

FLOW AND SEDIMENT DYNAMICS OF LOWER BRAZOS AND SAN BERNARD RIVER BASINS – PHASE I

Final Report

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Prepared by

Yu Zhang, Behzad Nazari and Habib Ahmari,
University of Texas at Arlington

Timothy Dellapenna,
Texas A&M University Galveston

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Contents

List of Figures	4
List of Tables	8
Executive Summary	10
1. Background and Project Overview	13
2. Compilation of Regional Models	22
3. Sediment Coring and Analysis	28
4. Bathymetric Survey	48
5. Evaluation of TxRR runoff estimates	54
6. Development of Regional Models	59
7. Scenario Analysis	69
8. Summary of Stakeholder Engagement, Findings and Recommendations	88
References	93
Appendix A: Coring Locations	97
Appendix B: Cedar Lake Sub-bottom	98
Appendix C: Core Sheets	116
Appendix D: Brazos River Bathymetry	138

List of Figures

Figure 1-1: Coastal zone of concern for the Texas Coastal Resilience Master Plan titled " <i>Lower Brazos and San Benard River Restoration Strategy and Management Plan</i> " formulated in 2018. Major coastal streams that drain to the Gulf include Brazos River, San Bernard River, Cedar Lake Creek and Caney Creek. Bottom panel is a blow-up of the study region. Source of basemap: USGS.	13
Figure 1-2: Satellite images of the coast zone centered at San Bernard River mouth taken in January of 1995 (left) and January of 2009 (right).	14
Figure 1-3: Satellite image taken on 11 November, 2015 during a flooding event, focusing on Cedar Lakes, GIWW, and offshore (left), and Brazos River, GIWW and offshore (right).	14
Figure 1-4: Satellite images of the coast zone centered at San Bernard River mouth taken in February of 2019 (left) and November of 2011 (right).	15
Figure 1-5: Left: inundation during Hurricane Harvey (source: Dartmouth Flood Observatory). Right: Aerial photo taken at the San Bernard River mouth after Hurricane Harvey.	15
Figure 1-6: Satellite photos showing the San Bernard River mouth taken in the November of 2021, January of 2022, and April of 2022.	16
Figure 1-7: Aerial photos taken at the San Bernard River mouth in February 2025 (left), and January 2026 (right). Image courtesy of Albert Smith.	17
Figure 1-8: Brazos River Flood Gates at the intersection with GIWW.	17
Figure 1-9: Satellite images of Sargent Beach taken in 2004 (left) and 2022 (right). The retreat of shoreline is evident.	18
Figure 1-10: Satellite image at Mitchell's cut. Note the formation of sandbar in the middle of the pass.	19
Figure 1-11: Study domain for the Phase-1 project, which covers the Cedar Lakes, lower portions of San Bernard River, Brazos River and the littoral zone.	20
Figure 1-12: Overall project strategy and elements.	21
Figure 2-1: Coastal watersheds for Brazos River, San Bernard River and Cedar Lake Creek. Source: TWDB.	22
Figure 2-2: Model domain of Lower Brazos HEC-RAS from USACE Fort Worth District.	24
Figure 2-3: Domain of HEC-RAS model for San Bernard River from Scheibe Consulting.	25

Figure 2-4: Model domain and mesh for the Delft-3D model USACE developed for the BRFG study.	26
Figure 2-5: Domain and computational mesh of TWDB SCHISM model. Upper left panel shows a blow-up of the mesh over the Cedar Lakes – Lower Brazos River region.	27
Figure 3-1: Basemap for Cedar Lakes Study area. Map showing the Cedar Lakes and other coastal lakes investigated west of the Brazos River channel. Core locations are noted with yellow thumbtacks and white labels.	28
Figure 3-2: Basemap showing the location of CHIRP Subbottom Profiler lines collected within the Cedar Lakes System.	29
Figure 3-3: Basemap showing the historical changes in shorelines of the Cedar Lakes System. Red lines show the 1933 shoreline, green lines show the 1961 shoreline and the background is from 2024.	30
Figure 3-4: A) Brazos River Drainage Basin map; B) Map showing the rain fall from Hurricane Harvey with the Brazos, Colorado, and San Bernard River drainage basins outlined.	31
Figure 3-5: Historical Brazos River Peak Discharge. The last three peak discharges are noted in the figure. Source: USGS.	33
Figure 3-6: Brazos River Hydrographs. A) River discharge in cubic meters per second in blue. B) Gage Height in meters in red. Data Source: USGS.	33
Figure 3-7: MODIS Satellite Image from August 31, 2017 showing various sediment plumes from Hurricane Harvey	34
Figure 3-8: An Edgetech SB424 subbottom profiler was used during this survey.	38
Figure 3-9: End-member XRF profiles for the Brazos River Sediment (BR-01) and Colorado River (CD-01).	39
Figure 3-10: Basemap referencing CHIRP Subbottom Profiler Lines K-K', A-A', C-C' and E-E', and the respective lines. The top of the Pleistocene is delineated in each line, showing that the top of the Pleistocene surface is generally less than 3 m below the bay bottom.	40
Figure 3-11: Core Cross Section A-A' extends across all cores collected within the Cedar Lakes south of the GICWW, with lithology plotted atop Red/Green Reflectance.	41
Figure 3-12: Core Cross Section B-B' extending across the inland cores collected north of the GICWW.	42

Figure 3-13: Core Cross Section C-C'. Both cores were collected in open embayments off the northside of the GICWW, east and west of the San Bernard River, respectively.	43
Figure 3-14: Sediment Transport Pathways during pre and post 1948 Gulf Intracoastal Waterway (GICWW) opening. A) pre-1948 and pre-GICWW opening, showing that Colorado River sediment was transported to the study area as well as Gulf of Mexico (GOM) overwash sediment, but other than proximal the Brazos Channel, no Brazos sediment was transported into the study area. B) post 1948 and post-GICWW opening showing that in addition to the Colorado River sediment and GOM overwash, Brazos River sediment was transported into most areas via the GICWW.....	45
Figure 3-15: Map showing the flow pathways of the Brazos and Colorado Rivers during Hurricane Harvey.	46
Figure 4-1: Single beam bathymetric survey lower San River conducted by EOS.	48
Figure 4-2: Elevation profiles derived from the 2023 and 2024 bathymetric surveys at the northmost cross-section along the Brazos River.	49
Figure 4-3: As Fig. 4-2, except at a cross-section along the Brazos River north of the crossing with GIWW.	49
Figure 4-4: As Fig. 4-2, except at a cross-section along the Brazos River south of the crossing with GIWW.	50
Figure 4-5: As Fig. 4-2, except at a cross-section at the Brazos River mouth.	50
Figure 4-6: Geographic extent of the offshore bathymetric survey.	51
Figure 4-7: The transects at which bathymetric survey was conducted.	52
Figure 4-8: Results of the bathymetric survey conducted offshore of Brazos River.	53
Figure 5-1: San Bernard River, lower Brazos River, and USGS gauging stations along the two streams (left). Land cover overlaid with TWDB watershed boundaries (right).	54
Figure 5-2: Cumulative annual runoff inferred from USGS observations and computed by TxRR for San Bernard River between Boling and Sweeny.....	56
Figure 5-3: Time series of runoff derived from USGS records and TxRR simulations for two events along the San Bernard River in 2021.....	56
Figure 5-4: As Fig. 5-3, except for two events in 2022.	57
Figure 5-5: Annual runoff for Brazos River between Rosharon and West Columbia based on TxRR simulations and USGS observations.	57

Figure 5-6: Time series of runoff derived from USGS records and TxRR simulations for two events along the lower Brazos River in 2021.	58
Figure 5-7: As Fig. 5-6, except for two events in 2022.	58
Figure 6-1: Computational meshes for the SWAN and Delft-3D models developed for this project. Note the SWAN is developed on a 2-way nested mesh.	61
Figure 6-2: Left panel: the mesh of the regional Delft-3D model. Right panel: the model mesh for a subdomain that covers the eastern portion of the study region.	62
Figure 6-3: Computation domain and mesh for the X-beach model developed in this project. ...	63
Figure 6-4: Time History of Hurricane Nicholas. Source: NOAA.	65
Figure 6-5: Wind fields at and after landfall of Hurricane Nicholas. Source: ECMWF.	65
Figure 6-6: Velocity fields simulated by Delft-3D at four snapshots around the landfall of Hurricane Nicholas.	66
Figure 6-7: Flow vector and cumulative erosion/deposition along the shoreline and San Bernard inlet.	67
Figure 6-8: Cumulative sediment flux in the littoral zone along five cross-sections between September 1 and 13.	68
Figure 6-9: Cumulative sediment flux in the littoral zone along five cross-sections between September 13 and 15.	68
Figure 7-1: Left: Rainfall map on August 29, 2017 during Hurricane Harvey. Right: hydrographs observed at two USGS gauges, namely San Bernard River near Sweeny, and Brazos River near West Columbia.	70
Figure 7-2: Elevation maps for the two scenarios: 1) with San Bernard Inlet closed and 2) with San Bernard Inlet open.	70
Figure 7-3: Simulated water depth on August 28 for the scenarios with San Bernard River inlet closed (left) and opening (right).	71
Figure 7-4: Time series of simulated water level at selected locations along the San Bernard River for the two scenarios.	72
Figure 7-5: Schematic of flow directions along the GIWW and lower San Bernard River during Harvey.	72
Figure 7-6: Topo-bathy data at the intersection between Brazos River and GIWW before (left) and after the modification of BRFG (right).	74

Figure 7-7: Locations of WIS virtual stations in the region (left) and the distribution of wave height characterized by average return period (right).....	74
Figure 7-8: Wave patterns for 2022 and 2023 based on ERDC Wave Information Study.....	75
Figure 7-9: Dominant wave regimes in 2022 and 2023.....	76
Figure 7-10: X-beach simulated sedimentation/erosion along the shoreline during the year of 2022: map of cumulative deposition/erosion (left), and distribution (right).	77
Figure 7-11: As Fig. 7-9, except for the year of 2023.....	77
Figure 7-12: Averaged monthly wind direction and intensity at the San Bernard River mouth... 78	
Figure 7-13: Observed discharge between November 17 and December 7 at USGS stations near Sweeny along the San Bernard River (left) and West Columbia on the Brazos River (right).....	78
Figure 7-14: Cross-sections where cumulative flow and sediment flux are computed.	79
Figure 7-15: Time series of cumulative water flux at X-section 1.	80
Figure 7-16: As Fig. 7-15, except at X-section 2.....	81
Figure 7-17: As Fig. 7-15, except at X-section 3.....	81
Figure 7-18: As Fig. 7-17, except at X-section 4.....	82
Figure 7-19: As Fig. 7-17, except at X-section 5.....	82
Figure 7-20: As Fig. 7-15, except at X-section 6.....	83
Figure 7-21: Discharge time series at the four cross-sections (2-5) at the intersection between GIWW and San Bernard River.	83
Figure 7-22: Cumulative sediment transport at X-section 1.....	84
Figure 7-23: As Fig. 7-21, except at X-section 2.....	85
Figure 7-24: As Fig. 7-21, except at X-section 3.....	85
Figure 7-25: As Fig. 7-21, except at X-section 4.....	86
Figure 7-26: As Fig. 7-21, except at X-section 5.....	86
Figure 7-27: As Fig. 7-21, except at X-section 6.....	87

List of Tables

Table 2-1: Selected Hydrologic and Hydrodynamic Models for the Region.....	22
Table 2-2: TWDB Coastal watersheds and drainage areas.	22
Table 2-3: Limitations of existing model systems	27
Table 3-1: Sediment Accumulation Rates.....	41

Table 4-1: Geodetics of Survey Data	51
Table 5-1: USGS stations and related TWDB watersheds.....	54
Table 5-2: Annual runoff based on TxRR simulations and USGS observations for lower San Bernard River between Boling and Sweeny.	56
Table 5-3: Annual runoff based on TxRR simulations and USGS observations at WS12001	57
Table 6-1: Comparisons between Delft-3D and X-beach models developed in this project	60
Table 8-1: Results from Stakeholder Survey: Regional Priorities	89
Table 8-2: Results from Stakeholder Survey: Breakdown of Interests from Stakeholders	90

Executive Summary

The coastal region extending from the lower Brazos River to east Matagorda Bay has undergone rapid, dynamic changes in hydrology, sedimentation, and shorelines, some of which are responses to major engineering modifications completed in the early 20th century, including the diversion of Brazos River mouth and the construction of Gulf Intracoastal Waterway (GIWW). These changes are manifested in repeated closures of San Bernard River inlet, accumulation of Brazos River sediment in the Cedar Lakes, rapid retreat of Sargent Beach, and shoaling at Mitchell's cut. Collectively, they threaten the long-term economic viability of the communities and ecological integrity of the region.

A Texas Coastal Resiliency Master Plan (TCRMP) Project entitled “**Brazos River and San Bernard River Restoration Strategy and Management Plan**” was formulated in 2018 with a broad aim of identifying concerted strategies to address the aforementioned changes and associated impacts in response to concerns raised by regional stakeholders. With sponsorship by Texas General Land Office Coastal Management Program (CMP) - Gulf of Mexico Energy Security Act (GOMESA), a team comprising of experts from University of Texas at Arlington (UTA) and Texas A&M University Galveston (TAMUG) undertook the first phase of the TCRMP project in partnership with federal, state and regional entities, including:

- Brazoria County, Matagorda County, and Fort Bend County
- Texas Water Development Board
- US Army Corps of Engineers Galveston District
- US Fish and Wildlife Service
- Texas General Land Office Sediment Management Program
- Texas Department of Transportation
- Brazos River Authority
- Friends of San Benard River
- Aqua Strategy
- Scheibe Consulting

The overarching goals of the Phase-I project were three-fold: 1) to attain conceptual, holistic understanding of flow regimes, sediment dynamics, and drivers underpinning their changes; 2) to establish foundational model tools for appraising and determining potential solutions; and 3) to conduct preliminary evaluations of impacts from current and potential changes in morphology, specifically closure of San Bernard River mouth and widening of Brazos River Floodgate. The project was carried out in coordination with concurrent, state-wide initiatives including Texas Coastal Sediments Geodatabase (TxSed) Project, Texas Longshore Transport Study, and Texas Integrated Flood Framework (TIFF).

The project included coordinated field campaigns led by TAMUG and modeling analysis led by UTA. The TAMUG team gathered sediment core data in the Cedar Lakes and to the east of lower San Bernard River, and performed two rounds of bathymetric survey along the lower Brazos and

San Bernard River. The UTA team compiled existing regional models and developed coupled hydrologic-hydrodynamic and sediment transport models for the region, and assessed freshwater inflow estimates in the ungauged watersheds along the Lower Brazos River and San Bernard River provided by the TWDB. The two teams conducted two scenario analyses to determine the impacts from opening of Brazos River Flood Gate and closure of San Bernard River mouth.

The key findings from the Phase-I project are summarized below.

Finding 1: The backwater effects during Hurricane Harvey induced by the closure of San Bernard River mouth were felt mostly in the vicinity of the mouth, whereas the impacts rapidly diminished upstream of the intersection between the GIWW and San Bernard River due to spillover of floodwater, which likely reached the Gulf through the Cider Lakes and bypassed the San Bernard inlet.

Finding 2: In absence of freshwater pulses with sufficient intensity and frequency capable of dislodging the littoral sediments at the lower portion of San Benard River, this net deposition Closure of mouth inevitably leads to mouth closure, as it did after the completion of the 2022-2023 dredging project.

Finding 3: Impacts from opening of west gate of BRFG are most likely muted on stability of San Bernard River mouth. The case study of the high flow episode in 2022 suggests that the configuration of BRFG limits the ability of high flow from Brazos River to enter the GIWW towards west. Perhaps more importantly, the GIWW serves as a barrier that inhibits the flow pulses along the San Bernard River from reaching the downstream portion. In the 2022 episode, the high flow pulse was diverted mostly to the east along the GIWW. Barring historical floods such as Harvey, moderately high pulses from the San Bernard are mostly unable to enter the inlet to flash out the littoral deposits. This highlights the critical role GIWW plays to disrupt the flow connectivity along the San Bernard and contributes to the repeated closure.

Finding 4: Prior to the completion of GIWW in 1948, Cedar Lakes received its majority of sediments from the Gulf of America through storm surge, and from Colorado River floodwater that crossed into San Bernard River. After 1948, Brazos River contributed to a major share of sediments deposited in the lakes south of the canal, whereas Colorado River sediments are still an important source for lakes north of the canal.

Finding 5: The bathymetry of lower Brazos underwent rapid changes between 2022-2024 due to accumulation of sediments brought by flood pulses. About a million cubic yards of sediment deposited near Brazos mouth between 2023 and 2024, comprising mainly sand that can be potentially harvested for beach nourishment.

Finding 6: Contributions of runoff from coastal watersheds to streamflow along lower Brazos River and San Bernard River remain uncertain as extant model simulations depart widely from gauge observations. Much remains to be done to refine the estimates of runoff volumes for major flow events.

On the basis of these findings, we make the following recommendations for the future phase of the TCRMP:

Recommendation 1: Determine possible complementary strategies to sustain the opening of San Bernard River mouth after the future dredging effort. Several options emerged through the Phase-1 project, including installation of a jetty to the east of the mouth, placing a flood gate on the GIWW west of San Benard River crossing, dredging the lower Brazos River to undercut the growth of Brazos River Delta, and creating a canal bypassing the sharp elbow between GIWW and San Bernard River.

Recommendation 2: Attain a more in-depth, qualitative understanding of flow connectivity among coastal streams including lower Brazos River, San Bernard River, Caney Creek, and GIWW by collecting flow observations and comparing these with runoff simulations. In particular, the direction and rates of flow along the GIWW impact flow along the tidal streams and have important implications for transportation (barge traffic), bank erosion and sedimentation. These variables should be monitored and analyzed.

Recommendation 3: Create a regional modeling framework that would encompass tidal portions of major streams and the coastal zone extending from Brazos River mouth to East Matagorda Bay, and account for interactions between wave, current, and sediment. This framework will combine the functions of X-beach morphodynamic model and Delft-3D hydrodynamic model to account for freshwater and sediment pulses in projecting coastline changes in response to modifications such as dredging, establishment of jetty, and installation of floodgates.

Recommendation 4: Conduct offshore data collection to determine the impacts from long-shore and cross-shore currents on the offshore sediment regime near the coast from Brazos River mouth to Sargent Beach. Use the data to refine the regional modeling framework for projecting shoreline changes.

Recommendation 5: Expand data collection to along the GIWW and Cedar Lakes, and possibly perform sediment tracing, to quantify the volumetric fluxes of sediments from Brazos River that reached the Cedar Lakes and further west at Mitchell's Cut under different flow conditions.

1. Background and Project Overview

The coastline that stretches from the mouth of Brazos River to east Matagorda Bay has experienced rapid, dynamic changes in shorelines (Fig. 1-1). These changes manifest themselves in repeated closures of San Bernard River mouth, accumulation of Brazos River sediment in the Cedar Lakes, rapid retreat of Sargent Beach, and shoaling at Mitchell's cut.

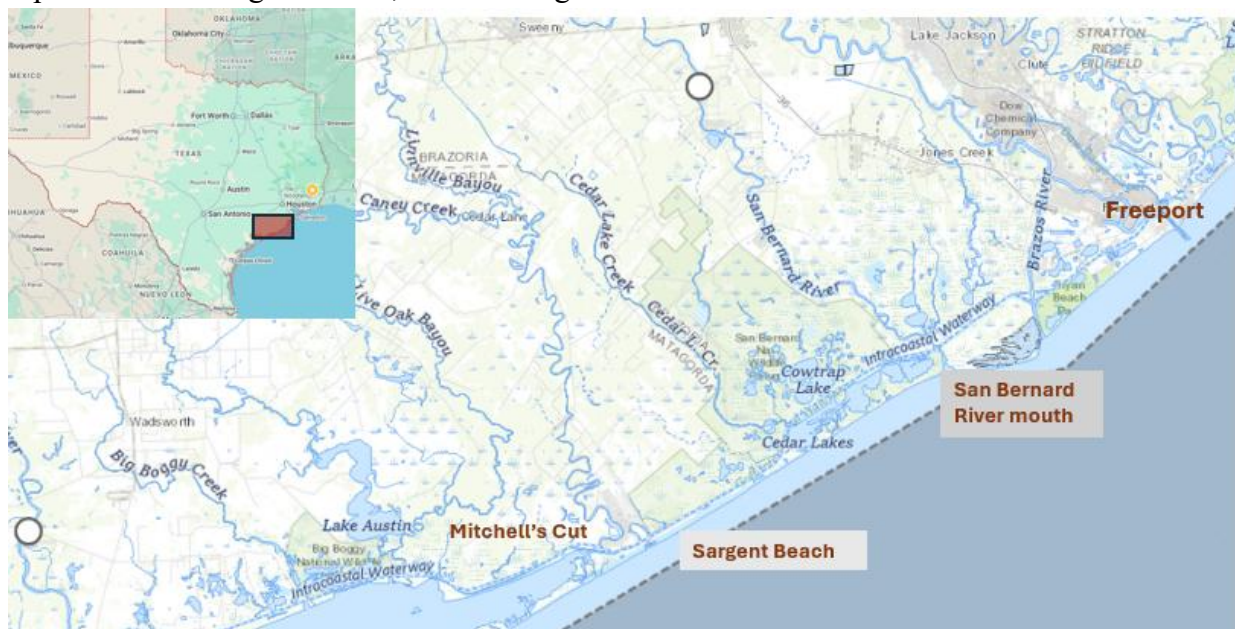


Figure 1-1: Coastal zone of concern for the Texas Coastal Resilience Master Plan titled "*Lower Brazos and San Benard River Restoration Strategy and Management Plan*" formulated in 2018. Major coastal streams that drain to the Gulf include Brazos River, San Bernard River, Cedar Lake Creek and Caney Creek. Bottom panel is a blow-up of the study region. Source of basemap: USGS.

