comparing different studies for which the sampling effort is unequal, uncontrolled, or unknown. The taxonomic diversity and distinctness measures will be used for the biological data (primarily finfish nekton and benthic infaunal invertebrates).

Assessment Methodology

The methodology for assessing ecosystem health and assigning site-specific uses and criteria within tidally influenced portions of river basin and coastal basin waterbodies relies heavily on the non-parametric ordination techniques outlined in the previous section. Schematically, this methodology is shown in Fig. 12. In Part A, MDS procedures are used to identify the configurations of the different datasets (e.g., biological, physiochemical, habitat. etc.). Distinction among stations located on a common stream (in terms of its biological communities, physical, and chemical properties), as well as the differences among them must first be established. Here, the goal of the MDS is to assess any agreement between the biological “picture” and the more traditional physical and chemical “pictures”. Spearman’s rank correlation is used to quantify the degree of agreement between the independent datasets (in Fig. 12, designation of 1, 2, and 3 in the hypothetical MDS plots represent the upper, middle, and lower station designations used for this study). The natural separation of the “biological” and the “physical and chemical” measurements are also evaluated with the same rank correlation method.

The biological communities are further assessed with the Average Taxonomic Distinctness measure. Any significant differences between tidal streams are identified with the ANOSIM procedure. The ANOSIM procedure is valid for not only the biological communities, but also for the physical and chemical constituents as well. The variables most responsible for the separations seen in the ANOSIM are identified with the SIMPER procedure. From this, a suite of indicator taxa can be identified, and their sensitivity to variability in the physical and chemical datasets assessed. Core metrics that include information about the taxonomic breadth of the study locations can then be developed. The threshold (biocriteria) for discriminating between impaired and unimpaired conditions provides the basis for the assessment.

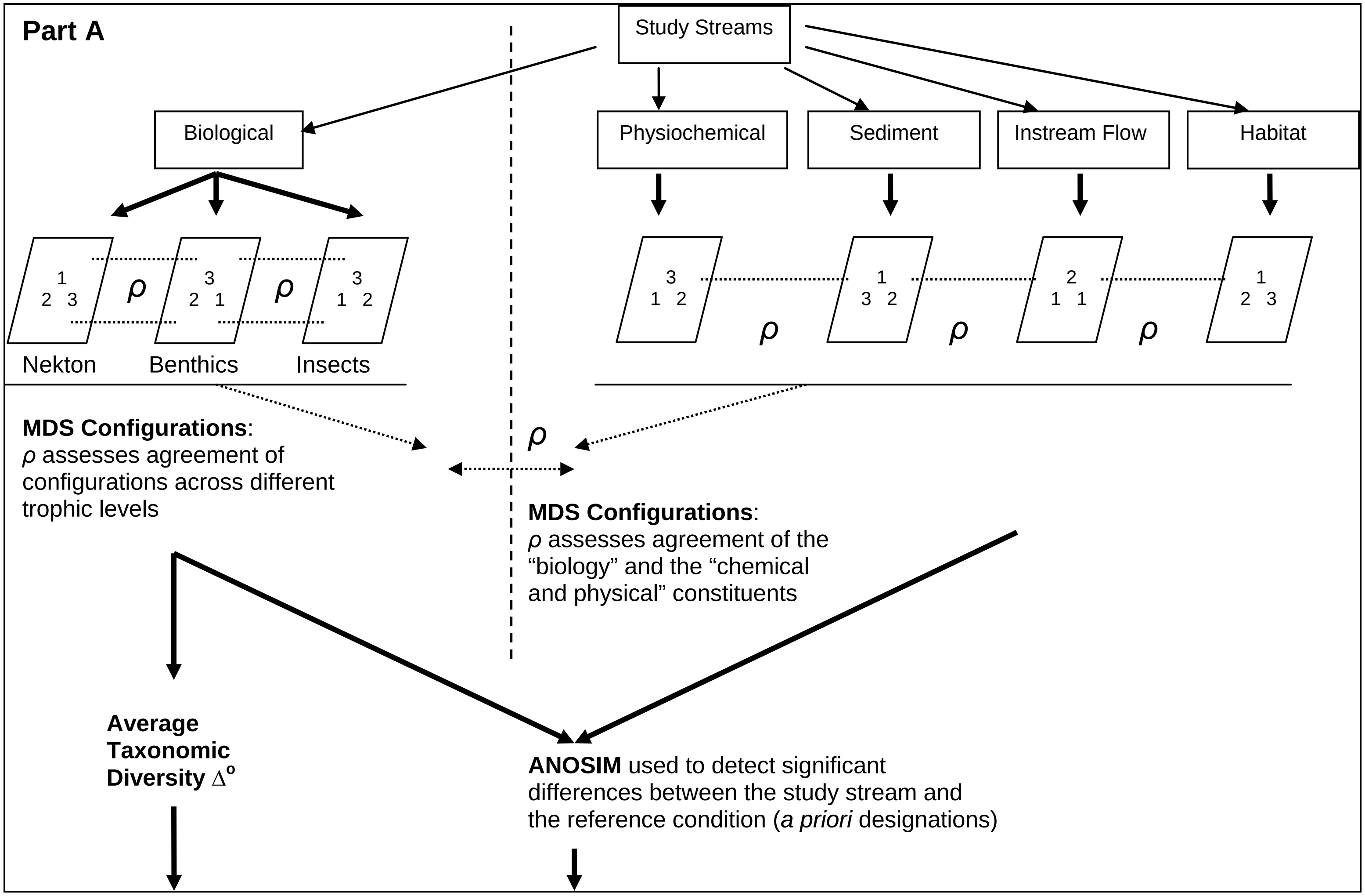


Figure 12. The process for assessing ecosystem health and determining biocriteria in tidally influenced streams.

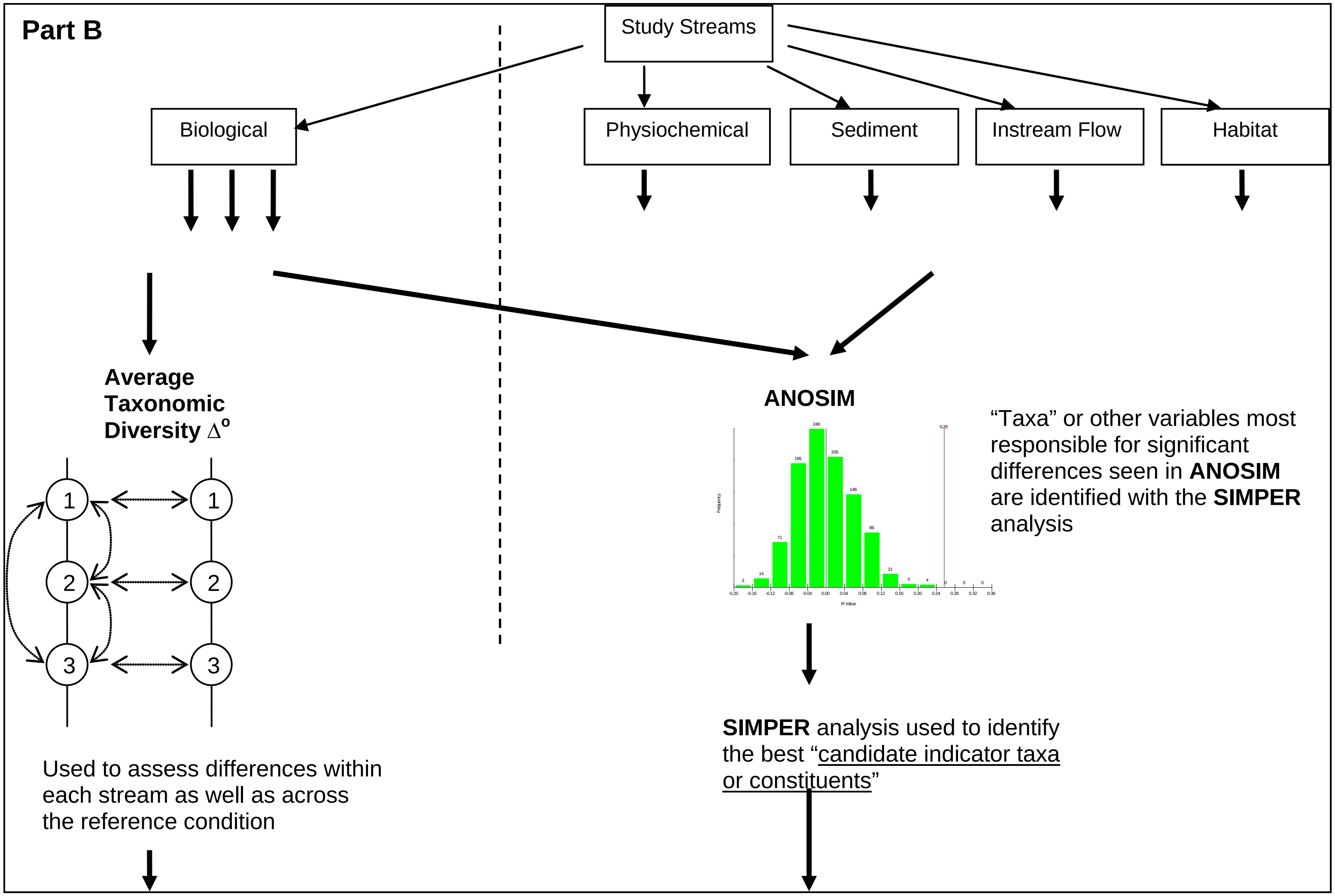


Figure 11. The process for assessing ecosystem health and determining biocriteria in tidal streams (cont.).

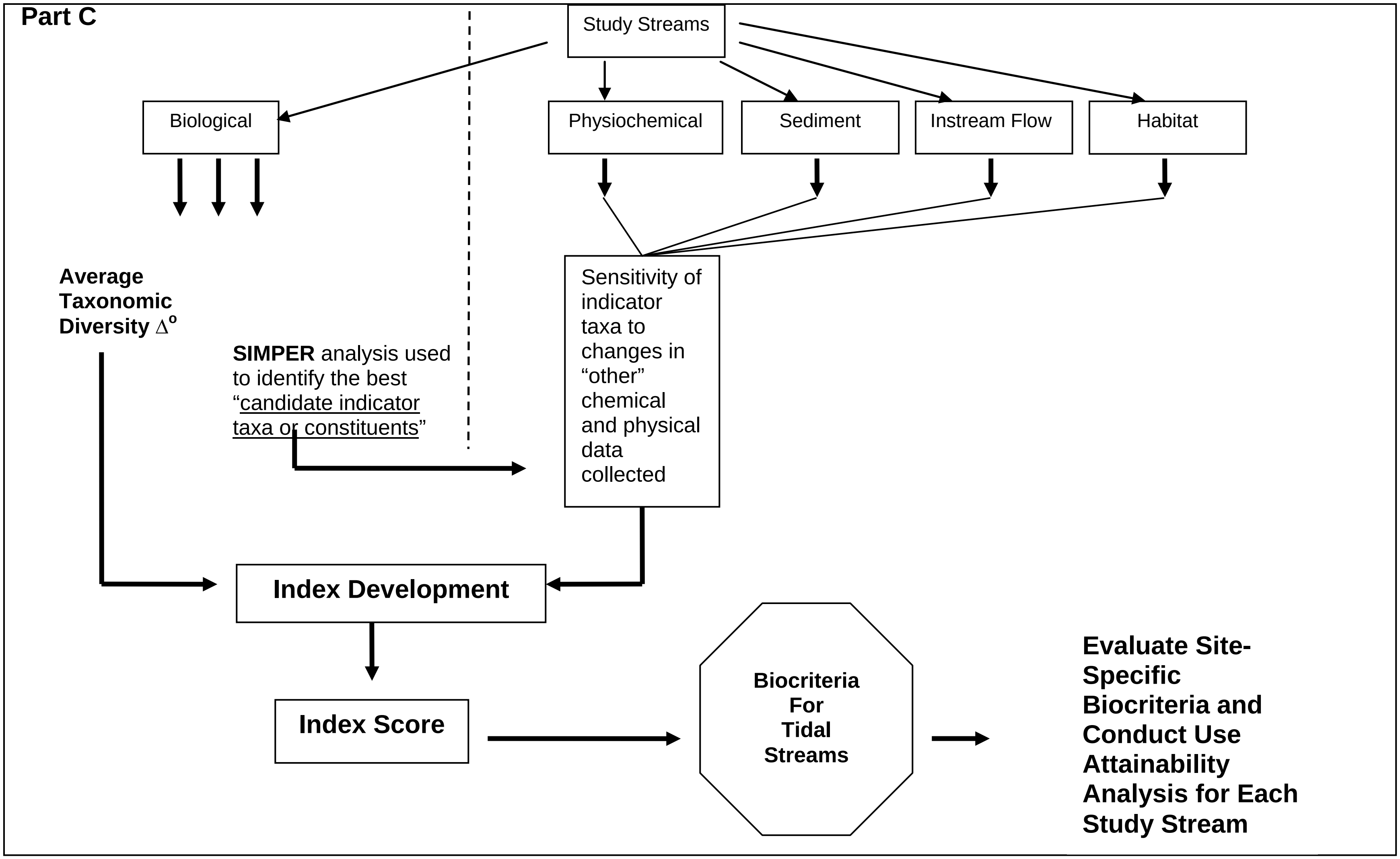


Figure 11. The process for assessing ecosystem health and determining biocriteria in tidal streams (cont.).

RESULTS

Landcover Analysis

The Ecological Systems and Mapping Subsystems were extracted by watershed (Figure 13 - 16). Summarized Ecological (Tables 7 and 8) and Mapping (Tables 9 and 10) systems data for Aransas River and Mission River watersheds include area (hectares) and relative cover (% cover). Percent cover is more useful in comparing the watersheds since they are of significantly different total areas.

Instream and Riparian Habitat Classification

Average thalweg (maximum channel depth) measurements were fairly similar between these two streams (Table 11). The Mission River had an overall average thalweg measurement of 2.5 ± 0.5 m, and the Aransas an average thalweg of 2.4 ± 0.6 m. Systematic measurements of shoreline depths for each stream reach revealed that both streams showed similar patterns along their shoreline edges, as well. Depths along the sides of channels in both streams were greatest at the uppermost sampling reaches (Mission reach 1 = 1.2 ± 0.4 m; Aransas reach 1 = 1.2 ± 0.4 m) and these channel-side depths decreased to their respective lower sampling reaches nearest the bay (Mission reach 3 = 0.8 ± 0.3 m; Aransas reach 3 = 0.6 ± 0.3 m). In-channel habitat for both streams was characterized entirely as glides. The number of side channels per 100 m rose and then fell for the Mission River from its upper to lower reach, but rose and remained generally the same for the Aransas from its upper to lower reach. The number of snags (a measure of fish cover complexity) along the bottom decreased from the upper to lower reaches of the Mission River, but increased from the upper to lower reaches of the Aransas River.

Wetted and bankfull channel width measurements were different for the two streams (Table 11). Mission River wetted width at reach 1 was 45.6 ± 5.4 m, decreased slightly to 44.8 ± 5.9 m at reach 2, and then increased to 60.4 ± 5.3 m at reach 3. Conversely, wetted widths for the Aransas River were 54.0 ± 4.7 m for reach 1, 66.5 ± 6.5 for reach 2, and 77.3 ± 15.7 m for reach 3, showing a continuous increase in width headed downstream. Bankfull widths followed the same patterns seen for each stream's respective wetted widths.

The Mission River had far more large woody debris when compared to the Aransas (Table 11). On average 9.5 pieces of woody debris was found per 100m in the Mission, while only 1.1 pieces were found per 100 m in the Aransas. Most of this difference occurred in the upper and middle reaches of the Mission River.

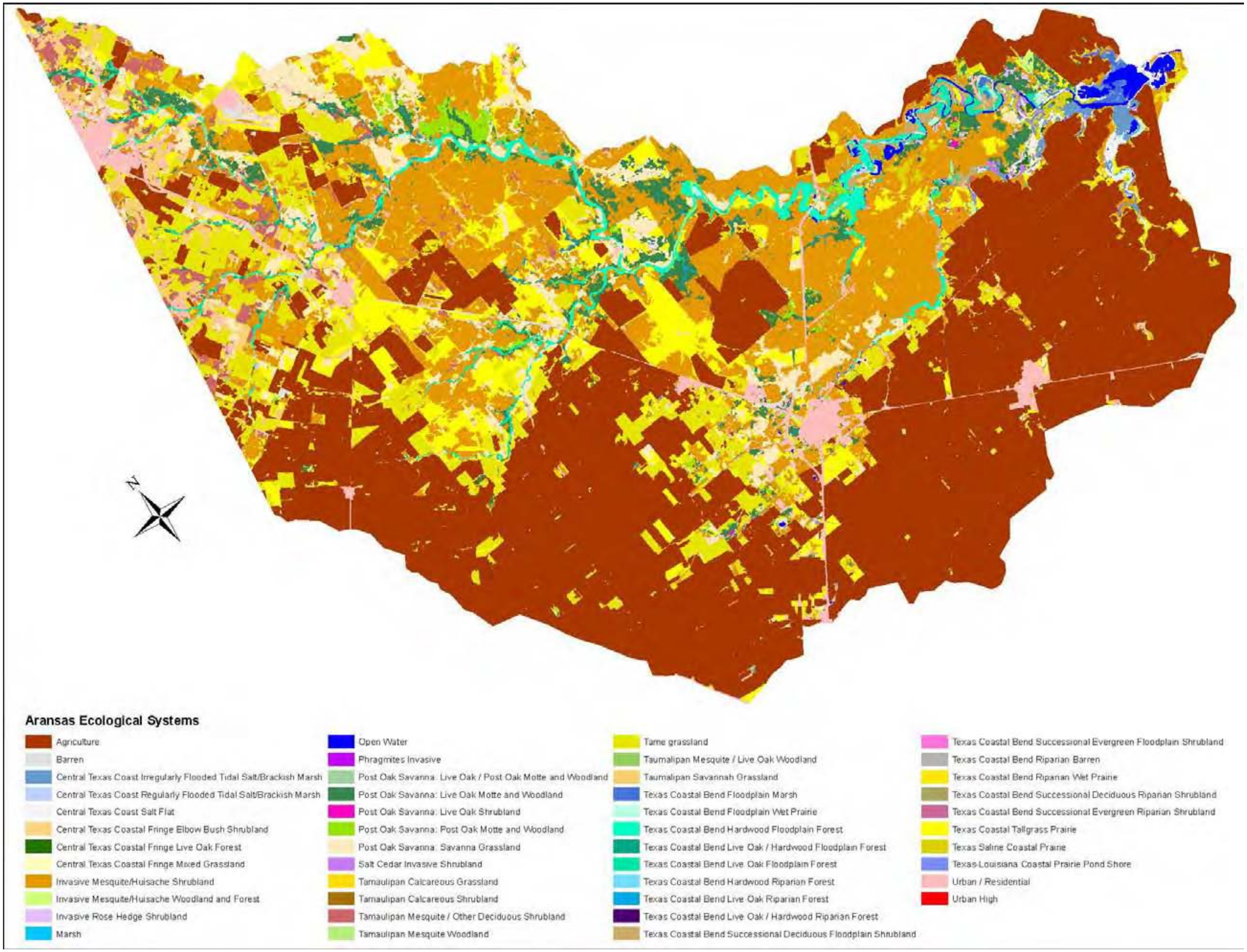


Figure 13. Aransas River Mapping Systems

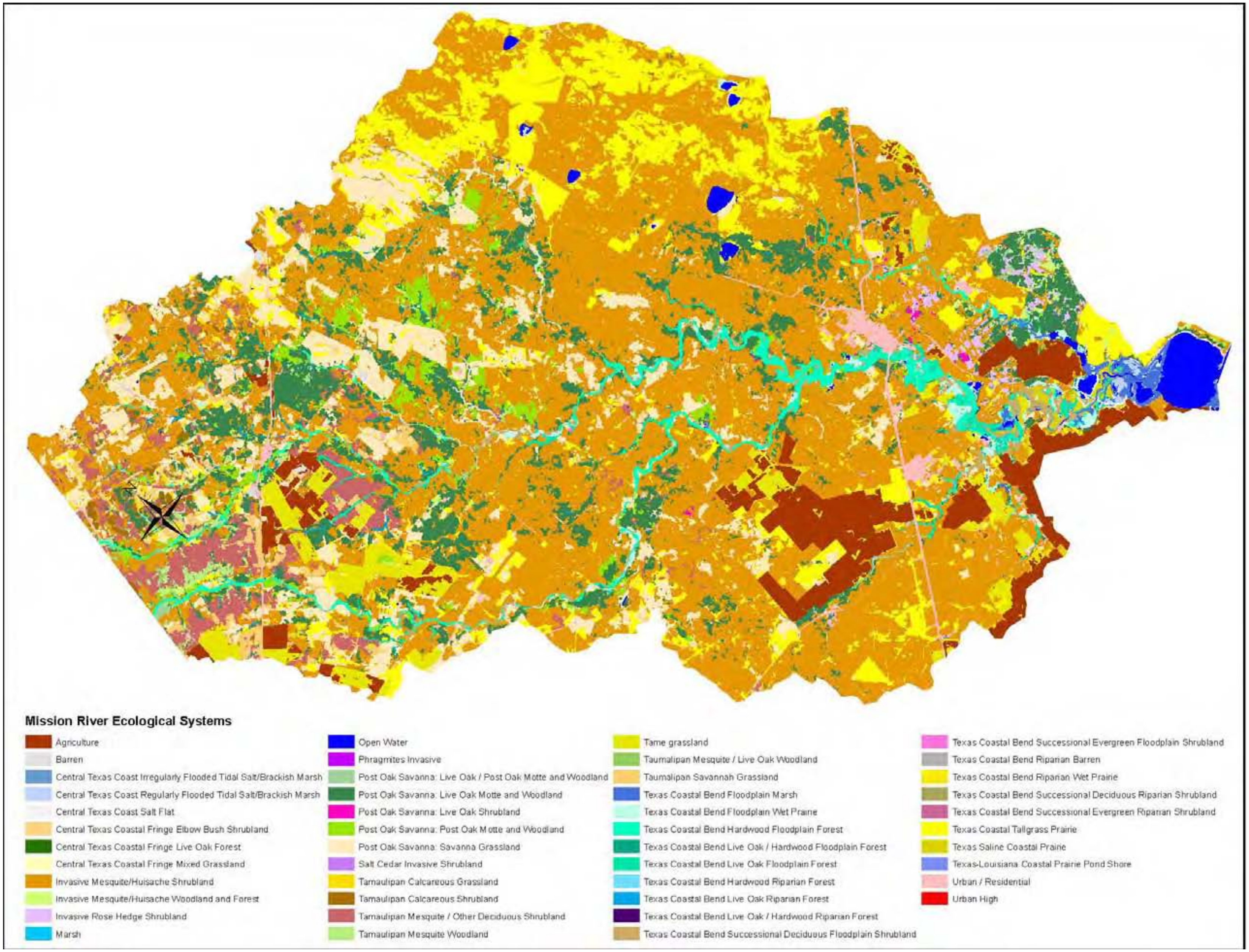


Figure 14. Mission River Mapping Systems

Table 7. Summarized Ecological systems data for Aransas River watershed.

Grid code	Ecological System Name	Mapping System Name	No. of Polys	% Polygons	Area (Ha)	% Area
1	Central and South Texas Coastal Fringe Forest and Woodland	Central Texas Coastal Fringe Live Oak Forest	288	0.259%	132.1	0.073 %
3		Central Texas Coastal Fringe Mixed Grassland	86	0.077%	52.7	0.029 %
60		Central Texas Coastal Fringe Elbow Bush Shrubland	4	0.004%	12.4	0.007 %
5	Tamaulipan Mixed Deciduous Thornscrub	Tamaulipan Mesquite Woodland	779	0.700%	218.3	0.120 %
6		Tamaulipan Mesquite / Other Deciduous Shrubland	3,029	2.722%	2,538.9	1.395 %
57		Tamaulipan Mesquite / Live Oak Woodland	306	0.275%	83.3	0.046 %
9		Tamaulipan Savannah Grassland	2,192	1.970%	2,644.8	1.453 %
7	Tamaulipan Calcareous Thornscrub	Tamaulipan Calcareous Shrubland	9	0.008%	3.9	0.002 %
8		Tamaulipan Calcareous Grassland	9	0.008%	21.6	0.012 %
10	Texas Coastal Bend Floodplain Forest	Texas Coastal Bend Live Oak Floodplain Forest	1,501	1.349%	1,200.5	0.660 %
11		Texas Coastal Bend Hardwood Floodplain Forest	1,370	1.231%	1,662.8	0.914 %
12		Texas Coastal Bend Live Oak / Hardwood	529	0.475%	226.0	0.124

Grid code	Ecological System Name	Mapping System Name	No. of Polys	% Polygons	Area (Ha)	% Area
		Floodplain Forest				%
13		Texas Coastal Bend Successional Deciduous Floodplain Shrubland	1,341	1.205%	1,128.8	0.620 %
14		Texas Coastal Bend Successional Evergreen Floodplain Shrubland	74	0.067%	16.3	0.009 %
16		Texas Coastal Bend Floodplain Wet Prairie	793	0.713%	528.4	0.290 %
62		Texas Coastal Bend Floodplain Marsh	299	0.269%	339.2	0.186 %
18	Texas Coastal Bend Riparian Forest	Texas Coastal Bend Live Oak Riparian Forest	303	0.272%	306.5	0.168 %
19		Texas Coastal Bend Hardwood Riparian Forest	118	0.106%	62.5	0.034 %
20		Texas Coastal Bend Live Oak / Hardwood Riparian Forest	11	0.010%	7.2	0.004 %
21		Texas Coastal Bend Successional Deciduous Riparian Shrubland	602	0.541%	353.3	0.194 %
22		Texas Coastal Bend Successional Evergreen Riparian Shrubland	7	0.006%	3.4	0.002 %
24		Texas Coastal Bend Riparian Wet Prairie	797	0.716%	573.7	0.315 %
64		Texas Coastal Bend Riparian Barren	441	0.396%	204.8	0.113 %
27	Central and Upper Texas Coast Salt and Brackish Tidal Marsh	Central Texas Coast Salt Flat	1,205	1.083%	645.6	0.355 %
28		Central Texas Coast Regularly Flooded	71	0.064%	31.8	0.017

Grid code	Ecological System Name	Mapping System Name	No. of Polys	% Polygons	Area (Ha)	% Area
		Tidal Salt/Brackish Marsh				%
29		Central Texas Coast Irregularly Flooded Tidal Salt/Brackish Marsh	501	0.450%	708.7	0.389 %
30		Salt Cedar Invasive Shrubland	265	0.238%	173.2	0.095 %
58		Phragmites Invasive	8	0.007%	2.1	0.001 %
31	Texas Saline Coastal Prairie	Texas Saline Coastal Prairie	1,839	1.653%	837.1	0.460 %
32	Texas-Louisiana Coastal Prairie	Texas Coastal Tallgrass Prairie	12,355	11.104%	13,617.2	7.483 %
33	Texas-Louisiana Coastal Prairie Pond Shore	Texas-Louisiana Coastal Prairie Pond Shore	703	0.632%	280.7	0.154 %
35	East-Central Texas Plains Post Oak Savanna and Woodland	Post Oak Savanna: Post Oak Motte and Woodland	4,946	4.445%	2,160.0	1.187 %
38		Post Oak Savanna: Savanna Grassland	9,733	8.747%	9,353.9	5.141 %
39		Post Oak Savanna: Live Oak Motte and Woodland	8,871	7.973%	6,753.8	3.712 %
40		Post Oak Savanna: Live Oak / Post Oak Motte and Woodland	1,213	1.090%	357.2	0.196 %
55		Post Oak Savanna: Live Oak Shrubland	388	0.349%	101.8	0.056 %
41	Human Induced Azonal Systems	Tame Grassland	7,082	6.365%	13,847.5	7.610 %
42		Invasive Rose Hedge Shrubland	1,040	0.935%	267.2	0.147

Grid code	Ecological System Name	Mapping System Name	No. of Polys	% Polygons	Area (Ha)	% Area
						%
43		Invasive Mesquite/Huisache Shrubland	25,751	23.143%	31,311.1	17.207%
45		Invasive Mesquite/Huisache Woodland and Forest	3,512	3.156%	1,236.0	0.679%
46		Urban High	256	0.230%	40.6	0.022%
47		Urban / Residential	8,511	7.649%	6,041.6	3.320%
49		Agriculture	4,013	3.607%	79,524.1	43.703%
48	Natural Azonal Systems	Barren	3,564	3.203%	1,392.0	0.765%
51		Open Water	544	0.489%	952.8	0.524%
63		Marsh	9	0.008%	5.8	0.003%
			111,268		181,962.9	

Table 8. Summarized Ecological systems data for Mission River watershed.

Grid code	Ecological System Name	Mapping System Name	No. of Polys	% Polygons	Area (Ha)	% Area
1	Central and South Texas Coastal Fringe Forest and Woodland	Central Texas Coastal Fringe Live Oak Forest	79	0.037%	31.4	0.015%
2		Central Texas Coastal Fringe Live Oak Shrubland	14	0.007%	2.8	0.001%
3		Central Texas Coastal Fringe Mixed Grassland	16	0.007%	24.3	0.012%
5	Tamaulipan Mixed Deciduous Thornscrub	Tamaulipan Mesquite Woodland	3,629	1.699%	1,258.9	0.599%
6		Tamaulipan Mesquite / Other Deciduous Shrubland	6,337	2.966%	5,866.6	2.791%
56		Tamaulipan Mesquite / Live Oak Shrubland	7	0.003%	2.3	0.001%
57		Tamaulipan Mesquite / Live Oak Woodland	984	0.461%	239.4	0.114%
9		Tamaulipan Savannah Grassland	2,912	1.363%	2,782.8	1.324%
7	Tamaulipan Calcareous Thornscrub	Tamaulipan Calcareous Shrubland	923	0.432%	778.6	0.370%
8		Tamaulipan Calcareous Grassland	391	0.183%	422.2	0.201%
10	Texas Coastal Bend Floodplain Forest	Texas Coastal Bend Live Oak Floodplain Forest	2,330	1.091%	1,763.6	0.839%
11		Texas Coastal Bend Hardwood Floodplain Forest	1,993	0.933%	2,554.9	1.216%

Grid code	Ecological System Name	Mapping System Name	No. of Polys	% Polygons	Area (Ha)	% Area
12		Texas Coastal Bend Live Oak / Hardwood Floodplain Forest	589	0.276%	158.0	0.075%
13		Texas Coastal Bend Successional Deciduous Floodplain Shrubland	2,247	1.052%	1,616.7	0.769%
14		Texas Coastal Bend Successional Evergreen Floodplain Shrubland	250	0.117%	89.1	0.042%
16		Texas Coastal Bend Floodplain Wet Prairie	1,351	0.632%	1,212.4	0.577%
62		Texas Coastal Bend Floodplain Marsh	456	0.213%	779.2	0.371%
18	Texas Coastal Bend Riparian Forest	Texas Coastal Bend Live Oak Riparian Forest	850	0.398%	739.6	0.352%
19		Texas Coastal Bend Hardwood Riparian Forest	510	0.239%	281.5	0.134%
20		Texas Coastal Bend Live Oak / Hardwood Riparian Forest	49	0.023%	24.2	0.012%
21		Texas Coastal Bend Successional Deciduous Riparian Shrubland	1,342	0.628%	925.9	0.441%
22		Texas Coastal Bend Successional Evergreen Riparian Shrubland	32	0.015%	12.5	0.006%
24		Texas Coastal Bend Riparian Wet Prairie	837	0.392%	636.4	0.303%
64		Texas Coastal Bend Riparian Barren	38	0.018%	11.2	0.005%
27	Central and Upper Texas Coast Salt and Brackish Tidal Marsh	Central Texas Coast Salt Flat	558	0.261%	233.3	0.111%
28		Central Texas Coast Regularly Flooded Tidal Salt/Brackish Marsh	181	0.085%	191.4	0.091%
29		Central Texas Coast Irregularly Flooded	282	0.132%	148.4	0.071%

Grid code	Ecological System Name	Mapping System Name	No. of Polys	% Polygons	Area (Ha)	% Area
		Tidal Salt/Brackish Marsh				
30		Salt Cedar Invasive Shrubland	1	0.000%	0.6	0.000%
31	Texas Saline Coastal Prairie	Texas Saline Coastal Prairie	1,396	0.653%	1,039.8	0.495%
32	Texas-Louisiana Coastal Prairie	Texas Coastal Tallgrass Prairie	26,860	12.573%	23,765.3	11.307%
33	Texas-Louisiana Coastal Prairie Pond Shore	Texas-Louisiana Coastal Prairie Pond Shore	291	0.136%	103.8	0.049%
35	East-Central Texas Plains Post Oak Savanna and Woodland	Post Oak Savanna: Post Oak Motte and Woodland	16,975	7.946%	6,840.7	3.255%
38		Post Oak Savanna: Savanna Grassland	22,228	10.405%	19,394.3	9.228%
39		Post Oak Savanna: Live Oak Motte and Woodland	24,488	11.463%	23,197.2	11.037%
40		Post Oak Savanna: Live Oak / Post Oak Motte and Woodland	4,135	1.936%	1,117.8	0.532%
55		Post Oak Savanna: Live Oak Shrubland	2,426	1.136%	582.1	0.277%
41	Human Induced Azonal Systems	Tame Grassland	2,442	1.143%	5,555.1	2.643%
42		Invasive Rose Hedge Shrubland	4,127	1.932%	1,712.1	0.815%
43		Invasive Mesquite/Huisache Shrubland	57,725	27.021%	84,033.6	39.983%
45		Invasive Mesquite/Huisache Woodland and Forest	5,519	2.583%	1,873.3	0.891%
46		Urban High	117	0.055%	22.2	0.011%

Grid code	Ecological System Name	Mapping System Name	No. of Polys	% Polygons	Area (Ha)	% Area
47		Urban / Residential	11,355	5.315%	4,093.6	1.948%
49		Agriculture	1,306	0.611%	10,444.7	4.970%
48	Natural Azonal Systems	Barren	2,576	1.206%	1,063.7	0.506%
51		Open Water	469	0.220%	2,545.4	1.211%
63		Marsh	4	0.002%	1.7	0.001%
			213,627		210,174.6	

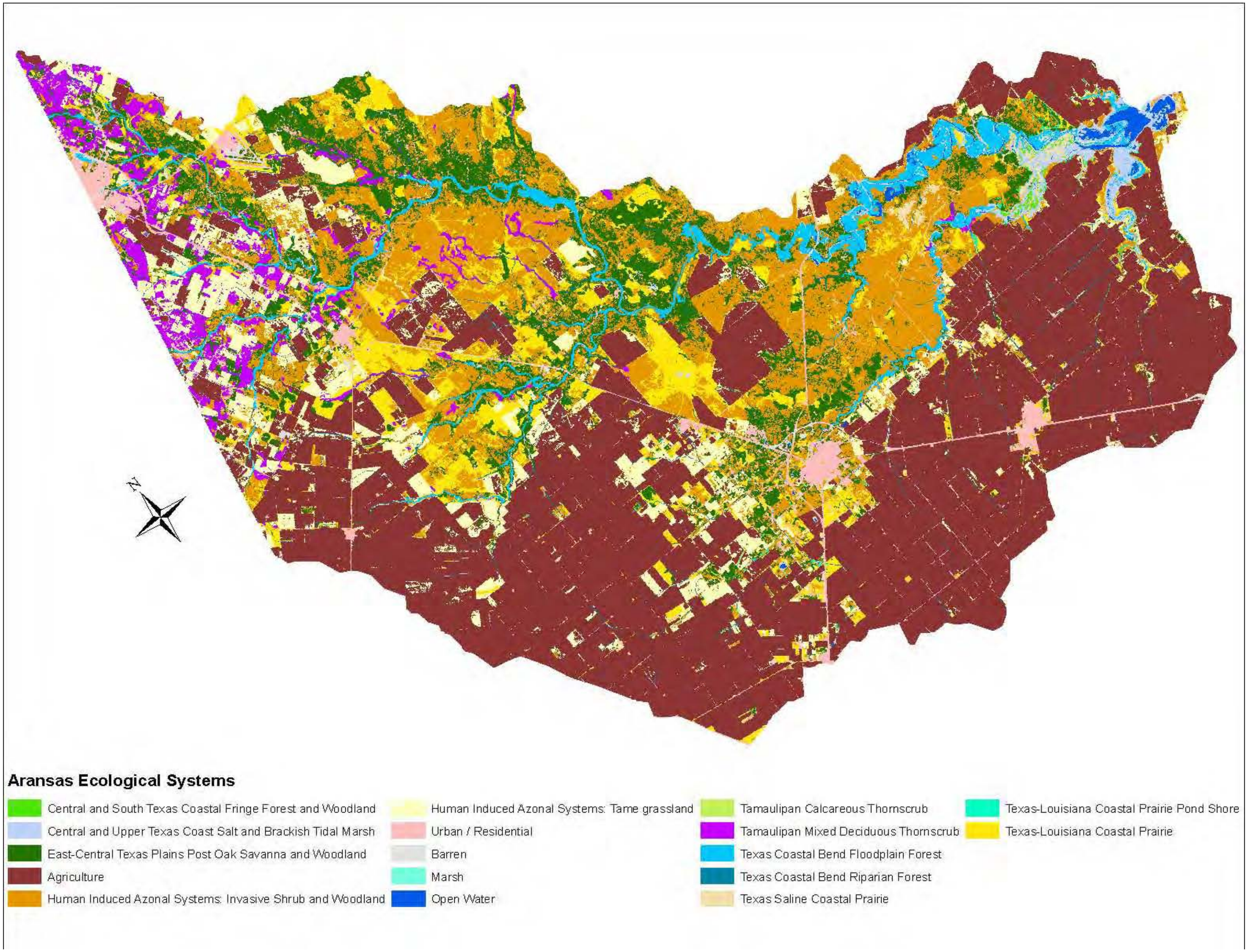


Figure 15. Aransas River ecological systems.

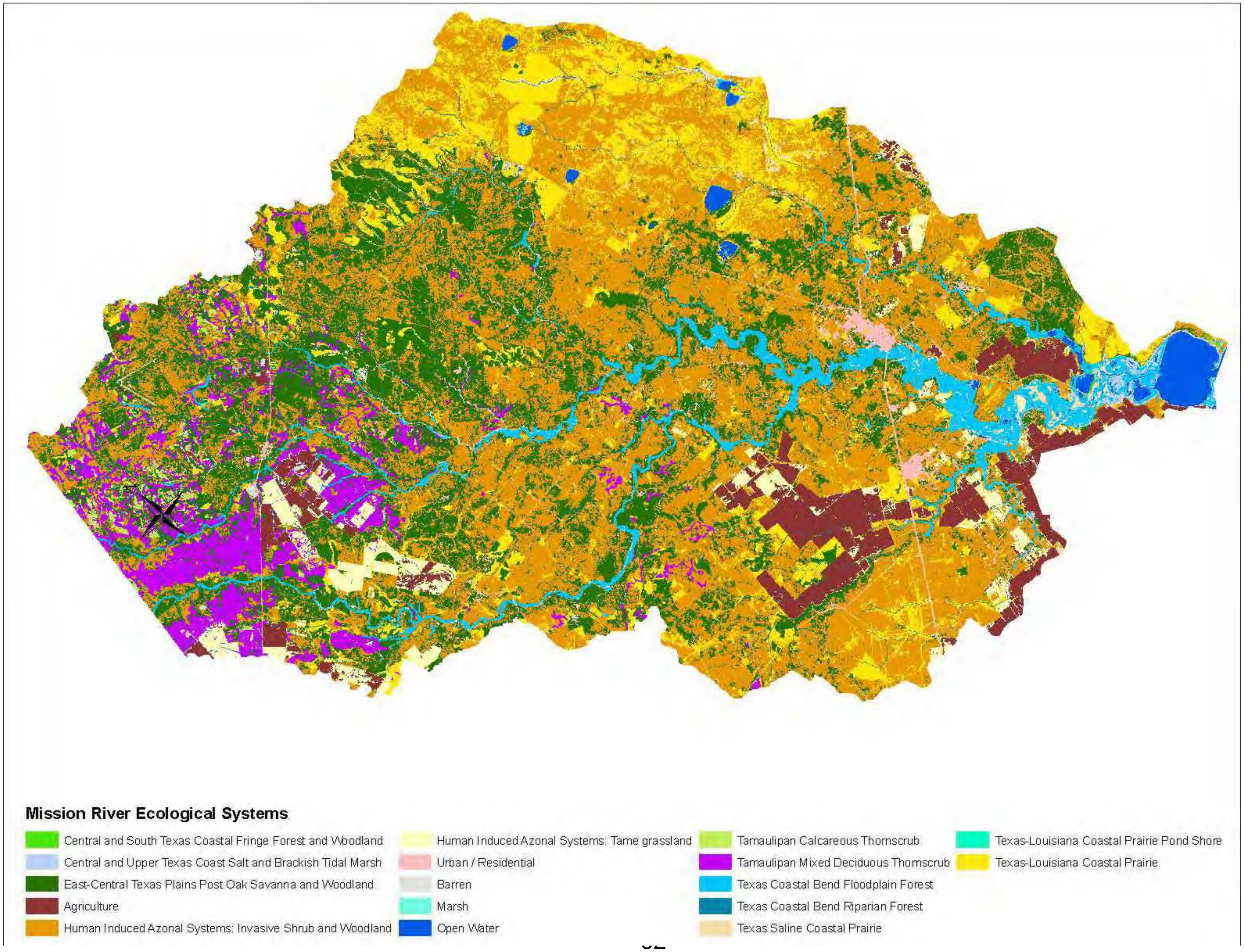


Figure 16. Mission River ecological systems.

Table 9. Aransas River ecological systems summary.

Ecological Systems	No. of Polygons	% Polygons	Area (Hectares)	% Area
Central and South Texas Coastal Fringe Forest and Woodland	378	0.34%	197.2	0.11%
Central and Upper Texas Coast Salt and Brackish Tidal Marsh	2,050	1.84%	1,561.3	0.86%
East-Central Texas Plains Post Oak Savanna and Woodland	25,151	22.60%	18,726.7	10.29%
Human Induced Azonal Systems	50,165	45.08%	132,268.1	72.69%
Natural Azonal Systems	4,117	3.70%	2,350.6	1.29%
Tamaulipan Calcareous Thornscrub	18	0.02%	25.5	0.01%
Tamaulipan Mixed Deciduous Thornscrub	6,306	5.67%	5,485.3	3.01%
Texas Coastal Bend Floodplain Forest	5,907	5.31%	5,102.0	2.80%
Texas Coastal Bend Riparian Forest	2,279	2.05%	1,511.3	0.83%
Texas Saline Coastal Prairie	1,839	1.65%	837.1	0.46%
Texas-Louisiana Coastal Prairie	12,355	11.10%	13,617.2	7.48%
Texas-Louisiana Coastal Prairie Pond Shore	703	0.63%	280.7	0.15%
Total	**111,268**		**181,962.9**	

Table 10. Mission River ecological systems summary.

Ecological Systems	No. of Polygons	% Polygons	Area (Hectares)	% Area
Central and South Texas Coastal Fringe Forest and Woodland	109	0.05%	58.5	0.03%
Central and Upper Texas Coast Salt and Brackish Tidal Marsh	1,022	0.48%	573.7	0.27%
East-Central Texas Plains Post Oak Savanna and Woodland	70,252	32.89%	51,132.2	24.33%
Human Induced Azonal Systems	82,591	38.66%	107,734.5	51.26%
Natural Azonal Systems	3,049	1.43%	3,610.8	1.72%
Tamaulipan Calcareous Thornscrub	1,314	0.62%	1,200.9	0.57%
Tamaulipan Mixed Deciduous Thornscrub	13,869	6.49%	10,150.0	4.83%
Texas Coastal Bend Floodplain Forest	9,216	4.31%	8,173.9	3.89%
Texas Coastal Bend Riparian Forest	3,658	1.71%	2,631.3	1.25%
Texas Saline Coastal Prairie	1,396	0.65%	1,039.8	0.49%
Texas-Louisiana Coastal Prairie	26,860	12.57%	23,765.3	11.31%
Texas-Louisiana Coastal Prairie Pond Shore	291	0.14%	103.8	0.05%
Total	213,627		210,174.6	

Table 11 Channel characteristics by stream reach for the Mission and Aransas Rivers. Data are means (n=11). Standard deviations are presented in parentheses. Overall stream means and standard deviations are also included below each stream's reach statistics (n=33).

Stream	Reach	Thalweg (m)	Shoreline Depth (m)	Wetted Width (m)	Bankfull Width (m)	Bankfull Height (m)	Incised Height (m)	Bank Angle (degrees)	Side channels (No./100m)	Snags (No./100m)	Large Woody Debris (No./100m)
Mission	1	2.7 (0.4)	1.2 (0.4)	45.6 (5.4)	47.1 (6.1)	1.1 (0.5)	2.0 (0.4)	17.5 (0.0)	0.1	2.8	16.4
Mission	2	2.4 (0.7)	1.2 (0.3)	44.8 (5.9)	46.0 (6.0)	0.8 (0.2)	1.5 (0.4)	17.5 (0.0)	0.2	2.0	10.9
Mission	3	2.4 (0.2)	0.8 (0.3)	60.4 (5.3)	61.0 (6.2)	0.3 (0.1)	0.6 (0.2)	3.9 (4.5)	0.0	0.8	1.4
MEAN		2.5 (0.5)	1.1 (0.3)	50.3 (9.0)	51.4 (9.1)	0.7 (0.5)	1.4 (0.7)	13.0 (7.0)	0.1	1.9	9.5
Aransas	1	3.0 (0.4)	1.2 (0.4)	54.0 (4.7)	55.6 (5.0)	0.8 (0.2)	2.6 (0.3)	39.8 (17.7)	0.0	0.3	2.3
Aransas	2	2.4 (0.6)	0.8 (0.3)	66.5 (6.5)	71.6 (8.5)	0.7 (0.2)	2.0 (0.5)	19.3 (11.9)	0.1	0.4	0.0
Aransas	3	1.9 (0.3)	0.6 (0.3)	77.3 (15.7)	86.5 (21.1)	0.6 (0.2)	1.5 (0.6)	21.6 (21.0)	0.1	0.4	0.9
MEAN		2.4 (0.6)	0.9 (0.4)	65.9 (13.8)	71.3 (18.3)	0.7 (0.2)	2.0 (0.7)	26.9 (19.1)	0.0	0.3	1.1

Overall average bankfull height for both streams was 0.7 m; however, inspection of bankfull heights by reach indicates that the Mission River showed a steeper decline in this parameter from 1.1 ± 0.5 m at the most upstream reach (reach 1) to 0.3 ± 0.1 m at the most downstream reach (reach 3) when compared to the Aransas. The Aransas River had similar bankfull heights at its three reaches with heights ranging only from 0.8 ± 0.2 m for reach 1 to 0.6 ± 0.2 m for reach 3. Channel incised heights for both streams were greater than their respective bankfull heights. Interestingly, channel incised heights appeared to be greater for the Aransas River (2.0 ± 0.7 m) versus the Mission River 1.4 ± 0.7 m. Both streams showed a progressive decrease in the degree of channel incision from their uppermost reach (reach 1) down to their downstream reach (reach 3). Channel incision observations were also reflected in the measurements of bank angles along the stream reaches with the overall bank angle. The average bank angle for the Aransas River (26.9%) was twice that of the Mission River (13.0%). All bank angles for transects along the Mission River were characterized as either flat (less than 5º) or gradual (between 5 and 30º) while the Aransas River had either flat, gradual or steep (between 30 and 75º) bank angles along its three reaches.

Dominant bottom substrate types measured during thalweg sampling were generally similar for the two streams (Table 12). Both streams had bottom substrates composed primarily of sand (0.6 to 2 mm, gritty). For the Mission, 81% of all bottom substrates measured were sand, while 80% of bottom substrates in the Aransas were in the sand category. However, both streams showed a pattern of increasing content of fine materials (<0.6 mm, not gritty) in their sediments at their most downstream reaches.

Likewise, dominant shoreline and shallow nearshore substrate types were generally similar to those found in the depths of these streams (Table 12). Sampling indicated that shallow nearshore habitats along the Mission and Aransas Rivers were primarily composed of sand at their uppermost and middle reaches, but showed an increase in fines at their lowest (most tidal) reach. Similarly, sediments along the exposed shoreline generally showed the same pattern in both streams with sand being predominant in the uppermost reach but with fines generally becoming increasingly common in the lower reaches. In fact, fines appeared to be slightly more prevalent in the most downstream reach of the Mission River as compared to sand on the shoreline.

Canopy densities of the riparian habitat along the sides of both streams, as measured using a densiometer, generally decreased from upper to lower stream reaches, but the patterns of change going downstream differed for each stream (Table 13). Canopy densities for the Mission River were 82% for reach 1, 84 % for reach 2, and 69% for reach 3. Canopy densities for the Aransas River were 94% for reach 1, 68% for reach 2 and 55% for reach 3.

Table 12. Dominant channel and shoreline substrate composition by stream reach for the Mission and Aransas Rivers (i.e., percent of sampling transects in each reach with given sediment type as dominant). Data are means (n=11). Overall stream means are also included below each stream's reach statistics (n=33).

Stream	**Reach**	**Thalweg**		**Shallow Nearshore**		**Shoreline**	
		Sand (%)	Fines (%)	Sand (%)	Fines (%)	Sand (%)	Fines (%)
Mission	1	100	0	100	0	100	0
Mission	2	100	0	100	0	100	0
Mission	3	44	56	55	45	45	55
MEAN		81	19	85	15	82	18
Aransas	1	79	21	100	0	73	27
Aransas	2	88	12	100	0	55	45
Aransas	3	74	26	64	36	55	45
MEAN		80	20	88	12	61	39

Table 13. Canopy density and percent vegetative cover by stream reach for riparian habitats along the Mission and Aransas Rivers. Data are means with standard deviations in parentheses (n=11). Overall stream means and standard deviations are also included below each stream's reach statistics (n=33).

Stream	**Reach**	**Canopy Density (%)**	**CANOPY**		**UNDERSTORY**		**GROUND COVER**			**TOTAL COVER**
			Big Trees	Small Trees	Woody Shrubs	Herbs, Grass, Forbs	Woody Shrubs	Herbs, Grass, Forbs	Bare/ Duff	
Mission	1	82	23(12)	19 (12)	30 (14)	11 (11)	5 (1)	56 (9)	10 (5)	143
Mission	2	84	6 (5)	26 (25)	35 (16)	10 (8)	6 (3)	49 (17)	24 (16)	132
Mission	3	69	1 (4)	9 (8)	35 (17)	22 (5)	8 (6)	82 (12)	0 (1)	157
MEAN		78	10 12)	18 (18)	33 (15)	15 (10)	6 (4)	62 (19)	11 (14)	144
Aransas	1	94	33(20)	33 (18)	17 (6)	15 (11)	6 (4)	45 (16)	25 (12)	148
Aransas	2	68	15(16)	22 (14)	24 (14)	26 (12)	15 (8)	34 (12)	19 (14)	136
Aransas	3	55	9 (10)	22 (11)	30 (17)	12 (7)	14 (11)	41 (13)	20 (11)	128
MEAN		72	19(19)	26 (15)	24 (14)	18 (12)	12 (9)	40 (14)	21 (12)	137

Visual estimates of riparian vegetative cover for the two streams also provided differing results. Total plant cover did not show a clear pattern of change from the upper to lower reaches of the Mission River and only a small decline for the Aransas River (Table 13). For the Mission, total vegetative cover at reach 1 was 143% (i.e., coverage from canopy, understory and ground cover layers summed to > 100%), 132% for reach 2, and rose to 157% for reach 3. Total cover for reach 1 of the Aransas was 148%, 136% for reach 2, and 128% for reach 3. Large trees were most prevalent in the uppermost reaches of both streams and decreased in percent cover in downstream sites. Small trees followed the same pattern in the Aransas River, but were most prevalent in reach 2 of the Mission before declining in reach 3. In contrast, woody shrubs increased in both systems downstream. Herbaceous cover in the understory increased downstream for the Mission River as well, but rose from reach 1 to 2 in the Aransas before declining in reach 3. Woody groundcover increased downstream in both reaches, but herbaceous cover at ground level was lowest in both streams at their middle reach (reach 2). Overall though, upstream sites were more forested while downstream sites were dominated by low growing woody and herbaceous species, especially grasses and forbs.

The two streams showed different patterns in terms of the types and total amounts of fish cover found in the shallow areas of their upper, mid, and lower reaches (Table 14). Fish cover in the Mission was highest at reach 1 with a total cover of 82%, a decline to 47% at reach 2, and a further decline to 39% for reach 3. The Aransas had a total fish cover of 48% for reach 1, 48% for reach 2, and its highest fish cover of 66% for reach 3. Almost all of this fish cover was composed of natural materials for both streams. The largest components of the fish cover for reaches 1 and 2 of the Mission River were live trees in stream and overhanging woody vegetation within 1 m of the water's surface. However, for reach 3 of the Mission, most of the fish cover was created by emergent macrophytes. Overhanging woody vegetation and macrophytes provided much of the fish cover for reach 1 of the Aransas. Fish cover for reaches 2 and 3 of the Aransas was primarily from macrophytes. As also reflected in riparian vegetation measurements, fish cover appeared to transition from woody material in the upper stream reaches to more herbaceous materials downstream.

The overall degree of human influence observed in the Mission River was lower than for the Aransas River (Table 15). Pasture, range, and hay fields were by far the most common signs of human influence in both streams, being observed at 30% of sampling sites in the Mission and 70% of sites in the Aransas. Power lines were the second most common sign of human influence for the Aransas at 21%, but pipes were the second most common sign of human influence in the Mission (9%). Power lines were observed at 8% of sites in the Mission. Pipes were observed at 9% of sites on the Aransas. Buildings were observed from 6% of sites along the Mission versus 9% of Aransas sites. Pavement/cleared lots were observed at 8% of sites on the Aransas. Overall, signs of human influence

Table 14. Percent fish cover by stream reach for the Mission and Aransas Rivers. Data are means with standard deviations in parentheses (n=11). Overall stream means and standard deviations are also included below each stream's reach statistics (n=33).

Stream	Reach	Filamentous Algae	Macrophytes	Large Woody Debris	Small Woody Debris	Live Trees in Stream	Overhanging Vegetation	Undercut Banks	Boulders/ Ledges	Artificial Structures	TOTAL COVER
Mission	1	0 (0)	1 (2)	12 (10)	10 (9)	20 (9)	32 (17)	5 (0)	0 (2)	1 (2)	82
Mission	2	0 (0)	8 (8)	6 (6)	5 (0)	10 (9)	12 (10)	5 (2)	0 (0)	0 (0)	47
Mission	3	0 (2)	21 (20)	2 (3)	4 (2)	4 (2)	4 (2)	3 (3)	0 (0)	0 (0)	39
MEAN		0 (1)	10 (15)	7 (8)	7 (6)	11 (10)	16 (16)	4 (2)	0 (1)	0 (1)	56
Aransas	1	4 (2)	9 (8)	7 (17)	5 (7)	7 (17)	12 (18)	4 (2)	0 (0)	0 (0)	48
Aransas	2	5 (0)	43 (34)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	48
Aransas	3	4 (7)	55 (27)	0 (2)	2 (3)	1 (2)	3 (3)	0 (2)	0 (0)	0 (0)	66
MEAN		4 (4)	35 (32)	2 (10)	3 (5)	3 (10)	5 (11)	1 (2)	0 (0)	0 (0)	54

Table 15. Percent frequency of occurrence of human influences by stream reach for the Mission and Aransas Rivers. Data are means (n=11). Overall stream means are also included below each stream's reach statistics (n=33).

Stream	Reach	Wall/Dike/ Revetment/ Riprap/Dam	Bldgs	Pavement/ Cleared Lot	Road/ Railroad	Pipes	Landfill/ Trash	Park/ Lawn	Row Crops	Pasture/ Range/ Hay	Power Lines	Weighted Average – All Human Influence*
Mission	1	9	14	0	5	9	5	9	0	45	5	0.55
Mission	2	5	5	0	0	0	0	5	0	45	0	0.34
Mission	3	0	0	0	0	18	0	0	0	0	18	0.15
MEAN		5	6	0	2	9	2	5	0	30	8	0.35
Aransas	1	5	9	14	5	0	0	0	0	50	0	0.51
Aransas	2	0	9	5	5	18	0	5	0	77	27	0.74
Aransas	3	0	9	5	5	9	0	0	0	82	36	0.79
MEAN		2	9	8	5	9	0	2	0	70	21	0.68

* For a detailed description of the procedure used for weighting human influences see Kaufmann et al. 1999

for both streams appear to be chiefly associated with cattle grazing. A weighted averaging method outlined in Kaufmann et al. (Kaufmann et al. 1999) which accounts not only for the presence of these human disturbances but also their distance from the transects, showed that the Aransas appeared to be more impacted by human influences. The Mission River's overall average degree of human influence was 0.35 versus 0.68 for the Aransas River with larger numbers indicating greater human influence.

Instream Flow Characterization

Mission River Tidal

Historical Hydrology

The long term mean annual discharge (1940 – 2009) in Mission River at a USGS gage near Refugio, TX was 145 cfs. In 2008, the stream flow was very low at about 5% of the long term mean annual discharge (Figure 17a). Similarly, in the first nine months in 2009, flow remained low (Figure 17b). However during October – December, there were high flow events that resulted in monthly mean discharges that exceeded the long term equivalents by 2-5 folds. The mean annual flow in 2009 recovered to 85% of the 70-year annual mean flow because of these flood events.

