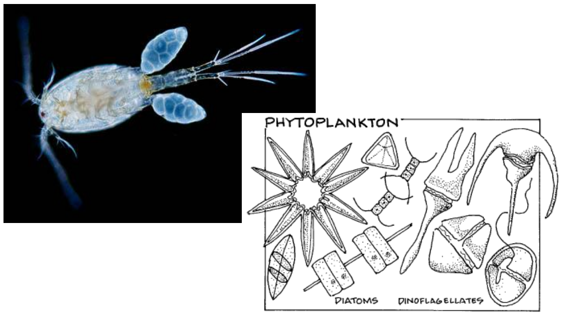
# "Effects of Freshwater Inflows on Estuarine Structure and Function"

**CE 394K.3 GIS in Water Resources**

**Fall 2010**

**Aubrey Lashaway**



## Contents

## Introduction

Estuaries are defined by the presence and magnitude of freshwater inputs they receive. (Turek *et al.*, 1987). The rivers and streams that drain the terrestrial environment transport not only water but also sediments, organic detritus, dissolved organic and inorganic materials, and pollutants to the coastal ocean (Chen *et al.*, 2009). Because they constitute the interface between the land and the ocean, estuaries are affected by changes in the biological, chemical and physical conditions of both the rivers and seas. In watersheds, human activities such as agriculture and sewage treatment have greatly influenced the amount and composition of river inflows. Climate change is predicted to further affect the amount and timing of rainfall and storm events (Cavazos, 1998; Philippart, 2007). Abiotic changes associated with climate disruption (e.g. temperature rise, sea level rise, increased risks of floods and droughts) may increase the risk of abrupt changes in many ecosystems, especially estuaries, which could potentially affect both their diversity and function (Norkko *et al.*, 2002). However, the importance of freshwater inflows required to maintain and manage a healthy and functioning estuarine ecosystem remains a matter of considerable debate.

Texas is an ideal location for studying the relationship between freshwater and estuarine health. Texas's climate has always been variable and sometimes extreme (Schnetzler *et al*., 2008). Along the Texas coast, general rainfall patterns result in low base river flows into estuaries, with episodic periods of high flow due to storm events (Orlando *et al*., 1993). These intense episodic rainfall events result in extreme pulses of nutrients that affect plankton growth and composition (Miller *et al*., 2008). In south Texas, where the Mission-Aransas NERR (MANEER) is located, rainfall patterns are projected to become even more variable as a result of changes in climate. Precipitation is projected to decrease in winter and increase in summer, with an accompanying increase in the magnitude of wet and dry events (EPA, 1997). The resulting changes in the timing and magnitude of freshwater inflows have the potential to greatly impact both the structure and function of estuarine ecosystems (Baird, 2009).

Estuaries are among the most biologically productive ecosystems in the world (Turek *et al*., 1987), with generally high primary and secondary production by plankton supporting correspondingly large yields at higher trophic levels (e.g. fisheries; Nixon 1982). Variations in freshwater flow, however, can affect plankton diversity and production in a variety of ways. In Pamlico Sound, North Carolina, elevated river discharge and flushing from Hurricane Fran in 1996 reduced both phytoplankton biomass and primary production for a four month period following the storm (Pinckney, 1998). In contrast, the passage of three sequential hurricanes (Dennis, Floyd and Irene) in the fall of 1999 led to large increases in phytoplankton biomass following the storms (Paerl, 2001). The effects of freshwater timing and magnitude on plankton populations from the Nueces Delta, TX, and Guadalupe Estuary, TX (Figure 1) have been investigated using microcosm studies (Buyukates and Roelke 2005, Miller et al. 2008).

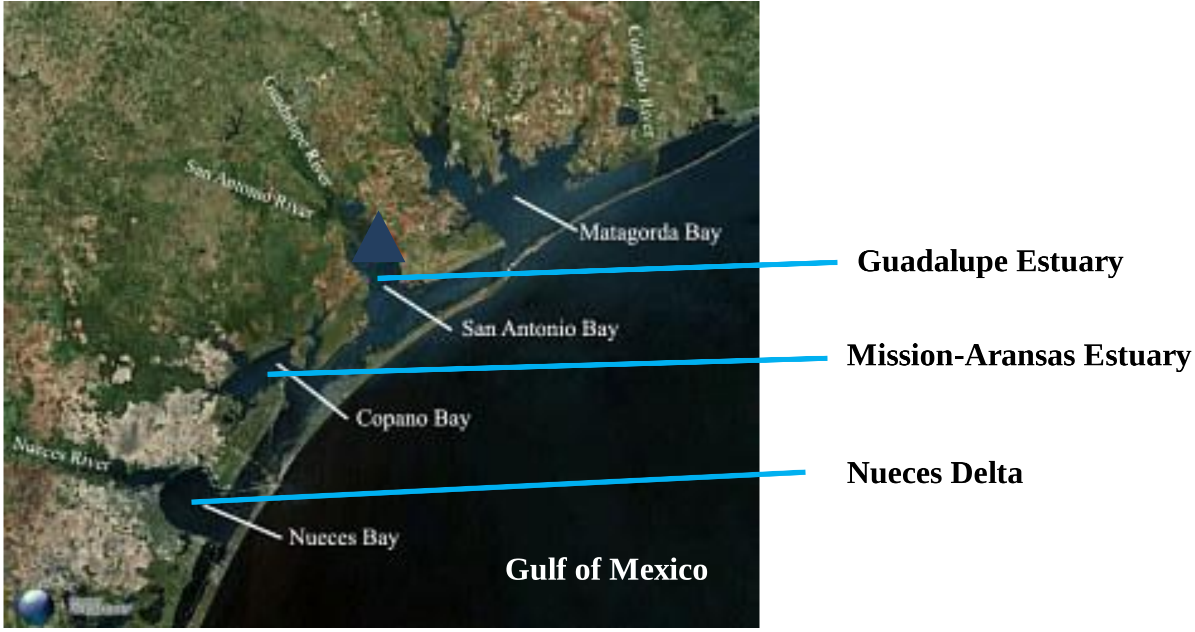


**Figure 1: Locations of microcosm experiments located in the Guadalupe Estuary and the Nueces Delta in relative proximity to the MANEER.**

In both studies, pulsed freshwater inflow increased copepod biomass. However, the responses of phytoplankton were variable, with higher abundance and lower diversity observed in the Guadalupe estuary samples under pulsed flow (Miller et al. 2008), and the inverse in the Nueces

Delta communities (Buyukates and Roelke 2005). Changes in the overall quantity of freshwater did not affect phytoplankton abundance. In contrast, an increase or decrease in the overall quantity of freshwater reduced copepod population density (Miller et al. 2008). These herbivorous zooplankton consume a major portion of phytoplankton and are a key link in energy transfer to higher trophic levels. Thus, variations in primary and secondary production due to changes in freshwater inflows ultimately affect the quality of the spawning, nursery, and forage habitats for many fish and shellfish species involved in commercial and recreational fisheries (Turek *et al.*, 1987; Hays *et al*., 2005; Harley *et al*., 2006**).**

Despite the value of estuaries and the ecosystem services they provide, the health of many estuaries is threatened by human alteration of their hydrology. Water diversion (e.g. dams), use of water for irrigation, and the re-use of wastewater reduces flow into estuaries. At the same time, changes in land use such as increasing agriculture or urbanization can increase nutrient loads into rivers and streams. Population development is an important factor in determining anthropogenic impacts on the natural resources of the MANEER and its surrounding area. Rapid population growth is a large concern among coastal communities because impacts associated with population growth have tremendous impacts on the relatively sensitive estuarine systems adjacent to them (Morehead *et al*., 2007). Although the watershed of the MANEER have relatively low populations (Figure 2), it is predicted that population change will increase because the South Texas coast is one of the few coastal areas in the United States that remains relatively undeveloped. For many systems, significant impacts have all ready occurred, despite our relative lack of knowledge about the flow levels needed to maintain stable and healthy ecosystems.

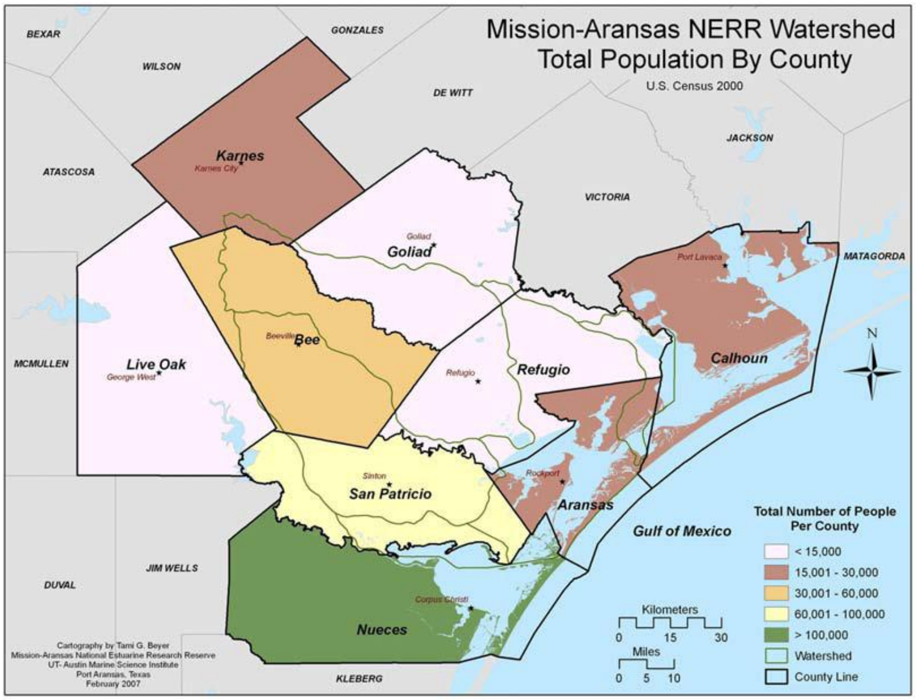


**Figure 2: Mission-Aransas NERR watershed population by county for the year 2000.**

The MANEER, in contrast, is a relatively pristine system, and one of only two estuaries in Texas that are considered at low risk for "problem conditions" related to freshwater demand (Johns, 2004). This makes it an ideal study site for understanding the baseline or 'natural' function of estuaries along the Texas coast. Further, the natural climate variability experienced in Texas may provide a model of the more changeable future conditions expected for other coastal areas. Understanding how a relatively unimpacted estuarine system responds to variations in freshwater inflows will aid resource managers and policymakers in determining the flows and flow regimes necessary to support healthy and productive estuarine systems.

