Stable Isotope Studies of the Natural Waters of Intra-Coastal Waterway and Rivers in Freeport Area, Brazoria County, Texas

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ABSTRACT

A hydrological study using oxygen isotopic ratios and salinities was carried out in the San Bernard - Brazos River Estuaries, Brazoria County, Texas, USA, to understand the influence of 4 fresh water sources draining into the area, Brazos River, San Bernard River, Oyster Creek, and Jones Creek, on various parts of the Gulf Intra-Coastal Waterway (GIW) that transects these rivers half to 1 mile inland of the Gulf of Mexico. The measured oxygen isotopic ratios and salinities of GIW waters are explained with simple mixing between one of the 4 fresh water sources with marine water. It is possible to identify 3 sub-areas of the GIW, each of which is influenced by a different freshwater source. These sub-areas are on the western part of the Brazos River, between the Brazos and Old Brazos River, and on the eastern part of the Old Brazos River, and have their freshwater source from the San Bernard River, Brazos River, and Oyster Creek, respectively. An interesting result was found in the GIW between the San Bernard and Brazos Rivers, where fresh water is mainly sourced from the San Bernard River although its discharge rate is 40 to 100 times less than that of the Brazos River. This westerly flow of the San Bernard River toward the larger Brazos River is due to the shallowing of the San Bernard River at the river mouth, which restricts free discharge of river water to the open sea and diverts the flow toward the GIW on both sides of the river. The influence of the other two creeks, Oyster and Jones, was minor and limited near the confluence with the GIW due to minor influxes. The effect of evaporation appeared most significantly during the summer period. Water bodies consisting of shallow lakes or the GIW near such lakes experienced high rates of evaporation that affected the water chemistry of the GIW during this season.

Introduction

A hydrological study employing measurements of both salinities and oxygen isotopic ratios ($H_2^{18}O/H_2^{16}O$) was carried out from October, 2001, to September, 2002, in cooperation with the Texas Water Development Board as part of a larger scale study to evaluate circulation hydrodynamics of the Cedar Lake - San Bernard - Brazos River Estuaries, Brazoria County, Texas (Fig. 1). The study area includes 4 fresh water sources: (1) San Bernard River (2) Brazos River (3) Jones Creek and (4) Oyster Creek. The Gulf Intra-Coastal Waterway (GIW) links these sources and several small isolated lakes such as Cedar Lakes and Jones Lake (Fig. 1). Mixing occurs between seawater from the Gulf of Mexico and these sources driven by tides and winds.

The use of oxygen isotope ratios combined with salinity measurements of estuarine water provides a better definition of mixing than salinity alone. Although salinity is a useful tool to define mixing between fresh water and marine waters, it cannot be used to distinguish between different fresh water sources where multiple fresh water sources are mixed with marine water. Large variations in oxygen isotope ratios occur in natural waters as a result of evaporation, distillation, and condensation processes that take place in the hydrologic cycle (Craig, 1961; Dansgaard, 1964; Freedman et al., 1964). These natural isotope variations cause different fresh water sources to have different isotope ratios. A river draining one region will have a different isotope ratio than a river draining another because the climatic regimes of the two drainage basins are different. Considerable differences in oxygen isotopic composition are expected in the two major rivers of the study site, San Bernard and

Brazos, because the San Bernard has a small drainage that extends to only 150 km northwest of the estuary while the Brazos River drainage basin comprises 15 % of Texas land area (Keeney-Kennicutt and Presley, 1986) and extends to further north across the border to New Mexico. In areas where evaporation rates are high, the oxygen isotope ratios of waters increase markedly relative to the corresponding increase in salinities. Shallow isolated water bodies such as Cedar Lake, Jones Creek, and Oyster Creek can develop unique isotope-salinity signatures due to evaporation that help to better define mixing relationship with larger more marine water bodies. Because of these differences in oxygen isotope ratios of natural water, estuarine waters plotted on salinity versus isotope ratio diagrams usually permit the discrimination of one fresh water source from another and allow evaluation of the relative importance of each source (e.g. Friedman et al, 1964; Lloyd, 1966; Ehhalt, 1969; Torgersen, 1979; Fairbanks, 1982; Anati and Gat, 1989; Lawrence, 1993).

The objective of this study is to determine how fresh water, fed by two rivers (Brazos and San Bernard) and other two creeks (Jones and Oyster), mixes along the GIW using oxygen isotope ratios and salinities of water. Problems to be solved include: 1) relative importance of four fresh water sources, Brazos, San Bernard, Jones, and Oyster along the GIW of the Freeport Area, 2) fresh water source of Cedar Lake; San Bernard or Brazos Rivers, and 3) Flow path of San Bernard River (Does the San Bernard detour NE along GIW to exit through the mouth of the Brazos?). The effect of East Matagorda Bay water in the mixing trend will also be studied.

Sample Collection and Analyses

The samples were collected from 49 sites along the GIW and 4 major freshwater sources (Fig. 1) through the 6 field trips carried on Oct. 10, 2001, Dec. 19, 2002, Jan. 28, 2002, Mar. 4, 2002, Aug. 14, 2002, and Sept. 4, 2002. Water samples were collected from the bottom and surface of each site in the GIW and in the rivers close to the GIW in order to study different mixing pattern at different depths due to stratification of water bodies, while only surface samples were collected for the inland river sites where the salt wedges are not likely present and the access to the center of the river was limited. The bottom samples were collected using a Nansen bottle and surface samples using a pail for surface samples. The salinity was measured on site upon the sampling or in the laboratory using refractometer. Samples for oxygen isotope analyses were collected in the Qorpak glass bottle with poly-seal lined cap without treatment and analyzed using Finnigan Mat Delta E mass spectrometer using CO_2 equilibration method (Epstein and Mayeda, 1953). The analyzed salinities and oxygen isotope compositions are listed in Table 1.

Other Background Data

For better understanding of the mixing in the area, the discharge rates at the Brazos and San Bernard River were monitored on the sampling dates. The tide level during the period of sampling was also recorded from the DNR web site (Division of Nearshore Research, Texas A&M Univ. – Corpus Christi). The data are listed in Table 2. The Brazos River is the third largest contributor of suspended sediment to the Gulf of Mexico (Keeney-Kennicutt and Presley, 1986) and has no obstructing offshore barrier islands. An average discharge of the river is much greater than other river and creeks in the study area. It is about 14 times greater than that of the San Bernard River, the 2nd largest freshwater source in the area (Table 2).

