THE IMPACT OF COLD FRONTS ON THE AGE OF SUSPENDED SEDIMENT IN GALVESTON BAY

An Undergraduate Research Scholars Thesis

by

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RESEARCH COMPLIANCE CERTIFICATION

Research activities involving the use of human subjects, vertebrate animals, and/or biohazards must be reviewed and approved by the appropriate Texas A&M University regulatory research committee (i.e., IRB, IACUC, IBC) before the activity can commence. This requirement applies to activities conducted at Texas A&M and to activities conducted at non-Texas A&M facilities or institutions. In both cases, students are responsible for working with the relevant Texas A&M research compliance program to ensure and document that all Texas A&M compliance obligations are met before the study begins.

I, Noah Cox, certify that all research compliance requirements related to this Undergraduate Research Scholars thesis have been addressed with my Research Faculty Advisor prior to the collection of any data used in this final thesis submission.

This project did not require approval from the Texas A&M University Research Compliance & Biosafety office.

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ABSTRACT

The Impact of Cold Fronts on the Age of Suspended Sediment in Galveston Bay

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Cold fronts are considered to be a significant cause of sediment resuspension and transport in estuarine systems. Cumulatively, cold fronts have a greater total impact on sediment resuspension and transport than less frequent, higher intensity tropical storms and hurricanes. This study was conducted to determine how sediment resuspension in Galveston Bay is impacted by the passage of cold fronts. Suspended sediment samples were collected at multiple points around Galveston Bay following cold front passages, and precipitation samples were also collected. By analyzing the ratio of the radionuclides ^{7}Be and ^{210}Pb in the suspended sediment samples from each site, as well as in the precipitation samples, it was possible to calculate the age of the resuspended sediment. It was possible to compare the differences in age to evaluate short-term sediment transport and deposition processes associated with cold front passages between the sample sites. The average suspended sediment ages during the entire study period for Upper and Lower Galveston Bay were 131.3 days and 204.7 days, respectively. Total Suspended Sediment and Radionuclide Activity were also assessed for each sample site.

DEDICATION

To Richard and Scott, my dear friends and colleagues. Your encouragement and support during this project were invaluable.

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NOMENCLATURE

CPM	Counts Per Minute
CPS	Counts Per Second
DPM	Decays Per Minute
DPS	Decays Per Second
OCSB	Ocean and Coastal Studies Building
TAMUG	Texas A&M University at Galveston
TCYC	Texas Corinthian Yacht Club
TSS	Total Suspended Sediment

1. INTRODUCTION

1.1 Overview

Ongoing research is being conducted focusing on the dynamics of cold front-driven resuspension of sediments in coastal systems. It has been expressed that, due to their higher frequency and larger area of impact, cold fronts likely have a greater overall impact on coastal environments than less frequent tropical storms (Moeller et al., 1993). This impact raises questions about the nature of the sediment that is being resuspended, particularly the age of said sediment. Thus, the goal of this study was to determine the age of sediment at various points around Galveston Bay following the passage of cold fronts.

The relevance of this project is that it is a continuation of ongoing research being conducted by graduate students and faculty at Texas A&M University at Galveston (TAMUG). Investigating the dynamics of resuspension and deposition of sediment that is driven by cold fronts in Galveston Bay provides another point of comparison with studies of anthropogenic and tropical storm-driven suspension and deposition (Dellapenna et al., 2006, Dellapenna et al., 2020). Broader impacts of this project will hopefully be an improved understanding of the impact of cold fronts on sediment resuspension and deposition in Galveston Bay, as well as the ability to apply this type of research to other estuarine systems.

1.2 Background

The use of the radionuclides Beryllium-7 and Lead-210 as indicators of age of suspended sediment is a proven method (Baskaran et al., 1997, Baskaran and Santschi, 1993, Le Gall et al., 2017, Fitzgerald et al., 2001, Taylor et al., 2012). Using ^{7}Be in particular as a tracer has been proven to be useful due to the correlation between the concentration of ^{7}Be in suspended sediment and the amount of time the sediment is in suspension (Olsen et al., 1986). Determining the correlation between age of suspended sediment and its spatial distribution in an estuarine environment can help us better understand the dynamics and rate of sediment resuspension and deposition (Ciffroy et al., 2003, Baskaran and Santschi, 1993).