At present, we do not have good information on plankton abundance and production in many of our estuarine systems, much less an assessment of how changes in freshwater inputs affect the function of these communities. As the base of the food chain, plankton growth and production affects the cycling of nutrients and organic matter within ecosystems, and supports production at higher trophic levels. Few studies have focused on the impact of large-scale weather events, such as flash flooding, on the trophic transfer of energy in estuarine communities (e.g. Norkko *et al*., 2002; Salen-Picard *et al*., 2003).

**The overall goal of this project is to examine the effects of changes in the magnitude and timing of freshwater inflows on one part of the plankton community, the phytoplankton.** To achieve this goal, I propose a project that will examine landcover/landuse of the watershed, responses in the phytoplankton biomass, using chlorophyll (as a proxy for biomass) data, to the variation in the timing and magnitude of freshwater inflows, utilizing salinity gradients and precipitation data from 2007 (Figure 3).

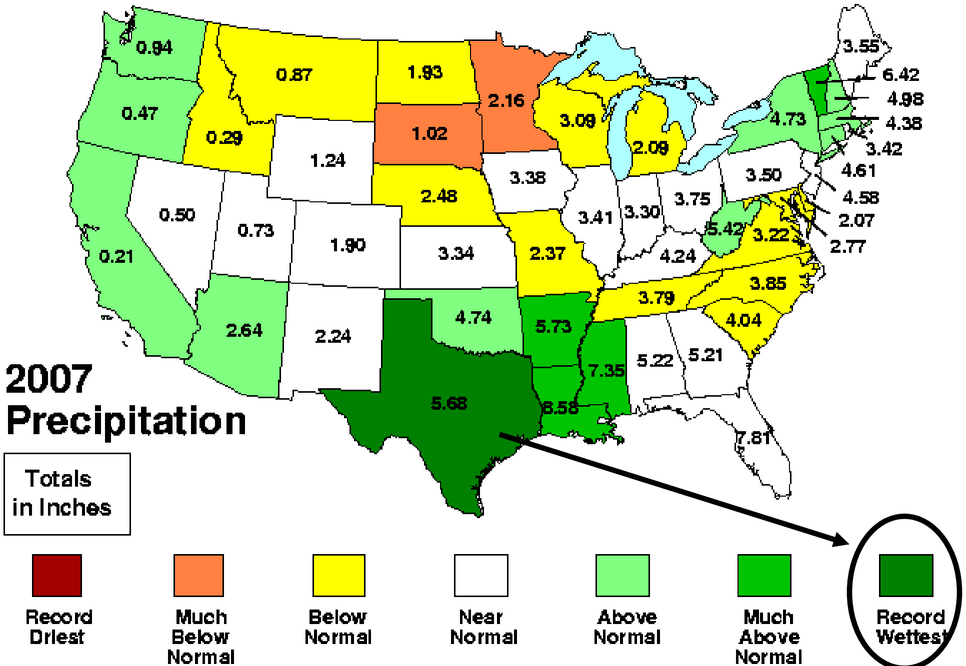


**Figure 3: In 2007, Texas recorded a "record wettest" year, with uncharacteristically high precipitation averages occurring in response to massive rogue rainfall events.**

Data will be used from this unusually high precipitation year to capture high, low, and medium flow impacts on the system. These results will be compared to changes in plankton biomass, diversity, and production through time in the MANEER. Data for this concurrent project is currently under construction.

# Methods

## Study Site and Sample Collection:

The MANEER is a relatively shallow (0.6-3m mean low water) subtropical estuary that is typical of the Western Gulf of Mexico. It is fed by the Mission and Aransas Rivers, and is connected to the Gulf of Mexico by an inlet at Port Aransas (Figure 4). There is generally a large salinity gradient within the system, and the restricted inlet at Port Aransas means that large freshwater inputs tend to be retained within the system for long periods of time.

As part of my graduate research at the University of Texas, I am currently involved with a project that is collecting samples for all analyses at six sites along the salinity gradient in the MANEER: Aransas River, Mission River, Copano West, Copano East, Aransas Bay, Ship Channel (Figure 5), and Mesquite Bay, the latter 5 are part of the Station-Wide Monitoring Program (SWMP). Four SWMP stations, all but Mesquite Bay, have relatively complete chemical and biological datasets (nutrients, salinity, chlorophyll-*a*) that will be used for analyses throughout this project. Salinity is continuously measured on the *insitu* datasondes located at each SWMP station. Monthly grab samples, to measure nutrients and chlorophyll-*a*, are taken at each of the MANERR SWMP stations where datasondes are located. All grab samples are taken on the same day. The chlorophyll-*a* processing includes mixing the sample and then measuring an aliquot for filtration. A fluorometer (Turner Designs TD-700) is used for measuring the chlorophyll-*a*.

Data for this project were collected from a variety of sources. The catchments, watersheds, and flow lines were downloaded and clipped accordingly from the National Hydrography Dataset Plus (NHDPlus). The landcover/landuse data was downloaded from the National Land Cover Dataset (NLCD). Lastly, actual measurements on the rivers and from the MANERR were recovered from the United States Geological Survey (USGS), the National Climate Data Center (NCDC) and from the Centralized Data Management Office (CDMO) for the different parameters examined in this project. The salinity, phosphorus, and chlorophyll-a measurements were downloaded from the CDMO and from the Texas Commission on Environmental Quality (TCEQ).

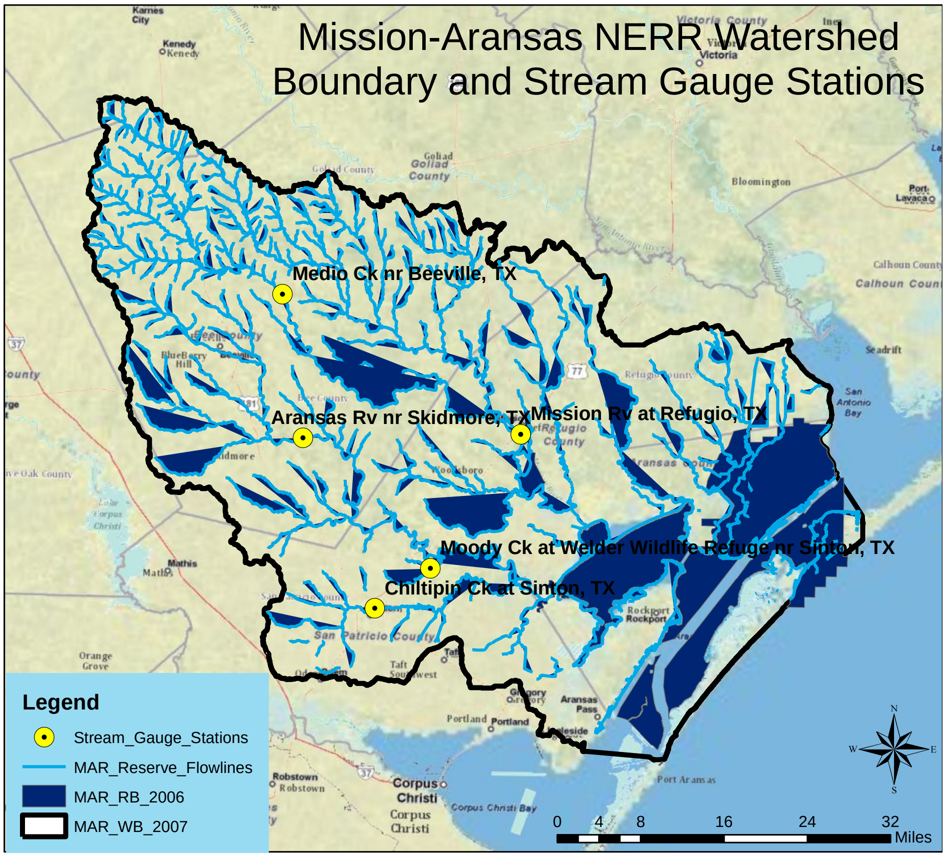


**Figure 4: Map of the MANEER watershed, gauging stations and the river system draining into the MANERR labeled with dark blue.**