Results and Discussion

The oxygen isotopic composition and salinity of estuarine water are determined by three major factors; freshwater influx from rivers, tidal exchange with open ocean, and evaporation of these waters. The oxygen isotopic composition of water is given in the standard δ notation:

$$\delta^{18}O = (R_{sample}/R_{SMOW} - 1) \times 1000,$$

where R_{SMOW} is $^{18}O/^{16}O$ ratio of Standard Mean Ocean Water that equals 0.0020052 and R_{sample} is that of sample. By this definition $\delta^{18}O$ value of SMOW is 0 ‰. Freshwater sources have a range of oxygen isotope values, usually less than that of oceanic water, with a salinity of 0 ppt. The $\delta^{18}O$ value of oceanic water can be assumed 0 ‰ with a salinity of 35.5 ppt by the above definition. The mixing relationship between oceanic water and various freshwater sources with different $\delta^{18}O$ values can be studied effectively in a salinity-$\delta^{18}O$ plot. Evaporation modifies salinity and $\delta^{18}O$ of a water mass, in which increase in $\delta^{18}O$ is much greater than the corresponding salinity increase.

The first sampling of the study area took place on October 10, 2001 along the Brazos River. The surface and bottom waters are distinctive in both salinity and oxygen isotope ratios (Table 1 and Fig. 2), indicating the presence of salt wedge extending to the Dow Pump Station near Brazoria city, about 30 miles inland. They, however, show a mixing relationship between two end-members, oceanic water and river water with a $\delta^{18}O$ value of around -3.8 ‰ (Fig. 2). The regression line extends to oceanic composition with a $\delta^{18}O$ of +0.5‰, reflecting generally high evaporation rates in the Gulf of Mexico over the summer season.

The next batch of samples was collected on Dec. 19 and 20, 2001. This 2nd batch of samples were collected right after the heavy rains across the northeast Texas Gulf Coast in order to assess the effect of heavy discharge by the major rivers on the GIW and bay areas. The water discharge on December 20, when the GIW water samples were collected, reached its maximum at 31,200 cubic feet per second in the Brazos River, three times higher than a 10-year average (Table 2). The water discharge in the San Bernard River was about 978 cubic feet per second, slightly higher than a 10-year average (Table 2).

As indicated in the salinity data, all major rivers and GIW were filled with fresh water excepting a few sites between the Old Brazos River and Drum Bay (Table 1, Figs. 3 and 4). However, there are three groups identified in a $\delta^{18}O$ – salinity plot. Each group shows influence of different freshwater source in its composition as labeled in Figure 3. The oxygen isotope ratios alone also provide useful information regarding the fresh water sources in various sites of the study area. The flow patterns deduced from them follow.

1. Between the Drum Bay and Old Brazos River

The salinity and oxygen isotope ratio of GIW water between Drum Bay and Old Brazos River can be explained with a mixing between seawater and Oyster Creek water (Fig. 3). The influence of lighter isotopic composition of Oyster Creek water (-2.3 ‰) appears only near the confluence with GIW (Fig. 4).

2. Between the Brazos River and Old Brazos River

The influence of Brazos River water along the GIW appears only in the interval between the Brazos and Old Brazos River. The isotopic value of –3.4 ‰ observed along this interval must be fed from the Brazos River as it is the only water source with such a low isotopic value (-3.6 ‰) (Figs. 3 and 4). This Brazos River water does not seem to pass across the Old Brazos River judging from a large difference in oxygen isotope ratios (east: -1.4 ‰, west:-3.4 ‰) of GIW water in the eastern and western sides of the Old Brazos River (Fig. 4).

3. Between the Cedar Lake and Brazos River

The oxygen isotopic ratios (–2.2 to –2.9 ‰) of the GIW water samples between the San Bernard River and the Brazos River in the first batch of samples are close to the end member composition (-2.8 ‰) of San Bernard river water and there is a decreasing trend toward the San Bernard River from -2.2 ‰ to -2.9 ‰ (Fig. 4), suggesting San Bernard River water as a possible source. The GIW water samples (GB-3 and GS-1) on the eastern and western sides of the Brazos River also shows a big difference in the oxygen isotope ratios (-3.4 and -2.2 ‰, respectively), indicating that oxygen-18 depleted water from the Brazos River has a more profound effect on the GIW on the eastern side of the river. The westerly flow of the San Bernard River was not expected because of its minor discharge that accounts for only 1 to 10 % of the Brazos River (Table 2). This westerly flow is probably caused by shallowing of the San Bernard River at the river mouth due to sand dune formation, which limits free discharge of river water to open sea and diverts the flow toward the GIW on both sides of the river. An exception is a site closest to the Brazos River where the bottom water has an oxygen isotope ratio of –3.2 ‰ (site GS-1), lighter than San Bernard River water (Table 1), suggesting a minor influence of Brazos River water near the Brazos River.

There are no differences in $\delta^{18}O$ values between the Cedar lakes samples and the GIW samples from the eastern side of the San Bernard River, suggesting the San Bernard River as a common source for the both sides of GIW and the Cedar Lakes. Bottom water samples show a $\delta^{18}O$-salinity trend similar to that of the surface water (Fig. 3). The Jones Creek water does not show any measurable effect on GIW water composition, probably due to a minor influx.

The sampling for this batch of samples was undertaken during a low tidal cycle, which might have signified the great influence of freshwater along the GIW, in addition to the large influx of fresh water from the two major rivers.

The 2nd batch of samples provided a good opportunity to evaluate a mixing and flow pattern along the GIW at a period of high discharges in the major rivers. On the other hand, the 3rd through 6th batches of samples, collected on January 18, March 14, August 14, and September 4, 2002, respectively, provide an opportunity to assess a mixing and flow pattern at low discharges in these rivers (Table 2). The river discharge rates in the two rivers on these days were about 10 to 30 times less than the river discharges on December 20 and about 3 to 12 times less than 10-year averages. In addition, the 3rd batch of samples were collected on a low tidal cycle, whereas the rest were on high tidal cycles, providing an opportunity to evaluate the different tidal conditions on a mixing and flow pattern at a similar river discharge condition.

In the 3rd batch of samples, oxygen isotope ratios of San Bernard and Brazos River waters are similar (Brazos: -3.3 ‰ at a salinity of 0 ppt, San Bernard: -2.7 at a salinity of 5 ppt) and are not an indicator of these two freshwater sources when the different salinities are considered (Fig. 5 and Table 1). However, there is a break in oxygen isotope ratios in the GIW across the Old Brazos River from -0.8 ‰ at the western side to -0.1 ‰ at the eastern side, suggesting the water in the GIW does not flow across the Old Brazos River (Fig. 6), supporting the interpretation presented with the 2nd batch of samples. In the eastern side of the Old Brazos River, the oxygen isotope ratios and salinities of water samples are explained by the mixing between freshwater fed from the Oyster Creek and oceanic water both from the Drum Bay and open sea connected through the Old Brazos River. In this interval, the effect of the freshwater only appears in the confluence of the GIW and Oyster Creek and diminishes in the either side away from the confluence (Fig. 6). There are a few samples that plot above the mixing trend between the Oyster Creek end member and oceanic water (circled samples in Fig. 5). These samples might reflect the effect of evaporated water mass in the nearby shallow lakes.