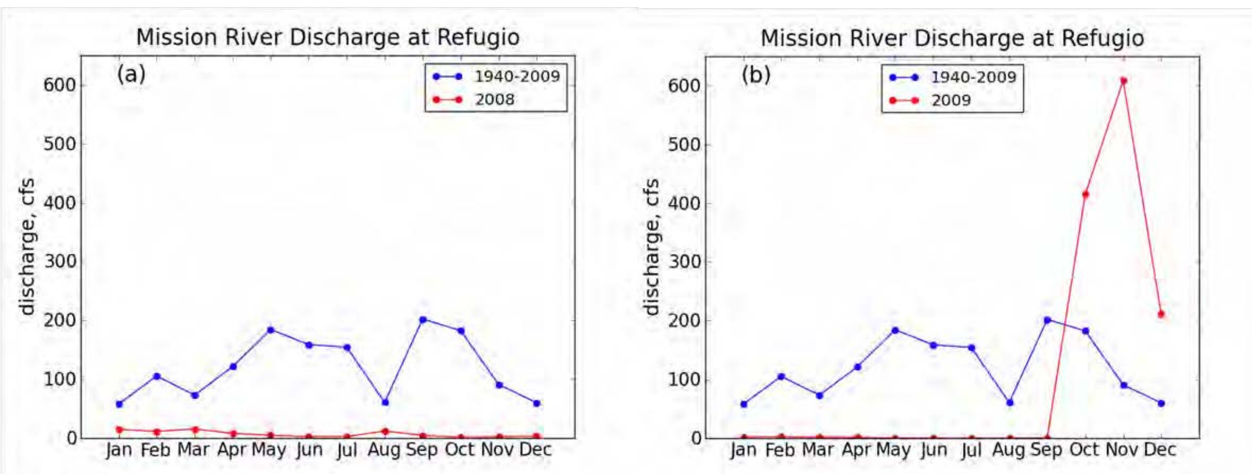


Figure 17. Monthly averaged discharge for Mission River for (a) 70 years (blue) and 2008 (red) (b) 70 years (blue) and 2009 (red).

Velocity Analysis Results

The flow pattern observed during the March 2008 ADV deployment is shown in Figure 18. The proportions of the tidal and residual components of flow at any point in time during the deployment are shown in this plot (top panel). The occurrence of maximum and minimum current velocities relative to the tidal periods are also elucidated through comparison of the date/time of occurrence of the maximum total velocities (top panel) and tidal velocities (top panel). Additionally, the presence of directional flow, and the relative magnitude of the upstream and downstream currents; and whether the residual currents augment downstream or upstream flow is shown in this plot. During the March 2008 deployments, currents that shifted direction with tidal cycles were seen at the middle station in Mission River. The downstream currents were relatively weaker (less than 0.65 ft/s; Figure 18, bottom panel) partly because of the dampening effect of upstream residual currents which were prevalent throughout the deployment event. The maximum flow velocities were in phase with the peaks of the flooding cycle of the tidal flow on both days.

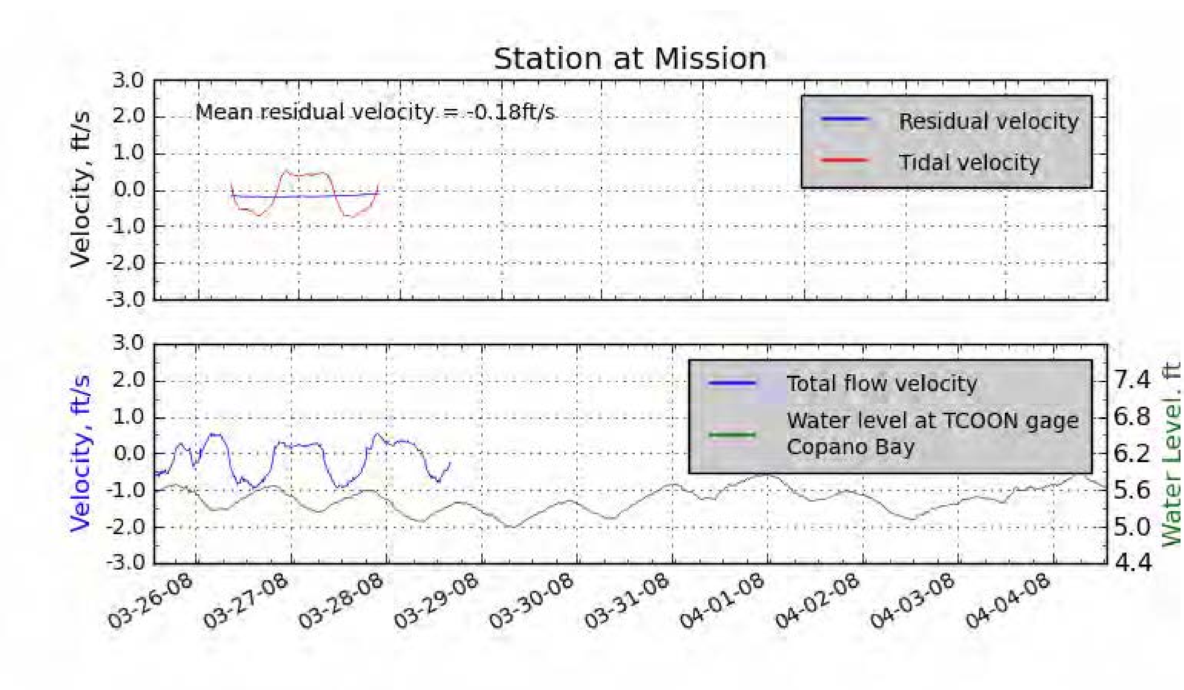


Figure 18. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) in Mission River during March 2008 deployment.

Similar plots for the other deployments for the Mission River Tidal ADV deployments are contained in Appendix 2. There, they summarize the findings of all the deployments: May 2008 and August 2008 currents displayed very weak tidal signal with the total velocity remaining less than 0.3 ft/s for more than 50% of the deployment lengths (Appendix 2, Figures 17 and 18). The August 2008 data set was filtered to extract the tidal and residual components. The analysis showed that there were no residual currents during the deployment period (Appendix 2, Fig. 18, top panel). The September 2008 velocity time series was the longest consisting of 10 days of measurements. The flow in the first 2 days was characterized by relatively strong tidal currents as high as 1.8 ft/s that dissipated consistently to velocities that were less than 0.65 ft/s during the last day (Appendix 2, Fig. 19). Flow direction reverses in-phase with the tidal cycles during the periods of strong tides. The highest residual velocity observed during the deployment period was 0.3 ft/s. In general, residual velocities in Mission River remained negligible throughout the study period, making up 7 – 42% of the tidal velocities (Appendix 2, Figures 17 to 25). In May 2009 and June 2009, both the upstream and downstream flow velocities were relatively strong (Appendix 2, Figures 21 and 22). Filtering of the June 2009 data showed that the maximum velocities (both upstream and downstream) were during the peaks of the respective tidal cycles (Appendix 2, Fig. 22, top panel). Flow was almost purely tidal as the residual components were negligible. High and low peak velocities were achieved once daily, implying that the diurnal components of the tide were dominant. In September 2009 and November 2009, the stream flow exhibited tidal oscillations with amplitudes of around 0.65 ft/s (Appendix 2, Figures 24 and 25).

Table 16 shows the mean residual velocity and the mean total velocity for all the deployments. The mean total velocity was calculated using all the complete tidal cycles present in the deployment while the mean residual velocity covers the middle portion of the deployment that remains after the application of the Dodson filter. Table 17 compares the net direction of flow (i.e upstream v.s. downstream) to the prevalent wind direction at the time. Neither table shows any strong seasonal or other correlation.

Flow Analysis Results

To compare the incoming freshwater flow with the estimated residual flow at M2, discharge data from USGS gage near Refugio, TX were averaged over 7 days during each of the ADV deployment. The mean discharge at the USGS gage during the March 2008 deployment was + 10.3 cfs. The residual flow noted at M2 was upstream throughout the deployment (Appendix 2, Fig. 26). The mean residual flow during the August deployment was 1.8 cfs while the USGS gage discharge remained very low during this period too (Appendix 2, Fig. 27). In September 2008, the residual flow at M2 was relatively higher and over the eight

Table 16. Mean residual and total flow velocities at M2, Mission River.

Deployment Start Date	Mean Residual Velocity (ft/s)	Mean Total Velocity (ft/s)
25-Mar-08	-0.18	-0.14
5-Aug-08	0.01	0.02
22-Sep-08	-0.07	-0.09
24-Mar-09	0.00	0.00
23-Jun-09	0.07	0.10
22-Sep-09	-0.13	-0.11
3-Nov-09	0.05	0.02

Table 17. Wind Speed and Direction in Copano Bay, TX (March 2008 – November 2009).

Deployment Month	Average Wind Speed (mph)	Wind Direction	Net Direction of Flow	
			Mission River	Aransas River
Mar-08	15.6	SSE	Upstream	Upstream
May-08	15.8	SE and NE	Upstream	No net flow
Jun-08	16.8	SSE	No good data	Upstream
Aug-08	11.8	SSE	No net flow	Upstream
Sep-08	11.6	NE	Upstream	No good data
Nov-08	11.0	SE	No data	Upstream
Mar-09	13.6	SE	No net flow	No good data
May-09	15.1	SE	Upstream	Upstream
Jun-09	13.0	SSE	No net flow	No good data
Aug-09	13.0	SSE	No net flow	Upstream
Sep-09	9.6	SE	No net flow	Downstream
Nov-09	9.9	NE	No net flow	No net flow

days, it had variable direction and magnitude while the gage flow remained nearly constant at about 1.5 cfs (Appendix 2, Fig. 28). Both the gage and estimated residual flows in the March and June 2009 were very low (Appendix 2, Figures 29 and 30). There was virtually no flow at the USGS gage during the September 2009 deployment whereas the residual flow at M2 was variable and remained upstream almost throughout the entire deployment period (Appendix 2, Fig. 31). In the November 2009 deployment, like in the rest, there was no clear relationship between the gage and estimated residual flow with residual flow that varied both in magnitude and direction while the gage flow remained fairly low and constant (Appendix 2, Fig. 32).

Despite the gage flow remaining low through most of the deployments, the residual flow at M2 was variable (Figure 19). This variation may be explained by combination of other factors such as wind forces and low frequency tidal components of flow passing through the filter used thereby affecting the residual flow results.

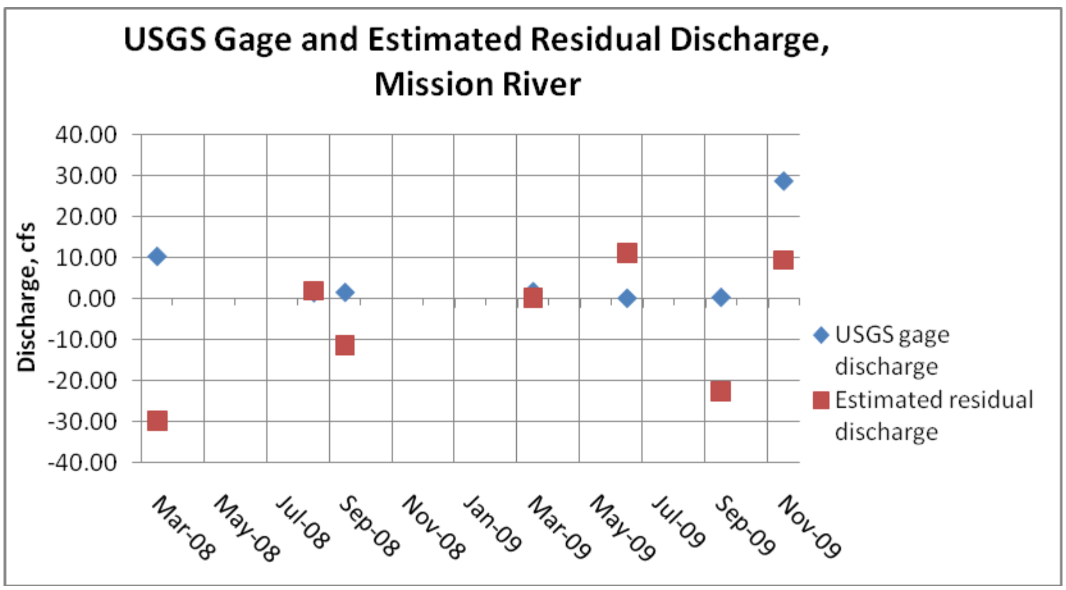


Figure 19. Deployment mean residual discharge (estimated) at M2 and mean measured discharge at USGS gage near Refugio, Mission River (March 2008 – November 2009).

To estimate the inflow contribution of a tributary located 6 miles upstream of M2, two ADCP deployments were set up directly upstream (station D-M2) and downstream(station D-M3) of the confluence of the river and tributary (Figure 20). Subtraction of the D-M3 flow from the D-M2 flow shows approximately twenty percent of the flow (60.3 cfs) was diverted into the tributary during the flood cycle.

Comparison of discharge measurements along the stream showed that the tidal flow dissipated at a more rapid rate going upstream. There was negligible difference in the discharge measurements at D-M3 and D-M4 that were 6 river miles apart. The discharge in D-M1 was however 70 cfs lower than the measured discharge in D-M2, which is the next downstream station located 4 river miles away. However, since these measurements were made at different times (there was up to 1.5 hrs difference between adjacent sampling events), the actual rate of the tidal flow dissipation may be less pronounced than what was seen in the data. Flow showed high variability in all the discharge measurement sites. The ratio of the standard deviation to the mean discharge ranged from 0.23 to 0.59. Generally, the ratio increased at low mean discharges. The estimated discharge was slightly higher than the measured discharge in D-M1 while it was about half of the measured discharge in the rest of the discharge measurement sites (Figure 21).

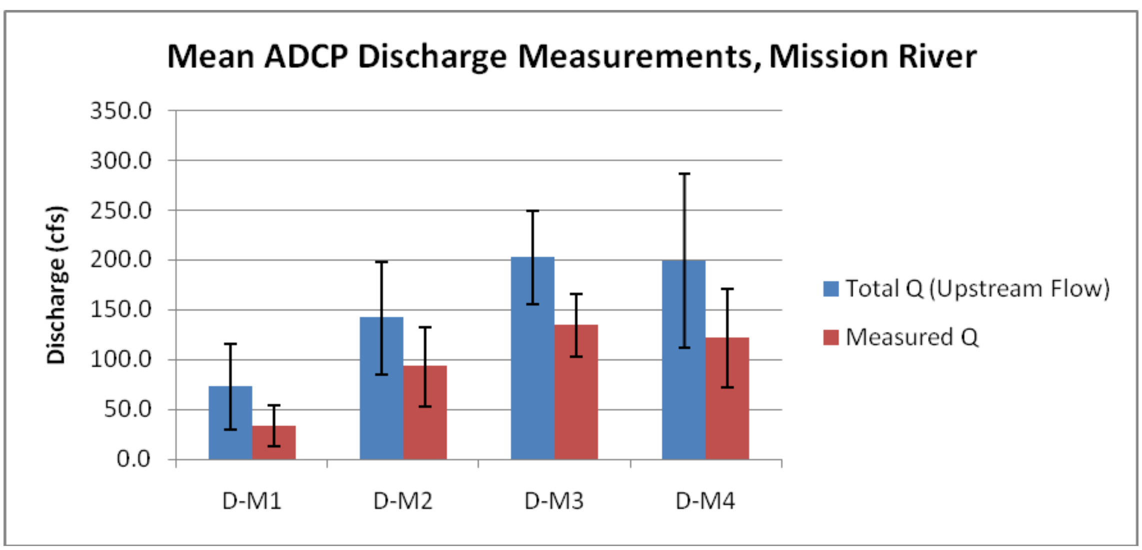


Figure 20. Mean measured and total (measured + estimated) ADCP discharge measurements at Mission River stations (June 23, 2009).

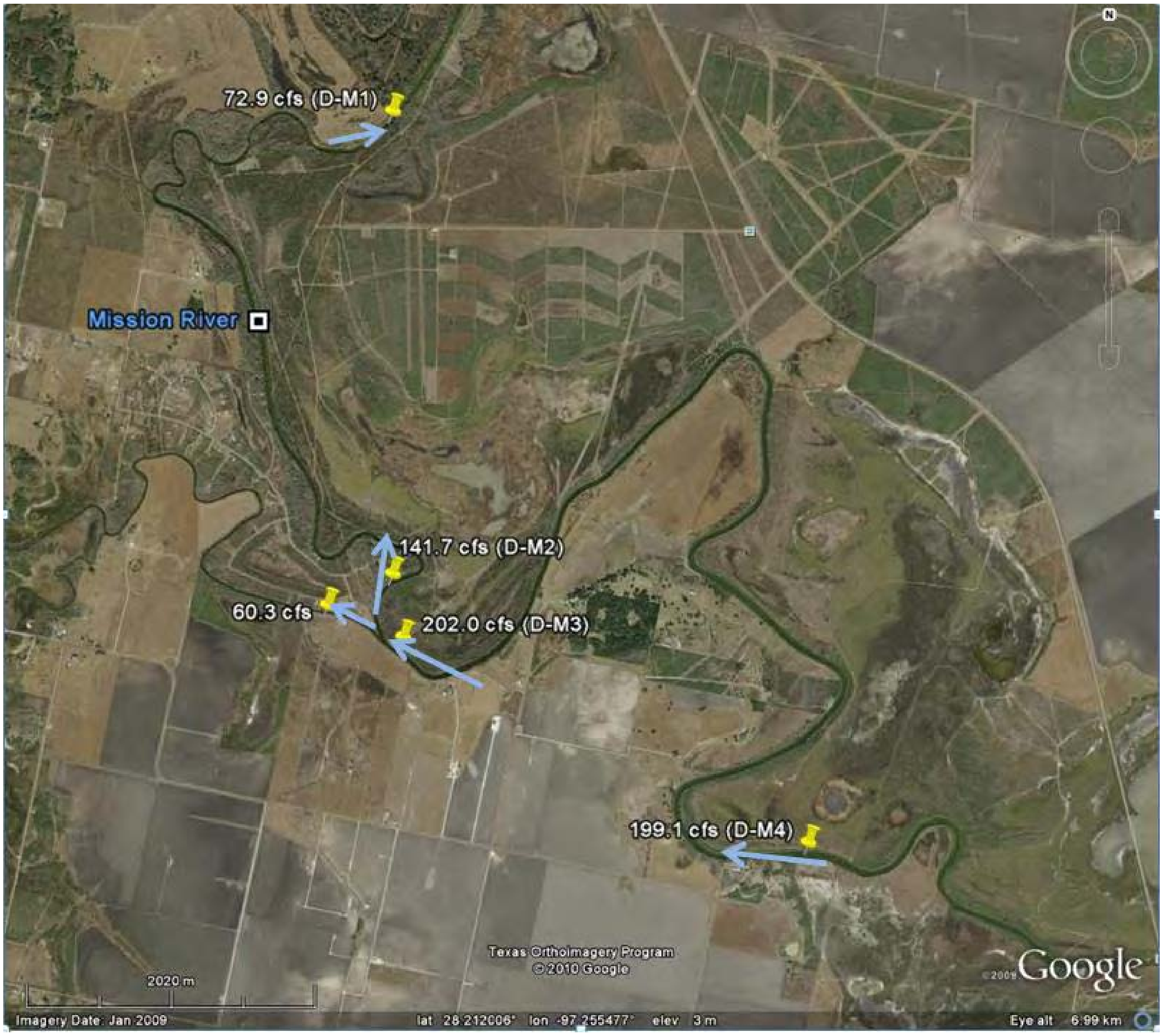


Figure 21. Net discharge volumes, and flow directions in Mission River (9 am – 12 pm June 23, 2009).

Aransas River Tidal

Historical Hydrology

The mean annual discharge in Aransas River near Skidmore, TX was 38 cfs as calculated from discharge data collected at an USGS gage. About 25% of the flow volume normally comes during September. Flow rates are quite low during the winter months and August (less than 20 cfs). The study period for the Aransas River (March 2008 – November 2009) represented a drought period (Fig. 22). In 2008 and 2009, the annual average discharges were 30% and 50% of the 45-year (1965 – 2009) mean discharge respectively. During the last three months in 2009 and August 2008, the flow volume had recovered to more than the long term means.

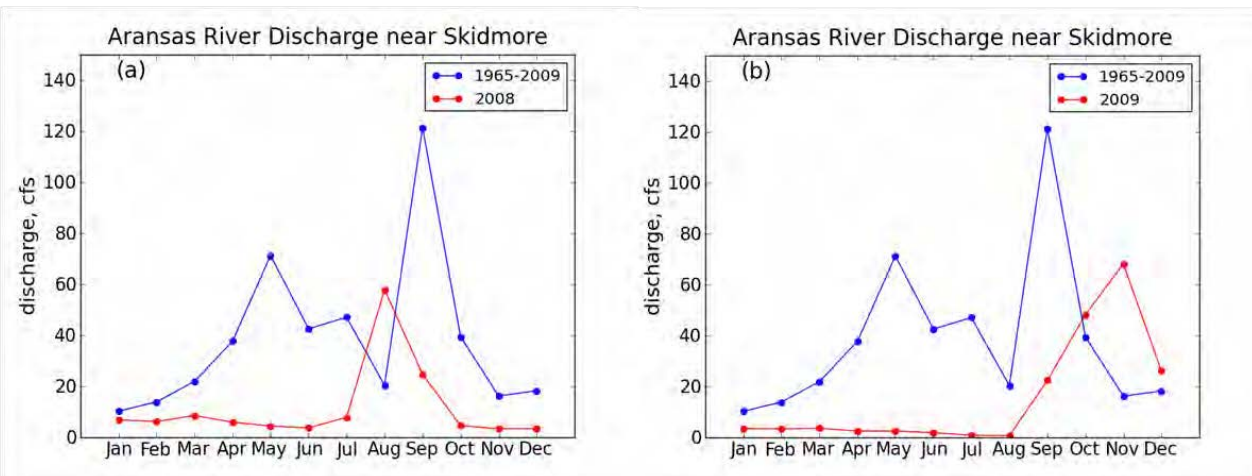


Figure 22. Monthly averaged discharge for Aransas River for (a) 45 years (blue) and 2008 (red) (b) 45 years (blue) and 2009 (red).

Velocity Analysis Results

Individual plots for the Aransas River Tidal ADV deployments can be found in Appendix 2. Here we present summary results of the analysis. Flow speed and direction exhibited diurnal variation with the flood and ebb cycles of the tide (Appendix 2, Figures 33 – 41). In May 2008, flow was quiescent with occasional strong upstream and downstream currents and showed high frequency oscillations (Appendix 2, Fig. 33). For this reason, extracting the tidal and residual velocity components using the low-pass filter was difficult. Currents in March 2008 (Fig. 23) as well as between June 2008 and September 2009 were characterized by oscillations that were of tidal nature and had amplitudes that varied among the different deployments. The maximum range was noted in August 2008 with upstream currents of 2.0 ft/s and downstream flow velocity of 0.65 ft/s. November 2009 had the weakest flow velocity within ± 0.30 ft/s except for few instances when it was close to 0.65 ft/s. Significant downstream flow (up to 1.0 ft/s; Figure 24) were seen in September 2009. In 2008, there was no notable change in the flow pattern among the different deployments, whereas in 2009, there was more pronounced variation in the mean current velocities and a shift in the net flow direction from upstream to downstream was noted in September 2009. This may be the typical flow pattern in the middle reach with tide driven upstream flow prevailing during the dry periods and flow direction becoming downstream with increased freshwater flows in the rainy season. Maximum velocities occurred in the summer in both study years and minimum velocities were recorded in the spring deployments in both 2008 and 2009.

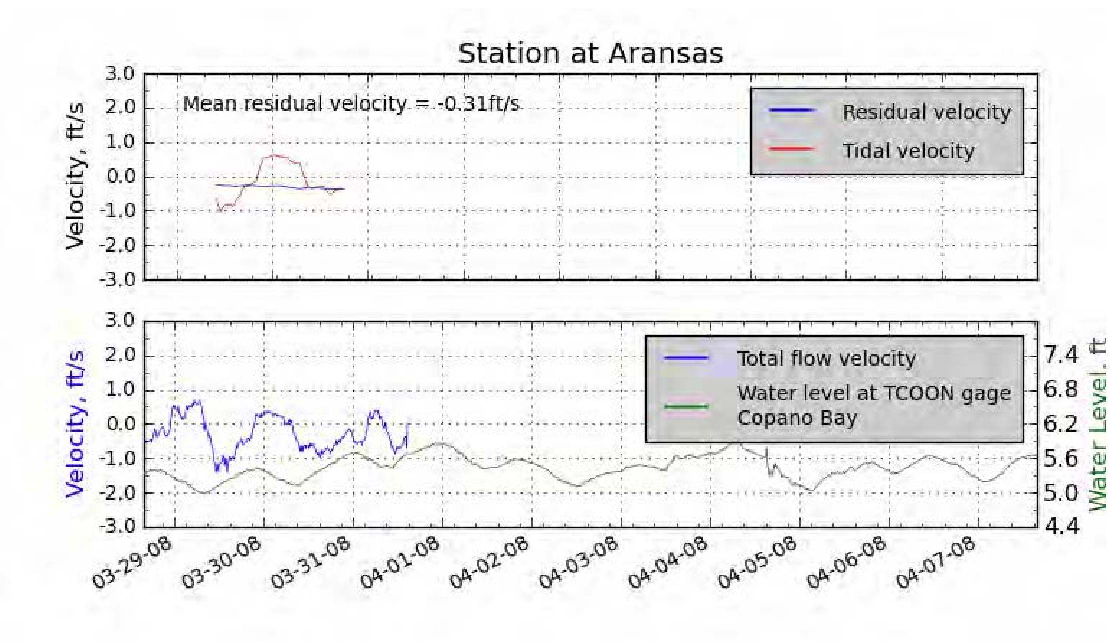


Figure 23. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) at A2, Aransas River during March 2008 deployment.

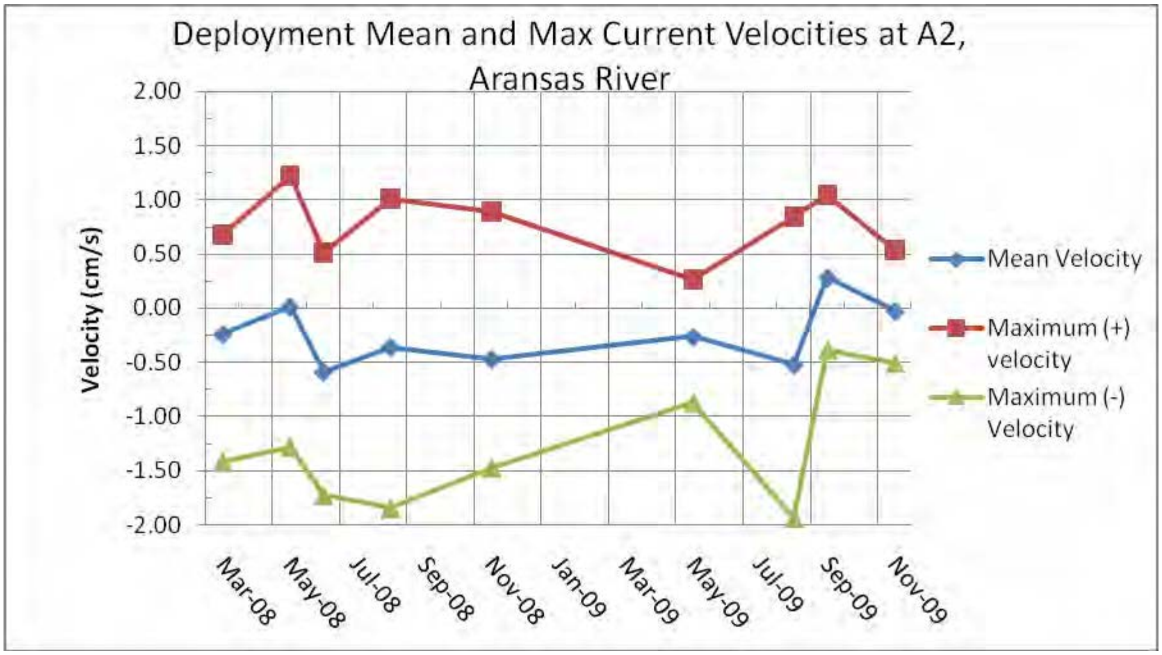


Figure 24. Deployment mean flow velocities at A2, Aransas River (March 2008 – November 2009).

Investigation of the mean flow velocities (Figure 25) shows a net upstream flow in six of the nine datasets that had sufficient length for statistical analysis. In general, the periods with upstream flow were associated with relatively strong upstream residual flow (Table 18) which is driven by south-easterly winds. From the low-pass filtering, it could be seen that the maximum current velocities coincided with the flooding cycle of the tidal flow (Appendix 2, Figures 33 – 41). All of the maximum flow velocities were upstream except in September 2009.

Flow Analysis Results

To gain more insight into the stream flow pattern during the study period, the stream discharges estimated from the regression equation were plotted against the discharge from a USGS gage located near Skidmore, TX. As in the case of Mission River, there was no correlation between gage flow and the estimated residual discharge. The estimated residual discharge in A2 was variable both in magnitude and direction of flow (Fig. 26) unlike the gage flow, with values ranging from – 309 cfs to 37 cfs. The variation in the net stream flow magnitude and direction noted during the study period was a strong function of the tidal forces. Moreover, south-easterly wind forces that were prevalent during the study period enhanced the upstream flow which was noted in all but the May 2008 and September 2009 residual flows (Appendix 2, Figures 42 - 48).

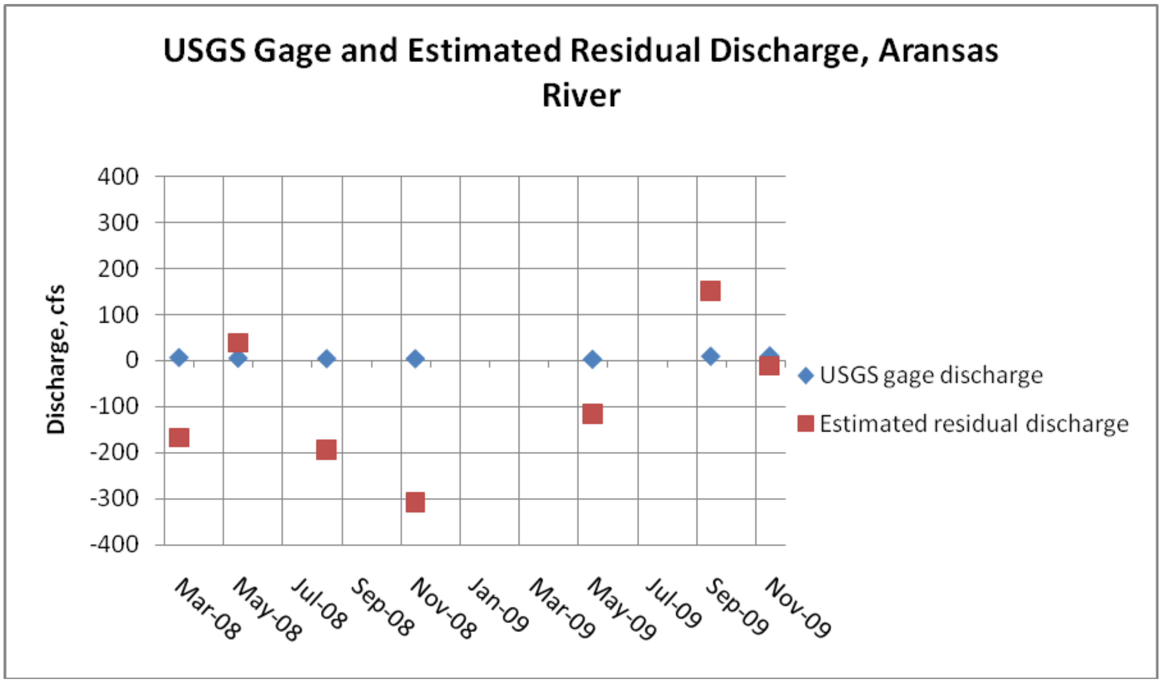


Figure 25. Deployment mean residual discharge (estimated) at A2 and mean measured discharge at USGS gage near Skidmore, Aransas River (March 2008 – November 2009).

Table 18. Mean residual and total flow velocities at A2, Aransas River.

Deployment Start Date	Mean Residual Velocity (ft/s)	Mean Total Velocity (ft/s)
28-Mar-08	-0.31	-0.24
13-May-08	0.07	0.02
5-Aug-08	-0.36	-0.36
3-Nov-08	-0.57	-0.47
12-May-09	-0.21	-0.26
22-Sep-09	0.28	0.28
3-Nov-09	-0.02	-0.03

Discharge was highly variable in both the D-A1 and D-A2 stations within the 15-20 minutes when the replicate discharge measurement transects were made (Fig. 26). The standard deviations for total discharge were 117 cfs and 109 cfs at D-A1 and D-A2 respectively making up 70% and 28% of the respective sampling mean discharges. The standard deviations for the measured discharges as percentage of the mean discharges were about the same as those for the total discharges at 73% and 28% for D-A1 and D-A2 respectively.

One indicator of the accuracy of discharge measurements given by the RiverSurveyor is the ratio of the estimated to measured discharge; lower ratio meaning that errors associated with assumptions made for extrapolating velocity profiles are minimized. In the Aransas River transects the estimated to measured discharge ratios were 0.77 and 0.60 at D-A1 and D-A2 respectively. The top and bottom discharge estimates together make up for 90% of the total estimated discharge (see Appendix 2).

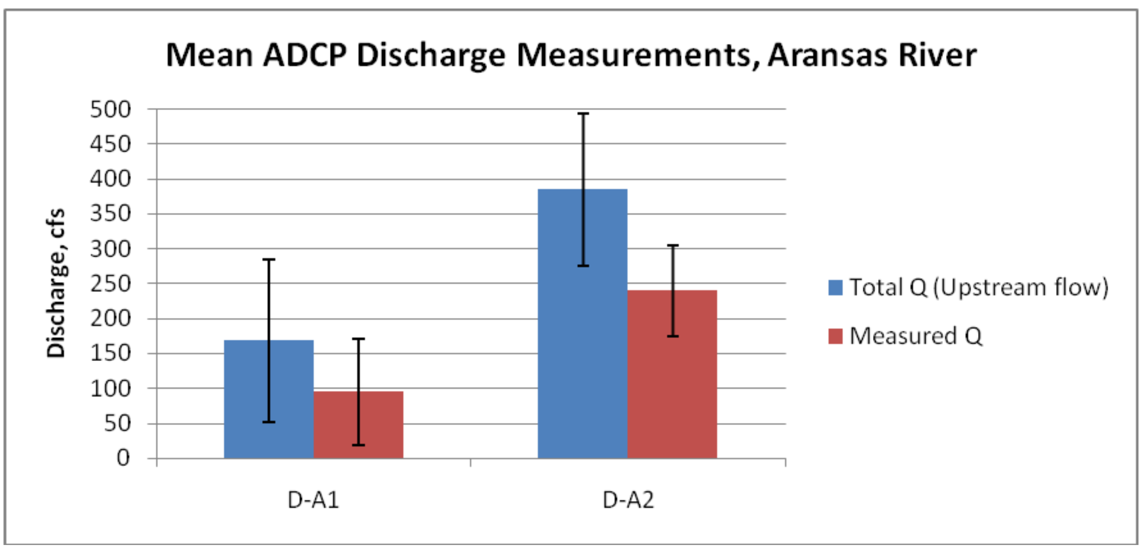


Figure 26. Mean measured and total (measured + estimated) ADCP discharge measurements at Aransas River stations (June 23, 2009).

Water Quality

Physiochemical Profiles

Field parameter surface measurements from each station are summarized in Table 19. Despite similar sized watersheds, mean salinities were approximately two-to-three times higher in the Mission River when compared to similar stations on the Aransas River, and these differences in salinities were also noted in the vertical water column profiles collected on each river. Additionally, temporal differences in mean salinity were also noted, with dramatically increasing salinity seen on both study streams during the entire sampling season of 2009 (Fig. 27). The drought of 2007-2009 was the most severe droughts to affect the region since the all-time record drought of the 1950s, with 2008 being one of the driest years on record. Rainfall in these watersheds were approximately 17 to 20 inches below normal, and overall rainfall between September 2007 and August 2009 was among the driest such periods on record (U.S. Drought Monitor Archive, 2010). This persistent drought was finally broken in the fall sampling period of 2009, as evidenced by the wide ranging error bars for this season (Fig. 27). Late summer and early fall rain events resulting from El Nino conditions allowed salinities to fall from their high of 41.02 at the Upper station on the Mission River and 15.82 on the Aransas River to more normal values of 0.2 and 1.4, respectively. While temperature, dissolved oxygen, and pH were quite similar between the upper stations on both streams, surface dissolved oxygen and pH were more generally higher in the Aransas River.

The mid-depth field parameters revealed little indication of vertical stratification in either of the water columns. Dissolved oxygen was the only parameter to show substantial differences from the surface to the bottom. While dissolved oxygen readings were generally higher on the Aransas River at all levels of the water column, bottom readings of dissolved oxygen were lowest at the Upper station (AR 1). Bottom measurements of dissolved oxygen ranged from anoxic (0.21 mg/L in Sep 2008) to nearly 100% saturated (8.84 mg/L in Apr 2008), with the mean value of 3.72 mg/L being slightly less than the water quality standard of 4.0 mg/L identified for tidally influenced systems. On both streams, vertical stratification was even less evident on the lower tidal reaches, and low dissolved oxygen concentrations were generally not encountered at these stations (see Table 20).

Principal component analysis of the surface field parameter measurements revealed that the first two components explained 70.4% of the variability (Table 22), and the ordination of these stations are presented in Fig. 28. The first component corresponds primarily to dissolved oxygen concentrations (negatively loaded) and inflows (salinity is positively loaded, see Fig.29), and this component

Table 19. Surface-water field parameters by station for the Mission and Aransas Rivers. Specific conductance (Sp. Cond) in µmhos/cm, salinity in PSU. Data are means (n=12, unless otherwise noted). Standard deviations are presented in parentheses.

	Temp (^oC)	pH	DO mg/L	DO %Sat	Sp. Cond	Salinity	Secchi (m)
MR 1	26.61 (4.3)	8.15 (0.3)	6.40 (1.4)	87.63 (18.2)	27110.1 (21477)	17.28 (14.4)	0.63 (0.2) [a]
MR 2	26.69 (4.2)	8.14 (0.2)	6.13 (1.2)	85.48 (12.7)	30350.3 (21853)	19.50 (14.9)	0.58 (0.2) [a]
MR 3	26.10 (4.2)	8.07 (0.2)	5.94 (1.4)	84.97 (16.4)	39175.0 (19989)	25.40 (14.0)	0.47 (0.1) [a]
AR 1	27.00 (4.4)	8.48 (0.2)	7.64 (1.1)	98.95 (10.5)	9236.6 (9242)	5.38 (5.6)	0.42 (0.2) [a]
AR 2	26.89 (4.2)	8.42 (0.2)	7.53 (1.1)	98.05 (14.2)	12779.2 (11880)	7.62 (7.4)	0.50 (0.2) [a]
AR 3	26.94 (3.9)	8.37 (0.2)	7.73 (1.2)	103.5 (20.4)	20571.7 (15434)	12.69 (10.1)	0.43 (0.1) [a]

[a] n=10, Secchi disk readings missing from Surface Profile measurements taken during September 2008 and May 2009.

Table 20. Mid-depth field parameters by station for the Mission and Aransas Rivers. Specific conductance (Sp. Cond) in µmhos/cm, salinity in PSU. Data are means (n=12, unless otherwise noted). Standard deviations are presented in parentheses.

	Temp (^oC)	pH	DO mg/L	DO %Sat	Sp. Cond	Salinity
MR 1	26.52 (4.3)	8.13 (0.3)	5.89 (1.7)	80.58 (19.0)	27687.9 (21406)	17.68 (14.4)
MR 2	26.66 (4.3)	8.11 (0.2)	5.58 (1.4)	77.06 (13.7)	31033.7 (22003)	19.95 (15.0)
MR 3	26.13 (4.0)	8.04 (0.2)	5.72 (1.4)	81.75 (14.0)	42138.3 (17046)	27.39 (12.2)
AR 1	26.76 (4.0)	8.32 (0.3)	5.77 (2.0)	74.18 (23.2)	10618.3 (9722)	6.22 (5.7)
AR 2	26.64 (4.2)	8.36 (0.3)	6.63 (1.9)	86.44 (22.9)	13357.9 (12260)	7.99 (7.7)
AR 3	26.85 (3.9)	8.35 (0.2)	7.52 (1.6)	100.7 (17.5)	21045.0 (15152)	12.95 (9.9)

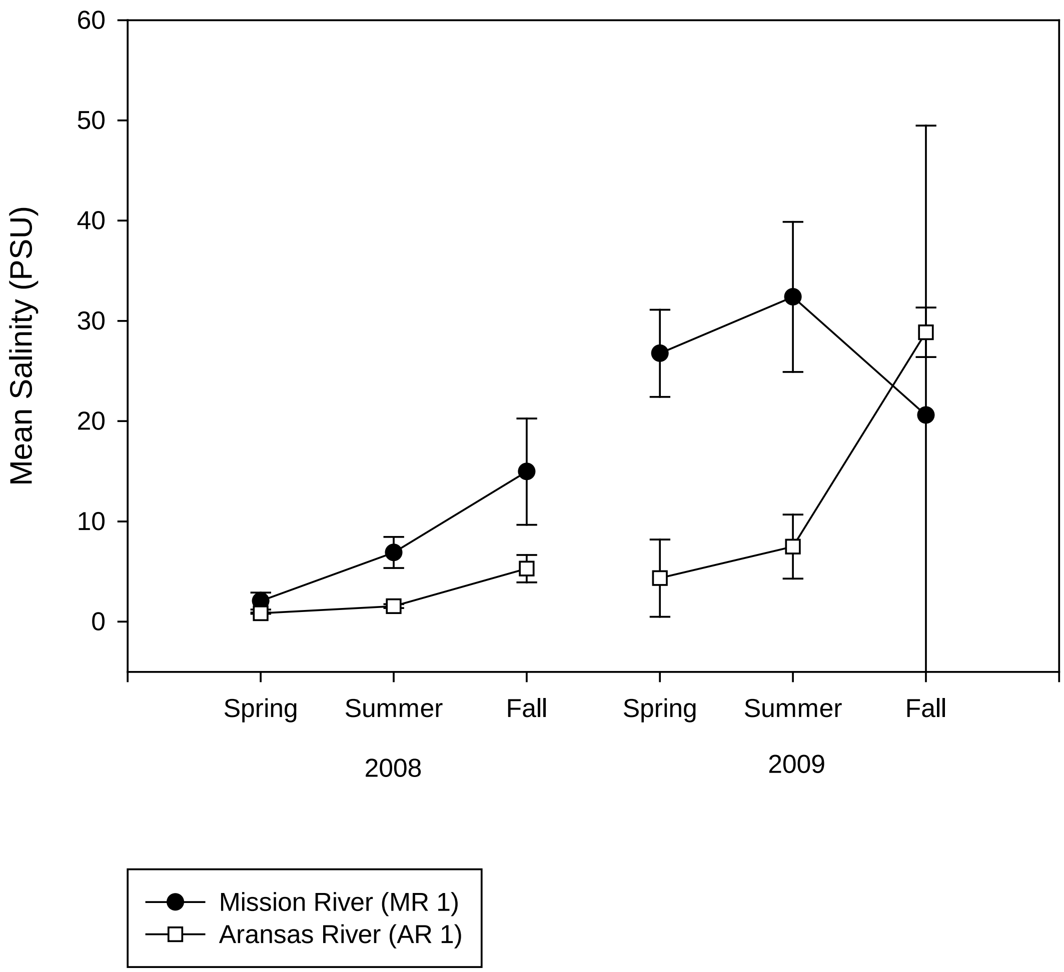


Figure 27. Time series of mean salinity measurements at the upper-most stations on the Mission and Aransas Rivers. Error bars are ± 1 standard deviation.

Table 21. Bottom-water field parameters by station for the Mission and Aransas Rivers. Specific conductance (Sp. Cond) in µmhos/cm, salinity in PSU. Data are means (n=12, unless otherwise noted). Standard deviations are presented in parentheses.

	Temp (^{o}C)	pH	DO mg/L	DO %Sat	Sp. Cond	Salinity
MR 1	26.86 (4.6)	7.98 (0.3)	4.06 (2.5)	57.72 (27.7)	30911.5 (21979)	19.88 (14.9)
MR 2	26.76 (4.5)	8.04 (0.2)	4.87 (1.6)	67.96 (18.8)	32800.8 (21427)	20.99 (16.7)
MR 3	26.05 (3.9)	7.94 (0.3)	5.26 (1.7)	74.63 (18.9)	42721.7 (16495)	27.80 (11.8)
AR 1	26.95 (4.1)	8.12 (0.5)	3.72 (2.6)	48.36 (31.3)	15230.0 (13618)	9.21 (8.7)
AR 2	26.72 (3.9)	8.21 (0.4)	5.36 (2.5)	70.48 (31.4)	16082.5 (12843)	9.67 (8.1)
AR 3	26.81 (3.9)	8.31 (0.3)	7.37 (1.7)	98.52 (19.8)	21526.7 (14956)	13.24 (9.8)

Table 22. Correlations of the field parameter surface measurements – temperature (^{o}C), salinity (in PSU), and Secchi depth (m) – with the first 3 principal components, percent variation (cumulative percentage) for each principal component, and eigenvalues for the Mission and Aransas Rivers.

Principal Component	Cumulative Percent	Eigenvalue	Temp	pH	DO mg/L	Salinity	Secchi
PC1	46.6	2.33	0.242	-0.485	-0.580	0.530	0.297
PC2	70.4	1.19	-0.795	-0.464	0.114	-0.131	0.349
PC3	87.1	0.84	-0.214	-0.347	-0.272	-0.029	-0.871

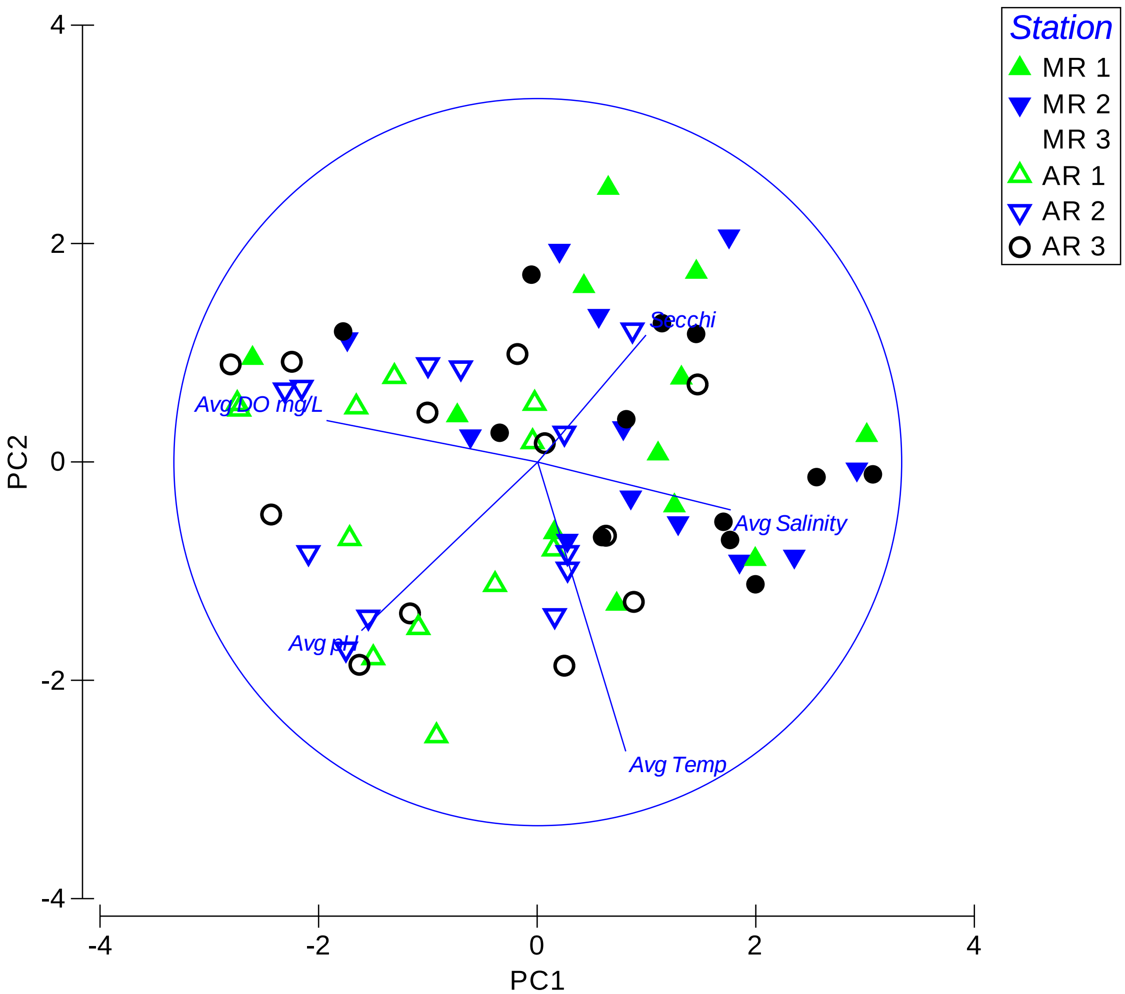
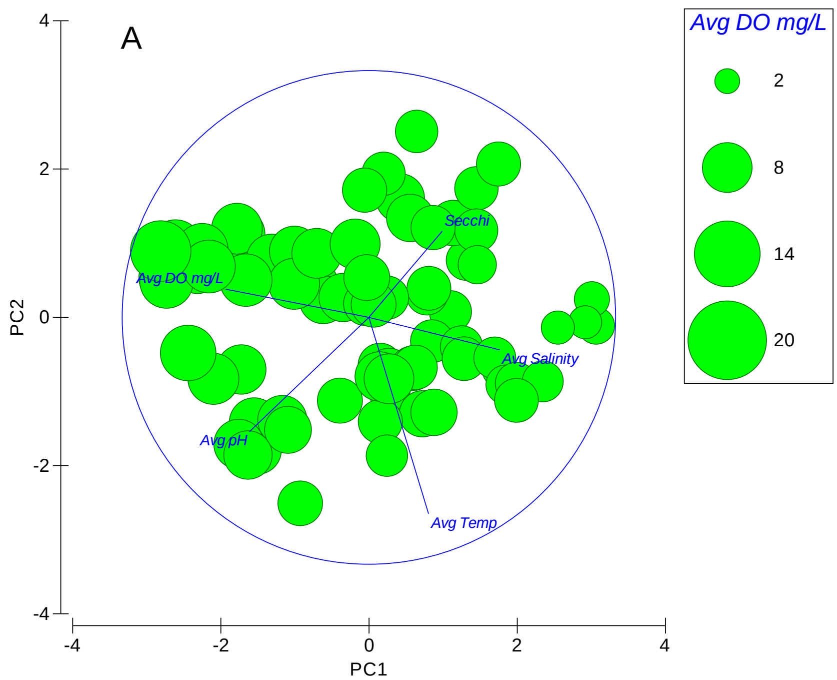


Figure 28. Principal component analysis ordination of the stations, based on surface measurements of field parameters, taken from the Mission and Aransas Rivers. Vector overlays of the variables used in the analysis correspond to Table 22. Length and direction of each vector reflects variable loading on each principal component axis.



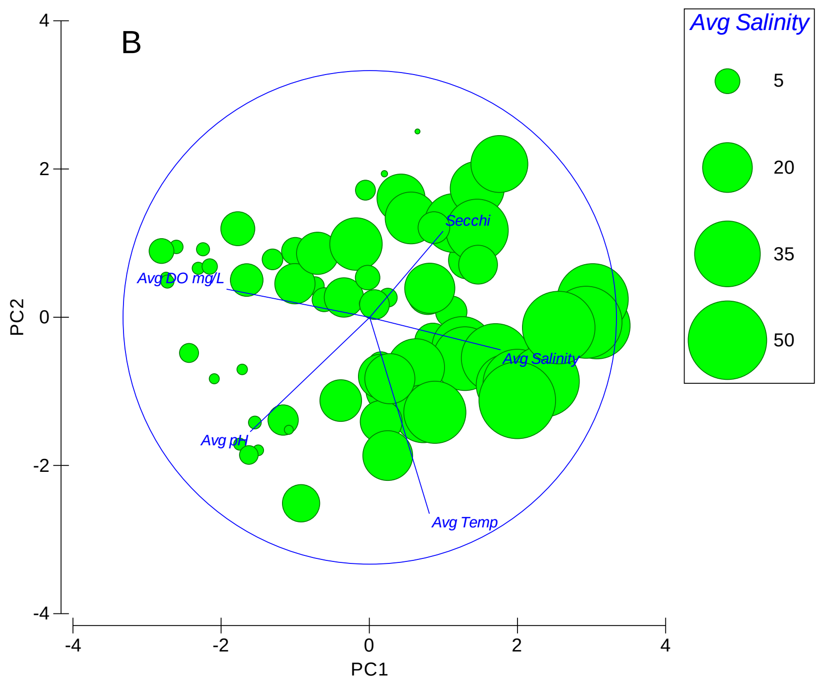


Figure 29. Principal component analysis ordination of the stations based on surface measurements of field parameters taken from the Mission and Aransas Rivers. Station configuration based on Fig. 27, but overlaid onto each station are: A = average DO measurements, and B = average salinity measurements. Size of each circle is represented by the scale at right for each figure.

generally separates the two study streams, with the Aransas River, being generally the fresher system, scoring much more negative values along principal component 1. Temperature, and secondarily pH, loaded most strongly on the second component, separating the summer sampling events from the other sampling seasons.

Spearman's rank correlations between the surface and mid-depth measurements (based on 1,000 permutations of the sample labels) was $\rho_S = 0.841$ (*prob*. = 0.001) for the Mission, and $\rho_S = 0.649$ (*prob*. = 0.001) for the Aransas River. Rank correlations between the surface and bottom-water measurements were similarly high on the Mission, $\rho_S = 0.745$ (*prob*. = 0.001), although the correlation coefficient dropped to $\rho_S = 0.379$ (*prob*. = 0.001) between surface and bottom measurements on the Aransas River. Mid-depth collections were also highly correlated with bottom-water collections, with rank correlation of $\rho_S = 0.883$ (*prob*. = 0.001) for the Mission, and $\rho_S = 0.645$ (*prob*. = 0.001) for the Aransas River. These correlations, especially the high degree of correlation found between surface and bottom measurements on the Mission River, confirm the near-absence of vertical stratification within both of these tidal stream systems as outlined in Tables 19 and 21.

Analysis of Similarity (ANOSIM) tests of the surface physiochemical profiles showed that all three stations within both the Mission and Aransas River systems were similar in their physiochemical properties (Global R = 0.119, $p = 0.001$, see Fig. 30). In both rivers, the upper and middle stations were very similar in their water column properties, and the lower-most station was different, albeit not significantly in each case. Cross river comparisons showed that the salinity gradient was the parameter most responsible for any significant differences seen. Pairwise R comparisons showed that the most saline stations (AR 3 and all stations on the Mission River) were significantly different from the fresher stations on the Aransas River (AR 1 and AR 2; R = 0.496 and 0.359, $p = 0.001$, respectively). Similar results can be found with either the mid-depth or the bottom-water measurements, reinforcing the results of the rank correlation tests which failed to find any strong vertical stratification among these study streams.

Short-Term 24-Hour Deployments

Of the 72 total sampling events, 61 (84.7%) had complete 24 hour records. During the 2008 sampling period, only the unit deployed during the May event on the middle station of the Aransas River (AR 2) failed to record any data. Similarly, units that failed to record any data during the 2009 sampling period included those located on the middle station on the Aransas River during May, August, and November, as did the units on the lower station on the Mission River (MR 3) during August and November. Other data deficiencies included dissolved oxygen sensor failures on units at AR 1 (June 2009, November 2009), AR 2 (November 2009), MR 2 (November 2009), and MR 3 (March 2008). Units that lacked pH probes or recorded only specific conductivity were included in the

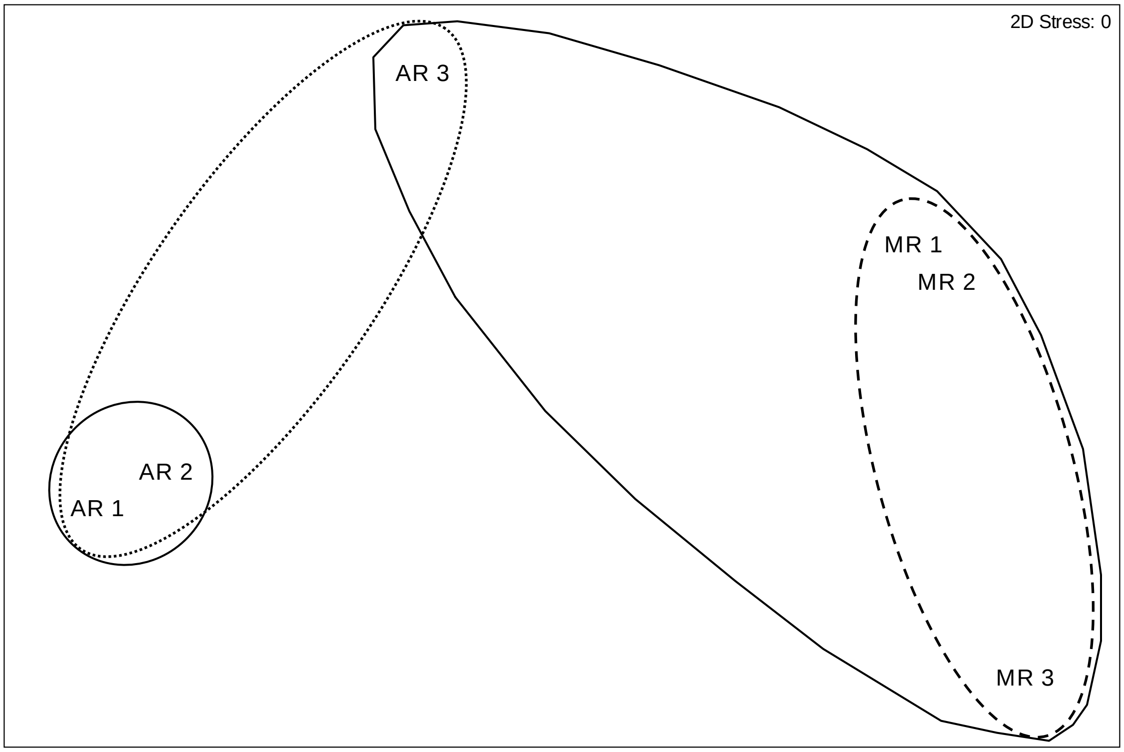


Figure 30. Means plot MDS ordination (Euclidean Distance measure) of the stations based on surface measurements of field parameters taken from the Mission and Aransas rivers. Stations within an ellipse (dashed lines represent within-stream comparisons [thick dashed line, within Mission River comparisons; thin dashed line, within Aransas River comparisons]; solid lines across-stream comparisons) are not significantly different (ANOSIM R < 0.3).

analysis, with the missing parameters estimated with regression relationships between either temperature or salinity. Due to the replicate sampling events, every station had at least one successful datasonde deployment in each season over both sampling years. A summary of the water quality parameters from the short-term deployments is presented in Table 23.