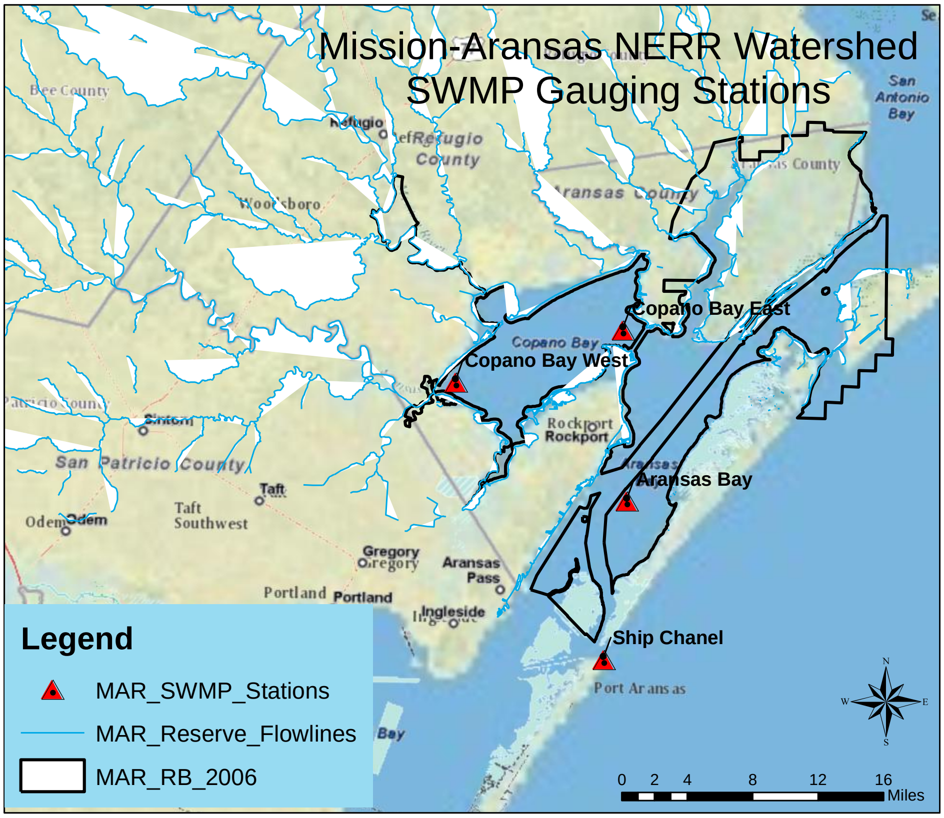


**Figure 5: SWMP gauging stations located at Copano West, Copano East, Aransas Bay, and the Ship Channel.**

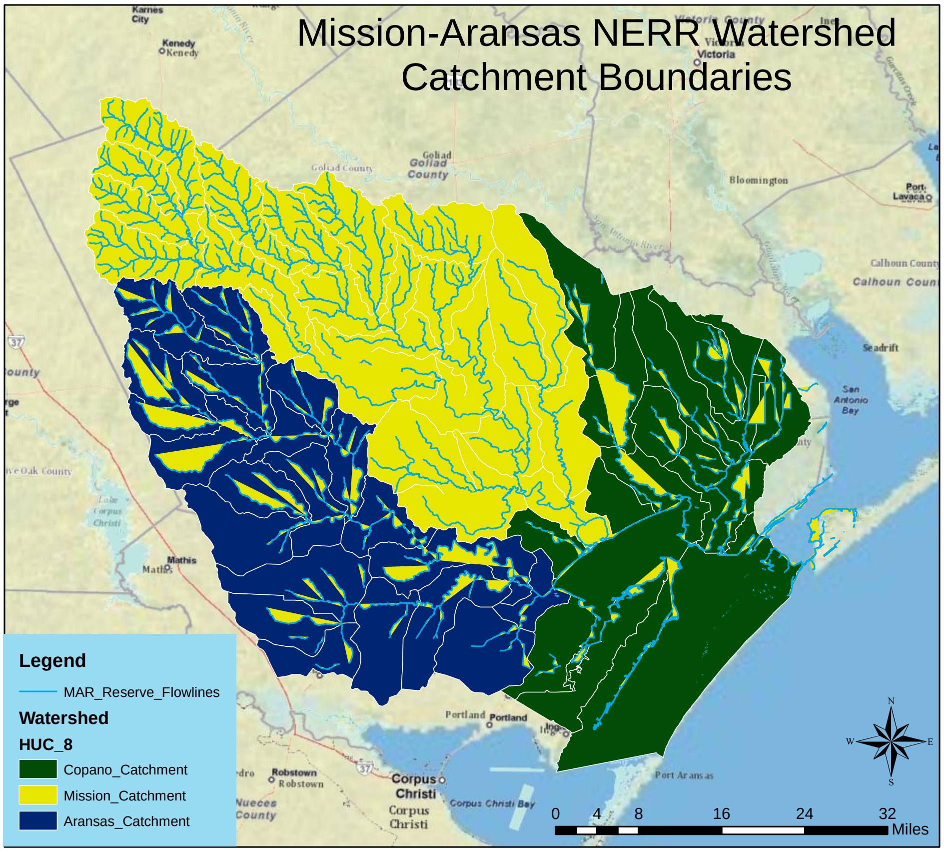


**Figure 6: Mission River (yellow), Aransas River (blue), and Copano Bay (green) watersheds. Watersheds also show catchments (outlined in white). Area of Mission River watershed = 2688.695 km$^2$ with 25 catchments. Area of Aransas River watershed = 2221.663 km$^2$ with 21 catchments. Area of Copano Bay watershed = 2202.243 km$^2$ with 17 catchments.**

There has been little published on the effects of extreme climate variability on this estuarine community. By using elevation data and Arc Hydro tools it is possible to delineate stream networks for the area, stream mouth locations, as well as watershed areas based on our estuarine sampling point locations. Physical watershed attributes such as slope, percent drop, and elevation can also be determined for each of the watersheds draining to our sampling locations. This physical watershed information for each of our sampling points may prove useful when we analyze our biological data between sites located near river mouths before and after significant rainfall events. Chlorophyll-*a* and salinity will be interpolated using SWMP station data from June 2007 through December 2007 to get a sense of gradient change with time.

## Results

### Delineation: Streams Networks, Stream Mouths, Watershed:

Stream networks can be delineated from a Digital Elevation Model (DEM) using the output from the ARCINFO Grid flow-direction and flow-accumulation functions. Flow-direction uses a DEM (Figure 7) to determine the direction of flow from every cell in the raster.

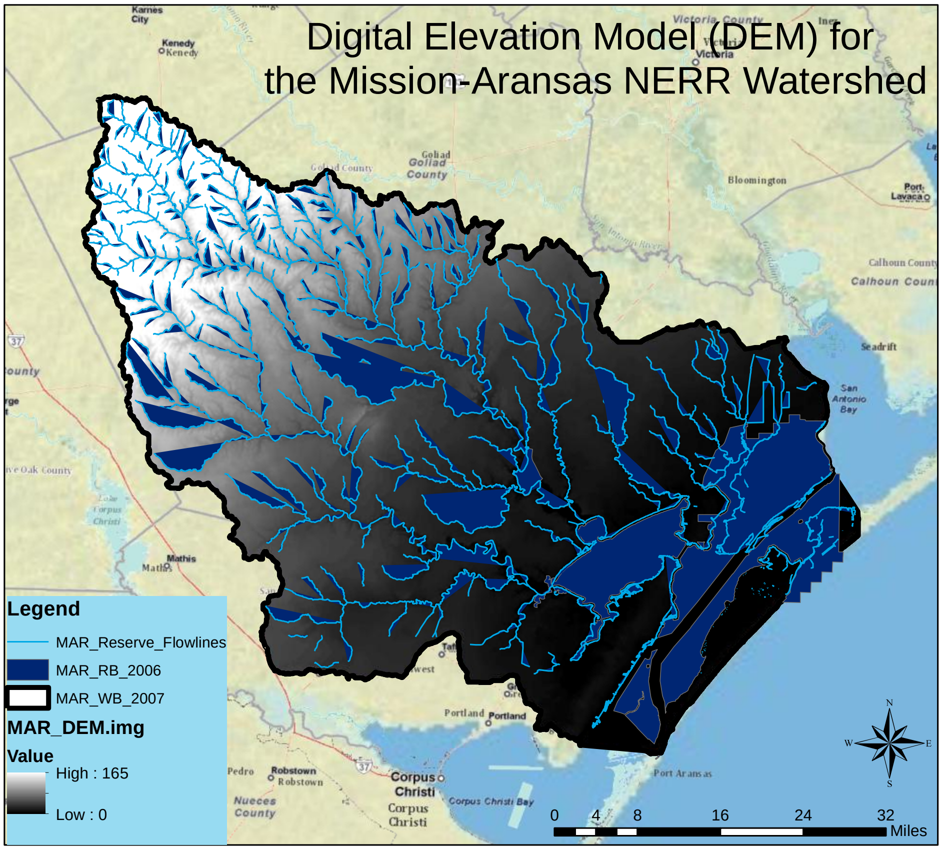


**Figure 7: This map shows the grayshaded image of the digital elevation data and an overlay of the principal streams and watersheds of the basin.**

Flow-accumulation, in its simplest form, is the number of upslope cells that flow into each cell. By applying a threshold value to the results of flow-accumulation, a stream network can be delineated (Figure 8 and Figure 9). This method is arbitrary, because it is based on the GIS user selecting a threshold value (ESRI Help documentation, 2010), but we will use it. Figure 7 shows the steepest downhill descent (the maximum change in elevation over the distance between the cell and its eight neighbors). Every cell in the output raster has a slope value. We can infer from the slope values that the lower the slope value, the flatter the terrain (shown by the black values, or near coastal values); and the higher the slope value, the steeper the terrain (shown by the white values, or upper watershed values). This DEM map will allow us to follow the water flow in the watershed from steeper to flatter terrain. Elevation data have many practical uses ranging from environmental to urban. Compiling elevation data will help this project understand the influences of runoff potential based on the landcover/landuse of the area (Figure 10). Slope and aspect can be directly derived from elevation. Stream delineation and subsequently watershed boundaries can also be derived in order to map out my sampling locations.