From the upstream of the Brazos River to the Old Brazos River, there is a gradual increase in oxygen isotope ratios from –3.3 ‰, an end member composition of Brazos River water, to -0.8 ‰ at the western side of the Old Brazos River (Fig. 6). For this interval, Brazos River water is the only freshwater source and thus this increasing trend in the oxygen isotope ratios indicates that a small part of Brazos River water flows toward the Old Brazos River mouth along the GIW and mixes with oceanic water from the inlet of the Old Brazos River. On the other side of the Brazos River from the upstream of the San Bernard River to the western side of the Brazos River, there is another increasing trend in oxygen isotope ratios from -2.8 ‰, an end member composition of San Bernard River water, to -1.1 ‰ at the western side of the Brazos River, suggesting the flow of the San Bernard River toward the Brazos River and mixing with marine water supplied through the Brazos River mouth (Fig. 6). If the Brazos River flows toward the San Bernard River, there should be an increasing trend in oxygen isotope ratios toward the San Bernard River, opposite to the observed trend. The San Bernard River also affects the GIW in the other side (western) of the river and the Cedar Lakes, indicated by their low oxygen isotope ratios varying from -0.9 to -1.1 ‰ (Fig. 6). The oxygen isotope ratios of GIW water samples on the western side of the San Bernard River gradually increases toward the East Matagorda Bay (Fig. 6), suggesting a mixing between San Bernard River water and oceanic water sourced from the East Matagorda Bay (Figs. 6). The effect of Johns Creek water on isotope composition of the GIW waters was not measurable again, due to the small discharge of water through this creek.

The similar variations in the oxygen isotope ratios discussed for the 3rd batch of samples are also observed in the 4th batch of samples, suggesting a similar mixing and flow pattern in the two different sampling days. One important difference between them that needs to be addressed is the oxygen isotope ratios of the 4th batch of samples slightly higher (up to 0.8 ‰) than those of the 3rd batch of samples (Figs. 6 and 7). The higher oxygen isotope ratios are only observed in the water samples from the GIW but not in the two major rivers, of which oxygen isotope ratios are similar to the 3rd batch. The higher oxygen isotope ratios are commensurate with higher salinities of these water samples (Figs. 6 and 7), suggesting a more effect of oceanic component in the mixing trend in the 4th batch of samples. This is a likely result considering the tidal conditions at the time of sampling. The 4th batch was collected during a high tide while the 3rd batch was collected during a low tide cycle (Table 2). The 3rd batch of samples between the Brazos River and San Bernard River shows a trend in which oxygen isotope ratio increases toward the San Bernard River from -1.6 ‰ to -1.0 ‰

with corresponding increases in salinities (Fig. 7), indicating a flow pattern from the Brazos River toward the San Bernard River. This is a reversed flow pattern from the Brazos to San Bernard River that prevails at low tidal conditions because only the 3rd batch of samples was collected during a low tidal period. However, this pattern also could be a result of the minor introduction of Brazos River water to the GIW close to the Brazos River due to frequent passages of barges along the GIW. This possibility is supported by the presence of a bottom sample with an exceptionally low oxygen isotopic ratio of -3.2 ‰ at the GS-1 site, closest to the Brazos River, in the 1st batch of samples (Fig. 1 and Table 2). This ratio is lighter than that (-2.8 ‰) of the San Bernard River end member and close to the Brazos River source (Table 2). This indicates that the westerly flow is dominant through this interval but a minor influence of Brazos River water could appear near the Brazos River (Fig. 6).

The 4 batches of samples collected during fall, winter and spring season and discussed earlier did not include significant effect of evaporation in its water chemistry excepting a few local areas as shown in the 3rd batch of samples (Fig. 5). In contrast, the 5th and 6th batches of samples are characterized by their highly enriched heavy oxygen isotopes compared to corresponding salinities (Figs. 8 and 9). Most samples excepting the main river samples plot above the mixing line between the oceanic water and the fresh water end member with the highest oxygen isotope ratio (Figs. 8 and 9). This phenomenon is commonly observed in a water body that has experienced high rate of evaporation, suggestive of high rate of evaporation through the study area. The oxygen isotope values higher than oceanic component (0 ‰) are observed in the Cedar lakes and from Old Brazos River to Drum Bay where shallow lakes are present (Fig. 10). These water bodies experienced high rates of evaporation that affected the water chemistry of GIW waters by elevating oxygen isotope values.

Summary and Conclusions

The combined use of oxygen isotopic ratios and salinities of the waters in the study of mixing in the San Bernard – Brazos Estuaries allowed for the identification of freshwater sources in various parts of the GIW and the derivation of a generalized flow pattern along the GIW. On the eastern side of the Old Brazos River, water composition was explained with mixing of Oyster Creek water with oceanic water fed from the Drum Bay and Old Brazos River, although the Oyster Creek does not cause significant changes in oxygen isotopic ratio and salinity of GIW water excepting near the confluence with the GIW. The Brazos River discharges most of water to open sea through the river mouth, but a minor part of the river water flows along the GIW toward the Old Brazos River and are mixed with oceanic water supplied from the Old Brazos River (Fig. 11). Despite of great discharge rate of the Brazos River, its influence on the GIW on the western side of the river was minimal. It was found that a part of the San Bernard River water flows eastward to the Brazos River and exit through the mouth of the Brazos River to open sea (Fig. 11). This westerly flow was caused by shallowing of the San Bernard River at the river mouth, which restricts free discharge of river water to open sea and diverts the flow toward the GIW on both side of the river. With an exception, the 4th batch samples indicated a reversed flow pattern from the Brazos to San Bernard. It might indicate the reversed flow pattern could appear during high tidal cycle. The San Bernard River also affects water composition of the Cedar Lakes and GIW on the western side of the river and is mixed with marine water from the East Matagorda Bay along the GIW (Fig. 11). The effect of evaporation appeared most significantly during the summer period. Water bodies that experienced high rates of evaporation affected the water chemistry of the GIW during this season by increasing oxygen isotope values.

The flow patterns derived in this study were consistent in all 6 batches of samples that were collected at significantly different hydrologic conditions. This suggests that the general flow pattern along the GIW in the study area is not significantly affected by variations in river discharges and different tidal levels. However, these factors have a significant effect on mixing trends. During a period of high river discharge and low tide, freshwater component dominates over oceanic component.

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TABLES

Table 1. Salinity (ppt) and oxygen isotope ratio (permil) of the samples.