Eigenvectors from the principal components analysis of the datasonde deployment records is presented in Table 24. Because two pairs of variables from each series were highly correlated (dissolved oxygen (DO mg/L) and dissolved oxygen percent saturation (DO % Sat); specific conductance (Sp. Cond) and salinity, DO % Sat and Sp. Cond. were eliminated as these were deemed redundant. The first 2 principal components explained 70.2% of the total variation, and similar to the instantaneous physiochemical profile collections, DO and salinity were also the factors that separated the two study streams (Fig. 31). Stations most positively correlated with the first principal component tended to be summer and fall collections taken during higher salinity and warmer water temperature conditions. These collections also tended to be from the Mission River, where overall DO concentrations were generally lower.

ANOSIM analysis of the datasonde deployments revealed that within each study stream, no differences among the stations were detected (Mission River Global R = -0.009, p = 0.545; Aransas River Global R = -0.032, p = 0.706), although across-streams, a significant difference among the rivers was evident (Global R = 0.06, p = 0.042). The upper stations on the Aransas River (AR 1 and AR 2) were identified as significantly different from all other stations (pairwise R values > 0.3; Fig. 32). This configuration is in agreement with the principle component analysis of Fig. 29, with the more saline and lower DO stations found on the Mission river clustering on the right side of the plot. A general left-to-right increase in mean salinity from AR 1 to MR 3 also reinforces the role of this parameter in identifying each of the study locations.

Water Chemistry and Sediments

Bottom water samples were collected on each sampling trip and summaries of the water chemistry parameters are presented in Table 25. In many cases, sample results reported by the laboratory for a number of parameters were below the established testing detection limits, and in order to include those samples in the multivariate analyses, results for each of these cases were set to one-half of the individual detection limit. Additionally, the reported values for Nitrite-Nitrogen concentrations were either below the detection limit or reported as the detection limit in all samples. Lacking any variability, Nitrite-Nitrogen concentration was excluded from the analysis.

Table 23. Summary statistics of the short-term 24 hour datasondes deployments by station for the Mission and Aransas Rivers. Specific Conductance (Sp. Cond) in µmhos/cm, salinity in PSU.

	MR 1	MR 2	MR 3	AR 1	AR 2	AR 3
Min Temp ^{o}C	19.44	19.39	18.54	21.34	21.73	21.62
Max Temp ^{o}C	33.38	33.26	33.41	33.89	32.41	33.16
Avg Temp ^{o}C	27.47	27.17	26.85	27.15	27.12	26.76
Min DO mg/L	0.99	1.93	1.79	2.27	2.70	1.02
Max DO mg/L	11.74	11.34	10.02	10.21	9.77	11.50
Avg DO mg/L	5.59	6.10	6.33	6.24	6.44	6.20
Min DO %Sat	13.80	31.10	25.30	30.80	36.40	13.50
Max DO% Sat	172.80	183.70	151.90	145.40	135.00	148.50
Avg DO %Sat	78.15	87.34	91.95	80.46	84.29	83.63
Min Sp. Cond	394.0	637.0	3830.0	1372.0	1920.0	1940.0
Max Sp. Cond	62500.0	67300.0	63700.0	30680.0	27000.0	55000.0
Avg Sp. Cond	28660.9	32562.5	39459.3	9893.7	12317.2	19827.9
Min Salinity	0.20	0.33	2.09	0.70	1.00	1.00
Max Salinity	42.10	45.78	45.04	18.89	16.60	39.20
Avg Salinity	18.39	20.89	25.53	5.97	7.24	8.19

Table 24. Correlations of the short-term 24-hour datasondes deployments – temperature (^{o}C), dissolved oxygen (DO mg/L), and specific conductance (in µmhos/cm) – with the first 2 principal components, percent variation (cumulative percentage) for each principal component, and eigenvalues for the Mission and Aransas Rivers.

Principal Component	Cumulative Percent	Eigenvalue	Temp	DO	pH	Salinity
PC1	45.3	1.81	0.324	-0.613	-0.448	0.564
PC2	70.2	0.99	-0.817	0.035	-0.537	0.053

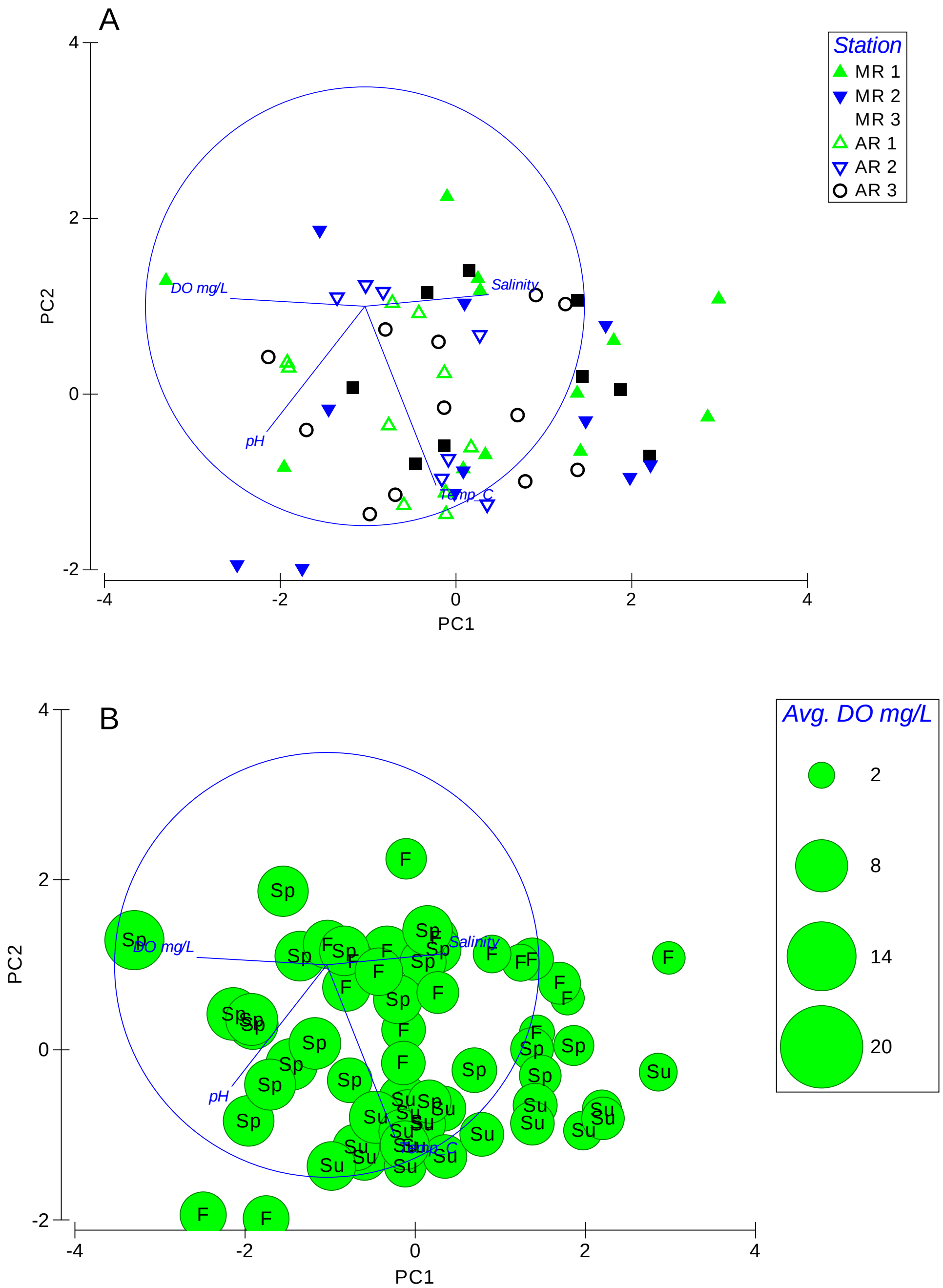


Figure 31. Ordination of stations based on principal components analysis of the short-term 24 hour datasondes deployments. A = Stations configuration with vector overlays of the variables used in the analysis. Length and direction of each vector reflects variable loading on each principal component. B = Configuration identical to A, but overlaid are average dissolved oxygen values for each observation (size of each circle is represented by the scale in the Figure) as well as season of collection designation (Sp = spring, Su =summer, F = fall).

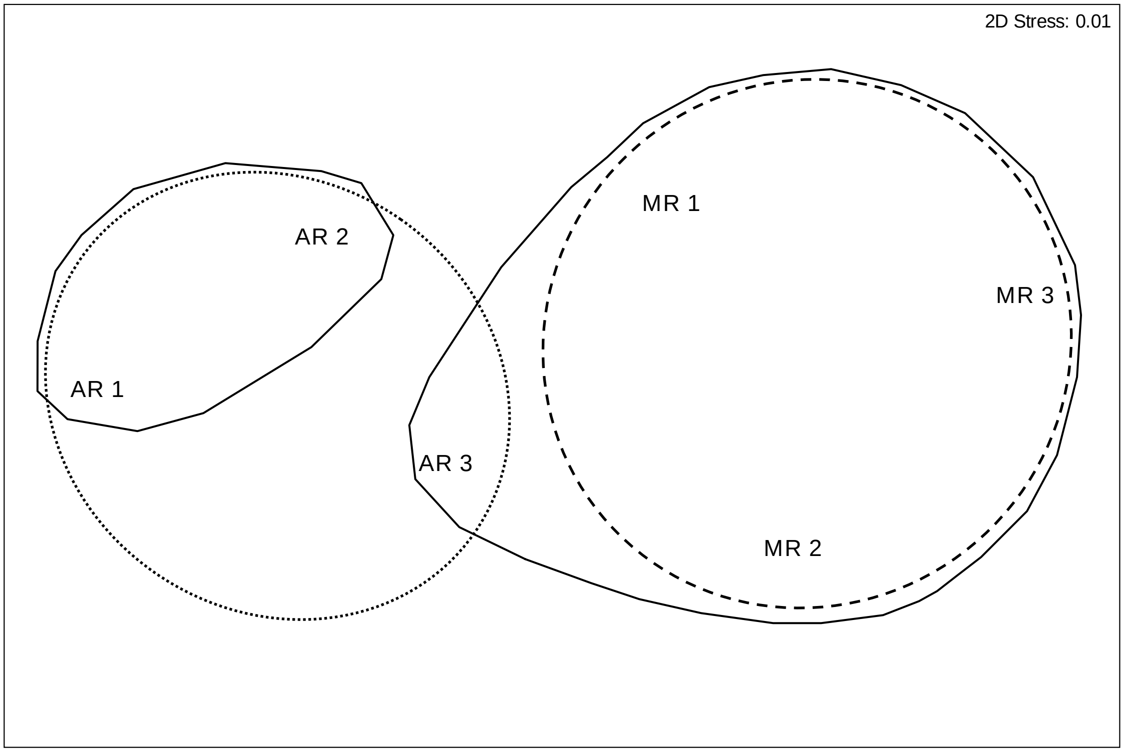


Figure 32. Means plot MDS ordination of the stations based on short-term 24 hour datasondes deployments taken from the Mission and Aransas Rivers. Stations within an ellipse (dashed lines follow Fig. 29) are not significantly different (ANOSIM R < 0.3).

Table 25. Bottom-water chemistry parameters by station for the Mission and Aransas Rivers. Data are means, standard deviations in parentheses. All units are reported as mg/L.

	MR 1	**MR 2**	**MR 3**	**AR 1**	**AR 2**	**AR 3**
BOD[1]	4.80 (2.8)	3.87 (1.6)	4.40 (1.5)	5.83 (2.5)	4.50 (2.0)	3.90 (1.6)
TSS[2]	28.57 (21.9)	36.09 (23.6)	72.50 (33.5)	36.73 (24.0)	36.73 (18.9)	46.37 (19.8)
VSS[3]	10.33 (5.9)	10.31 (5.3)	15.96 (6.9)	11.45 (4.8)	11.58 (4.3)	13.47 (4.7)
TDS[4]	19106.9 (15297)	21440.8 (15390)	28125.0 (12296)	8112.6 (7601.2)	9166.6 (7428.1)	12702.5 (10011)
Ammonia	0.09 (0.1)	0.06 (0.1)	0.06 (0.1)	0.44 (0.6)	0.22 (0.2)	0.04 (0.1)
Nitrate	0.14 (0.2)	0.12 (0.1)	0.10 (0.1)	0.19 (0.3)	0.11 (0.1)	0.12 (0.1)
Nitrite	ND	ND	ND	ND	ND	ND
Total Nitrogen	1.51 (1.0)	1.30 (0.9)	1.17 (0.7)	1.66 (0.9)	1.86 (1.2)	1.70 (0.9)
Phosphorus	0.15 (0.1)	0.13 (0.1)	0.12 (0.1)	0.62 (0.1)	0.45 (0.1)	0.30 (0.1)
Chloride	10683.3 (8176.4)	12095.0 (8397.3)	15787.5 (7226.6)	4130.2 (4026.9)	4526.2 (3659.6)	6899.3 (5456.5)
Sulfate	1391.52 (1040.8)	1556.50 (1074.7)	2051.83 (894.5)	591.69 (540.5)	642.08 (510.8)	927.83 (732.9)
Orthophosphate	0.07 (0.1)	0.05 (0.1)	0.05 (0.1)	0.35 (0.2)	0.21 (0.1)	0.13 (0.1)

[1] BOD – Carbonaceous Biological Oxygen Demand
[2] TSS – Total Suspended Solids (Residue, Non-Filterable)
[3] VSS – Volatile Suspended Solids
[4] TDS – Total Dissolved Solids (Residue, Filterable)

Highly correlated and redundant variables eliminated from the principle components analysis included Sulfate and Total Dissolved Solids (TDS), as both were nearly perfectly correlated with Chloride concentrations. The first 3 components explained 66.9 % of the total variation (Table 26). The first component is reflective of the overall lack of inflow, with increased chloride and suspended solids (both VSS and TSS) loading most positively along the x-axis (Fig. 33a). Stations scoring most positively along component 1 included all the locations on the Mission River, as well as the lower station on the Aransas River. Salinities were noted from these stations to be significantly higher, especially on the Mission River, as evidence by the ANOSIM results presented in Fig. 30. Phosphorus-based nutrients loaded most negatively on component 1, and these stations were physically located closest to the presumed source of these nutrient loads, the numerous wastewater discharge locations above the tidal segment in and around the cities of Beeville (WQ0010124-002 – City of Beeville: 3,000,000 gpd ; WQ0010124-004 – City of Beeville, Chase Field: 2,500,000 gpd), Skidmore (WQ0014112-001 – Skidmore WSC: 131,000 gpd) and Tynan(WQ0014123-001 – Tynan WSC: 45,000 gpd), see Tolan and Nelson, 2008. The second component is also reflective of inflow conditions, as both TSS and VSS loaded most positively. Nitrogen-based nutrient loads (Ammonia-Nitrogen) also loaded highly on the second principle component. The combination of these two components (overall salinity and nutrient loads) effectively separates the two study streams, despite both having approximately the same sized watersheds.

ANOSIM tests of the bottom water chemistry measurements revealed that within each stream, no significant differences in water chemistry was detected among the stations (Mission River Global R = 0.038, p = 0.145, and Aransas River Global R = 0.140, p = 0.002). Across streams, the ANOSIM test revealed that significant differences were evident, with the upper and middle stations on the Aransas River being unique from the remainder of the stations (Fig. 34). This configuration is quite similar to the ANOSIM results of the water quality and 24 hour datasonde deployments, as presented in Figures 30 and 32.

Table 26. Correlations of the surface water quality measurements with the first 3 principal components, percent variation (cumulative percentage) for each principal component, and eigenvalues for Mission River and Aransas River.

	PC 1	PC 2	PC 3
Cumulative Percent	30.2	51.1	66.9
Eigenvalue	2.72	1.89	1.42
BOD[1]	-0.272	0.194	-0.133
TSS[2]	0.371	0.489	0.216
VSS[3]	0.339	0.552	0.153
Ammonia	-0.257	0.375	-0.434
Nitrate	0.121	0.027	0.254
Total Nitrogen	-0.252	0.242	-0.503
Phosphorus	-0.454	0.356	0.228
Chloride	0.406	0.213	-0.345
Orthophosphate	-0.398	0.217	0.486

[1] BOD – Carbonaceous Biological Oxygen Demand
[2] TSS – Total Suspended Solids (Residue, Non-Filterable)
[3] VSS – Volatile Suspended Solids

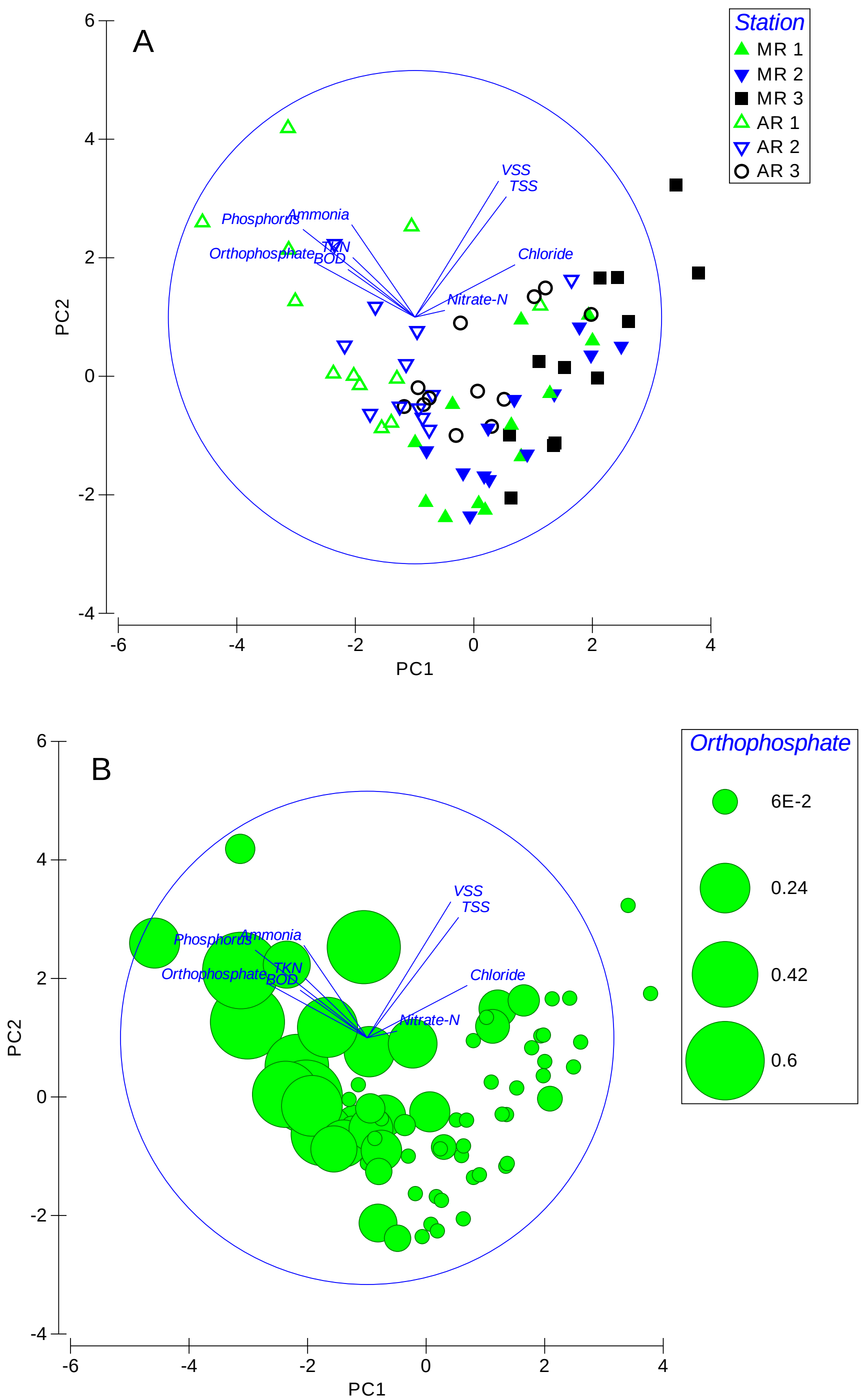


Figure 33. Ordination of the sampling stations based on principal components analysis of bottom water chemistry collections from the Mission and Aransas Rivers. A = Stations configuration with vector overlays of the variables used in the analysis (vectors have been shifted from the graph origin to aid in interpretation); B = Configuration identical to A, but overlaid with Orthophosphate concentrations.

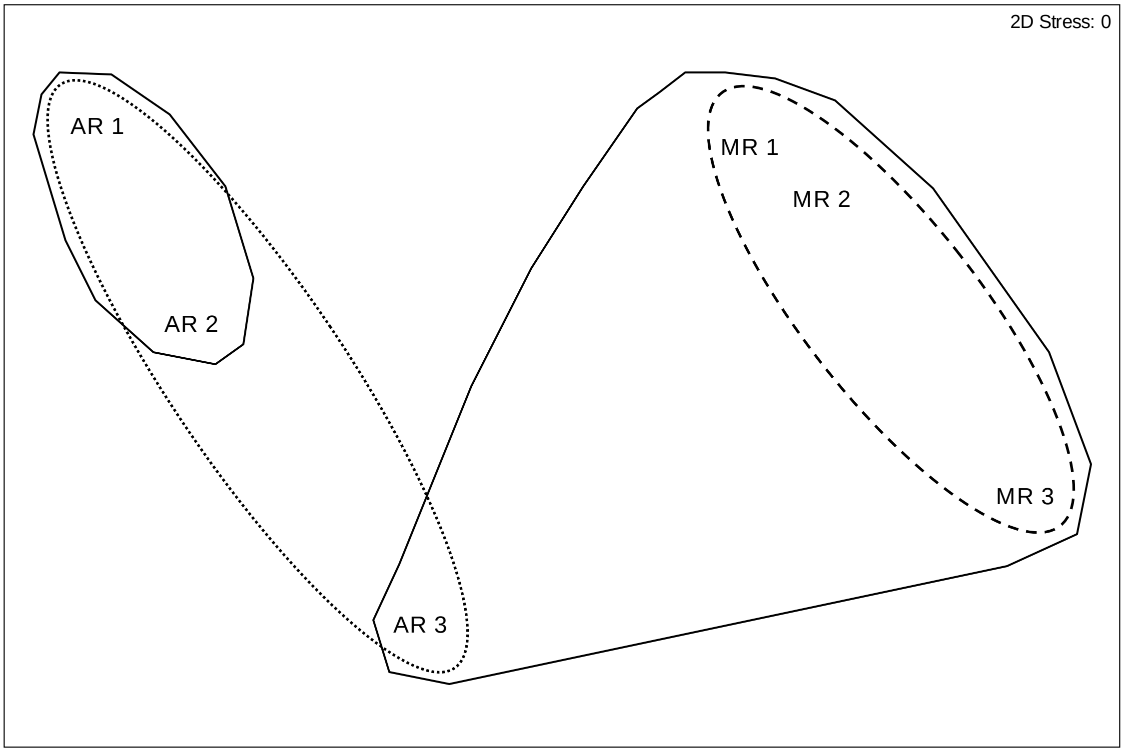


Figure 34. Means plot MDS ordination of the stations based on bottom water chemistry collections from the Mission and Aransas Rivers. Stations within an ellipse (dashed lines follow Fig. 29) are not significantly different (ANOSIM R < 0.3).

Sediment Compositions

Sediment samples were collected at every sampling event, although sediment samples were only collected from the middle of each study stream. Numerous results for Total Organic Carbon-Sediments were reported as 'Non-Detected', and each of these were set to one-half the test detection limit. Non-detected values for each of the fractional grain-size categories were set to 0.001%, as each is within 0.1% rounding error when all the categories are summed. Summary statistics for these collections are presented in Table 27. The first two principal components explain 87.6 % of the variation (Table 28), with the greatest degree of separation of the stations revealed in percent sand or percent clay compositions. Percent moisture content was highly correlated (positively) with percent clay and (negatively) with percent sand (Fig. 35). The only constituent loading heavily on the second component (percent gravel) was noted from only 2 sampling events on the upper station on the Aransas River, and a single event on the middle station on the Mission River. Most stations were dominated by hard sand bottoms, ranging from a low of 61.2% to a high of 94.6% of the mid-channel sediments.

ANOSIM results revealed significant differences in the sediment compositions found within each study stream (Fig. 36). On the Mission River, the lower station was significantly different from the middle and upper stations (Global R = 0.269, $p = 0.001$), while the on the Aransas River the middle station was similar to both the upper and the lower stations (Global R = 0.172, $p = 0.001$). Across-stream comparisons showed that, unlike the orderly arrangement of stations within the MDS plots of the water column parameters, sediment compositions were far more variable and the MDS configurations did not reflect any consistent spatial arrangement. For example, the lower station on the Mission River was most similar to the upper and middle station on the Aransas River. This grouping of stations tended to have higher Total Organic Carbon concentrations, higher percent moisture, and higher percentages of silt and clay. Additionally, despite this set of stations being the most geographically separated (AR 1 is farthest away from MR 3), they each shared the common trait of having the lowest percent sand composition.

Biological Sampling

Nekton Collections

Bag Seines

On the Mission River, a total of 36 bag seine collections yielded 13,119 fishes, representing at least 33 different species from 20 families. Additionally, 5,659

Table 27. Sediment parameters (mid-channel) by station for the Mission and Aransas Rivers. Data are means (n=12). Standard deviations are presented in parentheses.

	MR 1	MR 2	MR 3	AR 1	AR 2	AR 3
TOC[1] Sed	1783.3 (1512.2)	1055.0 (536.9)	3650.8 (3319.1)	6650.0 (7279.1)	2478.3 (3275.3)	1079.2 (620.7)
% Moisture	25.66 (5.8)	23.33 (6.3)	54.22 (16.4)	49.45 (19.2)	32.57 (14.0)	24.63 (3.8)
% Gravel	0.07 (0.1)	0.13 (0.3)	0.01 (0.1)	0.27 (0.5)	0.03 (0.1)	0.05 (0.1)
% Silt	1.98 (1.5)	2.33 (2.8)	9.49 (5.7)	10.98 (5.0)	4.68 (5.2)	2.83 (5.6)
% Clay	5.04 (4.0)	2.92 (3.2)	29.28 (18.4)	24.59 (19.8)	10.19 (2.2)	3.90 (2.2)
% Sand	92.89 (4.1)	94.60 (4.3)	61.22 (23.4)	64.16 (22.8)	85.10 (7.1)	93.21 (7.1)

[1] TOC Sed – Total Organic Carbon, Sediments

Table 28. Correlations of the sediment parameters (mid-channel) with the first 2 principal components, percent variation (cumulative percentage) for each principal component, and eigenvalues for the Mission and Aransas Rivers.

Principal Component	Cumulative Percent	Eigenvalue	TOC Sed	% Moisture	%Gravel	% Silt	% Clay	% Sand
PC1	71.6	4.30	-0.408	-0.457	-0.136	-0.407	-0.464	0.476
PC2	87.6	0.96	-0.125	0.092	-0.971	0.115	0.101	-0.099

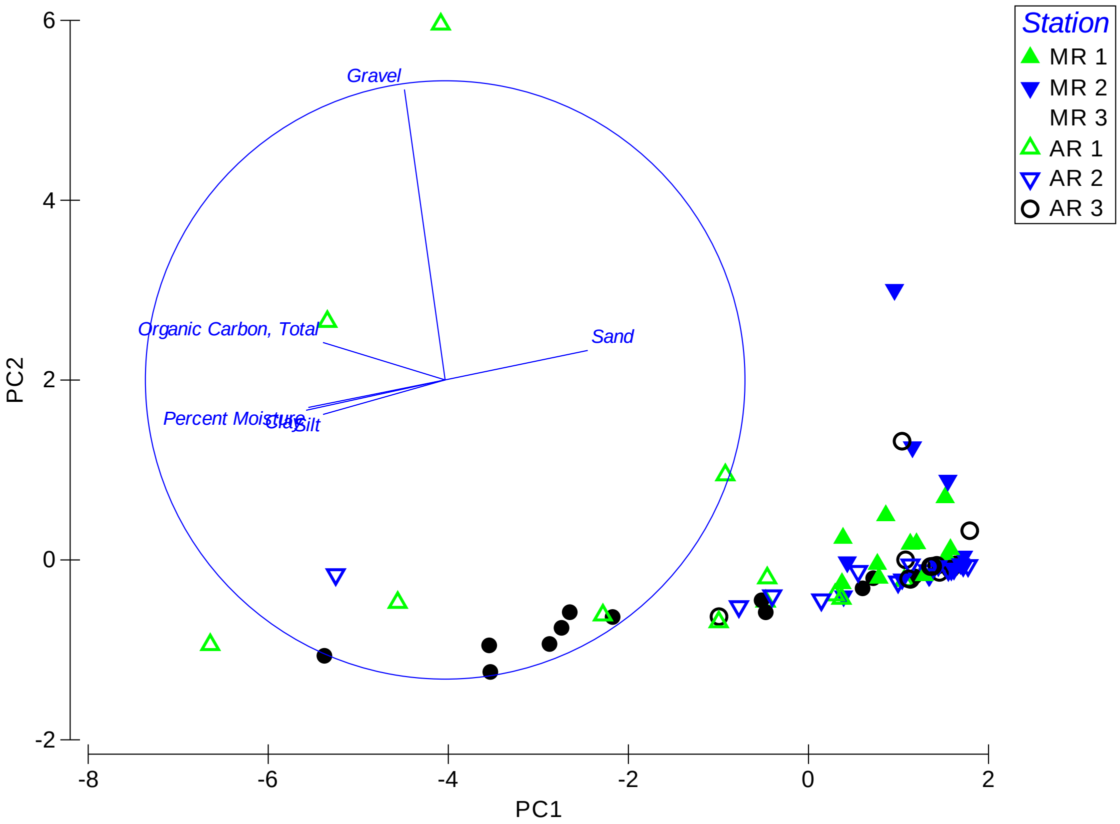


Figure 35. Ordination of the stations based on principal components analysis of sediment parameters (mid-channel) from the Mission and Aransas Rivers.

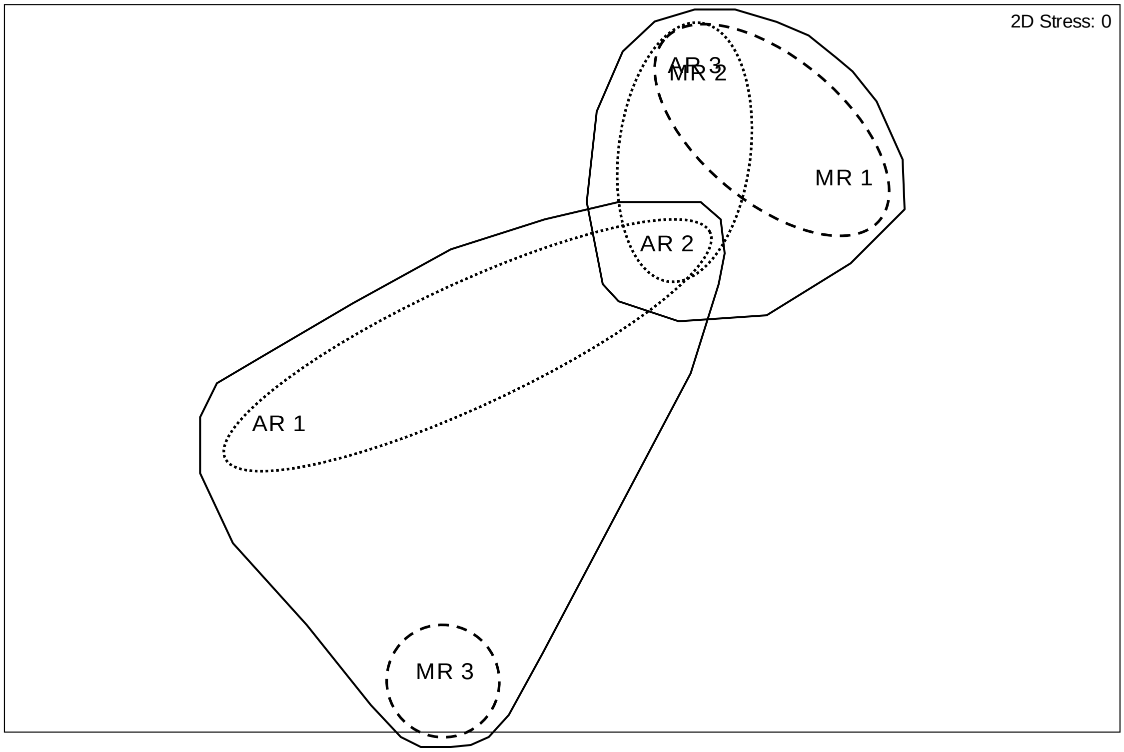


Figure 36. Means plot MDS ordination of the stations based on sediment parameters (mid-channel) taken from the Mission and Aransas Rivers. Stations within an ellipse (dashed lines follow Fig. 29) are not significantly different (ANOSIM R < 0.3).

invertebrates from 10 different species in 7 families were also collected. Numerically, three finfish species accounted for > 90 % of the total number of individuals (bay anchovy *Anchoa mitchilli* 42.5 %; Gulf menhaden *Brevoortia patronus* 42.1 %, and silversides *Menidia* spp. 3.1 %). The invertebrate collections were also dominated by just a few taxa, with >90 % of the collection comprised of brown shrimp *Farfantepenaeus aztecus* (45.2 %), grass shrimp *Palaemonetes* spp. (33.4 %) and white shrimp *Litopenaeus setiferus* (13.8 %). A complete taxonomic list of fishes, with total numbers of individuals, is given in Appendix 3. The invertebrate taxonomic list in presented in Appendix 4. Numerically, more individuals were collected with the bag seines on the Aransas River. A total of 21,645 fishes, representing 44 different species in 24 families were found. A total of 7,861 invertebrates from 7 species in 4 families were recorded. While a larger and mose diverse collection of finfish were noted from the Aransas River, the relative proportion of the dominant taxa was generally similar between the study locations. Bay anchovy (44.2 % of the catch), Gulf menhaden (26.6 % of the catch), and silversides (14.2 %), with the addition of sheepshead minnow *Cyprinodon variegatus* (2.2 %), sailfin molly *Poecilia latipinna* (2.1 %), and Gulf pipefish *Syngnathus scovelli* (1.5 %) making up > 90 % of the total finfish collections. Invertebrates on the Aransas River were also dominated by grass shrimp (42.9 %), brown shrimp (40.0 %), and white shrimp (14.2 %), with these three species making up > 90 % of the collections.

MDS configurations of the bag seine collections are shown in Fig. 37. Little degree of separation was seen within each stream, with only the lower-most station on the Aransas River (AR 3) noted as having a different community composition within the nekton. Across the study streams, a high degree of overlap was evident, with many of the marine species most prominent in the lower stations being found well upstream due to the general lack of inflows noted from the Fall 2008 period and lasting through the Fall 2009 period (see Fig. 27). ANOSIM results amongst the stations are presented in Fig. 37, with the high degree of community overlap among the stations evident by the low Global R value of this test (Global R = 0.178; *prob*. = 0.001). The only stations falling outside the resulting overlapping community compositions were located at the spatially and environmentally most disparate locations. The freshest station (AR 1) and the most saline station (MR 3) were the two locations physically farthest apart, and each noted from previous analyses as being physically and chemically distinct. Biologically, these two extremes had the most distinct communities over the course of this study, with all other stations within the gradient of conditions between the streams having similar nekton communities.

Comparisons of the nekton communities seen in these station groupings were explored with the SIMPER analysis (Table 29). Bay anchovies made up the majority of the catch among all the station groups, although they were more than twice as abundant in the highest salinity conditions, and were responsible for the greatest differences in the community compositions between the freshest and

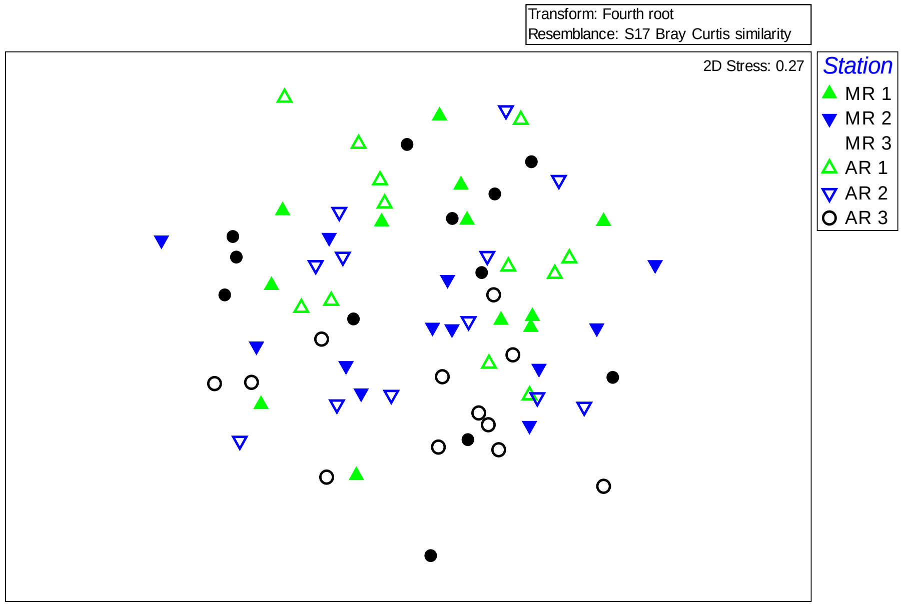


Figure 37. MDS configuration of the stations based on bag seine collections from the Mission and Aransas Rivers.

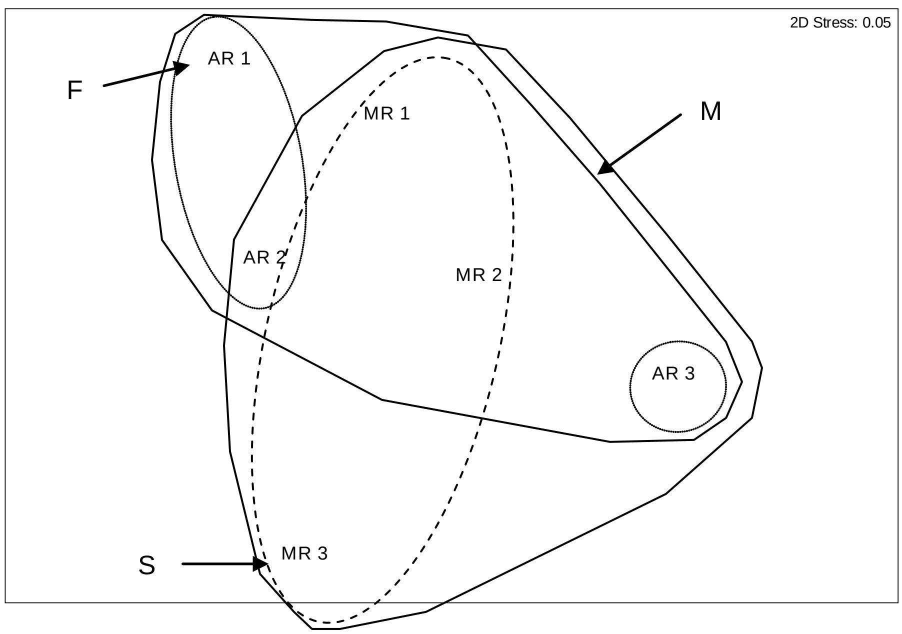


Figure 38. Means plot MDS ordination of the stations based on bag seine collections from the Mission and Aransas Rivers. Stations within an ellipse (dashed lines follow Fig. 29) are not significantly different (ANOSIM R < 0.3). Designations of the Freshest (F), Mixed (M), and Saline (S) conditions are used for subsequent SIMPER analysis.

Table 29. The contributions of species comprising the top 90 % of the nekton community as identified by bag seines among the overlapping groups of sations identified in the ANOSIM procedure. The freshest (Group F), mixed (Group M), and most saline (Group S) stations on the Mission and Aransas Rivers are those designated in Fig. 38. Average abundance (Av. Abund) is measured as number of individuals per 20 m shoreline. Percent contribution (%) to the average dissimilarity and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) value for the Group F and Group S comparison is also presented.

	Group F	**Group M**	**Group S**	**Group F vs. Group S**	
Species	**Av.Abund**	**Av.Abund**	**Av.Abund**	**%**	**Ratio**
Bay anchovy	90.86	112.07	188.29	37.03	1.12
Tidewater silverside	24.86	35.89	5.06	6.63	0.86
Grass shrimp	17.24	36.59	77.41	15.67	1.01
Western mosquitofish	5.93	3.10	0	1.34	0.45
Sailfin molly	3.79	5.59	0.13	1.39	0.57
Sheepshead minnow	3.33	4.96	0.67	0.84	0.42
Ladyfish	2.88	1.00	0.06	1.21	0.37
Striped mullet	2.17	4.99	8.69	2.18	0.50
Brown shrimp	2.00	56.20	32.65	6.73	0.69
Naked goby	1.94	3.22	0.92	0.77	0.40
White shrimp	1.11	18.69	8.48	3.24	0.61
Silver perch	1.00	0.58	2.67	1.30	0.41
Gulf menhaden	0.75	82.85	137.92	15.61	0.54
Total % Dissimilarity	67.82	76.66	73.56	76.10	

most saline groups. Grass shrimp, Gulf menhaden, and brown shrimp were similarly far more abundant in saline conditions, ranging from 4.5 times to many orders of magnitude more abundant, and each of these species contributed greatly to the differences seen in the station groupings. Species that were more abundant in the freshest conditions included silversides (4.9 times more abundant), western mosquitofish *Gambusia affinis* (not found in the most saline group), sailfin molly (29.2 times more abundant), and sheepshead minnow (4.9 times more abundant). While these species were characteristic of the freshest group, their contributions to the measured dissimilarity were generally low (see Table 29).

Community structure, as measured by the bag seines, was highly influenced by temporal seasonality, as can be seen in Fig. 39a (ANOSIM Global R = 0.433; *prob*. = 0.001 for Mission River and Global R = 0.375; *prob*. = 0.001 for Aransas River). Spring and fall collections had the most distinct nekton communities, with the summer nekton communities overlapping the summer and fall periods on each river. SIMPER results of the seasonality factor are presented in Table 30. Striped mullet *Mugil cephalus* CPUE is presented as an example of this seasonality (Fig. 39b), with this species found primarily in the more saline stations during the spring and summer seasons.

Trawls

Similar to the bag seine collections, total numbers in the trawl collections were lower in the Mission River, with 27,968 fishes representing 27 species from 17 different families recorded. Bay anchovy accounted for 91.2 % of the total, with Gulf menhaden comprising only 5.6 % of these collections. Together, these two species made up the vast majority of the trawl catch. Invertebrate numbers were far lower in the trawls, with only 169 individuals from 5 species in 4 families encountered. Brown shrimp (55.1 % of the total), white shrimp (30.2 %), and Atlantic brief squid *Lolliguncula brevis* (9.5 %) made up the majority of the collections. A total of 41,142 individuals from 29 species in 16 families were recorded from the Aransas River, with an additional 205 invertebrates (9 species from 7 families) taken with the trawls. Finfishes in the Aransas River were similarly dominated by bay anchovy (73.2 % of the total) and Gulf menhaden (23.0 %). A nearly identical makeup of the invertebrate collections accounted for > 90 % of the collections in this system, although white shrimp were most abundant (54.1 % of the total), followed by brown shrimp (35.6 %), and Atlantic brief squid (4.4 %).

MDS configurations of the trawl collections are shown in Fig. 40. No differences in the nekton communities were encountered within either river (Mission River Global R = 0.022; *prob*. = 0.206; Aransas River Global R = -0.032; *prob*. = 0.856;), nor across rivers (Global R = 0.018, $p = 0.153$, see means plot MDS of Fig. 41). Although the nekton communities amongst the stations within the

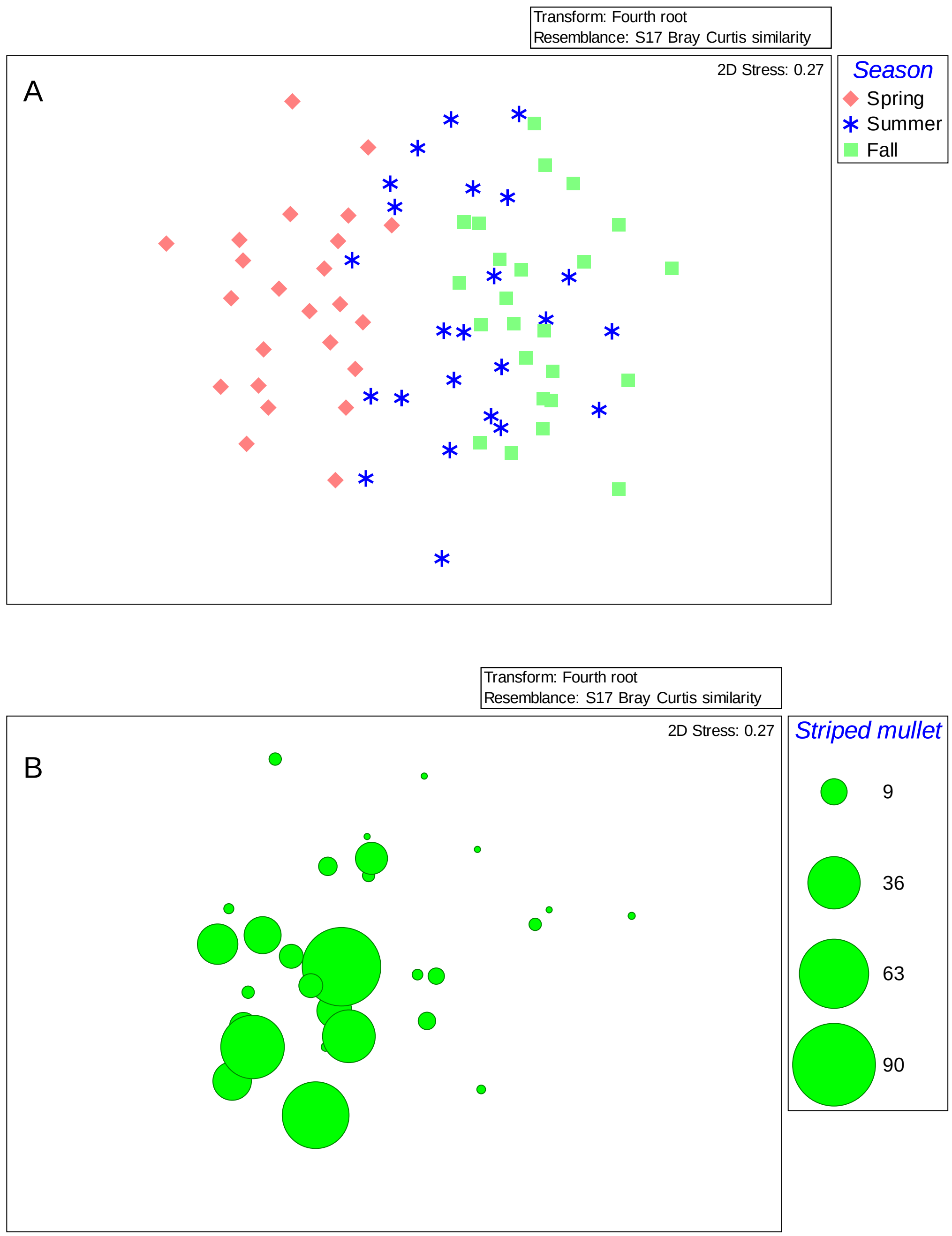


Figure 39. MDS configuration of the stations based on bag seine collections from the Mission and Aransas Rivers. Station configuration based on Fig. 36, but overlaid onto each station are: A = season of collection, and B = striped mullet CPUE. Size of each circle is represented by the scale at the right.

Table 30. Comparisons of the fish assemblages collected seasonally with bag seines during spring (Sp), summer (Su) and fall (Fa) on the Mission and Aransas Rivers. Percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. A dashed line (-) represents no species contribution to the comparison.

	Sp vs. Su		Sp vs. F		Su vs. F	
Species	**%**	**Ratio**	**%**	**Ratio**	**%**	**Ratio**
Gulf menhaden	9.69	1.19	9.33	1.21	2.11	0.37
Brown shrimp	7.83	1.38	7.98	1.38	5.44	1.34
Grass shrimp	5.73	1.37	5.65	1.44	6.32	1.37
Striped mullet	5.04	1.24	4.86	1.21	2.84	0.75
Bay anchovy	4.90	1.25	7.72	1.35	8.12	1.33
White shrimp	4.77	1.28	6.10	1.44	6.04	1.34
Atlantic croaker	4.07	1.21	3.90	1.22	-	-
Sheepshead minnow	3.74	1.08	3.48	1.16	5.02	1.22
Gulf pipefish	3.58	1.20	2.56	0.92	3.65	1.15
Naked goby	3.56	1.30	3.83	1.32	3.97	1.21
Tidewater silverside	3.47	1.18	3.18	1.20	4.03	1.13
Sailfin molly	3.38	1.04	4.08	1.25	5.03	1.29
Gulf killifish	3.37	1.01	2.52	0.90	4.16	1.13
Spotted seatrout	3.36	1.16	2.87	1.02	3.91	1.22
Blue crab	3.18	1.17	2.99	1.13	4.32	1.18
Ladyfish	3.14	0.99	2.52	0.77	2.10	0.77
Western mosquitofish	2.98	1.05	3.38	1.01	4.01	0.93
Rainwater killifish	2.78	0.90	2.30	0.86	2.44	0.82
Rio Grande cichlid	2.25	0.78	1.19	0.58	2.90	0.90
Pinfish	2.23	0.83	1.86	0.77	1.38	0.55
Silver perch	2.22	0.65	1.71	0.53	1.40	0.57
Family Xanthidae (mud crabs)	1.88	0.78	2.35	0.89	3.17	1.04
Hogchoker	1.12	0.51	2.22	0.89	2.63	0.84
Family Penaeidae (shrimp)	1.12	0.47	2.17	0.66	3.21	0.80
Atlantic needlefish	0.96	0.57	-	-	-	-
Pink shrimp	-	-	-	-	1.46	0.47
Mojarra species	-	-	-	-	1.12	0.53
Total Percent Dissimilarity	56.98		60.41		51.23	

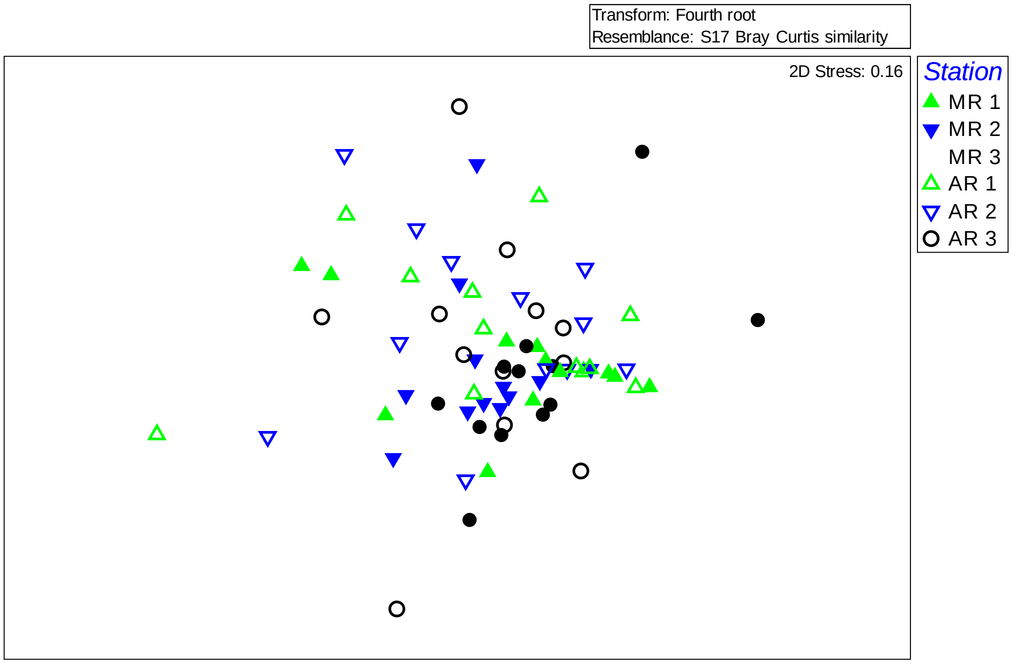


Figure 40. MDS configuration of the stations based on trawl collections from the Mission and Aransas Rivers.

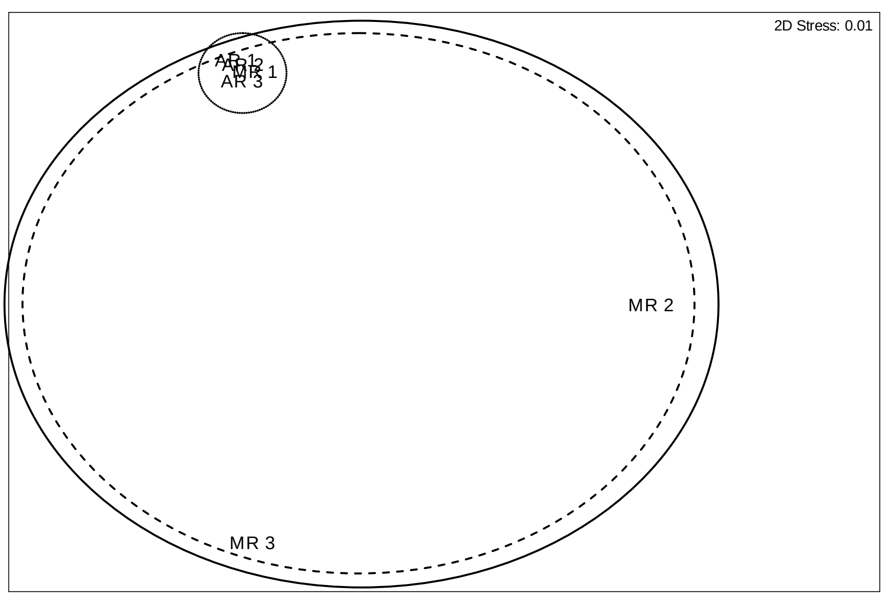


Figure 41. Means plot MDS ordination of the stations based on trawl collections from the Mission and Aransas Rivers. Stations within an ellipse (dashed lines follow Fig. 29 are not significantly different (ANOSIM < 0.30).

Mission River was much more spread out in the MDS means plot of Fig. 40, their community compositions were not significantly different. All of the stations within the Aransas River were virtually the same, clustering quite closely in the configuration presented in Fig 41.

Numerically, bay anchovies and Gulf menhaden dominated the trawl catches, and their overwhelming contributions to the derived measure of similarity on each river is evident in the SIMPER analysis presented in Table 31. These two species accounted for nearly 89 % of the overall community assemblage measure, and each was most abundant in the lower salinity environments encountered on the Aransas River. This is especially true for Gulf menhaden, where their abundance as measured with this gear was nearly 5-fold higher here. Other species that were well represented in the trawl catches and more abundant on the Aransas River included the blue catfish *Ictalurus furcatus*, striped mullet, and white shrimp. Species encountered in higher abundance in the more saline conditions of the Mission River included only spot *Leiostomus xanthurus* and Atlantic brief squid. All other species were either equally distributed between the two river systems, despite the obvious differences in salinity, or encountered in such low numbers with the trawls that meaningful patterns could not be ascertained.