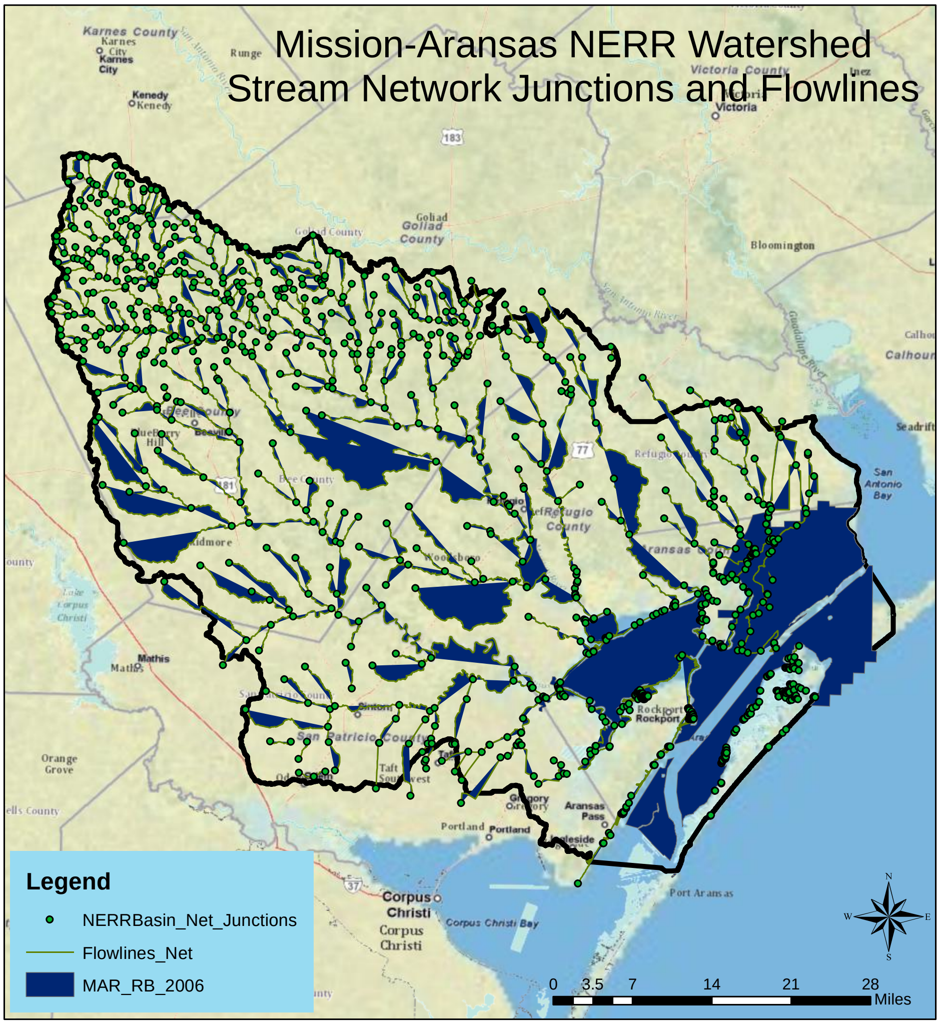


**Figure 8: Stream network junctions and flowlines for the MANERR watershed.**

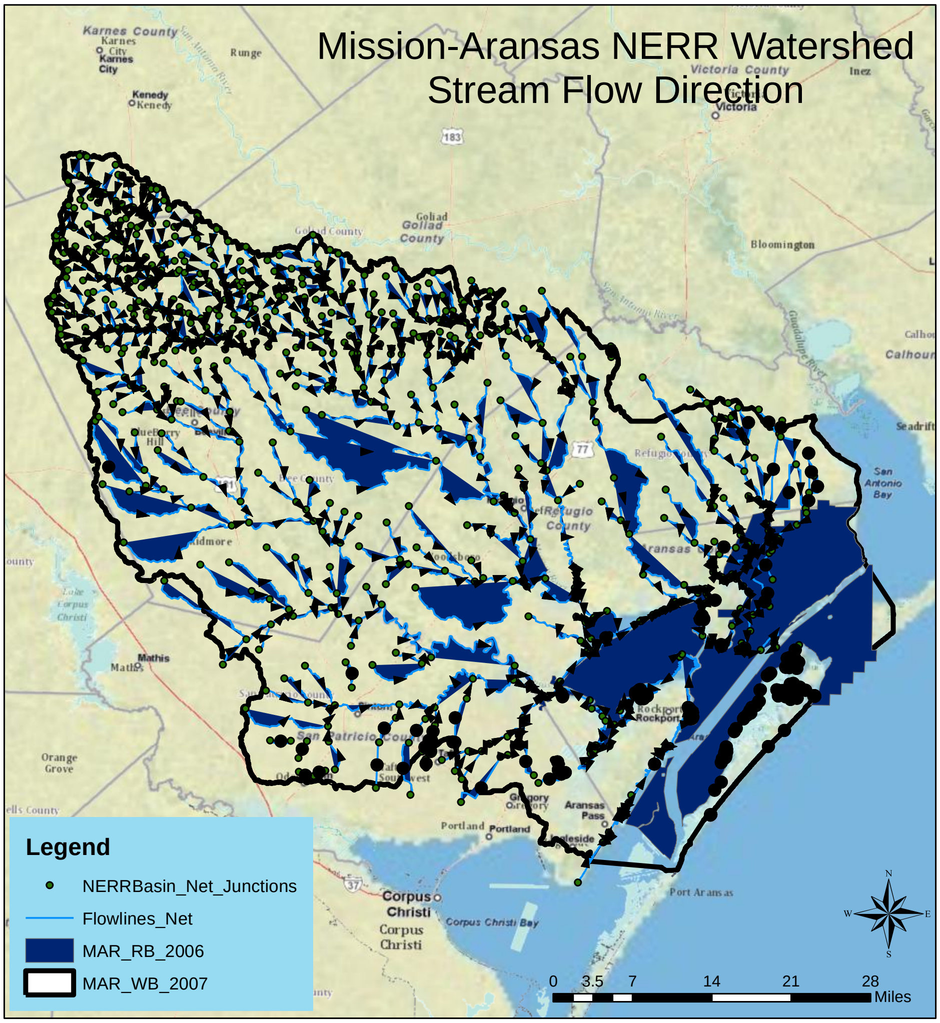
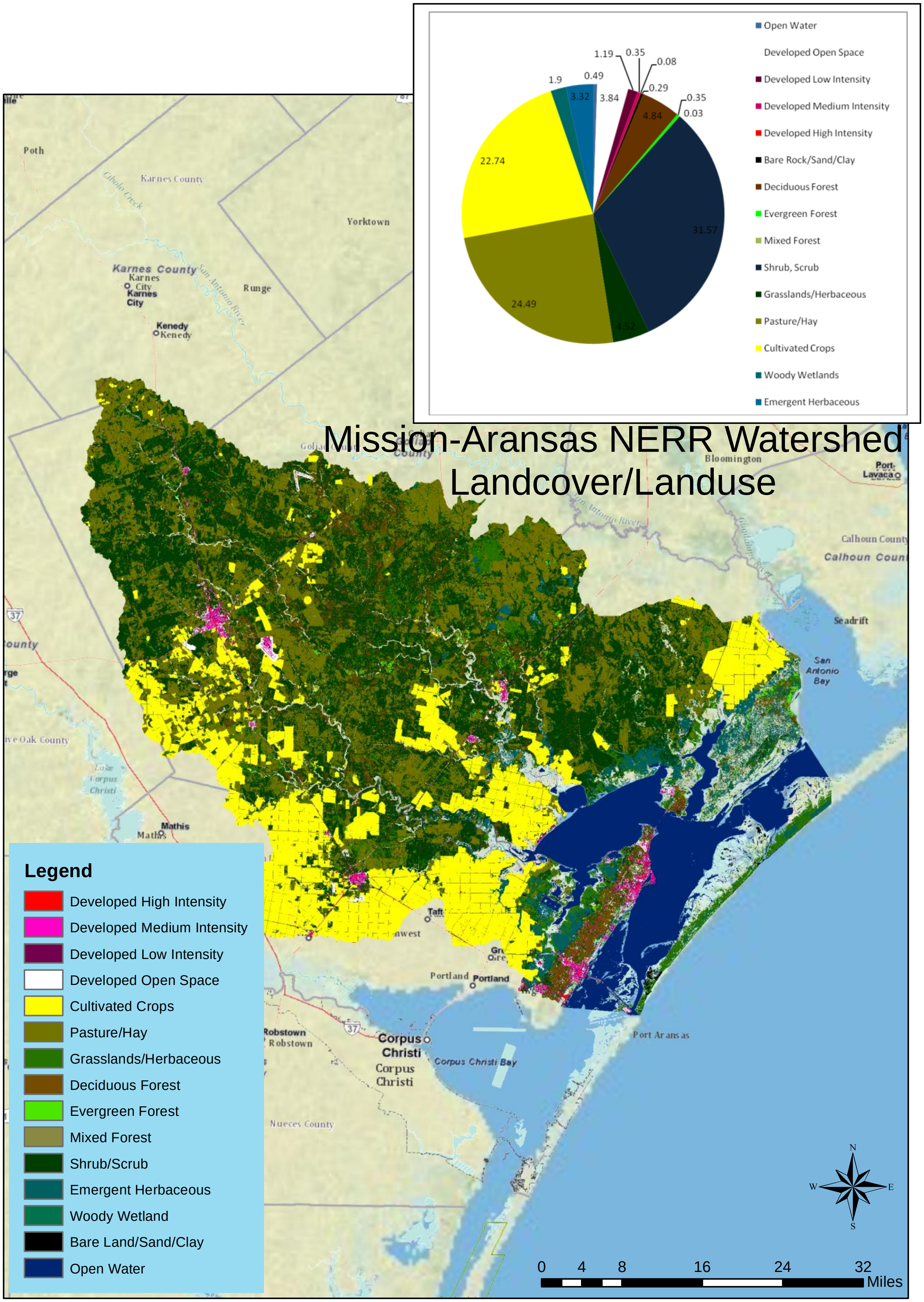


**Figure 9: Stream flow direction, as indicated by the balck arrows, for the MANERR watershed.**

## Landcover/Landuse:

The majority of the landcover/landuse in the MANERR watershed is found in three classes: scrub/shrub, cultivated crops, and pasture hay (Figure 10). Ultimately, this watershed is largely rural, with only 5.5% being developed. Therefore, we would expect most of our nutrient runoff to come from local farming practices, rather than from urban areas throughout the watershed. This data can be very useful when interpreting nutrient accumulations within the estuary.