Among these changes, closure of San Bernard River mouth has been a major concern raised by local regional communities. The San Bernard River features a much smaller drainage relative to the Brazos River (1800 mi² vs. 44,620 mi²), and is typically low in turbidity and sediment yield. The San Bernard River is a major source of freshwater to the Cedar Lakes (USACE), helping maintain the ecosystems in the San Bernad Wildlife Reserve. The Brazos River, whose drainage borders that of San Bernard River, delivers the largest quantity of sediments to the Gulf of America among coastal streams in the state of Texas (Kraus and Lin, 2002).

After the diversion of the Brazos River mouth in 1929 from Quintana to the west of Freeport, the Brazos Delta gradually migrated westward (Rodriguez et al., 2000; Miller, 2014). Eventually reaching its equilibrium in 1980s, the delta started to pass along sediments towards further west, facilitating littoral deposition along the San Bernard River mouth that led to its closure in the early 2000s (Kraus and Lin, 2002). Carlin et al. (2015) demonstrated that flood events export large volumes of sand and mud from the lower Brazos River to the adjacent continental shelf, which are

subsequently reworked by waves and coastal currents to modulate the evolution of the Brazos Delta.

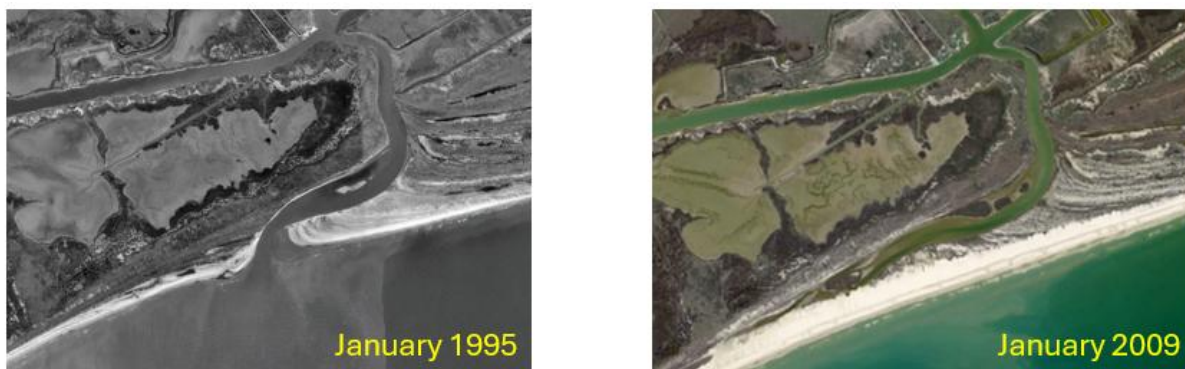


Figure 1-2: Satellite images of the coast zone centered at San Bernard River mouth taken in January of 1995 (left) and January of 2009 (right).

As shown in Fig. 1-2, between 1995 and 2009, a beach formed in the area that completely sealed off the mouth. Earlier works showed that stability of tidal inlet can only be achieved if littoral drift is counterbalanced by flushing by freshwater pulses (Mason and Sorensen, 1972). In the case of San Bernard River, the stream power associated with freshwater pulses reaching the inlet was clearly insufficient to counteract the intruding littoral materials brought by currents and tides (Kraus and Lin, 2002). While the size of drainage played a role, another potential contributing factor noted by stakeholders is the presence of Gulf Intercoastal Water Way (GIWW), which serves as a barrier that dampens large flow pulses arriving from upstream of San Bernard River (Sanchez and Parchure, 2001). Earlier work by Hyeong and Lawrence (2003) found that freshwater pulses from San Bernard River often flow eastward along the GIWW towards the Brazos River, though satellite images suggest that westward flow from Brazos River is dominant feature during major flood events. As shown in Fig. 1-3, a sediment plume that originated from Brazos River propagated westward through both GIWW and offshore.



Figure 1-3: Satellite image taken on 11 November, 2015 during a flooding event, focusing on Cedar Lakes, GIWW, and offshore (left), and Brazos River, GIWW and offshore (right).

The closure of San Bernard River mouth prompted concerns among regional stakeholders regarding its impacts on regional economy and ecosystems. These include a) potential increase in flood risks upstream of San Bernard River owing to the backwater effects induced by the presence of a downstream barrier; b) reduction in salinity that threatened habitats of shellfish and fish; and c) impairment to recreational fishing along the lower San Benard River. Recognizing these detrimental impacts, Brazoria County worked with the US Army Corps of Engineers to launch the first dredging project in 2009 that opened the mouth. The dredge material was placed to the west of the mouth to allow long-shore current to transport the sediments westward to help with replenishing Sargent Beach. This “sand engine” proved effective and led to a substantial growth of Sargent Beach in 2009-2010. However, only within a year, the mouth was almost completely closed again (Fig. 1-4).



Figure 1-4: Satellite images of the coast zone centered at San Bernard River mouth taken in February of 2010 (left) and November of 2011 (right).

During Hurricane Harvey in 2017, the historical flood produced widespread inundation in the region. According to Brazoria County, more than a thousand homes along the San Bernard River were flooded, and its exceptional stream power was able to open the San Bernard river mouth, albeit temporarily (Fig. 1-5).

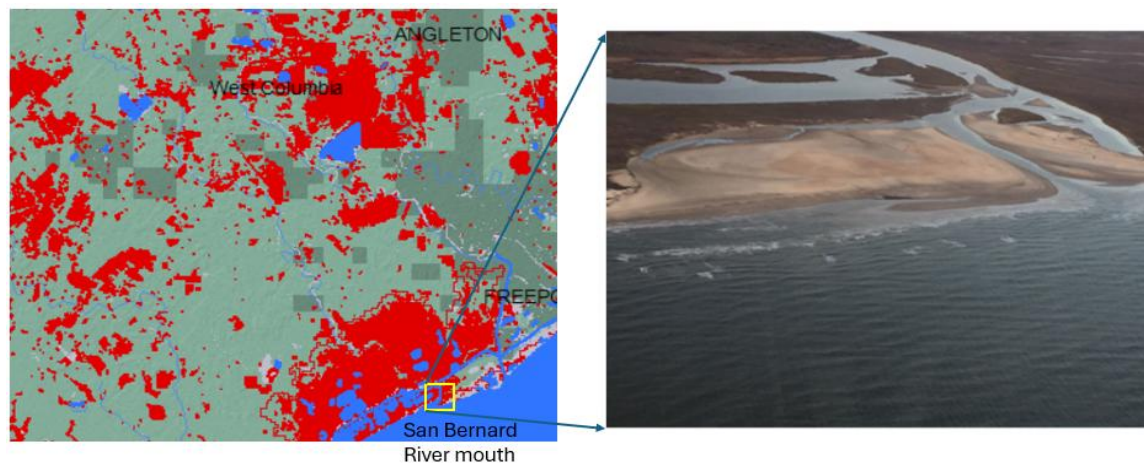


Figure 1-5: Left: inundation during Hurricane Harvey (source: Dartmouth Flood Observatory). Right: Aerial photo taken at the San Bernard River mouth after Hurricane Harvey.

With advocacy by regional stakeholders, the Brazoria County initiated a dredging project that opened the San Bernard River mouth. The project began on July 19, 2021 and was successfully completed on April 14, 2022, involving technical partners including HDR Engineering, Dannenbaum Engineering, Port of Freeport, and the USACE Galveston District. Fig. 1-6 shows the shoreline evolution between 2019 and 2023. The mouth remained partially open in November 2019, but the inlet is situated to the west of original one. Then it became progressively silted thereafter. The dredging project restored the original inlet over the east by April 2022, and the dredged material was placed to the west of the mouth to utilize the long-shore drift for transporting the sands to Sargent Beach. However, within a year, the mouth was mostly silted.



Figure 1-6: Satellite photos showing the San Bernard River mouth taken in the November of 2021, January of 2022, and April of 2022.

After briefly open during Hurricane Beyrl in 2024, the San Bernard River mouth has been mostly closed. In fact, the silting has become progressively worse. According to aerial photos along the coast by Albert Smith (Fig. 1-7), the mouth completed closed by February 2025, and a beach has

been developed and is steadily growing.

February 2025



January 2026



Figure 1-7: Aerial photos taken at the San Bernard River mouth in February 2025 (left), and January 2026 (right). Image courtesy of Albert Smith.

To facilitate navigation on GIWW to reduce impacts of flooding and sedimentation originating from upstream of Brazos River, the USACE constructed flood gates at its intersection with the GIWW (Fig. 1-8). The gates are typically closed during periods of flooding along the Brazos River to reduce impacts on barge traffic. Due to several needs such as improving safety of barge traffic and reducing inefficiencies related to delays caused by the narrow passage, the USACE has planned to remove the west gate, widen the channel and replace the east gate with a wider (125-ft) one. The USACE has conducted a modeling study to determine potential impacts of the planned project on sediment and flow dynamics in the vicinity of the intersection, including that on the stability of San Bernard inlet (USACE; 2019). The study found no significant change to sedimentation and flow as a result of the gate removal/widening that would detrimentally impact the San Bernard inlet. However, there were lingering concerns from regional communities, including:

- Increased flood risks along the GIWW and San Bernard River due to westward propagation of floodwater from Brazos River.



Figure 1-8: Brazos River Flood Gates at the intersection with GIWW.

- Increased sedimentation along to the south of San Bernard River-GIWW intersection, and in the Cedar Lakes
- A lack of long-term solution to the closure of San Bernard River mouth.

The Cedar Lakes System is a minor estuary or saltwater marsh that houses a rich variety of plant and wildlife species. The system features an ephemeral tidal inlet to the Gulf, and receives freshwater inflows primarily from San Bernard River, and to a lesser extent minor streams such as Cedar Lakes Creek. Over recent decades, Cedar Lakes System has experienced rapid sediment infilling that brought concerns about the future disappearance of the marsh if the trend continues. As San Bernard River itself carries a relatively low sediment load under normal conditions, it is suspected that the Brazos River sediments constitute a major source for the infilling.

To the west of Cedar Lakes, Sargent Beach is a major tourist attraction but has been known for its rapid erosion over years (Fig. 1-9). A study done by Morton (1991) found that erosion has been a persistent feature at Sargent, but the rate has apparently accelerated in the early 20th century. According to US Army Corps of Engineers, the rate of erosion at Sargent is the highest along the Texas Gulf Coast, reaching 32 ft in some years and seriously threatening the integrity of GIWW.



Figure 1-9: Satellite images of Sargent Beach taken in 2004 (left) and 2022 (right). The retreat of shoreline is evident.

A revetment wall was constructed in 1998 to safeguard the GIWW from the encroachment of sea water. However, erosion remained at an alarming pace; by 2022, much of the shoreline has retreated to near the revetment wall (Fig. 1-9, right panel). In 2024, two tropical storms, Hurricane Beyrl and Tropical Storm Alberto, accelerated the erosion and washed away the access road parallel to the revetment wall. The state and USACE have launched a shoreline stabilization project in 2025 that will install offshore structures to counteract the erosion and prevent potential breach of the revetment wall. Meanwhile, complementary measures are being sought to protect Sargent Beach, including the use of “Sand Engine” that uses long-shore current to transport sand for beach replenishment. After the completion of 2009 dredging project, the Sand Engine proved successful in temporally expanding the Sargent Beach in 2010-2011.

Further west, Mitchell’s cut is a narrow passage that connects East Matagorda Bay with the Gulf,

and it serves important navigational and ecological roles (Fig. 1-10). The primary challenges confronting Mitchell's cut include shoaling and shoreline retreat. A modeling study by Sun and Walther (2004) found that shoaling is likely due to settlement of eroded materials from nearby shoreline, though it is possible that Brazos River sediments that propagated through the GIWW may have played a role. The USACE has devised plans to reduce shoaling to facilitate navigation (Hamilton et al., 2021).



Figure 1-10: Satellite image at Mitchell's cut. Note the formation of sandbar in the middle of the pass.

In 2018-2019, the Texas General Land Office (TGLO) led the development of a Texas Coastal Resilience Master Plan (TCRMP) project titled “*Lower Brazos and San Bernard River Restoration Strategy and Management Plan*” with input from regional stakeholders. The TCRMP project recognizes interconnected nature of various issues confronting the region, and particularly the roles of major engineering alterations, specifically the diversion of the Brazos River mouth and the construction of the GIWW, in giving rise to these issues. The project intends to devise concerted strategies that would address these challenges in a holistic way.

A project team formed in 2020 led by UT Arlington with participation from Texas A&M Galveston. The project team collaborated with TGLO and AECOM to compile specific issues and priorities from regional, state and federal partners, which include:

- Friends of San Benard River
- Brazoria County, Matagorda County, and Fort Bend County

- Texas Water Development Board (TWDB)
- US Army Corps of Engineers Galveston District
- US Fish and Wildlife Service
- Texas General Land Office Sediment Management Program
- Aqua Strategy
- Scheibe Consulting

The outreach effort helped identify the following priorities for the initial phase of the TCRMP project:

- Collect critical sediment and bathymetric data to reconstruct flow and sediment pathways during historical events.
- Establish a foundational regional modeling system that system can be used to evaluate systemic impacts from potential intervention strategies.
- Perform case studies to re-assess the impacts of San Bernard inlet closure on the flooding upstream during Hurricane Harvey, and the impacts of BRFG west gate removal on the sedimentation patterns.
- Conduct a preliminary analysis of contributions of runoff in ungauged, coastal portions of San Bernard River and Brazos River on the freshwater inflows.



Figure 1-11: Study domain for the Phase-1 project, which covers the Cedar Lakes, lower portions of San Bernard River, Brazos River and the littoral zone.

In response to the priorities, the TCRMP project team formulated the Phase I project that focuses on the region encompassing Cedar Lakes, the lower portions of San Bernard River and Brazos River, and the littoral zone (Fig. 1-11). As shown in Fig. 1-12, the project consist of three major goals, namely: 1) establishing a regional model; 2) conducting field campaigns and analyzing the

resulting data; and 3) performing scenario analysis that would inform concurrent and future restoration/intervention strategies, including those related to dredging, inlet maintenance, erosion control, flood control, and environmental flows.

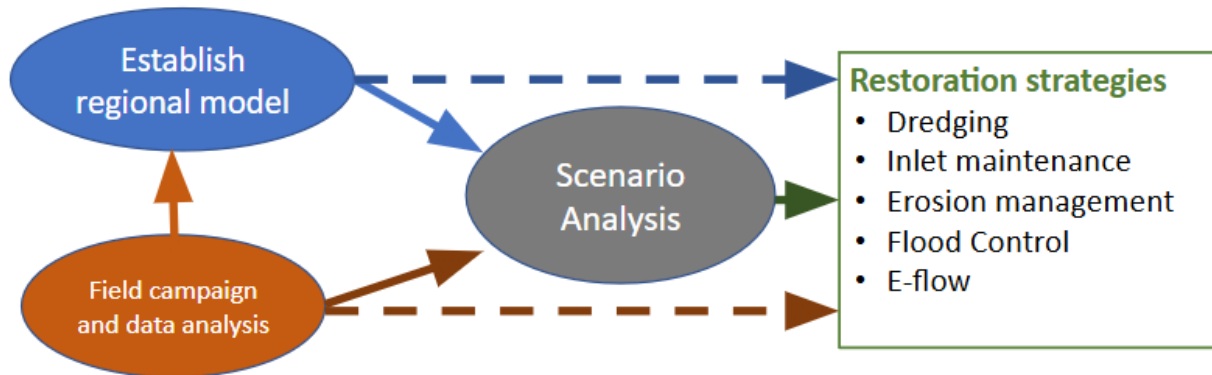


Figure 1-12: Overall project strategy and elements.

The project comprises seven tasks to achieve the aforementioned goals:

1. Acquisition of data and modeling tool
2. Field survey and collection of sediment cores
3. Configure and test hydrologic, hydrodynamic, and sediment transport models
4. Bathymetric survey to assess changes in Brazos River Delta
5. Model calibration and reconstruction of historical cases
6. Scenario Analysis
7. Outreach and stakeholder engagement

The project was complementary with ongoing state-wide initiatives including the Texas Sediments Geodatabase (TxSed) Project, Texas Longshore Transport Modeling Study, and Texas Integrated Flood Framework (TIFF), of which the first two are managed by the TGLO, and the third by the TWDB.

The remainder of the report will be organized as follows: Section 2 documents the regional models acquired from partnering institutions and describes their roles and limitations. Section 3 presents the sediment core collection and analysis. Section 4 describes the bathymetric survey and analysis. Section 5 summarizes the evaluation of TxRR runoff simulations along lower Brazos River and San Benard River using reconstructed flow observations. Section 6 presents the development and testing of regional models. Section 7 presents the scenario analysis. Section 8 summarizes stakeholder engagement, findings and recommendations for future phases of the project.

2. Compilation of Regional Models

A number of hydrologic and hydrodynamic models have been developed over the region for various purposes including salinity modeling, flood planning, shoreline restoration and environmental flow (Nazari et al, 2025). The project performed research on the following models listed in Table 2-1. Note that there have been concurrent developments during the performance of this project that are not reflected in the table.

Table 2-1: Selected Hydrologic and Hydrodynamic Models for the Region

Modeling System	Organization	Intended Purposes
TxRR	TWDB	Runoff in ungauged coastal watersheds
HEC-RAS for San Bernard River	Scheibe Consulting	Flood mapping
HEC-RAS for Brazos River	USACE Fort Worth	Flood mapping
SCHISM	TWDB	Estuary current and salinity modeling
DELFT-3D	USACE Galveston	Brazos River Flood Gate Study
TELEMAC/TOMAWAC	HR Wallingford	Wave hindcasts, longshore transport

The team acquired model and mesh for the first five systems as references in developing the regional model. The team did not acquire the TELEMAC/TOMAWC model developed by HR Wallingford for the Texas Long-shore Transport Study due to the difficulties in setting up the model in the team's computing platform and the different focuses of the current study.

TxRR

The TxRR modeling system comprises a single-layer soil moisture accounting model that computes rainfall excess and a unit hydrograph model that translates the excess rainfall into runoff. The TWDB delineates watersheds for each coastal stream, and the modules are implemented for each. The parameters of the modules are calibrated for watersheds with gauge records and are extrapolated to ungauged watersheds.

As shown in Fig. 2-1, the drainage of coastal Brazos River and San Bernard River each is partitioned into three watersheds in TxRR, and the drainage of Cedar Lake Creek is lumped in one watershed (Table 2-1).

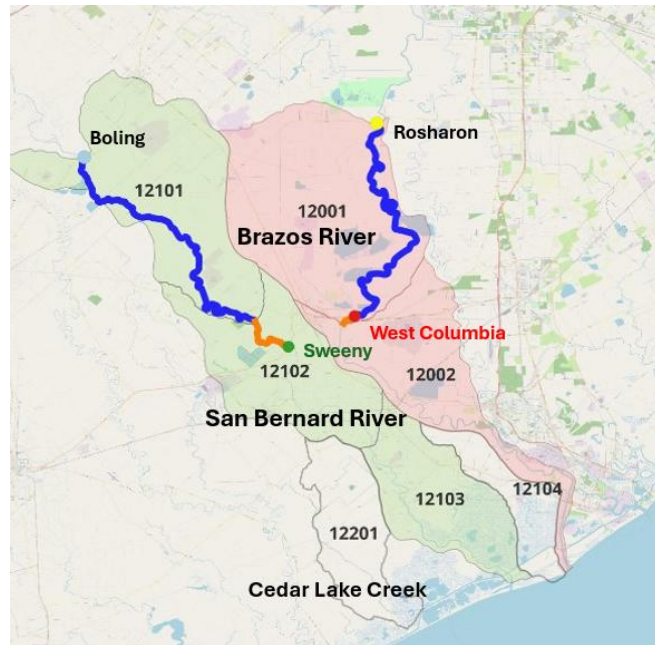


Figure 2-1: Coastal watersheds for Brazos River, San Bernard River and Cedar Lake Creek. Source: TWDB.

Table 2-2: TWDB Coastal watersheds and drainage areas.

Coastal Stream	Watershed ID	Drainage Area [mi ²]
----------------	--------------	----------------------------------

Brazos River	12001	151
	12002	83
	12104	33
San Bernard River	12101	132
	12102	85
	12103	68
Cedar Lake Creek	12201	54

Note that the watershed boundaries are not always aligned with the USGS stations. On the Brazos River, the USGS stations at Rosharon and West Columbia are situated right on the northern and southern border of watershed 12001. On the San Bernard River, the watershed 12101 spans the drainage downstream of the station at Boling but its southern boundary is upstream of the station at Sweeny. The project team also received the TxRR simulations from the TWDB and the evaluations will be shown in Section 5.

HEC-RAS

Fig. 2-2 shows the model mesh for the HEC-RAS 1D/2D model for the lower Brazos River built by the USACE Fort Worth District. The model mesh extends to the Gulf coast, spanning Austin, Waller, Fort Bend, and Brazoria Counties. At the time the team acquire the model, it only contained the spatial extent of the cross-sections but not the elevation.