SAMPLE	DEPTH	10/10/2001		12/19/2001		1/28/2002		3/4/2002		8/14/2002		9/4/2002	
		salinity	Oxygen	salinity	Oxygen	salinity	Oxygen	salinity	Oxygen	salinity	Oxygen	salinity	Oxygen
BR-1	TOP			0	-3.3	0	-3.3	1	-2.7				
BR-2	BOTTOM	0											
BR-2	TOP	0	-3.2										
BR-3	BOTTOM	21											
BR-3	TOP	1								1.7	-1.9		
BR-4	BOTTOM	24											
BR-4	TOP	2	-4.1										
BR-5	BOTTOM	22				5	-2.4	21	-1.5	29.0	0.0		
BR-5	TOP	3				4	-2.1	3	-2.7	3.0	-1.4		
BR-6	BOTTOM										0.0		
BR-6	TOP										-0.9		
BR-7	BOTTOM	25		1	-3.6	6	-2.1	18	-1.4	27.0	0.1		
BR-7	TOP	4		1	-3.4	4	-2.3	4	-2.3	3.0	-1.8		
BR-8	BOTTOM	27	-0.3	1	-3.5					28.0	-1.0		
BR-8	TOP	7	-3.1	1	-3.8					6.0	-1.2		
BR-9	BOTTOM	27	-2.6			14	-2.0			26.0	0.3		
BR-9	TOP	7	-0.1	1	-3.4	7	-2.1			7.0	-1.4		
BR-9-Mouth	TOP			1	-3.6								
CL-1	TOP					18	-0.9	22	-0.4	27.0	0.3	25.0	-0.4
CL-2	TOP			2	-2.5	16	-0.9	26	-0.4	25.0	0.7	24.0	-0.7
CL-3	TOP							27	-0.2	28.0	0.5	23.0	-0.8
CL-4	TOP							29	-0.2	29.0	1.2	20.0	
GB-1	BOTTOM			13	-2.3	25	-0.4	26	-0.7	31.0	0.8		
GB-1	TOP			2	-3.4	20	-0.8	26	-0.5	23.0	-0.8		
GB-2	BOTTOM			1	-3.2	20	-0.4	24	-1.2	32.0	0.6		
GB-2	TOP			1	-3.4	19	-1.1	21	-1.0	22.0	-0.4		
GB-3	BOTTOM	21	-0.8	1	-3.3	19	-1.0	20	-1.0	24.0	0.5		

GB-3	TOP	16	-1.3	1	-3.4	14	-1.1	16	-1.2	19.0	-0.3		
GB-4	BOTTOM	27	-0.3			20	-1.0						
GB-4	TOP	6	-3.0			6	-2.2						
GC-1	BOTTOM					20	-1.0	21	-0.6	32.0	-0.4	26.0	-0.4
GC-1	TOP			1	-2.6	19	-0.9	21	-0.7	27.0	0.3	25.0	
GC-1-West	BOTTOM			3	-1.9								
GC-2	BOTTOM			2	-2.1	19	-1.0	25	-0.4	27.0	0.0	27.0	0.0
GC-2	TOP			1	-2.5	17	-1.0	24	-0.6	27.0	0.2	26.0	-0.3
GC-2-East	BOTTOM			2	-2.3								
GC-2-West	TOP			2	-2.5								
GC-3	BOTTOM					20	-1.1			28.0	0.1	26.0	0.3
GC-3	TOP					16	-1.0			28.0	0.7	24.0	-0.9
GC-3-East	TOP			1	-2.8								
GC-4	Bottom							28	-0.3	28.0	0.0	24.0	0.0
GC-4	TOP							27	-0.5	29.0	0.6	23.0	-0.7
GC-5	Bottom							29	-0.1	29.0	0.4	22.0	-0.1
GC-5	TOP							29	-0.4	29.0	0.3	19.0	-0.5
GC-6	BOTTOM					19	-0.5	28	-0.2				
GC-6	TOP					19	-0.8	28	-0.2				
GD-1	BOTTOM					25	-0.6	28	-0.8				
GD-1	TOP					25	-0.6	29	-0.4				
GO-1	BOTTOM			17	-1.0	25	-0.6	28	-1.1	33.0	0.9		
GO-1	TOP			16	-1.3	25	-0.7	28	-0.8	33.0	1.4		
GO-2										33.0	0.7		
GO-2										32.0	0.3		
GO-3	BOTTOM			17	-0.9	25	-0.7	28	-1.1	33.0	0.4		
GO-3	TOP			16	-0.7	25	-0.7	28	-0.5	33.0	0.8		
GO-4	BOTTOM					25	-0.2	28	-0.5				
GO-4	TOP					25	-0.5	28	-0.3				
GO-5	BOTTOM			17	-1.4	25	-0.5	28	-0.6	33.0	0.5		
GO-5	TOP			3	-2.1	22	-0.7	28	-0.6	32.0	0.6		
GO-6	BOTTOM			17	-0.7	24	-0.2	28	-0.7	32.0	0.6		
GO-6	TOP			13	-1.4	24	-0.7	28	-0.5	32.0	0.7		
GO-7	BOTTOM					21	-0.8	27	0.5	32.0	0.8		

SAMPLE	DEPTH	10/10/2001		12/19/2001		1/28/2002		3/4/2002		8/14/2002		9/4/2002	
		salinity	Oxygen	salinity	Oxygen	salinity	Oxygen	salinity	Oxygen	salinity	Oxygen	-	Oxygen
GO-7	TOP					25	-0.1	27	-0.4	32.0	0.6		
GS-1	BOTTOM	25	-0.3	1	-3.2	21	-1.1	26	-0.4	28.0	0.0		
GS-1	TOP	23	-1.7	1	-2.2	22	-1.1	18	-1.1	23.0	-0.1		
GS-2	BOTTOM					21	-1.0	22	-0.6	28.0	0.4		
GS-2	TOP					20	-1.0	18	-1.6	24.0	-0.1		
GS-3	BOTTOM			1	-2.2			21	-0.8	28.0	0.3	26.0	-0.4
GS-3	TOP			1	-2.3			21	-1.0	28.0		26.0	0.3
GS-4	BOTTOM			1	-2.4	20	-1.1	21	-1.0		-0.6	26.0	-0.4
GS-4	TOP			1	-2.3	20	-1.2	20	-1.0	27.0	-0.3	25.0	-0.1
GS-5	BOTTOM			1	-2.6	20	-1.1	21	-1.0	30.0	0.7	25.0	-0.5
GS-5	TOP					19	-1.3	21	-1.0	27.0	0.1	25.0	-0.2
GS-6	BOTTOM					20	-1.0						
GS-6	TOP					18	-0.9						
JC-1	TOP			0	-1.7	0	-1.7	2	-0.4	1.0	-1.4	0.0	-1.6
JC-2	TOP			1	-2.1	19	-1.0	21	-0.6	27.0	-0.3	26.0	-0.2
OC-1	TOP			0	-2.1	6	-1.3	14	-0.6	17.0	-0.1		
OC-2	BOTTOM			0	-2.1	18	-0.4	27	-0.3	29.0	0.0		
OC-2	TOP			0	-2.0	16	-1.1	27	-0.4	29.0	0.7		
SB-1	TOP			0	-2.6			6	-2.5	4.0	-2.4		
SB-2	TOP			0	-2.8	5	-2.7					6.0	
SB-3	BOTTOM			1	-1.7	18	-1.1	23	-0.7	28.0	0.2	25.0	0.2
SB-3	TOP			0	-2.5	12	-1.8	23	-1.0	16.0	-0.6	17.0	
SB-4	BOTTOM					20	-1.1	27	-0.5	34.0	0.7	26.0	0.0
SB-4	TOP			0	-2.5	18	-1.2	21	-0.9	34.0	0.6	26.0	0.2
SB-4-Mouth	TOP					18	-1.2	29	-0.5				

Table 2. Discharge of the Brazos and San Bernard Rivers and tidal cycles on the sampling dates.