A series of calculations, referred to in this report as the Matisoff Method, utilize the ratios of ^{7}Be and ^{210}Pb in both a sediment sample and a precipitation sample to determine the sediment's age (Matisoff et al., 2005). This method utilizes the calculated activities of ^{7}Be and ^{210}Pb in sediment samples as well as a corresponding precipitation sample, in addition to the decay constants of the aforementioned radionuclides, to determine the age of the collected sediment. The formulae used in the Matisoff Method are given in Section 2.2.4 of this thesis.

Sediment suspension, transport, and deposition is not only initiated by regular wind and wave action; of particular interest is the initiation of these processes by meteorological phenomena– i.e. cold fronts (Carlin et al., 2016). This interest in the resuspension of sediment by cold fronts is due to the supposed magnitude of their impact compared to higher or lower energy phenomena. Until recently, however, sufficient investigation into the mechanisms by which cold fronts drive sediment resuspension and deposition had not been conducted (Carlin et al., 2016).

1.3 Hypothesis

Based on information gathered from the literature review regarding both sediment resuspension by cold fronts and the sediment transport dynamics of similar systems, it was hypothesized that "younger" suspended sediment would be found in the northern area of Galveston Bay, while "older" suspended sediment would be collected in the southern area. It was expected that the amount of the radionuclides ^{7}Be and ^{210}Pb would be lower in the samples collected near the mouth of Galveston Bay, thus indicating an increase in sediment age as it is transported toward the south.

1.4 Timeline and Study Sites

Due to the weather-dependent nature of this project, sample collection did not follow a pre-determined timeline. The initial precipitation collection occurred on September 11, 2020. However, the first suspended sediment collection event was not conducted until September 29, 2020. This was largely in part due to weather fluctuations. Suspended sediment samples were collected at the TAMUG boat basin site and the TCYC pier. Analysis of the first set of samples took nearly three weeks to complete.

The second precipitation and sediment collection event occurred on October 26, 2020. Due to a combination of scheduling conflicts and technical difficulties with the pump used to collect the sediment, a sample was only taken from the TAMUG boat basin site. The sample analysis process again took place over a period of two to three weeks.

A third sample collection event was conducted on November 30, 2020. Again, sample collection was only conducted at the TAMUG boat basin site. Sample analysis was completed within two weeks.

As the initial plan for this project was to conduct a minimum of three multi-site samplings, sample collection in the Spring of 2021 was required. The fourth and final round of precipitation collection was conducted on February 18, 2021, while the corresponding sediment sample collection was conducted on February 24, 2021. This round of sample collection consisted of three different sediment collection sites, including the previously unused Seawolf Park pier.

