CE394K3 Final Report
Salinity Distribution and Variation in Nueces Delta

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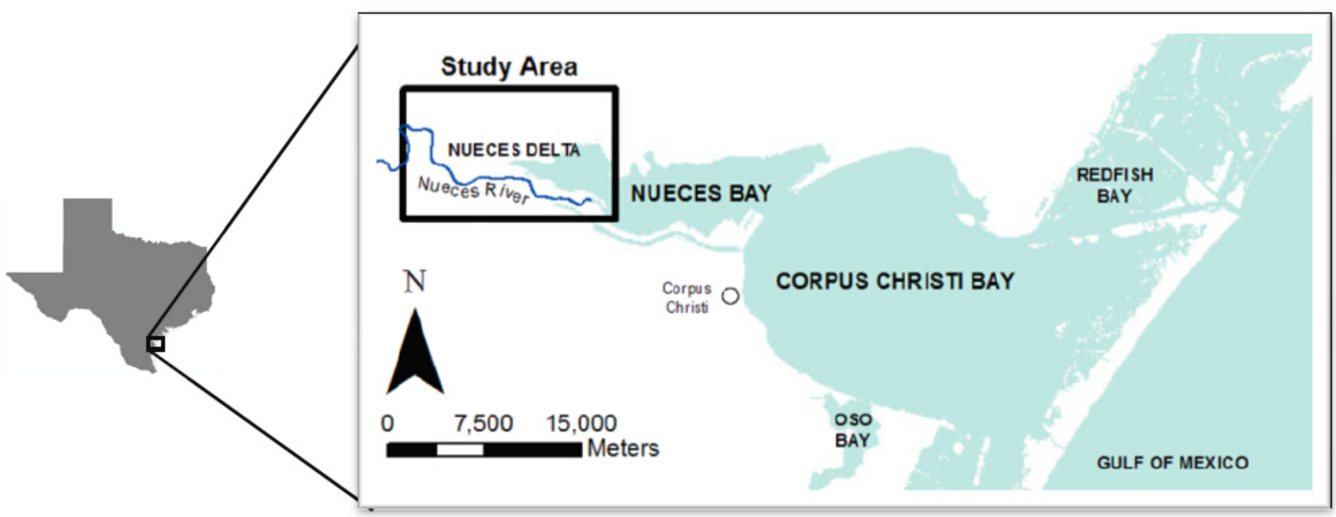
12/01/2014



Contents

1 INTRODUCTION

Nueces Delta is part of the Corpus Christi Bay system. It is an estuary that connects Nueces River to the Nueces Bay. Saline water enters Nueces Delta through Aransas Pass due to tidal effect while fresh water flows into Nueces Delta via the Nueces Overflow Channel built in 2001 (Fig.1). The exchange of saline and fresh water helps maintaining appropriate salinity in the Nueces Bay, which is necessary for local ecosystem to develop.

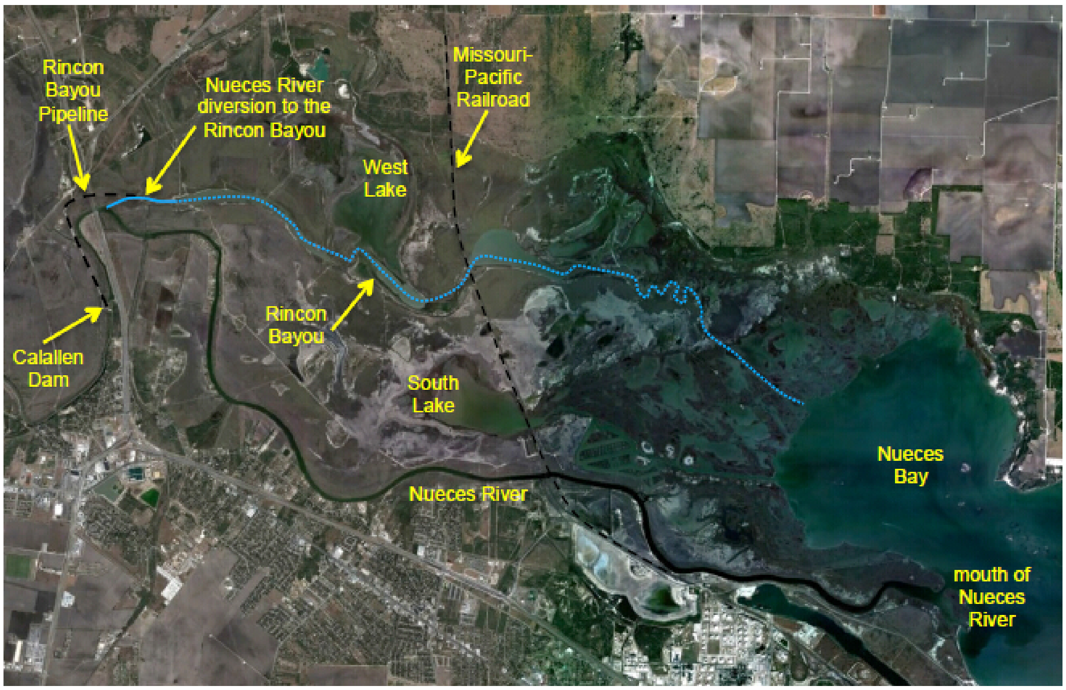


Figure 1: Layout of Nueces Delta (Blue dotted line represents Nueces Overflow Channel) [Hodges et al., 2012]

Over decades, an increasing demand of water use upstream of Nueces River and the dam built upstream has impaired the amount of fresh water injected into the Nueces Delta. Currently, the Nueces Delta is covered with fresh water only when severe flooding or heavy rainfall occur [Lloyd et al., 2013]. As a result, the salinity increased adversely, which was harmful to the estuary ecosystem. The observed amount of several kinds of fishes, shrimps and oysters have diminished [Hodges et al., 2012]. To solve this problem, fresh water has been pumped from upstream into the estuary using three pumps, but the pumps were not kept open due to high cost. The optimum location of the pump and the amount of water needs to be pumped remain unclear, which lowers the efficiency of using the pumps. Moreover, the salinity is governed by multiple factors such as wind, tide, land cover and temperature. Without a deep understanding of how these factors function together, it would be hard to determine the effect of pumping fresh water.