The data for the Brazos River are from the Rosharon site (08116650) and those for the San Bernard River from the Boiling site (08117500).

	12/19/01	1/28/02	3/4/02	8/14/02	9/4/02	Average [c]
Brazos River ($feet^3$/sec) [a]	31,200	3,060	3,220	1,910	1,380	10,600
San Bernard ($feet^3$/sec) [a]	978	67	32	98	59	760
Tidal Cycle [b]	Low	Low	High	High	High	

[a] Data are from Hyper20 data base (provided from TWDB).
[b] obtained from http://dnr.cbi.tamucc.edu
[c] An average of monthly discharge rates from 1991 to 2000 (USGS, 1992-2001)

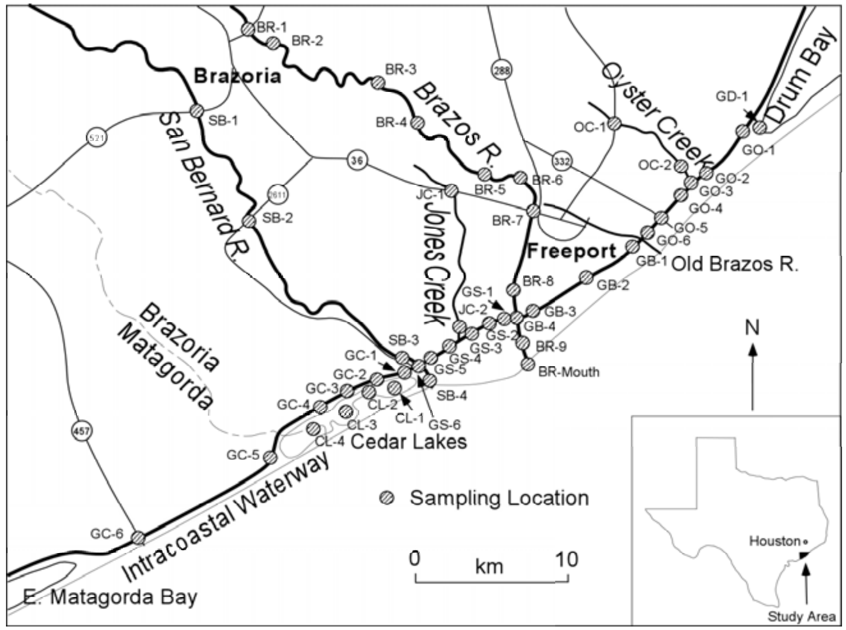

Figure 1. Study area and sampling locations

21

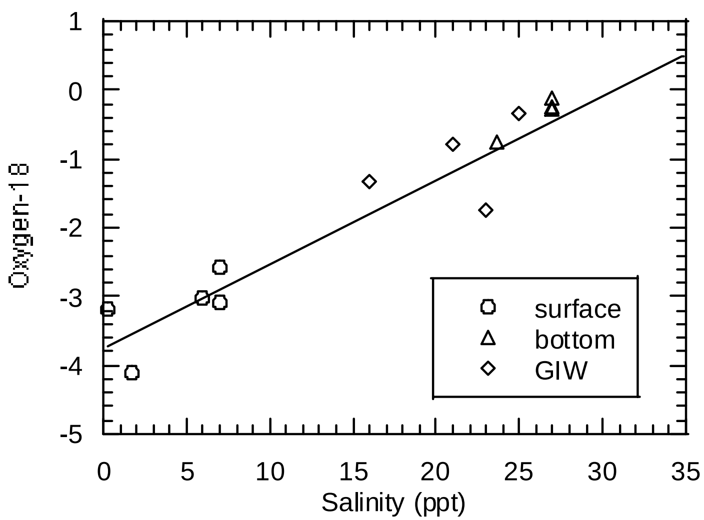

Figure 2. . 180 versus salinity plot for the samples collected on Oct. 10, 2001. The regression line was drawn for all the samples plotted.

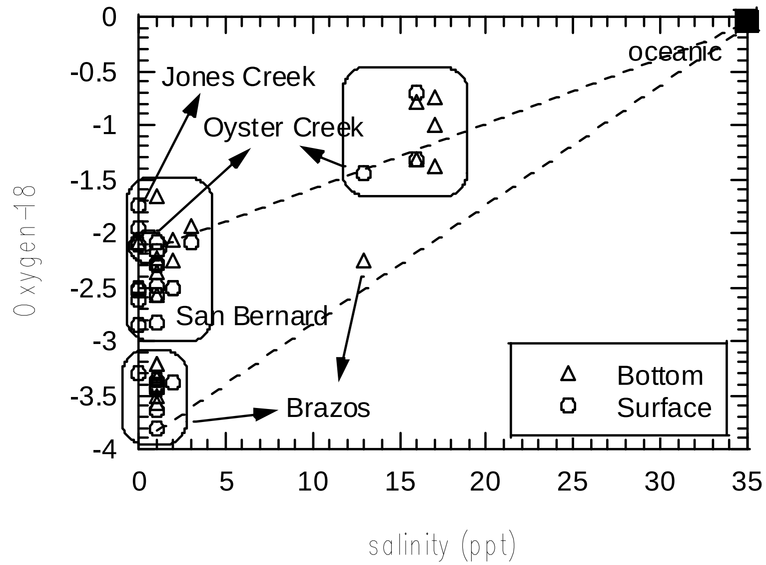

Figure 3. A plot of oxygen isotope ratios versus salinities of the surface and bottom samples collected on Dec. 19, 2001.