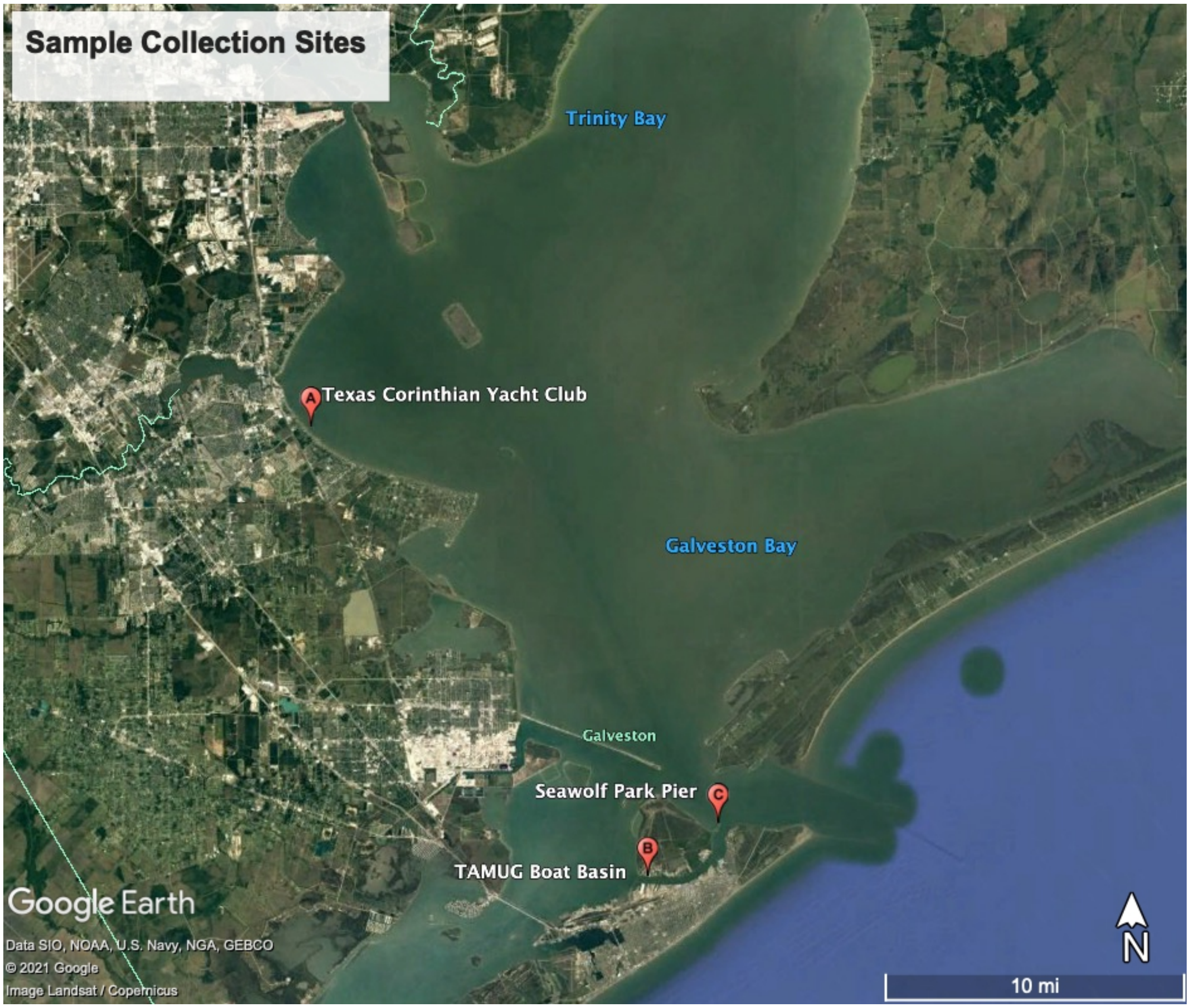

Figure 1: Sample Collection Locations in Galveston Bay, Texas.

2. METHODS

2.1 Sample Collection

The sample collection process for this project consisted of two parts: precipitation collection and suspended sediment collection. While these data were collected at different sites, both parts were conducted at the same time relative to the passage of a cold front.

2.1.1 Precipitation Collection

Precipitation collection took place on the roof the Ocean and Coastal Studies Building (OSCB) at Texas A&M University - Galveston. This site was chosen for its convenience as well as the assumption that precipitation collected there would be similar to that in other parts of Galveston Bay. Precipitation was collected in a 20-liter container using an affixed funnel for maximum collection. Following collection, the contents were acidified to prevent binding of any present radionuclides to the walls of the container.

2.1.2 Suspended Sediment Collection

Suspended sediment collection took place at three sites around Galveston Bay – Texas Corinthian Yacht Club (TCYC) pier, Seawolf Park Pier, and the Texas A&M University – Galveston Boat Basin. These sites were chosen due to their geographic separation as well as the ease with which samples could be collected using available equipment. Sample collection was achieved using a small electric pump attached approximately eight inches above the end of a 3.5-meter metal pole. At each site, water was fed from the pump into either two or three 20-liter containers per collection period. Over the course of this study, delays and equipment malfunctions resulted in sample collection only being conducted at one or two of the collection sites for some of the collection events.

2.2 Sample Analysis

2.2.1 Total Suspended Sediment

After the sediment samples were collected, approximately one liter from each site was extracted and used to calculate the Total Suspended Sediment (milligrams per liter) at each site. This was done by using a suction pump to force the water samples from each site through pre-weighed filters, which were then allowed to dry. Once dry, each filter was re-weighed to determine the weight of the collected sediment. By determining the weight of the sediment and knowing the volume of the sample that was filtered, it was possible to determine the TSS. For the February 24, 2021 sampling event, TSS was derived using the total sediment weight and initial collected sample volume instead of using the filtration method.

2.2.2 Suspended Sediment Sample Preparation

The rest of the suspended sediment sample was left to settle for roughly 48 hours. After settling, as much of the water was siphoned away as possible, leaving a manageable amount for further separation. The sediment was further separated out of the water via a Beckman Coulter Allegra X-12 Centrifuge. Once separated, the samples were dried overnight in a laboratory oven. Once dry, each of the samples were ground using a mortar and pestle and weighed before beginning radioisotope analysis in a gamma counter.