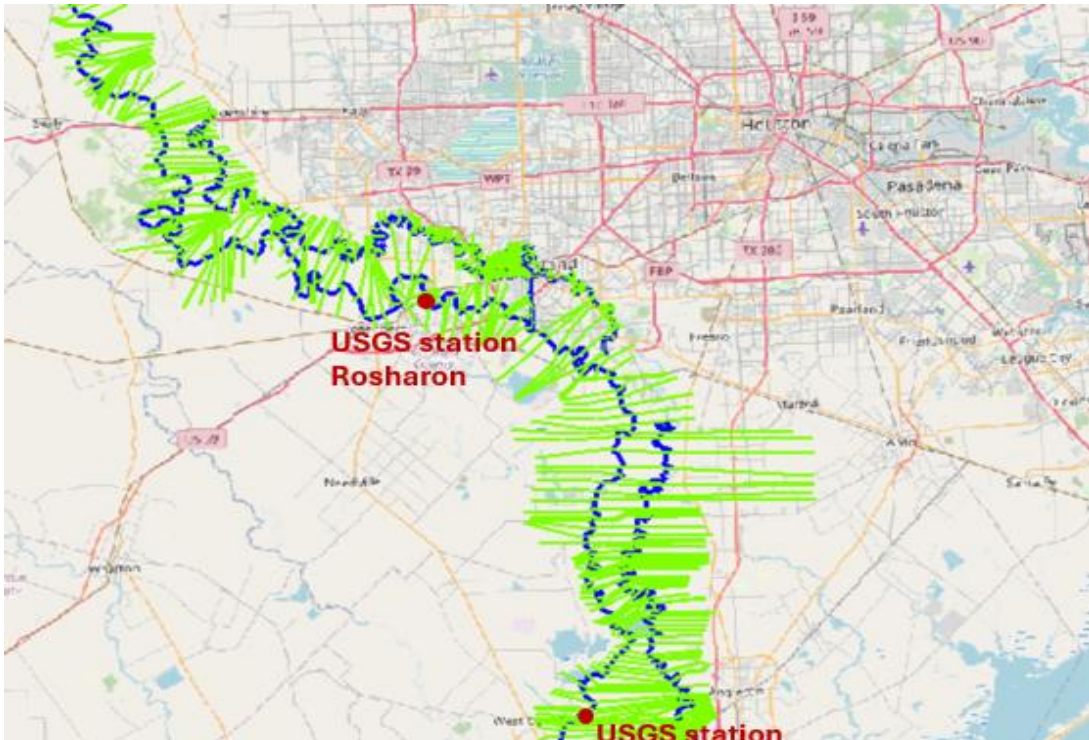


Figure 2-2: Model domain of Lower Brazos HEC-RAS from USACE Fort Worth District.



The
HEC-
RAS
model

from Scheibe Consulting is a 1-D model that covers the upper portion of San Bernard River north of the USGS station near Sweeny. The model's cross-sections were based on bathymetry survey completed prior to 2008, and its primary use was for flood mapping.

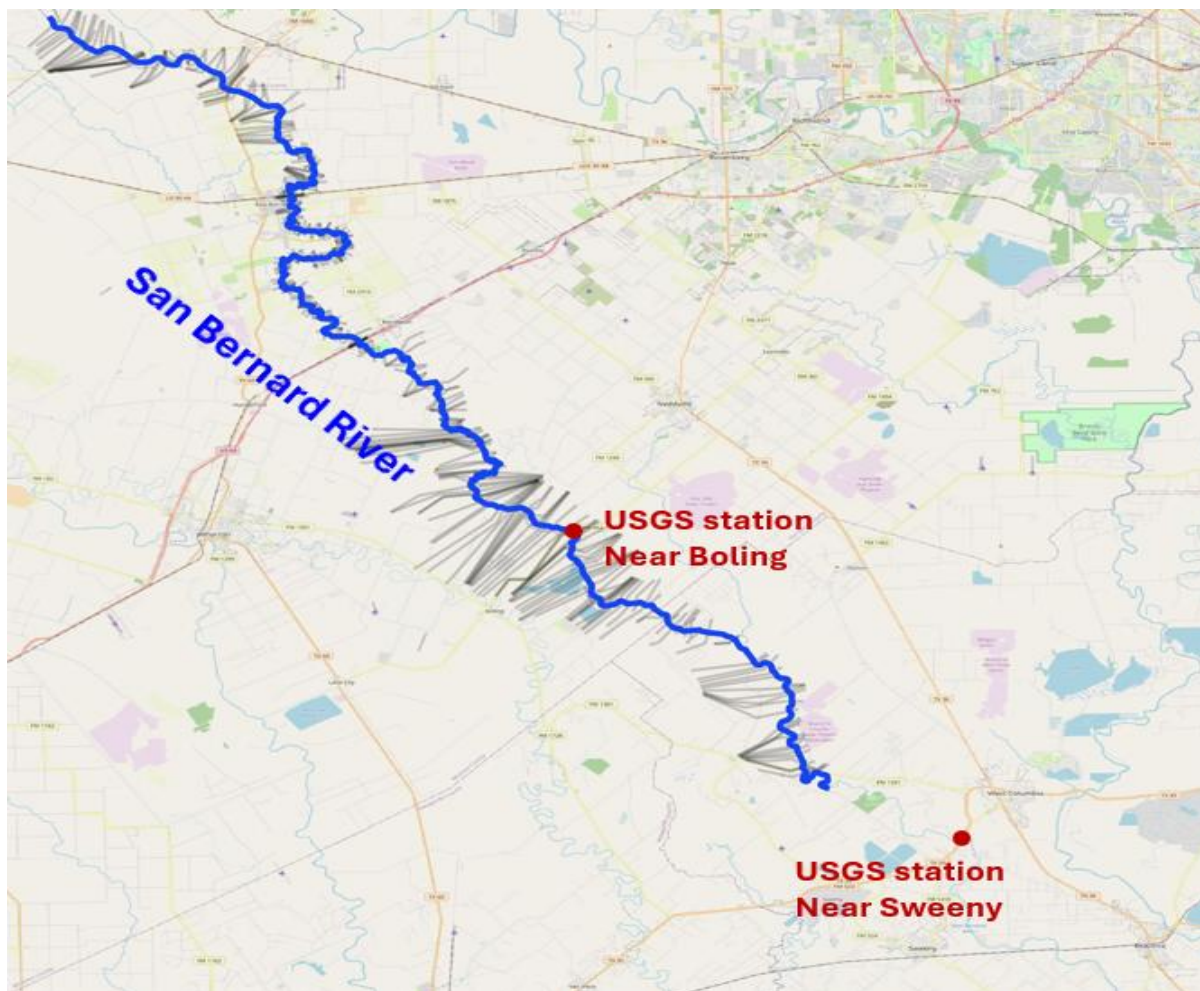


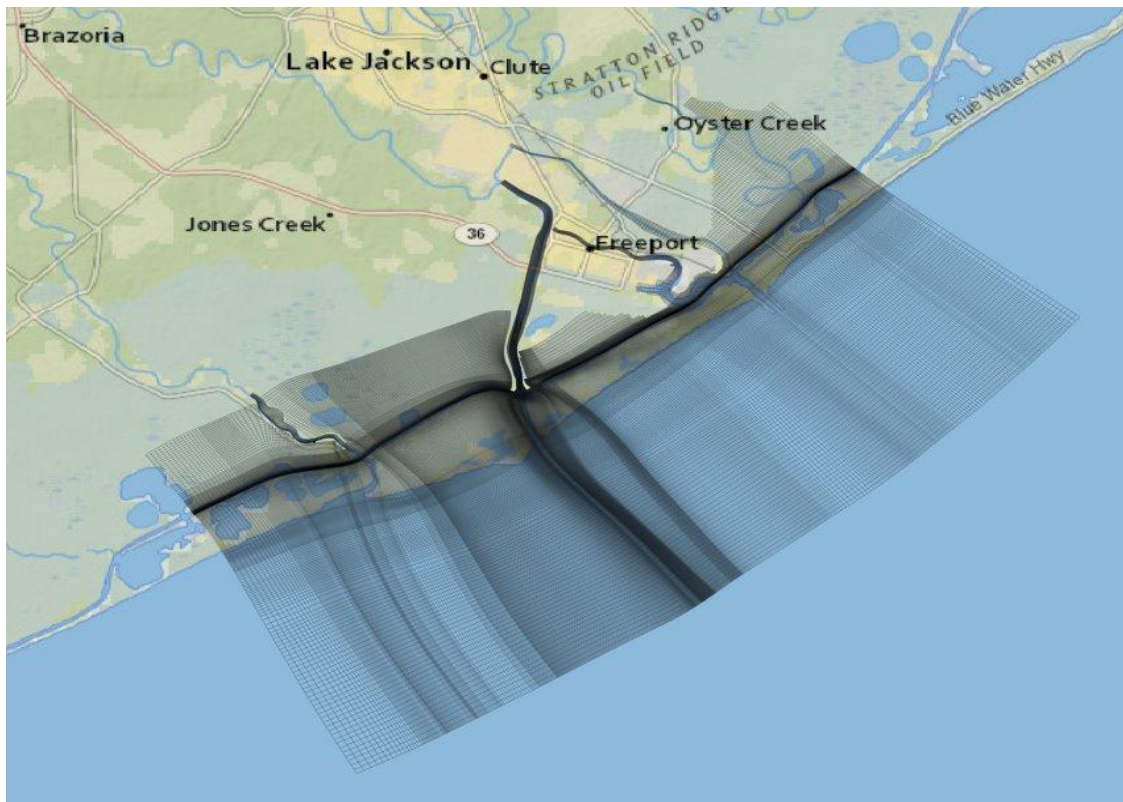
Figure 2-3: Domain of HEC-RAS model for San Bernard River from Scheibe Consulting.

USACE Delft-3D Model for BRFG Study

The USACE first developed and employed an ADH model in its BRFG study, and later a Delft-3D model. Both models were configured to simulate the flow, sedimentation, and morphologic changes in the vicinity of the BRFG under current conditions and after proposed gate removal and widening. In the BRFG study, the USACE also conducted laboratory-scale experiments using a physical analog model to corroborate the numerical model simulations.

The project team acquired the Delft-3D model as it was being actively used when the project started in 2022. As shown in Fig. 2-4, the Delft-3D model was implemented on a structured mesh which extends from the Cedar Lakes to the east of Oyster Creek, encompassing the coastal plains on both sides of the GIWW, the downstream portions of San Benard River and Brazos River. Mesh resolution is refined over the channels (Fig. 2-4). The model solves a 3-D version of the shallow water equation to derive flow fields (Lesser et al., 2004, Deltares Systems, 2026), and couples it with a sediment transport module that simulates bed and suspended loads from cohesive and non-

cohesive sediments, and produces dynamic updates of bathymetry in response to erosion/deposition.



The

Figure 2-4: Model domain and mesh for the Delft-3D model USACE developed for the BRFG study.

USACE performed simulations using both models for historical episodes including Hurricane Harvey (August 2017), Tropical Storm Beta (September 2020), January 2020 winter storm, and the shoaling event in the fall of 2021 (see USACE 2019 for results from ADH).

TWDB SCHISM Model

The TWDB has been in the process of developing and refining a SCHISM model for bays and estuaries along Texas coast. The model is intended primarily for modeling current and salinity dynamics and determining impacts from potential changes to freshwater inflows. At the start of this project, the TWDB completed a provisional, 2-D model for the coastline east of the Matagorda Bay. The project team acquired this model for reference. As shown in Fig. 2-5, the model uses unstructured mesh whose inland portion is confined to permanent water bodies such as bays and river channels. For the study domain of this project, the model mesh covers the entire Cedar Lakes, part of the GIWW, the lower San Bernard River, and the lower Brazos River. The coastal plain outside of the water bodies is not explicitly modeled.

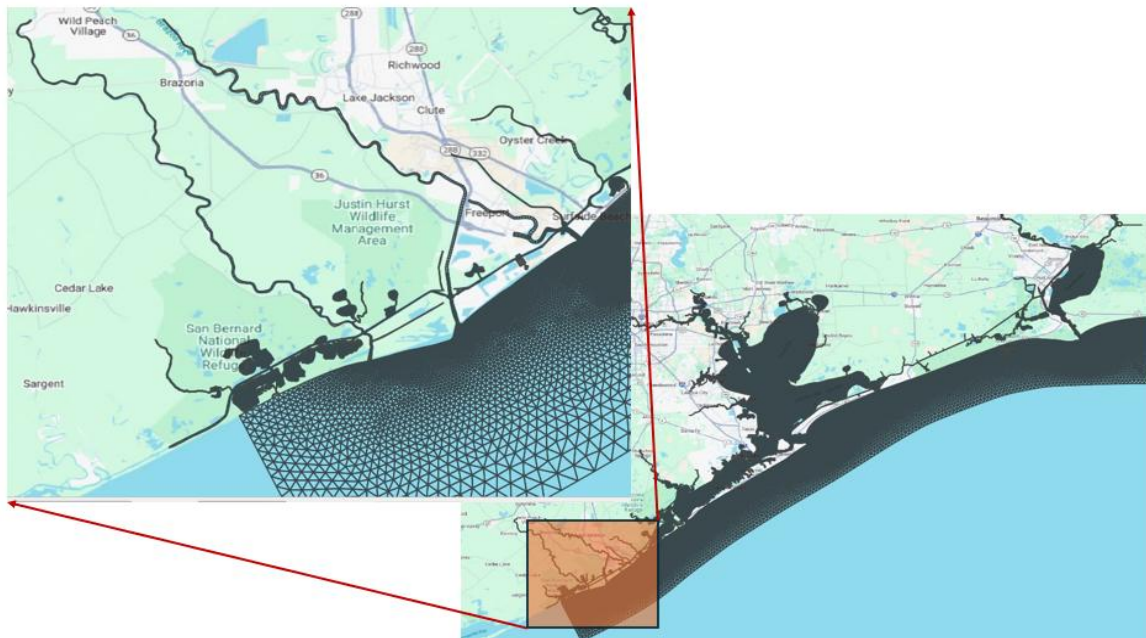


Figure 2-5: Domain and computational mesh of TWDB SCHISM model. Upper left panel shows a blow-up of the mesh over the Cedar Lakes – Lower Brazos River region.

The project team reviewed the mesh extents and quality, physics, and boundary conditions of the hydrodynamic/morphodynamic models (two HEC-RAS models, Delft-3D, and SCHISM) to determine the relevance of each to the current study. The findings are summarized in Table 2-2. The team therefore decided to develop a regional modeling system by adapting data and features from existing models, and this will be discussed in Section 5.

Table 2-3: Limitations of existing model systems

Modeling System	Mesh	Physics
HEC-RAS models	Does not cover lower portion of San Bernard River, Cedar Lakes, coastal plain and littoral zone. Lower Brazos River model does not have bathymetry.	Lack sediment transport morphodynamic modules
DELFT-3D	Covers only parts of Cedar Lakes. Does not cover entire tidal portions of San Bernard River/Brazos River	Lacks offshore wave-current-sediment coupling
SCHISM	Does not cover coastal plains Limited resolution for channels	Lacks sediment transport model 2-D rather than 3-D
TELEMAC/TOMAWAC	Limited resolution along channels	Lacks representation of dynamic morphodynamic changes at San Benard River mouth

3. Sediment Coring and Analysis

The study area for this project comprises a series of coastal estuarine lakes (Fig. 3-1), including the Cedar Lakes, as well as Cedar Lake Creek, Cowtrap Lake, McNeal Lake, Pelican Lake, and Jones Creek Lakes (collectively referred to herein as the Cedar Lakes system), which are all located west of both the mouth of the San Bernard. The purpose of this portion of the study is to characterize the geological setting along the Cedar Lakes portion of the combined Brazos/San Bernard Delta and determine the sources of the sediment deposited within the Cedar Lakes system. Historically, the Cedar Lakes were part of the Cedar Lakes Bayou drainage basin. With the 1929 movement of the mouth of the Brazos River 10 km west of its historical position and the installation of the Gulf Intracoastal Water Way (GICWW) in the late 1940's, the Cedar Lakes system is now part of the joint delta system and receives sediment from Cedar Lakes Bayou, and through the GICWW. The GICWW also receives sediment from the San Bernard and Brazos Rivers and potentially the Colorado River, all of which have the potential of being deposited within various portions of the Cedar Lakes system. The Brazos River has a 117,970 km² drainage basin, whereas the San Bernard drainage basin is 4,800 km² and the Cedar Lake Bayou is approximately 3,000 km². At flood stage, the Brazos River is likely a significant contributor of sediment to the Cedar Lakes system.



Figure 3-1: Basemap for Cedar Lakes Study area. Map showing the Cedar Lakes and other coastal lakes investigated west of the Brazos River channel. Core locations are noted with yellow thumbtacks and white labels.

It is essential that a thorough understanding of the geological framework of these coastal lakes, including the Cedar Lakes, as well as sediment sources and composition within the Cedar Lakes system is reached to determine strategies for mitigating hazards including flooding and siltation. The focus of this field campaign was on the southern portion of the Cedar Lakes system, an area

susceptible to coastal flooding via the GICWW and barrier island hurricane overwash from the Gulf of Mexico (GOM). To accomplish this, a series of 19 vibrators were collected from the study area (see Appendix A for core locations), as well as a series of ultra-high resolution CHIRP seismic lines (Fig. 3-2 and Appendix B). Each core was split axially, and each half was x-rayed to image internal sedimentary structures. The cores were run through a Geotech Multi-sensor core logger equipped with an X-ray Fluorescence (XRF) scanner for elemental analyses. The core logger also has a high-resolution line scanner for color digital photography and a color spectrometer for color spectrum analyses. Each core was subsampled at 5 cm intervals for grain size analysis, water content, and $^{210}\text{Pb}_{\text{xs}}$ age dating, and select samples were analyzed for ^{137}C geochronology as well (see Appendix C for Core sheets). CHIRP subbottom profiler lines were collected across each of the lakes to determine the depth and extent of the lake deposits. Collectively, these data sets were used to develop a geological framework of the Cedar Lakes system and an assessment of the sediment fill within the lakes.

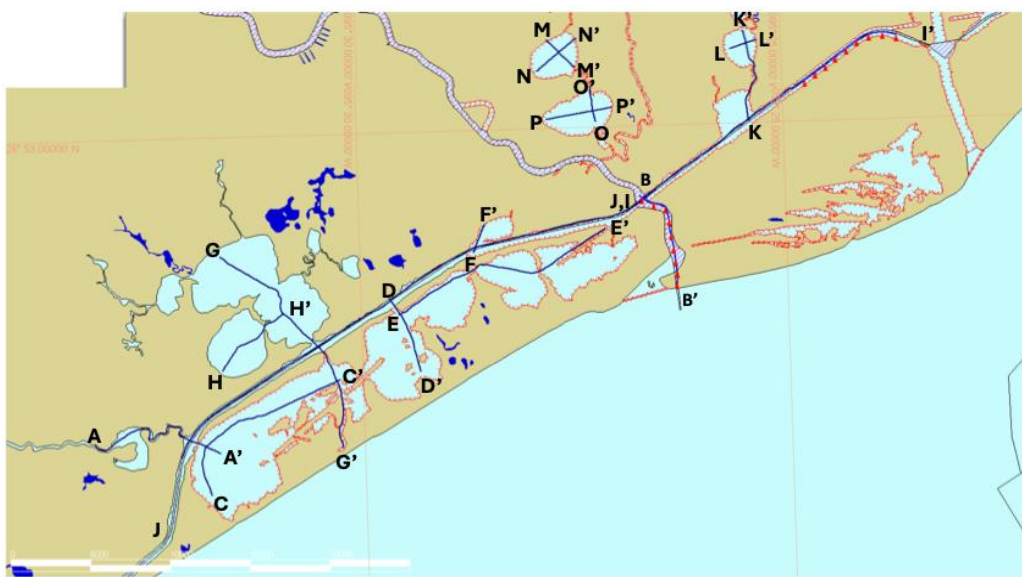


Figure 3-2: Basemap showing the location of CHIRP Subbottom Profiler lines collected within the Cedar Lakes System.

3.1 Background

The Cedar Lakes system consists of a series of connected shallow lakes within Brazoria County (Fig. 3-1), TX. The average depth of the Cedar Lakes is 2.1 feet (0.64 m), and Cedar Lake Creek historically flowed into the Cedar Lakes on the western end of the westernmost lake. Cedar Lake Creek is one of few coastal marshlands/bayous in Texas that has not been anthropogenically altered. Flood attenuation remains an important function of the surrounding bayou, as the bayou and lakes absorb excess water from storm events and slow down the rate of wetland run-off. The Cedar Lakes region within the (GOM) has undergone large morphological changes since the mid-1800s (Morton, 1975; Paine et al., 2012). Figure 3-3 shows a comparison of historical coastlines from

1933 (red lines), 1961 (green lines), and 2024 (background). Note, that the maps do not encompass the entire Cedar Lake system as data west of the mapped area is not available, but overall, the maps show the general trends. In 1929 the mouth of the Brazos River was relocated 10 km to the west of its original location at the mouth of Freeport Harbor (Fig. 3-3). The mouth of the Brazos River was originally 15 km to the east of the mouth of the San Bernard River, but the relocation brought the mouth of the Brazos River 5 km to the east of San Bernard River. The Brazos River is the 11th longest river in the United States with a watershed of about 118,000 km² (Carlin et al., 2014; Carlin et al., 2015). The Brazos is second only to the Mississippi River for rivers that consistently drain directly into the GoM without an estuary. The Brazos River has an average suspended sediment load of approximately 10-16 Mt/yr (Ludwig, 1998; Rodriguez et al., 2000; Carlin, 2013). The river sediment is largely dominated by fine-grained sediment (>65%), characterized by a distinctive red color derived from Triassic red beds further upstream (Rodriguez et al., 2000; Dunn and Raines, 2001).

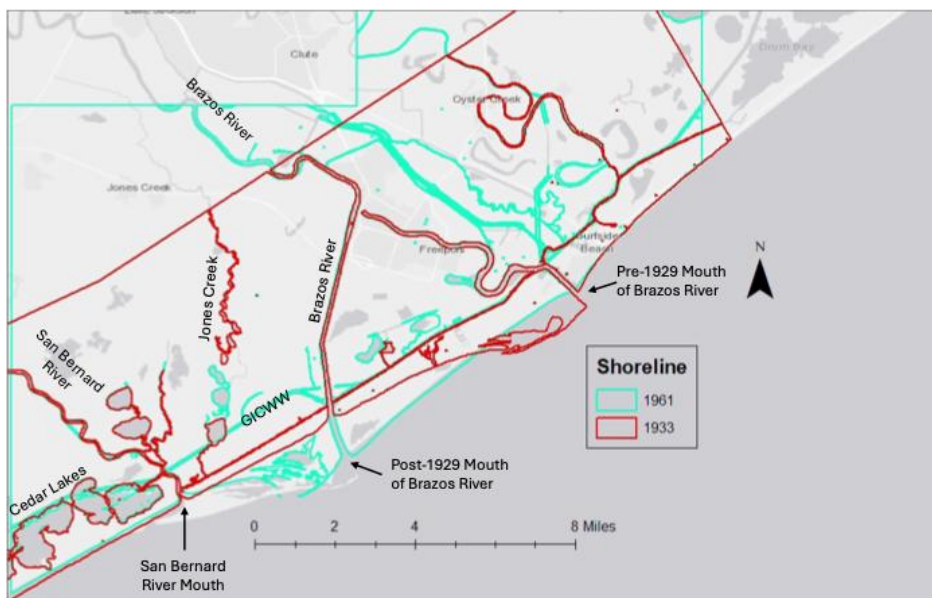


Figure 3-3: Basemap showing the historical changes in shorelines of the Cedar Lakes System. Red lines show the 1933 shoreline, green lines show the 1961 shoreline and the background is from 2024.