This project studied the spatial distribution and temporal evolution of salinity in the Nueces Delta based on data measured at several sites, aiming at gaining an initial understanding of the relationships between natural factors and salinity. For this project, only pump flow, wind and precipitation are taken into account. More natural forces such as tide, evaporation will be included in the future analysis. This project could be the first step of rebuilding the local ecosystem. Based on the salinity distribution and the causes of the distribution, further actions could be executed purposefully.

2 DATA ACQUISITION

2.1 Salinity Data

The salinity data was measured by Texas Water Development Board (TWDB) at 14 stations in the Nueces Delta. Most of them were recorded from August of 2012 to October of 2013, which was used as the study time period of this project. A map showing the locations of the 14 stations can be found in Fig.2. The salinity was measured on an hourly basis, but studying hourly salinity variations is not meaningful because they do not cause instantaneous influence on the ecosystem. Salinity variation on larger time scale is the focus of this project. Therefore, the weekly and monthly averaged salinity was calculated for each station. The monthly averaged salinities were spatially interpolated to the entire Nueces Delta using Spatial Analysis tool (Kriging) of ArcGIS. A MATLAB plot showing the salinity variation with time at each station was also created based on the weekly averaged salinities. These figures will be discussed in the following sections.

The salinity of Nueces Bay was acquired as the background salinity from Texas Coastal Ocean Observation Network (TCOON). The data at station SALT03 (27.8516N, 97.4820W) was used.

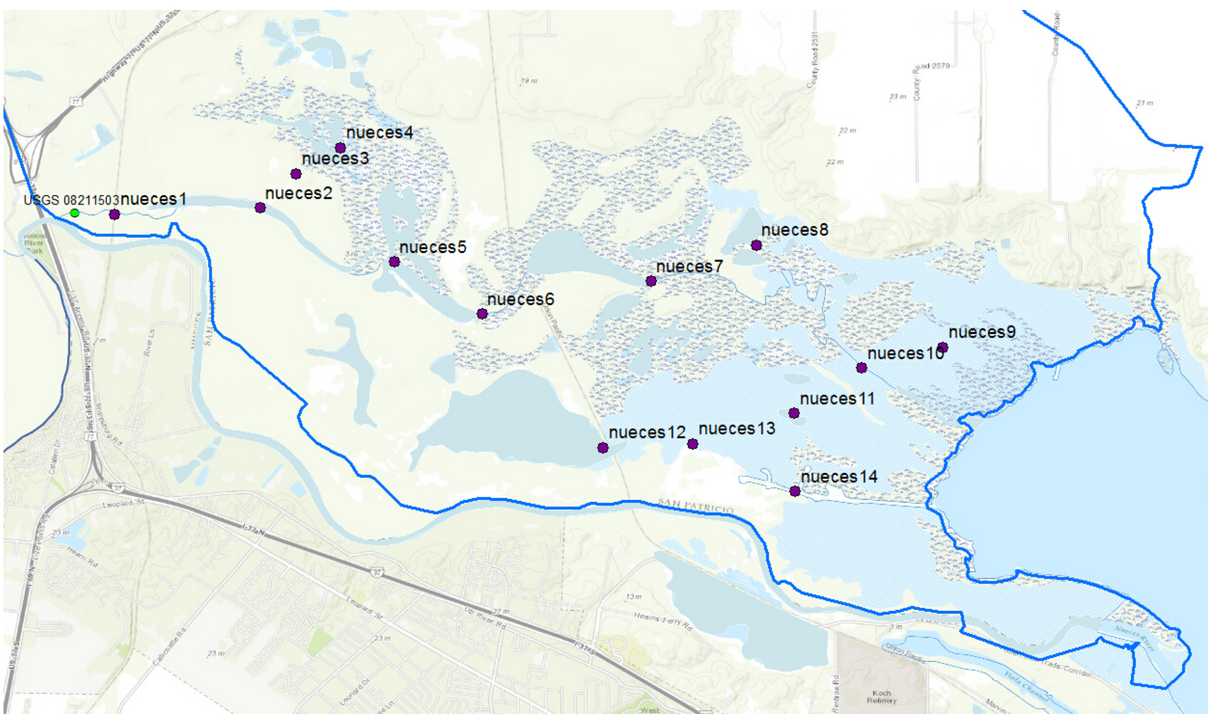


Figure 2: Locations of Salinity Stations

2.2 Data of Other Forces

The pump flow rates were obtained from the website of Nueces River Authority (http://www.nueces-ra.org/CP/CITY/rincon/). The flow rates were given in acre-ft per day. The location of the pumps was next to the USGS Gage 08211503 (Fig.2).