2.2.3 Radionuclide Analysis

Once both the precipitation sample and the sediment sample for a particular data collection event were prepared for analysis, each site's sample was analyzed individually in the gamma counter for two to three days. Utilizing the gamma counter made it possible to determine the exact concentration of a wide spectrum of isotopes within each sample, though only ^{7}Be, ^{210}Pb, and ^{226}Ra were important for the purposes of this project. Radium-226, while not directly used as a tracer, needed to be measured and subtracted from ^{210}Pb to generate a more accurate measurement of ^{210}Pb present in the sample at the time of collection. Once the radionuclides for a sample were counted, it was possible to calculate the age the sediment that had been resuspended by analyzing how much of the radionuclides has decayed. The activity of the radionuclides in the suspended sediment sample had to be compared to the radionuclide activity ratio of the precipitation sample to determine the actual impact of the cold front passage on the sediment age.

Data collected from the gamma counter for each sample per round of sampling included the counting time in seconds, the "area" of ^{7}Be, ^{210}Pb, and ^{226}Ra in the samples, and the percent error for the area of each radionuclide. Since the samples from each round of sampling were not counted simultaneously, it was necessary to take into account the number of days that had elapsed between sample collection and sample counting. From this collected data, it was possible to calculate the Counts Per Second (CPS) and Counts Per Minute (CPM) per sample for each radionuclide. Using the gamma counter's counting efficiency for given sample weights, which is Decays Per Minute (DPM)/Counts Per Minute (CPM), it was possible to determine the activity of the radionuclides.

The activity of a radionuclide is the Decays Per Second (DPS). By correcting for the number of days that elapsed between sample collection and sample counting, the true DPS of each radionuclide was determined. The activity of ^{7}Be did not need any further correction. Since ^{210}Pb is a product of the ^{226}Ra decay chain, it was necessary to subtract the DPS of ^{226}Ra in the sample from the DPS of ^{210}Pb prior to time-correction. This yielded the amount of $^{210}Pb_{xs,}$ the amount present at the time of sample collection, without the addition of extra ^{210}Pb from the decay of ^{226}Ra. This refined measure of ^{210}Pb was then able to be time-corrected

2.2.4 *The Matisoff Method for Sediment Age*

Once the corrected activity of the radionuclides ^{7}Be and $^{210}Pb_{xs}$ were determined in the precipitation and sediments for each site, the Matisoff Method was used to determine the age in days of the suspended sediments. The formula used in the Matisoff Method and the definitions of the variables are given in below:

$$t = \frac{-1}{(\lambda_{7Be} - \lambda_{210Pb})} ln\left(\frac{A}{B}\right) + \frac{1}{(\lambda_{7Be} - \lambda_{210Pb})} ln\left(\frac{A_0}{B_0}\right) \quad (1)$$

$$A = (^{7}Be)_{sediment}$$

$$A_0 = (^{7}Be)_{precipitation}$$

$$B = (^{210}Pb_{xs})_{sediment}$$

$$B_0 = (^{210}Pb_{xs})_{precipitation} \quad (2)$$

where λ_{7Be} is 0.01300 d^{-1}, the decay constant for ^{7}Be, and λ_{210Pb} is 8.50999$e^{-5}d^{-1}$, the decay constant of ^{210}Pb (Matisoff et al., 2005). Using this formula provided the final data for Suspended Sediment Age.

3. RESULTS

Analysis of the suspended sediment samples in the gamma counter and through the use of the Matisoff Method yielded results that aligned with the hypothesis and expected outcome. The relevant results generated in this study are divided into three categories: Radionuclide Activity of Collected Samples, Suspended Sediment Age, and Total Suspended Sediment.

3.1 Radionuclide Activity of Collected Samples

The activity of the radionuclides in each sample was determined to follow a trend generally similar to the hypothesized sediment age trend. The two sample collection events that included multiple sites allowed for comparisons of the activities of both ^{7}Be and ^{210}Pb$_{xs}$. As seen in Figure 2 and Figure 3, the corrected DPS of both ^{7}Be and ^{210}Pb$_{xs}$ exhibited a significant degree of variability temporally, and did not follow a clear trend when compared between sites. However, the corrected DPS of ^{7}Be in each precipitation sample was higher than the ^{210}Pb$_{xs}$ DPS.