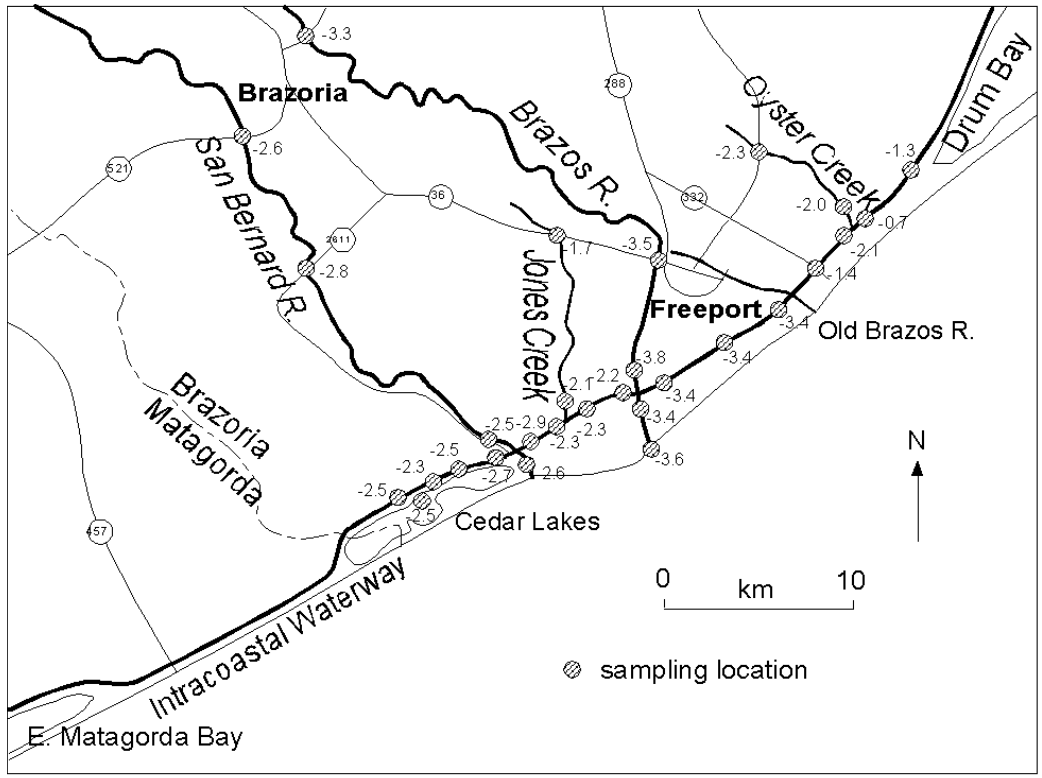

Figure 4. The oxygen isotope ratios of the surface water samples collected on Dec. 19 and 20, 2001. Most samples have salinities less than 3ppt, which allows direct comparison of oxygen isotope values without considering salinities. Exceptions are the samples collected along the GIW between the Old Brazos River and Drum Bay, of which salinities are as high as 17 ppt.

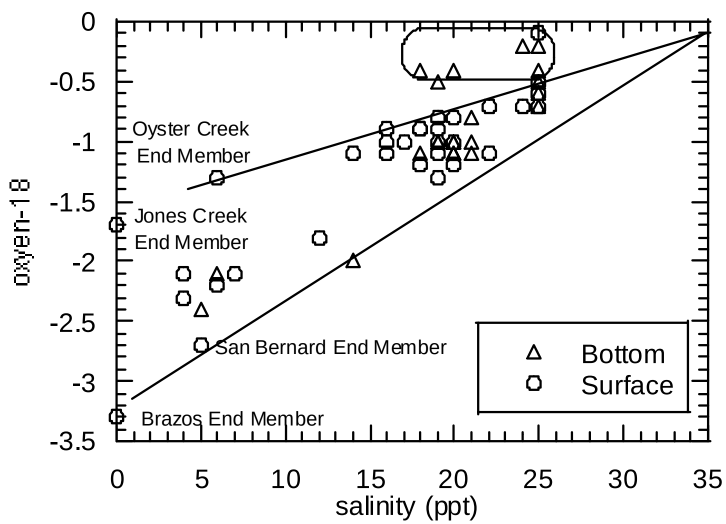

Figure 5. A plot of oxygen isotope ratio versus salinity for the samples collected on Jan. 28, 2002. The circled samples are from GIW between the Old Brazos River and Oyster Creek that possibly Includes the effect of evaporation.

26

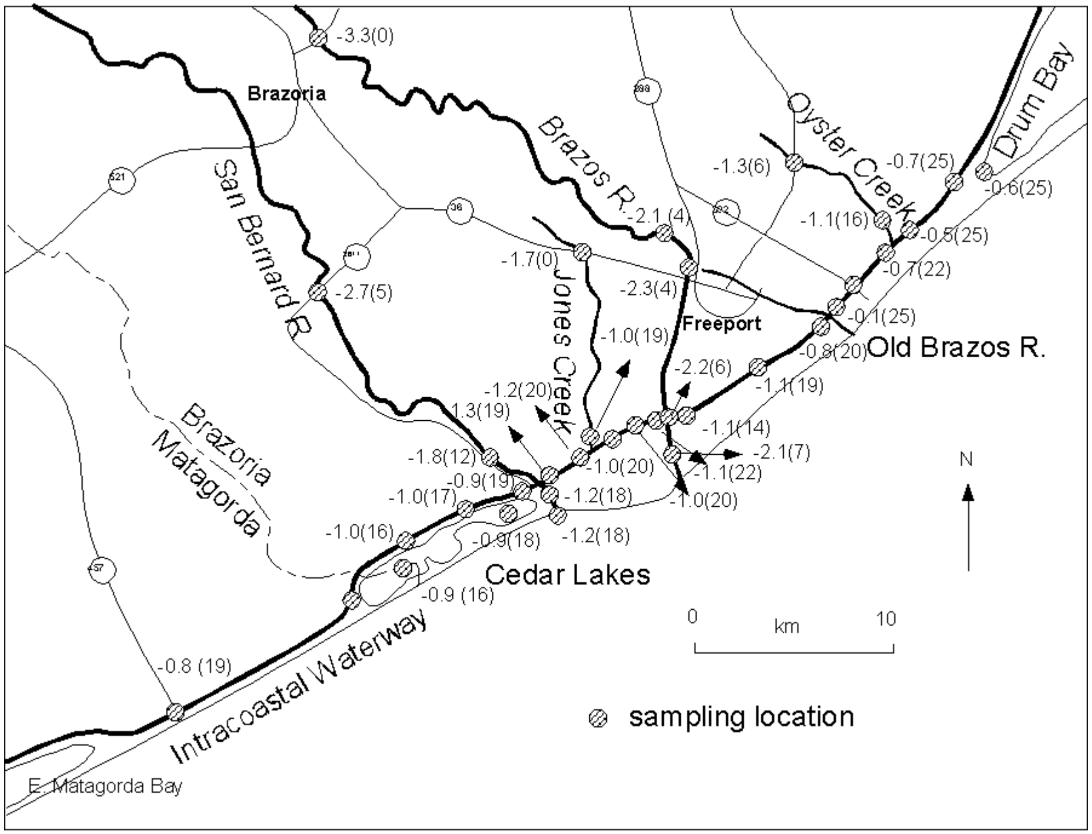

Figure 6. The oxygen isotope ratios and salinities of the surface water samples Collected on Jan. 28, 2002.