Mission-Aransas NERR Watershed Landcover/Landuse

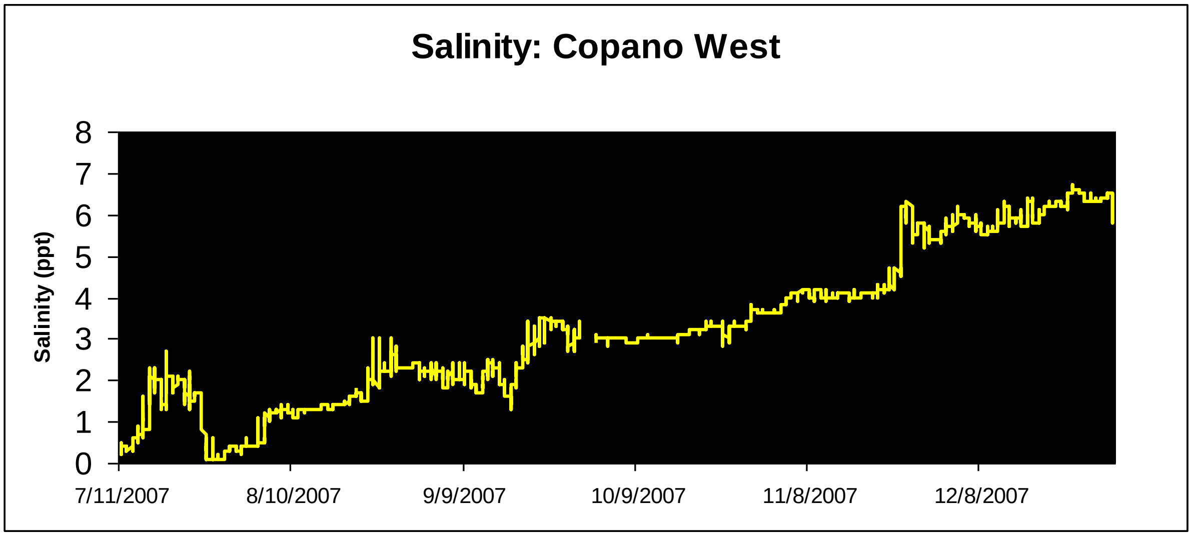
**Figure 10: MANERR Landcover/Landuse for 2006. Shrub/Scrub = 31.57%. Pasture/Hay = 24.49%. Cultivated Crops = 22.74% (2006 NLCD).**

## Interpolation:

Interpolation of salinity and chlorophyll-*a* were completed for two distinct time periods in 2007. The first interpolation shows a massive precipitation event affecting the MANERR in July and the second portrays a recovered MANERR. We are not able to measure the values of the particular phenomenon in all points of the sphere, but only in sample points. The interpolation gives us values in such points where we have no measurements. The goodness of interpolation can be characterized by the discrepancy of the interpolated value from the true value. Because the true value is not known in general, we can select some measured points for testing the interpolation procedure.

### *Salinity*

As expected, salinity was drastically affected by the rain events of July 2007. Figures 11, 12, and 13, portray the effects of this massive rainfall with plummeting salinity values a few days after the precipitation event occurred and increased stream discharge at each gauging station. The salinity interpolation (Figures 14 and 15) further justifies these predictions and results by showing a range of low salinity values after the July precipitation event and increased salinity values in late November, after the MANERR has had time to recover.



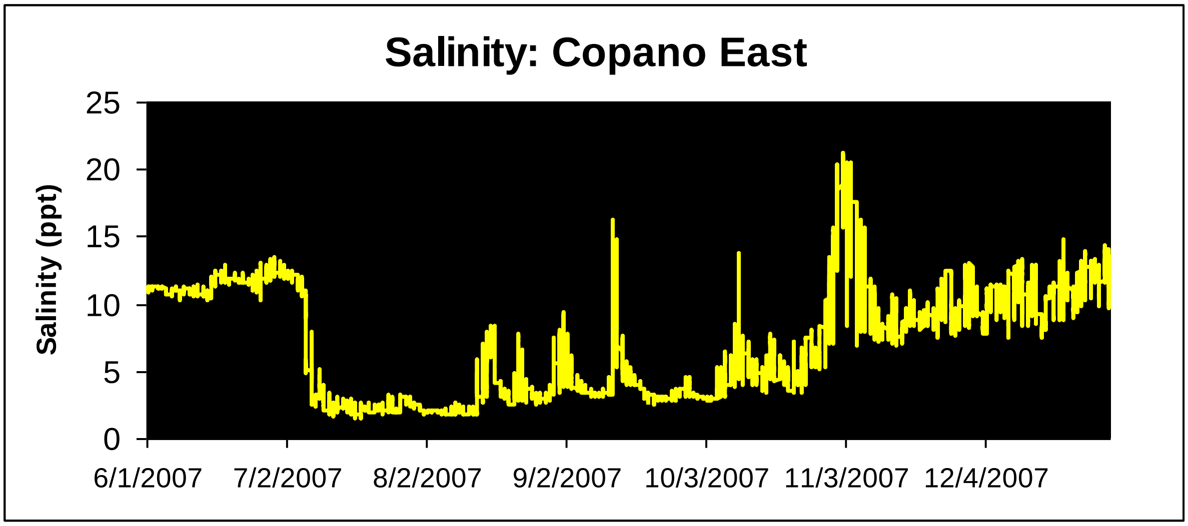


**Figure 11 and Figure 12: A picture of salinity in the MANEER at Copano East and Copano West SWMP stations in the summer of 2007 occurring after a large rainfall in July, salinity was observed to take 5-6 months to recover to pre-storm levels.**

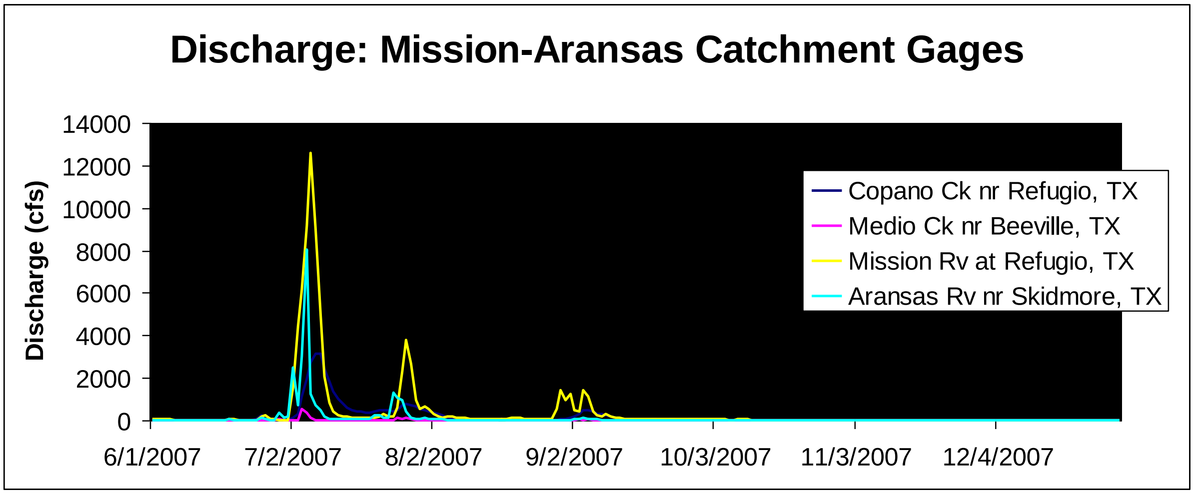
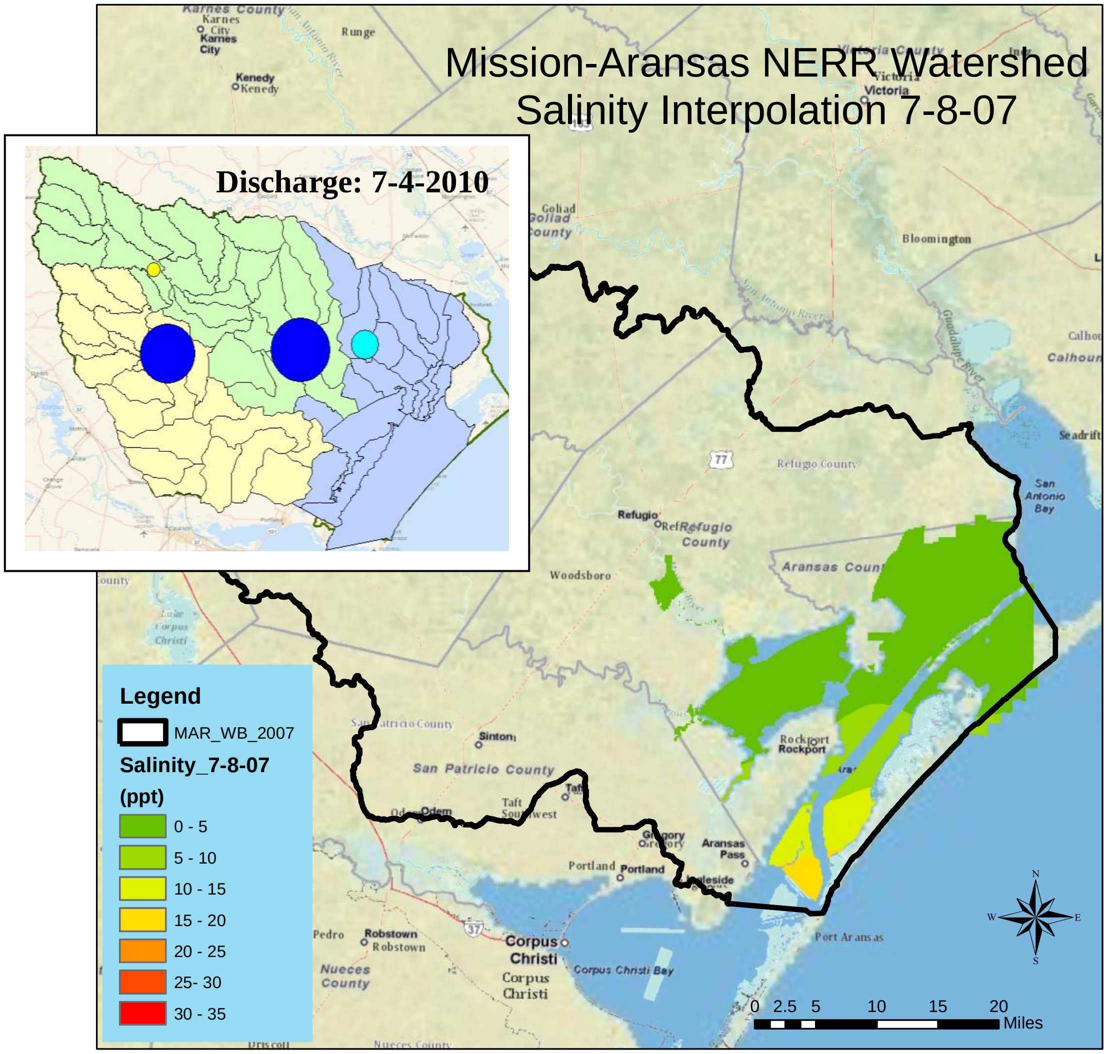