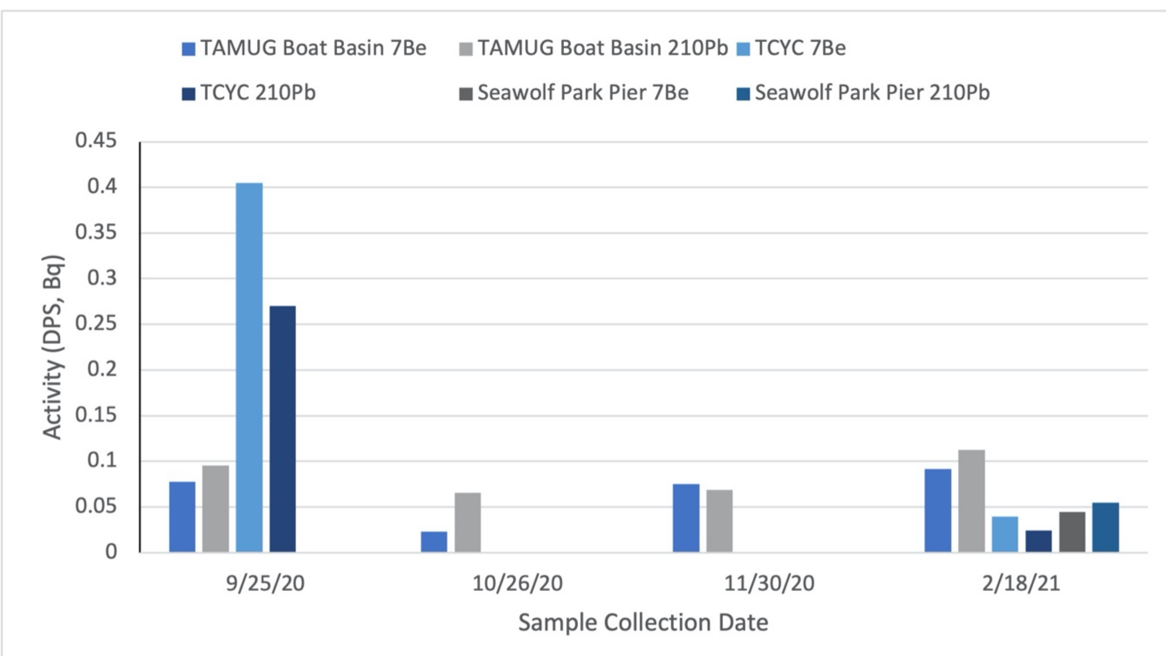

Figure 2: Radionuclide Activities (DPS, Bq) for Each Sample Collection Site

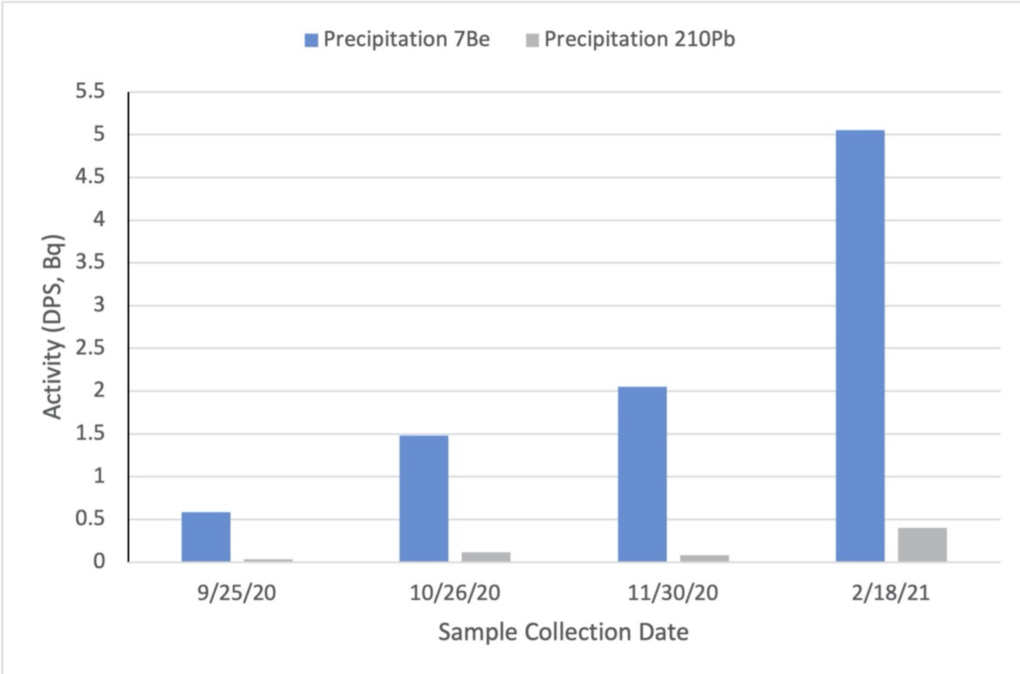

Figure 3: Radionuclide Activities (DPS, Bq) for Collected Precipitation Samples

3.2 Suspended Sediment Age

The ages of the suspended sediment samples that were calculated using the Matisoff Method were all consistent with the initial hypothesis and expected outcomes. For the two multi-site sampling events, the calculated sediment ages were consistently lower/younger at the TCYC site in Upper Galveston Bay. Conversely, the calculated sediment ages were higher/older at the TAMUG Boat Basin site in Lower Galveston Bay. All of the calculated sediment ages are shown in Figure 4 below.

The average sediment age at the TCYC site for the two multi-site sampling periods was 131.312 days, while the average age at the TAMUG Boat Basin site for the two multi-site sampling events was 194.953 days. For all four sampling events, the