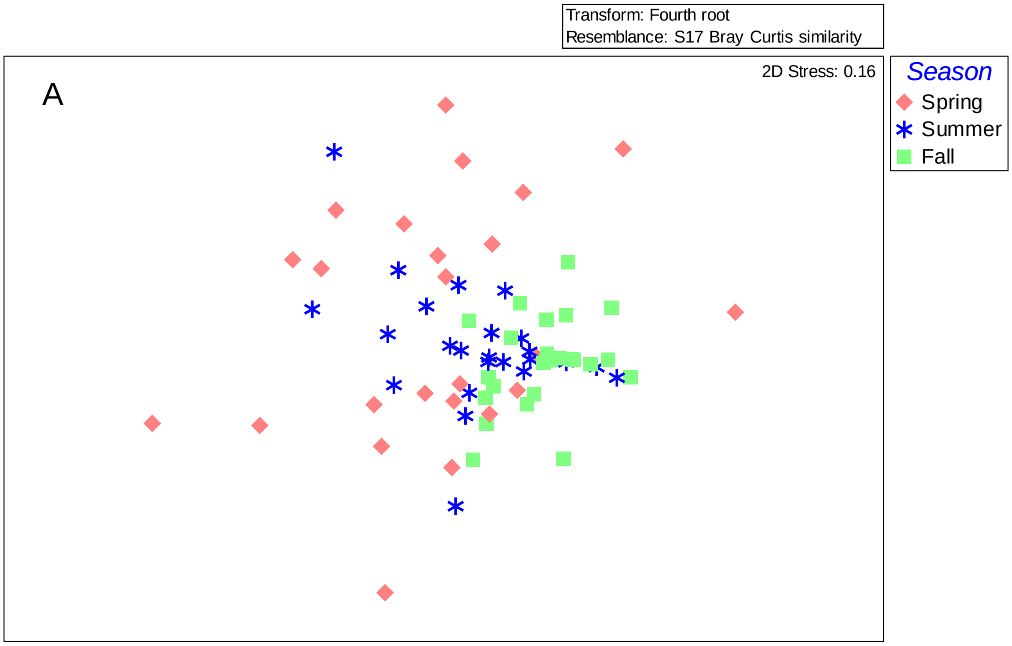
Although not as pronounced as with the bag seine collections, seasonality was still evident in the trawl collections, as can be seen in Fig. 42a (ANOSIM Global R = 0.205; *prob*. = 0.001). Spring and fall collections had the most distinct nekton communities, while the summer collections spanned across the two seasons. SIMPER results of this seasonality factor are presented in Table 32. Atlantic croaker *Micropogonias undulatus* CPUE (the species with the highest ratio values for the comparisons involving spring vs. summer and spring vs. fall) is shown as an example of trawl-based seasonality, with this species collected primarily in the upper to middle stations during the spring and summer seasons (Fig. 41b).

Benthic Macroinvertebrate / Infaunal Collections

Benthic infaunal sampling was conducted on each sampling event, in conjunction with the sediment collections, and the MDS configuration of the benthic community composition is shown in Fig. 43. Absent from Fig. 44 are any distinct groupings of stations in either river system, as the infauna communities were quite similar between the two systems. Equivalent numbers of taxa were collected from both tidal segments (27 total taxa from 4 Phyla and 10 different Classes), although the total number of individuals was higher on the Aransas River (n = 4,260) when compared to the Mission River (n = 3,082). A complete taxonomic list of the benthic infauna is presented in Appendix 5. Within the

Table 31. The contributions of selected individual species to the total average dissimilarity between fish assemblages as measured by trawls in the Mission and Aransas Rivers. Average abundance (Av. Abund), as measured by catch per hour; percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. Species are listed in order of relative contribution to the total dissimilarity.

Species	**Mission Av.Abund**	**Aransas Av.Abund**	**%**	**Ratio**
Bay anchovy	2917.58	3361.19	75.89	1.65
Gulf menhaden	224.90	1054.29	12.91	0.52
Blue catfish	35.83	100.86	4.62	0.39
Atlantic croaker	51.12	34.28	3.11	0.39
Brown shrimp	10.62	8.13	0.83	0.23
Striped mullet	1.56	24.00	0.71	0.2
White shrimp	5.85	12.37	0.61	0.48
Ladyfish	5.25	6.12	0.27	0.37
Black drum	2.85	2.22	0.24	0.31
Spot	4.28	1.90	0.18	0.41
Atlantic brief squid	1.80	1.00	0.09	0.31
Blue crab	0.90	0.56	0.08	0.26
Alligator gar	0.23	0.67	0.05	0.27
Silver perch	0.78	1.00	0.05	0.37
Spotted gar	0.12	0.55	0.04	0.2
Channel catfish	0.66	0.56	0.04	0.25
Hardhead catfish	0.45	0.44	0.03	0.14
Sand seatrout	0.44	0.67	0.03	0.21
Spotted seatrout	0.77	0.23	0.03	0.32
Naked goby	0.34	0.33	0.03	0.34
Smallmouth buffalo	0.14	0.26	0.02	0.23
Macrobrachium ohionie	-	0.30	0.02	0.14
Threadfin shad	0.12	0.10	0.02	0.14
Total Percent Dissimilarity			61.69	



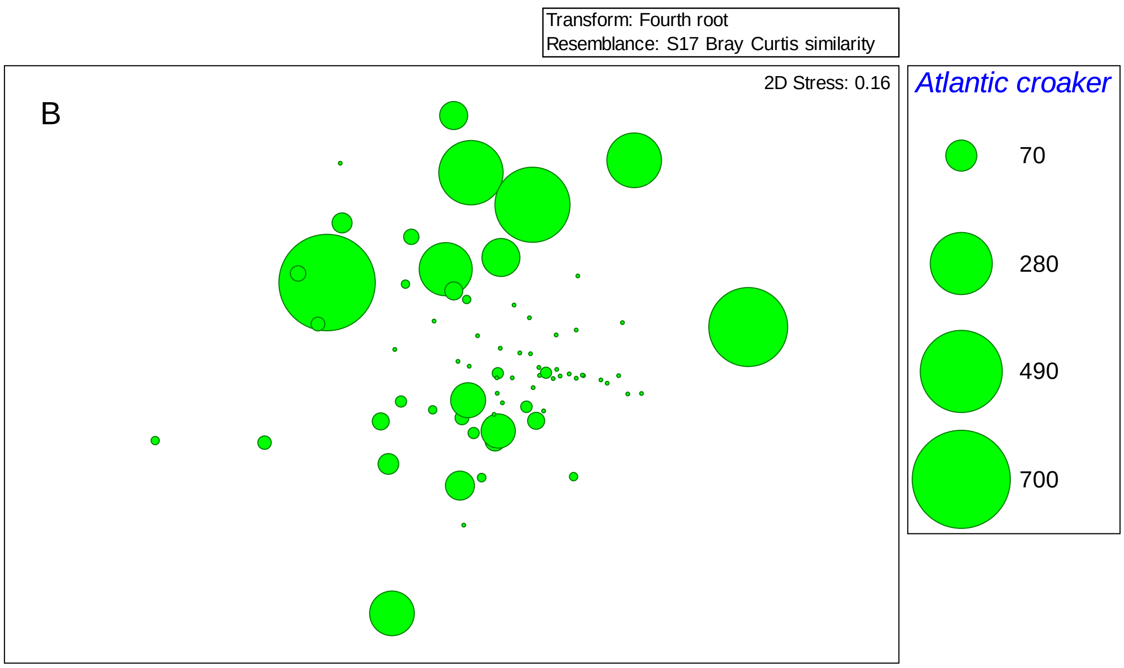


Figure 42. MDS configuration of the stations based on trawl collections from the Mission and Aransas Rivers. Station configuration based on Fig. 39, but overlaid onto each station are: A = season of collection, and B = Atlantic croaker CPUE. Size of each circle is represented by the scale at the right.

Table 32. Comparisons of the fish assemblages collected seasonally with otter trawls during spring (Sp), summer (Su) and fall (Fa) on the Mission and Aransas Rivers. Percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. A dashed line (-) represents no species contribution to the comparison.

	Sp vs. Su		Sp vs. F		Su vs. F	
Species	**%**	**Ratio**	**%**	**Ratio**	**%**	**Ratio**
Bay anchovy	19.94	1.24	21.79	1.24	33.37	1.37
Gulf menhaden	19.49	1.01	20.06	0.93	16.19	0.99
Atlantic croaker	13.56	1.56	13.59	1.62	3.340	0.68
Blue catfish	9.79	0.93	8.78	0.87	12.97	0.87
Brown shrimp	5.31	0.80	5.09	0.79	-	-
White shrimp	4.60	1.06	5.06	1.07	7.43	1.02
Ladyfish	4.06	0.71	3.43	0.60	1.90	0.40
Striped mullet	3.33	0.50	2.40	0.64	2.88	0.28
Spot	2.98	0.76	2.73	0.66	2.87	0.80
Black drum	1.85	0.63	2.82	0.73	2.80	0.46
Silver perch	1.43	0.52	-	-	1.89	0.47
Blue crab	1.34	0.62	1.36	0.63	-	-
Atlantic brief squid	1.14	0.40	1.80	0.55	1.46	0.36
Channel catfish	1.08	0.50	0.83	0.40	-	-
Spotted seatrout	0.97	0.48	-	-	1.41	0.47
Alligator gar	-	-	1.08	0.54	1.59	0.50
Total Percent Dissimilarity	10.72		11.23		7.32	

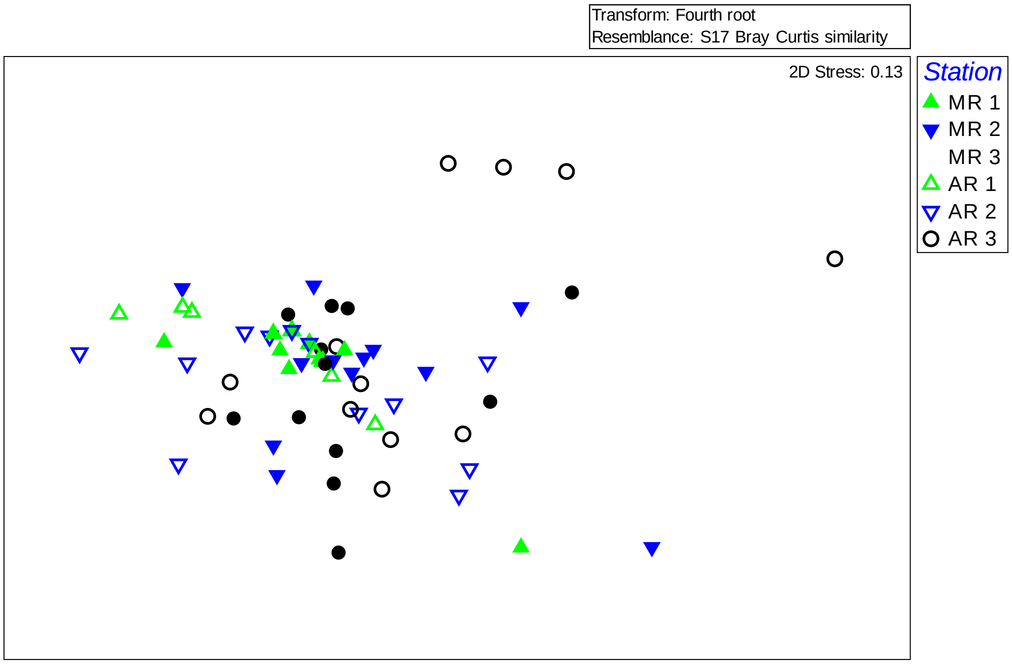


Figure 43. MDS configuration of the stations based on benthic infauna (mid-stream locations) collections from the Mission and Aransas Rivers.

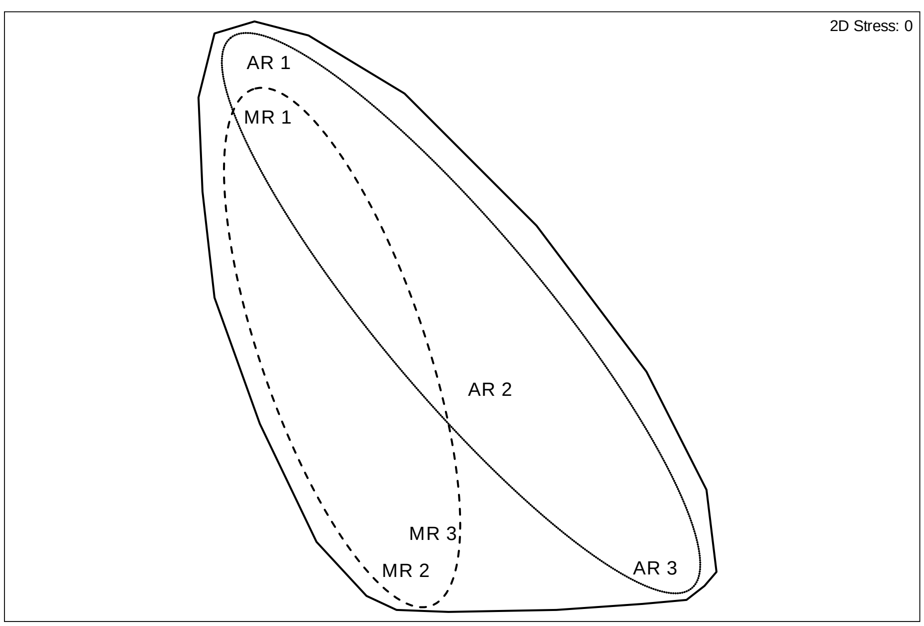


Figure 44. Means plot MDS ordination of the stations based on benthic infauna (mid-stream locations) collections from the Mission and Aransas Rivers. Stations within an ellipse (dashed lines follow Fig. 29) are not significantly different (ANOSIM $p < 0.3$).

Mission River, the upper, middle, and lower stations all had very similar infaunal communities (Global R = 0.045, *prob*. = 0.056), with greater than 90 % of the individuals dominated by polychaetes (*Streblospio benedicti*, *Mediomastus* spp.,and *Amphicteis floridus*), bivalve mollusks (family Mactridae), oligochaetes, and chironomids (Table 33). Within the Aransas River, all the stations shared these same dominant organisms, with the addition of a malacostracean arthropod (*Corophium louisianum*) rounding out the top 90 % of the collections. No significant difference in community compositions were found among the stations on the Aransas River (Global R = 0.108, *prob*. = 0.05) or the Mission River (Global R = 0.045, *prob*. = 0.06. Unlike the nekton collections, the presence of seasonality in the benthic communities was not evident from either stream (Mission River Global R = 0.096, *prob*. = 0.03; Aransas River Global R = 0.048; *prob*. = 0.06).

MDS Configuration Agreement

Spearman's rank correlation was used to quantify the degree of agreement among the biological, chemical, and physical MDS configurations, and these correlations are presented in Table 34. Among the biological components, the spatio-temporal patterns revealed with the bag seines were marginally related to trawl and surface-water column profiles, and the trawl collections themselves were most closely related to the patterns seen with the bottom-water column profiles as well as the benthic infauna. BEST (Biota and/or Environmental Matching) analysis revealed that the agreement between the trawl collections and the bottom water column profile configurations were driven primarily by three species; Atlantic croaker, blue catfish *Ictalurus furcatus*, and white shrimp. In each case, the total numbers of each species collected was far greater during the 2008 sampling year, when salinities on both streams were lowest. This is especially true of the numbers of blue catfish collected with the trawls, where 1,208 individuals were collected in 2008 (75 % of those were found in the Aransas River), while a total of only 2 individuals were collected in the 2009 sampling year. No blue catfish were found on the Mission River in 2009, when seasonal mean salinities were > 20 (see Fig. 27). Neither the water chemistry nor the sediment constituents were closely related to the biological components of ecosystem health. The greatest degree of agreement was found between abiotic measurements of the mid-water column profiles and the water chemistry collections (Spearman's rank correlation ρ_S = 0.471, see Table 34), and these agreements were also driven by the role of increasing salinities as a result of the drought conditions. These two components of ecosystem health were most closely linked to salinity-related parameters, primarily chloride, sulfate, and total dissolved solids related to the spatial and temporal patterns of the overriding salinity gradient. As an example, Fig. 45 shows the relationship between mid-water column profiles and trawl collections of white shrimp, a species collected primarily in the summer and fall throughout both river systems before the salinities became exceedingly high during 2009. The largest value of white shrimp abundance seen in Fig. 45 came during the Fall 2009 sampling season,

Table 33. The contributions of selected individual taxa to the total average dissimilarity between benthic infaunal assemblages as measured by mid-channel sediment collection in the Mission and Aransas Rivers. Average abundance (Av. Abund), as measured by catch per square meter; percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. Taxa are listed by order of relative contribution to the total dissimilarity.

Taxa	**Mission Av.Abund**	**Aransas Av.Abund**	**%**	**Ratio**
Streblospio benedicti	37.21	52.30	46.03	1.06
Oligochaeta	2.76	12.23	10.86	0.46
Chironomidae	2.98	7.55	8.70	0.54
Mactridae	5.63	4.78	7.31	0.59
Amphicteis floridus	1.70	4.04	5.26	0.49
Mediomastus	1.49	7.12	5.19	0.46
Nemertea	0.64	2.66	2.65	0.49
Rictaxis punctostriatus	-	3.51	2.28	0.31
Hydrobiidae	0.85	0.96	1.69	0.39
Mysidacea	1.17	0.43	1.47	0.35
Total Percent Dissimilarity			61.69	

Table 34. Matrix of Spearman's rank correlations between MDS configurations of the biological, chemical, and physical components of ecosystem health measures in the Mission and Aransas Rivers. Only the lower panel of the correlation matrix is presented. Probability of obtaining a larger correlation coefficient by random chance (based on 1,000 permutations) denoted by: * = *prob*. < 0.01, ** = *prob*. < 0.001. Significant correlations ($\rho_s > 0.3$) identified in bold.

	Bag Seine[a]	Trawl[b]	Benthic Infauna[e]	Water Column Profile[d]	Water Chemistry
Bag Seine	___				
Trawl	0.158*	___			
Benthic Infauna	0.099	0.230*	___		
Water Column Profile	0.125*	0.230*	0.033	___	
Water Chemistry	0.063	0.024	-0.033	**0.471****	___
Sediments	-0.002	0.051	-0.148	0.084	0.276*

[a] Bag Seines related to Surface Water measurements.

[b] Trawls related to Bottom Water measurements.

[c] Benthic Infauna related to Bottom Water measurements.

[d] Mid-Water Column Profile related to Water Chemistry measurements.

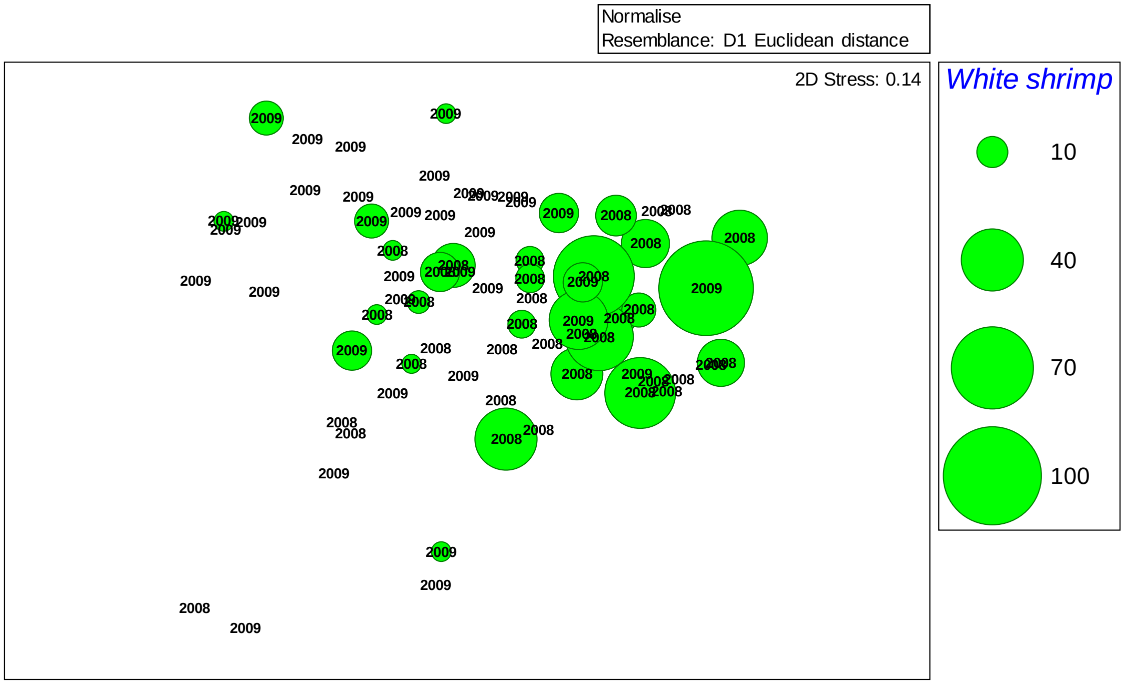


Figure 45. MDS configurations of the stations based on mid-water column profiles, with the designation of the different sampling years identified. Original configuration is similar to Fig. 27, which denotes surface-water column profiles. Overlaid onto each station is the catch rate for white shrimp as determined by otter trawls. Size of each circle is represented by the scale at the right.

when salinities were lowered by the inflows that effectively broke the drought.

The trawl-based community structure differences related to bottom-water profiles were also linked to dissolved oxygen concentrations, as noted by their high component loadings in the principal component analysis presented in Table 22. The MDS configuration of the sampling stations, based on bottom-water column profiles are presented in Fig. 46, with the spatial and temporal differences in DO concentrations identified. While dissolved oxygen concentrations was an important factor in the MDS configuration, blue catfish catch rates do not appear to be limited by low DO conditions exclusively, but tend to be more influenced by the dramatic salinity differences between the two sampling years. Despite relatively low bottom-water DO conditions indicative of the upper left-hand quadrant of this configuration (upper and middle stations on the Aransas River), blue catfish were still collected with the otter trawls during 2008. Comparing Fig. 46b and 46c, blue catfish were absent from waters that were quite high in dissolved oxygen concentrations in 2009, with the only two individuals collected during 2009 coming from the upper and middle sampling station on the Aransas River during the Fall season once the drought was broken.

Average Taxonomic Distinctness

From Fig. 11, the Average Taxonomic Distinctness measure (Δ*, identified hereout as Delta+) takes the form of Delta+ = 16.7 if two individuals drawn at random from a sample are the same species; Delta+ = 33, different species but from the same genera; Delta+ = 50, different genera from the same family, etc. In order to simplify the biological interpretation of this measure, all invertebrates were excluded from the nekton collections such that the distinctness measures for bag seines and trawls reflects the taxonomic breadth of the finfish communities exclusively.

Average Delta+ values for the bag seine collections revealed that much of taxonomic diversity was at the genus level (mean Δ* = 33.57 ± 16.3 SD, see Fig. 47), and this procedure agreed with the results of the ANOSIM test of the bag seine collections, namely finding significantly different compositions in the finfish communities between the freshest and most saline stations (see Nekton Collections – Bag Seines; Fig. 38). Seasonality was not evident in the taxonomically-derived measure of the bag seine collections, ($F_{2,69}$ = 2.066, p = 0.077). This result could be a function of grouping the two very different sampling years together for this seasonality test, as the collections in 2008 were numerically dominated by bay anchovy and gulf menhaden catches that greatly outnumbering all other taxa. While the total numbers of individuals were lower in the higher salinity conditions present for most of the 2009 sampling year, (bay anchovy and Gulf menhaden catch numbers were each reduced by a factor of 4

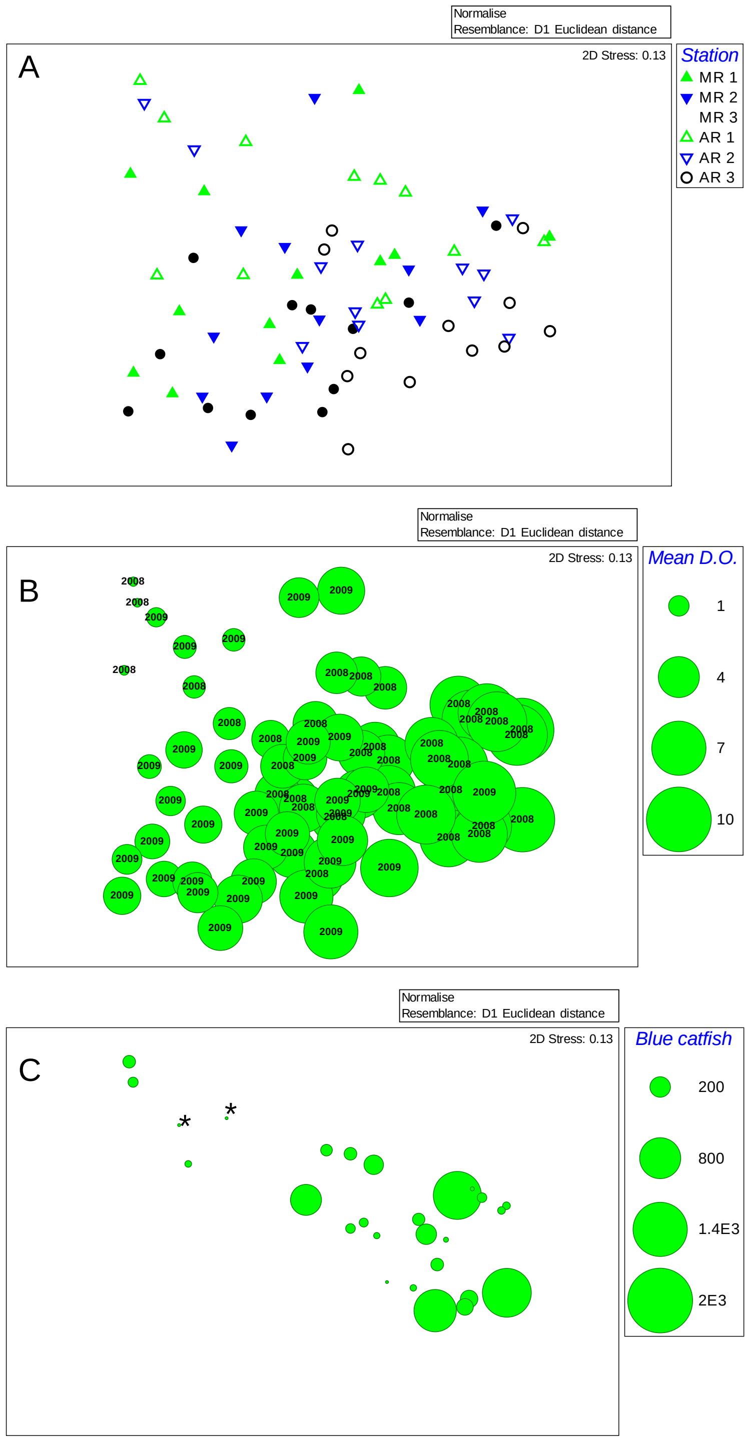


Figure 46. MDS configuration of the stations based on bottom-water column profiles from the Mission and Aransas Rivers. A = Station configuration; B = overlay with bottom-water column dissolved oxygen measurements and sampling year; and C = catch rates for blue catfish, * = only catch in 2009. Size of each circle is represented by the scale at the right.

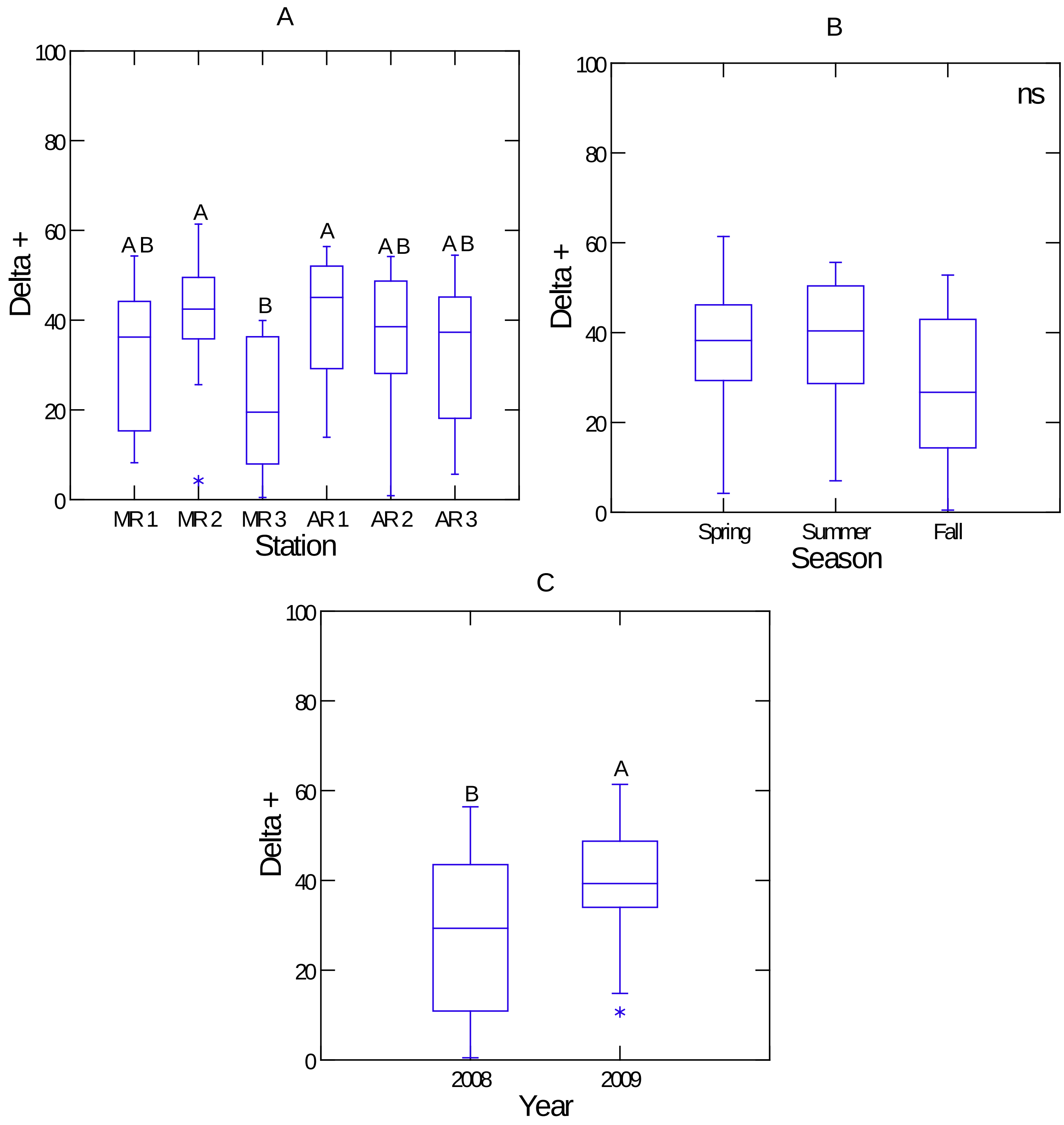


Figure 47. Box plots of Average Taxonomic Diversity values (Delta+) of the finfish nekton as recorded by otter trawl collections from the Mission and Aransas Rivers. A = among Stations comparisons; B = among Season comparisons; and C = Sampling Year comparisons. Categories within each plot with the same letter are not significantly different (test results and probability levels reported in the text). No significant difference identified by ns.

when compared to 2008), average taxonomic distinctness was enhanced by these higher salinities (Fig. 47c). Comparing to the two systems, the Aransas River had more total species (44 vs. 33 nekton taxa), but was not statistically more diverse based on the Delta + values (separate variance t = 1.43, df = 69.8, p = 0.157).

Trawl collections had markedly lower average Delta+ values (mean Δ^* = 10.12 ± 12.34 SD), reflecting both lower numbers of taxa susceptible to collection with this gear and the overwhelming dominance of bay anchovy and Gulf menhaden catches in both these systems. Average Delta + values appeared to be higher among the Aransas River stations (Fig. 48a), but the range of extreme values from the Mission River made this test non-significant. Seasonality was detected in the trawl collections ($F_{2,69}$ = 6.70, p = 0.002), with the spring season having the highest degree of diversity (Fig. 48b). The dramatic differences in the physical environments between 2008 and 2009 were also evident in the trawl catches (Fig. 48c), although unlike the bag seine collections, mean taxonomic distinctness with the otter trawls was reduced in the higher salinity conditions. The influence of bay anchovy and Gulf menhaden catches in 2009 (contributing >93 % of the community composition as measured by this gear) helped to depress the overall Delta + values across both river systems. As was the case with the bag seines, the finfish community on the Aransas River was more rich when compared to the Mission River (29 taxa vs. 27 taxa), and these differences were significantly different when measured by the taxonomic distinctness measure (separate variance t = 3.11, df = 66.1, p = 0.003). Between the two systems, 26 taxa were common to both rivers, while an additional eight genera were unique to the Aransas River and only three genera unique to the Mission River. These differences in unique taxa are important in the calculation of the Delta + values, as these eight genera were from 3 different phylogenetic Orders (Cyprinidontiformes, Pleuronectiformes, and Tetraodontiformes), greatly enhancing the average taxomonic distinctness measure on the Aransas River, even though the difference total numbers of taxa were relatively small.

Benthic collections were similar in diversity to the bag seine collections, with average Delta+ values (mean = 32.58 ± 26.6 SD) characterized by differences at the genus and Family levels (see Fig. 49). The ranges of values were similar among the streams, with the lower and middle stations having the highest degree of taxonomic richness. Taxonomic diversity in the infaunal collections was lowest in the fall, and this pattern is in agreement with the finfish collections with both the bag seines and the otter trawls. Unlike the finfish collections, the differences in environmental conditions between 2008 and 2009, as a result of the drought conditions, did not translate into any taxonomic differences in the infanal communities. Overall, taxonomic diversity of the infaunal communities were similar among the two river systems (separate variance t = -1.06, df = 69.9, p = 0.292).

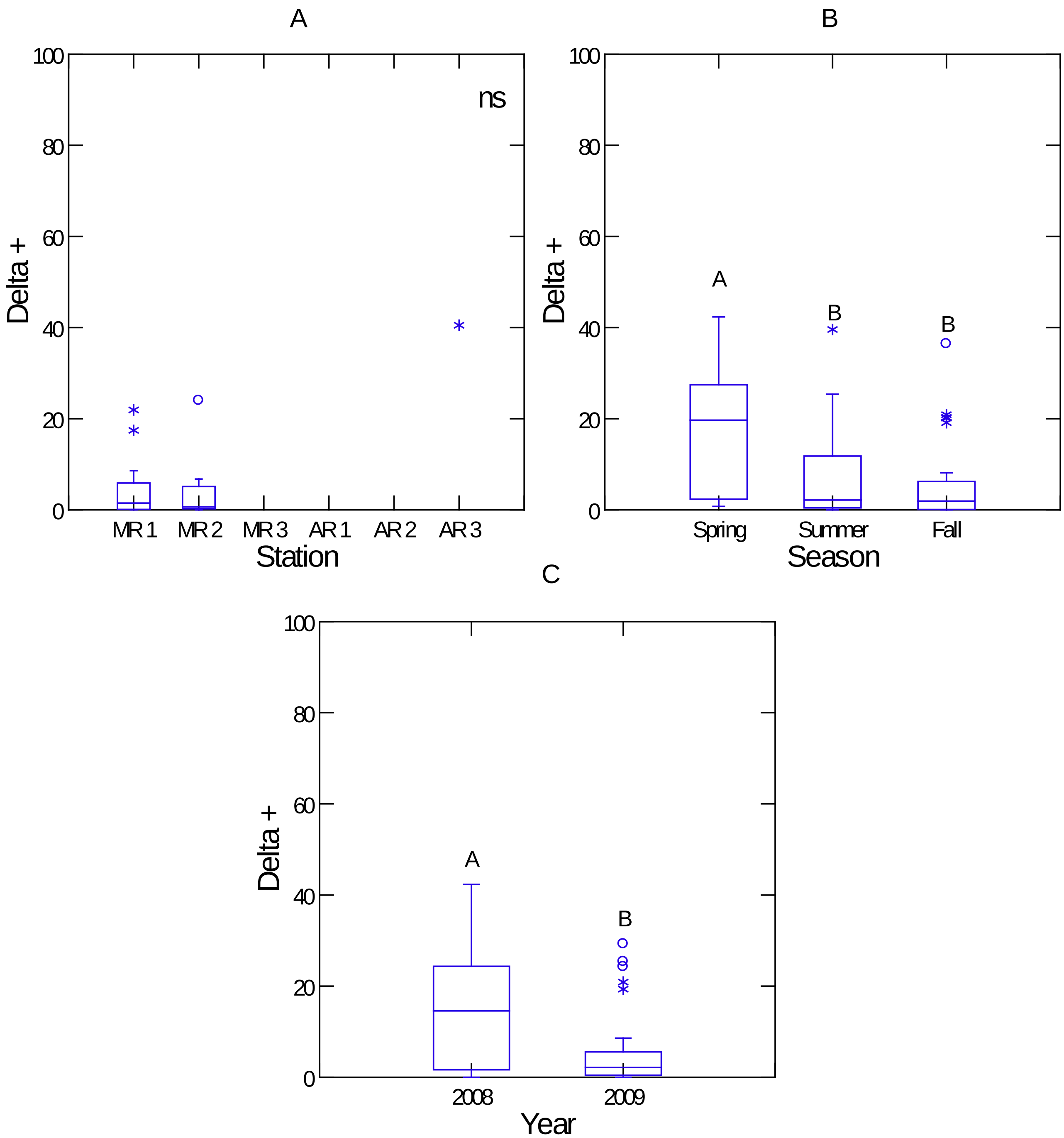


Figure 48. Box plots of Average Taxonomic Diversity values (Delta+) of the finfish nekton as recorded by otter trawl collections from the Mission and Aransas Rivers. Plot designations follow Fig. 46.

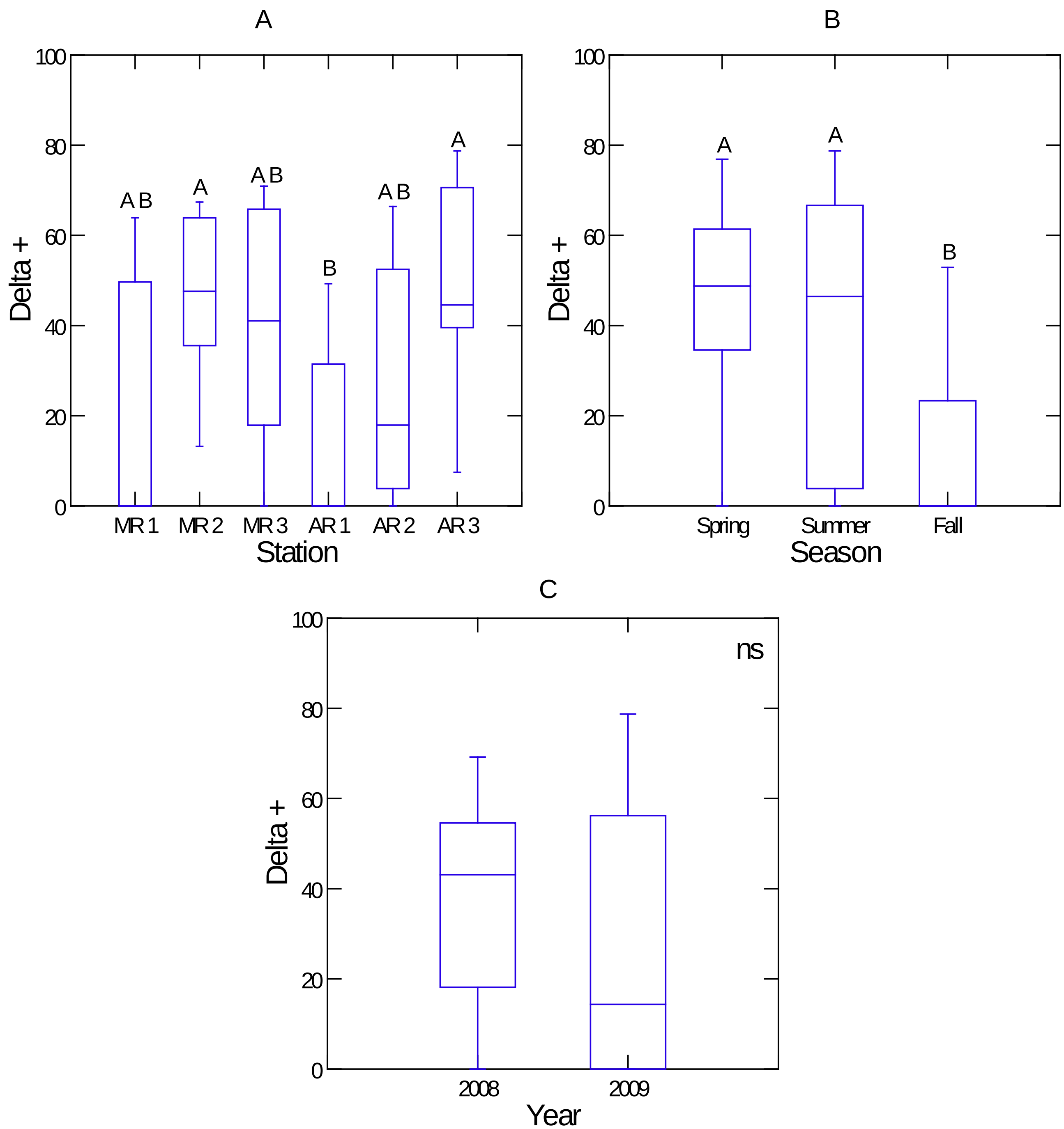


Figure 49. Box plots of Average Taxonomic Diversity values (Delta+) of the infaunal invertebrates as recorded by the ponar device benthic collections from mid-stream in the Mission and Aransas Rivers. Plot designations follow Fig. 46.

DISCUSSION

This study furthered the task of determining whether differences in the physical, chemical, or biological components of "ecosystem health" could be found among tidally influenced streams with varying degrees of freshwater inflows. Previous works focusing on components of ecosystem health have typically relied on univariate methods which may not fully integrate any synergistic (or antagonistic) effects of the many variables under consideration (Twidwell and Davis, 1989; Michael and Moore, 1997; Davis, 1998). The Mission-Aransas Tidal Steam study utilized the more encompassing multivariate assessment methodologies, in order to integrate the seemingly disparate physical, chemical, and biological components of ecosystem health. These techniques allows for more robust comparisons of tidally influenced systems, with the ultimate goal of deriving a set of comprehensive metrics that can be used to appropriately classify aquatic life uses in the numerous tidally influenced streams within the State.

The following presents the results from the sampling program conducted from March 2008 – November 2009 on the tidal portions of the Mission and Aransas Rivers. Results will be discussed in the context of the major ecosystem health components: physical (landcover and land use, instream and riparian habitat, and instream flow), chemical (transitory and synoptic water quality, water and sediment chemistry), and biological (nekton assemblages, benthic invertebrate assemblages, and aquatic invertebrate assemblages). Finally, the appropriate aquatic life use designation, based on these more robust methods, is recommended for both the Mission and Aransas River tidal systems.

Instream and Riparian Habitat Classification

Both streams had similar thalweg patterns as might be expected given their relatively close proximity on the landscape. Both appear to have not experienced much if any channelization or dredging. Both streams showed a decrease in their respective maximum depths in their downstream reaches relative to their upper reach. Both streams became shallower and wider at their lower ends. Due to the increased tidal nature of their lowest reaches flows alternately travel up and down these streams thus sediments would be expected to fall out of suspension and accumulate due to the decreased flow velocities and variable direction of flows. The same factors may have operated to cause the gradual shallowing along the sides of both streams downstream. The slow flowing nature of Texas tidal streams was apparent in the stream habitat data, as well. Both streams were characterized as glides at all their sampling reaches. These streams pass through very flat coastal landscapes, so there are no instances where water flows down any significant gradient such as a riffle or rapid. Thus the low stream gradients and relatively flat watersheds associated with them resulted in only calm flowing stream habitat types in the reaches sampled (Rosgen 1996). Channel width increased from upper to lower reaches. Bank incision and bank angle decreased in both streams. These measurements are typical of most rivers and streams (Rosgen 1996). Areas lower in the watershed receive more water, thus requiring a wider channel in order to conduct water and sediments to their eventual destination in the bay. Incision was likely greater in the upper reaches because the more woody vegetative cover found in these areas would better hold sediments and resist erosive forces during flooding, thus confining that erosion to the stream channel itself. Similar results were found for the tidal portions of Tres Palacios, Carancahua and Garcitas creeks in a previous study along the mid-Texas coast (Tolan et al., 2007).

The sediments in the Mission and Aransas Rivers were primarily composed of sand and are likely a reflection of their respective local source materials. White et al. (1988) indicate that this material was likely composed of shell materials or possibly rock. Both stream showed signs of increasing clay and silt in their downstream-most sites. This increase in fine materials at the lower sites may be a product of the relatively low flow velocities and alternating tidal flows. As is typical in coastal environments such as marshes, low energy sites typically accumulate more finer sediment materials (Chabreck 1988). Unlike previous studies along the middle coast (Tolan et al., 2007), gravel and or cobble were not found along the bottoms of these streams.

Vegetation followed a similar pattern in both streams, with woody materials, especially large trees, being dominant in the upper reaches and herbaceous species and low growing woody shrubs dominating the lower reaches. This is a reflection of the increasing influence of salt and tides in the lower reaches of both streams as well as the tolerance limits of local plant species and is generally typical of the entire Texas coast including Tres Palacios, Carancahua, and Garcitas creeks (Tolan et al., 2007). Since there are no endemic tree species adapted to surviving higher salinities in this part of Texas, this cover component falls out of the vegetative measurements at the lower reaches and is replaced by more salt tolerant herbaceous and woody marsh-type species. The sampling transects on the lower portions of the streams did not extend downstream far enough to pick up the full transition of the landscape into bay delta habitats. However, the edges of both streams do eventually transition from a riparian forest wetland community in their upper reaches to a salt marsh type of wetland community as they intersect with their receiving bay. This pattern was found in previous studies of mid coast streams (Tolan et al., 2007) and is typical for all riverine habitats.

The Mission River had more in-channel fish cover in its upper reach than in its lower ones, while the Aransas showed the opposite pattern having the most fish cover in its lowest reach. The pattern in the Mission was due mainly to a decrease in the amount of woody material (i.e., trees) present in-stream as well as along the immediate stream edges in lower stream reaches. This pattern appears to be the typical pattern for mid coast streams along the Texas coast (Tolan et al., 2007). The Aransas system however, diverged from the typical pattern, because although it did exhibit a decline in woody fish cover heading downstream, this loss was more than compensated for by a large increase in fringing macrophyte cover along the shoreline edges of its lowest reach, especially in the form of submerged aquatic vegetation (*Ruppia maritima*). The Mission showed a similar though not as marked increase in macrophyte cover at its lowest reach. Many parts of the lower portions of each stream were edged by thick macrophyte cover, which provides excellent fish cover. This was borne out by fisheries sampling conducted as part of this study as well. Furthermore, as revealed in the land cover analysis section, portions of these lower reaches, not directly measured by the instream and riparian habitat classification study, were composed of marsh wetlands, which are also known to be excellent fish habitat.

Indicators of human influence in these two streams appear to be dominated mainly by agriculture. A review of the land cover analysis section for both these streams reveals that a sizable portion of their respective watersheds are devoted to agriculture, pasture, and/or grazing. Human influences attributable to direct human habitation were less, likely because this area is relatively less populated than other parts of the Texas coast.

Instream Flow Characterization

Flow direction in the river Mission River was either upstream or there was no net flow in all the deployments. Wind-driven upstream flow was also noted in the Laguna Madre estuary (USGS, 1998). During the Mission-Aransas study period, south-easterly winds prevailed in the study area as it can be seen from wind data obtained from a National Estuarine Research Reserve System (NERRS; Table 5) weather station in Copano Bay, TX. These winds enhance upstream flow in both streams since the mouths of both streams are located to the west. In November 2009, the maximum flow velocity was downstream although the net flow was nearly zero. This was most likely associated with relatively higher freshwater flow rates during the month. Flow was quite low throughout the study period with mean flow velocities bound in the range (+0.15 ft/s – - 0.65 ft/s). The maximum velocity in most deployments coincided with the peak of the tidal cycles, hence near-maximum or maximum velocities being reached repeatedly in-phase with the peaks of the tidal cycles. No seasonal pattern of flow could be seen from the velocity data. Maximum current velocity was seen in September during the 2008 deployments and in May during the 2009 deployments.

As it can be seen from historical flow data collected at USGS gages in these streams, the two years when the tidal stream study was conducted were drought years with extremely low flows except for flood events during the three last months in 2009 in the Mission River watershed that resulted in the annual mean flow recovering to 75% of the historical annual mean. The seven-day mean discharges during the ADV deployments were 6.2 cfs and 5.5 cfs for the Mission and Aransas Rivers respectively. Estimated discharge at the middle stations in both streams was much higher and variable than what was observed at the USGS gage stations. Flow in the middle reach of the Mission and Aransas rivers was tidally driven during the study period and residual flows were only small fraction (7 – 42%) of the tidal flow. The residual flow in both streams was upstream in most of the deployments owing to the coupled effect of very low inflow from the feeding watersheds and south-easterly winds that prevail during most of the year.

The flow pattern in the Aransas River exhibited some seasonality in that the maximum flow velocities which were upstream were reached in the summer in both study years. This was most likely due to the strong winds during the summer months that steadily blow toward the northwest coupled with lower flows. Minimum flow velocities occurred during the spring. In the Mission River however, no seasonal pattern in the stream flow was evident despite similar inflow, meteorological and tidal conditions existing in both streams.

Water Quality Characterization

Transitory Water Quality

Water quality was not markedly different between either of the study streams, with salinity and dissolved oxygen being the variables most responsible for any differences noted. Along the entire reach of each stream, salinity values responded to the onset of the drought conditions, ranged from very fresh in the upper stations to hypersaline in the lower stations. The influence of these drought conditions were most evident when comparing sample years, as salinity was markedly higher on both river systems in 2009, when compared to 2008. The influence of the drought was most noticeable on the Mission River (see Fig. 27), despite similar size watersheds for both rivers. In the absence of riverine inflows, the effects of wind-driven salinity intrusion had a dramatic effect on transitory water quality readings. While the ANOSIM procedure failed to find any major differences in the water quality within each stream (the lower station was marginally different from the upper and middle stations on the Aransas, see Fig. 30) the influence of the drought conditions on surface water quality readings are quite evident.

Vertical depth profiles of field measurements (temperature, pH, dissolved oxygen, and salinity) collected from 0.3 m below the surface, 0.3 m above the bottom, and at stations with sufficient depth, halfway between the surface and the bottom, failed to find any appreciable vertical stratification of the water column. Generally, salinity increased with depth, and dissolved oxygen decreased with depth. Surface waters were generally more saturated than were either the mid- or bottom-water measurements, with hypoxic and at times anoxic conditions encountered in the bottom waters on each study stream. Low dissolved oxygen conditions were noted most often from the upper station on the Aransas River, although bottom water measurements showed average dissolved oxygen readings were very close to the standard of 4 mg/L (Table 21). Low dissolved oxygen conditions were not as prevalent at the lower stations on either stream, which may be a reflection of the prominence of wind-driven mixing as outlined in the section on instream flow characterizations.

Synoptic Water Quality

While dissolved oxygen was one of the primary focuses of the datasonde deployments, as sampling water quality parameters over a full diurnal cycle allows for a better understanding of temporal variability. Sampling locations for the datasondes were approximately 0.3 m below the surface, so conditions recorded with these instruments were more like those of the surface grab samples. Similar to the profile measurements, the ANOSIM procedure only detected salinity-mediated differences in synoptic water quality between the study streams, with the upper and middle station on the Aransas River (fresher in general, from surface to bottom) being different from all other stations.

The synergistic role of salinity as one of the abiotic factors controlling surface water dissolved oxygen levels can be found in the component loadings along the first principal component in Table 24 (PC1 loading = 0.564). With the stations arranged on a seasonal basis, there was a mixture of upper, middle, and lower fixed sampling stations within the principal component analysis ordination (see Fig. 31). This temporal-based mix of sampling locations leads to the result of no difference among the stations with the ANOSIM procedure.

Water and Sediment Chemistry

Analysis of the water quality data, with respect to both a transitory and a synoptic frame of reference, revealed that inflows were the variables most responsible for structuring the physical realm of the aquatic environment in each of the study streams. Treatment of the water chemistry data by similar techniques also revealed that proxies for inflow (e.g., chloride, total dissolved solids, total phosphorus, and orthophosphorus) were highly influential in determining the placement of stations in both PCA ordinations (see Fig 33) and MDS space (Figs. 34). This overriding role of inflows, especially the extreme lack of inflows as recorded by the hypersaline conditions on the Mission River, adds a large amount of variability to the data (see Fig. 27). It is therefore not surprising that the ANOSIM procedure failed to detect any significant difference in either the water quality or the water chemistry among stations on a common stream, and the only difference in water chemistry parameters between streams was the result the elevated suspended solids and chloride ions in the hypersaline conditions of the drought (Fig. 33).

The UAA studies from the upper-coast (Contreras and Whisenant, 2007) and mid coast (Tolan et al., 2007) showed that flows far less than extreme flooding events can still be quite instrumental in structuring the chemical components of the aquatic environment characteristic of tidally influenced systems. As stated in the Surface Water Quality Monitoring Manual (TCEQ 1999a), "water quality in small and medium streams and in the headwaters of many reservoirs is influenced by runoff during and immediately after rainfall event". For this study, we attempted to collect physical, chemical, and biological parameters during all environmental conditions in order to use a holistic approach to ecosystem health. Due to the drought of 2007-2009, post-rainfall events were unavailable for sampling in the current study, save for the inflow events of fall 2009. While the overall effect of these floods has been shown to reset the aquatic environment along the entire reach of the stream (chemical constituent levels that are essentially uniform from upper, middle, and lower stations; see Tolan et al., 2007, West Carancahua creek), no dramatic post-flood effects were noted in the chemical constituents on either study stream. How quickly each system returns to "tidally influenced" depends upon the physical drivers responsible for moving saltwater back into the river portions of the estuary, and from the Instream Flows Characterizations, both the Mission and Aransas Rivers are heavily influenced by meteorological influences, as their chemical constituents never deviated dramatically from tidally influenced .

The lack of flooding events was also evident in the sediment collections, as the composition of the sediments ranged from mostly sands to high degrees of silts and clays within the same locations over the two years of this study. Across-stream comparisons showed that, unlike the orderly arrangement of stations within the MDS plots of the water column parameters (either synoptic or transitory measures), sediment compositions were far more variable and the MDS configurations did not reflect any consistent spatial arrangement. For example, the lower station on the Mission River was most similar to the upper and middle station on the Aransas River, and the lower station on the Mission River had the softest sediments (as measured by % silt), yet the upper station on the Aransas was the only one with this high a percentage of silt. Consistent patterns in the sediment compositions among the stations was virtually absent, as shown in the mixture of stations within Fig. 35.

Nekton Assemblages

The distribution and abundance of nekton species, and thus community similarity, varied spatially and most importantly seasonally along the gradient from freshwater tidal to hypersaline sites, yet dramatic differences in the community composition between the study locations were generally lacking. The greatest changes occurred in response to seasonal changes that were recorded in water temperature, and the overarching effect of the drought as measured by salinity and the various chemical constituents that serve as a proxy for salinity. The nekton communities at all stations were comprised of a mixture of highly euryhaline/marine taxa (Clupeidae, Engraulidae, Sciaenidae, Penaeidae, Paleomonidae, Portunidae) that numerically dominated the collections, and these same taxa are numerically abundant in estuaries all along the Gulf of Mexico and Atlantic coasts (Rozas and Hackney, 1984; Fleming et al., 1989; Peterson and Ross, 1991; Baltz et al., 1993; Ogburn-Matthews and Allen, 1993). Many of the estuarine forms that used the tidal habitats within the study streams were collected at post-larval and juvenile stages, suggesting that each of the streams is serving important nursery functions for the fisheries of Copano and Aransas Bays. Spatially consistent patterns of high juvenile abundance do exist within estuarine environments (McNeill et al., 1992; Smith and Suthers, 2000), with these areas receiving high numbers of initial settlers, being advantageous for growth and survival, or a combination of both (Beck et al., 2001). The identification of such critical habitats supporting high juvenile abundances across the spectrum of inflow conditions, coupled with the physical and biological mechanisms behind them, are a necessary step towards uncovering a spatially applicable biocriteria for Texas tidal systems.

For a number of common taxa, differences in nekton abundance were far more affected by salinity than any other physical or chemical parameter measured, irrespective of the season of collection. The agreement of the MDS configurations between the biotic and abiotic components of the ecosystem (Table 34) was driven by salinity-related distributional differences (for examples of salinity-mediated distributional differences, see Fig. 45 for white shrimp; and Fig 46 for blue catfish). Seasonality was a very important factor for a number of other taxa, and the strength of this seasonality factor was gear-dependent, as the bag seines recorded the most distinct seasonal communities, while the trawls catches were less distinct across seasons (compare Figures 39a and 42a). Many marine forms (e.g., sand trout, red drum, Atlantic croaker, brown shrimp, white shrimp, and spot) were far more abundant in very specific, and in some cases, very limited, seasons, and their abundance did not appear to be negatively affected by the extreme salinities that took place during the drought periods that characterized this study. These same taxa were also abundant in oligohaline (Contreras and Whisenant, 2007) and mesohaline (Tolan et al., 2007) conditions, and each are adapted to be able to utilize the tidal portions of rivers as nursery grounds in spite of any fluctuating salinity regimes.

Hypoxic events, or low dissolved oxygen conditions, were routinely encountered, although these conditions did not appear to be a major factor in structuring overall community composition. The dissolved oxygen regimes within both study streams were heavily influenced by the interaction of temperature, (a general lack of) precipitation, nutrient-loading, and salinity stratification, as the most negative correlations between low dissolved oxygen and elevated bottom water salinities were found on the Aransas River. Despite these large spatial extents of hypoxic bottom waters, there was little to no relationship between dissolved oxygen measurements and community structure (see trawl results from the Aransas River, Fig. 40). These results are in close agreement with studies by

McNatt and Rice (2004) and Shimps et al. (2005), in that they showed that dissolved oxygen levels must be severely depressed, in some cases approaching lethal limits, to negatively impact the population dynamics of spot (a sciaenid collected from each of the study streams, see Appendix 3) and Atlantic menhaden (a congeneric equivalent of the very abundant Gulf menhaden collected in this study). Shimps et al. (2005) points out that the ability of fish to behaviorally avoid hypoxia may limit the mortality directly due to hypoxia. The greatest effects due to hypoxia may be caused by the stress imposed by sublethal hypoxic conditions alone or in concert with other stressors, or by indirect effects incurred by avoiding hypoxia conditions (McNatt and Rice, 2004).