The data of wind was obtained from TCOON. The wind speed was averaged between two stations, the Nueces Delta Weather Station (27.8976N, 97.6165W) and the Nueces Bay (27.8328N, 97.4860W), which was located upstream and downstream of Nueces Delta correspondingly.

The precipitation was obtained from Corpus Christi Meteorological Station No.1 (27.8321N, 97.5516W) in mm/h.

3 RESULT

This section shows the result of the project. It includes the spatial and temporal analysis of salinity distribution, the analysis of pump flow rate, wind direction and precipitation. The relationships between natural forces and variation in salinity are discussed.

3.1 Spatial Interpolation of Salinity

The result of spatial salinity distribution for different months can be found in Fig.3 through 6. The salinity was displayed in practical salinity units (psu). Red meant high salinity and blue represented low salinity. As mentioned in §2.1, the monthly averaged salinity was used for spatial interpolation. However, the quality of data was not always good enough. Sometimes big portions of data were missing at some salinity stations. As a result, the spatial distribution was not always obtained from a 14-station interpolation. Sometimes fewer stations were used.

The salinity showed significant variation with both space and time. Relatively lower salinity was found upstream of the Nueces Overflow Channel, which was a combination effects of inflows from Nueces River and the pumps. The salinity became higher when it moved to downstream. While the salinity in summer is generally low, it increased severely in spring of 2013. Fig.5 indicated that a great portion of Nueces Delta had a salinity higher than bay salinity in May of 2013. The salinity near the South Lake (Nueces 12 and 13) was higher than the bay salinity through the entire year. The absence of fresh water inflow made South Lake the worst place in Nueces Delta for estuary creatures.