The current Brazos River delta began forming in 1929, when the river mouth was relocated 10 km west of its current location to maintain the port of Freeport, TX (Carlin and Dellapenna, 2015). Brazos River forms a muddy, asymmetric, wave-dominated delta with an area of 35 km², of which 70% is subaqueous, which has expanded 10 km to the west since its initiation (Rodriguez et al., 2000; Bhattacharya and Giosan, 2003; Carlin and Dellapenna, 2014). The growth of the Brazos River Delta caused the mouth of the San Bernard River to continually migrate to the west until it originally closed in 2006, 2.6 km to the west of its original position. The San Bernard mouth was reopened in 2010 but closed again in 2012. The floods associated with Hurricane Harvey (2017) reopened the mouth again, and in 2022 the mouth was dredged to expand its opening. By 2024 the mouth had largely re-silted in again.

Sedimentation processes in this area tend to modulate between multi-year drought or flood conditions such as the El Niño (i.e., flood conditions) and La Niña (i.e., drought conditions) cycles (Fratice, 2006). During drought conditions, sediment transport is minimal ~85% of the time so that sediments tend to trap within the lower portions of the river, yet during flood conditions, the trapped sediment is then remobilized and exported (Carlin et al., 2015). Consequently, stratigraphic records on the shelf directly seaward of the river mouth contain a clear pattern of alternating layers of Brazos sediment and non-event background GoM sediments (Carlin and Dellapenna, 2014). However, these flood deposits can be quickly remobilized and transported along the continental shelf (Carlin and Dellapenna, 2014), likely by the passage of cold fronts during winter months (Carlin et al., 2021). The northern GoM is highly impacted by these meteorological events, experiencing between 30-40 cold fronts per year (Roberts et al., 1987; Moeller et al., 1993; Carlin et al., 2016) that potentially favors sediment dispersal away from the subaqueous delta towards the Texas Mud Blanket (TMB), an ~300 km² deposit located in the northwestern GOM along the central Texas shelf (Carlin et al., 2021).

The central Texas coast yields an annual rainfall range between 104 to 125 cm. The amount of rainfall within the coast varies heavily in response to tropical storms, relating to the size and effective drainage of the San Bernard, Colorado, and Brazos River sediments (Figs. 3-4A&B). Within the Texas Coast, the Brazos River remains the primary source of sediment along the GOM shoreline, and much of the longshore transport is to the southwest (Kraus & Lin, 2002). With the river mouth having been moved 10 km to the west, not only does sediment come from within the basin but also from offshore, as the former Brazos Delta is heavily eroded and transported to the west (Carlin and Dellapenna, 2014). The river formed a new delta at its new position, which appears to express significant control on the morphology of the Texas coast to the southwest, especially the San Bernard River Mouth (Kraus & Lin, 2002). Large storm events are easily observed from areal imagery of the sediment plumes of the respective river basins. The Brazos River drainage basin passes through similar climates as the Colorado, however, the sourcing of Colorado sediment results in a much coarser sediment load with lower discharge rates

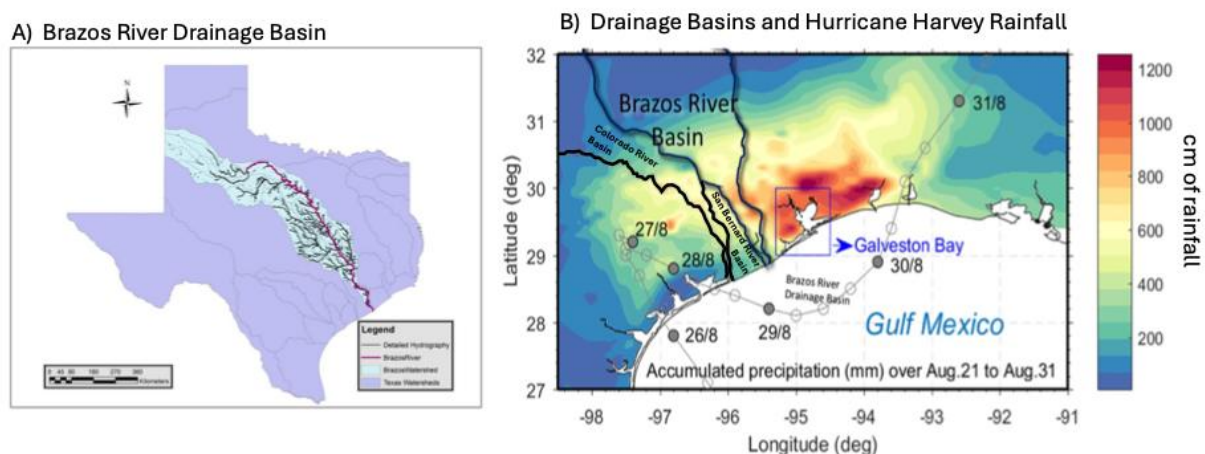


Figure 3-4: A) Brazos River Drainage Basin map; B) Map showing the rain fall from Hurricane Harvey with the Brazos, Colorado, and San Bernard River drainage basins outlined.

et., 2004). The flooding associated with Hurricane Harvey temporarily opened the mouth of the San Bernard River and the flooding of the Brazos River, resulting in a large amount of sediment discharge. Among the sediments being transported and stored within the westward longshore drift include finer sediments, particularly red clays, sediment often associated with the Brazos River Drainage basin. Studies examining Brazos River sedimentation confirm that the mineral composition of Brazos makes its sediment red to red-brown. The red color of the material originates from Triassic red beds located in the upper portion of the drainage basin. Moreover, the predominant chemical found through XRF analysis was cited to be calcium (Ca) due to the carbonate-dense nature of the surrounding watershed (Carlin and Dellapenna, 2014).

As of now, there are floodgates within the GICWW on both the east and west side of the intersection with the Brazos River, as well as a navigation lock, which provides barge traffic the means to overcome tidal/river level variations and promote vessel operations. Shallow lakes, such as the Cedar Lakes just west of the San Bernard Basin, are cited as disturbing the hydraulic conditions within the gates due to the storage of water (Sanchez and Parchure, 2001). The west gate is designed to be kept closed to reduce sedimentation with the GCIWW, however, the passage of vessels requires the opening of the gate for passage (Kraus and Lin, 2002). Issues arising from the variable nature of the current San Bernard River mouth are promoting efforts to re-open the mouth of the San Bernard to restore the basin and current within the GCIWW to the natural hydrologic conditions (Lin et., 2004). Moreover, low-lying coastal communities are put at risk from both storm surges and high fluvial discharges due to the sediment deposition that has occurred near the mouth of the San Bernard.

Hurricane Harvey

Episodic events play a crucial role in determining the distribution and magnitude of sediment deposition in estuarine and deltaic systems, where rainfall from large storms greatly increases sediment discharge to the near-shore region – in particular in rivers with smaller catchments (Chen et al., 2017; Carlin et al., 2021). Hurricane Harvey (hereinafter referred to as Harvey), a slow-moving tropical cyclone, made landfall in Texas as a Category 4 hurricane in August 2017, where it delivered between 0.6 to 0.9 m of rainfall across the lower portions of the Brazos drainage basin (Fig. 3-4B) (Blake and Zelinsky, 2018). This record rainfall resulted in a river discharge of $3,766.1 \text{ m}^3 \text{ s}^{-1}$ (Figs. 3-5 and 3-6), and delivery delivered 24.5×10^6 metric tons of sediment to the GOM through the Brazos River, 80% of which was captured by the subaqueous delta (Hoelscher 2022).

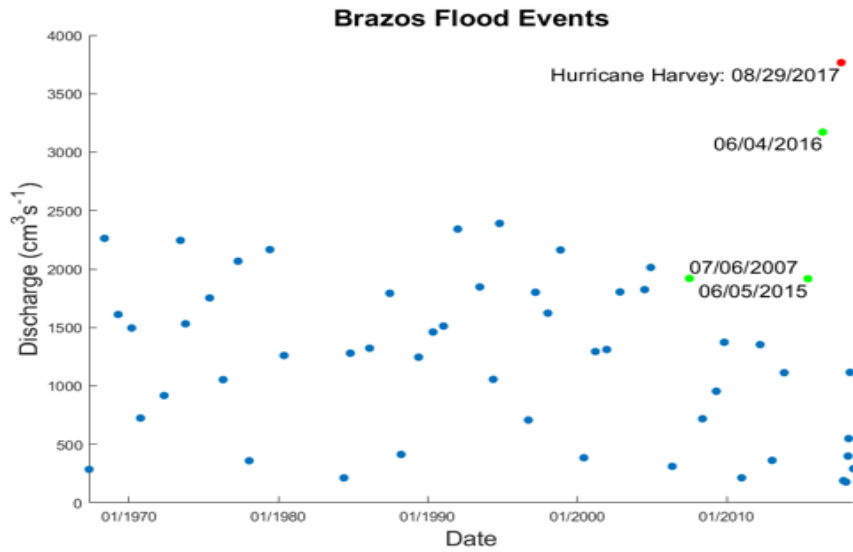


Figure 3-5: Historical Brazos River Peak Discharge. The last three peak discharges are noted in the figure. Source: USGS.

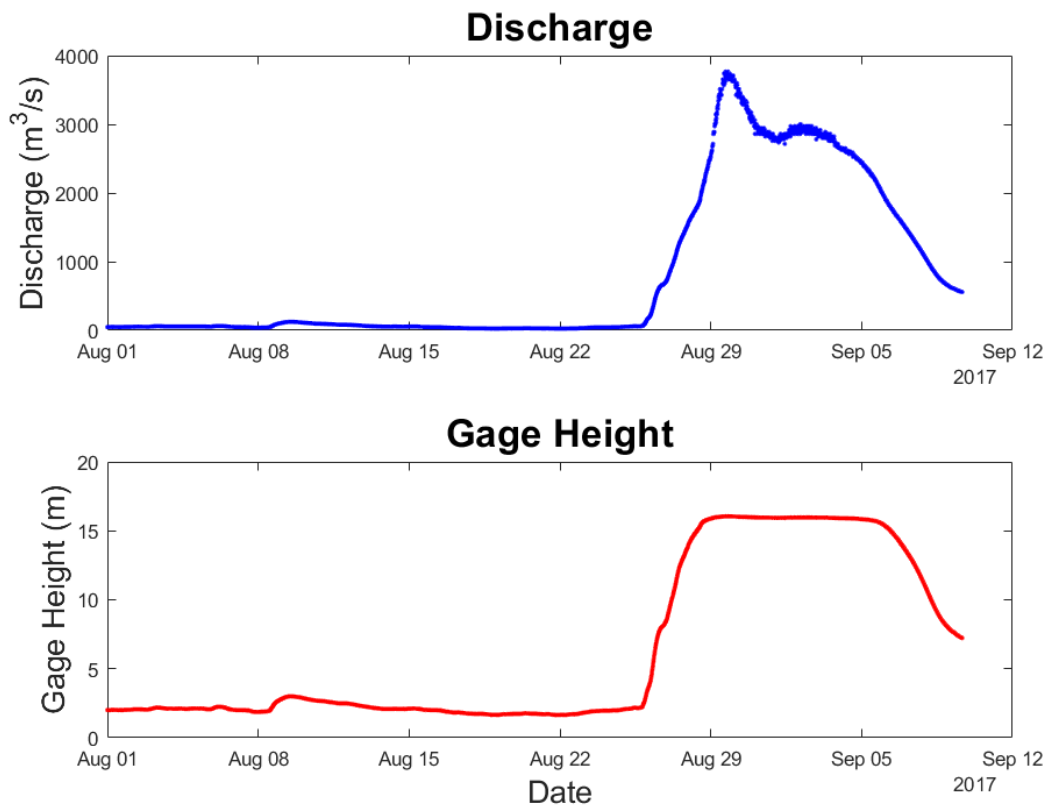


Figure 3-6: Brazos River Hydrographs. A) River discharge in cubic meters per second in blue. B) Gage Height in meters in red. Data Source: USGS.

It is unknown how much sediment was delivered by the Colorado River, but its lower basin received comparable precipitation. Fig. 3-7 shows the MODIS Satellite image collected on August 31, 2017, during the Hurricane Harvey flood, showing the suspended sediment plumes associated with both the Brazos and Colorado Rivers. The Colorado River flood waters cross the drainage basin divide between the Colorado and San Bernard Rivers and add to the discharge of the San Bernard River. It is unknown how much sediment was dispersed within the Cedar Lakes system during Hurricane Harvey, but it was likely the largest single event to bring sediment to this portion of the system.



Figure 3-7: MODIS Satellite Image from August 31, 2017 showing various sediment plumes from Hurricane Harvey

One of the goals of this portion of the study is to attempt to quantify the provenance of the Cedar Lakes system sediment deposits. Elemental ratios from X-ray fluorescence (XRF) analysis are commonly used to determine terrestrial sediments' provenance (source). These ratios help identify the geological characteristics of the sediment source, such as the type of parent rock and the processes that affect the sediment during transport and deposition (e.g., weathering, erosion). The following ratios will be used in this study:

Ti/Zr (Titanium/Zirconium) Ratio helps distinguish between different igneous rock sources and can indicate the sorting of heavy minerals. Titanium (Ti) is abundant in minerals like ilmenite and rutile, which are common in mafic (iron- and magnesium-rich) rocks. Zirconium (Zr) is often found in zircon, which is more resistant to weathering and is usually derived from felsic (silica-rich) igneous rocks. High Ti/Zr ratios suggest a mafic source, while low Ti/Zr ratios** point to a felsic source or more weathered sediments.

Si/Zr (Silicon/Zirconium) Ratio helps differentiate between quartz-dominated sediments and zircon-dominated sediments. Zirconium (Zr) is highly resistant to weathering and is often used to track sediment recycling or provenance of felsic rocks. Silicon (Si), primarily present in quartz, is indicative of high mechanical weathering. Low Si/Zr ratios suggest a source that is rich in zircon, while high Si/Zr ratios indicate a sediment source dominated by quartz.

Rb/Sr (Rubidium/Strontium) Ratio indicates weathering intensity and can suggest the degree of sediment maturity. Rubidium (Rb) is enriched in felsic rocks and is often concentrated in clays during weathering. Strontium (Sr) is associated with carbonates and feldspars. High Rb/Sr ratios suggest strong weathering or a felsic source, while low Rb/Sr ratios indicate a less weathered or more mafic source.

Ti/Ca (Titanium/Calcium) Ratio is a proxy for the relative contribution of terrigenous (Ti) vs biogenic (Ca) inputs. Ti is associated with associated with terrigenous (land-derived) material, such as weathered rock and soil. It is resistant to chemical weathering and is primarily delivered to sedimentary environments via rivers, wind, or other terrestrial processes. Ca is often associated with biogenic (marine-derived) material, such as carbonate shells and skeletons of marine organisms like foraminifera and coccolithophores. It reflects marine productivity and carbonate sedimentation. High Ti/Ca: Indicates dominant terrigenous input, suggesting proximity to land, increased weathering, or riverine/aeolian transport. Low Ti/Ca: Suggests dominant biogenic input, indicating open marine conditions with high carbonate productivity.

3.2 Methods

Sediment Core Splitting and Preparation

Before splitting, sediment cores were X-Rayed using a MinX-Ray HF100 + [Amorphous Silicon](#) Imaging System 4030R (USA), X-Ray unit at an energy level of 56 keV exposure time of 0.15 s. Cores were then split into two halves, where an even cut down the center of each core was achieved using a DEWALT 20 Volt Cordless Circular Saw with the core resting in a wooden stand for stability. Excess sediment from the split cores was then scraped off and discarded, and each core was prepared to where each half was perfectly flat, therefore the halves would run through further analysis techniques seamlessly. As each core had two halves, one half was designated the “working side” and the other the “archive”. The working side was stored and used for sub-sampling for grainsize and radioisotope geochronology, while the other was run for XRF, spectral analysis,

and imaging. Split sediment cores were then X-Rayed again as half cores provide better resolution as the core is thinner. Full-round cores are X-Rayed as a backup in case the cores are damaged during splitting.

XRF, Spectroscopy, and Imaging

X-ray Fluorescence (XRF) data was collected with an Olympus Vanta XRF Core Scanner attached to a Geotek Multisensory Core Logger (MSCL). The MSCL was set to measurement XRF for every 1 cm of the core. Archived core halves were run first through the MSCL for XRF and spectral analysis, and re-run to obtain digital line scan imagery (high resolution digital color core photography) from the core scanner. The XRF measurements were made at 10 keV and 30 keV, using a multichannel analyzer at a resolution of 2048 channels at 20 eV/channel. To prepare the archive side for logging, a thin film of plastic was gently placed over the top of the core face to reduce obstruction to the facies within the core as well as to not dirty the lens of the automated core logger. The film was then removed for line-scan imagery to maintain a consistent and clear core image.

Raw XRF and image data were digitally exported through designated workflows, where the metadata was converted to a comma-delineated Excel spreadsheet. Color spectroscopy data was analyzed using the ratio of Red/Green Reflectance to enhance the variation between these two colors. The river sediment is red and the GOM muds are gray to black. Target elements from the XRF spreadsheets were determined through analysis as to what elemental ratios were displayed at peak intensity throughout proposed deposition events down-core. The target elements within this study include the ratios of Ti/Si, Ca/Si, Fe/Si, and Ti/Ca. The usage of elemental ratios decreases the rate of certain systematic errors dramatically, as opposed to the usage of individual chemical abundances (Rothwell and Rack, 2006). The XRF core scanner results are expressed in parts per million (ppm) for the entirety of the study. XRF data has been plotted at depth with multiple elemental/reflectance parameters set across core depth, coupled with processed line-scan and X-ray imagery. Differentiation in sediment type and grain size at depth promotes changes in elemental composition, therefore, the most abundant elements present in lacustrine sediments were selected for the line plots. Moving down core, the ratios of titanium (Ti), calcium (Ca), and iron (Fe) are plotted against silicon (Si) to denote the dominant sediment composition.

Grainsize Analysis

The Grain size analysis was conducted using the Malvern Mastersizer 2000 laser particle diffractometer (England) at 5cm increments moving down-core. The Malvern was set to run an ABM standard wash. Working halves of each core were sub-sampled for approximately two to five grams of sediment starting at a depth of zero. Sediment was collected with a collection tool and placed in small plastic tubes. Sodium metaphosphate dispersant solution was then added to each sample to keep sampled sediment in suspension before adding to the Malvern. Each sediment samples were then poured into the Malvern until a sufficient obstruction level was achieved. Sub

samples were passed through a 2mm sieve for removal of extremely coarse grains or shells as samples were disturbed into the Malvern.

Radioisotope Analysis

^{210}Pb activity concentrations are determined directly from its daughter radionuclide, i.e., ^{210}Po measured by alpha-spectroscopy, assuming their activity concentrations are in equilibrium. In brief, certain amounts of dried samples (~0.5 g) are digested with concentrated HNO_3 with the spike of ^{209}Po . The samples are heated at 100 °C for 2 hrs, followed by the centrifugation to collect the supernatant for further processing. After the evaporation to incipient dryness, the samples are dissolved by 3 M HCl solution for silver plating. Before the addition of 2 ml of 20% hydroxylamine hydrochloride and 2 ml of 25% sodium citrate, certain amount of ascorbic acid is added into the solution until the color disappears. The mixed solution is placed on an electromagnetic stirrer at 85-90°C for 4 h after the adjustment of pH to 1.5 with ammonia solution. The silver disk is rinsed with Milli-Q water and dried in the air for the measurement of ^{209}Po and ^{210}Po activities with alpha-spectroscopy. $^{210}\text{Pb}_{\text{xs}}$ is determined from total ^{210}Pb by either directly measuring the supported ^{210}Pb from following Nittrouer et al. (1979) or by taking the average activity of ^{210}Pb deeper in the core, below the depth where excess activity is found, which is the approach used in this study. Note, in this study, $^{210}\text{Pb}_{\text{xs}}$ is used simply to determine the depth at which the supported ^{210}Pb ceases to be recorded in the sediment (i.e., goes to background activities). Accumulation rates have not been calculated from the decay curves.

Water Content

As sediments were dried for radioisotope procedure, wet and dry weights were recorded to discern percent water content of CL08 moving downcore. Samples were placed in aluminum weigh boats and the following calculation was run at each depth utilizing Microsoft Excel.

$$1. \quad \frac{(\text{wet weight} - \text{weight boat}) - (\text{dry weight} - \text{weight boat})}{(\text{wet weight} - \text{weight boat})} (\times 100) \quad (1)$$

Subbottom Profiler

An Edgetech SB424 subbottom profiler (Fig. 3-8) was used to image the strata below the seafloor. The SB424 was operated at full output power with a ping rate of 6 Hz. The 4-20 kHz CHIRP pulse (Edgetech code SB424_4_20_10WB) was used with a pulse width of 10 ms. The subbottom profiler was towed from the center towpoint on the outrigger boom installed on the port side of the vessel. An A4 size, inflatable buoy was used to keep the subbottom profiler at a fixed depth of approximately 2.5 ft below the water surface. The subbottom profiler was interfaced to the Edgetech Discover software and the raw sonar data were recorded by the Hypack software in the SEG Y file format.