average sediment age at the TAMUG Boat Basin site was 204.692 days. Though sampling at the Seawolf Park Pier was only conducted during the February 24,2021 sampling event, the calculated age of the sediment from that site were also consistent with the expected results.

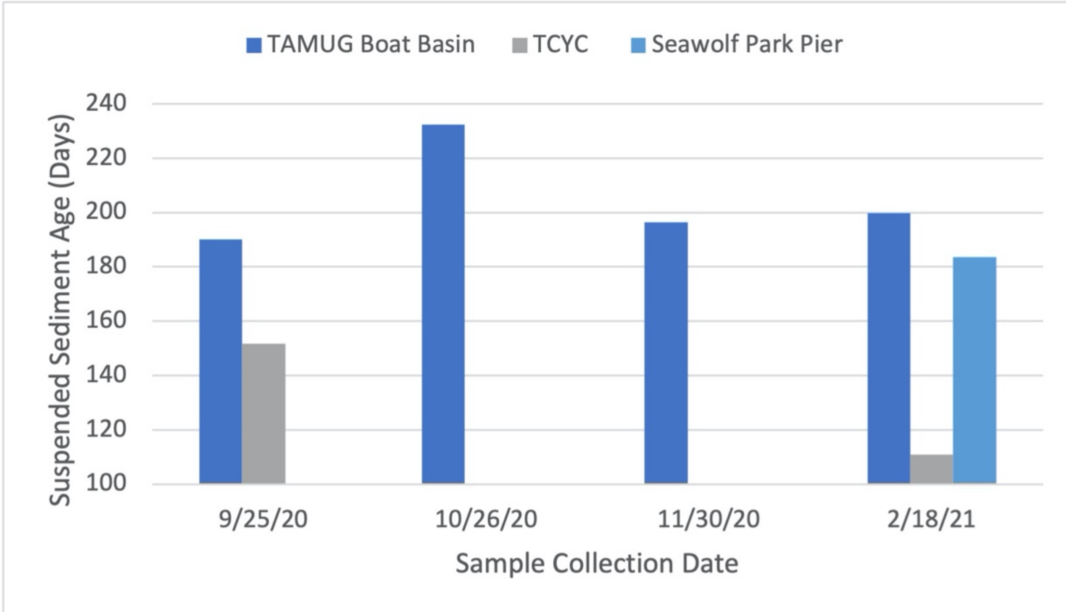

Figure 4: Calculated Suspended Sediment Age (Days) for Each Sample Collection Site

3.3 Total Suspended Sediment

Calculated TSS for each site and round of sample collection were also fairly consistent with the expected outcomes. As seen in Figure 5, all TSS measurements became progressively lower over the course of this study. Comparisons of TSS between the TCYC and TAMUG Boat Basin sites clearly show that TSS was higher at the TAMUG Boat Basin in Lower Galveston Bay than at TCYC in Upper Galveston Bay. Due to the change in TSS calculation method for the February 24, 2021 sampling event, the results of the TSS calculation were less precise and possibly inaccurate.