Benthic Invertebrate Assemblages

For this study, sampling frequency for the benthic invertebrates matched the sampling frequency that was utilized for the nekton, in the hopes that this increased temporal resolution would compensated for the lowered spatial resolution when compared to the previous UAA studies (i.e., 3 replicated from the middle of the station on each sampling event, versus 5 replicates from the middle and sides of each station on every other sampling trip). Despite this change in protocol, the analysis failed to detect any significant differences in overall community assemblages from either stations within a common stream, or between each of the study streams. Significant seasonality was missing from the benthic collections, although the lack of temporal resolution could have made this a far less powerful test.

The organisms that dominated the benthics in these tidal systems can best be described as ubiquitous. Polychaetes (especially *Streblospio benedicti*), oligochaetes, and chironomids were common across the salinity gradient-based station design, and these organisms all have wide ranging distributions. Despite their ubiquitous nature in estuarine systems along the Texas coast, these organisms, and especially their dominance patterns, are sometimes used as indicators of pollution. Many polycheate species (particularily *S. benedicti*) are tolerant to elevated levels of sediment organics (Reish et al., 2005), and these organisms typically dominate the community of “impacted” or “disturbed” areas. Polychaetes are often one of the first groups to recolonize an area impacted by some disturbance (Lundquist et al., 2004). Oligochaetes are also used as an indicator of pollution, because of their tolerance to organic enrichment. In enriched or oxygen-deficient areas, there are typically high densities of oligochaetes (Lerberg et al., 2000). Diaz (1979) showed that there is an abrupt shift in the community composition of tubificid oligochaetes as one proceeds from tidal freshwater to estuarine habitats. Not only does the species composition change but also their relative trophic importance and their importance to the community. The results of this study are consistent with this finding, as little differences in the upper, middle, or lower stations on any of the tidal streams were markedly different in their community composition.

The results of the Average Taxonomic Distinctness measure reinforces the evenness of the benthic communities across nearly all the environmental conditions encountered, although this measure did uncover a consistent trend of increased taxonomic diversity in the lower-most stations in each of the study streams (for an example, see Fig 49a). This would be consistent with the salinity preferences of a number of polychaetes, with their abundance levels found to be typically higher in mesohaline conditions (Montagna and Kalke, 1992). Also consistent with these results was a general drop-off of taxonomic diversity during the height of the drought in 2009, as salinity levels could have been approaching the environmental limits for even the most robust Polycheate taxa (Blank et al., 2004).

RECOMMENDATIONS FOR DETERMINING AQUATIC LIFE USE IN THE MISSION AND ARANSAS RIVER TIDAL SYSTEMS

This study furthered the application of the new multivariate assessment methodology to integrate the physical, chemical, and biological components of ecosystem health. The strength of this community-based approach lies in the differential sensitivity of the individual species, functional groups, and/or trophic levels to different levels of stress, and the ability to apply those functional responses to a wide variety of taxa that are sampled; each with unique life histories capable of being disrupted by these differently scaled stressors. Specific uses are evaluated on the basis of an established criteria, or a set standard, which is a numerical or narrative statement established by an authority upon which judgment can be based. To date, the many tidally-influenced coastal streams within the State of Texas have been classified as having “High” aquatic life use and the corresponding dissolved oxygen criteria (minimum average of 4.0 mg/L DO over a 24 hour period, a minimum of 2.0 mg/L allowed on a daily variation down to 1.5 mg/L for no more than eight hours per 24-hour period: dissolved oxygen criteria of 1.0 mg/L are considered minimum values at anytime, see Table 1) have been used to evaluate their attainment.

The suggested framework for conducting a Use Attainability Analysis (UAA) involves comprehensive, contemporaneous, high-quality data that can be used as a basis for water quality management decisions, including designation and water quality criteria development (Michael and Moore, 1997). In most instances, a waterbody under consideration is compared to a presumptive “reference condition”, and the appropriateness of any designated “use” can then be compared to a reference waterbody of some known condition. The choice of a reference stream is therefore critical in the context of evaluating uses. In the current study, both the Mission and Aransas River tidal segments are classified as having “High” aquatic life use, and either could have been used as the presumptive “reference condition”. Because Mission River had the lowest degree of anthropogenic disturbances, as measured by wastewater outfalls in the watershed, the Mission River was used as the default reference stream for this study.

Based on the dissolved oxygen criteria, both the Mission and the Aransas tidal segments appear to be fully supporting for a “High” aquatic life use based on DO grab minimum and no concern for DO grab screening levels, although both locations did had transitory instances of low DO events (Nelson and Tolan, 2008, see Table 23). While salinity is not explicitly part of the attainment criteria narrative in tidal segments, salinity intrusions have historically been noted for both of these rivers. The influence of salinity on the water quality comparisons for this study was quite evident, as the drought conditions of nearly all of the calendar year 2009 defined the differences between the two systems. Despite these obvious salinity differences, the more comprehensive multivariate evaluation of the data found little to no differences in either the physical, chemical, or biological structure between the Mission and Aransas River tidal segments. The greatest degree of difference among the integrated indicators of ecosystem health seemed to occur in response to seasonal changes that were recorded in water temperature, coupled with and the overarching effect of the drought as measured by salinity and the various chemical constituents that serve as a proxy for salinity. This calendar year variability, which was a direct response to the drought, cut across the many different levels of ecological integrity that were measured for this study. For example, the means plot MDS ordination of surface water quality (Fig. 32) matches quite well the chemical-based configuration of the bottom waters (Fig. 34), and this same pattern is repeated with the bag seine-based finfish collections in Fig. 38. What is not seen is a clear separation of either stream from the other at any level of ecosystem health. It should be noted that with only two streams to portray within each multivariate ordination, the differences between a reference condition and any study stream must be quite large to show any clear separation. The general overlap of ecological conditions of these two streams within this presumptive High aquatic life use category shows that ultimately, the Mission River is inherently similar to the Aransas River, even during the ecologically challenging periods of an extended drought.

Similar to other studies of ecological condition within tidally influenced segments along the Texas coast (Contreras and Wisenant, 2007; Tolan et al., 2007), the results of this study showed that dissolved oxygen concentration does not appear to be a primary structuring factor in the integrated physical, chemical, and biological components of ecosystem health. The attributes used in the present multivariate analysis assessing ‘use’ (habitat characteristics, diversity, species richness, and trophic structure) were generally similar in both systems, despite the obvious differences in salinity structure that was the result of the extended drought. One final attribute in assessing ‘use’ is the abundance or prevalence of “sensitive species” (see Table 1). Given the extreme euryhaline / physiological abilities found in many of the species that comprise the biological communities found within tidal systems, few estuarine taxa earn a true description of "sensitive". This is especially true of the biological communities found on the Mission River (see Tables 29 and 31), as many of the taxa most abundant in the most saline conditions were the same organisms that were found in the freshest conditions, albeit at either low or higher abundance levels. The greatest degree of differences in community composition was most closely tied to the combination of seasonality and the effects of the drought, and these differences were consistent across both stream systems.

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Appendix 1. Ecological Systems Descriptions.

Appendix 1 – Ecological Systems Descriptions

Contents

Central and South Texas Coastal Fringe Forest and Woodland

Identifier: CES203.464

Geology: Pleistocene and Holocene aged sand deposits

Landform: This system occupies flat topography. It is moderately dissected by drainages.

Soils: This system usually occurs on sandy soils. Typical Ecological Sites include Coastal Sand, Sand Hills, Sandy Coastal Flat.

Description: This system includes oak-dominated forests woodlands, shrublands and savannas occurring on deep sands of the Pleistocene-aged Ingleside barrier-strandplain of the central Texas coast and the Holocene-aged eolian sand deposits of the South Texas Sand Sheet. Topography varies from larger dunes to smaller ridges and swales. Vegetation of this physiognomically variable and dynamic system primarily includes patches (mottes) of forests, woodlands and shrublands dominated by *Quercus fusiformis*. Associated species vary in a north/south manner across the range of this system. Other canopy species in the vicinity of Aransas National Wildlife Refuge, at the northern end of the range, include *Quercus marilandica, Quercus hemisphaerica, Persea borbonia*, and *Celtis laevigata*. In this area, understory species include *Ilex vomitoria, Smilax bona-nox, Vitis mustangensis*, and/or *Morella cerifera*. Other canopy species on the South Texas Sand Sheet, at the southern end of the range, include *Prosopis glandulosa var. glandulosa*, *Zanthoxylum hirsutum, Condalia hookeri, Lantana urticoides (= Lantana horrida), Ziziphus obtusifolia var. obtusifolia*, and a very few other species. Many of the species found in the northern parts of the range of this system are absent in the southern occurrences. A characteristic component of the sparse ground cover within the mottes and forests across the entire range is *Malvaviscus arboreus var. drummondii*. Canopy openings are similar in composition to surrounding grasslands. In addition to *Schizachyrium littorale*, other herbaceous species common in canopy openings across the range of this system include *Paspalum plicatulum, Paspalum monostachyum, Andropogon gerardii, Sorghastrum nutans, Muhlenbergia capillaris, Helianthemum georgianum, Croton argyranthemus*, and *Froelichia floridana*. Minor changes in drainage can cause major differences in species composition. On the Ingleside barrier-strandplain, while *Paspalum monostachyum* may dominate slightly lower areas, deeper swales are typically dominated by *Panicum virgatum, Spartina patens, Fimbristylis spp., hydrocotyle bonariensis, Rhynchospora spp., Fuirena spp., Eleocharis spp., and Cyperus spp.*

MAPPING SUBSYSTEMS:

Central and South Texas Coastal Fringe Live Oak Forest

Central and South Texas Coastal Fringe Live Oak Forest

Description: As described for the system, but dominated by *Quercus fusiformis* (plateau live oak) or *Q. virginiana* (coastal live oak).

Central and South Texas Coastal Fringe Live Oak Shrubland

Central and South Texas Coastal Fringe Live Oak Shrubland

Description: As described for the system, but dominated by *Quercus fusiformis* (plateau live oak) or *Q. virginiana* (coastal live oak) in shrub variant.

Central and South Texas Coastal Fringe Mixed Grassland

Central and South Texas Coastal Fringe Mixed Grassland

Description: As described for the system, dominated by *Schizachyrium littorale* and other herbaceous species common in canopy openings across the range of this system including *Paspalum plicatulum, Paspalum monostachyum, Andropogon gerardii, Sorghastrum nutans, Muhlenbergia capillaris, Helianthemum georgianum, Croton argyranthemus*, and *Froelichia floridana*. Lower areas may be dominated by *Panicum virgatum, Spartina patens, Fimbristylis spp., hydrocotyle bonariensis, Rhynchospora spp., Fuirena spp., Eleocharis spp., and Cyperus spp.*

Central and South Texas Coastal Fringe Elbow Bush Shrubland

Central and South Texas Coastal Fringe Elbow Bush Shrubland
Description: As described for the system, dominated by *Forestiera angustifolia* with other shrub species, including *Quercus fusiformis,* and/ or *Morella cerifera*, being minor components.

Tamaulipan Mixed Deciduous Thornscrub

Identifier: CES301.983
Geology:
Landform: This system occupies flat to slightly rolling topography. It is moderately dissected by drainages.
Soils: This system typically occurs on sandy loams, sometimes with clay under-layer. Typical Ecological Sites include Gray Sandy Loam, Shallow, Shallow Sandy Loam, Tight Sandy Loam, Sloping Clay Loam and drier Claypan Prairies.
Description: This thornscrub ecological system occurs throughout much of northeastern Mexico and southern Texas. It occurs on a variety of substrates and landforms. Dominant species include *Acacia roemeriana*, *Leucophyllum frutescens*, and *Prosopis glandulosa*. Other species present to codominant include *Acacia berlandieri, Acacia farnesiana, Amyris madrensis, Amyris texana, Celtis pallida, Parkinsonia texana*, and cacti such as *Opuntia engelmannii var. lindheimeri.*

MAPPING SUBSYSTEMS

Tamaulipan Mesquite Woodland

Tamaulipan Mesquite Woodland
Description: As described for the system, but dominated by *Prosopis glandulosa* (Mesquite) woodlands or forests.

Tamaulipan Mesquite / Other Deciduous Shrubland

Tamaulipan Mesquite / other Deciduous Shrubland
Description: As described for the system, but dominated by *Prosopis glandulosa* (Mesquite) and other deciduous shrubs.

Tamaulipan Mesquite / Live Oak Shrubland

Tamaulipan Mesquite / Live Oak Shrubland
Description: As described for the system, but dominated by *Quercus fusiformis* (Live Oak) shrubs with significant *Prosopis glandulosa* (Mesquite) shrubs.

Tamaulipan Mesquite / Live Oak Woodland

Tamaulipan Mesquite / Live Oak Woodland
Description: As described for the system, but co-dominated by *Quercus fusiformis* (Live Oak) and *Prosopis glandulosa* (Mesquite).

Tamaulipan Savannah Grassland

Tamaulipan Savannah Grassland
Description: As described for the system, but dominated by graminoid vegetation.

Tamaulipan Calcareous Thornscrub

Identifier: CES301.986
Geology:
Landform: This system occupies flat to slightly rolling topography. It is moderately dissected by drainages.
Soils: This system typically occurs on shallow clayey to loamy soils with limestone and caliche substrates. Typical Ecological Sites include Shallow Ridge and Gravelly Ridge.
Description: This xeric thornscrub ecological system is restricted to limestone and calcareous sandstone hills and caliche substrates such as along the Bordas Scarp in southern Texas and northeastern Mexico. Soils are shallow, alkaline, strongly calcareous and underlain by bedrock or a caliche layer. It has a shorter, more open shrub canopy (usually less than 2 m) when compared to more typical thornscrub growing on more favorable sites. However, shrub cover is generally greater than 70% and often greater than 85%. Dominant species include *Leucophyllum frutescens*, *Acacia berlandieri*, and *Acacia farnesiana* with many other shrub species that may be locally dominant such as *Acacia rigidula, Amyris madrensis, Amyris texana, Castela erecta ssp. texana, Celtis pallida, Eysenhardtia texana, Helietta parvifolia, Koeberlinia spinosa, Parkinsonia texana var. macra, Sophora secundiflora, or Yucca spp*. The sparse to moderately dense herbaceous layer is dominated by perennial graminoids.

MAPPING SYSTEMS

Tamaulipan Calcareous Shrubland

Tamaulipan Calcareous Shrubland
Description: As described for the system, but dominated by *Acacia berlandieri*, and *Acacia farnesiana.*

Tamaulipan Calcareous Grassland

Tamaulipan Calcareous Grassland
Description: As described for the system, but dominated by graminoid vegetation. Usually appears as small openings within the shrub matrix.

Texas Coastal Bend Floodplain Forest

Identifier:

Geology: This system generally occupies Quaternary alluvium.
Landform: This floodplain forest occupies relatively broad flats at low topographic positions, along large streams where alluvial deposition dominates.
Soils: Bottomland Ecological Sites (including Loamy, Sandy, and Clayey) characterize this system.
Description: Dominant communities within this system range from floodplain forests to wet meadows to gravel/sand flats; however, they are linked by underlying soils and the flooding regime. Canopy dominants may include *Carya illinoinensis* (pecan), *Fraxinus americana* (white ash), *Quercus nigra* (water oak), *Ulmus crassifolia* (cedar elm), *Celtis laevigata* (sugar hackberry), *Ulmus americana* (American elm), *Quercus fusiformis* or *Q. virginiana* (plateau or coastal live oak), *Platanus occidentalis* (American sycamore), *Acer negundo* (boxelder), *Quercus macrocarpa* (bur oak), *Morus rubra* (red mulberry), *Fraxinus pennsylvanica* (green ash), and *Sapindus saponaria* var. *drummondii* (western soapberry). Overgrazing and/or overbrowsing may influence recruitment of overstory species and composition of the understory and herbaceous layers. Shrub species may include *Callicarpa americana* (American beautyberry), *Ilex decidua* (possumhaw), *Ilex vomitoria* (yaupon), *Sideroxylon lanuginosum* (gum bumelia), *Diospyros virginiana* (eastern persimmon), *Juniperus virginiana* (eastern redcedar), *Cornus drummondii* (roughleaf dogwood), and *Viburnum rufidulum* (rusty blackhaw), which may occur as dense patches following disturbance, but are otherwise generally fairly sparse. Vines such as *Berchemia scandens* (Alabama supplejack), *Campsis radicans* (common trumpetcreeper), *Vitis* spp. (grape), *Parthenocissus quinquefolia* (Virginia creeper), and *Ampelopsis arborea* (peppervine) may be conspicuous. Herbaceous cover includes *Elymus virginicus* (Virginia wildrye), *Verbesina virginica* (frostweed), *Chasmanthium latifolium* (inland sea-oats), *Chasmanthium sessiliflorum* (narrowleaf woodoats), *Tripsacum dactyloides* (eastern gamagrass), *Panicum virgatum* (switchgrass), *Galium* spp. (bedstraw), and *Carex* spp. (caric sedge). Non-native grasses that may dominate these sites include *Cynodon dactylon* (Bermuda grass) and *Sorghum halepense* (Johnson grass). Herbaceous cover may be quite high, especially in situations where shrub cover is low.

MAPPING SUBSYSTEMS:

Texas Coastal Bend Floodplain Live Oak Forest

Texas Coastal Bend Floodplain Live Oak Forest and Woodland
Description: As described for the system, but dominated by *Quercus fusiformis* (plateau live oak) or *Q. virginiana* (coastal live oak). Deciduous species can be, and frequently are, common in the canopy, but *Q. fusiformis* (plateau live oak) or *Q. virginiana* (coastal live oak) clearly dominates. *Juniperus virginiana* (eastern redcedar) may also be present.

Texas Coastal Bend Floodplain Hardwood Forest

Texas Coastal Bend Floodplain Hardwood Forest and Woodland
Description: As described for the system with a mix of deciduous species in the canopy.

Texas Coastal Bend Floodplain Live Oak / Hardwood Forest

Texas Coastal Bend Floodplain Live Oak - Hardwood Forest and Woodland
Description: As described for the system with a mix of Live Oak and a mix of deciduous species in the canopy.

Texas Coastal Bend Floodplain Successional Evergreen Shrubland

Texas Coastal Bend Floodplain Successional Evergreen Shrubland
Description: Shrublands of the floodplains of the region that are dominated by *Juniperus* spp. (juniper) occurring as shrubs, or other evergreen shrubs, such as *Ilex vomitoria* (yaupon).

Texas Coastal Bend Floodplain Successional Deciduous Shrubland

Texas Coastal Bend Floodplain Successional Deciduous Shrubland
Description: Shrublands of the floodplains of the region that are dominated by deciduous shrubs such as *Ilex decidua* (possumhaw), *Prosopis glandulosa* (mesquite), *Salix nigra* (black willow), *Cornus drummondii* (roughleaf dogwood), and/or *Cephalanthus occidentalis* (common buttonbush).

Texas Coastal Bend Floodplain Wet Prairie

Texas Coastal Bend Floodplain Wet Prairie
Description: Floodplains of the region that lack a significant overstory or shrub canopy, but retain cover in the herbaceous layer. Non-native grass species such as *Cynodon dactylon* (Bermuda grass) and *Sorghum halepense* (Johnson grass) may frequently dominate this vegetation type. *Tripsacum dactyloides* (eastern gamagrass) – *Panicum virgatum* (switchgrass) dominated prairies on lowlands may also be mapped as this vegetation type.

Texas Coastal Bend Floodplain Barren

Texas Coastal Bend Floodplain Barren
Description: Areas devoid of vegetation within the mapped floodplain soils.

Texas Coastal Bend Riparian Forest

Identifier:
Geology: As defined, this system occupies buffer zones of headwater streams and soils develop in place over a variety of geologic surfaces
Landform: Valleys and drainages along headwater streams of Mission and Aransas Rivers
Soils: By definition, this system is mapped along drainages upstream of the Bottomland Ecoclasses, so they will be mapped on soils of the surrounding uplands.
Description: Trees that may be present in stands of this system include *Celtis laevigata* (sugar hackberry), *Ulmus crassifolia* (cedar elm), *Platanus occidentalis* (American sycamore), *Populus deltoides* (eastern cottonwood), *Juglans major* (Arizona walnut), *Quercus fusiformis* (plateau live oak), *Quercus nigra* (water oak), *Quercus phellos* (willow oak), *Sapindus saponaria* var. *drummondii* (western soapberry), *Salix nigra* (black willow), *Fraxinus americana* (white ash), *Fraxinus pennsylvanica* (green ash), *Gleditsia triacanthos* (common honeylocust), and *Carya illinoinensis* (pecan). The shrub layer development is variable, sometimes with species such as *Amorpha fruticosa* (indigobush), *Forestiera acuminata* (swamp privet), *Ilex decidua* (possumhaw), *Ilex vomitoria* (yaupon), *Sideroxylon lanuginosum* (gum bumelia), *Juniperus virginiana* (eastern redcedar), *Diospyros virginiana* (eastern persimmon), *Cornus drummondii* (roughleaf dogwood), and/or *Viburnum rufidulum* (rusty blackhaw). Herbaceous cover is also

variable, depending on overstory and shrub canopies and recent flooding history. Herbaceous species may include *Elymus virginicus* (Virginia wildrye), *Verbesina virginica* (frostweed), *Chasmanthium latifolium* (inland sea-oats), *Chasmanthium sessiliflorum* (narrowleaf woodoats), *Tripsacum dactyloides* (eastern gamagrass), *Symphyotrichum drummondii* var. *texanum* (Drummond's aster), *Geum canadense* (white avens), *Sanicula canadensis* (Canada snakeroot), *Panicum virgatum* (switchgrass), *Galium* spp. (bedstraw), and *Carex* spp. (caric sedge). Non-native grass species that may be common to dominant on these sites include *Cynodon dactylon* (Bermuda grass) and *Sorghum halepense* (Johnson grass). The environment and characteristics of the vegetation of this system become drier from east to west, with moister representatives (such as communities containing *Quercus nigra* (water oak)) occurring in the eastern parts of the range.

MAPPING SUBSYSTEMS:

Texas Coastal Bend Riparian Live Oak Forest

Texas Coastal Bend Riparian Live Oak Forest and Woodland
Description: As described for the system, with *Quercus fusiformis* (plateau live oak) or *Quercus virginiana* (coastal live oak) dominating the canopy. Deciduous species can be, and frequently are, common in the canopy, but *Q. fusiformis* (plateau live oak) or *Q. virginiana* (coastal live oak) clearly dominates. *Juniperus virginiana* (eastern redcedar) may also be present.

Texas Coastal Bend Riparian Hardwood Forest

Texas Coastal Bend Riparian Hardwood Forest and Woodland
Description: As described for the system, with deciduous species dominating the canopy.

Texas Coastal Bend Riparian Live Oak / Hardwood

Texas Coastal Bend Riparian Mixed Live Oak - Hardwood Forest and Woodland
Description: As described for the system, with a mix of evergreen species (including *Juniperus spp.* (junipers) and/or *Quercus fusiformis* (plateau live oak) or *Quercus virginiana* (coastal live oak)) and deciduous species in the canopy.

Texas Coastal Bend Riparian Successional Evergreen Shrubland

Texas Coastal Bend Riparian Successional Evergreen Shrubland
Description: Shrublands in riparian sites that are dominated by *Juniperus* spp. (juniper) or, sometimes broadleaf evergreen shrubs such as *Ilex vomitoria* (yaupon) or *Quercus fusiformis*. The juniper is usually *Juniperus virginiana* (eastern redcedar). This is a minor component of the system.

Texas Coastal Bend Riparian Successional Deciduous Shrubland

Texas Coastal Bend Riparian Successional Deciduous Shrubland
Description: Shrublands in riparian sites dominated by deciduous shrubs such as *Ilex decidua* (possumhaw), *Prosopis glandulosa* (mesquite), *Salix nigra* (black willow), *Cornus drummondii* (roughleaf dogwood), and/or *Cephalanthus occidentalis* (common buttonbush).

Texas Coastal Bend Riparian Wet Prairie

Texas Coastal Bend Riparian Wet Prairie
Description: Riparian sites lacking overstory or shrub canopy but retaining herbaceous cover. *Tripsacum dactyloides* (eastern gamagrass) – *Panicum virgatum* (switchgrass) dominated prairies on lowlands may also be mapped as this vegetation type.

Texas Coastal Bend Riparian Barren

Texas Coastal Bend Riparian Barren
Description: Areas devoid of vegetation within the buffer zones of headwater streams.

Central and Upper Texas Coast Salt and Brackish Tidal Marsh

Identifier: CES203.473
Geology: Pleistocene and Holocene aged sand deposits and also on Quaternary alluvium.
Landform: This system occupies low, flat tidally flooded areas.
Soils: This system usually occurs on fine silts and clays, sometimes with significant sand inclusions. Typical Ecological Sites include Marsh, Salt Flat and Salty Bottomland.
Description: This ecological system encompasses the brackish to salt intertidal marshes of the central and upper coast of Texas. These marshes typically occur on the bay side of barrier islands. Vegetation includes *Spartina alterniflora, Distichlis spicata, Spartina patens, Batis maritima, Juncus roemerianus, Iva frutescens ssp. Frutescens, Schoenoplectus spp*. and *Sporobolus virginicus*. It also includes extensive irregularly flooded tidal flats and salt pannes, some vegetated by succulent herbs such as *Sarcocornia, Salicornia*, and *Batis*; some are nonvegetated. This system ranges from Galveston Bay in Chambers County, Texas, south to approximately Corpus Christi Bay.

MAPPING SUBSYSTEM

Central Texas Coast Salt Flat

Central Texas Coast Salt Flat
Description: As described for the system, salt pan areas, some with limited succulents herbs such as *Sarcocornia, Salicornia*, and *Batis.*

Central Texas Coast Regularly Flooded Tidal Salt/Brackish Marsh

Central Texas Coast Regularly Flooded Tidal Salt/Brackish Marsh
Description: As described for the system, areas that are flooded on a regular basis due to normal tidal fluctuation. Dominant vegetation includes Spartina alterniflora, Distichlis *spicata, Spartina patens,* and *Juncus roemerianus.*

Central Texas Coast Irregularly Flooded Tidal Salt/Brackish Marsh

Central Texas Coast Irregularly Flooded Tidal Salt/Brackish Marsh
Description: As described for system, areas that are only flooded on higher tides such as during spring and fall tides and also tropical storm and hurricanes. Vegetation dominated by *Spartina patens, Iva frutescens ssp. Frutescens,* and *Borrichia frutescens.*

Salt Cedar Invasive Shrubland

Salt Cedar Invasive Shrubland
Description: As described for the system, dominate vegetation is invasive *Tamarix spp.*

Phragmites Invasive

Phragmites Invasive
Description: As described for the system, dominate vegetation is invasive *Phragmites australis* (Common Reed).

Texas Saline Coastal Prairie

Identifier: CES203.543
Geology: Pleistocene and Holocene aged sand deposits
Landform: This system occupies flat topography near coastal bays and estuaries. It is moderately dissected by drainages.
Soils: This systems usually occurs on sandy, sandy loam and clayey soils with high salinity contents. Typical Ecological Sites include Salty Prairie, Coastal Sand, and Salty Bottomland.
Description: This system encompasses grassland vegetation occurring on saline soils that are often saturated by local rainfall and periodically flooded by saline waters during major storm events. It is located along the Gulf Coast of Texas. Saline prairie continues to occupy extensive areas, though quality of the system is often degraded by the invasion of woody shrubs due to the absence of regular fire. Fire is an important ecological process needed to maintain this system, though periodic submersion with saltwater during storm events also helps to control the invasion of woody species. This system is characteristically dominated by Spartina spartinae; other dominants may include Schizachyrium littorale and Muhlenbergia capillaris. This system includes depressions often dominated by Spartina patens.

Texas-Louisiana Coastal Prairie

Identifier: CES203.550
Geology: Pleistocene terraces.
Landform: This system occupies flat topography near coast. It is moderately dissected by drainages.
Soils: This systems usually occurs on loamy, sandy loam and clay soils. Typical Ecological Sites include Blackland, Rolling Blackland, Claypan Prairie, Lowland, Lakebed, Loamy Prairie and Sandy.
Description: This system encompasses non-saline tallgrass prairie vegetation ranging along the coast of Louisiana and Texas. This vegetation is found on Vertisols and Alfisols which developed over Pleistocene terraces flanking the Gulf Coast. It is often characterized by a ridge-and-swale or mound-and-intermound microtopography and encompasses both upland and wetland plant communities. Upland dominants include *Schizachyrium scoparium, Paspalum plicatulum, Sorghastrum nutans*, and *Andropogon gerardii*. Wetland dominants in undisturbed occurrences include *Panicum virgatum* and *Tripsacum dactyloides*; disturbed occurrences may

be dominated by *Andropogon glomeratus*. Some estimates state that 99% of coastal prairie has been lost through conversion to other uses and environmental degradation due to the interruption of important ecological processes, such as fire, needed to maintain this system. In the absence of regular fire, this system will be invaded by woody shrubs and trees. Much of this community has been degraded by introduction of exotic grass species such as *Cynodon dactylon*, *Paspalum notatum, Paspalum urvillei, Sporobolus indicus* and *Panicum coloratum.*

Texas-Louisiana Coastal Prairie Pond Shore

Identifier: CES203.541
Geology: Pleistocene terraces.
Landform: This system occupies flat topography near coast. It is moderately dissected by drainages.
Soils: This systems usually occurs on loamy, sandy loam and clay soils. Typical Ecological Sites include Blackland, Rolling Blackland, Claypan Prairie, Lowland, Lakebed, Loamy Prairie and Sandy.
Description: This system includes small to moderately large ponds and swales in the coastal prairie of southeastern Texas and adjacent Louisiana. These wetlands contain surface water during much of the year, desiccating only in the driest summer months. They are often fed by water runoff but may result from percolation from adjacent sandy areas. Soils in the basins are finer-textured than surrounding areas and may be underlain by pans that enhance perched water tables in the winter. These wetlands occur within the coastal prairie matrix of southeastern Texas and Louisiana and are wetter than wet prairie dominated by *Tripsacum dactyloides* and *Panicum virgatum*. These wetlands may be dominated by *Eleocharis quadrangulata*. Other species that may be present include *Sagittaria papillosa, Sagittaria longiloba, Steinchisma hians, Panicum virgatum, Cyperus haspan, Cyperus virens, Ludwigia glandulosa, Ludwigia linearis, Fuirena squarrosa, Xyris jupicai, Leersia hexandra, Centella erecta, Symphyotrichum subulatum (= Aster subulatus), Sesbania* spp., and *Rhynchospora* spp. Open areas in the ponds may contain floating and submersed aquatic vegetation, including *Stuckenia pectinata, Ceratophyllum demersum, Brasenia schreberi, Nymphoides aquatica, Nuphar lutea*, and *Nelumbo lutea*.

East-Central Texas Plains Post Oak Savanna and Woodland

Identifier: CES205.679
Geology: Typical on sedimentary formations of Eocene age, generally of the Wilcox and Claiborne groups.
Landform: This system occupies gently rolling to hilly topography. It is moderately dissected by drainages.
Soils: This system usually occurs on sandy to sandy loam soils, often with a marked clay subsurface horizon. Soils of this system are generally Alfisols, and are typically acidic to neutral. Typical Ecological Sites include Claypan Savannah, Claypan Prairie, Sandy Loam, Sandy, and Deep Sand.
Description: This system represents a transition from the woodlands and forests of East Texas to the prairies to the west, specifically the Blackland Prairie. Savannas and woodlands are typically

dominated by *Quercus stellata* (post oak), *Quercus marilandica* (blackjack oak), and *Carya texana* (black hickory). Other species, such as *Quercus incana* (bluejack oak) (on more xeric sites), *Quercus fusiformis* (plateau live oak), *Ulmus alata* (winged elm), *Juniperus virginiana* (eastern redcedar), and *Prosopis glandulosa* (mesquite), can also be present in the overstory. In some sites, particularly in the south, *Quercus fusiformis* (plateau live oak) may codominate the woodlands. Shrubs may attain significant cover in the understory, with species including *Ilex vomitoria* (yaupon) (often dominant), *Callicarpa americana* (American beautyberry), *Vaccinium arboreum* (farkleberry), *Sideroxylon lanuginosum* (gum bumelia), *Crataegus* spp. (hawthorn), *Ilex decidua* (possumhaw), *Toxicodendron radicans* (poison ivy), and *Symphoricarpos orbiculatus* (coral-berry). Mid- and tallgrass species including *Schizachyrium scoparium* (little bluestem), *Sorghastrum nutans* (Indiangrass), and *Panicum virgatum* (switchgrass) are frequent in the understory where light penetration supports herbaceous cover, and also form prairie patches within the savanna, particularly on tighter soils. Other grasses present include *Andropogon gerardii* (big bluestem), *Bothriochloa laguroides* ssp. *torreyana* (silver bluestem), *Paspalum plicatulum* (brownseed paspalum) (to the south), *Nassella leucotricha* (Texas wintergrass), and *Sporobolus cryptandrus* (sand dropseed). Non-native grass species such as *Bothriochloa ischaemum* var. *songarica* (King Ranch bluestem), *Paspalum notatum* (bahiagrass), and *Cynodon dactylon* (Bermuda grass) may dominate some sites. Post Oak Savanna (at least north of the Colorado River) contains species of more eastern affinities such as *Callicarpa americana* (American beautyberry), *Sassafras albidum* (sassafras), *Cornus florida* (flowering dogwood), *Vaccinium arboreum* (farkleberry), *Ulmus alata* (winged elm), and particularly *Ilex vomitoria* (yaupon), the latter species being absent from similar savannas of the Crosstimbers.

Drought, grazing, and fire are the primary natural processes that affect this system. Much of this system has been impacted by conversion to improved pasture or crop production. Overgrazing and fire suppression have led to increased woody cover on most extant occurrences and the invasion of some areas by problematic brush species such as *Juniperus virginiana* (eastern redcedar) (to the north) and *Prosopis glandulosa* (mesquite) (to the south).

MAPPING SUBSYSTEMS:

Post Oak Savanna: Post Oak Motte and Woodland

Post Oak Savanna: Post Oak Motte and Woodland

Description: This vegetation type generally represents the deciduous woodland component of the system. The typical occurrence is dominated by *Quercus stellata* (post oak), with *Quercus marilandica* (blackjack oak) and/or *Quercus fusiformis* (plateau live oak) (particularly in the south) also present. *Carya texana* (black hickory) may be a significant component of the overstory, particularly on deep sands. Depending on site history and edaphic conditions, other species may be present in the overstory or may be better represented as shrubs. Such species may include *Diospyros virginiana* (eastern persimmon), *Juniperus virginiana* (eastern redcedar), *Ulmus alata* (winged elm), and *Ulmus crassifolia* (cedar elm), and as overstory components, are often stunted (< 12 m in height). The shrub layer includes species such as *Callicarpa americana* (American beautyberry), *Ilex decidua* (possumhaw), *Ilex vomitoria* (yaupon), *Sideroxylon lanuginosum* (gum bumelia), *Smilax bona-nox* (greenbrier), *Symphoricarpos orbiculatus* (coral-berry), *Vaccinium arboreum* (farkleberry), and *Zanthoxylum clava-herculis* (Hercules-club). Herbaceous components are often represented by components of the surrounding prairies, primarily *Schizachyrium scoparium* (little bluestem), but also *Sorghastrum nutans* (Indiangrass), *Andropogon gerardii* (big bluestem), and, to the south and east, *Paspalum plicatulum* (brownseed paspalum). Other grass species may include *Bothriochloa laguroides* ssp. *torreyana* (silver bluestem), *Elymus canadensis* (Canada wildrye), *Panicum virgatum* (switchgrass), *Paspalum floridanum* (Florida paspalum), *Paspalum setaceum* (fringeleaf paspalum), *Sporobolus compositus* (tall dropseed), and *Tridens flavus* (purpletop). *Quercus nigra* (water oak) may be co-dominant on more mesic sites, particularly in the eastern portion.

Post Oak Savanna: Savanna Grassland

Post Oak Savanna: Savanna Grassland
Description: This vegetation type represents the herbaceous expression of the overall system, which is a mosaic of woody and herbaceous cover types as suggested by reference to a savanna. These grasslands are often dominated by mid- and tallgrass species often present in the understory of woody expressions of the system. Dominant species include *Schizachyrium scoparium* (little bluestem), *Sorghastrum nutans* (Indiangrass), and *Panicum virgatum* (switchgrass). Other grasses present include *Andropogon gerardii* (big bluestem), *Bothriochloa laguroides* ssp. *torreyana* (silver bluestem), *Paspalum plicatulum* (brownseed paspalum) (to the south), *Nassella leucotricha* (Texas wintergrass), and *Sporobolus cryptandrus* (sand dropseed). Non-native grass species such as *Bothriochloa ischaemum* var. *songarica* (King Ranch bluestem), *Paspalum notatum* (bahiagrass), and *Cynodon dactylon* (Bermuda grass) may dominate some sites. These grasslands may be difficult to differentiate in areas of transition to Blackland Prairie or Coastal Prairie.

Post Oak Savanna: Live Oak Motte and Woodland

Post Oak Savanna: Live Oak Motte and Woodland
Description: *Quercus fusiformis* or *Quercus virginiana* (live oak) may dominate sites within the Post Oak Savanna. *Quercus stellata* (post oak) may be present in these woodlands, but typically only as a minor component of the canopy, or it may be completely absent. These occurrences become more common and may occupy large areas in the southeastern part of this region, but occur elsewhere as well. *Ilex vomitoria* (yaupon), *Callicarpa americana* (American beautyberry), *Smilax bona-nox* (greenbrier), *Sideroxylon lanuginosum* (gum bumelia), *Toxicodendron radicans* (poison ivy), and *Zanthoxylum clava-herculis* (Hercules' club) may be present in the shrub layer. *Schizachyrium scoparium* (little bluestem), *Bothriochloa laguroides* ssp. *torreyana* (silver bluestem), and *Nassella leucotricha* (Texas wintergrass) are among the many species of grass that may be present in the herbaceous layer.

Post Oak Savanna: Live Oak / Post Oak Motte and Woodland

Post Oak Savanna: Live Oak / Post Oak Motte and Woodland
Description: *Quercus fusiformis* or *Quercus virginiana* (live oak) and *Quercus stellata* (post oak) may co-dominate sites within the Post Oak Savanna. *Quercus stellata* (post oak) will be present in these woodlands, typically only as a large to dominant component

of the canopy. These occurrences become more common and may occupy large areas in the southeastern part of this region, but occur elsewhere as well. *Ilex vomitoria* (yaupon), *Celtis pallida* (Spiny hackberry), *Smilax bona-nox* (greenbrier), *Sideroxylon lanuginosum* (gum bumelia), *Toxicodendron radicans* (poison ivy), and *Zanthoxylum clava-herculis* (Hercules' club) may be present in the shrub layer. *Schizachyrium scoparium* (little bluestem), *Bothriochloa laguroides* ssp. *torreyana* (silver bluestem), and *Nassella leucotricha* (Texas wintergrass) are among the many species of grass that may be present in the herbaceous layer.

Post Oak Savanna: Live Oak Shrubland

Post Oak Savanna: Live Oak Shrubland
Description: *Quercus fusiformis* or *Quercus virginiana* ("running" live oak) shrubs may dominate sites within the Post Oak Savanna. *Quercus stellata* (post oak) and large *Quercus fusiformis* or *Quercus virginiana* (live oak) may be present in these shrublands, typically only as scattered individuals in the canopy. These occurrences become more common and may occupy large areas in the southwestern part of this region, but occur elsewhere as well. *Ilex vomitoria* (yaupon), *Celtis pallida* (Spiny hackberry), *Smilax bona-nox* (greenbrier), *Sideroxylon lanuginosum* (gum bumelia), *Toxicodendron radicans* (poison ivy), and *Zanthoxylum clava-herculis* (Hercules' club) may be present also. *Schizachyrium scoparium* (little bluestem), *Bothriochloa laguroides* ssp. *torreyana* (silver bluestem), and *Nassella leucotricha* (Texas wintergrass) are among the many species of grass that may be present in the herbaceous layer.

Human Induced Azonal Systems

Description: Areas that are maintained or created through human actions.

MAPPING SUBSYSTEMS:

Tame Grassland

Tame Grassland
Description: Areas dominated by cultivated grassland systems, dominant species include *Cynodon dactylon*, *Paspalum notatum, Paspalum urvillei, Sporobolus indicus* and *Panicum coloratum.*

Invasive Rose Hedge Shrubland

Invasive Rose Hedge Shrubland
Description: Usually prairie areas that are now dominated by *Rosa bracteata* (Macartney rose) shrub thickets.

Invasive Mesquite/Huisache Shrubland

Invasive Mesquite/Huisache Shrubland
Description: Usually prairie areas that are now dominated by *Prosopis glandulosa* (mesquite) and / or *Acacia farnesiana* (Huisache) shrubs.

Invasive Mesquite/Huisache Woodland and Forest

Invasive Mesquite/Huisache Woodland and Forest
Description: Usually prairie areas that are now dominated by *Prosopis glandulosa* (mesquite) and / or *Acacia farnesiana* (Huisache) trees.

Urban High

Urban High
Description: This type consists of built-up areas and wide transportation corridors that are dominated by impervious cover.

Urban / Residential

Urban / Residential
Description: This type includes areas that are built-up but not entirely covered by impervious cover, including most of the area within cities and towns.

Agriculture

Agriculture
Description: This type includes all cropland where fields are fallow for some portion of the year. Some fields may rotate into and out of cultivation frequently, and year-round cover crops are generally mapped as tame grassland.

Natural Azonal Systems

Description: Areas of natural vegetation that are not limited to a single ecological system.

MAPPING SUBSYSTEMS:

Barren

Barren
Description: This type includes areas where little or no vegetative cover existed at the time of image data collection. Large areas cleared for development are included, as well as rural roads and buildings and associated clearing in primarily rural areas. Stream beds with exposed gravel or bedrock, rock outcrops, and year-round fallow fields are also included.

Open Water

Open Water
Description: Most open water in Phase 1 consists of reservoirs or large ponds, although large rivers and streams are also mapped as open water.

Marsh

Marsh
Description: Areas mapped as marsh are small, and consist of wet or alternately wet and dry soils with herbaceous vegetation.

Appendix 2. Analysis of stream flow data in the Mission and Aransas Rivers.

TEXAS PARKS AND WILDLIFE DEPARTEMENT

TIDAL STREAM USE ASSESSMENT PROJECT PHASE II

FY 2008

Final Report

ANALYSIS OF STREAM FLOW DATA IN TIDAL STREAMS OF THE TEXAS COAST: MISSION AND ARANSAS RIVERS

Prepared by:

Texas Water Development Board

June 2010

Texas Water Development Board

Prepared for:

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Published and Distributed by the
Texas Water Development Board
P.O. Box 13231
Austin, TX 78711-3231

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1. Introduction

1.1. Study Objectives

Tidal streams are important nursery habitats for many commercially important fish and shellfish found along the Gulf Coast of Texas. Some of these streams are listed as impaired but cannot be evaluated as such because there is no generally accepted methodology for assessing the health of tidal streams. While instream flow is widely recognized as an influential component of stream health, few studies have documented the hydrology of tidal streams beyond the basic knowledge that tidal streams continually oscillate between freshwater and saltwater conditions as downstream freshwater inflow intersects tidal flow being carried upstream. The constantly changing conditions of tidal streams increase complexity of the stream ecosystem as well as complicate efforts to determine health and impairment according to more commonly employed methodologies.

The Texas Commission on Environmental Quality (TCEQ) and Texas Parks and Wildlife Department (TPWD) are working to develop a set of useful criteria for assessing aquatic life use within tidally influenced streams. A major task of the study of the tidal streams is collecting and analyzing physical, chemical, and biological data from tidal streams. A previous use attainability analysis on five tidal streams in Texas completed in 2007 introduced a new assessment methodology to integrate the physical, chemical, and biological components of ecosystem health. The current TPWD project applies this methodology to data collected in a new sampling effort on the Mission River Tidal (TCEQ Segment 2001) and the Aransas River Tidal (TCEQ Segment 2003). In support of this effort, and under contract, the Texas Water Development Board (TWDB) assisted TPWD project staff by processing and analyzing velocity data collected by TPWD from the Mission and Aransas Rivers in 2008 and 2009 as well as analyzing supplemental stream discharge data for both streams that was collected by the TWDB in June of 2009.

The objectives of the velocity data analysis were the extraction of the tidal and residual components of the current velocity, examination of directionality of flow and the determination of statistical characteristics of the data. The stream discharge data was used to examine spatial variations in flow and also to construct a simple velocity-discharge rating curve for the velocity dataset. Both the TPWD and the TWDB collected the stream discharge and velocity data using acoustic Doppler technology.

This report contains basic analysis of this data, including summary discharge and velocity data, as well as results of analyses conducted to separate tidal and non-tidal (residual) components of stream flow velocity.

1.2. Study Region

The current tidal stream study is focused on the tidal segments of the Mission and Aransas Rivers. These segments are defined by TCEQ as follows: Aransas River Tidal (Segment 2003) begins at a point one mile upstream of US 77 in Refugio/San Patricio County, is 6 miles in length, and flows into Copano Bay. The Aransas River forms a portion of the boundary between Refugio and San Patricio Counties, from the Bee County line to the bay. Mission River Tidal (Segment 2001) begins at a point 4.6 miles downstream of US 77 in Refugio County, is 19 miles in length, and flows into Mission Bay. Figure 1 shows the general location of the both study areas.

Figure 1. Location of Mission and Aransas Rivers.

1.3. Data Collection

As part of the Mission and Aransas UAA study, the TPWD collected data at 3 monitoring stations for each tidal stream. These included an upper station, a middle station and a lower station. In this report, the monitoring stations are referred to as M1, M2 and M3 for the Mission River and as A1, A2 and A3 for the Aransas River with M1 and A1 being the most upstream sites and M3 and A3 being the most downstream sites for each of the rivers. For the flow analysis however, only the middle stations, M2 and A2, were studied. Figure 2 shows the locations of the TPWD UAA monitoring stations along with other long term monitoring stations that were used in this report.

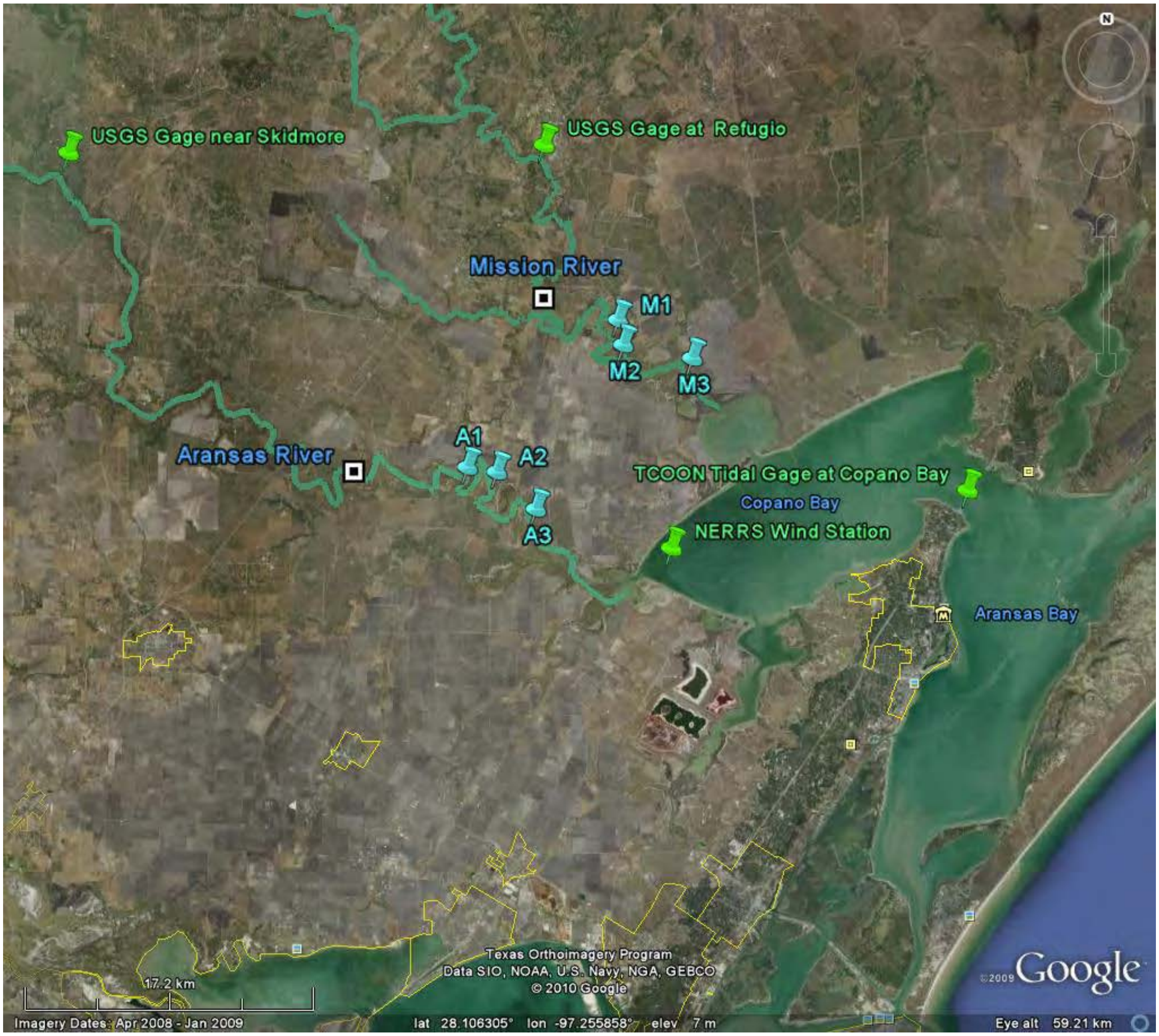

Figure 2. Monitoring Station Locations.

TPWD collected flow velocity data in Aransas River Tidal and Mission River Tidal six times annually for two consecutive years in conjunction with the physicochemical, water chemistry and benthos sampling events. Replicate seasonal sampling took place twice each in the spring, summer, and fall of 2008 and 2009. SonTek's bottom-mounted up-looking Argonaut XR ADV (1500 kHz and 3000 kHz) was deployed at the middle stations (M2 and A2; Figure 2) in each of the two streams to measure flow velocity and direction. A total of eleven deployments in the Mission River and twelve deployments in Aransas River were carried out between March 2008 and November 2009 with sampling events lasting for 45 – 260 hours to capture at least one tidal cycle. (Tables 2 and 3). Data collected during two deployments in Aransas River and one deployment in

Mission River were not usable and five more deployments could only be used partially (Appendix C; Figures 49 - 53).

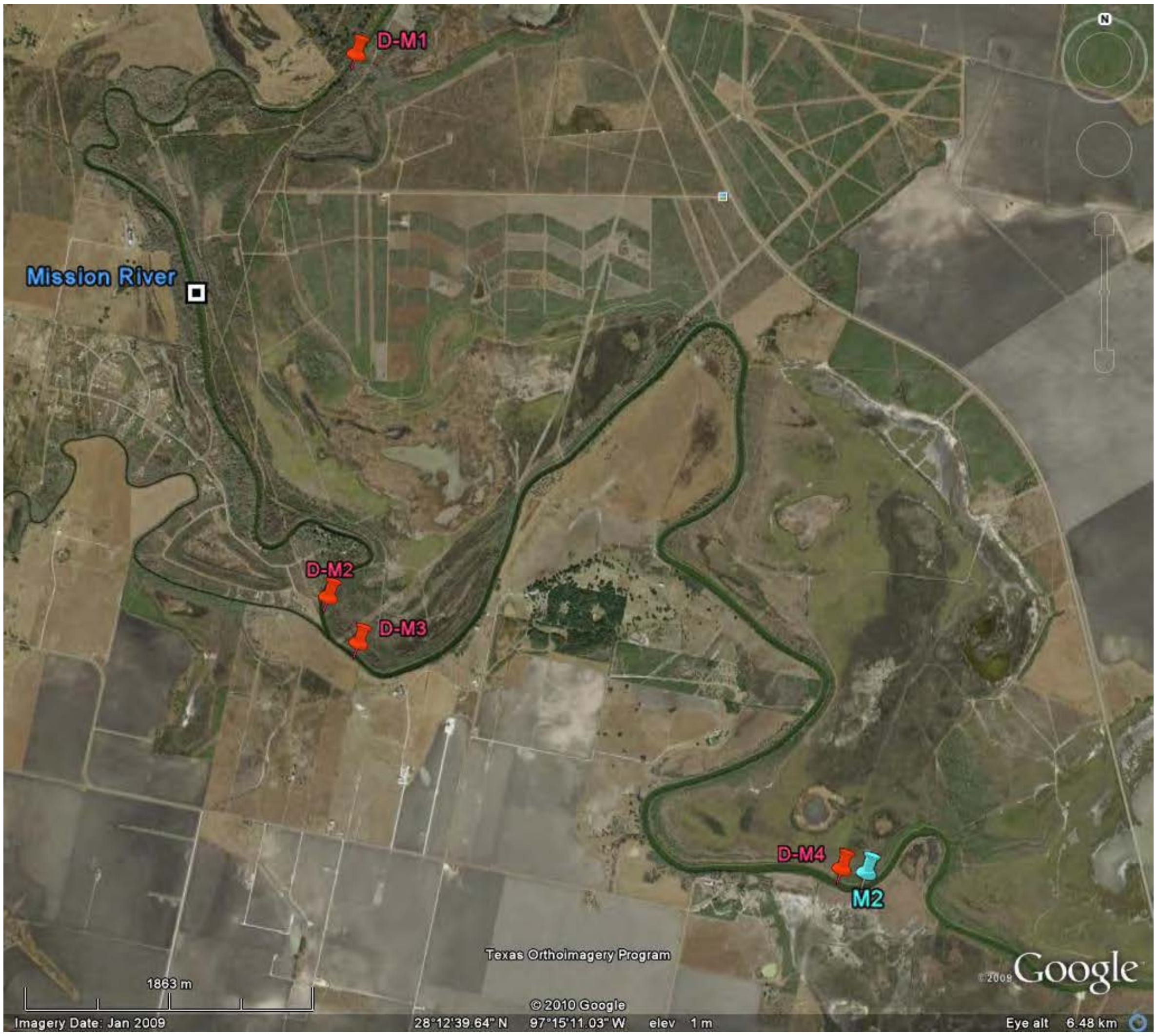

Figure 3. Velocity measurement station (M2) and discharge measurement stations at Mission River.

Figure 4. Velocity measurement station (A2) and discharge measurement stations at Aransas River.

TWDB measured discharge in the two streams on June 23, 2009 using SonTek's boat-mounted ADCP (Appendix D). Discharge measurements at stations D-M4 and D-A2 (Figures 3 and 4) were done at/very close to the ADV deployment stations, i.e. M2 and A2, at the same time with the ADV deployments. These data were used to relate the average velocity data collected by the ADCP to the discharge measurements. Three more discharge measurements were made in Mission River at various locations upstream of D-M4 (Figure 3). Two of these measurements, D-M2 and D-M3 were set up within 20 minutes of each other, directly upstream and downstream of a tributary in order to investigate inflow from/diversion into this tributary. The third transect in Mission River, D-M1, was located 10 river miles upstream of M2 and discharge data from this station was used in this analysis to study changes in the flow regime along the stream. There was one more discharge measurement site in Aransas River, in addition to the transects near A2 (Figure 4). Each of the discharge sampling events lasted for 17 – 22 minutes.

Table 1. Discharge and flow velocity measurement stations.

Station	Latitude	Longitude	Measurement
Mission River			
M-2	28.189522	-97.23408	Velocity
D-M1	28.237187	-97.268574	Discharge
D-M2	28.205296	-97.269906	Discharge
D-M3	28.202639	-97.26786	Discharge
D-M4	28.18984	-97.23566	Discharge
Aransas River			
A-2	28.12076	-97.309471	Velocity
D-A1	28.12315	-97.3542	Discharge
D-A2	28.123505	-97.311026	Discharge

Table 2. Aransas River Argonaut XR Deployment Detail.

Start Date	Deployment length(hrs)	% of usable data	# of tidal cycles	File name	Coordinate system	Argonaut	Argonaut Frequency (MHz)
28-Mar-08	71.0	100%	2	0308A002	ENU	XR-E740	1.5
13-May-08	138.8	100%	5	0508A003	ENU	XR-E740	1.5
25-Jun-08	45.6	61%	1	0608A004	XYZ	XR-E740	1.5
5-Aug-08	69.8	100%	2	0808A004	XYZ	XR-E740	1.5
24-Sep-08	259.0	0%	0	0908A007	XYZ	XR-E737	3.0
3-Nov-08	69.8	100%	2	1108A003A	XYZ	XR-E740	1.5
24-Mar-09	69.6	27%	0	0309A003	XYZ	XR-E740	1.5
12-May-09	69.8	100%	2	0509A002	XYZ	XR-E737	3.0
23-Jun-09	69.6	0%	0	0609A002	XYZ	XR-E737	3.0
5-Aug-09	46.0	100%	1	0809A004	ENU	XR-E740	1.5
22-Sep-09	61.2	100%	2	0909A002	ENU	XR-E737	3.0
3-Nov-09	141.8	100%	5	1109A006	XYZ	XR-E737	3.0

Table 3. Mission River Argonaut XR Deployment Detail.