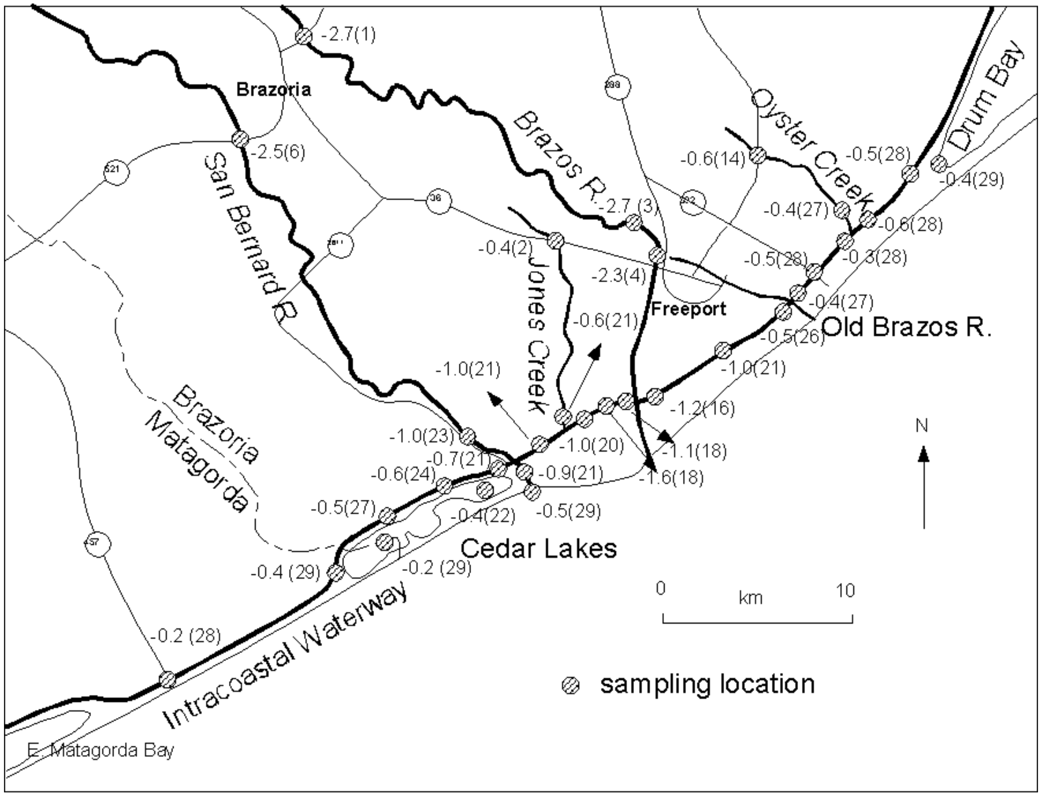

Figure 7. The oxygen isotope ratios and salinities of the surface water samples Collected on March 14, 2002.

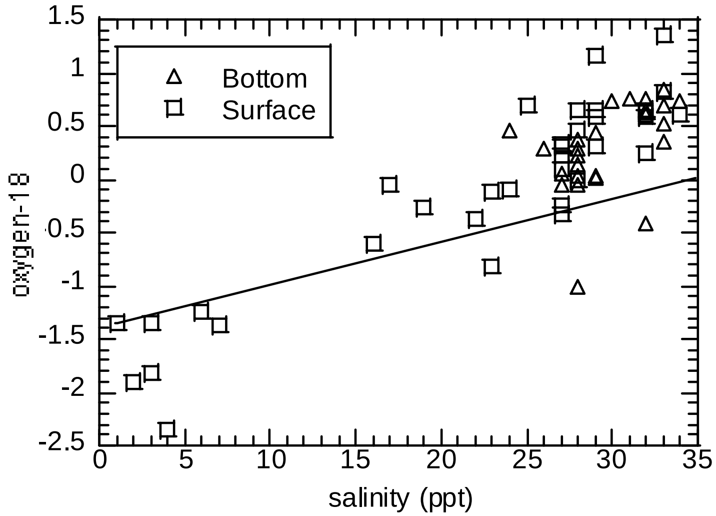

Figure 8. A plot of oxygen isotope ratio versus salinity for the samples collected on Aug. 14, 2002. The solid line represents a mixing trend between the freshwater end member with the highest oxygen isotope value and oceanic water (35 ppt, 0‰).

28

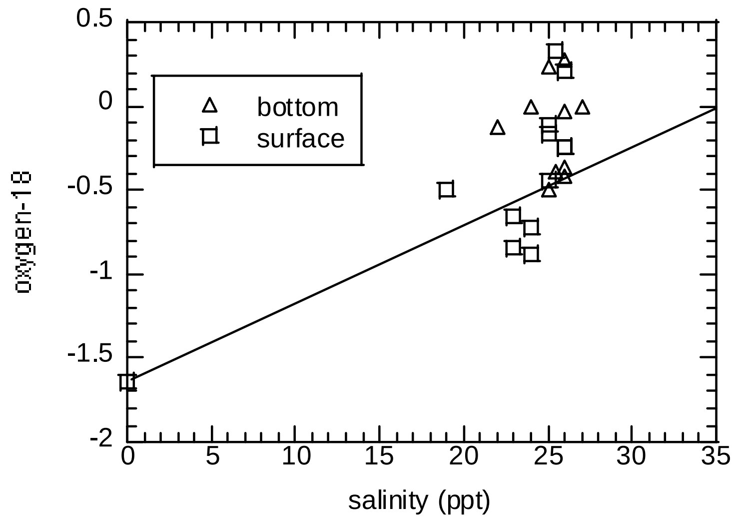

Figure 9. A plot of oxygen isotope ratio versus salinity for the samples collected on Sep. 4, 2002. The solid line represents a mixing trend between the San Bernard end member and oceanic water (35 ppt, 0.).