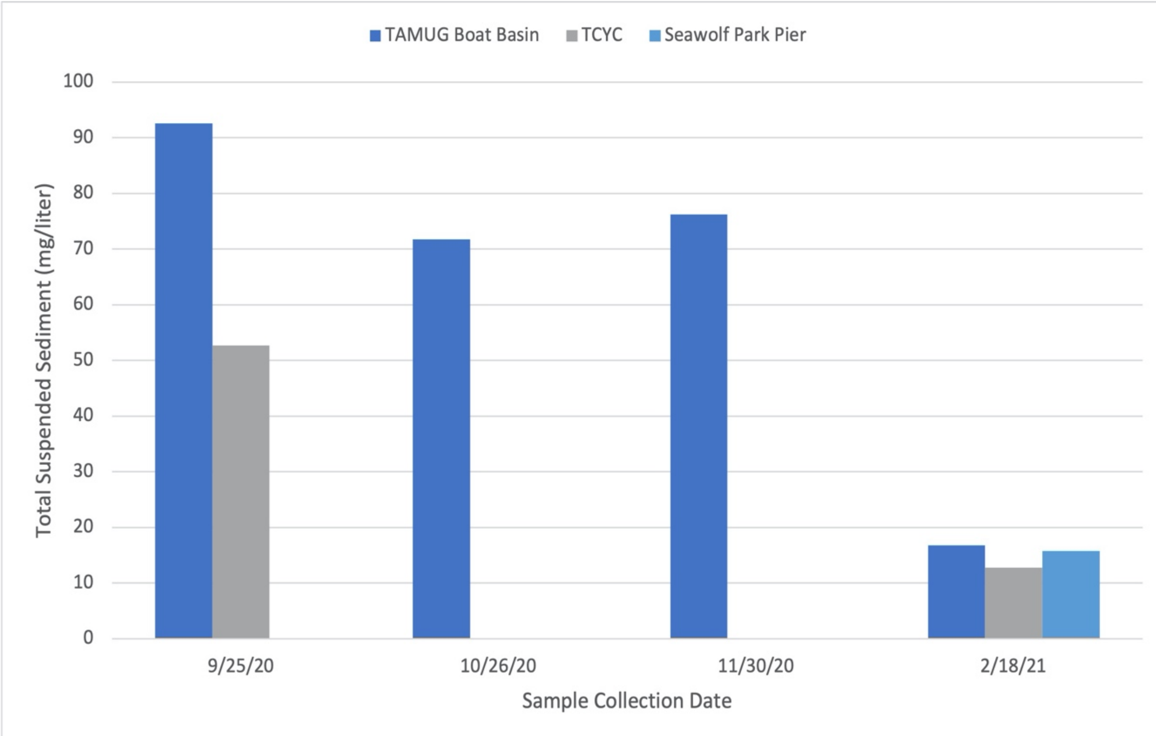

Figure 5: Calculated Total Suspended Sediment (mg/liter) for Each Sample Collection Site

4. DISCUSSION

4.1 Assessment of Results

4.1.1 Radionuclide Activity

As mentioned in Section 3.1, the calculated activity of the radionuclides ^{7}Be and $^{210}Pb_{xs}$ did not follow a clear trend of being greater in the Lower Galveston Bay sites, and lower in the Upper Galveston Bay site. It could be expected for ^{7}Be to have a generally higher level of activity due to its half-life of only 52 days. Since the DPS calculations compensate for the differences in half-life, this would not explain the occurrences of ^{210}Pb in the sediments showing higher degrees of activity than the corresponding ^{7}Be values. The precipitation samples, however, did exhibit a clear trend of the DPS of ^{7}Be being significantly greater than the corresponding ^{210}Pb DPS values. As discussed by Matisoff et al., factors such as the depth of the sediment that are disturbed and resuspended can cause lower than expected levels of ^{7}Be in sediments (Matisoff et al., 2005). Further analysis of sediment origin in a similar study would likely yield insight into these questions.

4.1.2 Suspended Sediment Age

The use of the Matisoff Method to determine the age of suspended sediment yielded results that confirmed the initial hypothesis. The average sediment age for the TAMUG Boat Basin site for the two multi-site sampling events was 194.952 days. The average sediment age for the TCYC site for the two multi-site sampling events was 131.312 days. Even though the Seawolf Park Pier site was only sampled once, the calculated sediment age at that site was 183.605 days. This also supports the hypothesis, as the Seawolf Park Pier site is in Lower Galveston Bay as well. The difference in sediment age between the TAMUG Boat Basin and

Seawolf Park Pier for February 24, 2021 can likely be attributed to the time it would take for sediment to be transported from Seawolf Park Pier on the northeast side of Pelican Island to the TAMUG Boat Basin on the southwest side of Pelican Island.