Start Date	Deployment length(hrs)	% of usable data	# of tidal cycles	File name	Coordinate system	Argonaut	Argonaut Frequency (MHz)
25-Mar-08	144.0	52%	3.0	0308M002	ENU	XR-E895	3.0
13-May-08	139.2	19%	1.0	0508M002	ENU	XR-E895	3.0
25-Jun-08	50.4	0%	2.0	0608M002	XYZ	XR-E737	3.0
5-Aug-08	74.3	100%	3.0	0808M002	XYZ	XR-E737	3.0
22-Sep-08	262.2	100%	10.0	0908M005	XYZ	XR-E740	1.5

24-Mar-09	70.0	100%	2.0	0309M003	XYZ	XR-E737	3.0
12-May-09	72.0	44%	1.0	0509M002	XYZ	XR-E740	1.5
23-Jun-09	70.8	100%	2.0	0609M002	XYZ	XR-E740	1.5
5-Aug-09	46.5	100%	1.0	0809M002	ENU	XR-E737	3.0
22-Sep-09	141.5	100%	5.0	0909M003	ENU	XR-E740	1.5
3-Nov-09	143.8	100%	5.0	1109M003	XYZ	XR-E740	1.5

2. Methodology

2.1. Acoustic Doppler Theory

Stream flow data were collected using acoustic Doppler technology, which measures water motion by transmitting sound through the water column at a fixed frequency and then measuring the Doppler-shifted echoes. The echoes are influenced by backscatter from scatterers (plankton and sediment) in the water and are converted to along beam (acoustic) velocity components. There are two main methods of deploying these instruments. The first involves mounting the instrument to a boat and making transects across an area of interest. The second involves mounting the instrument on a fixed structure, either on the river bed looking up or submerged at the river's edge looking sideways.

A boat-mounted SonTek RiverCat acoustic Doppler current profiler (ADCPs) was used by TWDB to record instantaneous measurements of velocity and discharge in the stream channel. The bottom-mounted, up-looking SonTek Argonaut XR acoustic Doppler velocimeter (ADV) was used by TPWD to measure stream flow direction and velocities over periods of time to include at least one complete tidal cycle. Both instruments use the same technology and provide a detailed level of cross-sectional data that is unprecedented in the history of stream flow data collection. The RiverCat system in addition is equipped with compass/tilt sensor and bottom-tracking circuitry to enable calculation of stream discharge. Documents on appropriate techniques for use and analyses of ADP collected data have been made available from the U.S. Geological Survey (USGS) testing and open file reports (e.g., Rantz *et al.* 1982, Morlock 1996, Norris 2001, Morlock and Fisher 2002). Since different companies have different nomenclature for these instruments and since the same instruments can be used in both roles, we refer to the boat-mounted current profilers as ADCP and the stationary up-looking velocimeters as ADV.

2.1.1. Measurement of Stream Discharge

When performing water-current surveys covering large areas, or when monitoring river discharge, it is often convenient to use a boat-mounted system. Following the USGS basic stream flow protocol for collecting flow data with boat-mounted ADCPs (Norris 2001), TWDB recorded instantaneous measurements of discharge for a total of six sampling events on the two streams for the June 23, 2009 sampling event.

When operating from a moving platform, an ADCP measures relative currents. As such, it is important to measure independently the speed of the platform so that it can be subtracted from the instrument's measure of raw current. This procedure then establishes residual water currents relative to the fixed Earth. It is generally desirable to perform these calculations in real-time (SonTek 2005a). This usually is done either by the ADCP tracking the river bed (bottom-tracking) or by using differential GPS. Both techniques require driving the platform or boat along transects across an area of interest, during which time, velocities are measured in 'depth bins'. Depth and width of each depth bins are also measured during the transect and instantaneous discharge across the 'measured' cross-section is given as the sum of the calculated discharges in each bin. Hence, this technique can obtain very accurate instantaneous flow discharge measurements over a large area.

The USGS protocol recommends performing four transects in close succession at a site to establish accuracy of the stream discharge measurements. For typical streams under steady-flow conditions, the USGS expects replicate measurements of total discharge to differ by no more than 5% (Norris 2001). Expectations for this kind of agreement are unrealistic for tidal streams. Within a tidal stream segment, there is continual variation in the forces acting on stream waters. This complicates the implicit assumption that the four transects replicate flow. In tidal waters, the USGS therefore suggests reducing the time variant element in estimates of flow by using individual transects as representative measures of discharge (Norris 2001). This is in contrast to their recommendation to conduct more than four transects in turbulent water, but recognizes the difficulty of measuring discharge under rapidly changing conditions. Clearly, there is no standard methodology for tidal streams, but by conducting four or more transects the range of variability can be documented for future use in determining an appropriate methodology. For each site and sampling event, ADCP transects were summarized and compared on the basis of total discharge. Total discharge is a function of the instantaneous discharge measured by the instrument and a volume transport estimated in the cross-sectional areas where the instrument cannot record data.

ADCPs and ADVs (discussed separately below, see *Measurement of Stream Velocity*) cannot measure flow across the entire width of the channel. The acoustic Doppler technology and methods of deployment prevent measuring flow near the surface and bottom layer, as well as any portion of the channel too shallow for boat access such as portions near the banks. These non-measured areas must therefore be estimated. Discharge in the surface and bottom layers is estimated according to a power equation by the ADCP software. Discharge along the stream edges also is estimated according to an equation that the user selects based on the expected angle (steep or shallow) of the bank. In this equation, the distance between the last good measurement and the edge of the bank is necessary to accurately estimate flow along the non-measured edges. In large channels and rivers, the non-measured portion of the channel may be very small. For small streams and shallow bayous, the non-measured portion may be relatively large compared to the area directly measured. For comparison among the streams in this study, this is not likely to be a problem; however, the difference between measured and estimated discharge is documented. The selection of an ADCP with the appropriate frequency of operation is important in minimizing the area in front of the transducer commonly known as the blanking distance, where no measurements can be made. In shallow depth waters, use of high frequency ADCPs(3.0 MHz) gives sufficient depth of measurement (up to 6m) while providing a minimum blanking distance of 0.6m.

2.1.2. Measurement of Stream Velocity

Time-series data is invaluable when investigating flow regimes affected by tidal currents and freshwater inflow, such as in these tidally influenced study streams. ADVs represent flow by averaging velocity across the water column from surface to bottom. They are usually either mounted on river beds looking upward or submerged at one edge of the river looking sideways. These instruments measure a cone-shaped segment of the water column over a user defined start and end distance. The cone is divided into ‘bins’ with each bin representing a velocity measurement at a specific distance from the transducer. These measurements are then averaged to obtain the current velocity. Since ADVs can be installed for extended periods of time, they are useful for obtaining flow history at a site.

The Doppler technology employed by the ADV instruments is reliable for low flow situations, as is found in many coastal streams, because there is no minimum velocity detection level (SonTek 2005b). However as with any technique, there are concerns for establishing the accuracy and reliability of the data. ADVs, being essentially identical to ADCPs, are also prone to the blanking distance drawback mentioned above. This depth may be a large part of the water depth in shallow streams over which the velocity will not be measured hence reducing the reliability of measurements. Another drawback of these instruments is that based on the river profile and size there may be significant parts of the water column that are not captured by the cone of measurement. Although velocity measurements given by the ADV may be reliable, measures of stream discharge may be inaccurate for this reason, though reliable estimates can be obtained by applying the ADV velocity data to a discharge rating curve generated by ADCP data. Rating curves are determined from measures of stream discharge collected by an ADCP for various flow regimes (section 2.2 has more on rating curve computation). The USGS uses this technique for their stream gage program. Additionally, the USGS has established a considerable body of literature documenting and testing appropriate practices for using ADVs and analyzing associated data (e.g., Lipscomb 1995, Norris 2001). However, much of the literature concerns non-tidally influenced streams and it is not known how well these procedures work in tidal streams.

2.2. *Velocity Data Analysis*

The raw velocity data for each of the ADV deployments were saved in binary files (.arg) for processing using SonTek's ViewArgonaut software. ViewArgonaut's data filtering and screening features were implemented on the files to remove high frequency noises and bad data when deemed necessary. To conduct more extensive statistical and graphical analysis using external scripts, these files were batch-exported as spaced delimited text files from ViewArgonaut. Some of the deployments were set up in XYZ coordinate system where the velocity components along each axis of the instrument's Cartesian coordinate system were measured while in others the East North Up (ENU) coordinate system was used and time series of the velocity components in the true North, East and Up direction are reported in the binary files. To maintain consistency and simplify the velocity computations, all measurements conducted with XYZ coordinates were converted to ENU system within ViewArgonaut before they were exported for processing. This process doesn't change the original files.

To calculate the magnitude of the resultant velocity (speed of flow), the river flow was assumed to have no lateral and vertical components in both study sites since the preliminary investigation of the velocity data showed laminar one-dimensional flow. The river velocity was then computed from the velocities along the true east and north as:

$$X = \pm\sqrt{E^2 + N^2} \qquad \textbf{(eq. 1)}$$

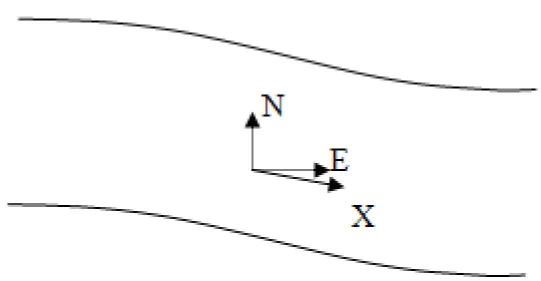

Figure 5. Resultant Velocity Calculation Diagram.

where:

E is the velocity component along true East

N is the velocity component along true North

X is the velocity in the direction of flow.

Upstream flow is negative, downstream flow is positive.

The direction of flow (upstream versus downstream) was determined from the sign of the east/north components of the velocity. Since the channels at the sampling stations were oriented in the south east and east direction (Figure 2), negative east velocity indicates upstream flow. Python scripts were developed to do the above velocity computations and other analysis of the velocity data in an efficient manner. To avoid bias in our statistical analysis, velocity data that included full tidal cycles were used in the computations. The outputs from these analyses are given in this report.

2.3. Discharge Analysis

Processing of discharge data collected using ADCPs was done using SonTek's RiverSurveyor software. The RiverSurveyor software has graphical interfaces for displaying color contours of bin velocities for the entire measurement cross-section, depth averaged velocity profile along the transect path, as well as tabular summary of discharge, velocity and cross-sectional areas of flow for multiple transects. This software makes it easy to investigate velocity profiles and presence of bi-directional flows. Moreover, faulty measurements can be identified and diagnosed quickly.

When ADCPs are set up at one location on the channel, they measure the depth averaged velocity for a small portion of the river channel. This may not give an accurate estimation of the river discharge in wide streams due to the velocity variation across the channel. Hence, boat mounted ADCPs are used to measure river discharge across a stream. However this is a costly procedure compared to deploying stationary ADVs. Hence regression equations for estimating discharge from velocity measurements are developed from concurrent velocity and discharge measurements under varying flow conditions. This method is cost-efficient and can give good discharge estimates. In the Mission-Aransas study, 8-11 continuous ADCP transects each lasting approximately 20 minutes were taken in conjunction with the June 23, 2009 ADV deployments at the middle stations in both Mission and Aransas rivers.

The discharge rating curve was based on the total discharge (Q_{Tot}) which is the sum of the discharge measured by the ADCP (Q_M) and estimated discharge near the banks (Q_L and Q_R for the left and right banks) as well as near the surface and bottom (Q_T and Q_B for the near surface and bottom estimates) of the channel where the ADCP doesn't not take measurements.

$$Q_{Tot} = Q_M + (Q_L + Q_R + Q_T + Q_B) \qquad \textbf{(eq. 2)}$$

The power fit with the default exponent of 1/6 was used for extrapolating the vertical velocity profile in the unmeasured top and bottom portions. The sloped bank option was selected in the software for calculating the discharge volume near the banks. The software computes the discharge volume near the banks as a product of the last velocity measurement near the bank and the cross-section of flow (area of the triangle between the edge of the bank and last velocity profile measurement in the case of sloped banks). Normally, multiple measurements taken during different stream flow conditions are required to develop discharge rating curves. However in this study, due to the presence of only a single discharge sample for each site, a linear regression (Equation 3) with zero intercepts was assumed. Moreover, the performance of this regression equation in predicting discharge could not be evaluated due to the lack of multiple discharge measurements.

The linear regression equation normally used for developing the rating curve for tidal streams (Dunn et al., 1997) is:

$$Q = B_1 + B_2V + B_3S \qquad \textbf{(eq. 3)}$$

where Q is the estimated discharge in cubic meters per second, B1, B2, and B3 are the regression coefficients, V is the measured velocity in meters per second, and S is the measured stage in meters above (+) or below (-) the mean stage measured during the hydrographic survey.

The coefficients B1 and B3 are assumed to be zero as more than one coinciding discharge and velocity measurements are required to estimate them. The coefficient B2 is computed as:

$$B2 = Q_{av}/V_{av} \qquad \textbf{(eq. 4)}$$

where Q_{av} is the average of the eight discharge measurements and V_{av} is the time averaged velocity over the 20 minutes when the ADCP transects were made. The procedures for computing the regression coefficients for the two streams are shown in Appendix E.

2.4. Tidal Analysis and Estimation of Residual Velocity and Discharge

The non-tidal flow velocity components associated with freshwater water flow and wind driven currents were extracted using a script that implemented the Doodson X_0 low pass filter (Doodson 1928; UAA 2008) . Since this filter needs at least 39 hours of hourly data, only velocity datasets that were 60+ hours long were filtered using this technique to extract non-tidal (residual) components for at least one tidal cycle (24.8 hrs) and the datasets were averaged to hourly frequency beforehand. Once the residual components were extracted with the filter, the tidal components of flow velocity and the estimated residual discharge used in this analysis were calculated as:

$$V_{Tid} = V_T - V_R \qquad \textbf{(eq. 5)}$$

$$Q_{est} = A.B2.V_R \qquad \textbf{(eq.6)}$$

where V_{Tid} and V_R are the tidal and non-tidal components of the flow velocity (V_T), A is the cross-sectional area of flow, B2 is the regression coefficient calculated in equation 4, and Q_{est} is the estimated residual discharge.

3. Summary of Flow Characteristics

In this section, we present summary characteristics of flow for the M2 and A2 monitoring stations on the Mission River Tidal and the Aransas River Tidal segments. Individual plots of each ADV deployment can be found in Appendices A and B.

3.1. Mission River Tidal

3.1.1. Historical Hydrology

The long term mean annual discharge (1940 – 2009) in Mission River at a USGS gage near Refugio, TX was 145 cfs. During spring and winter months as well as August, the mean monthly discharge is about half of the discharge during the wet months when stream flow remains fairly constant from May – July and September – October. In 2008, the stream flow was very low at about 5% of the long term mean annual discharge (Figure 6 (a)). Similarly, in the first nine months in 2009 flow remained low (Figure 6 (b)). However during October – December, there were high flow events that resulted in monthly mean discharges that exceeded the long term equivalents by 2-5 folds. The mean annual flow in 2009 recovered to 85% of the 70-year annual mean flow because of these flood events.

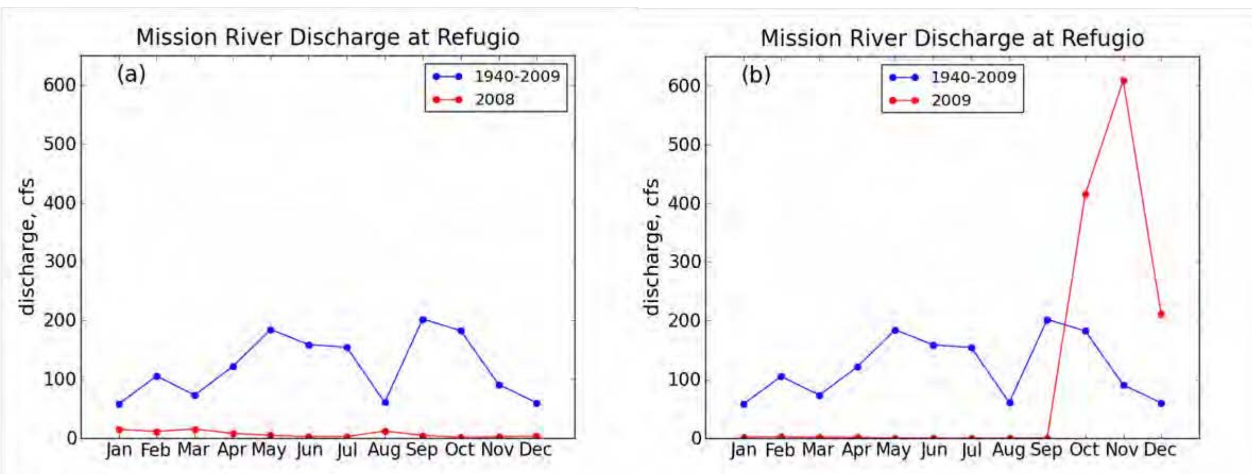

Figure 6. Monthly averaged discharge for Mission River for (a) 70 years (blue) and 2008 (red) (b) 70 years (blue) and 2009 (red).

3.1.2. Velocity Analysis Results

Figure 7 shows the flow pattern observed during the March 2008 ADV deployment. The proportions of the tidal and residual components of flow at any point in time during the deployment are shown in this plot (top panel). The occurrence of maximum and minimum current velocities relative to the tidal periods are also elucidated through comparison of the date/time of occurrence of the maximum total velocities (top panel) and tidal velocities (top panel). Additionally, the presence of directional flow, and the relative magnitude of the upstream and downstream currents; and whether the residual currents augment downstream or upstream flow is shown in this plot. During the March 2008 deployments, currents that shifted direction with tidal cycles were seen at the middle station in Mission River. The downstream currents were relatively weaker (less than 0.65 ft/s; Figure 7, bottom panel) partly because of the dampening effect of upstream residual currents which were prevalent throughout the deployment event. The maximum flow velocities were in phase with the peaks of the flooding cycle of the tidal flow on both days.

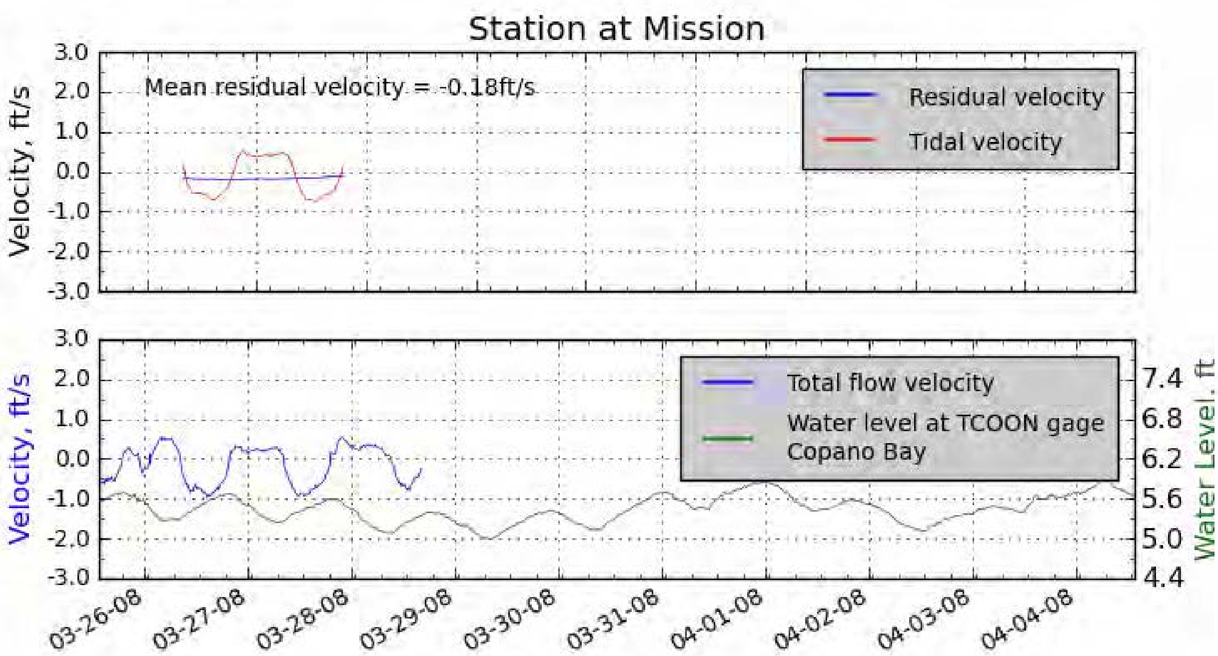

Figure 7. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) in Mission River during March 2008 deployment.

Similar plots for the other deployments for the Mission River Tidal ADV deployments are contained in Appendix A. Here, we summarize the findings of all the deployments: May 2008 and August 2008 currents displayed very weak tidal signal with the total velocity remaining less than 0.3 ft/s for more than 50% of the deployment lengths (Figures 17 and 18). The August 2008 data set was filtered to extract the tidal and residual components. The analysis showed that there were no residual currents during the deployment period (Figure 18, top panel). The September 2008 velocity time series was the longest consisting of 10 days of measurements. The flow in the first 2 days was characterized by relatively strong tidal currents as high as 1.8 ft/s that dissipated consistently to velocities that were less than 0.65 ft/s during the last day (Figure 19). Flow direction reverses in-phase with the tidal cycles during the periods of strong tides. The highest residual velocity observed during the deployment period was 0.3 ft/s. In general, residual velocities in Mission River remained negligible throughout the study period, making up 7 – 42% of the tidal velocities (Figures 17 to 25). In May 2009 and

June 2009, both the upstream and downstream flow velocities were relatively strong (Figures 21 and 22). Filtering of the June 2009 data showed that the maximum velocities (both upstream and downstream) were during the peaks of the respective tidal cycles (Figure 22, top panel). Flow was almost purely tidal as the residual components were negligible (Table 4). High and low peak velocities were achieved once daily, implying that the diurnal components of the tide were dominant. In September 2009 and November 2009, the stream flow exhibited tidal oscillations with amplitudes of around 0.65 ft/s (Figures 24 and 25).

Table 4 shows the mean residual velocity and the mean total velocity for all the deployments. The mean total velocity was calculated using all the complete tidal cycles present in the deployment while the mean residual velocity covers the middle portion of the deployment that remains after the application of the Doodson filter. Table 5 compares the net direction of flow (i.e upstream v.s. downstream) to the prevalent wind direction at the time. Neither table shows any string seasonal or other correlation.

Table 4. Mean residual and total flow velocities at M2, Mission River.

Deployment Start Date	Mean Residual Velocity (ft/s)	Mean Total Velocity (ft/s)
25-Mar-08	-0.18	-0.14
5-Aug-08	0.01	0.02
22-Sep-08	-0.07	-0.09
24-Mar-09	0.00	0.00
23-Jun-09	0.07	0.10
22-Sep-09	-0.13	-0.11
3-Nov-09	0.05	0.02

Table 5. Wind Speed and Direction in Copano Bay, TX (March 2008 – November 2009).

Deployment Month	Average Wind Speed (mph)	Wind Direction	Net Direction of Flow	
			Mission River	Aransas River
Mar-08	15.6	SSE	Upstream	Upstream
May-08	15.8	SE and NE	Upstream	No net flow
Jun-08	16.8	SSE	No good data	Upstream
Aug-08	11.8	SSE	No net flow	Upstream
Sep-08	11.6	NE	Upstream	No good data
Nov-08	11.0	SE	No data	Upstream
Mar-09	13.6	SE	No net flow	No good data
May-09	15.1	SE	Upstream	Upstream
Jun-09	13.0	SSE	No net flow	No good data

Aug-09	13.0	SSE	No net flow	Upstream
Sep-09	9.6	SE	No net flow	Downstream
Nov-09	9.9	NE	No net flow	No net flow

Flow direction in the river was either upstream or there was no net flow in all the deployments (Figure 8). This pattern of flow was observed in Lost River and Cow Bayou – tidal streams studied in the previous UAA study (UAA report, 2007). Wind-driven upstream flow was also noted in the Laguna Madre estuary (USGS, 1998). During the Mission-Aransas study period, south-easterly winds prevailed in the study area as it can be seen from wind data obtained from a National Estuarine Research Reserve System (NERRS; Table 5) weather station in Copano Bay, TX (Figure 2). These winds enhance upstream flow in both streams since the mouths of both streams are located to the west. In November 2009, the maximum flow velocity was downstream although the net flow was nearly zero (Figure 8). This was most likely associated with relatively higher freshwater flow rates during the month (Figure 6). Flow was quite low throughout the study period with mean flow velocities bound in the range (+0.15 ft/s – - 0.65 ft/s). The maximum velocity in most deployments coincided with the peak of the tidal cycles, hence near-maximum or maximum velocities being reached repeatedly in-phase with the peaks of the tidal cycles. No seasonal pattern of flow could be seen from the velocity data. Maximum current velocity was seen in September during the 2008 deployments and in May during the 2009 deployments.

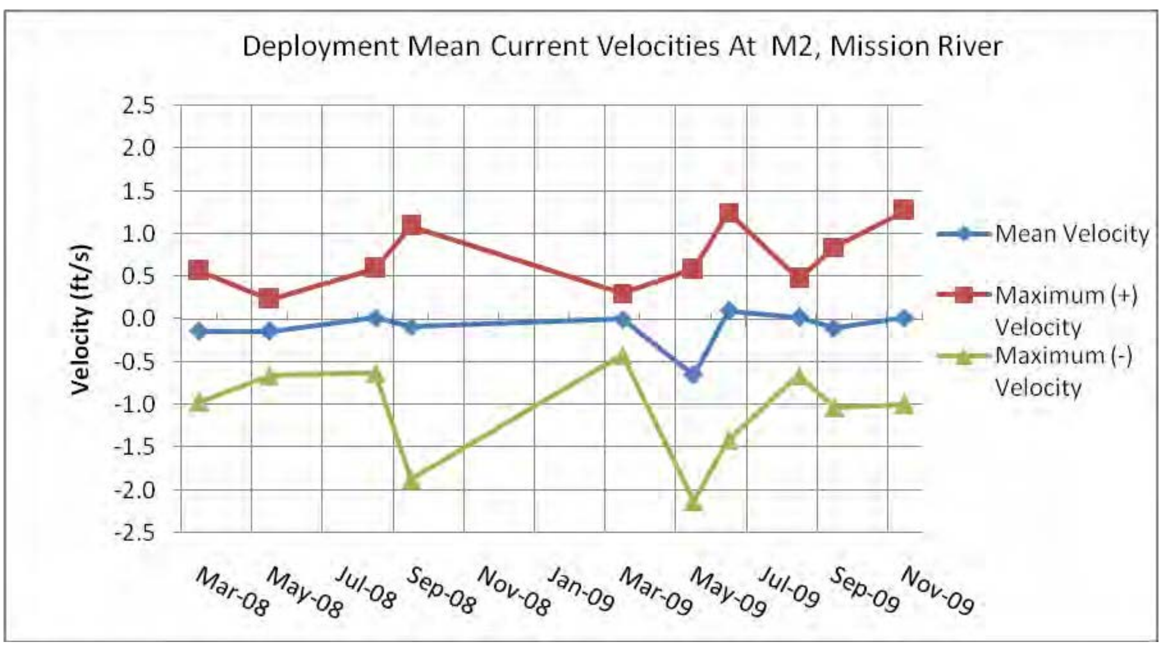

Figure 8. Deployment mean flow velocities at M2, Mission River (March 2008 – November 2009).

3.1.3. Flow Analysis Results

To compare the incoming freshwater flow with the estimated residual flow at M2, discharge data from USGS gage near Refugio, TX were averaged over 7 days during each of the ADV deployment. The mean discharge at the USGS gage during the March 2008 deployment was + 10.3 cfs. The residual flow noted at M2 was upstream throughout the deployment (Figure 26). The mean residual flow during the August deployment was 1.8 cfs while the USGS gage discharge remained very low during this period too (Figure 27). In September 2008, the residual flow at M2 was relatively higher and over the eight days, it had variable direction and magnitude while the gage flow remained nearly constant at about 1.5 cfs (Figure 28). Both the gage and estimated residual flows in the March and June 2009 were very low (Figures 29 and 30). There was virtually no flow at the USGS gage during the September 2009 deployment whereas the residual flow at M2 was variable and remained upstream almost throughout the entire deployment period (Figure 31). In the November 2009 deployment, like in the rest, there was no clear relationship between the gage and estimated residual flow with residual flow that varied both in magnitude and direction while the gage flow remained fairly low and constant (Figure 32).

Despite the gage flow remaining low through most of the deployments, the residual flow at M2 was variable (Figure 9). This variation may be explained by combination of other factors such as wind forces and low frequency tidal components of flow passing through the filter used thereby affecting the residual flow results.

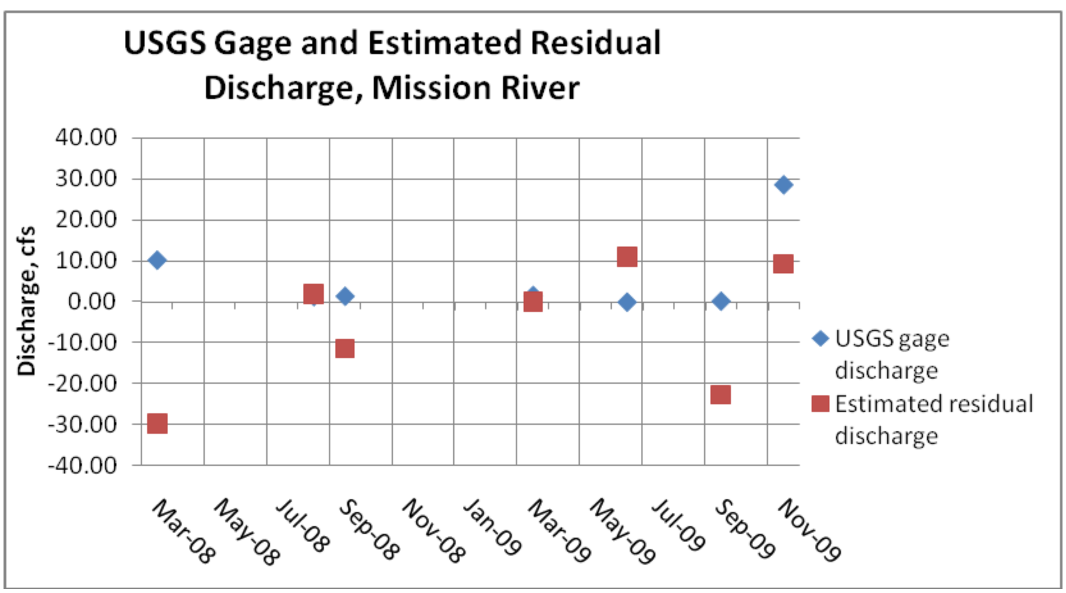

Figure 9. Deployment mean residual discharge (estimated) at M2 and mean measured discharge at USGS gage near Refugio, Mission River (March 2008 – November 2009).

To estimate the inflow contribution of a tributary located 6 miles upstream of M2, two ADCP deployments were set up directly upstream (station D-M2) and downstream(station D-M3) of the confluence of the river and tributary (Figure 3). Subtraction of the D-M3 flow from the D-M2 flow shows approximately twenty percent of the flow (60.3 cfs) was diverted into the tributary during the flood cycle.

Comparison of discharge measurements along the stream showed that the tidal flow dissipated at a more rapid rate going upstream (Figure 11). There was negligible difference in the discharge measurements at D-M3 and D-M4 that were 6 river miles apart. The discharge in D-M1 was however 70 cfs lower than the measured discharge in D-M2, which is the next downstream station located 4 river miles away. However, since these measurements were made at different times (there was up to 1.5 hrs difference between adjacent sampling events; Appendix D), the actual rate of the tidal flow dissipation may be less pronounced than what was seen in the data. Flow showed high variability in all the discharge measurement sites. The ratio of the standard deviation to the mean discharge ranged from 0.23 to 0.59. Generally, the ratio increased at low mean discharges. The estimated discharge was slightly higher than the measured discharge in D-M1 while it was about half of the measured discharge in the rest of the discharge measurement sites (Figure 10).

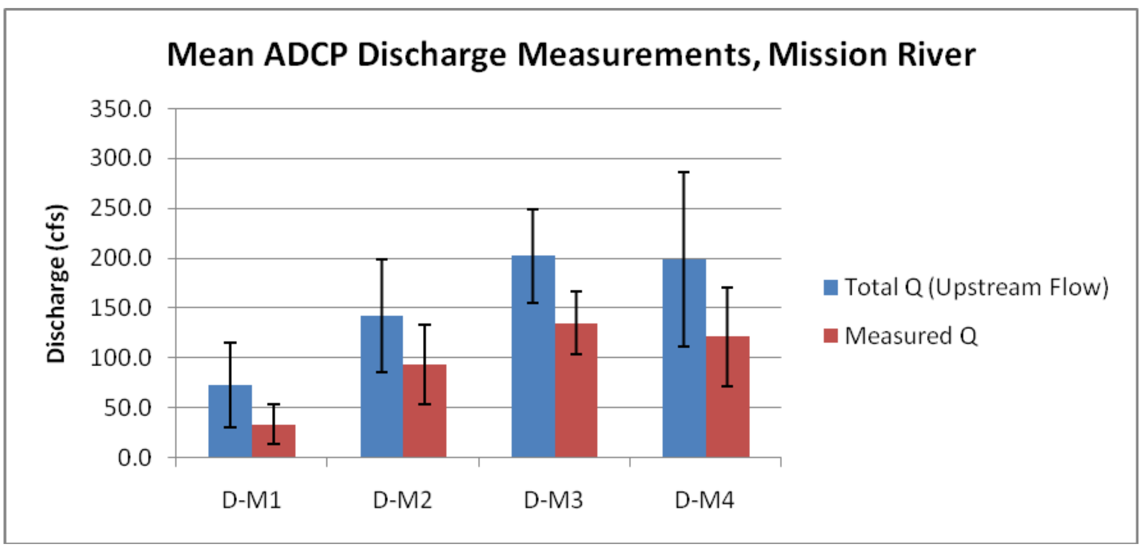

Figure 10. Mean measured and total (measured + estimated) ADCP discharge measurements at Mission River stations (June 23, 2009).

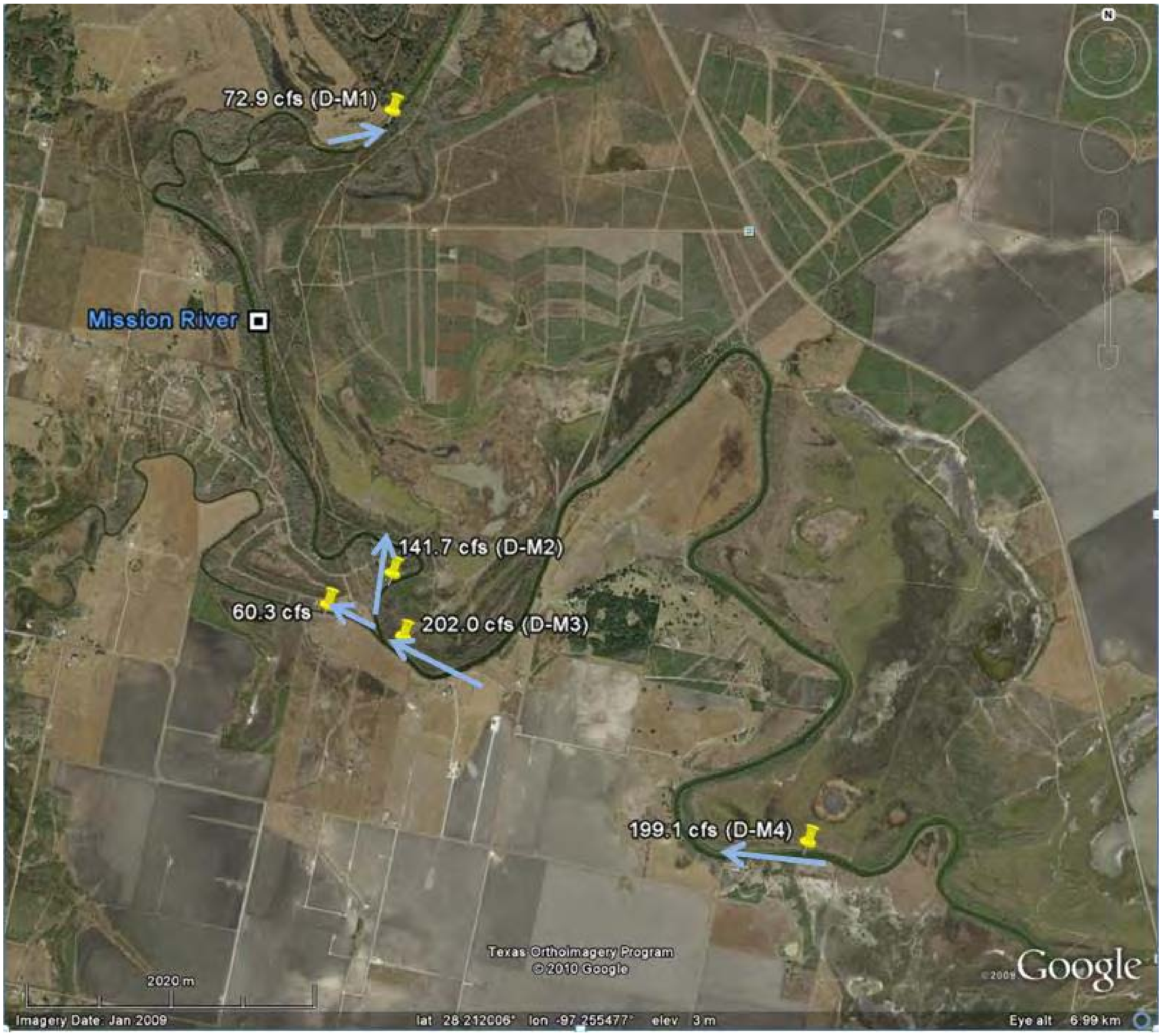

Figure 11. Net discharge volumes, and flow directions in Mission River (9 am – 12 pm June 23, 2009).

3.2. Aransas River Tidal

3.2.1. Historical Hydrology

The mean annual discharge in Aransas River near Skidmore, TX was 38 cfs as calculated from discharge data collected at an USGS gage. About 25% of the flow volume comes in during September while flow rates are quite low during the winter months and August (less than 20 cfs). Most of the UAA study period for the Aransas River (March 2008 – November 2009) represented a drought period (Figure 12). In 2008 and 2009, the annual average discharges were 30% and 50% of the 45-year (1965 – 2009) mean discharge respectively. During the last three months in 2009 and August 2008, the flow volume had recovered to more than the long term means (Figure 12 (b)).

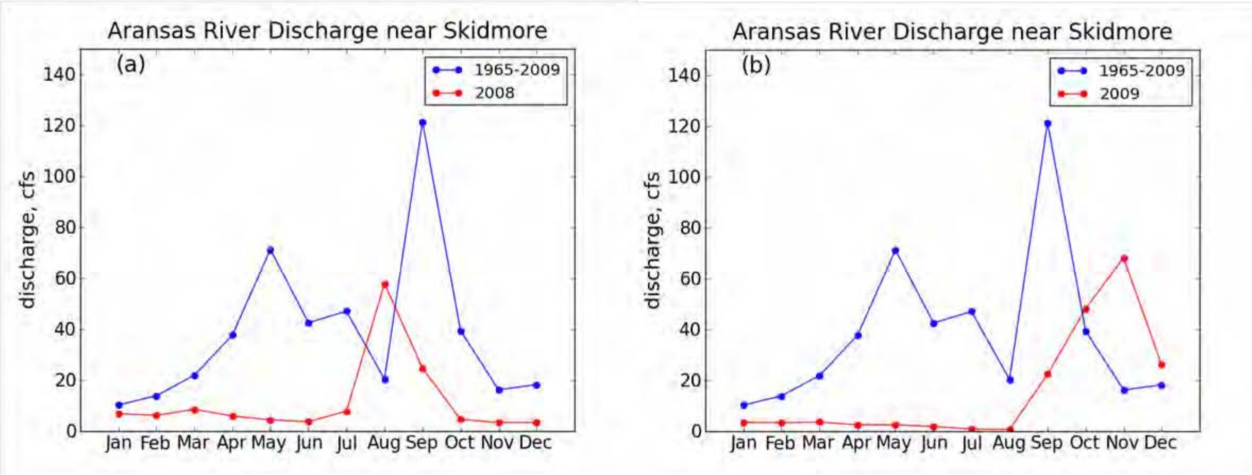

Figure 12. Monthly averaged discharge for Aransas River for (a) 45 years (blue) and 2008 (red) (b) 45 years (blue) and 2009 (red).

3.2.2. Velocity Analysis Results

Individual plots for the Aransas River Tidal ADV deployments can be found in Appendix B. Here we present summary results of the analysis. Flow speed and direction exhibited diurnal variation with the flood and ebb cycles of the tide (Figures 33 – 41). In May 2008, flow was quiescent with occasional strong upstream and downstream currents and showed high frequency oscillations (Figure 33). For this reason, extracting the tidal and residual velocity components using the low-pass filter was difficult. Currents in March 2008 as well as between June 2008 and September 2009 were characterized by oscillations that were of tidal nature and had amplitudes that varied among the different deployments. The maximum range was noted in August 2008 with upstream currents of 2.0 ft/s and downstream flow velocity of 0.65 ft/s. November 2009 had the weakest flow velocity within ± 0.30 ft/s except for few instances when it was close to 0.65 ft/s. Significant downstream flow (up to 1.0 ft/s; Figure 13) were seen in September 2009 possibly due to increased freshwater flow enhanced by tidal flows. In 2008, there was no notable change in the flow pattern among the different deployments, whereas in 2009, there was more pronounced variation in the mean current velocities and a shift in the net flow direction from upstream to downstream was noted in September 2009 (Figure 13). This may be the typical flow pattern in the middle reach with tide driven upstream flow prevailing during the dry periods and flow direction becoming downstream with increased freshwater flows in the rainy season. Maximum velocities occurred in the summer in both study years and minimum velocities were recorded in the spring deployments in both 2008 and 2009.

Investigation of the mean flow velocities (Figure 13) shows a net upstream flow in six of the nine datasets that had sufficient length (≥ 24 hrs) for statistical analysis. In general, the periods with upstream flow were associated with relatively strong upstream residual flow (Table 6) which is driven by south-easterly winds. From the low-pass filtering, it could be seen that the maximum current velocities coincided with the flooding cycle of the tidal flow (Figures 33 – 41). All of the maximum flow velocities were upstream except in September 2009.

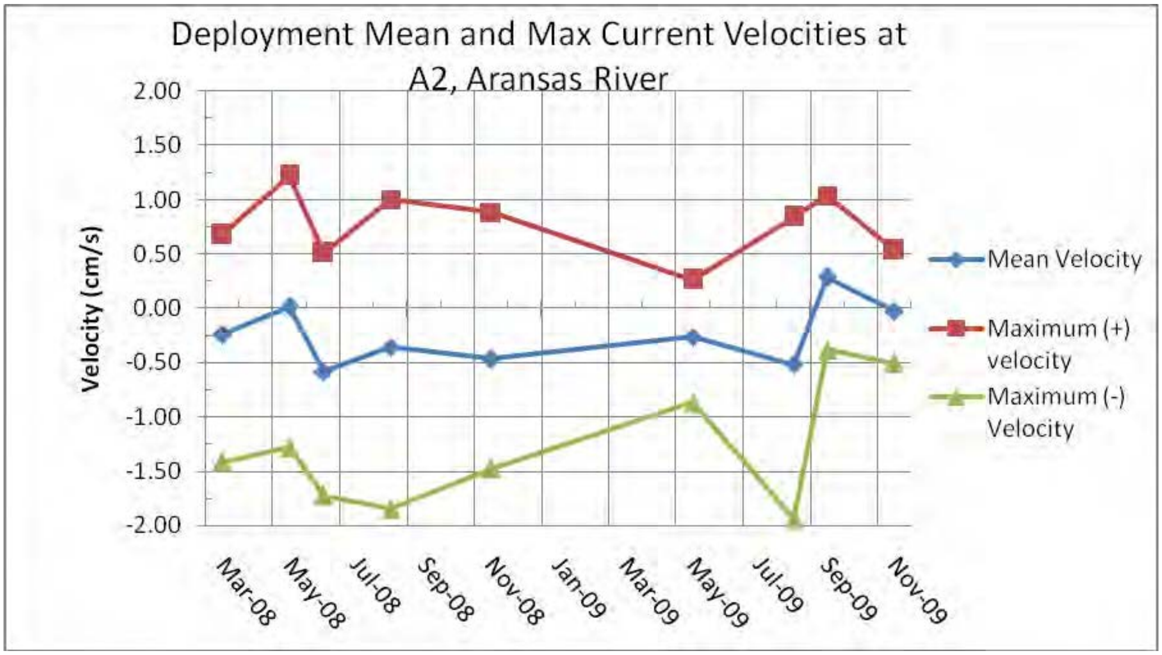

Figure 13. Deployment mean flow velocities at A2, Aransas River (March 2008 – November 2009).

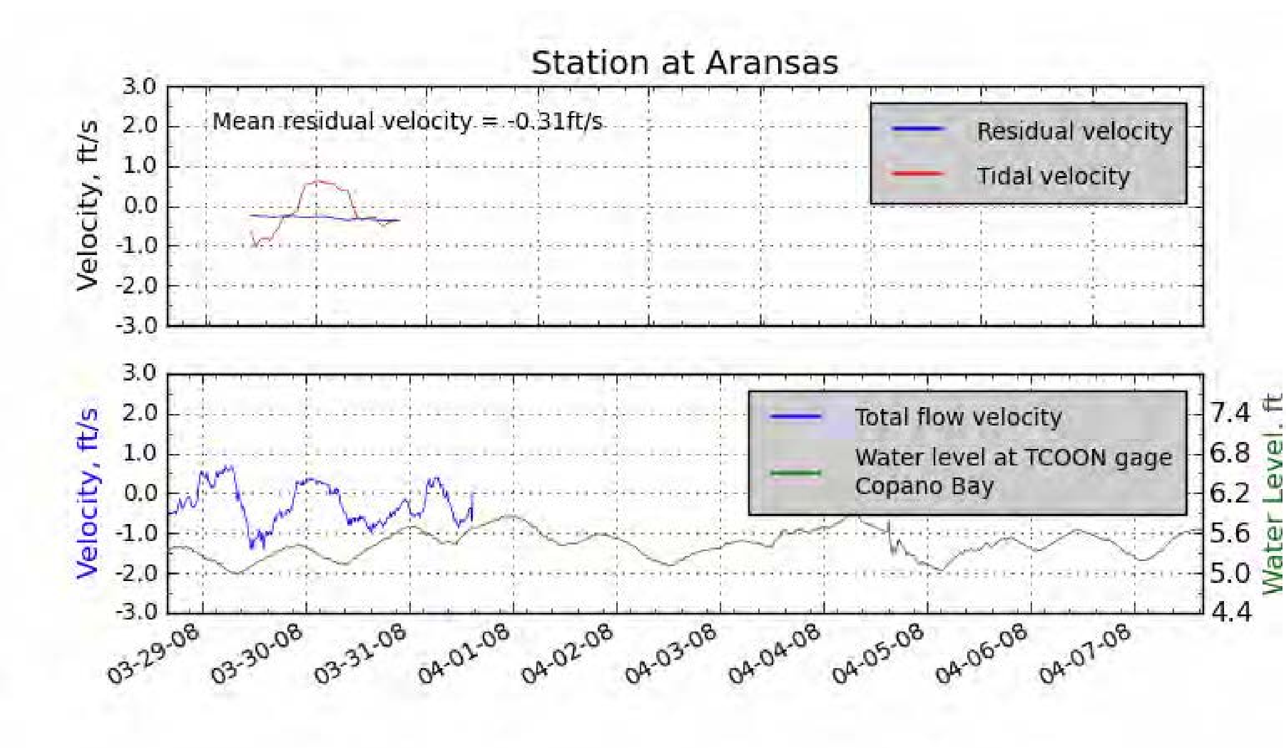

Figure 14. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) at A2, Aransas River during March 2008 deployment.

Table 6. Mean residual and total flow velocities at A2, Aransas River.

Deployment Start Date	Mean Residual Velocity (ft/s)	Mean Total Velocity (ft/s)
28-Mar-08	-0.31	-0.24
13-May-08	0.07	0.02
5-Aug-08	-0.36	-0.36
3-Nov-08	-0.57	-0.47
12-May-09	-0.21	-0.26
22-Sep-09	0.28	0.28
3-Nov-09	-0.02	-0.03

3.2.3. Flow Analysis Results

To gain more insight into the stream flow pattern during the study period, the stream discharges estimated from the regression equation were plotted against the discharge from a USGS gage located near Skidmore, TX. As in the case of Mission River, there was no correlation between gage flow and the estimated residual discharge. The estimated residual discharge in A2 was variable both in magnitude and direction of flow (Figure 15) unlike the gage flow, with values ranging from – 309 cfs to 37 cfs. The variation in the net stream flow magnitude and direction noted during the study period was a strong function of the tidal forces. Moreover, south-easterly wind forces that were prevalent during the study period enhanced the upstream flow which was noted in all but the May 2008 and September 2009 residual flows (Figures 42 - 48).

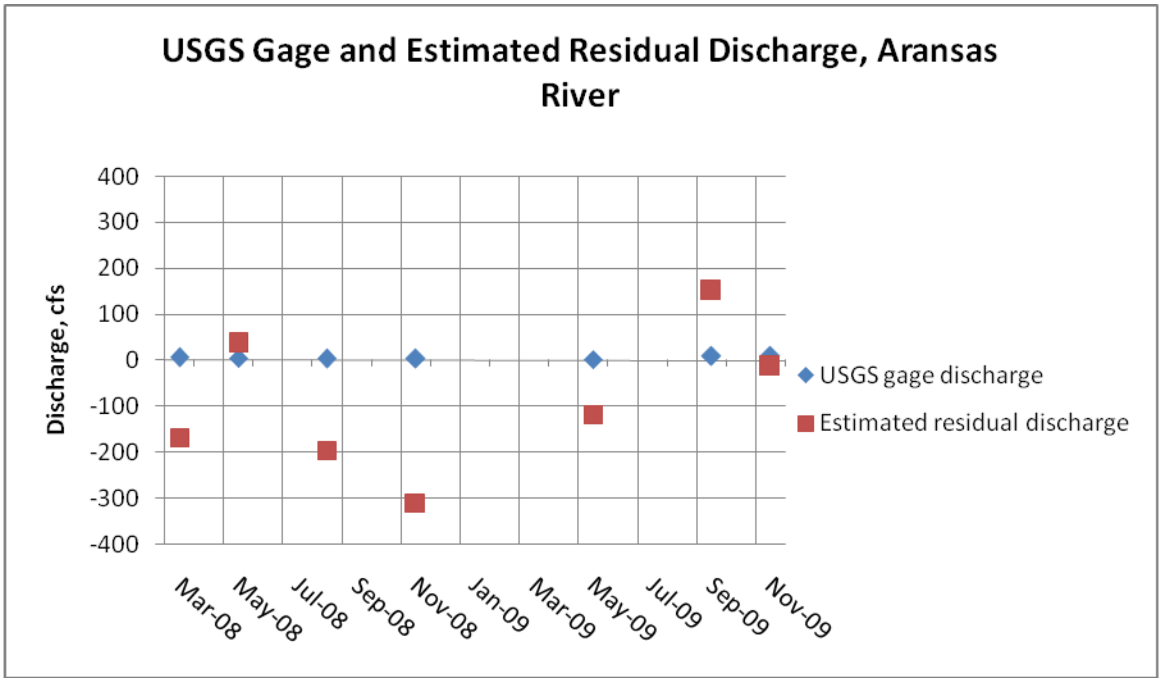

Figure 15. Deployment mean residual discharge (estimated) at A2 and mean measured discharge at USGS gage near Skidmore, Aransas River (March 2008 – November 2009).

Discharge was highly variable in both the D-A1 and D-A2 stations within the 15-20 minutes when the replicate discharge measurement transects were made (Figure 16). The standard deviations for total discharge were 117 cfs and 109 cfs at D-A1 and D-A2 respectively making up 70% and 28% of the respective sampling mean discharges. The standard deviations for the measured discharges as percentage of the mean discharges were about the same as those for the total discharges at 73% and 28% for D-A1 and D-A2 respectively.

One indicator of the accuracy of discharge measurements given by the RiverSurveyor is the ratio of the estimated to measured discharge; lower ratio meaning that errors associated with assumptions made for extrapolating velocity profiles are minimized. In the Aransas River transects the estimated to measured discharge ratios were 0.77 and 0.60 at D-A1 and D-A2 respectively. The top and bottom discharge estimates together make up for 90% of the total estimated discharge (Appendix D).

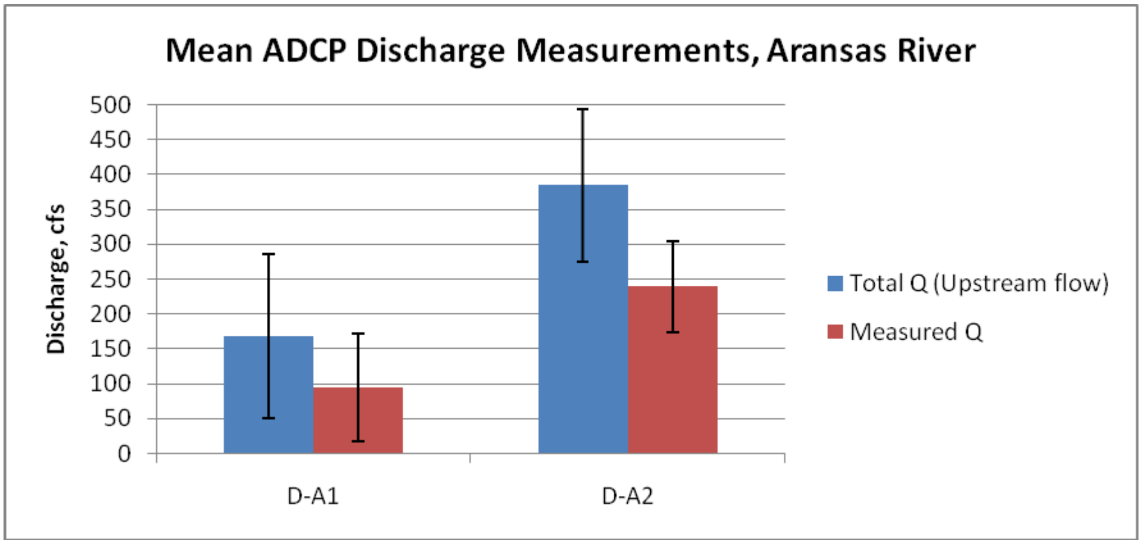

Figure 16. Mean measured and total (measured + estimated) ADCP discharge measurements at Aransas River stations (June 23, 2009).

4. Discussion

TWDB processed and analyzed velocity data that TPWD collected in a total of 23 ADV deployments between March 2008 and November 2009 at stations located in the middle reaches of the tidal portions of Mission and Aransas Rivers. Tidal effects on the flow pattern were examined by extracting the residual and tidal velocity components using the Doodson X0 filter. Statistical analysis was done to examine variability in flow magnitude and direction during the different deployment periods to examine diurnal and seasonal patterns of flow in the streams. As per TWPD's request, TWDB also deployed boat-mounted ADCP to measure discharge on June 23, 2009 at the ADV stations and additional locations within 10 river miles of the ADV stations in both streams. Rating curves for estimating discharge from velocity measurements were developed from coincident velocity and discharge measurements.

As it can be seen from historical flow data collected at USGS gages in these streams, the two years when the UAA study was conducted were drought years with extremely low flows except for flood events during the three last months in 2009 in the Mission River watershed that resulted in the annual mean flow recovering to 75% of the historical annual mean. The seven-day mean discharges during the ADV deployments were 6.2 cfs and 5.5 cfs for the Mission and Aransas Rivers respectively. Estimated discharge at the middle stations in both streams was much higher and variable than what was observed at the USGS gage stations. Flow in the middle reach of the Mission and Aransas rivers was tidally driven during the study period and residual flows were only small fraction (7 – 42%) of the tidal flow. The residual flow in both streams was upstream in most of the deployments owing to the coupled effect of very low inflow from the feeding watersheds and south-easterly winds that prevail during most of the year.

The flow pattern in the Aransas River exhibited some seasonality in that the maximum flow velocities which were upstream were reached in the summer in both study years. This was most likely due to the strong winds during the summer months that steadily blow toward the northwest coupled with lower flows. Minimum flow velocities occurred during the spring . In the Mission River however, no seasonal pattern in the stream flow was evident despite similar inflow, meteorological and tidal conditions existing in both study streams. This calls for a study identifying all parameters governing the flow pattern and conducting multivariate analysis or process-based hydrodynamic modeling to characterize the stream flow pattern. Collecting more extensive velocity, discharge and other related data spanning longer periods would enhance this analysis' usability in some ways:

1. There would be more confidence in the assessment made here on the seasonal pattern of the flow in these streams. Noises such as occasional shifting winds can affect the reliability of data collected for short time intervals such as a few days.
2. More appropriate techniques could be implemented in analyzing the collected velocity data. For instance, tidal harmonic analysis would be used to extract the tidal and non-tidal flow velocity components which would give more accurate results than the low-pass filter employed in this analysis.
3. Capturing a higher range of variability of discharge in coincident discharge and velocity measurements would enable the development of a more reliable rating curve capable of predicting discharge from velocity measurements under varying flow conditions.

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Appendix A - Mission River Velocity and Discharge Plots

Current Velocity at M2

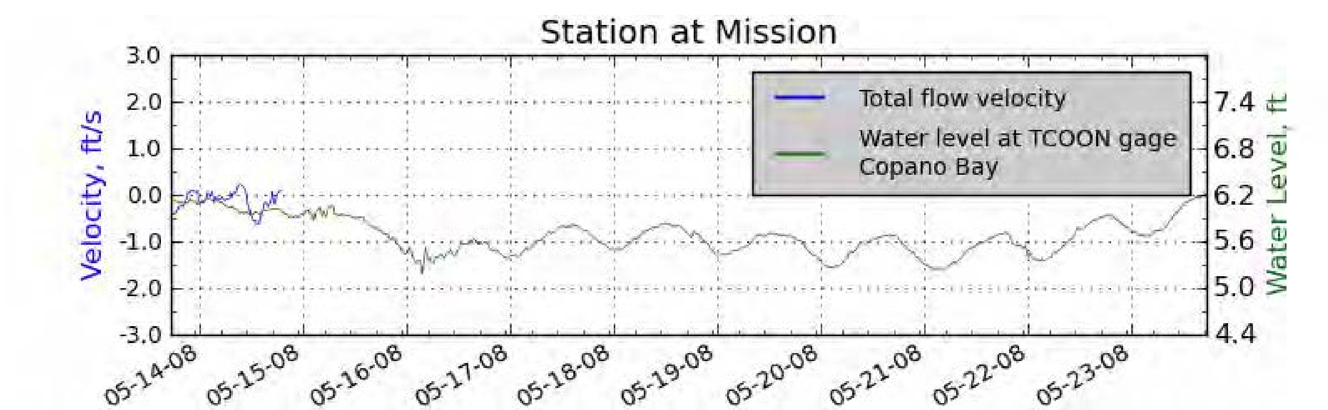


Figure 17. Total Current Velocity in Mission River during May 2008 deployment.