**Figure 13: June-December 2007 discharge for each stream gauging station (USGS) located in the MANERR watershed.**


Mission-Aransas NERR Watershed
Salinity Interpolation 7-8-07
Discharge: 7-4-2010
Legend
MAR_WB_2007
Salinity_7-8-07
(ppt)
0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25- 30
30 - 35
0 2.5 5 10 15 20
Miles
N
S
E
W
Karnes County
Karnes City
Runge
Kenedy
Victoria
Goliad County
Bloomington
Calhoun
Seadrift
San Antonio Bay
Refugio County
Refugio
Woodsboro
Aransas County
Rockport
San Patricio County
Sinton
Taft
Odem
Gregory
Aransas Pass
Portland
Ingleside
Port Aransas
Robstown
Corpus Christi
Corpus Christi Bay
Nueces County
Pedro

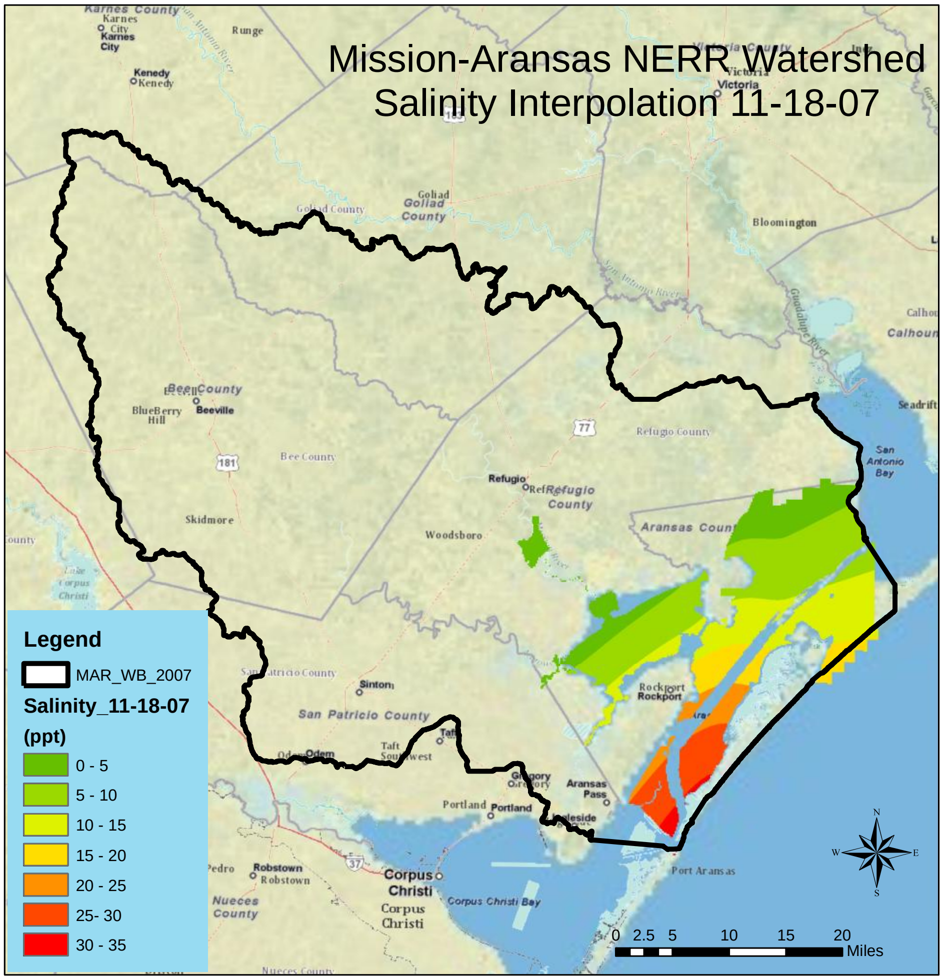
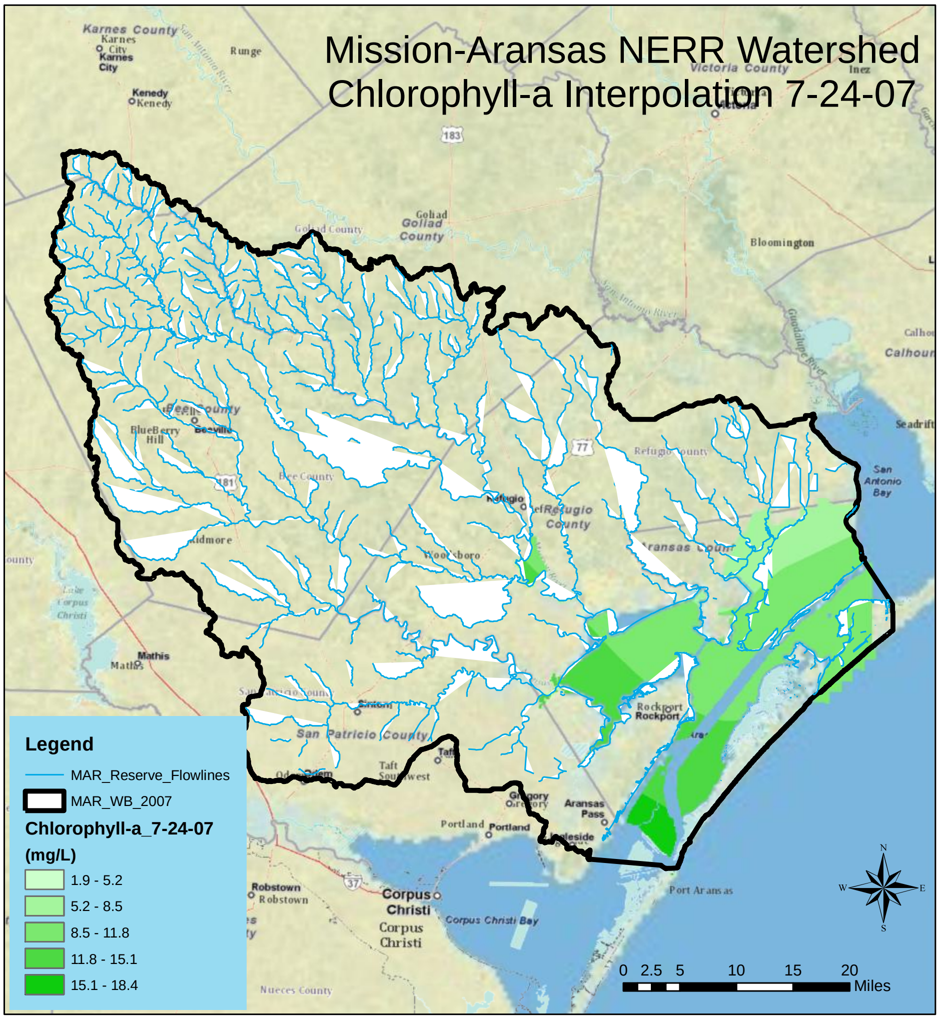


**Figure 14 and Figure 15: Salinity interpolation for the MANERR on July 8, 2007 and November 18, 2007. Green values indicate a lesser salinity value; whereas, red values indicate a higher salinity value.**

### *Chlorophyll-a and Phosphorus*

Strong currents and freshwater flushing events were predicted to likely inhibit chlorophyll-*a* increases, while calmer water will enhance phytoplankton productivity. With a restricted connection to the sea, the MANERR generally allows for large freshwater inputs to be retained within the system for long periods of time. This could provide a sink of nutrients for the system and a lag in the primary production (Figures 18-25). Periods of low flow increase water clarity, reduce excess nutrient loading, and increase the likelihood of nutrient limitation after the peek in production has occurred. Interpolation was completed for chlorophyll-*a* using SWMP station data for the months of July and December (Figure 16 and Figure 17). These maps portray chlorophyll-*a* gradients directly after the precipitation event and five months after the event in December. These maps are somewhat variable. In July, it appears that higher chlorophyll-*a* values are being flushed outward toward the cost; whereas, in December, chlorophyll-*a* values are starting to reestablish themselves near the river mouths, as the freshwater inflow has subsided.


Mission-Aransas NERR Watershed
Chlorophyll-a Interpolation 7-24-07
Legend
MAR_Reserve_Flowlines
MAR_WB_2007
Chlorophyll-a_7-24-07
(mg/L)
1.9 - 5.2
5.2 - 8.5
8.5 - 11.8
11.8 - 15.1
15.1 - 18.4
0
2.5
5
10
15
20
Miles
N
S
E
W
Karnes County
Karnes City
Runge
Kenedy
Victoria County
Inez
Victoria
Goliad
Goliad County
Bloomington
Calhoun
Seadrift
San Antonio Bay
Bee County
Beeville
Blue Berry Hill
Refugio
Refugio County
Aransas County
Woodsboro
Skidmore
Mathis
Lake Corpus Christi
Sinton
San Patricio County
Taft
Rockport
Aransas Pass
Gregory
Portland
Ingleside
Port Aransas
Robstown
Corpus Christi
Corpus Christi Bay
Nueces County
183
77
181
37