Figure 3-8: An Edgetech SB424 subbottom profiler was used during this survey.

3.3 Results

Cedar Lakes

Core BR-01 was collected within the subaerial portion of the Brazos River, 750 m west of the Brazos River. The upper 80 cm of the core contains over 90% mud, allowing for a representative XRF elemental “fingerprint” (Fig. 3-9) for the river’s suspended load (mud). It is this suspended load that is transported to the Cedar Lake system as the bedload (sand) would be deposited within the river channel and the nearshore delta. Core CD-01 was collected in Matagorda Bay, 7 km west of the mouth of the Colorado River, and provides a representative XRF signature for the Colorado River suspended load. Figure 9 shows a comparison of the XRF ratios used in this study. Vertical red lines were drawn as estimated thresholds for the respective XRF ratios, with ratios below this

threshold being more representative of a Brazos source and above being representative of a

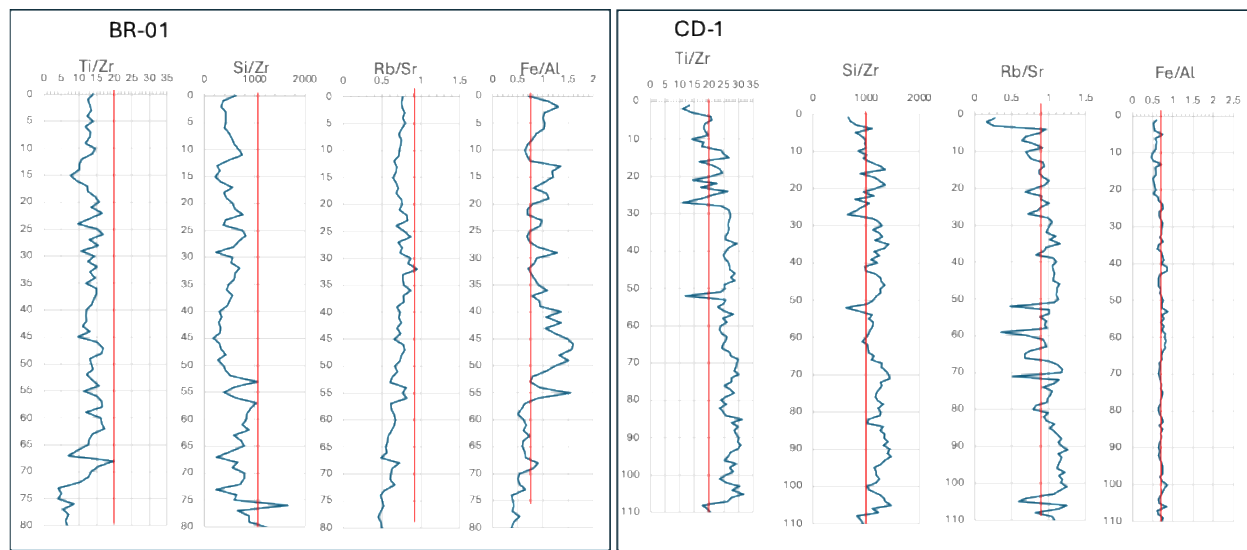


Figure 3-9: End-member XRF profiles for the Brazos River Sediment (BR-01) and Colorado River (CD-01). Colorado River source.

Four distinct stratigraphic/lithologic units were identified in this study, which are: 1) Brazos mud, 2) GOM over wash sand and mud, 3) Colorado River mud, and 4) Pleistocene. The XRF profiles for BR-01 and CD-01 were used as end-member standards for comparison with XRF responses for the respective sediment sources (Fig. 3-9). The Pleistocene deposit has variable lithologies and XRF characteristics but is distinct in its hardness and low water content, which were noted when the cores were subsampled. Low Red/Green reflectance ratios, as well as Ti/Zr ratios less than 15 and Si/Zr ratios less than 1000 are assumed to be representative of GOM-derived mud, and if the sediment contains more than 10% sand, then it is considered to be GOM derived over wash muds and sands.

The Subbottom profiler data (Fig. 3-10) reveal that the entire study site sits atop a Pleistocene Fluvial Terrace, which is generally flat and sits approximately 2 m below the bay bottom in most places. This correlates to the Beaumont Terrace, which was found to be approximately at the same elevation in West Galveston Bay (Lavery, 2014). The Brazos River mouth was moved 10 km to the west in 1929, and the new river mouth sits outside of the bounds of the Brazos River incised valley. The subbottom data reveals that the base of many of the cores contained the top of the Pleistocene-aged Beaumont Formation. The Beaumont Formation is an indurated paleosol (paleosol), which is an unconformity surface that underwent prolonged subaerial exposure before submergence and deposition of Holocene overburden. As it is a fluvial terrace, it was originally deposited as a fluvial flood plain, as such, it is generally mud-dominated but can also contain sand deposits and may have fluvial channels incised into it. As a paleosol, it contains oxidized iron sediment and carbonate concretions. It is typically dry (low water content). Where encountered

in the cores, the Pleistocene sediment is either reddish, white, or green, and water content shows it to be very dry in comparison to the rest of the cores.

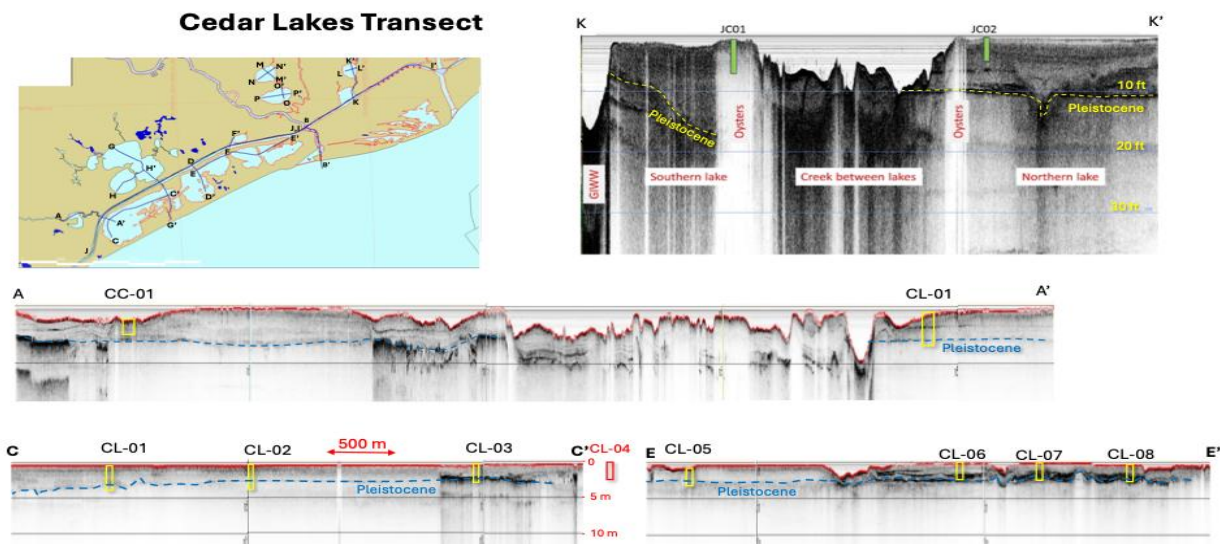


Figure 3-10: Basemap referencing CHIRP Subbottom Profiler Lines K-K', A-A', C-C' and E-E', and the respective lines. The top of the Pleistocene is delineated in each line, showing that the top of the Pleistocene surface is generally less than 3 m below the bay bottom.

Appendix C sheets for each of the cores used in the study, showing core x-radiographs, color photographs, and XRF profiles for Ti/Zr, Si/Zr, Ti/Ca, Rb/Sr, Red/Green Reflectance and $^{210}\text{Pb}_{\text{xs}}$ profiles. The lithological units were identified and delineated in each core based on the characteristic XRF ratios, as well as color/color reflectance ratios. Where we were able to determine the base of ^{137}Cs is also noted (Table 3-1). It is assumed that the first appearance of ^{137}Cs correlates to the 1954 atmospheric testing of the atomic bomb when ^{137}Cs was first introduced to the environment in measurable quantities. Sediment accumulation rates based on ^{137}Cs was determined by dividing the depth at which it first appeared by 68, which is the number of years between when the cores were collected in 2023 and the first appearance of ^{137}Cs in the environment in 1954. As the lakes receive sediment as episodic events from different sources, the activity profiles contain too much heterogeneity to permit sedimentation rates using $\text{Pb}_{\text{xs}}-210$. The noted exception is core ML-01, where an accumulation rate of 1.1 cm/yr was estimated based on $\text{Pb}_{\text{xs}}-210$ and 1.46 cm/yr based off ^{137}Cs . The difference between these two rates results because in the $\text{Pb}_{\text{xs}}-210$ there is a 10 cm surface mixed or episodic flood layer, so was assumed to be of a uniform age. The ^{137}Cs age dating technique does not take these factors into consideration.

Table 3-1: Sediment Accumulation Rates

Core	Depth (cm)	Accumulation Rate (cm/yr)
CL-01	121	1.75
CL-02	81	1.17
CL-03	131	1.90
CL-04	81	1.17
CL-05	101	1.46
CL-06	0	0.00
CL-07	91	1.32
CL-08	140	2.03
CW-01	151	2.19
JC-02	101	1.46
ML-01	101	1.46

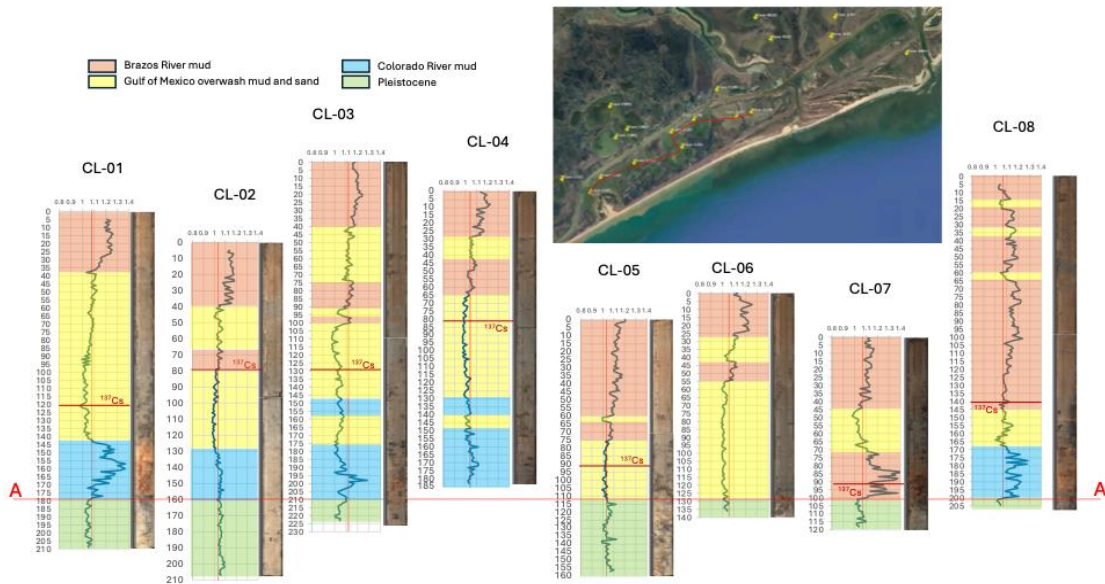


Figure 3-11: Core Cross Section A-A' extends across all cores collected within the Cedar Lakes south of the GICWW, with lithology plotted atop Red/Green Reflectance.

To better understand the distribution of the various lithological units and sources of sediment within the Holocene fill within the lakes, a series of cross sections were assembled (Figs. 3-11 – 3-13), with A-A' extending across the Cedar Lakes, north of the GICWW, B-B' extending across the lakes inland from the GICWW and C-C' for the two cores which are located as embayments along the northern shoreline of the Cross section A-A' extends west to east across the Cedar Lakes and shows deposits of Brazos River mud in the upper portions of all the cores. Cores CL-05 and CL-06 were collected in locations along the northern edge of the middle Cedar Lake, just north of an old, dredged navigation channel, and CL-07 was collected in the western portion of the easternmost Cedar Lake. CL-08 was collected at the most eastern portion of the eastern Cedar Lake, just south of a crevasse splay formed where the old navigation channel intersects with the GICWW, and where a small delta has formed as sediment flows in from the GICWW, ~750 m west of where the San Bernard River cross the GICWW. Cores CL-01, 02, 03, and 04 all contain Brazos River-derived sediment in the upper portion of the core and a basal deposit of Colorado River-derived sediment just above the Pleistocene surface.

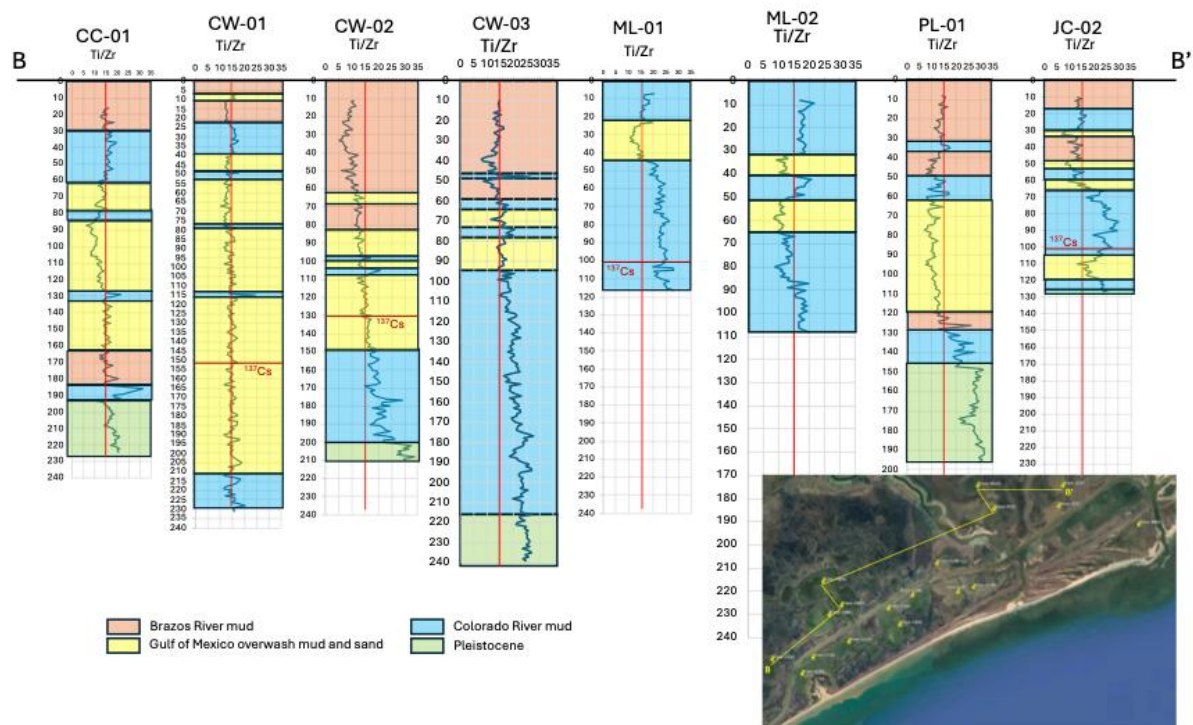


Figure 3-12: Core Cross Section B-B' extending across the inland cores collected north of the GICWW.

The base of ^{137}Cs lies above the Colorado River deposits in each of these cores, indicating the Colorado River sediment was deposited before 1954. Given that they are each at least 40 cm below the first appearance of ^{137}Cs , these deposits were likely formed before the installation of the GICWW in 1949 and the movement of the mouth of the Brazos River in 1929. Cores CL-05, 06, and 07 are shorter than the other cores and may have been located at elevations that were too high for Colorado River deposits to have accumulated at these locations at the time these deposits were

formed. In general, further west across the Cedar Lakes, there is a general trend of thinner and less Brazos River-derived sediment and more GOM. It should be noted that there is an ephemeral overwash cut (Cedar Lake Cut) at the western end of the Cedar Lakes, proximal to cores CL-01, 02, and 03. Cedar Lake Cut was open from at least 2004 through 2010 and was re-opened in 2015, closed by 2017 by Hurricane Harvey, and closed again around 2021, where it has remained closed. The Pb_{xs} -210 profile for CL-01 shows a linear profile (Appendix C) from the surface down to 21 cm, suggesting a uniform age. CL-02 has a similar profile extending down to 30 cm, which suggests that this is a Brazos River-derived deposit that was formed during the Hurricane Harvey flood. A significant flood plume can also be seen flowing in from Cedar Lake Bayou, suggesting a mixed source deposit, but considering the size of the Brazos River drainage basin, it was likely primarily derived from the Brazos River.

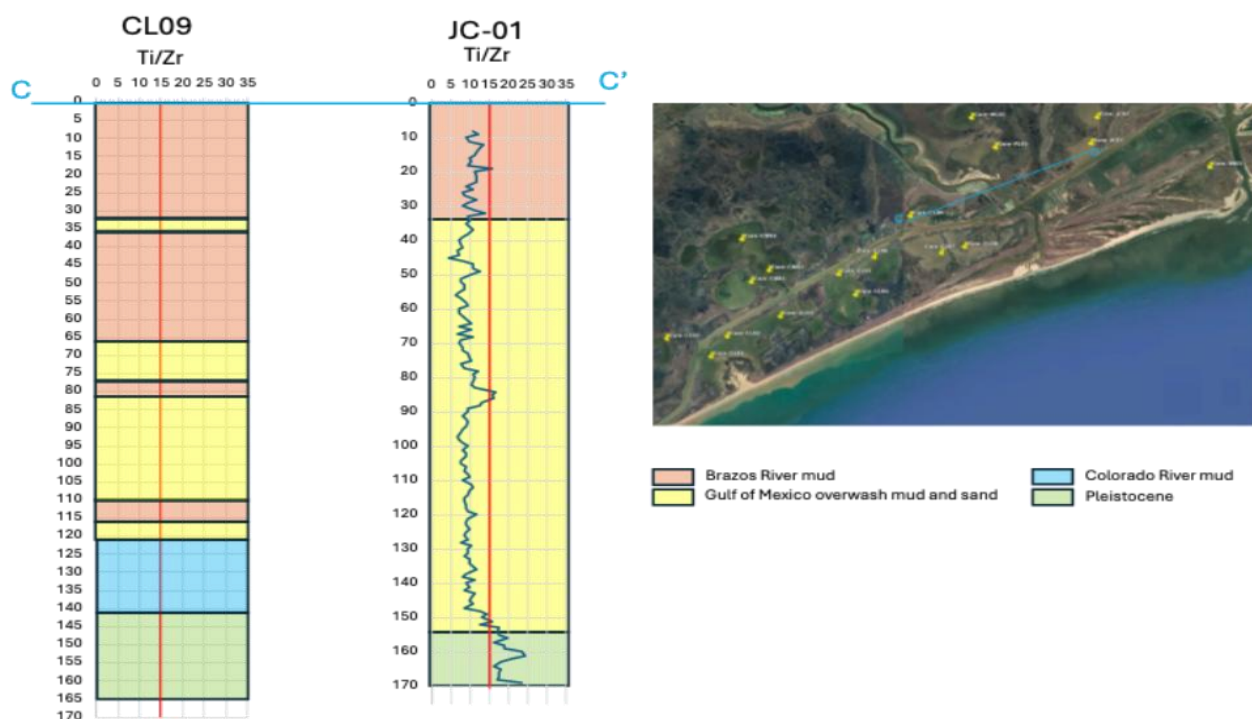


Figure 3-13: Core Cross Section C-C'. Both cores were collected in open embayments off the northside of the GICWW, east and west of the San Bernard River, respectively.

Cross Section B-B' (Fig. 3-12) represents the cores collected inland, north of the GICWW. Cores CC-01, CW-01, CW-02, and CW03 were collected from sites west of the San Bernard River, and Cores ML-01, ML-02, PL-01, and JC-02 were collected between the San Bernard and Brazos Rivers. All the cores other than ML-01 and ML-02 have Brazos River-derived sediment forming a surface layer 5-60 cm thick. The ML cores were collected from Mud Lake, which lies east of the San Bernard River, and inflow from the south first would have to flow through Pelican Lake through a narrow channel before entering Mud Lake. During Hurricane Harvey, flood waters from

the Colorado River flowed out through the San Bernard River, and during the peak flood, it would have also flowed into Mud Lake. The Mud Lake cores do not contain any Brazos River-derived deposits but do contain both GOM Overwash muds as well as Colorado River-derived sediment, but the majority of the sediment was Colorado River-derived, with at least three separate layers, as shown in ML- 02, suggesting multiple Colorado flood events, separated by two storm surge deposits. PL-01 was collected in Pelican Lake, south of Mud Lake, and contains three sets of Brazos River-derived deposits sitting atop a Colorado River-derived deposit, a surface deposit likely formed during Hurricane Harvey. Between the second and third coupled Brazos-Colorado River deposits, there is an intervening GOM storm surge deposit, suggesting at least one major hurricane separating the second and third Brazos-Colorado River flood events. JC-02, collected in upper Jenkins Creek is from a site closer to the Brazos River. JC-02 also contains a coupled Brazos-Colorado derived flood deposit but also contains both Brazos and Colorado derived deposits at depth, suggesting a more complicated flooding history, but which is dominated primarily by Colorado River-derived sediment.