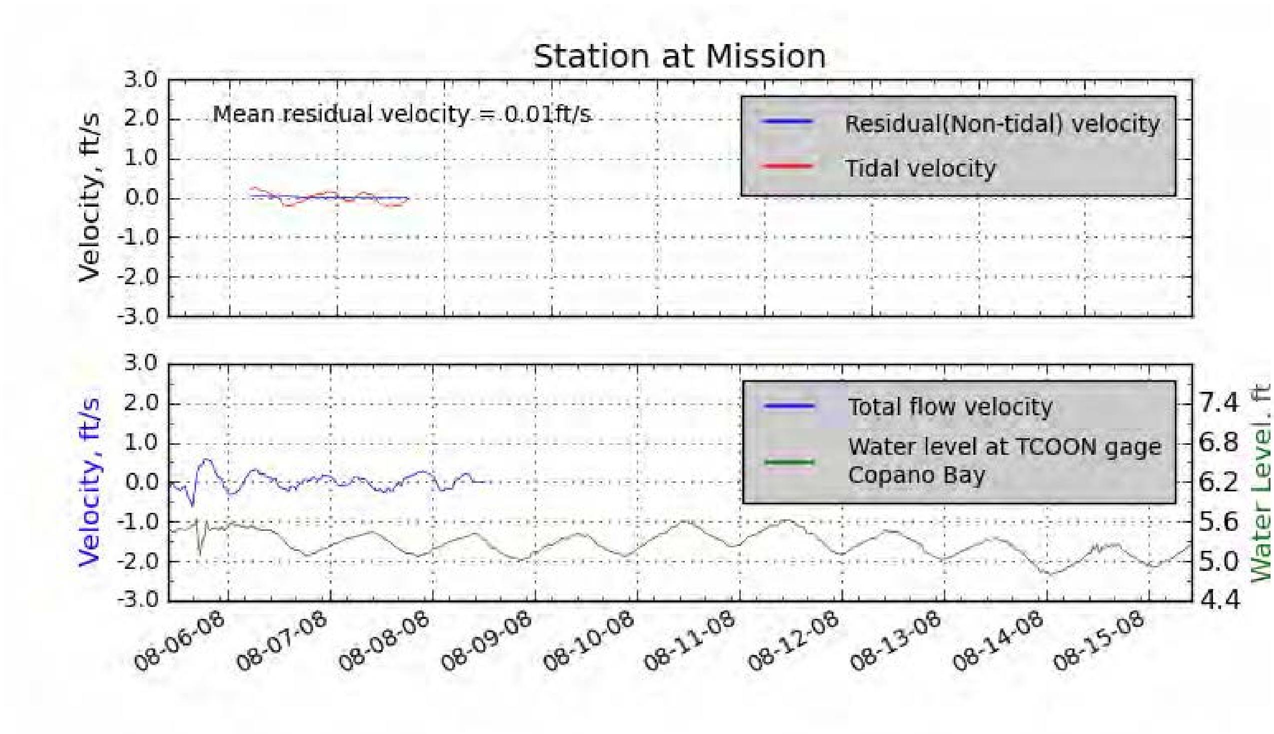


Figure 18. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) in Mission River during September 2008 deployment.

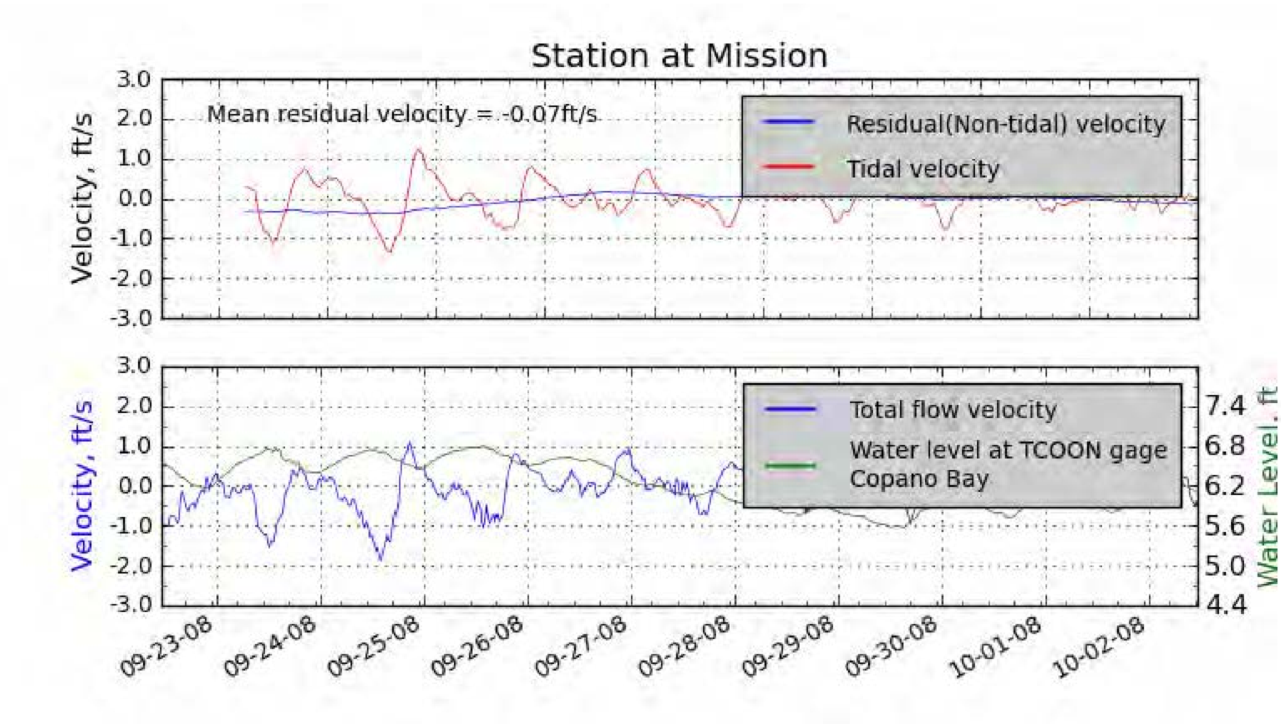


Figure 19. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) in Mission River during September 2008 deployment.

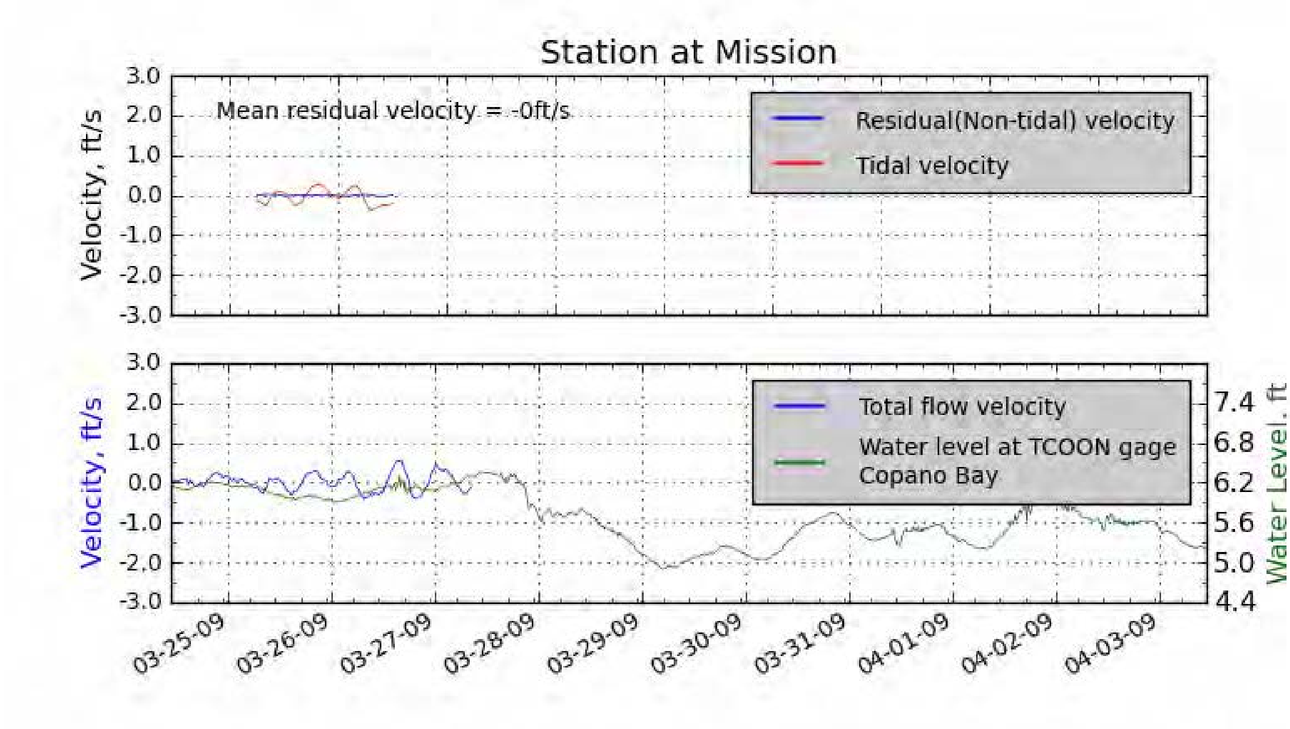


Figure 20. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) in Mission River during March 2009 deployment.

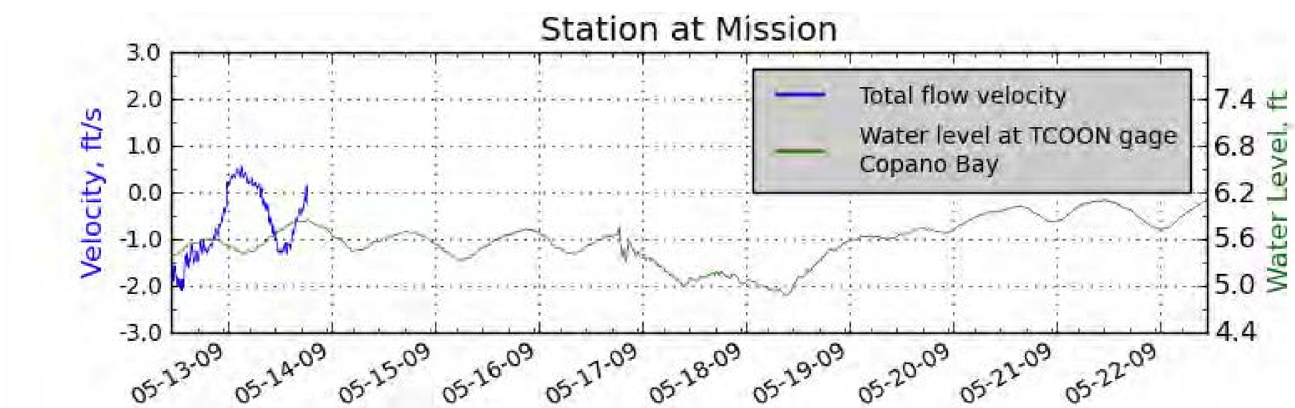


Figure 21. Total current velocity and water level in Mission River during May 2009 deployment.

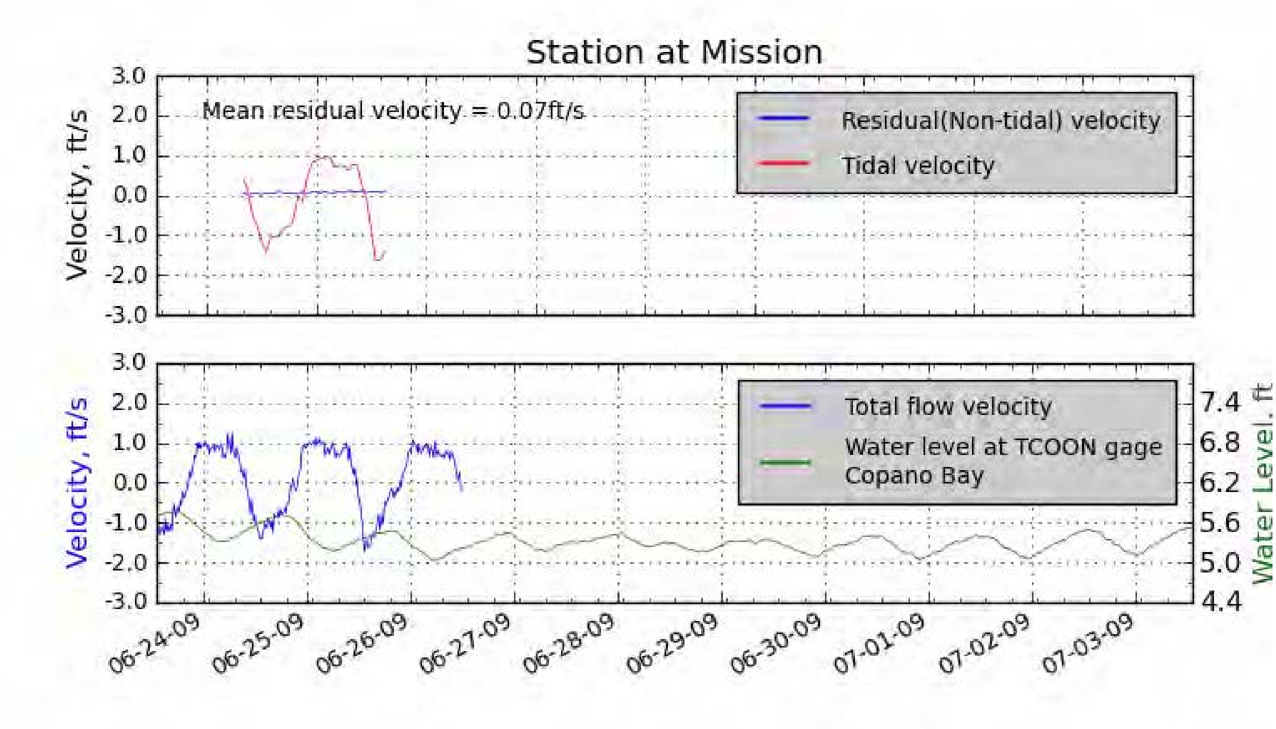


Figure 22. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) in Mission River during June 2009 deployment.

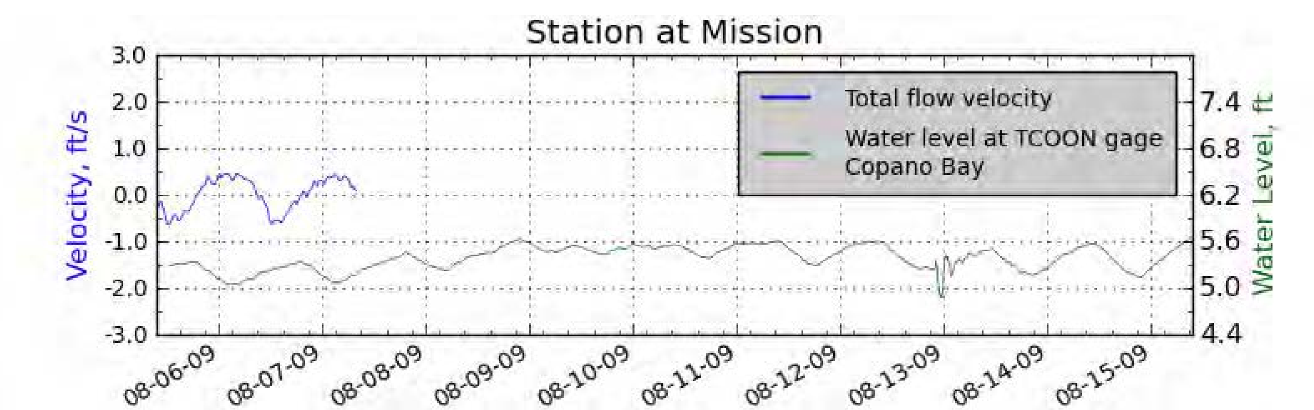


Figure 23. Total current velocity and water level in Mission River during August 2009 deployment.

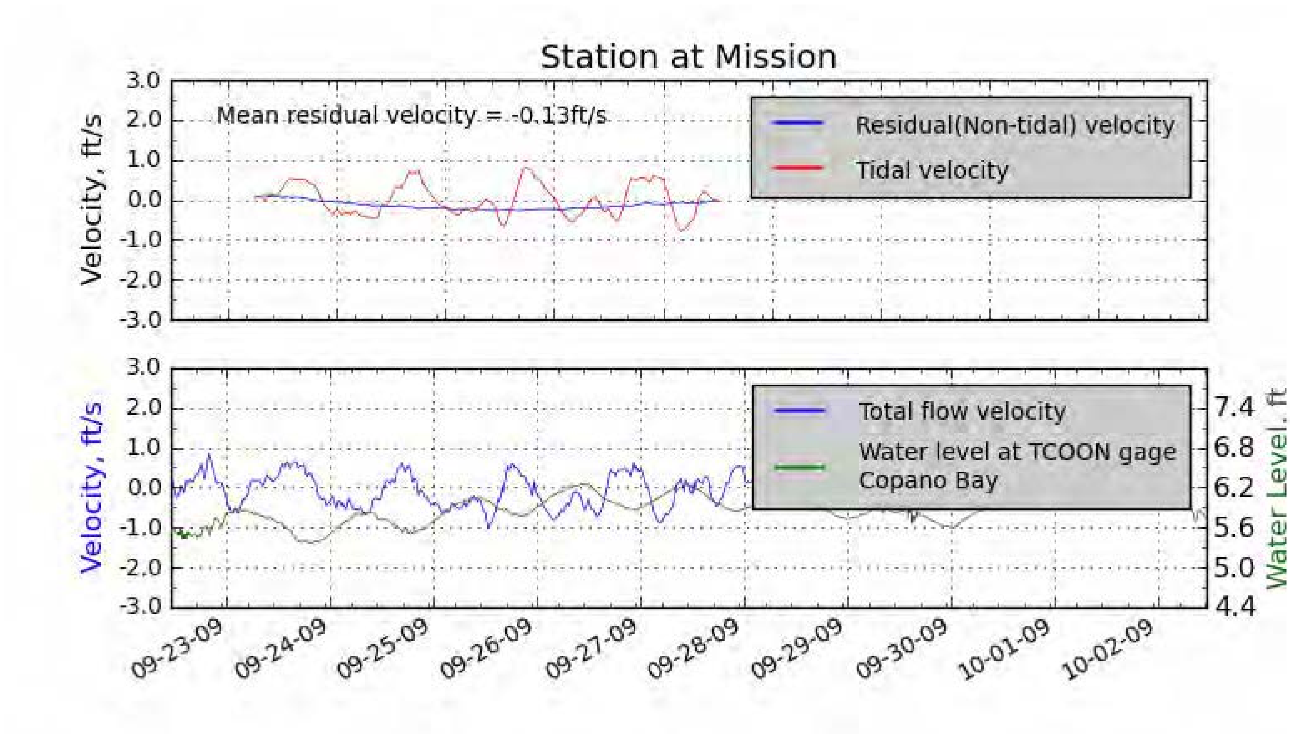


Figure 24. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) in Mission River during September 2009 deployment.

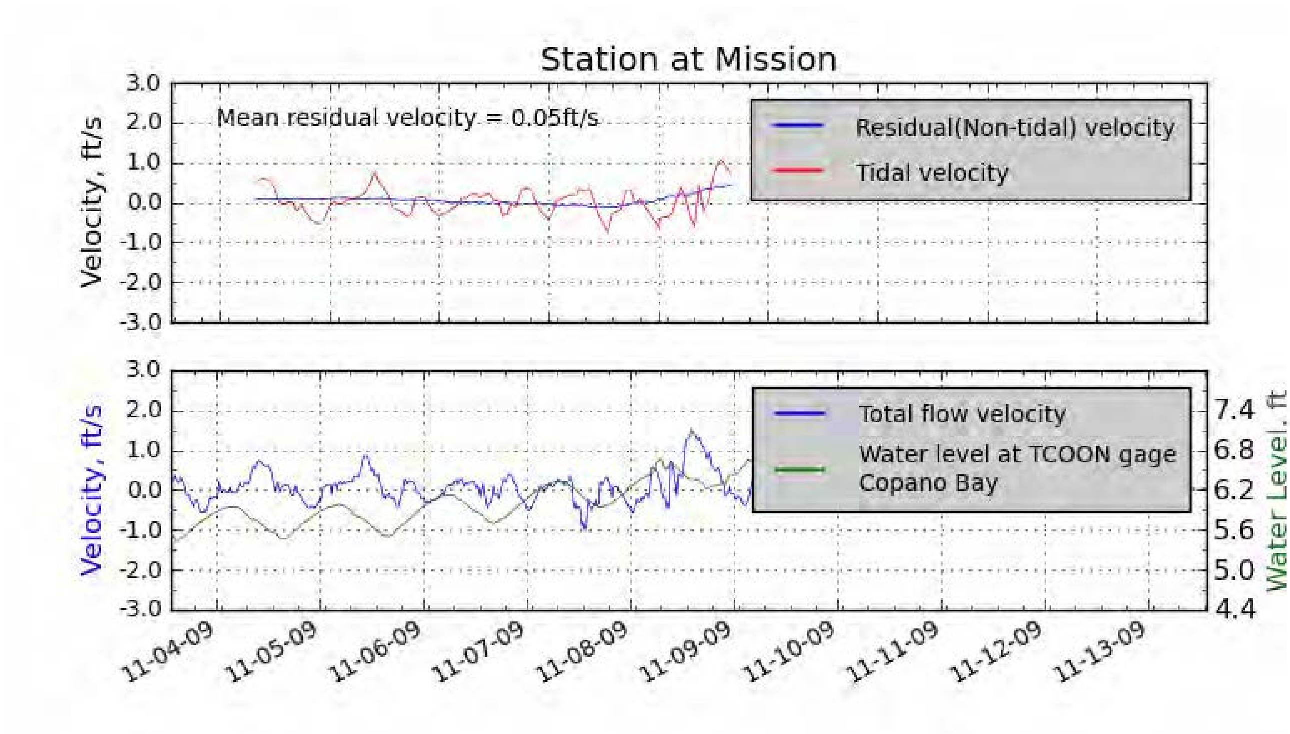


Figure 25. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) in Mission River during November 2009 deployment.

Estimated Residual Discharge at M2

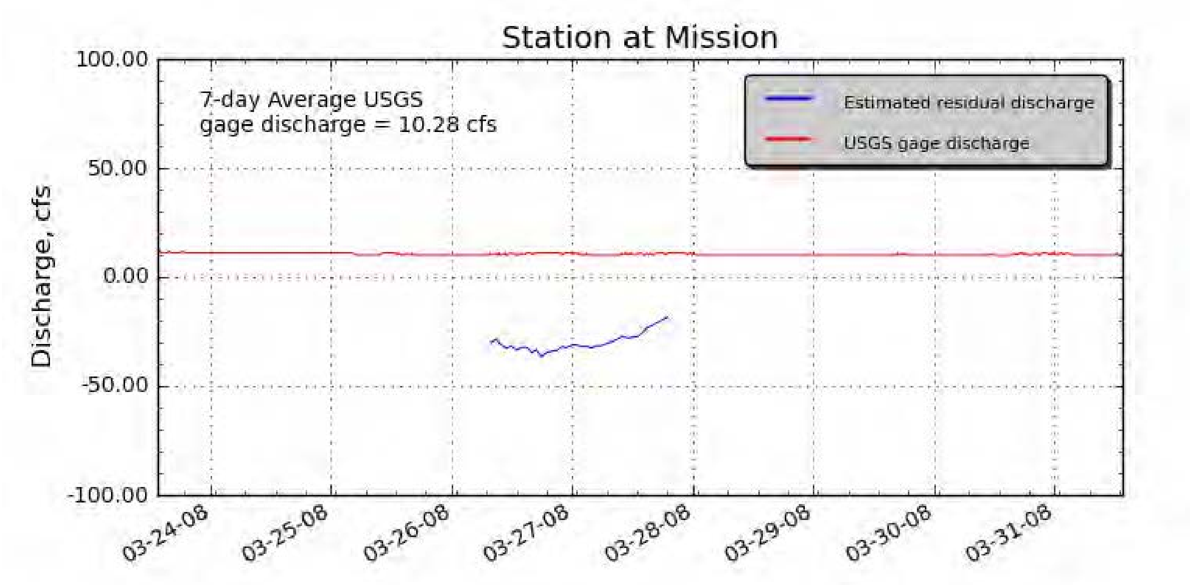


Figure 26. Estimated residual discharge at M2 and measured discharge at USGS gage near Refugio, Mission River (March 26 – 27, 2008).

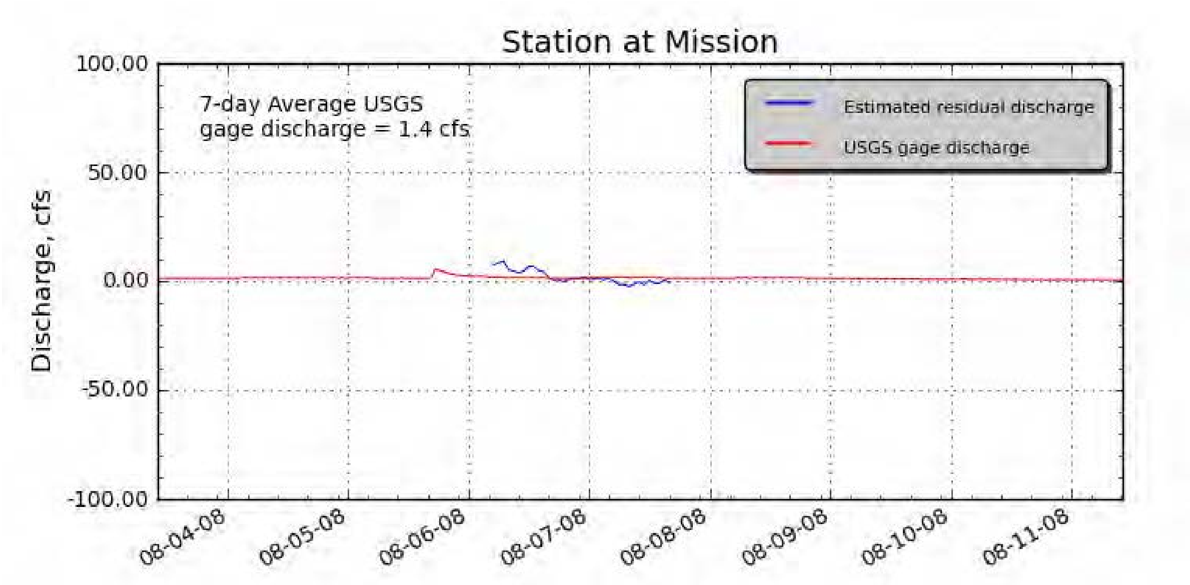


Figure 27. Estimated residual discharge at M2 and measured discharge at USGS gage near Refugio, Mission River (August 6 – 7, 2008).

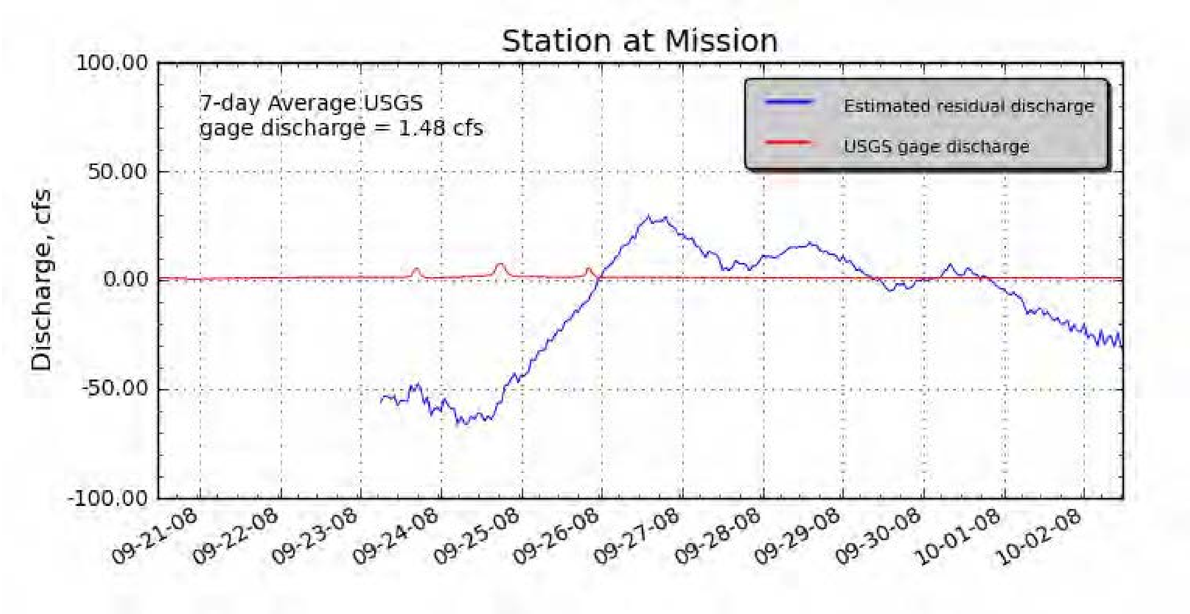


Figure 28. Estimated residual discharge at M2 and measured discharge at USGS gage near Refugio, Mission River (September 23 – October 02, 2008).

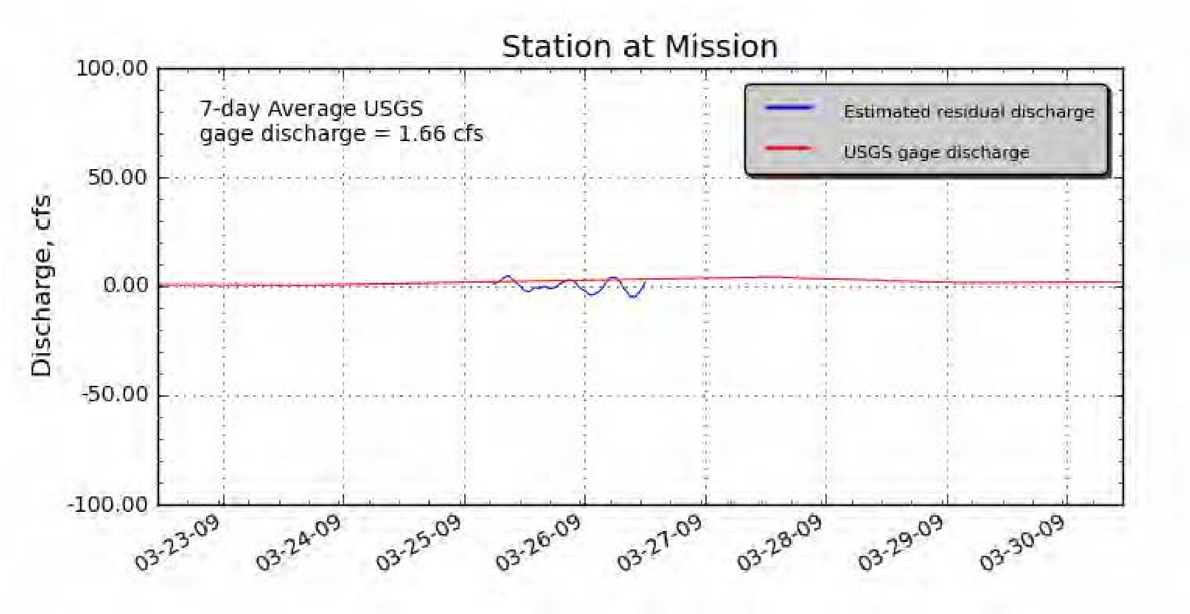


Figure 29. Estimated residual discharge at M2 and measured discharge at USGS gage near Refugio, Mission River (March 25 -- 26, 2008).

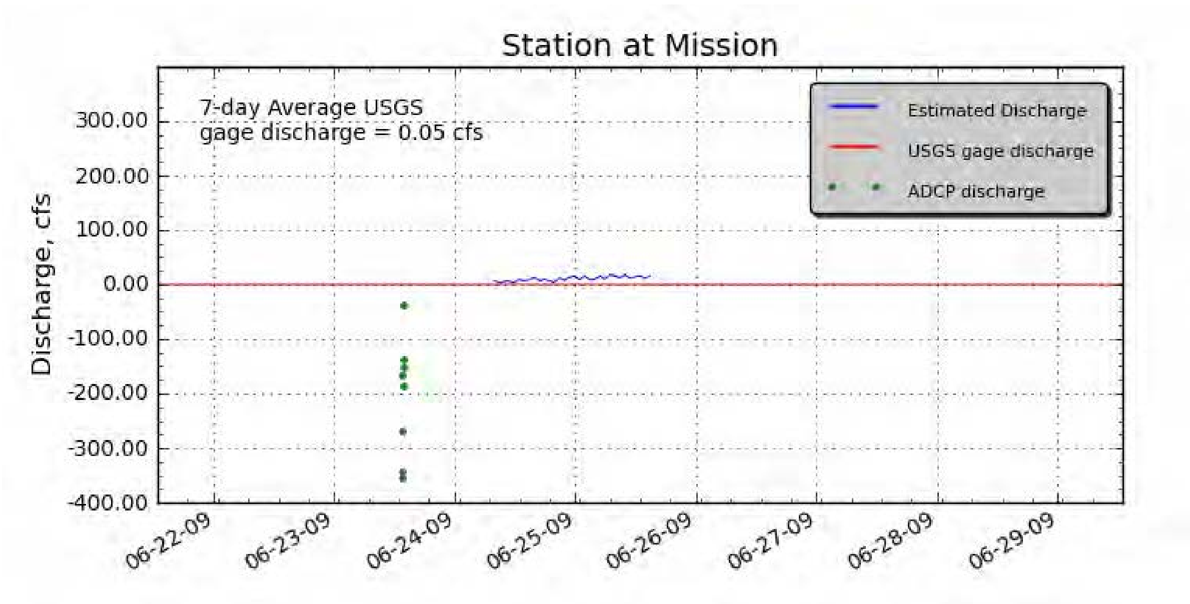


Figure 30. Estimated residual discharge at M2 (blue), measured discharge at USGS gage near Refugio (red), and ADCP measured discharge at TPM2(symbols), Mission River (June 23 – 25, 2009).

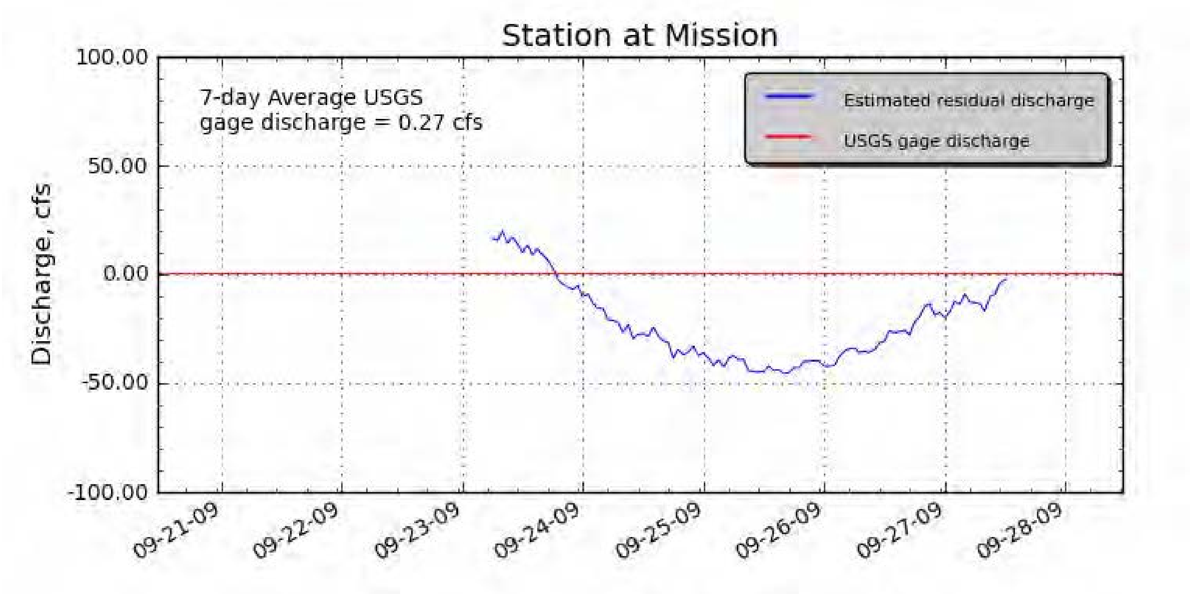


Figure 31. Estimated residual discharge at M2 and measured discharge at USGS gage near Refugio, Mission River (September 23 – 27, 2009).

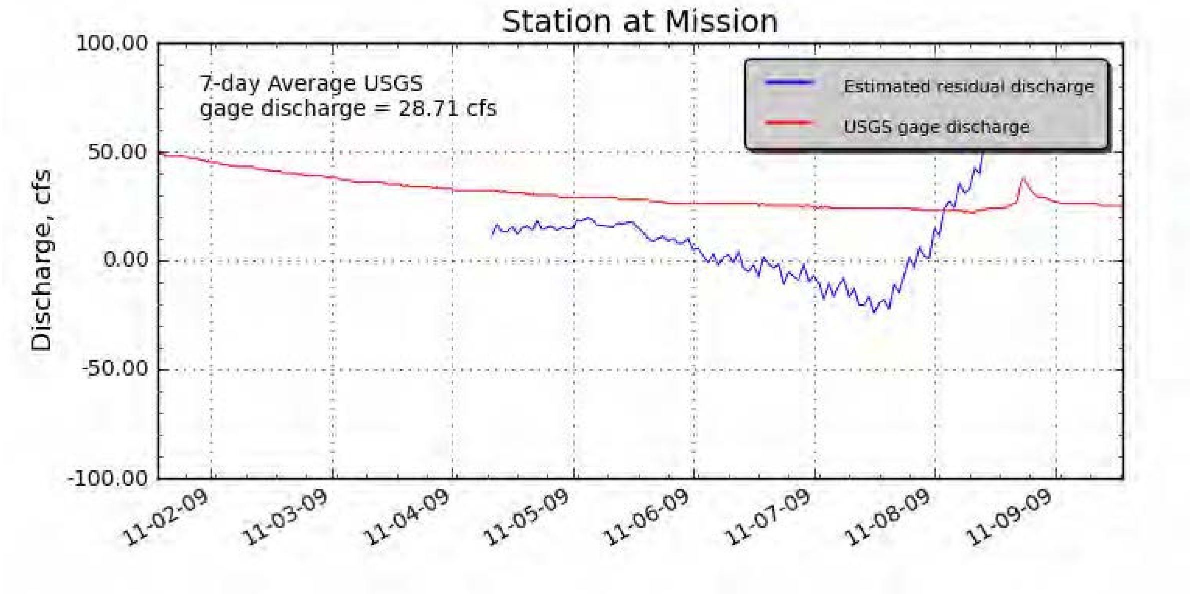


Figure 32. Estimated residual discharge at M2 and measured discharge at USGS gage near Refugio, Mission River (November 04 – 08, 2009).

Appendix B - Aransas River Velocity and Discharge Plots

Current Velocity at A2

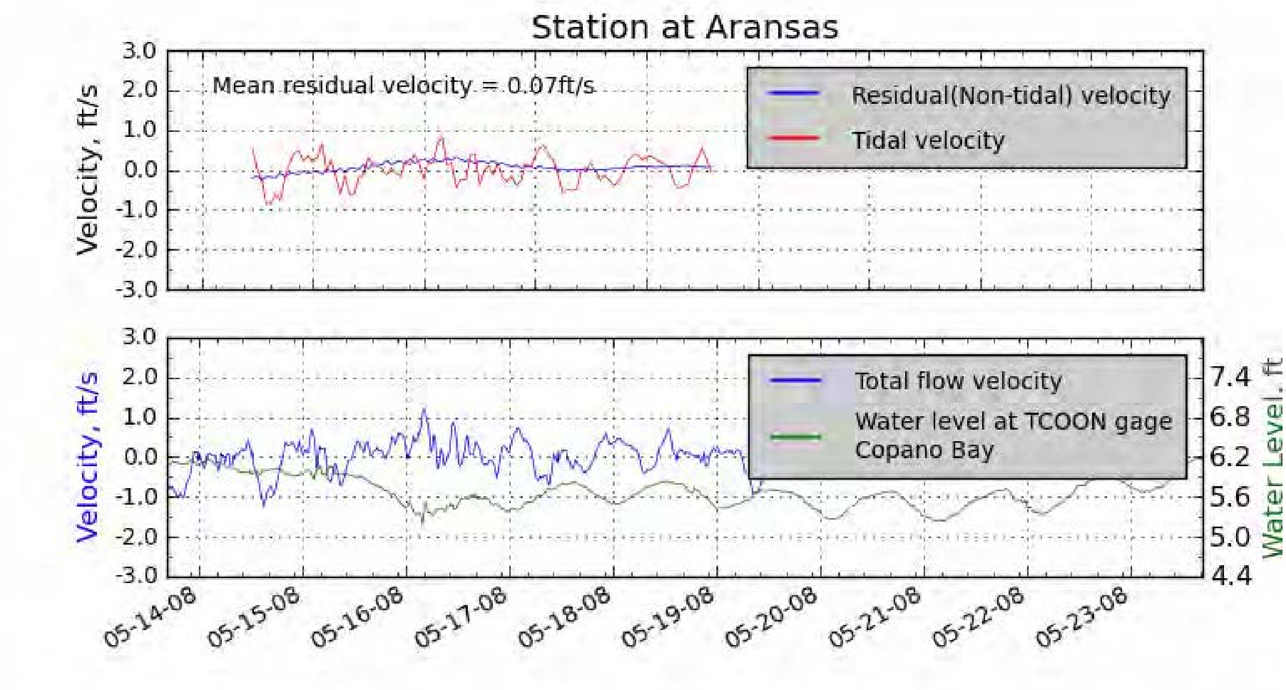


Figure 33. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) in Aransas River during May 2008 deployment.

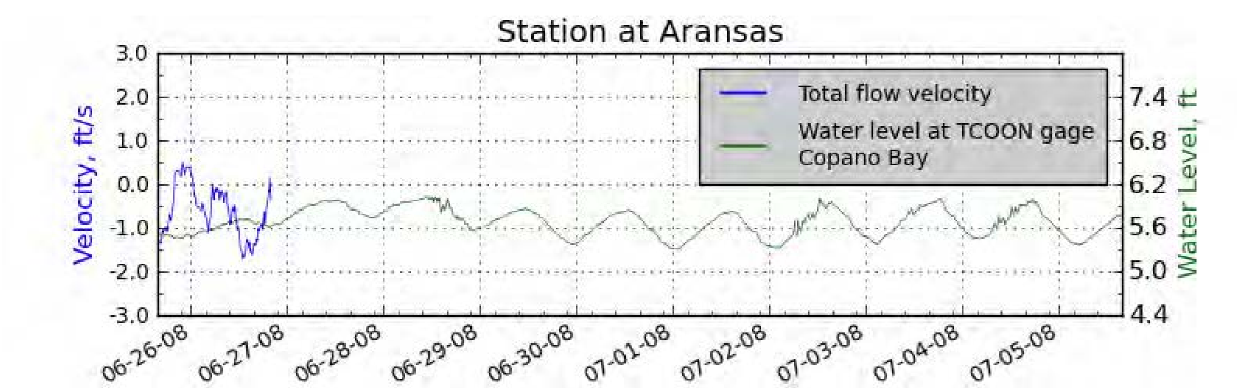


Figure 34. Total current velocity and water level in Aransas River during June 2008 deployment.

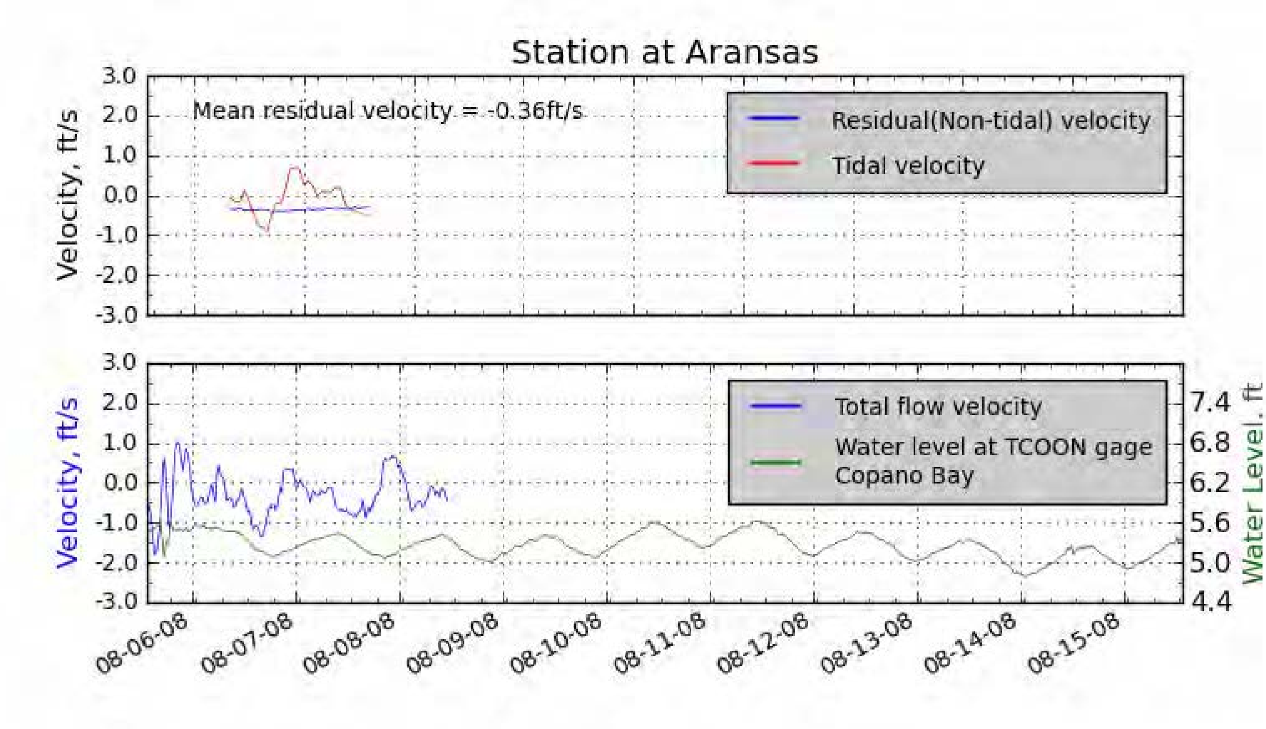


Figure 35. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) in Aransas River during August 2008 deployment.

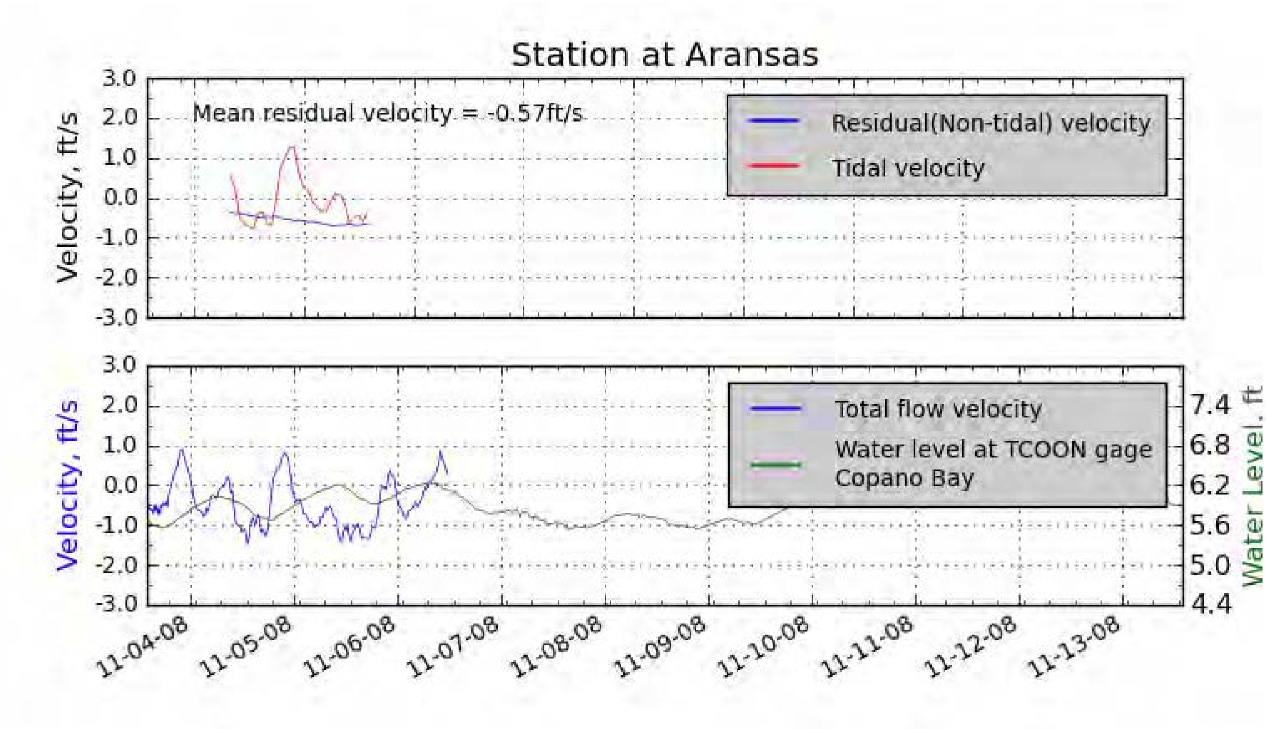


Figure 36. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) in Aransas River during November 2008 deployment.

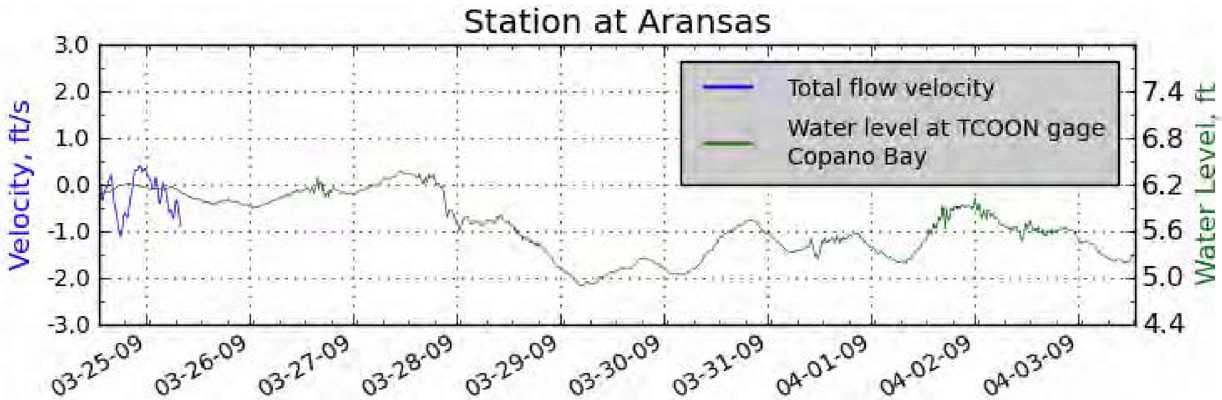


Figure 37. Total current velocity and water level in Aransas River during March 2009 deployment.

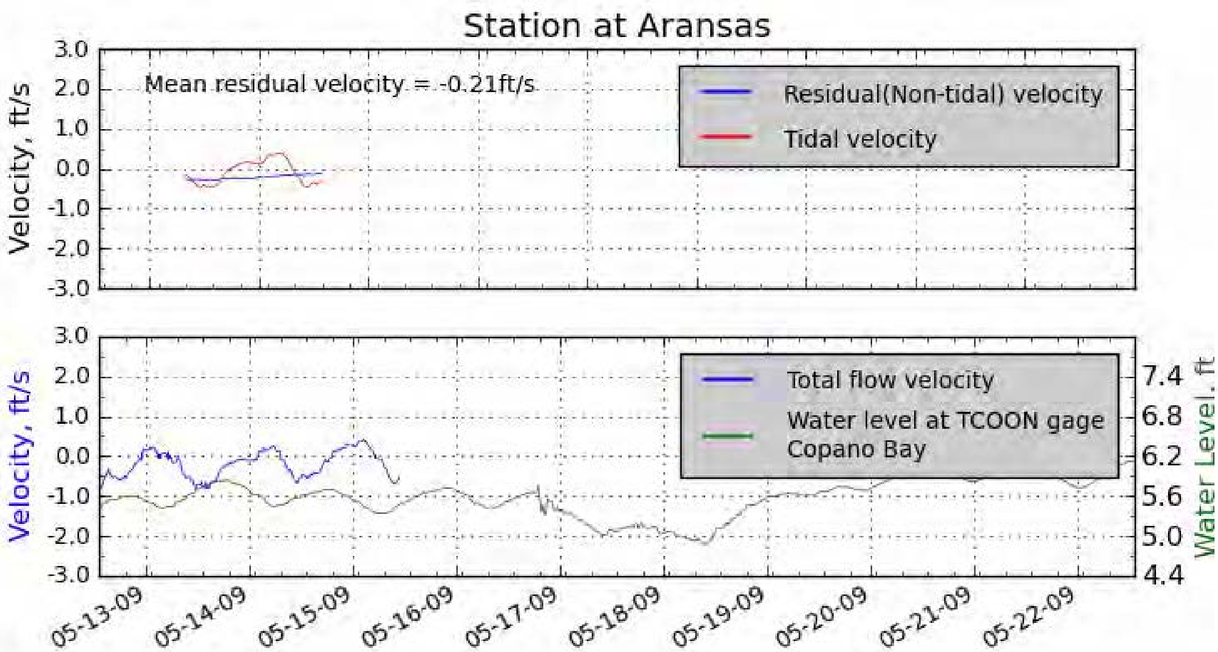


Figure 38. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) in Aransas River during May 2009 deployment.

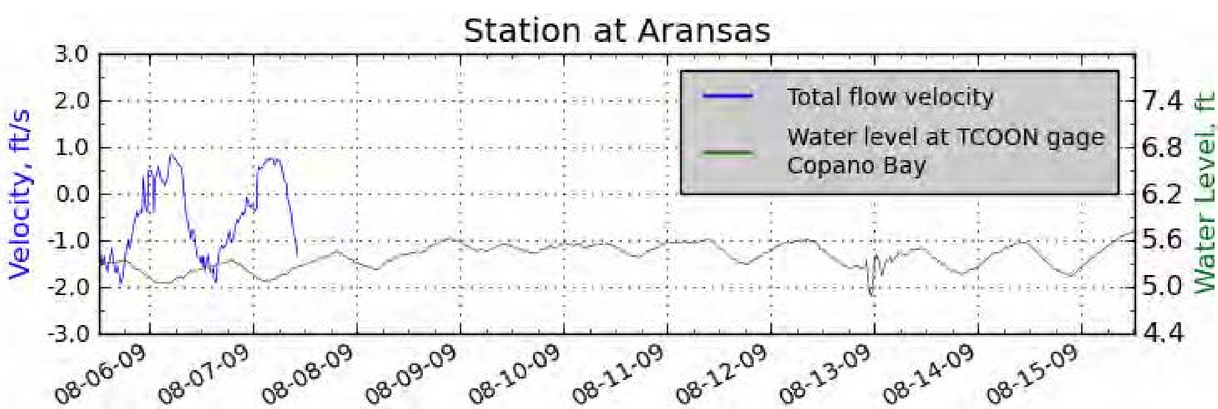


Figure 39. Total current velocity and water level in Aransas River during August 2009 deployment.