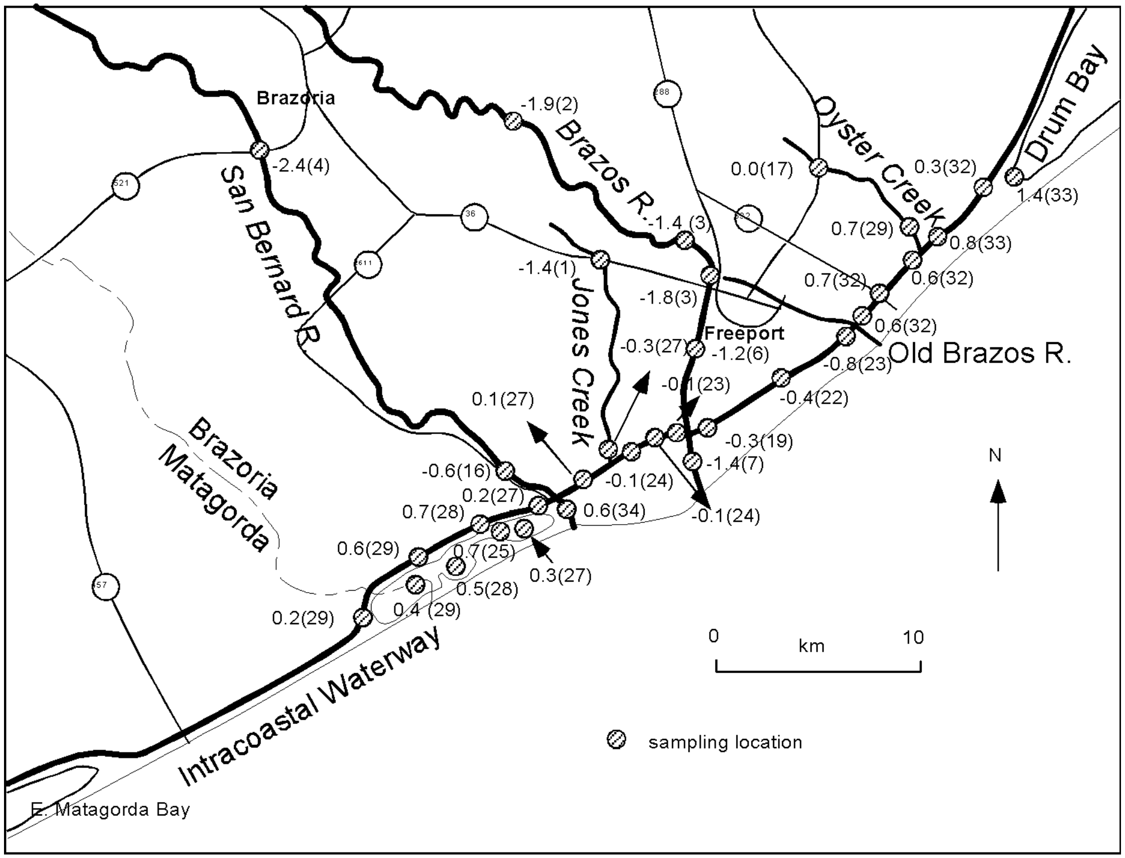

Figure 10. The oxygen isotope ratios and salinities of the surface water samples Collected on August 14, 2002.

31

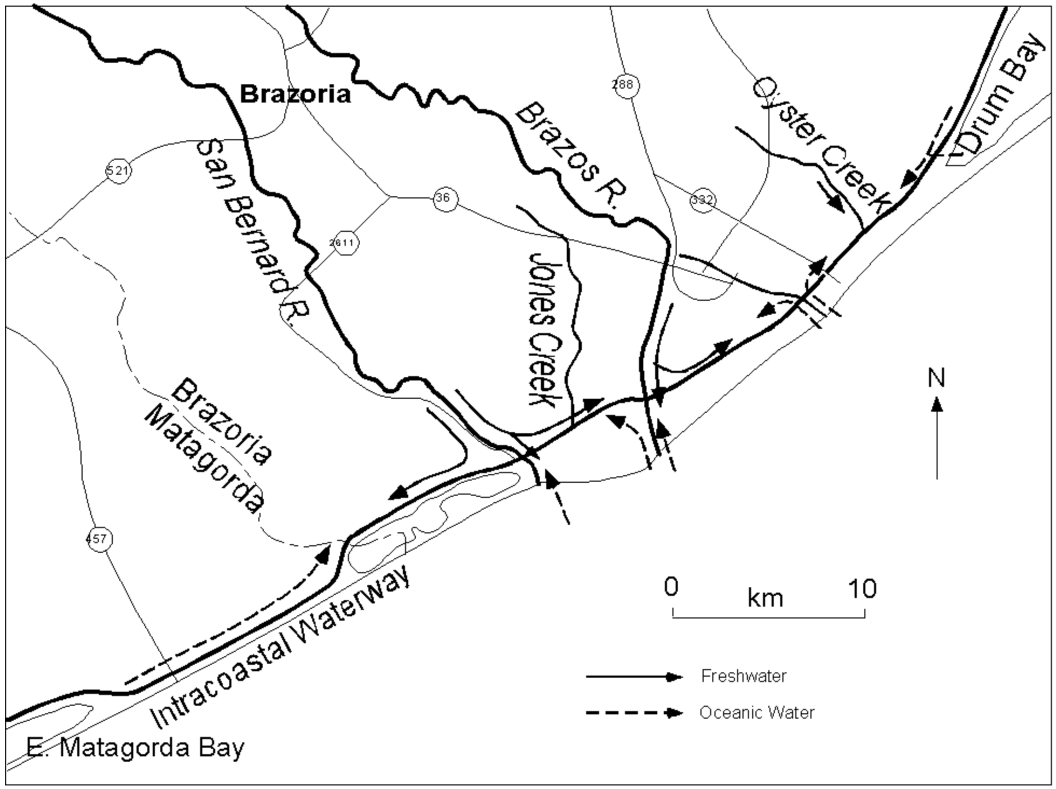

Figure 11. A schematic diagram showing the flow pattern in the GIW of the Freeport Area.

ATTACHMENT 1

TEXAS WATER DEVELOPMENT BOARD COMMENTS ON
"Stable Isotope Studies of the Natural Waters of Intra-Coastal Waterway
and Rivers in Freeport Area, Brazoria County, Texas"
Contract No. 2002-483-418

The report does not seem to incorporate the final two sets of data. Table 1 should show data from the August or September 2002 site visits, or that data should be placed in another table. Likewise, this data is not shown in plots, and is only briefly mentioned in the text.

- Page 1, third sentence from bottom, the phrase "in precipitation" seems too limiting. Perhaps it could be omitted.

- Page 7, regarding different salinities on both sides of the Old Brazos River, the statement is made that the salinities "cannot cause a 0.7…." Please clarify what the authors is implying.

- Page 8, in discussion of mixing trend by Oyster Creek, clarify what author means by "samples that plot over the mixing trend". Maybe wording needs to be changed to "plot above the mixing trend line"?

- Page 8, Matagorda is misspelled.

- On page 9, the sentence that begins "A portion of the Brazos River…" is awkward and should be rewritten to read correctly.

- Please create a reference for the Finnigan Mat Delta E mass spec. CO2 equilibration method.

- Table 2:

As mentioned, there is little to no sampling data displayed for the 8/14/02 and 9/4/02 dates. The tidal and discharge data seem rather meaningless for these dates since there's nothing else to go with them. The report should use 3 dates, or 4 if data from the post river and tide data from 10/10/01 can be used. The discharge data on Hyper20 is availabe from TWDB as is the tide information from TCOON.

Some values for discharge data in the table were different than the same information stored on TWDB's "database". For example, on 12/19/01, the Brazos discharge was around 31,000 cfs, not 60,000, and the S. Bernard was around 940 cfs, not 700. At least those were the mean flows for that day. The Brazos rose to almost 50,000 cfs two days later. Please check the USGS website to make sure the USGS didn't revise them. A lot of the discharge data was a little off as well, but not significantly.

- The one conclusion that a portion of the S. Bernard exits through the mouth of the Brazos should be qualified. Conflicting data during high tide are shown on Fig. 8 and Table 2 vals for GS-1 and GS-2 for 3/4/02. Since values in the Brazos near the mouth are not indicated, the Brazos might flow west into the Gulf Intra-coastal Waterway (GIW) then.

- Missing end of caption in Fig. 6.

- Show Old Brazos River and Cedar Lake on at least one map.

Plot symbols should be consistent. Using circles (instead of x's) for surface measurements in Fig. 6 would be clearer.