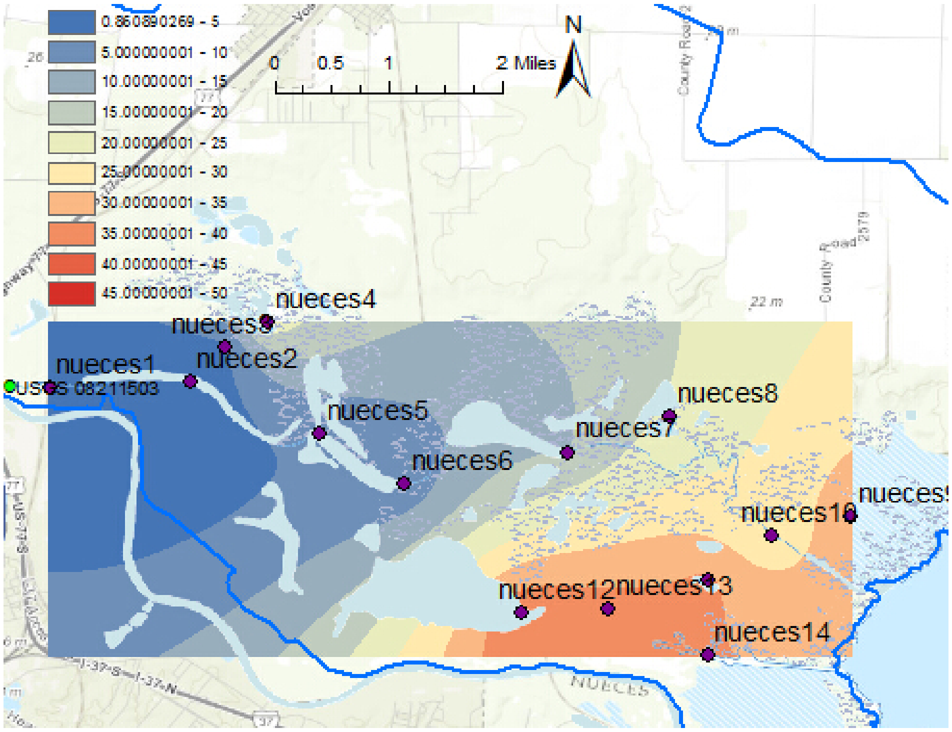


Figure 3: Salinity Distribution on Aug.2012

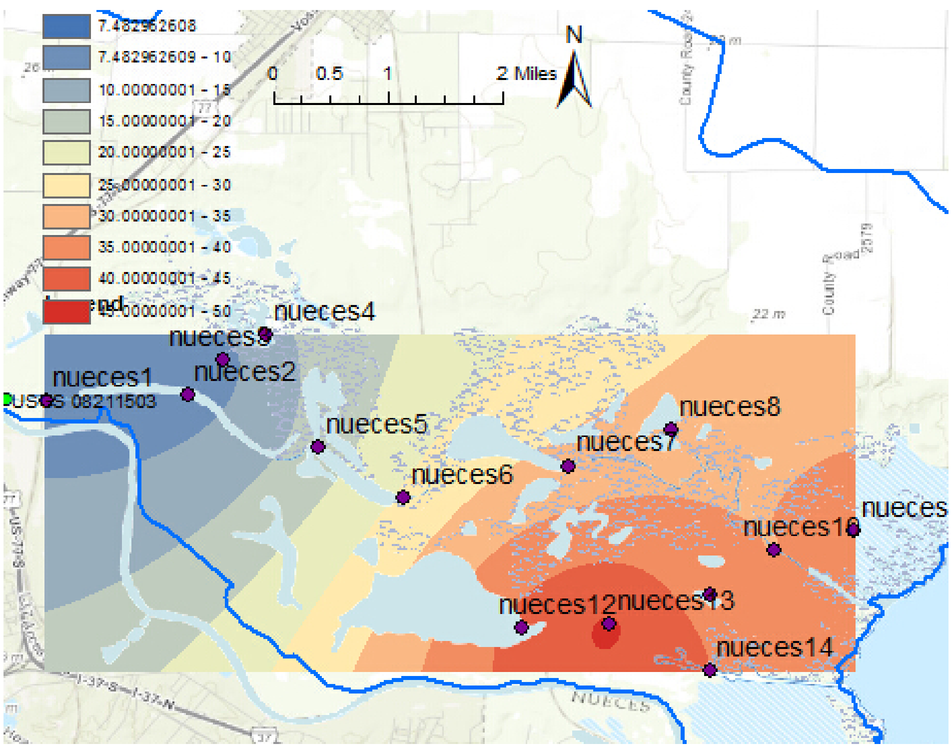


Figure 4: Salinity Distribution on Nov.2012

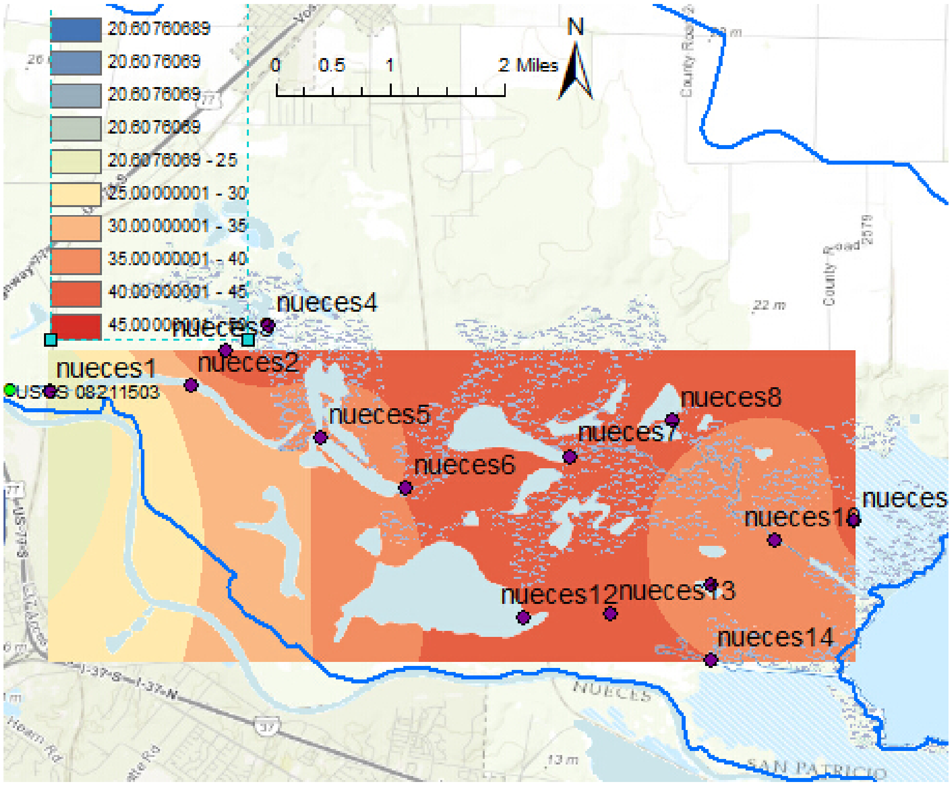


Figure 5: Salinity Distribution on May.2013

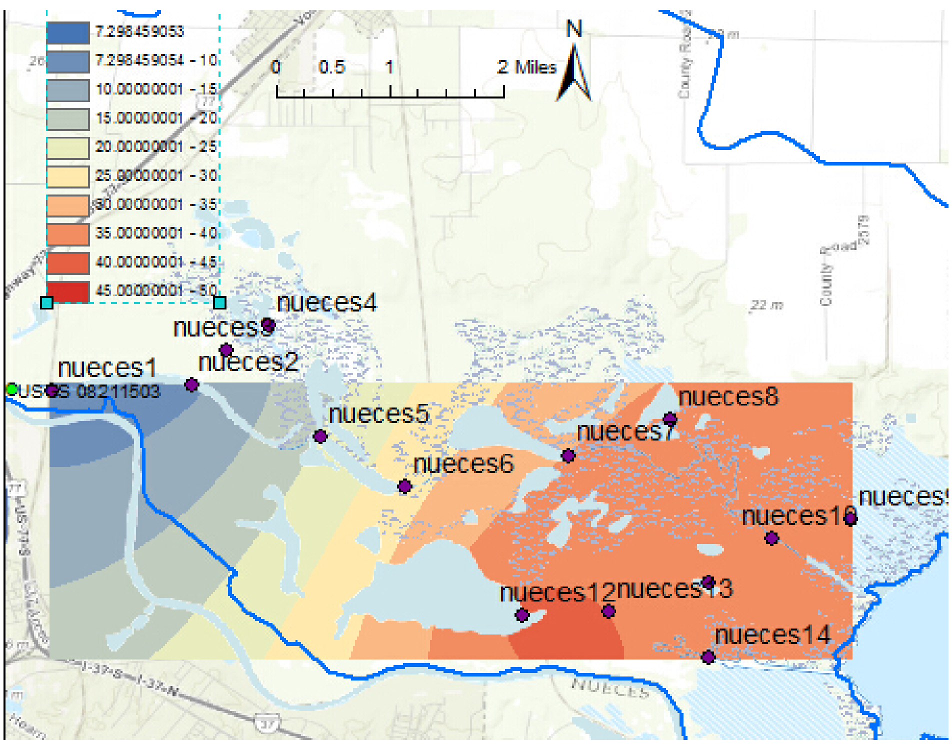


Figure 6: Salinity Distribution on Aug.2013

3.2 Temporal Analysis of Salinity

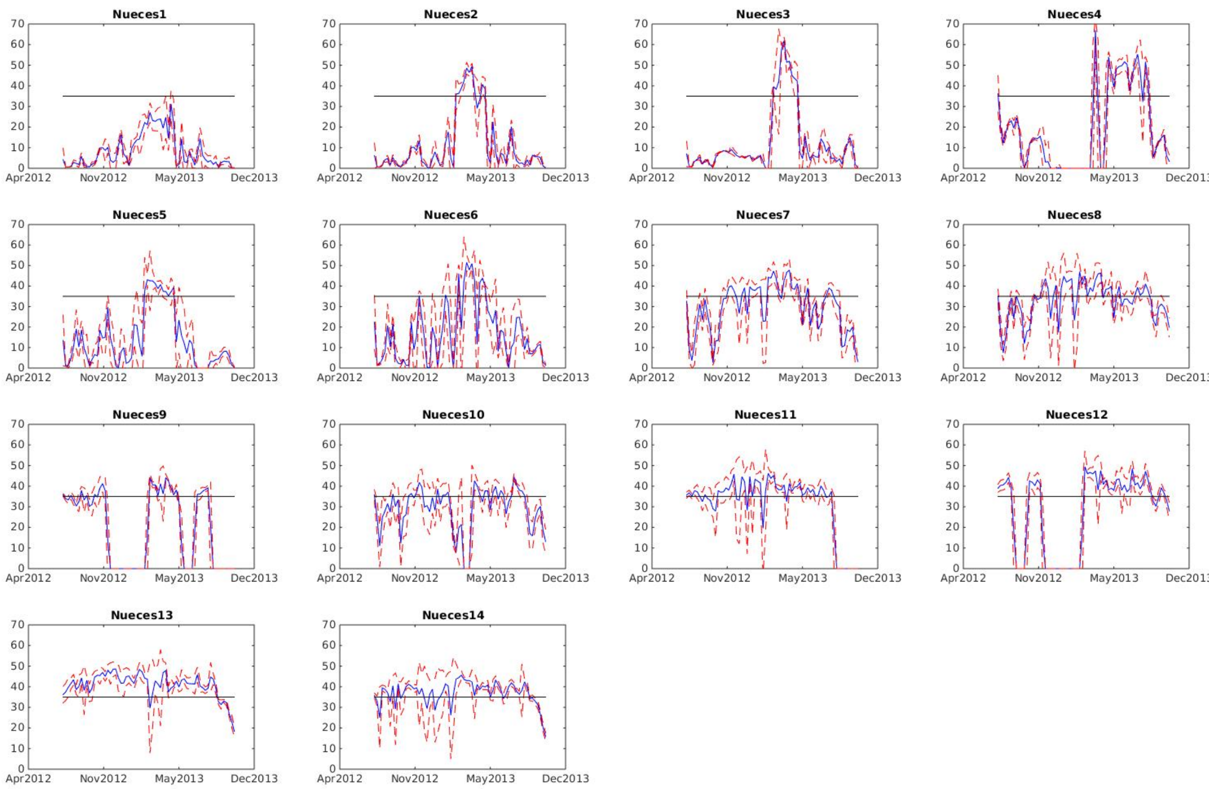


Figure 7: Salinity vs. time at Each Station

The time variation of salinity at each station was plotted using MATLAB (Fig.7), where blue curves were the daily mean salinity and red dashed lines were the daily standard deviation. The horizontal black line was the typical salinity of ocean, which was 35 practical salinity units (psu). The missing data was plotted as equal to the last valid data, which caused flat lines in Fig.7. An increase of salinity was observed at upstream stations (Nueces 1 through 6) in spring of 2013, which met the result of §3.1. The salinity at downstream stations Nueces 9, 11, 12, 13, and 14 were relatively stable with time. In the fall of 2013, the salinity at Nueces 12, 13 and 14 decreased. The salinity at downstream stations 7, 8 and 10 showed higher magnitudes of variations. These three stations were located in the Nueces Overflow Channel, where upstream fresh water and downstream brine water exchanged every now and then. The salinity at these stations was highly dependent on the tide elevation and inflow rate, which might be the cause of the frequent and severe salinity variations.

The background salinity in Nueces Bay was presented as Fig.8. It had a similar trend with downstream stations. The differences occurred in summer, where significantly lower salinity was observed in the Nueces Bay. The background salinity was higher than typical ocean salinity during most of the year, this phenomenon explained the observation that the salinity at some downstream stations was higher than ocean salinity through the entire year. It indicated that investigating the reason of high salinity in the Nueces Bay was necessary to control the salinity of the delta. This task was beyond the scope of the current project and it would be completed in the future.