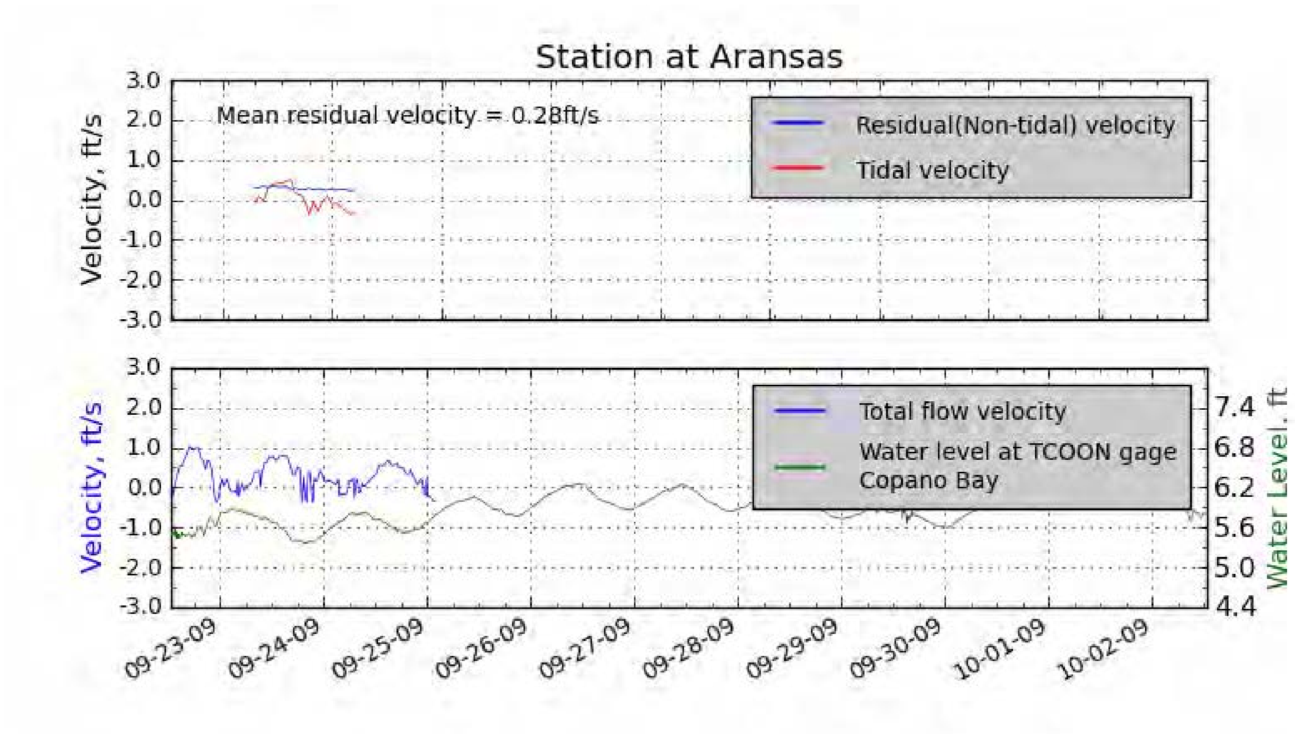


Figure 40. Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) in Aransas River during September 2009 deployment.

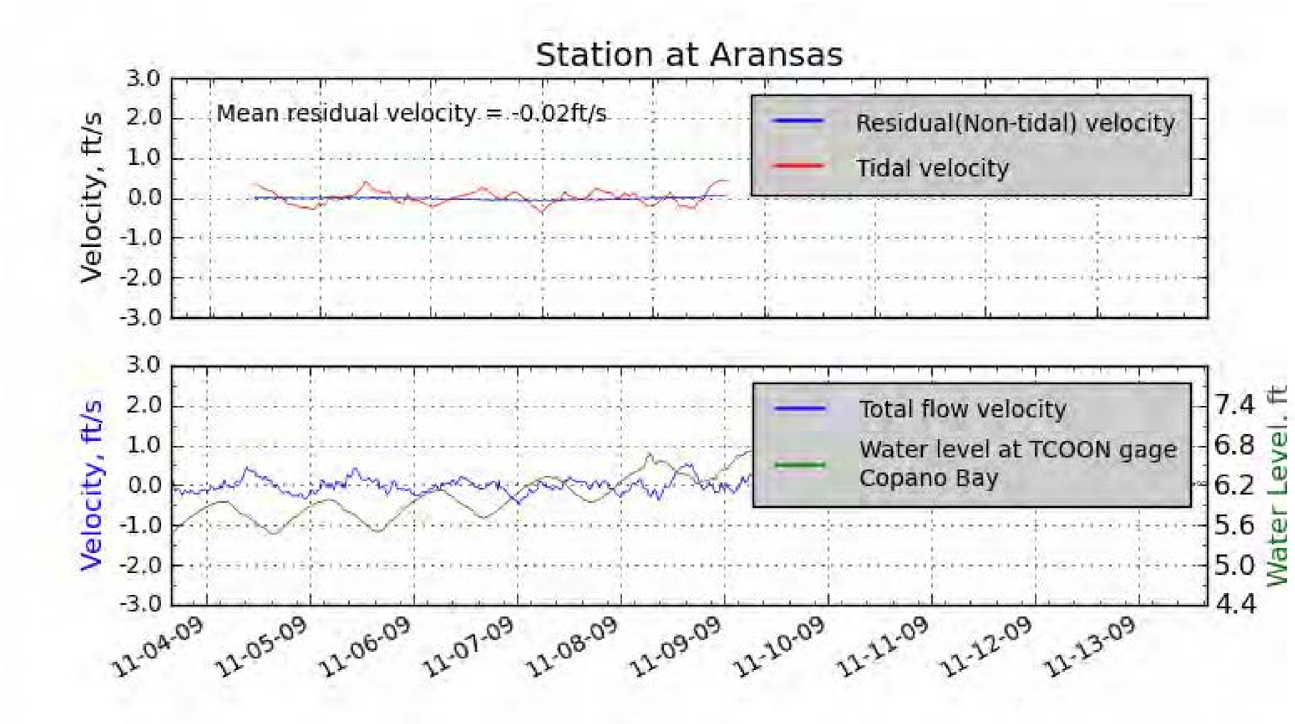


Figure 41. Total Total current velocity and water level (bottom panel); residual and tidal velocity components (top panel) in Aransas River during November 2009 deployment.

Estimated Residual Discharge at A2

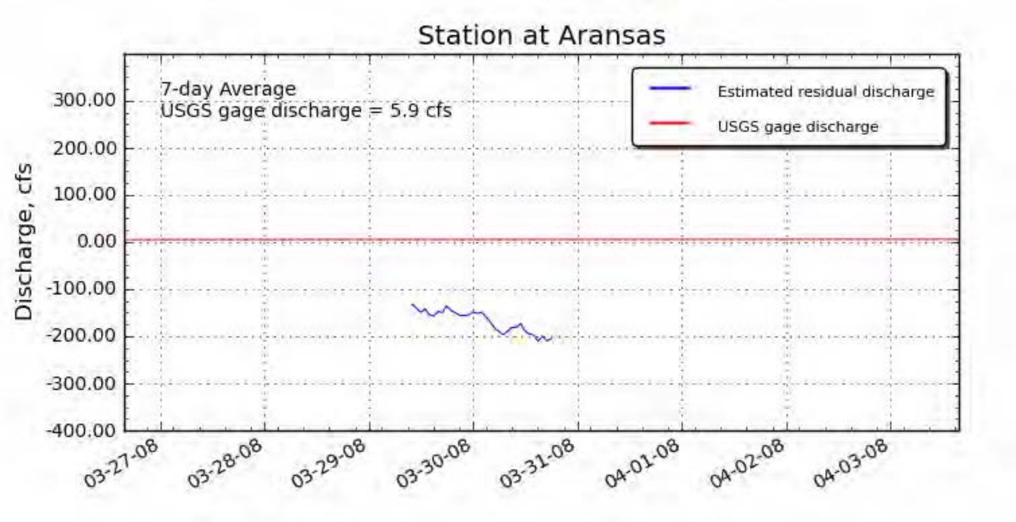


Figure 42. Estimated residual discharge at A2 and measured discharge at USGS gage near Skidmore, Aransas River (March 29 – 30, 2008).

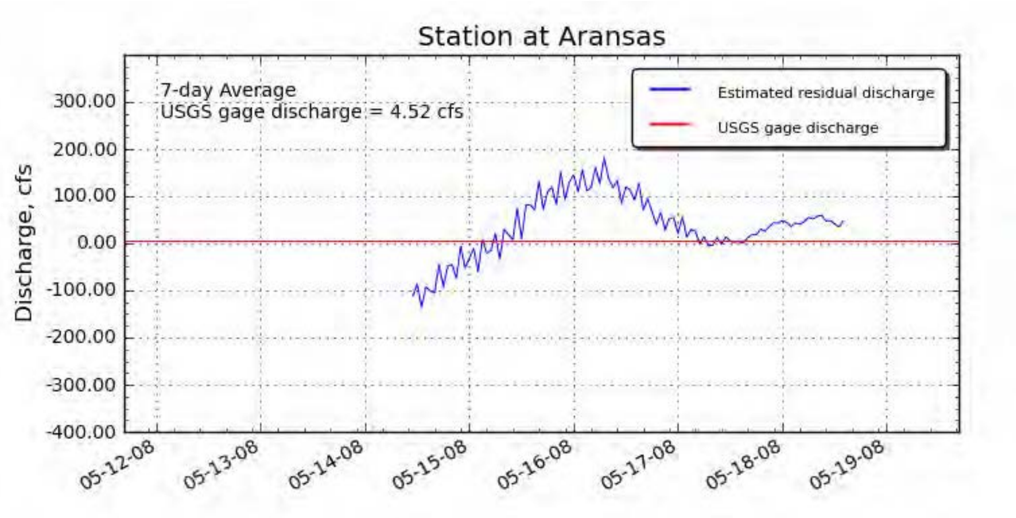


Figure 43. Estimated residual discharge at A2 and measured discharge at USGS gage near Skidmore, Aransas River (May 14 – 18, 2008).

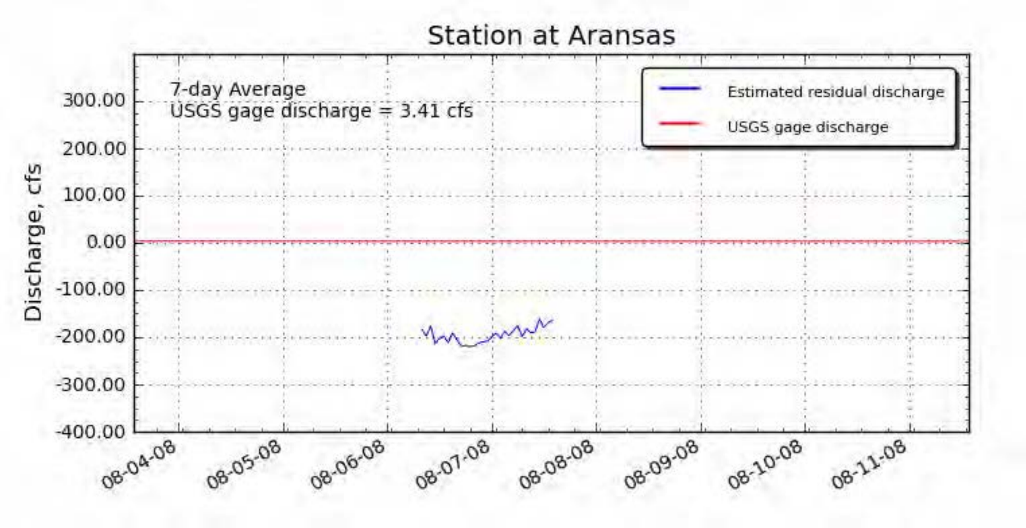


Figure 44. Estimated residual discharge at A2 and measured discharge at USGS gage near Skidmore, Aransas River (August 6 – 7, 2008).

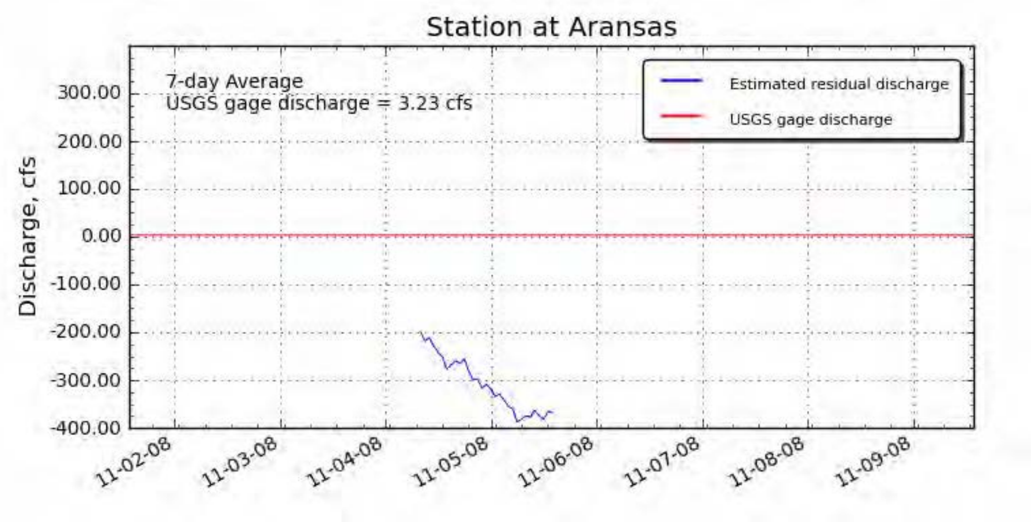


Figure 45. Estimated residual discharge at A2 and measured discharge at USGS gage near Skidmore, Aransas River (November 04 – 05, 2008).

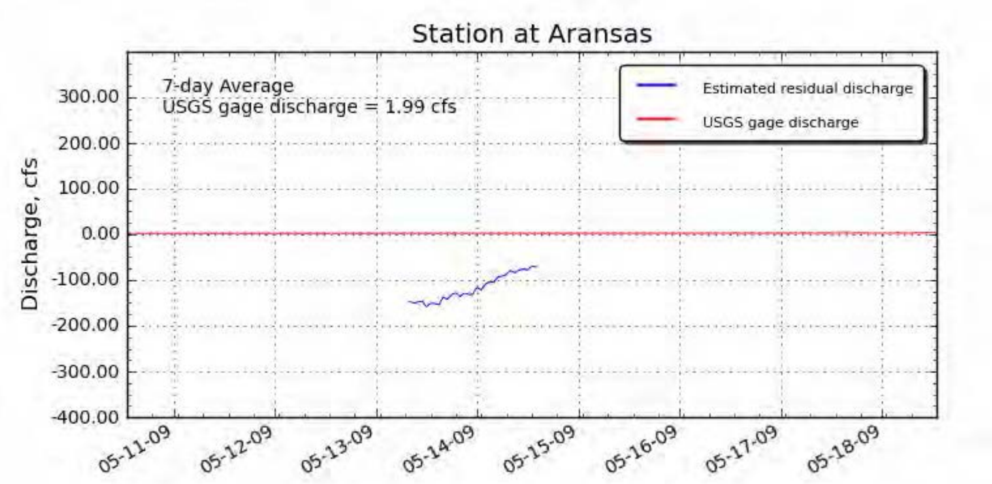


Figure 46. Estimated residual discharge at A2 and measured discharge at USGS gage near Skidmore, Aransas River (May 13 – 14, 2009).

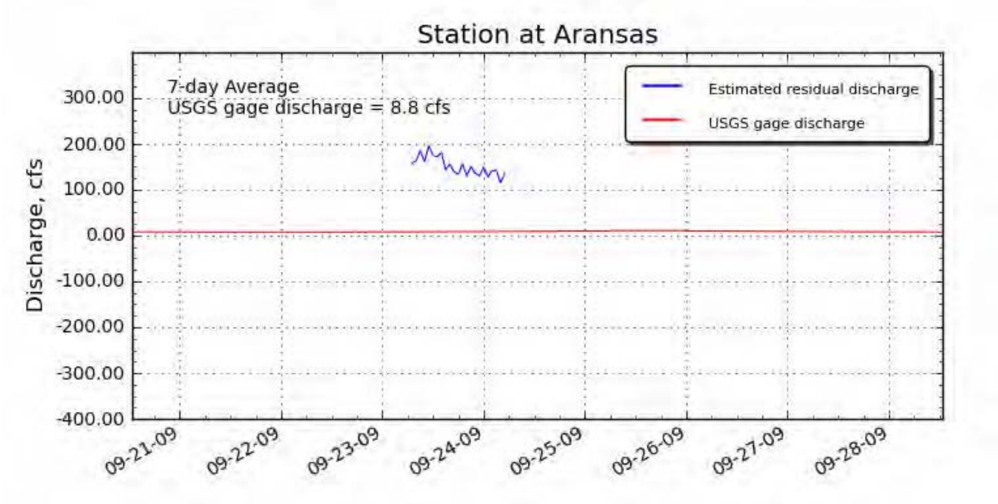


Figure 47. Estimated residual discharge at A2 and measured discharge at USGS gage near Skidmore, Aransas River (September 29 – 30, 2009).

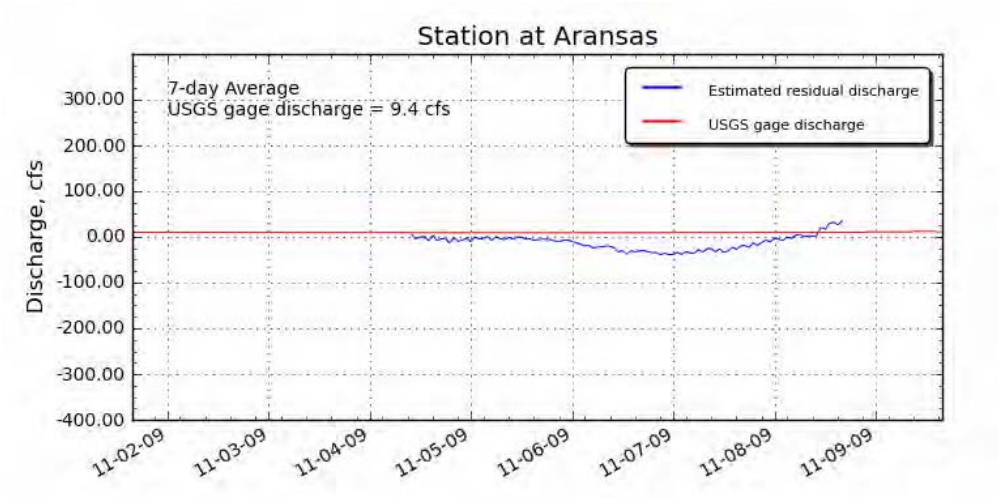
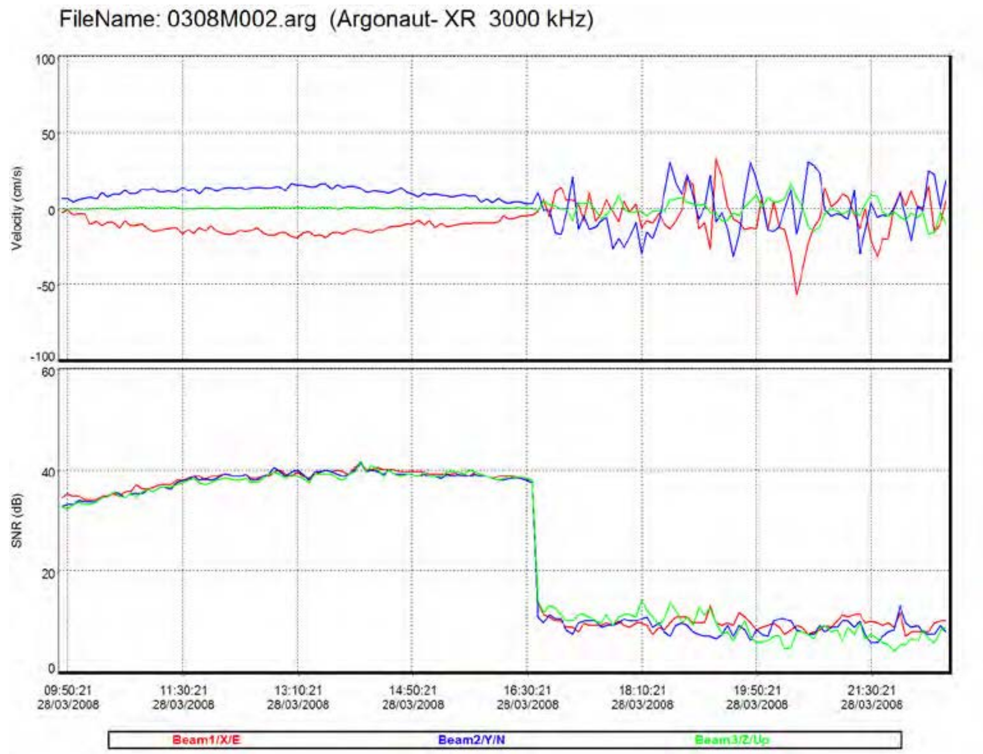


Figure 48. Estimated residual discharge at A2 and measured discharge at USGS gage near Skidmore, Aransas River (November 04 – 08, 2009).

Appendix C - Faulty ADV Deployments



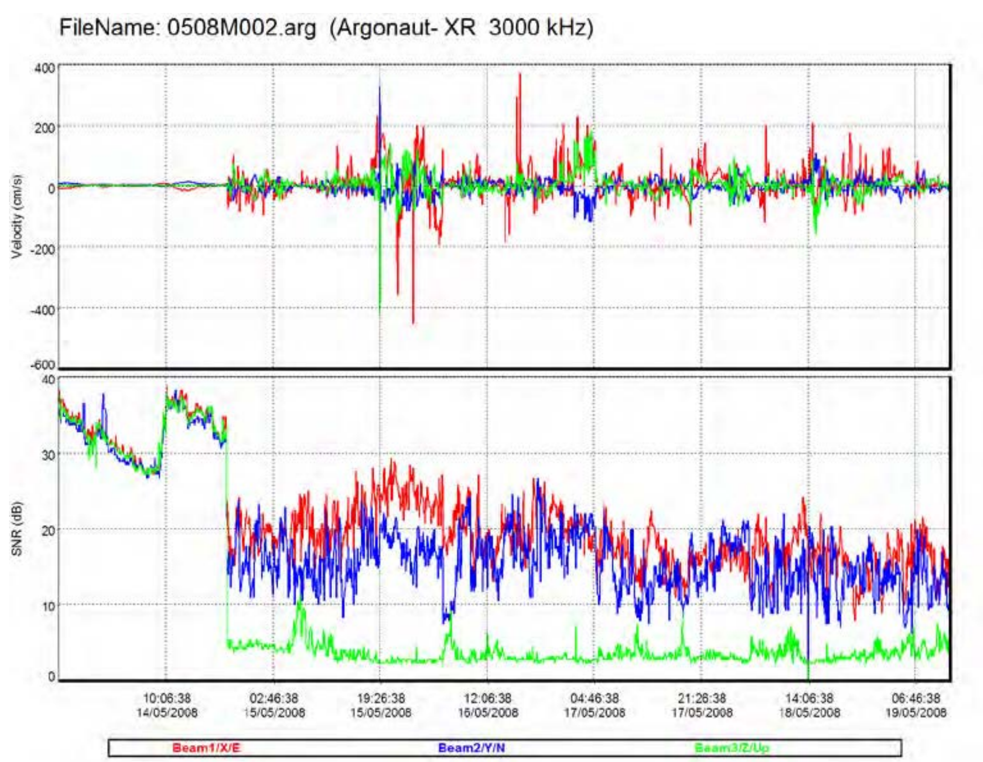


Figure 49. Faulty ADV deployments during March and May 2008 at Mission River.

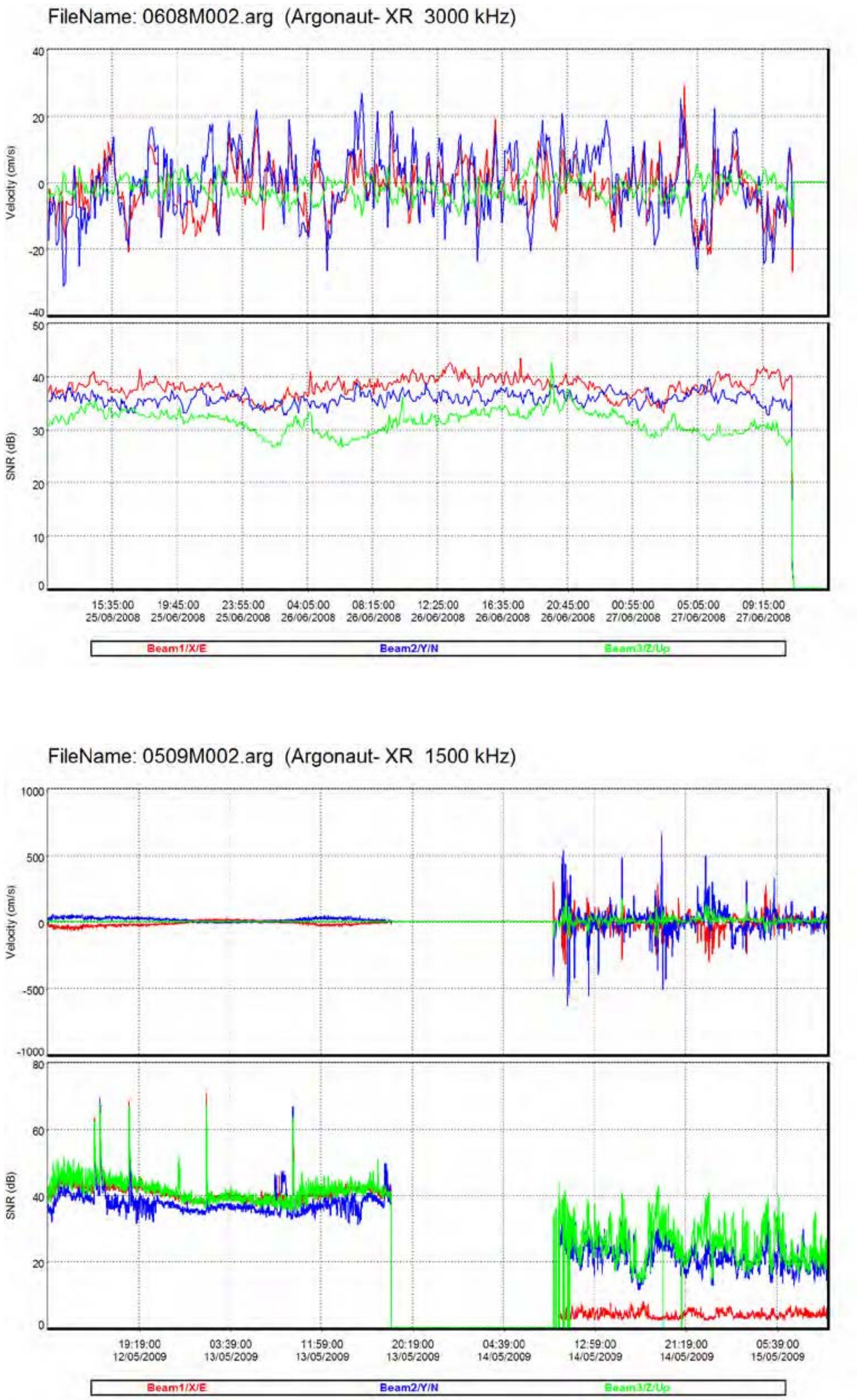


Figure 50. Faulty ADV deployments during June 2006 and May 2009 at Mission River.

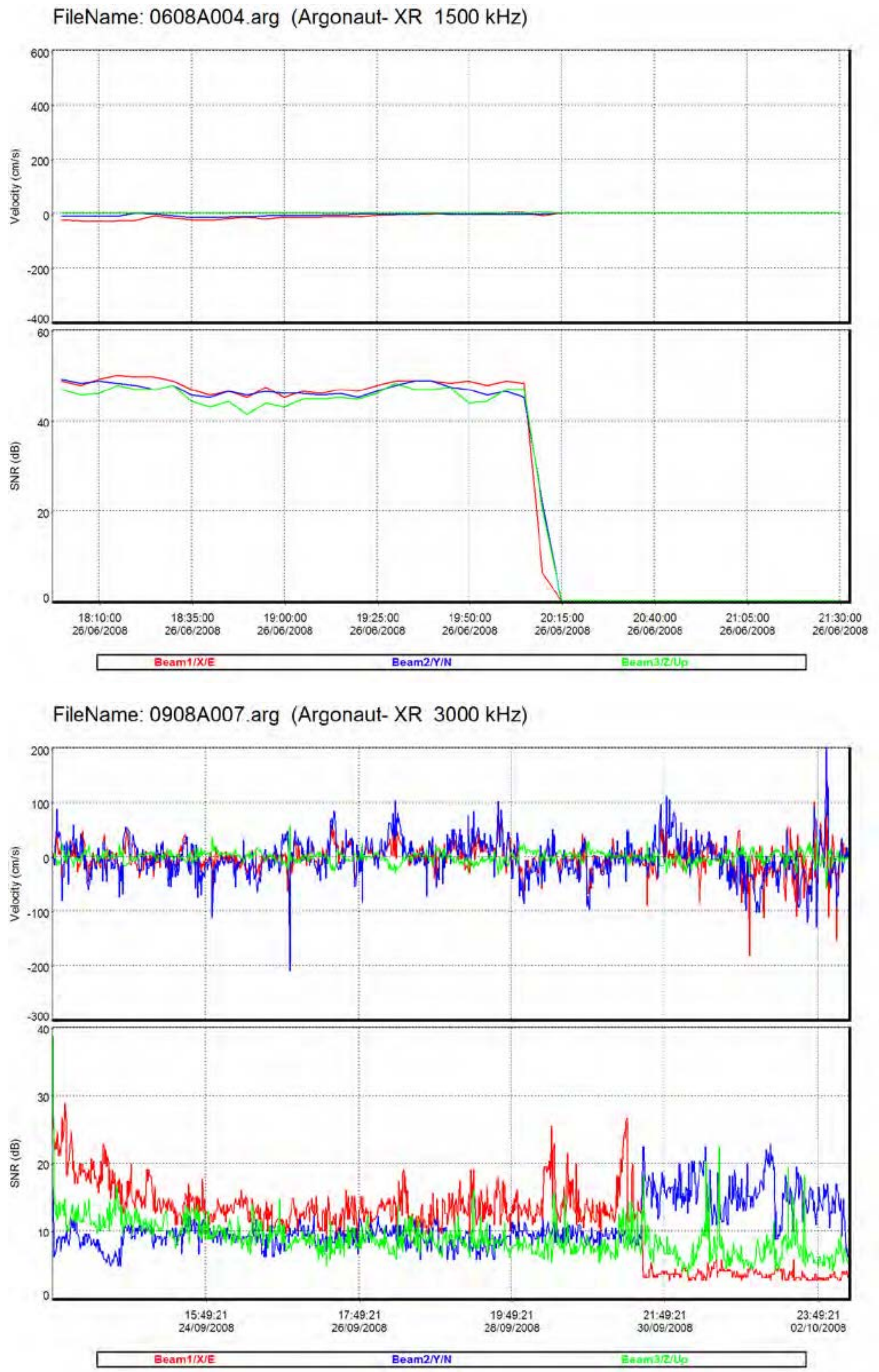


Figure 51. Faulty ADV deployments during June 2008 and September 2008 at Aransas River.

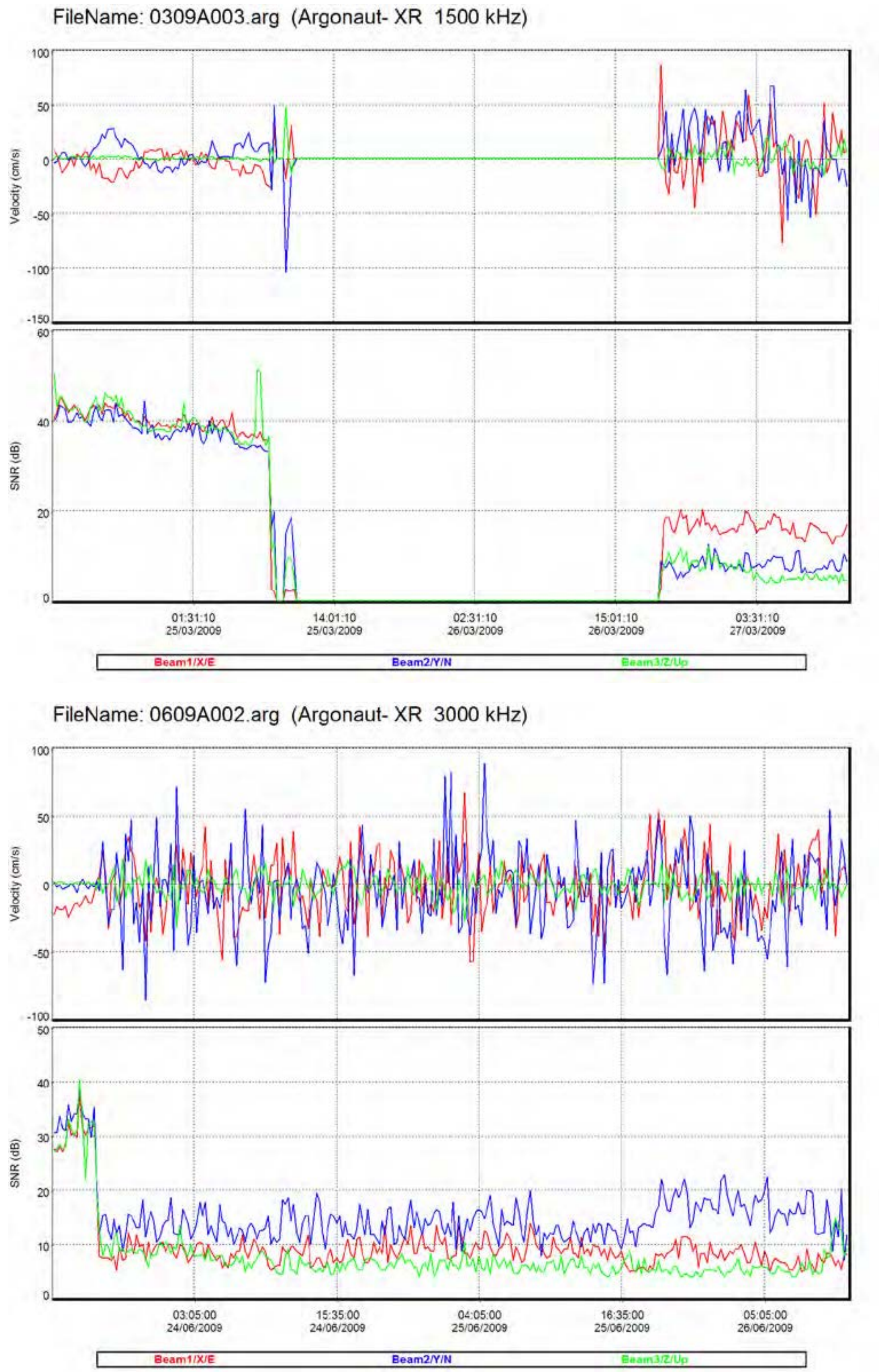


Figure 52. Faulty ADV deployments during March and June 2009 at Aransas River.

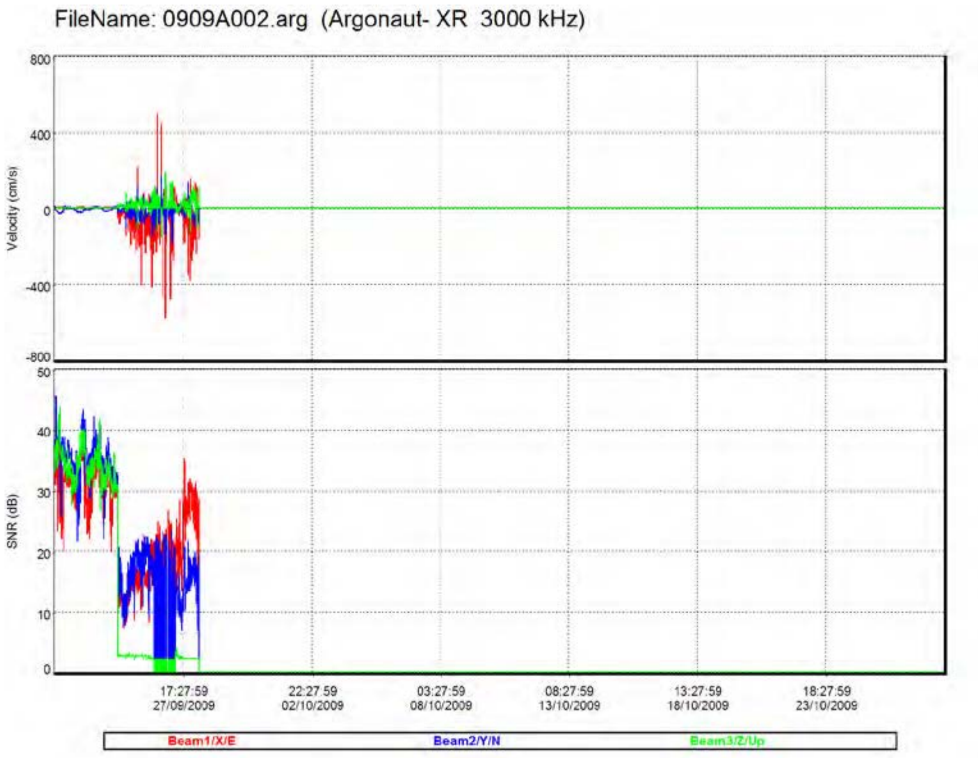


Figure 53. Faulty ADV deployments during September 2009 at Aransas River.

Appendix D - ADCP Discharge Data

1. Mission River

Station D-M1

File Name	Start Date	Start Time	End Time	Mean Vel (ft/s)	Top Discharge (cfs)	Middle Discharge (cfs)	Bottom Discharge (cfs)	Left Discharge (cfs)	Right Discharge (cfs)	Total Discharge (cfs)
TPM30906231037	23/06/2009	10:33:51	10:34:41	0.13	-8.52	-13.52	-3.01	-5.75	-11.47	-42.27
TPM30906231039	23/06/2009	10:35:41	10:36:41	0.23	-17.09	-27.47	-13.44	3.23	-4.63	-59.38
TPM30906231040	23/06/2009	10:37:15	10:38:01	0.20	-24.87	-29.18	-9.06	3.54	2.36	-57.20
TPM30906231042	23/06/2009	10:38:41	10:39:41	0.10	-6.13	-10.07	-2.51	-0.96	-5.82	-25.49
TPM30906231044	23/06/2009	10:41:15	10:42:51	0.36	-30.07	-51.63	-15.49	-7.30	-6.87	-111.36
TPM30906231048	23/06/2009	10:45:35	10:47:05	0.10	-11.98	-17.43	-5.52	0.00	3.48	-31.45
TPM30906231051	23/06/2009	10:48:01	10:49:31	0.46	-47.02	-55.43	-25.24	0.00	1.59	-126.10
Mean				0.23	-23.34	-33.33	-11.69	-0.61	-3.92	-72.89
Std. Dev.				0.13	15.14	20.28	8.13	4.02	5.75	42.91
Coefficient of Variation				1.97	22.87	21.43	24.53	233.32	51.67	20.76

Station D-M2

File Name	Start	Start	End	Mean Vel	Top Discharge	Middle Discharge	Bottom Discharge	Left Discharge	Right Discharge	Total Discharge
	Date	Time	Time	(fps)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
TPM40906231130	23/06/2009	11:27:33	11:28:57	0.33	-38.99	-110.27	-19.48	1.73	1.51	-165.50
TPM40906231134	23/06/2009	11:31:03	11:32:13	0.13	-17.15	-41.88	-10.52	-3.41	-3.80	-76.76
TPM40906231136	23/06/2009	11:33:27	11:34:43	0.30	-40.02	-105.89	-25.00	1.34	2.29	-167.28
TPM40906231138	23/06/2009	11:35:17	11:36:47	0.39	-48.68	-141.25	-31.30	4.51	-2.10	-218.82
TPM40906231140	23/06/2009	11:37:13	11:38:27	0.16	-23.68	-63.28	-12.45	1.72	1.61	-96.08
TPM40906231143	23/06/2009	11:39:53	11:41:07	0.10	-11.99	-40.25	-5.10	2.62	-4.92	-59.65
TPM40906231145	23/06/2009	11:41:43	11:43:03	0.30	-35.25	-117.62	-19.63	0.00	5.92	-166.58
TPM40906231147	23/06/2009	11:43:33	11:44:53	0.30	-40.31	-130.77	-21.15	16.13	-6.69	-182.79
Mean				0.26	-32.01	-93.91	-18.08	3.08	-0.77	-141.68
Std. Dev.				0.10	12.88	39.82	8.40	5.74	4.28	56.70
Coefficient of Variation				1.35	14.19	14.97	16.41	65.83	196.02	14.12

Station D-M3

File Name	Start	Start	End	Mean Vel	Top Discharge	Middle Discharge	Bottom Discharge	Left Discharge	Right Discharge	Total Discharge
	Date	Time	Time	(fps)	(cfs)	(cfs)	(cfs/s)	(cfs)	(cfs)	(cfs)
TPM50906231153	23/06/2009	11:50:21	11:51:41	0.36	-38.88	-151.55	-26.29	-9.61	-7.43	-233.76
TPM50906231158	23/06/2009	11:55:01	11:56:07	0.23	-28.47	-101.63	-22.28	-0.58	-4.59	-157.56
TPM50906231200	23/06/2009	11:57:01	11:58:17	0.30	-32.87	-132.68	-22.44	-3.50	-1.49	-192.98
TPM50906231211	23/06/2009	12:08:07	12:09:02	0.33	-41.06	-152.04	-34.37	5.71	-9.62	-231.38
TPM50906231213	23/06/2009	12:09:36	12:10:42	0.39	-48.75	-176.01	-34.10	0.00	-1.42	-260.27
TPM50906231214	23/06/2009	12:11:16	12:12:22	0.20	-22.33	-95.39	-16.77	-1.80	-4.41	-140.71
Mean				0.30	-35.38	-134.85	-26.03	-1.63	-4.83	-202.72
Std. Dev.				0.07	9.46	31.40	7.03	5.00	3.25	47.05
Coefficient of Variation				0.80	9.43	8.22	9.53	108.16	23.72	8.19

Station D-M4

File Name	Start Date	Start Time	End Time	Mean Vel (fps)	Top Discharge (cfs)	Middle Discharge (cfs)	Bottom Discharge (cfs)	Left Discharge (cfs)	Right Discharge (cfs)	Total Discharge (cfs)
TPM20906230908	23/06/2009	9:04:36	9:06:02	0.26	-62.47	-104.79	-27.29	2.57	-3.23	-195.22
TPM20906230910	23/06/2009	9:06:36	9:08:06	0.13	-29.33	-81.92	-14.27	13.75	5.91	-105.86
TPM20906230916	23/06/2009	9:13:06	9:14:16	0.30	-76.90	-159.11	-36.07	-1.73	7.41	-266.40
TPM20906230924	23/06/2009	9:21:16	9:22:46	0.20	-45.11	-107.26	-19.98	12.23	-3.63	-163.74
TPM20906230926	23/06/2009	9:23:06	9:24:16	0.39	-82.85	-169.70	-31.73	-5.33	8.11	-281.50
TPM20906230928	23/06/2009	9:24:56	9:26:17	0.10	-21.74	-46.90	-12.70	-1.10	3.06	-79.37
TPM20906230931	23/06/2009	9:28:17	9:29:17	0.43	-92.10	-179.52	-38.24	0.00	8.32	-301.54
Mean				0.26	-58.64	-121.31	-25.76	2.91	3.71	-199.09
Std. Dev.				0.13	27.26	49.53	10.30	7.29	5.19	87.66
Coefficient of Variation				1.56	16.39	14.38	14.10	88.15	49.31	15.51

2. Aransas River

Station D-A1

File Name	Start Date	Start Time	End Time	Mean Vel (fps)	Top Discharge (cfs)	Middle Discharge (cfs)	Bottom Discharge (cfs)	Left Discharge (cfs)	Right Discharge (cfs)	Total Discharge (cfs)
TPA30906231625	23/06/2009	16:22:32	16:23:32	0.13	-34.94	-86.95	-22.84	-8.75	-6.01	-159.50
TPA30906231627	23/06/2009	16:24:07	16:25:02	0.36	-86.82	-236.99	-60.53	-3.30	4.71	-382.93
TPA30906231628	23/06/2009	16:25:17	16:26:17	0.20	-37.78	-155.12	-33.44	0.00	1.96	-224.38
TPA30906231630	23/06/2009	16:27:07	16:28:12	0.07	-20.61	-38.72	-22.08	5.56	-4.55	-80.40
TPA30906231631	23/06/2009	16:28:27	16:29:37	0.03	-9.66	-25.04	-10.49	-4.54	5.80	-43.93
TPA30906231633	23/06/2009	16:30:02	16:31:12	0.20	-51.23	-177.84	-36.72	-2.76	2.78	-265.79
TPA30906231634	23/06/2009	16:31:27	16:32:27	0.10	-34.72	-70.95	-22.18	-6.31	1.05	-133.11
TPA30906231636	23/06/2009	16:32:47	16:34:12	0.07	-3.85	-45.07	-3.57	-1.39	-2.12	-56.01
Mean				0.14	-34.95	-104.59	-26.48	-2.69	0.45	-168.26
Std. Dev.				0.10	26.12	76.63	17.50	4.32	4.28	117.01
Coefficient of Variation				2.40	38.62	33.43	41.44	24.36	87.83	34.49

Station D-A2

File Name	Start	Start	End	Mean Vel	Top Discharge	Middle Discharge	Bottom Discharge	Left Discharge	Right Discharge	Total Discharge
	Date	Time	Time	(fps)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
TPA20906231530	23/06/2009	15:27:01	15:28:23	0.20	-64.17	-169.90	-32.10	-1.68	0.66	-267.19
TPA20906231534	23/06/2009	15:31:17	15:32:37	0.46	-147.04	-336.38	-77.74	3.64	-3.64	-561.13
TPA20906231536	23/06/2009	15:33:07	15:34:38	0.26	-80.49	-216.05	-44.93	6.39	0.00	-335.08
TPA20906231538	23/06/2009	15:35:08	15:36:28	0.33	-98.57	-290.98	-52.21	-2.05	7.09	-436.70
TPA20906231540	23/06/2009	15:36:52	15:38:18	0.30	-90.27	-248.49	-44.97	25.90	-4.93	-362.74
TPA20906231542	23/06/2009	15:38:52	15:40:18	0.46	-153.77	-347.57	-73.69	4.00	-15.91	-586.93
TPA20906231544	23/06/2009	15:40:48	15:42:02	0.26	-92.73	-221.26	-42.47	2.03	2.66	-351.78
TPA20906231545	23/06/2009	15:42:28	15:43:48	0.30	-100.72	-238.11	-53.23	6.32	-1.14	-386.85
TPA20906231545	23/06/2009	15:42:42	15:43:48	0.30	-101.47	-242.80	-54.73	11.89	0.00	-387.10
TPA20906231549	23/06/2009	15:46:22	15:47:42	0.23	-100.38	-172.30	-43.20	0.00	-4.76	-320.63
TPA20906231552	23/06/2009	15:49:07	15:50:37	0.16	-54.93	-148.36	-24.02	-9.07	5.55	-230.83
Mean				0.30	-98.59	-239.29	-49.39	4.31	-1.31	-384.28
Std. Dev.				0.10	29.88	65.09	15.85	9.01	6.20	109.72
Coefficient of Variation				1.00	10.70	9.60	11.33	73.85	166.90	10.10

Appendix E - Discharge Rating Curve Scaling Factor Computation

1. Mission River

	Time		Discharge (cms)						Mean Vel (m/s)		ADV Velocity (m/s)
Tr#	Start	End	Top	Middle	Bottom	Left	Right	Total	Boat	Water	
1	*13:37*	*13:38*	*-2.30*	*-4.15*	*-1.06*	*0.00*	*-0.12*	*-7.63*	*0.82*	*0.11*	
2	*13:40*	*13:41*	*-2.93*	*-5.20*	*-1.30*	*-0.35*	*0.04*	*-9.74*	*0.79*	*0.14*	
3	*13:41*	*13:43*	*-1.43*	*-2.32*	*-0.75*	*-0.11*	*-0.08*	*-4.70*	*0.52*	*0.07*	
4	*13:44*	*13:45*	*-3.10*	*-5.11*	*-1.57*	*-0.15*	*-0.09*	*-10.01*	*0.76*	*0.14*	*-0.39*
5	*13:47*	*13:48*	*-1.75*	*-2.79*	*-0.70*	*0.00*	*0.00*	*-5.24*	*0.53*	*0.08*	
6	*13:50*	*13:51*	*-1.07*	*-2.16*	*-0.55*	*0.00*	*-0.09*	*-3.87*	*0.61*	*0.06*	
7	*13:52*	*13:53*	*-0.32*	*-0.61*	*0.07*	*-0.14*	*-0.06*	*-1.05*	*0.57*	*0.01*	
8	*13:54*	*13:55*	*-1.61*	*-2.41*	*-0.70*	*0.44*	*0.02*	*-4.26*	*0.54*	*0.06*	
	14:00										*-0.35*
Mean			-1.81	-3.09	-0.82	-0.04	-0.05	**-5.81**			**-0.37**
SDev			0.93	1.60	0.50	0.23	0.06	3.09			
COV			0.52	0.52	0.61	5.87	1.22	0.53			

Scaling Factor, B2= **15.71**

(Total discharge/Mean measured velocity)

2. Aransas River

Tr#	Time		Discharge (cms)						Mean Vel (m/s)		ADV Velocity (m/s)
	Start	End	Top	Middle	Bottom	Left	Right	Total	Boat	Water	
1	*15:27*	*15:28*	*-1.82*	*-4.81*	*-0.91*	*-0.05*	*0.02*	*-7.57*	*0.72*	*0.06*	
2	*15:31*	*15:32*	*-4.17*	*-9.51*	*-2.22*	*0.15*	*0.00*	*-15.74*	*0.81*	*0.14*	
3	15:33	15:34	-2.28	-6.12	-1.27	0.18	0.00	-9.49	0.71	0.08	
4	*15:35*	*15:36*	*-2.58*	*-8.01*	*-1.39*	*-0.06*	*0.00*	*-12.04*	*0.73*	*0.1*	*-0.20*
5	*15:36*	*15:38*	*-2.56*	*-7.04*	*-1.27*	*0.73*	*-0.14*	*-10.28*	*0.69*	*0.09*	
6	*15:38*	*15:40*	*-3.52*	*-9.57*	*-1.80*	*0.11*	*0.00*	*-14.77*	*0.72*	*0.13*	
7	*15:41*	*15:42*	*-2.72*	*-6.37*	*-1.24*	*0.00*	*-0.29*	*-10.63*	*0.91*	*0.09*	
8	*15:42*	*15:43*	*-2.87*	*-6.88*	*-1.55*	*0.34*	*0.00*	*-10.97*	*0.95*	*0.09*	
9	15:46	15:47	-2.84	-4.88	-1.22	0.00	-0.13	-9.08	0.91	0.07	
10	*15:49*	*15:50*	*1.56*	*4.20*	*0.68*	*-0.16*	*0.26*	*6.54*	*0.66*	*0.05*	*-0.17*
Mean			-2.381	-5.899	-1.22	0.1251	-0.029	**-9.404**	0.78	0.09	**-0.19**
SDev			1.526	3.9124	0.7587	0.2568	0.1414	6.1312	0.1	0.03	
COV			0.641	0.663	0.622	2.052	4.888	0.652	0.135	0.298	

Scaling Factor, B2= **50.83**
(Total discharge/Mean measured velocity)

Appendix 3. Taxonomic list and total numbers of vertebrate taxa collected, by gear, from the Mission and Aransas Rivers during the 2008-2009 Tidal Stream Study. List arranged by taxa rank as measured by total number of individuals collected.

		Bag Seines		Otter Trawls	
Common Name	Taxa	Mission	Aransas	Mission	Aransas
Bay anchovy	*Anchoa mitchilli*	5572	9564	25498	30125
Gulf menhaden	*Brevoortia patronus*	5528	5754	1567	9470
Tidewater silverside	*Menidia spp.*	844	3083	1	
Blue catfish	*Ictalurus furcatus*	1		317	893
Atlantic croaker	*Micropogonias undulatus*	43	143	421	281
Striped mullet	*Mugil cephalus*	331	264	12	216
Sailfin molly	*Poecilia latipinna*	124	463		
Sheepshead minnow	*Cypinodon variegatus*	75	468		1
Western mosquitofish	*Gambusia affinis*	107	259		
Naked goby	*Gobiosoma bosc*	50	302	3	3
Gulf pipefish	*Syngnathus scovelli*	21	333		
Gulf killifish	*Fundulus grandis*	110	188		
Ladyfish	*Elops saurus*	11	153	46	55
Spotted seatrout	*Cynoscion nebulosus*	64	147	7	2
Rainwater killifish	*Lucania parva*	15	204		
Silver perch	*Bairdiella chrysoura*	79	47	7	9
Rio Grande cichlid	*Herichthys cyanoguttatum*	5	121		

Appendix 3 (cont.)

Common Name	Taxa	Bag Seines		Otter Trawls	
		Mission	Aransas	Mission	Aransas
Spot	*Leiostomous xanthurus*	1	9	37	17
Pinfish	*Lagodon rhomboides*	16	42		2
Hogchoker	*Trinectes maculatus*	33	16		3
Sand seatrout	*Cynoscion arenarius*	35	2	4	6
Black drum	*Pogonias cromis*		2	25	20
Bay whiff	*Citharichthys spilopterus*	14			
Atlantic needlefish	*Strongylura marina*	3	11		
Spotted gar	*Lepisosteus oculatus*		8	1	5
Hardhead catfish	*Ariopsis felis*	1	4	4	4
Bayou killifish	*Fundulus pulvereus*	9	3		
Channel catfish	*Ictalurus punctatus*		1	5	5
Diamond killifish	*Adinia xenica*	8	1		
Mojarra species	*Eucinostomus spp.*	4	5		
Alligator gar	*Atractosteus spatula*			2	6
Bluegill	*Lepomis macrochirus*		7		
Irish pompano	*Diapterus auratus*			1	6
Sheepshead	*Archosargus probatocephalus*	1	2	1	2
Red drum	*Sciaenops ocellatus*		5		1
Saltmarsh topminnow	*Fundulus jenkinsi*	4	1		
Least puffer	*Sphoeroides parvus*		4		1

Appendix 3 (cont.)

Common Name	Taxa	Bag Seines Mission	Bag Seines Aransas	Otter Trawls Mission	Otter Trawls Aransas
Bluntnose jack	*Hemicaranx amblyrhynchus*	3		1	
Green goby	*Microgobius thalassinus*		4		
Largemouth bass	*Micropterus salmoides*		4		
Sharptail goby	*Gobionellus oceanicus*		3	1	
Threadfin shad	*Dorosoma petenense*		2	1	1
Darter goby	*Gobionellus boleosoma*	3			
Golden topminnow	*Fundulus chrysotus*	3			
Southern flounder	*Paralichthys lethostigma*	1		2	
Clown goby	*Microgobius gulosus*		3		
Family Cyprinidae	*Cypinidae*		3		
Smallmouth buffalo	*Ictiobus bubalus*			1	2
Striped anchovy	*Anchoa hepsetus*		3		
Code goby	*Gobiosoma robustum*		2		
Common snook	*Centropomus undecimalis*		2		
Flathead catfish	*Pylodictis olivaris*				2
Gizzard shad	*Dorosoma cepedianum*				2
Southern stingray	*Dasyatis americana*		2		
Finescale menhaden	*Brevoortia gunteri*			1	
Lepomis species	*Lepomis sp.*		1		
Warmouth	*Chaenobryttus gulosus*			1	

Appendix 4. Taxonomic list and total numbers of invertebrate taxa collected, by gear, from the Mission and Aransas Rivers during the 2008-2009 Tidal Stream Study. List arranged by taxa rank as measured by total number of individuals collected. Incidental catches of non-target species (Other Taxa) are also listed.

		Bag Seines		Otter Trawls	
Common Name	Taxa	Mission	Aransas	Mission	Aransas
Brown shrimp	*Farfantepenaeus aztecus*	2557	3148	93	73
Grass shrimp	*Palaemonetes spp.*	1890	3373	1	1
White shrimp	*Litopenaeus setiferus*	780	1117	51	111
Blue crab	*Calinectes sapidus*	174	76	8	5
Family Penaeidae	*Penaeidae*	201	36		1
Pink shrimp	*Farfantepenaeus duorarum*	10	72		
Family Xanthidae	*Xanthidae*	35	39		1
Atlantic brief squid	*Lolliguncula brevis*	1		16	9
Arrow shrimp	Tozeuma carolinense	10			
Family Macrobrachium	*Macrobrachium*	1			4
Other Taxa					
Diamondback terrapin	*Malaclemys terrapin*				1
Redear slider turtle	*Trachemys scripta*				1
Softshell turtle	*Trionychidae*			1	

Appendix 5. Taxonomic list and total numbers of benthic macroinvertebrates collected from the Mission and Aransas Rivers during the 2008-2009 Tidal Stream Study. List arranged by taxa rank as measured by total number of individuals collected.

Taxa	Mission	Aransas
Streblospio benedicti	1055	1251
Oligochaeta	80	205
Chironomidae	78	189
Mediomastus	41	118
Mactridae	114	101
Amphicteis floridus	32	83
Rictaxis punctostriatus		68
Nemertea	10	44
Hydrobiidae	9	12
Tellina texana	3	8
Mysidacea	11	7
Corophium louisianum	38	6
Glycinde solitaria	11	6
Pectinaria gouldii	2	5
Texadina barretti	4	5
Capitella capitata	3	4
Eteone lactea	13	4
Haustoriidae		3
Caridean shrimp	9	2
Laeonereis culveri	5	2
Ampelisca		1
Corixidae		1
Dispio uncinata		1
Edotea montosa	6	1
Ostracoda		1
Prionospio		1
Pyramidellidae		1
Acteocina canaliculata	5	
Cumacea	1	
Grandidierella bonnieroides	4	
Macoma tenta	2	
Nereididae	1	
Oxyurostylis smithi	2	

Appendix 5 (cont.)

Taxa	Mission	Aransas
Parandalia	1	
Prionospio heterobranchia	1	

Appendix 6. Photographs of the sampling locations on the Mission and Aransas Rivers.

Mission River Station 1 (MR 1), looking upstream.

Mission River Station 1 (MR 1), looking downstream.

Appendix 6 (cont.)

Mission River Station 2 (MR 2), looking upstream.

Mission River Station 2 (MR 2), looking downstream.

Appendix 6 (cont.)

Mission River Station 3 (MR 3), looking upstream.

Mission River Station 3 (MR 3), looking downstream.

Appendix 6 (cont.)

Aransas River Station 1 (AR 1), looking upstream.

Aransas River Station 1 (AR 1), looking downstream.

Appendix 6 (cont.)

Aransas River Station 2 (AR 2), looking upstream.

Aransas River Station 2 (AR 2), looking downstream.

Appendix 6 (cont.)

Aransas River Station 3 (AR 3), looking upriver.

Aransas River Station 3 (AR 3), looking downstream.