4.1.3 Total Suspended Sediment

Like the calculated sediment age, the calculated TSS for the entire study period followed the expected trend for all sites. TSS was greater in Lower Galveston Bay than in Upper Galveston Bay. Despite aligning with the hypothesis and expected outcomes, TSS for all sites gradually decreased during the course of the study period, with a drastic decrease for the February 24, 2021 sampling event. While this can possibly be attributed to an unknown factor that influenced sediment transport, a change in the TSS calculation method for this sampling event could also be the cause of the significantly lower TSS values. The average TSS value for the TAMUG Boat Basin for the entire study period was 64.330 mg/liter, while the average TSS value for TCYC was 32.708 mg/liter. If the February 24, 2021 sampling event is disregarded, these averages become 80.190 mg/liter and 52.667 mg/liter for the TAMUG Boat Basin and TCYC, respectively. Further studies of suspended sediment age that incorporate TSS calculations should consistently utilize the filtration method for more accurate results.

4.2 Potential Sources of Error/Inaccuracy

There were a number of factors throughout the course of this study that may have introduced error into the results, or may have otherwise negatively impacted the study. The three most significant of these factors are listed in this section.

4.2.1 Limited Number of Sampling Events

Only conducting sample collection four times over the study period likely limited the accuracy of the results that were generated. The limited number of sampling events was largely due to the weather-dependent nature of this study. Each sampling event required not only the passage of a cold front, but also corresponding precipitation in order to collect all of the necessary initial data. Minor technical difficulties with the sediment sample collection pump were also a hindrance. While the four sampling events each included data from the TAMUG Boat Basin site, sampling at an increased frequency could have potentially yielded even greater insight into how cold fronts impact Lower Galveston Bay. A greater number of sampling events also would have allowed for more effective comparisons of data between sites.

4.2.2 Limited Amount of Multi-Site Sampling

As stated in Section 4.2.1, there was a need for a greater number of multi-site sampling events. In addition to a greater amount of data providing more accurate results, additional data for TCYC and Seawolf Park Pier would have been useful. With that additional data, it would have been possible to gain a better understanding of the differences between sites for TSS, Suspended Sediment Age, and Radionuclide Activity. While having two multi-site sampling events made comparisons between the TAMUG Boat Basin and TCYC possible, the same cannot be said for Seawolf Park Pier. Ideally, each sampling event would have collected data from all three sites. In future studies, multi-site sampling should be utilized more consistently.

4.2.3 Inconsistency of TSS Calculation

The filtration method for calculating TSS was used for the first three sampling events. However, it was not used for the February 24, 2021 event. Instead, TSS was calculated based on the total collected sediment sample and the total water volume of the sample. While the collected sediment was theoretically in suspension at the time of collection, this method of calculating TSS is naturally less precise than the filtering and weighing used in the filtration method. However, it is unclear if this change in measurement was responsible for the significantly lower TSS values of the February 24, 2021 event.

5. CONCLUSION

This study served the purpose of expanding the depth of collected data regarding the impact of cold fronts on the resuspension and transport of sediments in Galveston Bay. The primary results of the study– the ages of the suspended sediment– confirmed the hypothesis that older sediments would be found in suspension in Lower Galveston Bay, while younger sediments would be found in suspension in Upper Galveston Bay. Despite potential inaccuracies with the February 24, 2021 TSS data, the overall TSS data for the study was also aligned with expected outcomes. The increased amount of TSS in Lower Galveston Bay is a potential result of the transport of sediment that experienced resuspension from the passage of a cold front. A future comprehensive study that includes tidal and atmospheric data could produce a more definitive assessment of the impact of cold front passages in Galveston Bay.

This study also served to demonstrate the effectiveness of the Matisoff Method in calculating sediment age using the radionuclide tracers ^{7}Be and ^{210}Pb in an estuarine system. In addition to expanding the amount of data that has been collected about Galveston Bay, this study will hopefully inspire additional research into the impact on high-frequency meteorological phenomena such as cold fronts on similar systems. Ultimately, the results generated in this study are a fair indicator that cold fronts have a significant impact on the age of suspended sediment.

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