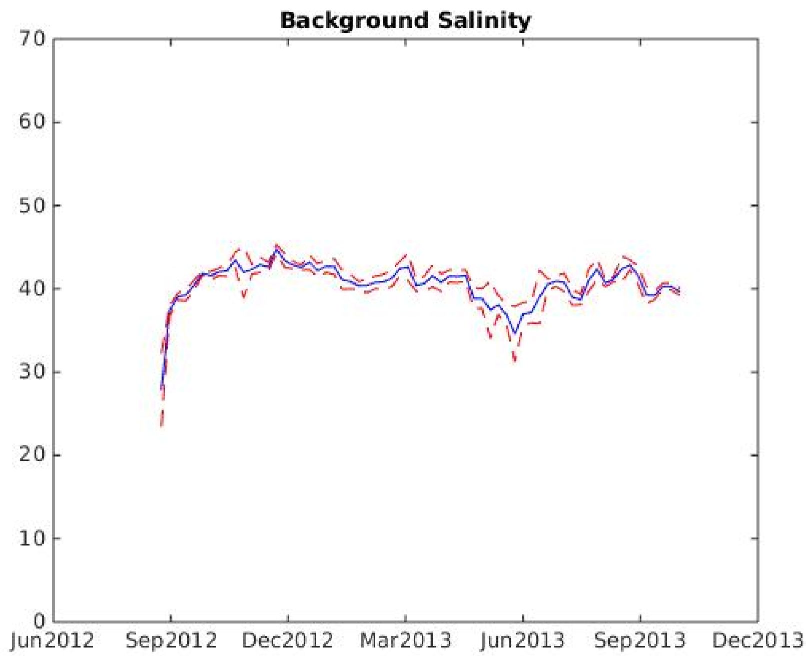


Figure 8: Background Salinity

3.3 Effect of Environmental Forces on Salinity

This section showed the analysis of natural forces. In this project, only pump flow, precipitation and wind were taken into account. Other factors, such as river inflow, tide and evaporation, might have significant effect on salinity as well. Those factors will be analyzed in the future.

3.3.1 Pump

The histogram of pump flow rate can be found in Fig.9. The operation of the pumps seemed random. The pump was turned off for a long time in the spring of 2013, which was the time when significant salinity increase was observed (Fig.5 and 7). It can be inferred that the open and close of the pumps has a direct impact on the salinity of Nueces Delta, especially the upstream section of Nueces Delta. The temporal variation of upstream salinity was not seasonal but determined by the operation method of the pumps. Without the pumps, the inflow from Nueces River was not able to maintain low upstream salinity alone. While more frequent openings of the pumps were preferred ecologically, it might not be affordable economically. A cost analysis should be carried out in the future to obtain the optimal operation frequency of the pumps.