Cross section C-C' (Fig. 3-13) contains CL-09, which was collected from an un-named embayment off the north side of the GICWW west of the San Bernard River, and JC-01, which was collected from a shallow embayment just east of the San Bernard River, at the mouth of Jenkins Creek. Both sites are open to the GICWW. JC-01 contains a surface Brazos River-derived deposit, 35 m thick, below which the core contains 120 cm of GOM-derived mud, all of which sits atop the Pleistocene surface. CL-09 contains primarily Brazos-derived mud but also contains GOM-derived mud, all of which sit atop a basal Colorado River-derived deposit that sits atop the Pleistocene. JC-01 is a very shallow site, and it had likely filled in with GOM mud before Hurricane Harvey and only contains Harvey deposits because of the elevated water level during the flood, creating a brief period where the elevated flood waters created accommodation space for a deposit to form. In contrast, CL-09 is a deeper site, with enough accommodation to accumulate a more complete record of deposition, which has recorded a record of both Brazos River-derived floods as well as GOM storm surges. The basal Colorado River-derived deposit likely formed before the installation of the GICWW.

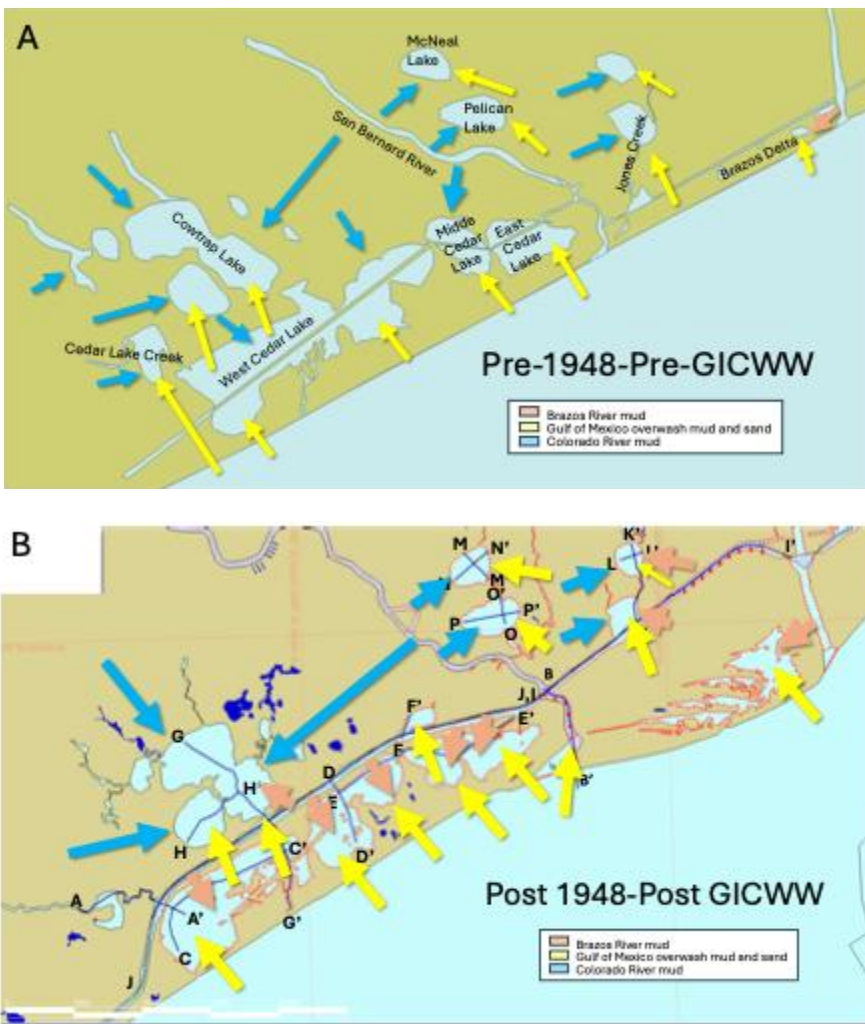


Figure 3-14: Sediment Transport Pathways during pre and post 1948 Gulf Intracoastal Waterway (GICWW) opening. A) pre-1948 and pre-GICWW opening, showing that Colorado River sediment was transported to the study area as well as Gulf of Mexico (GOM) overwash sediment, but other than proximal the Brazos Channel, no Brazos sediment was transported into the study area. B) post 1948 and post-GICWW opening showing that in addition to the Colorado River sediment and GOM overwash, Brazos River sediment was transported into most areas via the GICWW.

Fig. 3-14 was created to summarize the sediment transport pathways during pre-GICWW (pre-1948) and the post-GICWW (post-1948) periods. Figure 16A is a map from 1933 and reflects the conditions after the westward movement of the new Brazos River channel but during the pre-GICWW period, when the San Bernard River flowed directly into the GOM west of the new Brazos Delta. Although there were two small canals, one extending across the north half of the new Brazos Delta and a second extending from the lower San Bernard across the Cedar Lakes, these two canals were not connected and there was no direct pathway for Brazos sediment to move into the Cedar Lakes or the lakes and creeks north of the Cedar Lakes (e.g., McNeal Lake, Jones Creek, Pelican Lake, Cowtrap Lake, and Cedar Lakes Creek). As a result, during the pre-ICWW opening period, the Cedar Lakes as well as the lakes and creeks north of the Cedar Lakes would only receive sediment from the flooding of the San Bernard River, the flooding of the Colorado River and Gulf of Mexico overwash due to storm surge, as is supported from the core data. It should be noted that given the small size of the San Bernard River basin, flooding derived sediment would be very minor when compared with the sediment derived from the Colorado River and would likely occur from the same events. Figure 16B represents the period after the opening of the GICWW (post-1948). After the opening of the GICWW, the GICWW provided a direct path for the conveyance

of water and sediment from the Brazos River into the Cedar Lakes as well as most of the lakes north of the GICWW. The core data shows that after the opening of the GICWW, the Cedar Lakes cores show deposition from the Brazos River as well as the Gulf of Mexico overwash, but do not show any deposition of Colorado River sediment. This is likely a combination of two factors, the first being that the GICWW acted as a barrier to the transport of Colorado River sediment to the Cedar Lakes and the second being that even if there was Colorado River sediment transported into the Cedar Lakes, it was minor compared with the Brazos sediment and not discernable. North of the GICWW, after the opening of the GICWW, the core data reveals that there was both Brazos and Colorado River sediment transported into these lakes, with the noted exceptions are McNeal and Pelican Lakes, which are not directly connected to the GICWW, and the cores do not show any Brazos deposition in these lakes. Figure 3-15 shows the inferred pathways of both Brazos and Colorado River discharge into the lakes and estuaries of the lower coast. Although not addressed in this study, it was well documented that during Hurricane Harvey, the Brazos River crossed over to Chocolate Bayou and flowed into West Galveston Bay. It also entered the Cedar Lakes area through the GICWW. In contrast, the Colorado River crossed over into the San Bernard River and flood into the lakes north of the GICWW through flooding north of the GICWW.



Figure 3-15: Map showing the flow pathways of the Brazos and Colorado Rivers during Hurricane Harvey.

3.5 Conclusions

Overall, the sediment cores reveal a few trends. First, across the Cedar Lakes, there are basal deposits of Colorado River-derived sediment indicating that before the installation of the GICWW in 1949 and the movement of the mouth of the Brazos River in 1929, this area primarily received Colorado River-derived sediment rather than Brazos River-derived sediment. After the installation of the GICWW, the western end of the Cedar Lakes primarily records GOM over wash muds and sands, with a few Brazos River-derived flood deposits. Two things are notable, which are: 1) Colorado River-derived sediment deposits within the Cedar Lakes were all formed before the

installation of the GICWW, and 2) Post-GICWW, only Brazos River-derived sediment and GOM overwash deposits formed. These observations demonstrate that the GICWW provides a conduit for the transport of Brazos River-derived sediment also, potentially a barrier to the transport of Colorado River-derived sediment. In contrast, north of the GICWW, within the inland cores, there is a mixed record of both Brazos River and Colorado River-derived deposits. For sites to the east of the San Bernard River, the deposits are either entirely Colorado River-derived, mixed with GOM over wash, as seen in the Mud Lakes, or coupled deposits of upper Brazos and basal Colorado River-derived deposits, as seen in Pelican Lake and Jenkins Creek, suggesting a record of large, coupled flood events where both rivers were flooding together. In contrast, CL-09 reveals that for the embayments along the GICWW west of the San Bernard River, before the installation of the GICWW and movement of the mouth of the Brazos River, there exists a Colorado River-derived deposit, but during the post-GICWW installation period, the deposit consists of a mix of storm surge GOM derived mud and Brazos River derived mud. In conclusion, before the installation of the GICWW and the western movement of the mouth of the Brazos River, the Cedar Lakes system was only flooded with Colorado River-derived sediment as well as storm surge overwash. Post-GICWW and the movement of the Brazos River, north of the GICWW the Cedar Lakes system received both Brazos and Colorado River-derived sediment as well as storm surge overwash, however, south of the GICWW, the sediment record is devoid of Colorado River-derived sediment, indicating that the Brazos River is the primary source of fluvial sediment within the Cedar Lakes. Additionally, it should be noted that there is a gradient of Brazos-derived sediment, with cores CL-07 and CL-8, which are closest to the San Bernard River, primarily containing Brazos River-derived deposits rather than GOM overwash muds.

The coring data sets and documentation have been shared with the Texas Coastal Sediment Geodatabase (TxSed) Project led by the TGLO.

4. Bathymetric Survey

Prior to the launch of this project, the TAMU-G team had partnered with Echo Ocean Science LLC (EOS) to conduct a single-beam bathymetric survey in May of 2021 along the lower part of the San Bernard River. The survey was done prior to the dredging project that was performed in the fall of 2022, and it covered the San Benard River between the intersection with GIWW and its mouth, and a part of the GIWW to the east of the intersection. The result is shown in Fig. 4-1.

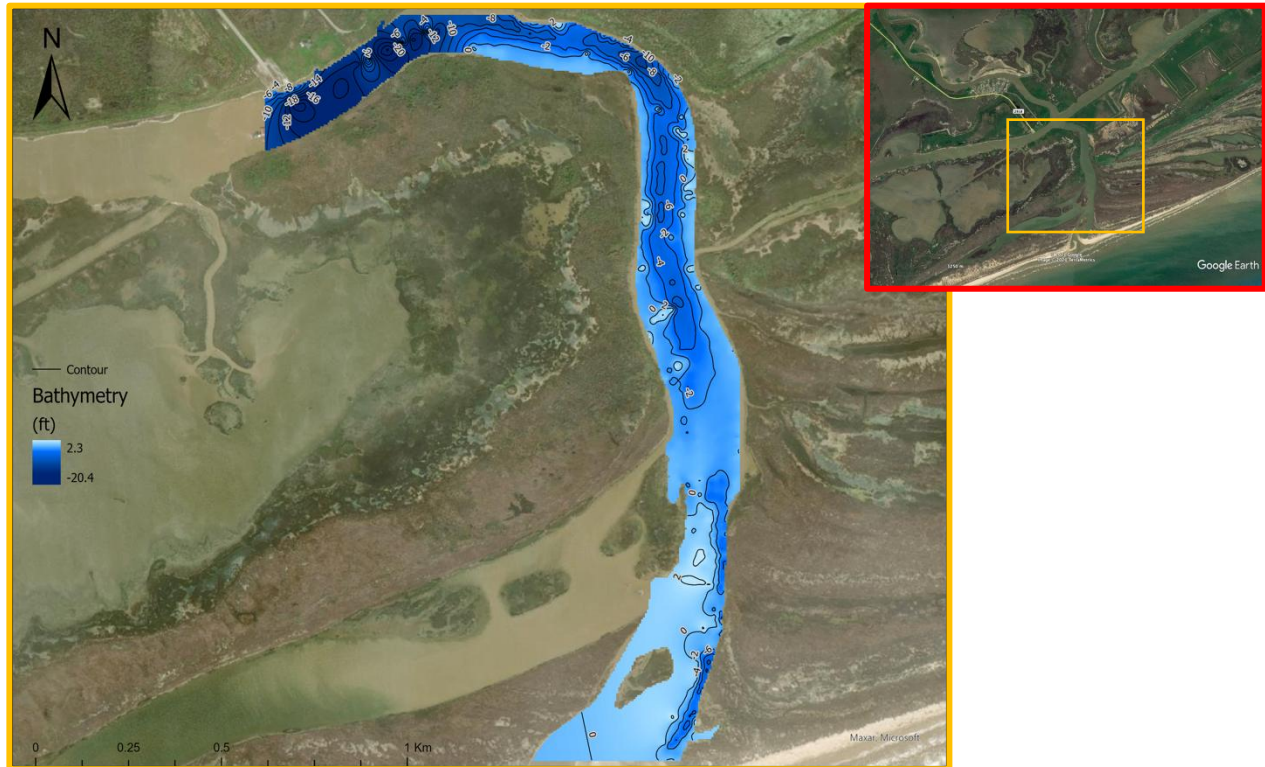


Figure 4-1: Single beam bathymetric survey lower San River conducted by EOS.

During the project, TAMU-G team contracted EOS to conduct two bathymetric surveys along the lower portion of the Brazos River in May 2023 and May 2024. The results are shown in Figs 4-2 - 4-5 for selected cross-sections, whereas the complete data sets can be found in Appendix A. One notable feature is that there is a clear signature of erosion seen among all cross-sections marked by a drop of elevation profile in 2024. This drop is particularly pronounced at cross-sections close to the GIWW, and is mostly likely a result of erosion brought by the high-flow pulses in late 2023 and early 2024 between the two surveys. Our estimate is that about one million cubic yards were eroded away during these episodes.

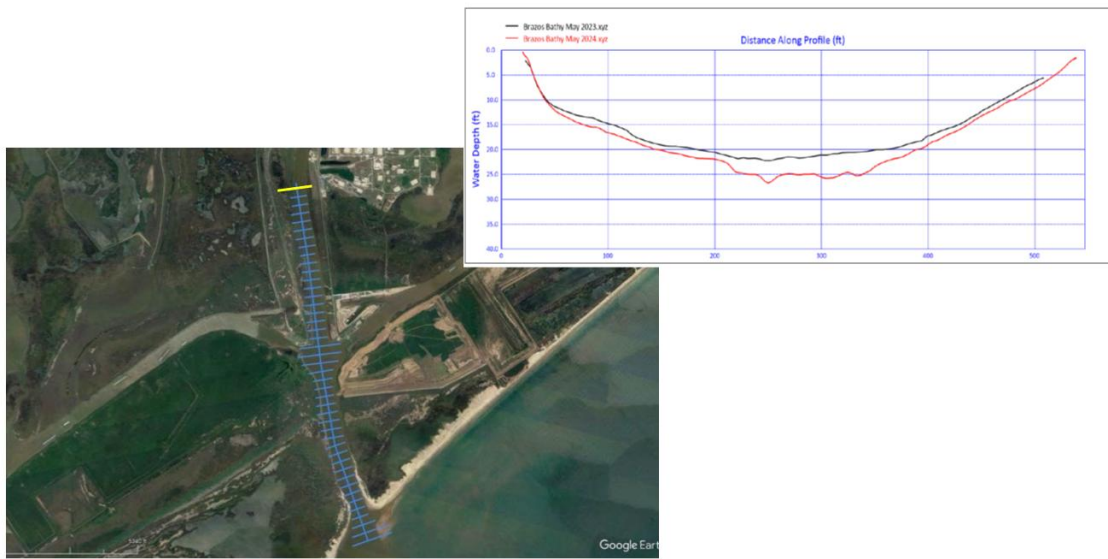


Figure 4-2: Elevation profiles derived from the 2023 and 2024 bathymetric surveys at the northmost cross-section along the Brazos River.

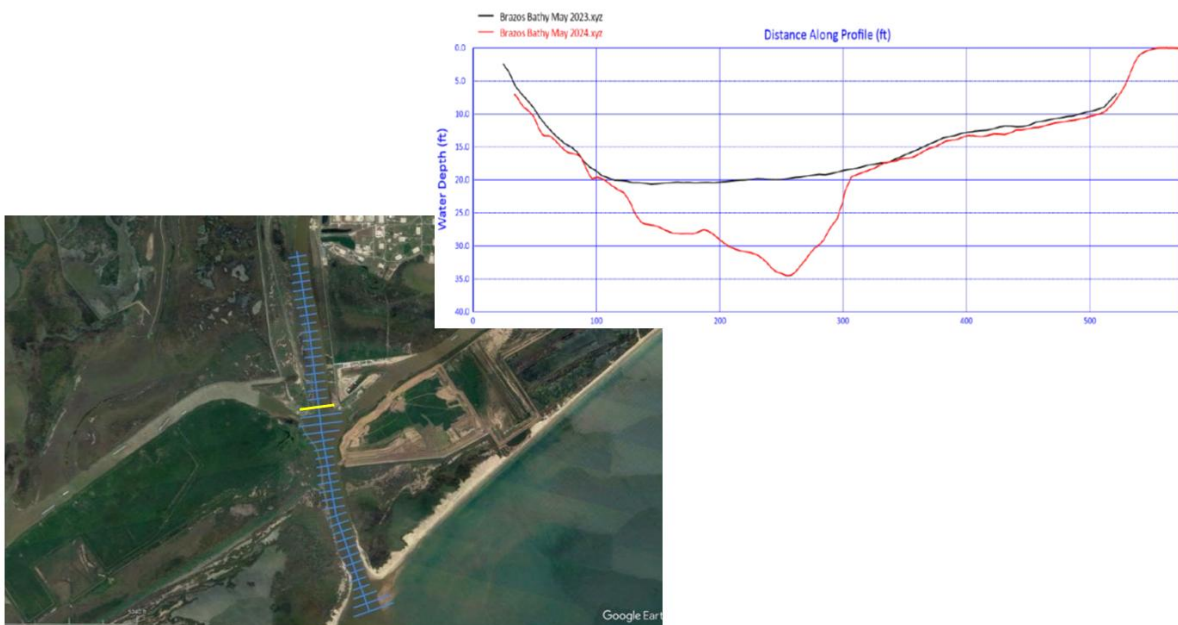


Figure 4-3: As Fig. 4-2, except at a cross-section along the Brazos River north of the crossing with GIWW.

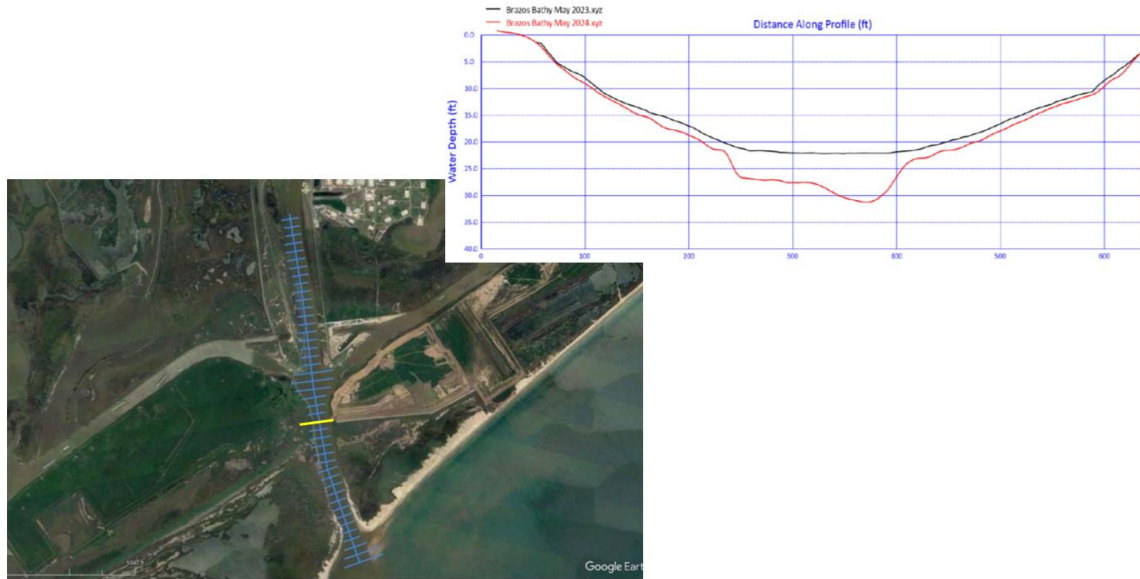


Figure 4-4: As Fig. 4-2, except at a cross-section along the Brazos River south of the crossing with GIWW.

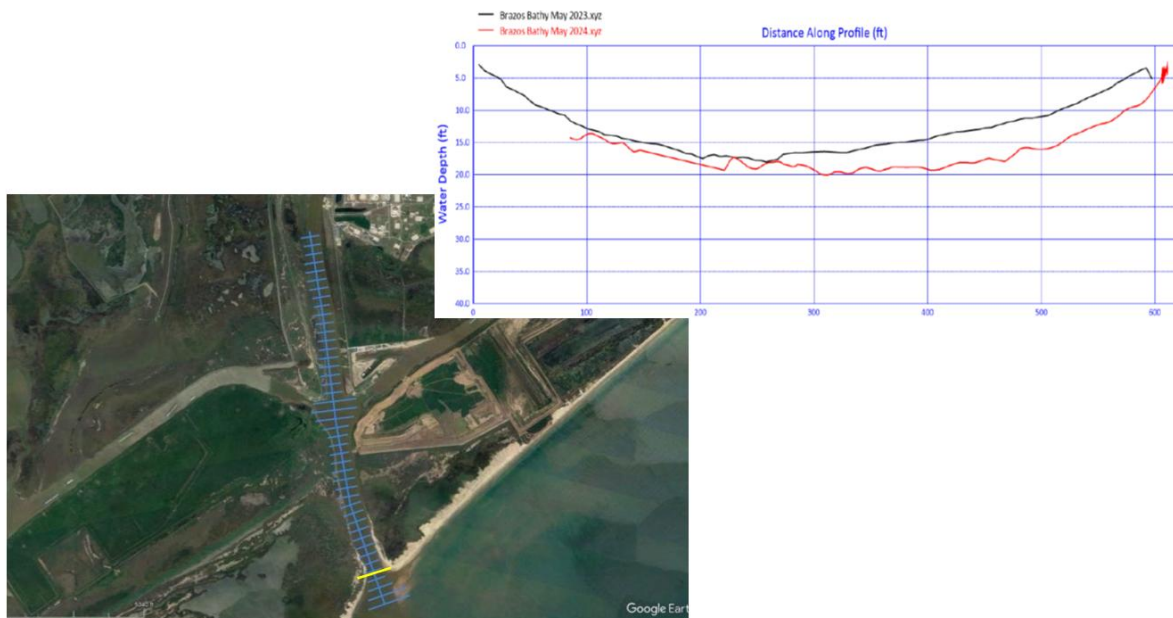


Figure 4-5: As Fig. 4-2, except at a cross-section at the Brazos River mouth.