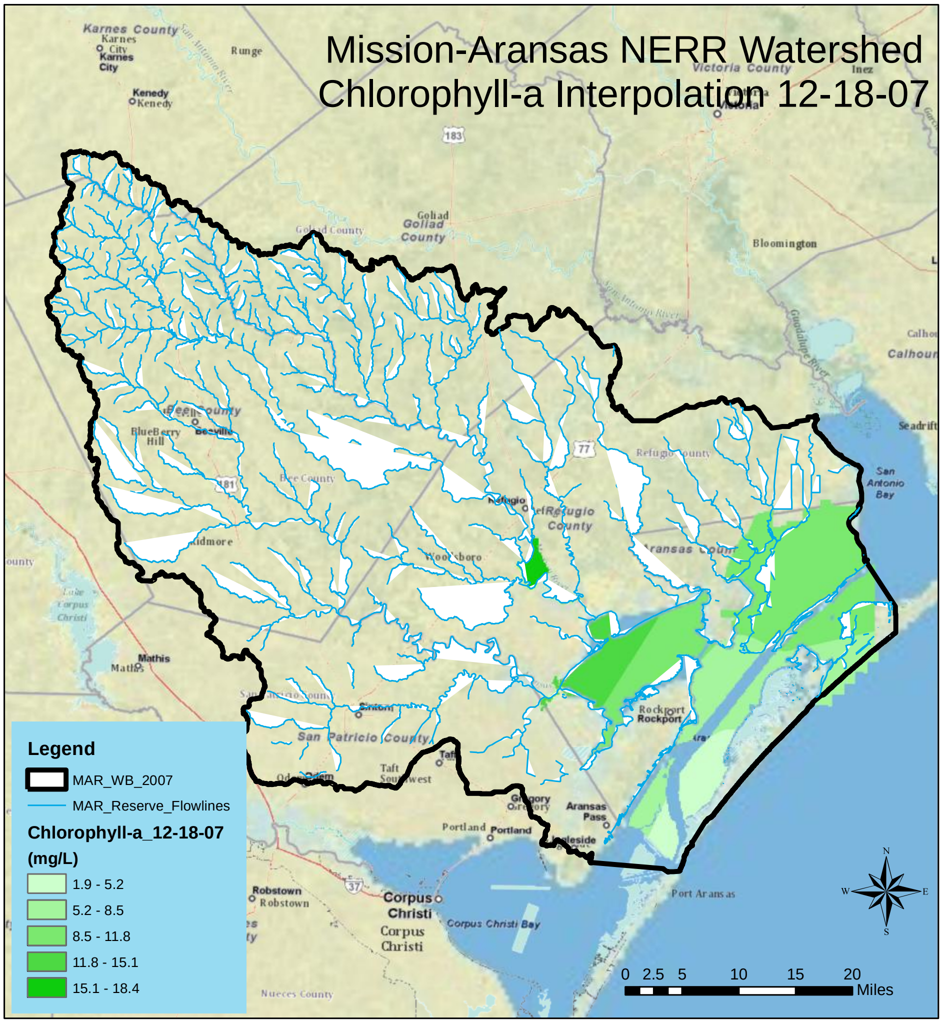
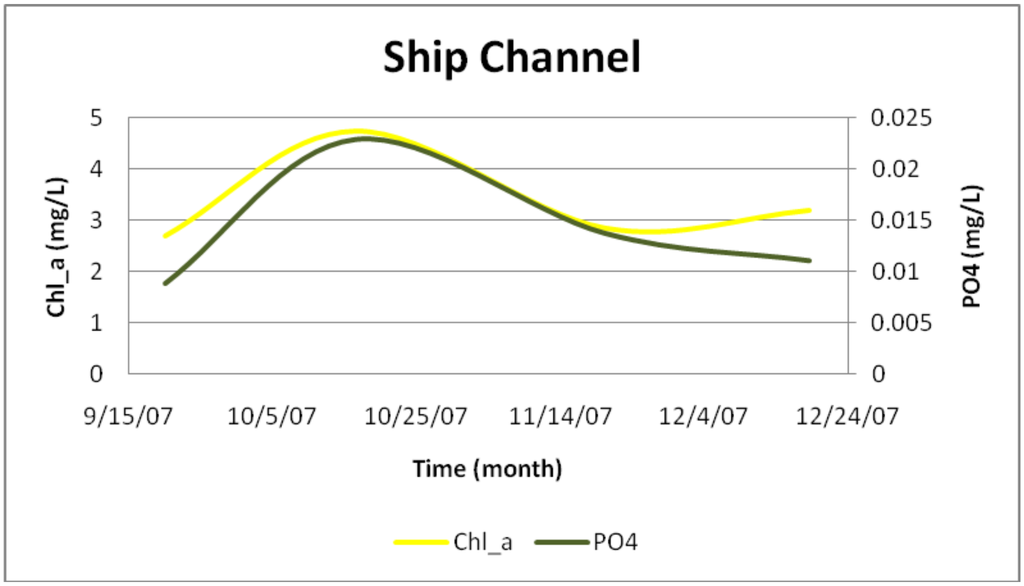
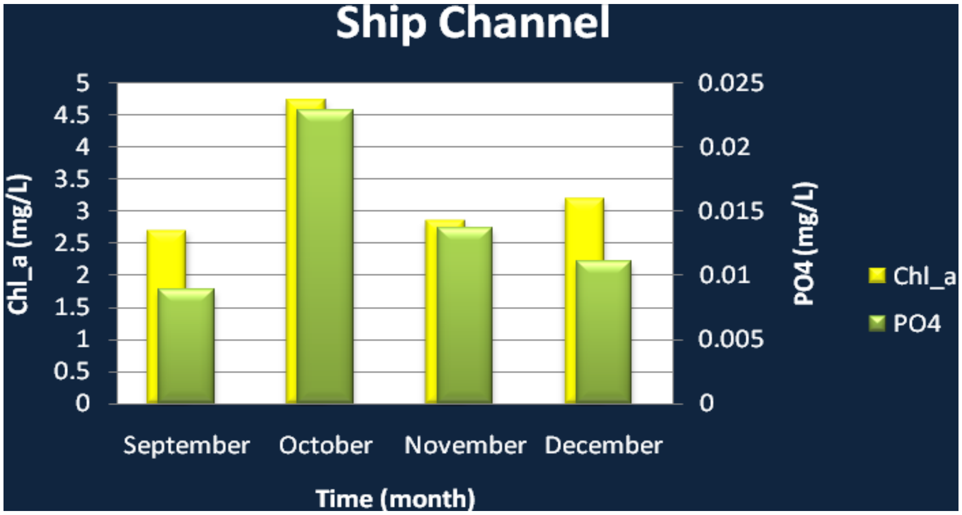
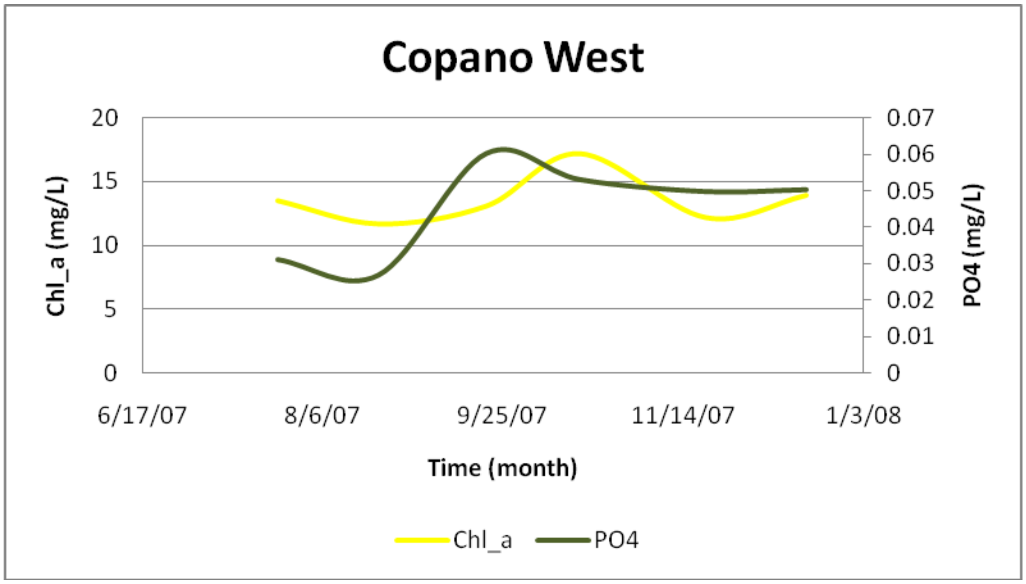


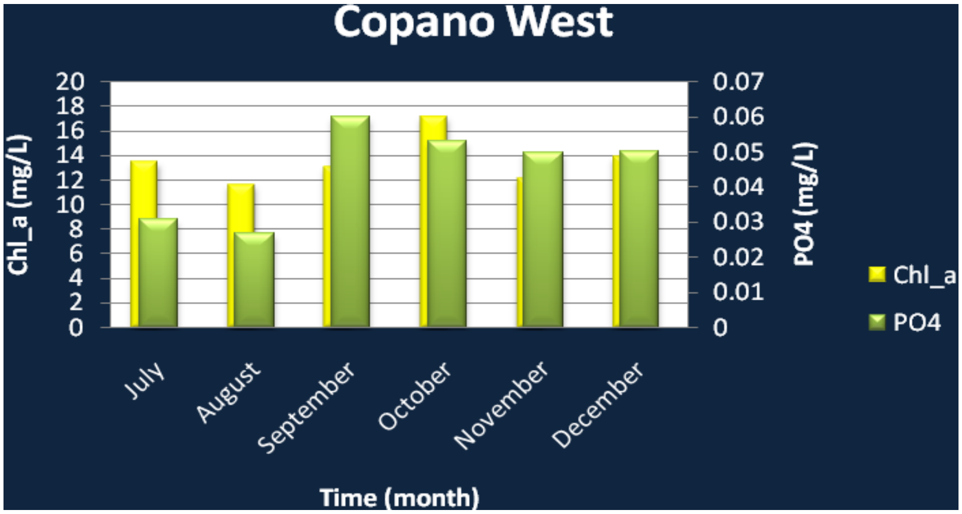
**Figure 16 and Figure 17: Chlorophyll-*a* interpolation for the MANERR on July 24, 2007 and December 18, 2007. Light green values indicate a lesser chlorophyll-*a* value; whereas, the darker green colors indicate higher chlorophyll-*a* value.**