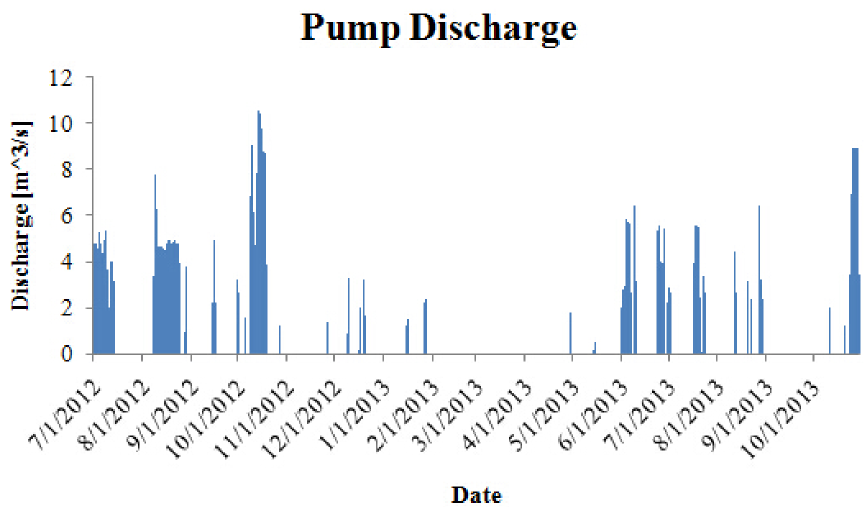


Figure 9: Pump Discharge

3.3.2 Precipitation

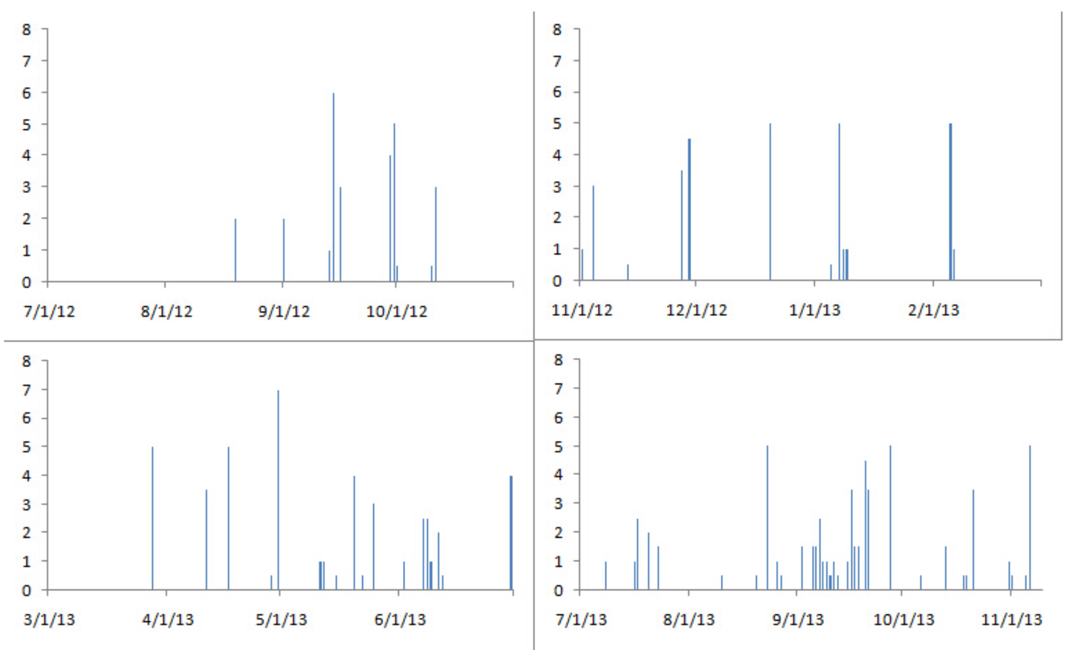


Figure 10: Precipitation at Corpus Christi Meteo Station No.1

The histogram of precipitation can be found in Fig.10. The seasonal trend of precipitation events were not observed, which meant that the effect of precipitation on salinity was not controllable. A group of dense rainfall events were found in the fall of 2013, which might be responsible for the decrease of salinity at Nueces 12, 13 and 14. Other stations did not show salinity changes due to precipitation, which indicated that the rainfall events could be very local. Precipitation data from other locations in Nueces Delta was required for more complete analysis.

3.3.3 Wind

The wind speed did not show seasonal variations, but the wind direction did. Fig.11 used dots to represent the measurements of wind directions. If wind in one direction was frequently observed, the density of dots in that direction would increase, which resulted in a continuous solid line. On the contrary, less frequent winds resulted discrete lines. For example, southeast winds were more frequent in summer than in winter. West winds were not frequent over the entire year. The background salinity was measured at station SALT03 (Fig.12), which was north of the Nueces River outlet. Under the effect of southeast wind in the summer, fresh water from Nueces River was pushed north through SALT03, which lowered the measured background salinity. The decrease of salinity in summer was not observed in any of the 14 salinity stations, so the change of wind directions was not a major factor that altered the salinity in Nueces Delta.

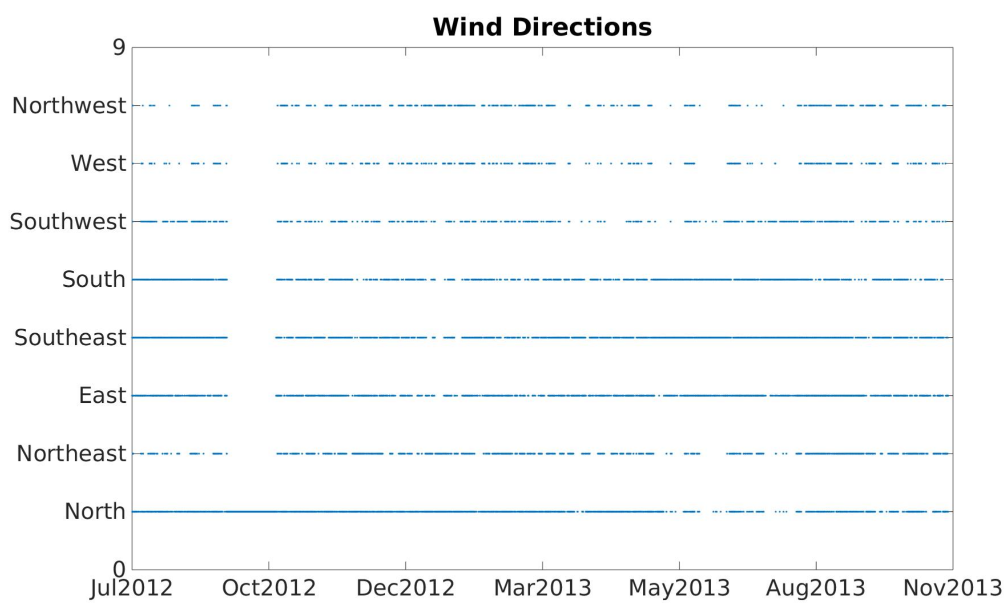


Figure 11: Wind Directions

4 DISCUSSION

Several questions arose regarding to the result of this project. The major question was that the accuracy of the spatial interpolation could be low because it assumed uniform rate of

Figure 12: Location of the Background Salinity Station [Ryan and Hodges, 2011]

salinity transportation over Nueces Delta. However, a more realistic situation was that salinity only transported when water existed. The transport of salinity was not isotropic because water movements might be altered or prevented by local topography. So this assumption neglected the effect of topography and the existence of land surface, which played important roles in salinity transportation. To better understanding the spatial distribution of salinity, the inundation area should be calculated. The inundation area changed significantly based on different natural conditions. During dry years, the inundation area diminished due to evaporation, leaving salt in the soil. When wet year came, an increased inundation area could dissolve the salt left previously, which caused even higher salinity. Including inundation into the analysis is one important objective of future research.

Although the analysis of salinity distribution was not perfect, some useful results were obtained. As can be seen from §3.3.1, the opening of the pumps have direct and significant effect on reducing upstream salinity of Nueces Delta. If the cost permits, building more pumps at downstream locations, especially near the South Lake where highest salinity was measured, could help further reducing salinity. The operation of the pumps could depend on current weather conditions. §3.3.2 illustrated that precipitation was another factor that made salinity decrease. The pumps could be turned off during heavy rainfall events.

Inexpensive solutions exists other than pumping. For example, a channel could be built to connect Nueces River and the South Lake. It will provide continuous fresh water into the South Lake, which might be even more effective than pumping.