Echo Ocean Science LLC (EOS) was contracted by Texas A&M University – Galveston (TAMUG) to conduct a bathymetry survey of the nearshore region offshore of the Brazos River mouth. The objective of this program was to measure the bathymetry of along discrete transects extending

from 7 to 30 ft water depths. The survey was conducted during July and August of 2024. TAMUG was contracted by the Texas General Land Office's Coastal Management Program to conduct this study. This report details the equipment and methods implemented by EOS on this project.



Figure 4-6: Geographic extent of the offshore bathymetric survey.

Table 4-1: Geodetics of Survey Data

Parameter	Value
Horizontal Datum	NAD83 (2011)
Projection	State Plane, Texas South Central
Horizontal Units	US Survey Feet
Vertical Datum	Mean Lower Low Water (MLLW)
Vertical Units	Feet

A total of 23 survey transects were planned for this survey (Fig. 4-7). These transects were spaced at intervals of 3,200 ft. Transects were planned to extend from the shoreline out to a water depth of 30 ft.

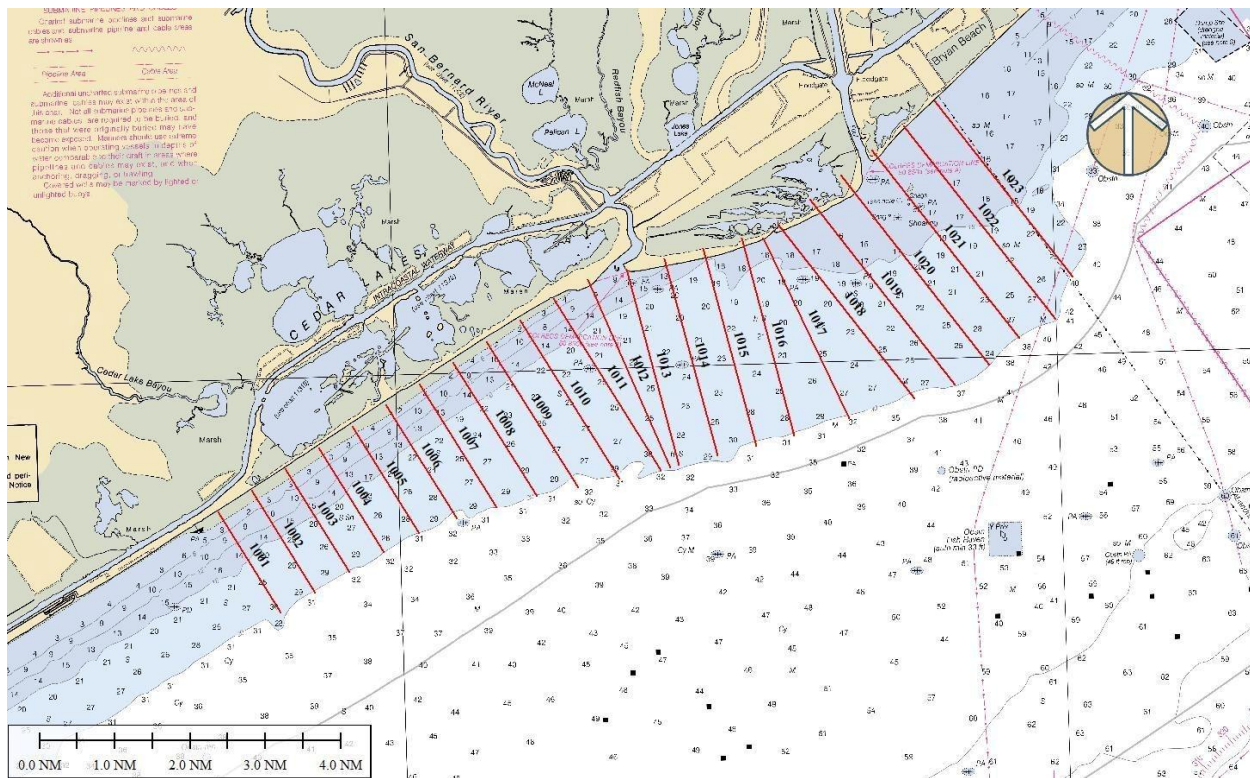


Figure 4-7: The transects at which bathymetric survey was conducted.

Field operations were conducted onboard the EOS survey vessel *Echo Scout*, a 25-ft long, fiberglass vessel, based in Sea Isle, TX and transited the intracoastal waterway to Freeport, TX and into the Gulf of Mexico via the Freeport Ship Channel each day. During the survey, the vessel was positioned using a differentially corrected Trimble MPS-865 GPS receiver. Position and heading information from the GPS receiver were sent to an SBG Ekinox inertial navigation system (INS). The INS calculated the lever arm position of the echosounder transducer and this position was provided to the Hypack survey software. The 200 kHz transducer for the Odom CV-100 singlebeam echosounder was pole mounted amidships on the starboard side of the vessel. The transducer draft of 1.33 ft was applied within the Odom eChart software. Sound velocity profiles were measured using a Valeport SWIFT CTD. Survey data were logged and post-processed using the Hypack software. Singlebeam echosounder data were collected by surveying along the planned survey lines.

Measured bathymetric data were corrected to mean lower low water (MLLW) datum by using the water level observations from the NOAA tidal gauge 8772471, located within the jetties at the Freeport Ship Channel. Data for this gauge were extracted in units of feet relative to MLLW for the time range of the survey. These data were applied to the raw bathymetry soundings in Hypack post-processing software. The results of the survey are shown in Fig. 4-8.

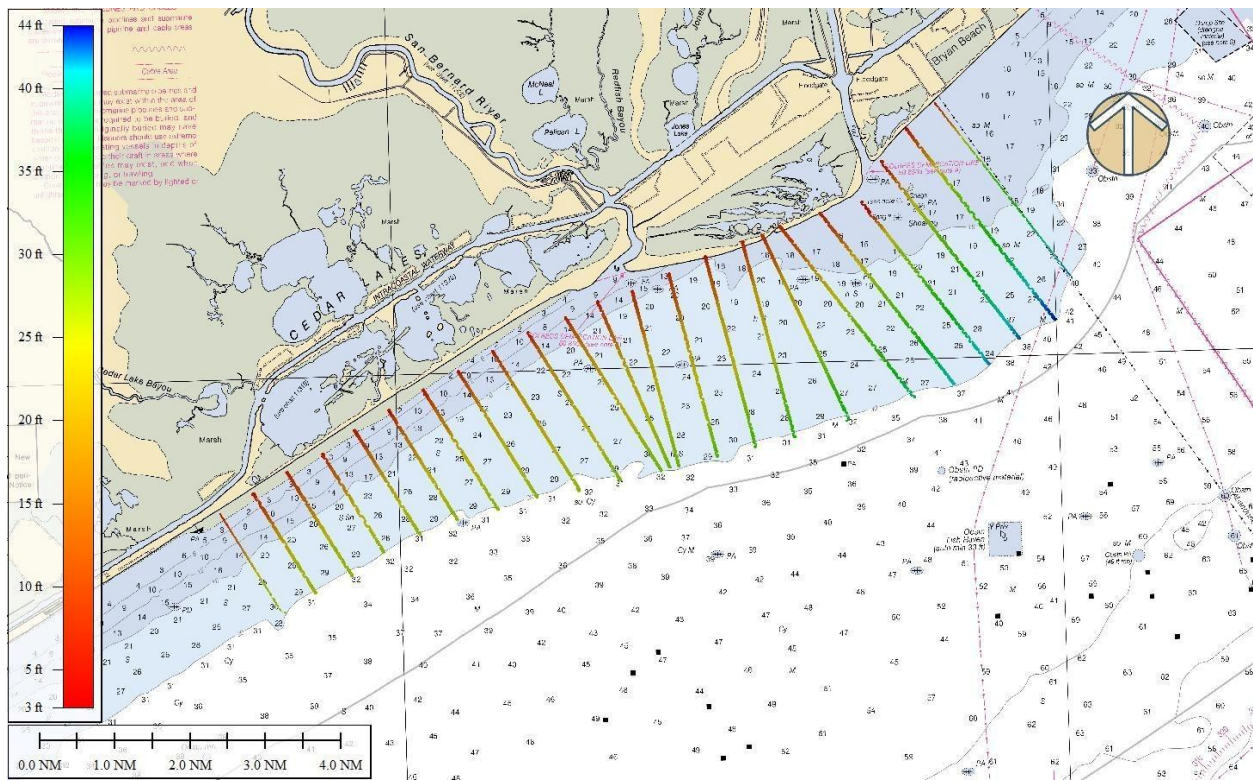


Figure 4-8: Results of the bathymetric survey conducted offshore of Brazos River.

5. Evaluation of TxRR runoff estimates

We acquired the runoff simulations from TxRR from the TWDB for the coastal watersheds shown in Fig. 2-1, and compared these simulations against USGS observations at Rosharon and West Columbia on the Lower Brazos River, and Boling and Sweeny on the San Bernard River (Fig. 2-1). Prior to the comparison, we examined the drainage and land cover across the study area (Fig. 5-1). The San Bernard-Lower Brazos River Basins comprise mainly pasture, cultivated cropland, forested regions, and extensive wetland areas. Wetlands are especially prominent near the coast, possibly supplying substantial floodplain storage and serving to slow hydrologic responses to rainfall. The land cover distribution suggests that runoff is often delayed, redistributed, and gradually released into the river system rather than being delivered as rapid surface flow.

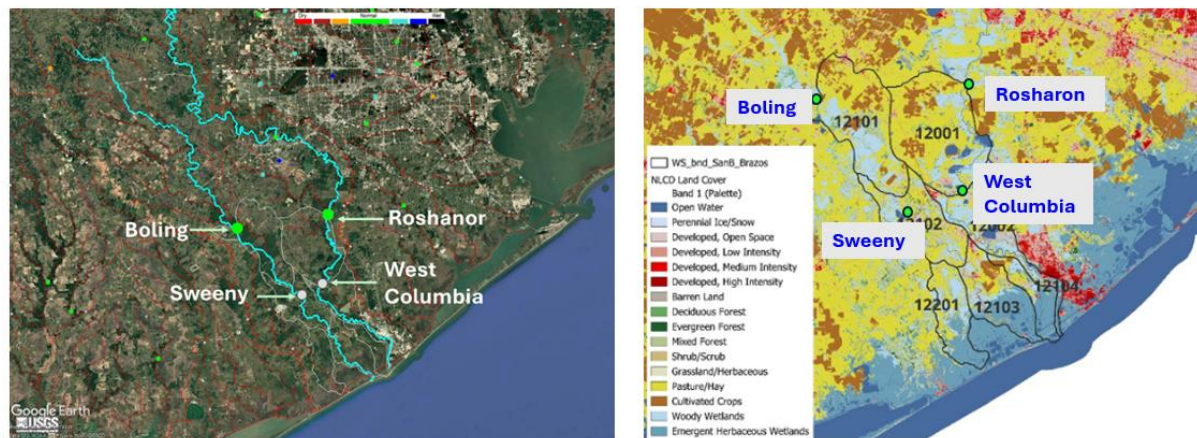


Figure 5-1: San Bernard River, lower Brazos River, and USGS gauging stations along the two streams (left). Land cover overlaid with TWDB watershed boundaries (right).

Four USGS stations in the region maintain flow observations, two on the San Benard River and two on the Brazos River (Table 5-1). Among these, three are situated right at the boundary of each TWDB watershed, and one (San Bernard River near Sweeny) is located downstream of watershed 12101 and within 12102.

Table 5-1: USGS stations and related TWDB watersheds

USGS ID	Station Location	TWDB Watershed	Alignment
08117500	San Bernard Rv near Boling	12101	Immediately Upstream
08117705	San Bernard Rv near Sweeny	12102	Within
08116650	Brazos Rv near Rosharon	12001	Immediately Upstream
08116850	Brazos Rv near West Columbia	12002	Immediately Upstream

In order to compare TxRR observations against USGS observations, we first applied Muskingum routing scheme to route the observed flow at each upstream USGS station to the downstream station, and then subtracted this routed flow from the observation at the downstream USGS station to obtain the lateral contributions, which will be referred to as runoff or lateral inflow. This practice

allowed us to account for phase change of hydrograph due to attenuation of flood waves when they propagate from the upstream to the downstream station. As the USGS station near Sweeny is not located along the border between 12101 and 12102, we scaled the TxRR simulated runoff using a flow-length-based coefficient, defined as the ratio of flow length to the downstream outlet to that of the upstream outlet, to obtain model-implied lateral inflow. Model performance was evaluated using percent bias (PBIAS) at monthly, annual, and event scales over the period of 2018-2024. The PBIAS is defined as follows:

$$PBIAS = \frac{\sum_1^n (Q_{sim} - Q_{obs})}{\sum_1^n Q_{obs}} \times 100$$

The runoff series simulated by TxRR and USGS flow records are compared for watershed 12101 along the San Bernard River and watershed 12001 along lower Brazos River. The comparisons are performed for annual cumulative runoff and selected events.

San Bernard River

The model accurately reproduced the annual runoff for the segment of San Bernard River between Boling and Sweeny for 2022, but underestimated the runoff for 2023 and 2024 (Fig. 5-2). The largest positive biases were seen in 2018 and 2021, with PBIAS values of 136% and 79%, respectively. Moderate overestimation was observed in 2019 and 2020, while 2022 shows close agreement between observed and simulated values (PBIAS = 6%). By contrast, TxRR underestimated lateral inflow in 2023 and 2024, with negative PBIAS values of -54% and -23%, highlighting a shift in model behavior in the later years (Table 5-2). To further assess the model performance, we selected four events, two in 2021 and two in 2022, and compared the runoff time series based on USGS observations and TxRR simulations (Figs. 5-3 and 5-4).

2021: The first event in May of 2021 featured a peak at around 3000 cfs on May 10. For this event, TxRR produced a much higher peak around May 5 (> 4000 cfs), five days ahead of the peak based on USGS records. The second event took place in early October, with a peak on October 8 below 500 cfs. TxRR again produced a peak that is much higher (> 2000 cfs) and earlier in time (Oct 3).

2022:

The first event in 2022 spans late April to early May, and it featured a minor peak of less than 40 cfs on May 4. TxRR produced a peak of 120 cfs on April 30, five days ahead of the former. The second event is a larger event that peaked on November 30, 2022 at 1600 cfs. For this event, TxRR produced a peak that is quite close in magnitude and timing to the observed, though the rising limb of the simulated hydrograph still preceded the observed.

Table 5-2: Annual runoff based on TxRR simulations and USGS observations for lower San Bernard River between Boling and Sweeny.

Year	Reconstructed Flow from USGS records (cfs)	TxRR (cfs)	PBIAS (%)
2018	31817	75039	136
2019	66699	97455	46
2020	36549	51999	42
2021	75986	135680	79
2022	18392	19503	6
2023	32038	14725	-54
2024	53970	41490	-23

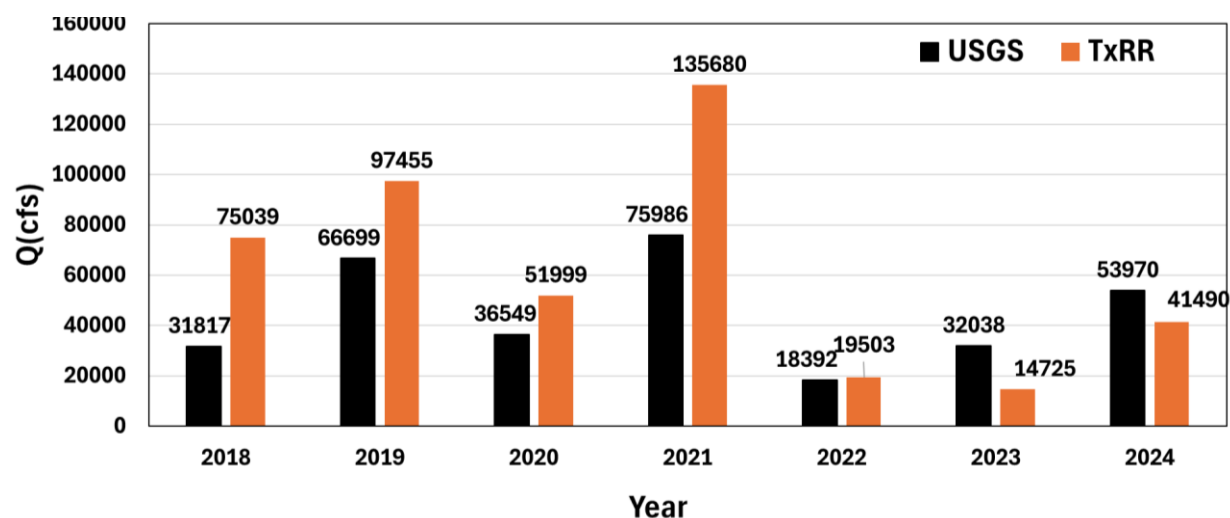


Figure 5-2: Cumulative annual runoff inferred from USGS observations and computed by TxRR for San Bernard River between Boling and Sweeny.

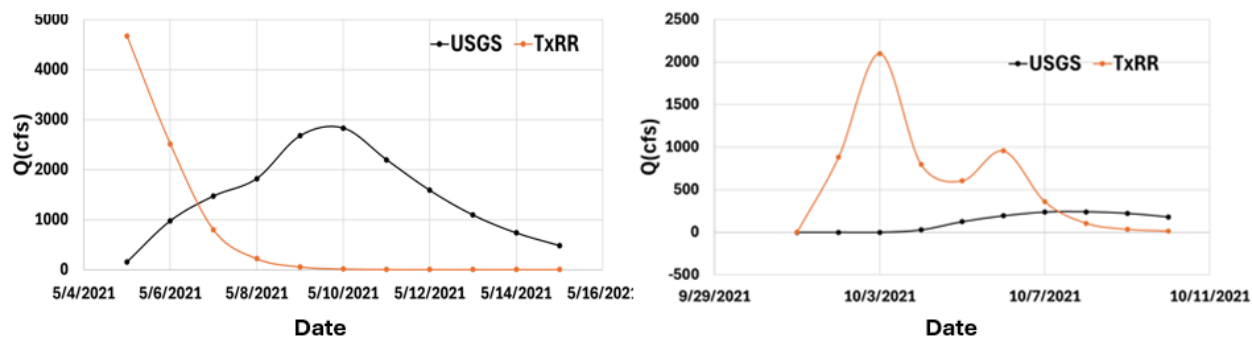


Figure 5-3: Time series of runoff derived from USGS records and TxRR simulations for two events along the San Bernard River in 2021.

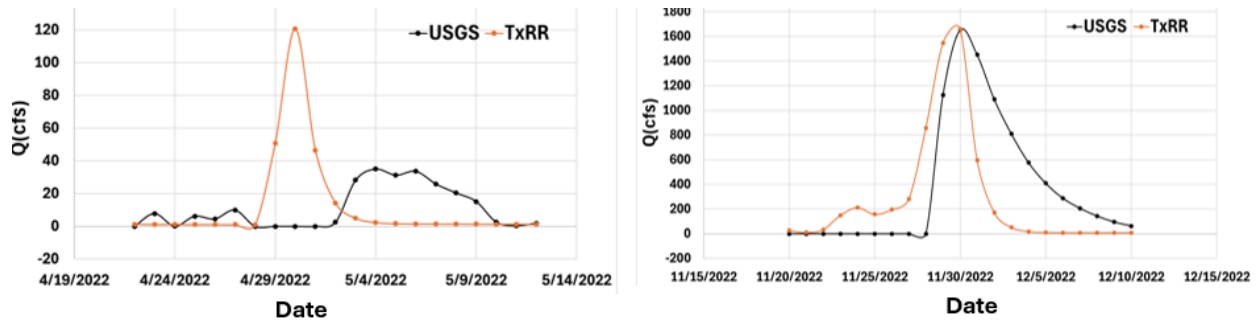


Figure 5-4: As Fig. 5-3, except for two events in 2022.

Brazos River

The annual runoff produced by TxRR and reconstructed from USGS record for the segment of Brazos River between Rosharon and West Columbia is compared in Table 5-4 and Fig. 5-5. It is evident that TxRR simulations suffer severe, negative biases across all years, with PBIAS ranging from -89 to -73. In contrast to the lower San Bernard River, the bias of TxRR simulation is relatively consistent among years, without exhibiting a conspicuous trend. The volumetric difference appears wider over the wetter years such as 2019 and 2024, and narrower in the drier years including 2021 and 2023.