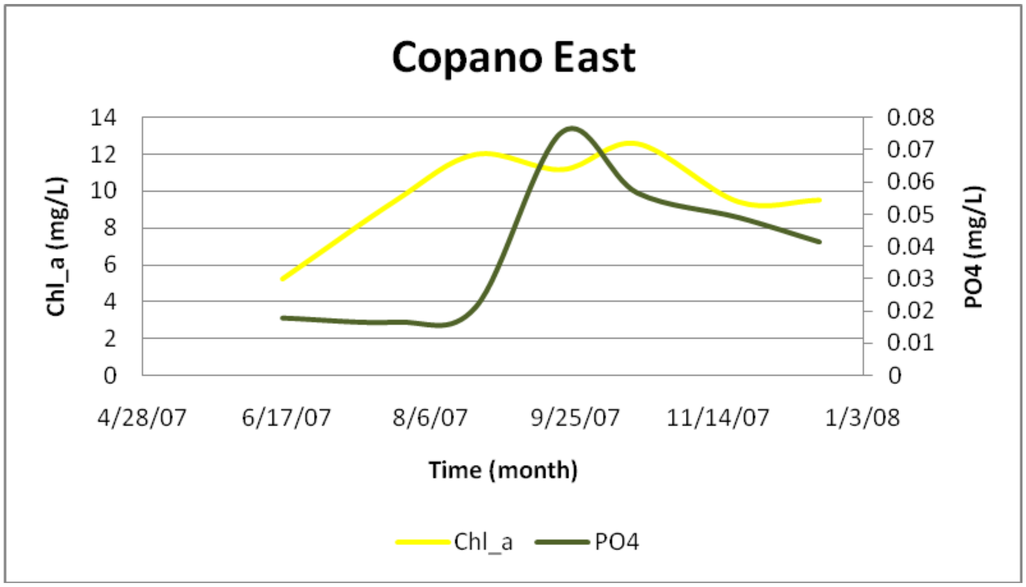
Phosphorus is not considered a water pollutant but a mineral and not very harmful to humans. However, phosphorus can have detrimental effects to the aquatic environment even at low levels. Phosphorus is usually a limiting factor in aquatic ecosystems, especially in limnetic environments; therefore, a large influx would “over fertilize” the water and create algal blooms or eutrophication. These algal blooms create blankets over the water surface, blocking light penetration for the photosynthetic organisms deeper in the water column. However, it is harder to predict the impact phosphorus will have on an estuarine system as the water movements are much more variable. Generally, increases in phosphorus inputs should reveal an increase in chlorophyll.

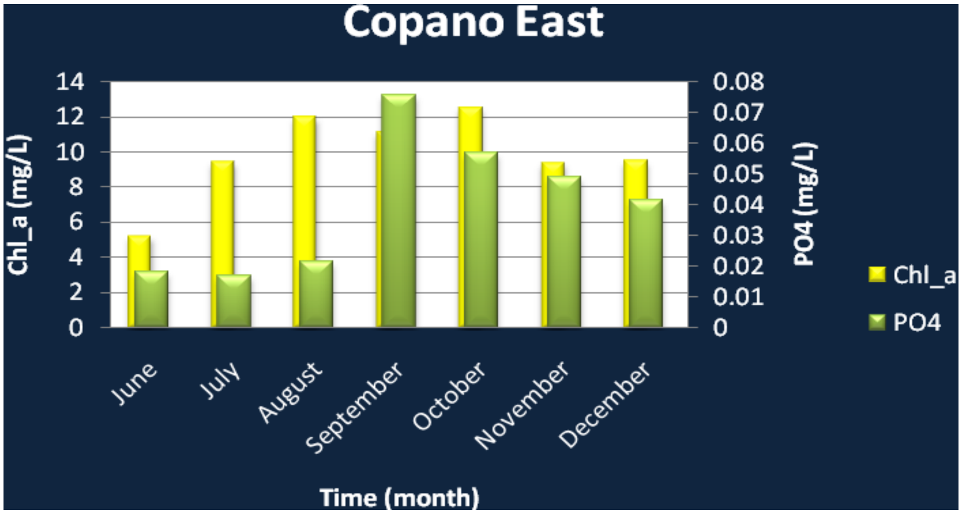

Ship Channel
Chl_a (mg/L)
5
4
3
2
1
0
0.025
0.02
0.015
0.01
0.005
0
PO4 (mg/L)
9/15/07
10/5/07
10/25/07
11/14/07
12/4/07
12/24/07
Time (month)
Chl_a
PO4

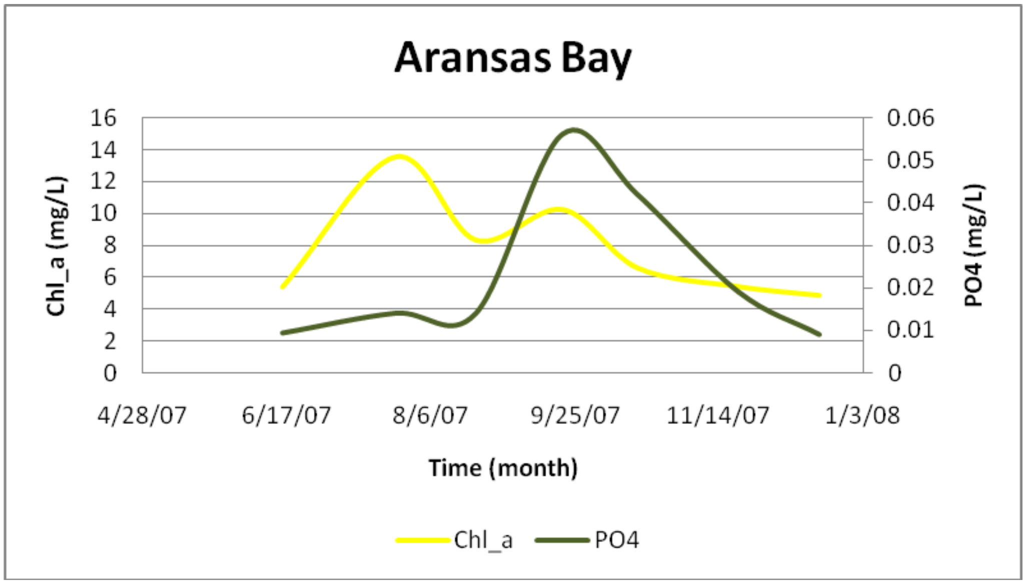

Ship Channel
Chl_a (mg/L)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.025
0.02
0.015
0.01
0.005
0
PO4 (mg/L)
September
October
November
December
Time (month)
Chl_a
PO4

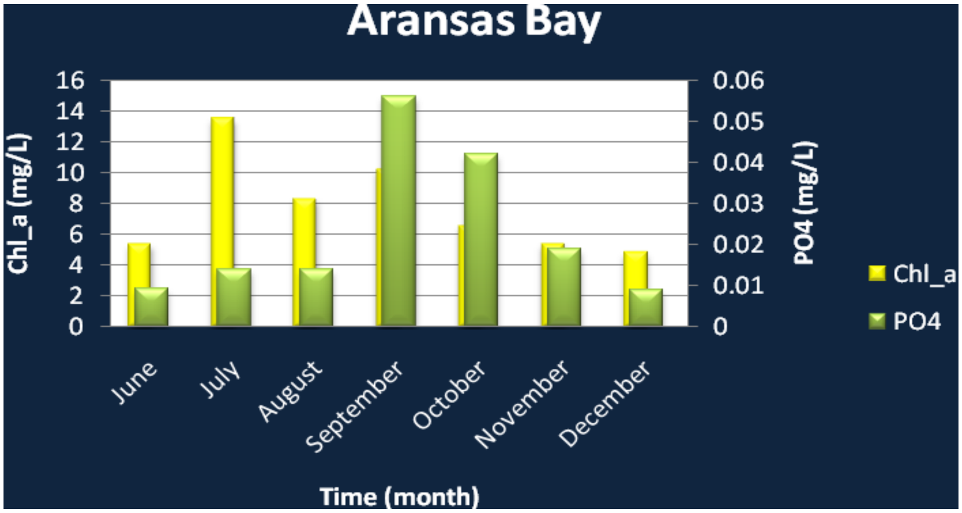

Copano West
20
15
10
5
0
Chl_a (mg/L)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
PO4 (mg/L)
6/17/07
8/6/07
9/25/07
11/14/07
1/3/08
Time (month)
Chl_a
PO4


Copano West
20
18
16
14
12
10
8
6
4
2
0
Chl_a (mg/L)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
PO4 (mg/L)
Chl_a
PO4
July
August
September
October
November
December
Time (month)


Copano East
Chl_a (mg/L)
14
12
10
8
6
4
2
0
PO4 (mg/L)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
4/28/07
6/17/07
8/6/07
9/25/07
11/14/07
1/3/08
Time (month)
Chl_a
PO4


Copano East
Chl_a (mg/L)
14
12
10
8
6
4
2
0
PO4 (mg/L)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
June
July
August
September
October
November
December
Time (month)
Chl_a
PO4





**Figures 18-25: Chlorophyll-a and PO4 measurements for the SWMP stations Aransas Bay, Copano East, Copano West, and the Ship Channel from June-December 2007.**

## Project Significance and Conclusions

An understanding of temporal and spatial variations in abundance and composition is an essential prerequisite for assessing changes caused by climatological perturbations (Underwood, 1992; Dalal, 2001). Watershed discharges and estuarine responses can fluctuate at a variety of time scales (Jordan *et al.*, 1991). For example, over a few days, individual rain events induce short-lived pulses of watershed discharge and correspondingly short-lived effects in the estuary. However, changes in the frequency of rain events may produce effects over months or even years. Despite the importance of plankton as major components of the estuarine trophic system, the magnitude of temporal and spatial variations in abundance is largely unknown in these systems (Dalal, 2001). Alterations in freshwater inflow could affect phytoplankton/zooplankton composition by ultimately altering the water column stratification or patterns of flow occurring in the estuarine system (Tyler, 1986).

Many plankton taxa are known to be indicator species whose presence or absence may represent the relative influence of different water types on ecosystem structure. Long term data are essential when analyzing these forms of natural variation. Unfortunately, very few aquatic studies have gone long enough to accomplish this (Cloern, 1996). Therefore, the populations have the potential to respond to seasonal changes in environmental conditions which are now becoming more pronounced due to increased variability from climate change (Mackas *et al.*, 2001).

Knowledge is essential on this estuarine system to get a better understanding of structure and function of the system. The major motivation for this renewed interest in community composition is the unprecedented global biodiversity loss that is occurring not only in terrestrial habitats but in the aquatic realm as well (Caliman 2010; Chapin *et al.* 2000). By completing this study, the MANERR will be one of the first estuarine systems to have community composition and trophic system dynamics explored based on climatic variability and the role that it plays in regime shifts and ecosystem functioning (McGowan *et al.* 1998). This 2007 historic precipitation study has generated predictions as for what to expect from future events of similar magnitude.

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