Other natural forces might play important roles effecting salinity distribution. Tidal flow was the main mechanism that brought brine water into the delta. Analyzing temporal variation of tide elevation could help better predicting salinity and inundation. Strong evaporation might be the main reason that delta salinity was higher than the background salinity. Investigating evaporation, or even evapotranspiration could be useful as well. Although an increasing salinity was generally not desired for animals and plants, different species adapted to salinity variations differently [Hodges et al., 2012]. Reducing salinity could save some species but eliminate others. Any changes to the current ecosystem should be performed with cautious.

The Fine Resolution Environmental Hydrodynamic Model (FREHD) is under test in the Center of Research in Water Resources, University of Texas at Austin. It combines multiple natural factors, including inundation, and predicts the salinity of Nueces Delta quantitatively [Ryan and Hodges, 2011]. The possible solutions (e.g. adding pumps, excavating channels) will be modeled using FREHD prior to being executed, which lowers the risk and saves the cost. Once calibrated, FREHD could be a powerful tool in the restoration of Nueces Delta ecosystem.

5 CONCLUSION

The salinity distribution of Nueces Delta was studied both in time and in space. The variation of salinity was linked with fresh water pumping, precipitation and wind. The results showed that pumping and precipitation had direct and significant impact on salinity. Considered that precipitation had no seasonal characteristics and was not controllable, the operation of the pumps could be based on current weather conditions. Seasonal trend of wind direction effected the background salinity in the Nueces Bay, but its impact on delta salinity was limited. The analysis on inundation area should be performed in the future to overcome the deficiencies of current research. More environmental factors such as tide and evaporation could be added in the future too.

References

B.R Hodges, K.H Dunton, P.A Montagna, and G.H Ward. Nueces delta restoration study. Technical report, Center of Research in Water Resources, University of Texas at Austin, December 2012.

L Lloyd, J Tunnell, and A Everett. Nueces delta salinity effects from pumping freshwater into the rincon bayou: 2009 to 2013. Technical report, Conrad Blucher Institute for Surveying and Science, August 2013.

A.J Ryan and B.R Hodges. Modeling hydrodynamic fluxes in the nueces river delta. Technical report, Center of Research in Water Resources, The University of Texas at Austin, October 2011.

Appendices

MATLAB Codes for §3.2

```
%% load the data and remove bad data
action = 'interpolate'; %action to bad date, can be 'remain','remove','interpolate'
salinity = xlsread('~/Research_NDHM/Salinity_Analysis/Salinity_Site.xlsx',1,'A:Q');
sitename = char('Nueces1', 'Nueces2', 'Nueces3', 'Nueces4', 'Nueces5', 'Nueces6', 'Nueces7',...
     'Nueces8', 'Nueces9', 'Nueces10', 'Nueces11', 'Nueces12', 'Nueces13', 'Nueces14');
rowbad = 1; %index of bad data
columebad = 4;
counter = 0; %count the number of bad data
for columebad = 4:size(salinity,2)
    for rowbad = 1:size(salinity,1)
        if salinity(rowbad, columebad) < 0
            switch action
                case remain
                    counter = counter + 1;
                case remove
                    salinity(rowbad, columebad) = 0;
                    counter = counter + 1
                case

            %salinity(rowbad, columebad) = 0; %set the bad measurement to be 0
            counter = counter + 1;
        end
    end
    badratio = counter/size(salinity,1); %calculate the proportion of bad data
    disp([num2str(badratio) , ' data were missing at site ',sitename(columebad-3,:)]);
    counter = 0; %reset counter for next site
end
```

```
ii = 4; %index of site
jj = 1; %index of number of rows in salinity
kk = 0; %index of number of weeks
rr = 1; %index of output vector
calculate = 1; %true if continue calculation
numweeks = floor(size(salinity,1)/672); %total number of weeks
weekavg = zeros(numweeks, length(sitename)); %initialize avg matrix
weekstd = zeros(numweeks, length(sitename)); %initialize std matrix
date = zeros(numweeks, 1); %initialize date vector
for ii = 4:size(salinity,2)
    while calculate
        kk = kk + 1;
        jj = jj + 672;
        if kk >= numweeks
            calculate = 0;
        end
        weekavg(kk,ii-3) = mean(salinity((jj-672):(jj-1),ii)); %calculate the mean salinity
        weekstd(kk,ii-3) = std(salinity((jj-672):(jj-1),ii)); %calculate the standard deviation
        if ii == 4 %output the date vector for plotting
            dattt = strcat(num2str(salinity((jj-1),(ii-3))),'-',...
                num2str(salinity((jj-1),(ii-2))),'-',num2str(salinity((jj-1),(ii-1))));
            date(kk) = datenum(dattt);
        end
    end
    calculate = 1;
    kk = 0;
    jj = 1;
end
```

```
%% Plotting
figure(1);
fignum = 1;
%convert xlabel into 'mmmyyyy'
simpdate = {datestr(date(1),28),datestr(date(ceil(0.3*length(date))),28),...
    datestr(date(ceil(0.7*length(date))),28),datestr(date(length(date)),28)};
for fignum = 1:length(sitename)
    subplot(4,4,fignum)
    plot(date,weekavg(:,fignum),'b-',date,(weekavg(:,fignum)+weekstd(:,fignum)),'r--',...
        date,(weekavg(:,fignum)-weekstd(:,fignum)),'r--');
    xax = gca;
    xax.XTickLabel = simpdate; %xlabel
    ylim([0 70]); %range of y-axis
    title(sitename(fignum,:));
end
```