Table 5-3: Annual runoff based on TxRR simulations and USGS observations at WS12001

Year	USGS (cfs)	TxRR (cfs)	PBIAS (%)
2018	575337	105719	-82
2019	824462	92705	-89
2020	383189	59545	-84
2021	509186	135046	-73
2022	164779	29468	-82
2023	272155	49590	-82
2024	793763	132339	-83

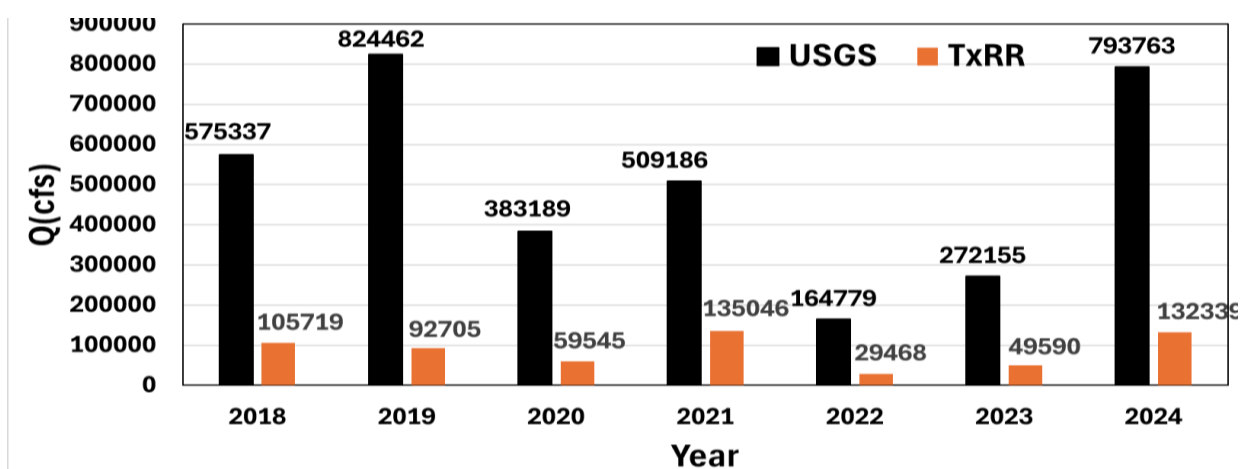


Figure 5-5: Annual runoff for Brazos River between Rosharon and West Columbia based on TxRR simulations and USGS observations.

Similar to what has been done for San Bernard River, we selected four events, two in 2021 and two in 2022, to determine the impacts from one containing a high flow pulse and one containing a moderate-low flow pulse, and compared the runoff time series based on USGS observations and TxRR simulations (Figs. 5-3 – 5-7).

2021: The first event spanned late June to early July with a peak at around 14000 fs. For this event, TxRR vastly underpredicted the magnitude of the peak, with around 5000 cfs (Fig. 5-6). The model also was not able to reproduce the timing of the peak – the simulated hydrograph continued to rise till early July. The second event was a minor one that occurred in late October and early November, with a prolonged period of high flow at around 900 cfs. The model produced a sharper peak of around 1200 cfs, and was unable to mimic the prolonged high flow.

2022: The first event in 2022 occurred in mid-late February, featuring a peak exceeding 5000 cfs on February 13 (Fig. 5-7). The model was broadly unable to resolve this event, and produced only a minor peak (around 1500 cfs) on February 4th. The second event occurred in early July, and was much smaller in magnitude, with a peak of less than 200 cfs (Fig. 5-7). The model produced a peak slightly above 250 cfs, but its timing is behind the observed by six days.

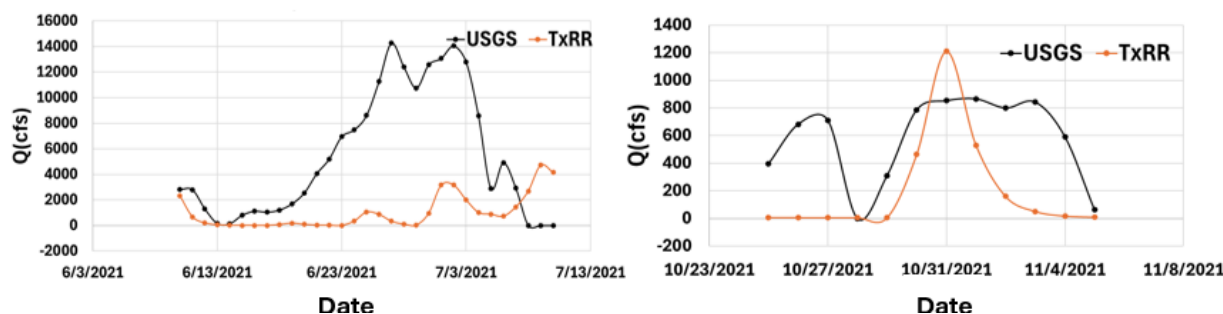


Figure 5-6: Time series of runoff derived from USGS records and TxRR simulations for two events along the lower Brazos River in 2021.

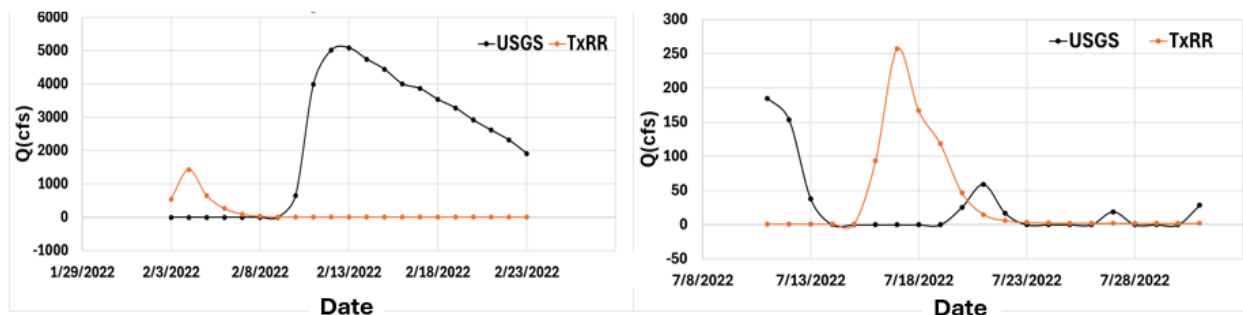


Figure 5-7: As Fig. 5-6, except for two events in 2022.

To summarize, the following observations were evident in evaluating the performance of TxRR model:

- For the segment of lower San Bernard River between Boling and Sweeny, the model tended to produce an earlier peak while under-predict the magnitude of peak. Though only a limited number of cases were included in this report, this appears to be a consistent pattern for events prior to 2022.
- After 2022, the model bias was much improved on an overall basis and for specific events, though a slight negative overall volume bias was seen.
- For the segment of lower Brazos River between Rosharon and West Columbia, the model was broadly unable to reproduce the runoff reconstructed from USGS records. The negative bias is particularly severe for major high flow events.
- Unlike lower San Benard River, the negative bias in TxRR simulation was persistent across years.

Note that the TxRR model had undergone calibration according to TWDB staff, and it is likely that the improvement in bias for the lower San Bernard River from 2022 onward was a result of this calibration effort. However, the bias for the earlier period remained severe and it is not clear if this lingering bias was a result of calibrating only the later period. For the lower Brazos River, it is possible that calibration has yet to be carried out. The mismatch in timing of flow over the lower San Bernard River is intriguing, as simulated peaks appear to consistently predate the reconstructed ones for a majority of events (including events not shown in the analysis). It is worth pointing out that the fidelity of reconstructed runoff over each segment was predicated on the validity of Muskingum routing scheme and associated parameter values. As the routing scheme did not undergo calibration or validation, its output is subject to biases and errors of unknown magnitude. There is a possibility that the routing scheme routed the upstream flow too fast, and once this routed flow was subtracted from the downstream record, the result was a shift in the runoff estimates. We recommend that ancillary data sets, such as remote sensing products, be leveraged to assess channel-floodplain interactions and determine the potential role of floodplain storage that is not explicitly accounted for in the Muskingum scheme.

6. Development of Regional Models

6.1 Modeling needs

After reviewing the models acquired from regional partners and outcomes from earlier studies, the project team decided on a set of requirements for the modeling system/suite:

- Model domain needs to cover the entire coastal zone extending from Freeport to East Matagorda Bay
- Model mesh needs to be sufficiently over the Lower San Bernard River, Brazos River, GIWW, and Cedar Lakes to resolve the hydraulic processes and sediment dynamics
- Model mesh needs to cover the coastal zone outside of water bodies to represent inundation during major flood events such as Hurricane Harvey

- Model needs to cover littoral zone and accounts for wave transport that is the primary driver of sediment infilling at San Bernard River mouth
- Model needs to project long-term shoreline changes and simulate, if necessary, episodic disturbances from major storms.

6.2 Model development

In response to these requirements, the project team developed two models, one using Delft-3D that accounts for flow connectivity inland and is able to simulate sediment transport across the river-estuary-ocean interface, and one using X-beach for projecting shoreline changes. In addition, we developed a two-way nested wave model for simulating nearshore waves, though we decided not to use this model due to constraints of the current version of Delft-3D as detailed below.

Table 6-1: Comparisons between Delft-3D and X-beach models developed in this project

Configuration/Processes	Delft-3D	X-beach
Grid mesh	Unstructured	Curvilinear
Physical depth	2D depth averaged	2D depth averaged
Freshwater pulse	USGS	USGS
Flow-sediment dynamics in estuaries/GIWW	Resolved	None
Offshore current-sediment interactions	Resolved	Resolved
Current-wave interactions	None (without SWAN)	Resolved
Swash zone dynamics	None	Resolved

As Table 6-1 shows, the Delft-3D system provides physics packages to model the sediment transport and morphological changes across the river-estuary-ocean continuum. In addition, the Delft-3D Flexible Mesh (FM) uses unstructured mesh that offers flexibility and parsimony in representing complex geometries often seen at the estuary-ocean interface. However, it suffers several limitations that make it non-ideal for projecting shoreline changes and inlet stability. These include its inability to account for offshore current-wave interactions and to resolve swash zone dynamics. In this region, the longshore drift that contributes to infilling of San Bernard mouth is driven mostly by near-shore waves, and therefore resolving these processes is critical. Though Delft-3D system incorporates a wave model (Simulating WAVes Nearshore, or SWAN), and allows for online coupling of the hydrodynamic and wave modules, there remain technical challenges in coupling the Delft-3D model built on an unstructured mesh with the wave model that uses a curvilinear mesh. Moreover, SWAN is a phase-averaged wave model that does not explicitly resolve infragravity waves (Roelvink et al., 2009), which play major roles in modulating the sediment processes in the Swash zone.

On the other hand, X-beach was developed specifically to simulate processes in the swash and surf zones. It is capable of resolving infragravity waves and dynamic wave runups, and therefore it is

often used for modeling dune erosion and overwash during specific storm events. X-beach's key limitation is its poor representation of freshwater pulses and current-wave interactions in the estuary without accounting for density stratification (Bai et al., 2025; Mora-Urbe et al., 2025). Despite its limitations, however, X-beach's ability to resolve wave-driven littoral transport is a critical advantage vs. Delft-3D without SWAN coupling. In addition, it is easy to configure, and can project long-term morphological changes at and adjacent to the inlet with limited computational demand.

Delft-3D Model:

The computational meshes of the Delft-3D and SWAN models are shown in Fig. 6-1. The Delft-3D model extends from Oyster Creek which lies to the east of Freeport to Matagorda Bay, covering the Gulf, lower portions of coastal streams including Brazos River, San Bernard River, and Caney Creek. The mesh is gradually refined towards shoreline and along coastal waterways.

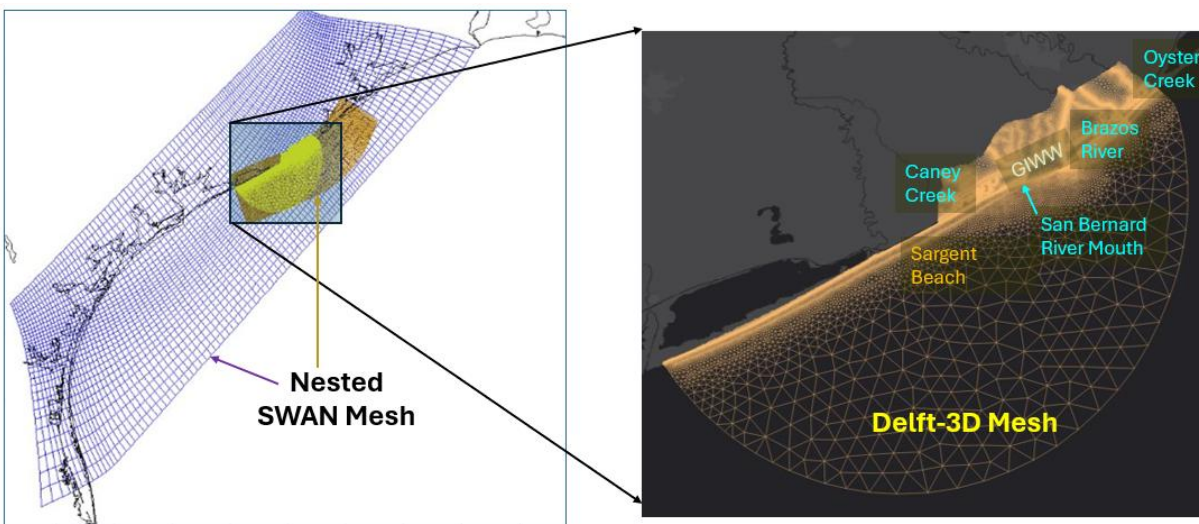


Figure 6-1: Computational meshes for the SWAN and Delft-3D models developed for this project. Note the SWAN is developed on a 2-way nested mesh.

To further reduce computational demand and facilitate scenario analysis, we subset the regional Delft-3D to cover the eastern portion of the study domain encompassing Cedar Lakes, GIWW, San Bernard River and Brazos River that is of focus in this project (Fig. 6-2). Note that the model mesh encompasses both land and water bodies to simulate flow and sediment delivery during major flooding events.

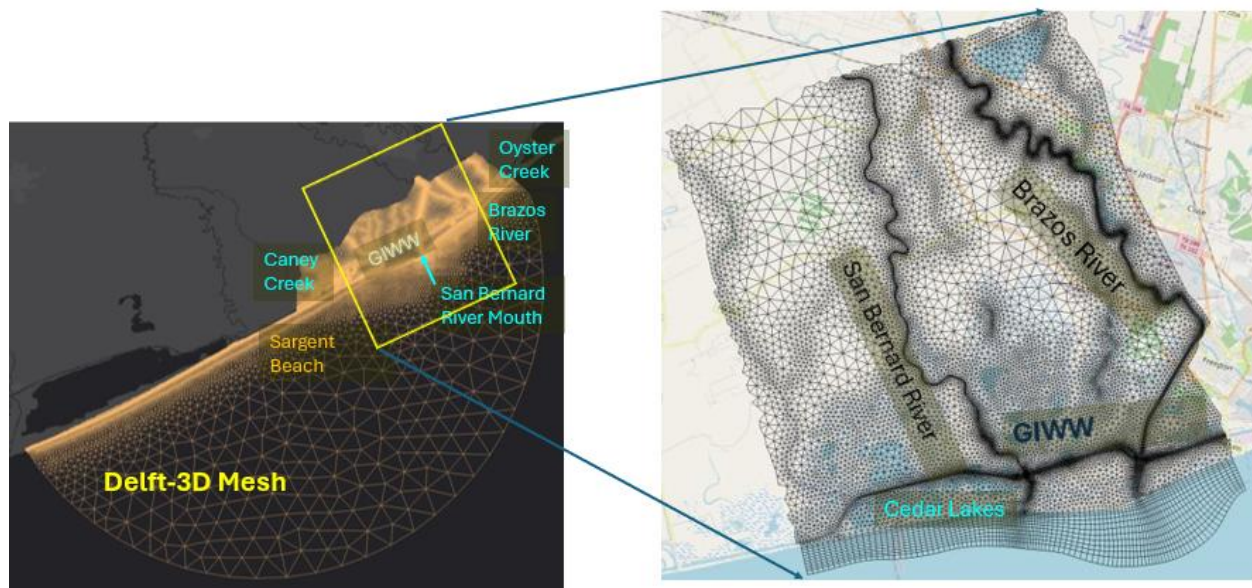


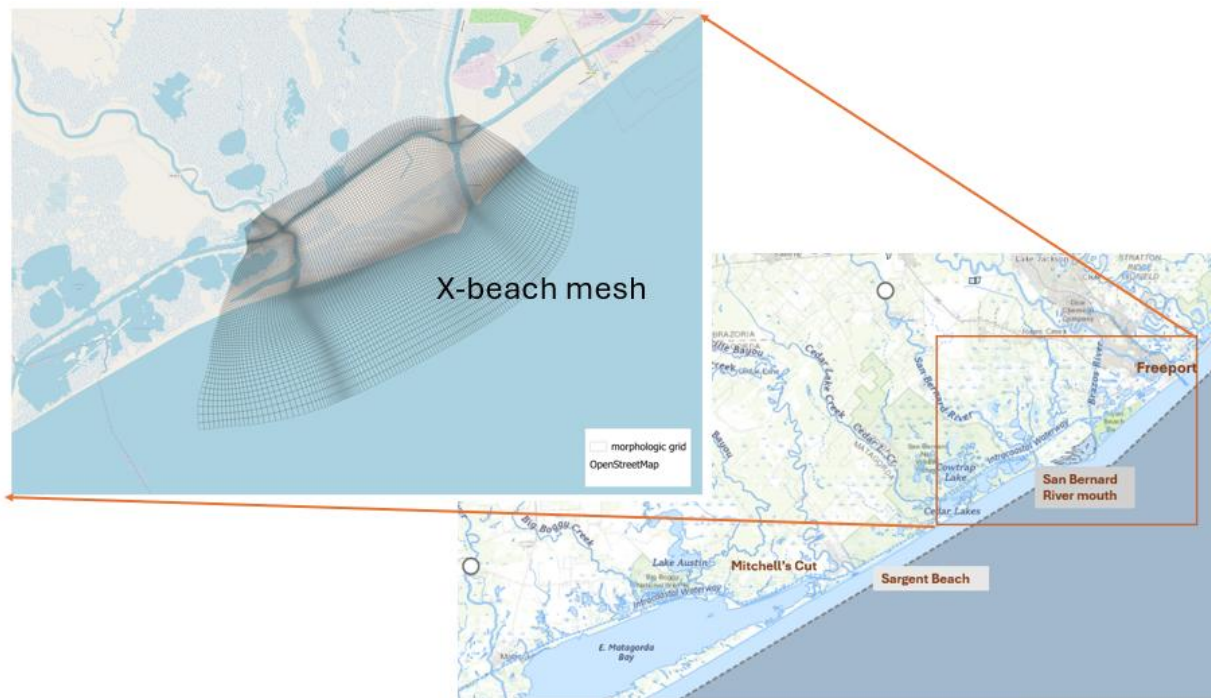
Figure 6-2: Left panel: the mesh of the regional Delft-3D model. Right panel: the model mesh for a subdomain that covers the eastern portion of the study region.

Both the hydrodynamic and sediment transport modules were developed in 2D (depth-averaged) mode. The former solves the unsteady shallow water equations for the flow fields. The limitations of the 2D formulation include not explicitly resolving vertical shear and ignoring vertical stratification or mixing. The sediment transport module computes movement of suspended and bed load. As the 2D hydrodynamic model produces only depth-averaged velocity field, the model typically creates a logarithmic velocity profile from this velocity on the basis of bed shear stress.

The sediment transport module distinguishes between sand (non-cohesive) and mud (cohesive) in its formulation. Sand particles can be transported either through bed load under low velocity or suspended load once velocity exceeds a threshold. By contrast, cohesive particles are modeled entirely as suspended load. The module further simulates bed load using empirical formulations such as Van Rijn (1984), and suspended load using 2-D advection diffusion equation. Erosion and deposition constitute the source and sink of sediment. For cohesive sediment, the module uses thresholds on depth-averaged bed shear stress to trigger erosion and deposition. As the hydrodynamic module produces only depth-averaged velocity, the sediment module applies a prescribed vertical velocity profile to create distributed velocity at different depths. Similarly, the sediment module uses a vertical sediment concentration profile (e.g., the Rouse profile; Boudreau and Hill, 2020) to distribute depth-averaged sediment concentrations vertically. Note that the velocity from the hydrodynamic module feeds to the sediment module by allowing the latter to update the bed shear stress, friction velocity and Rouse number, and in turn determine erosion and deposition.

The SWAN model was developed on a structured (curvilinear) mesh. It solves the spectral action balance equation to simulate spatio-temporal evolution of wave energy density spectrum. Being a spectral model, SWAN is computationally efficient and well-suited for simulating large-scale wave setup offshore and in estuaries, but it is unable to explicitly resolve intra-phase variations in shape, amplitude and velocity (see Ferdaus et al., 2025, for a more in-depth review). The 2-way nested model allows for the use of 2D spectra from the outer model as boundary conditions to the inner model.

The X-beach model domain and mesh are shown in Fig. 6-3. As our primary goal is to project shoreline changes near the San Bernard River inlet, the model domain covers lower portions of San Bernard River and Brazos River, and parts of the littoral zone offshore. The model uses a curvilinear mesh that is refined along the coastal streams.



The model was configured in a depth-averaged, 2D mode to simulate wave-driven hydrodynamics, sediment transport, and morphological change. The model uses absorbing boundary conditions at the offshore and onshore edges to minimize artificial wave reflection, while the lateral boundaries were configured as zero-gradient boundaries to limit lateral constraint effects.

63

dynamics. Point discharges were included for freshwater inflow forcing to simulate the interaction with the nearshore hydrodynamics and sediment dynamics in the presence of inflow jets.

Sediment transport and bed updating were activated, using a representative sediment grain-size specification. Morphological change was accelerated using a morphological factor corresponding to the number of days the wave regime was observed, and applied to the 24-hour simulation period to efficiently represent longer-term bed evolution within feasible computational time. Bed slope limiting was applied to avoid unrealistic bed gradients that could be artifacts of temporal elongation. Bed shear stress was parameterized using Manning-type bed friction. Numerical stability and convergence were controlled through a Courant-type stability constraint and a minimum water depth threshold for wetting–drying behavior.

X-beach provides three operating modes: 1) stationary, 2) surfbeat (hydrostatic) and 3) non-hydrostatic. The stationary mode solves wave-averaged equations to determine radiative stress from short waves, and neglects infragravity waves. Nonetheless, it resolves key processes including wave propagation, directional spreading, shoaling, refraction, bottom dissipation, and wave breaking, and it is effective for projecting morphological dynamics with temporally consistent wave conditions. We chose the stationary mode for the scenario analysis as our primary focus was on projecting long-term shoreline changes as the wave regime within the domain appears stable over time.

Model Testing: Hurricane Nicholas

We tested the Delft-3D coupled flow-wave-sediment models for a historical storm, namely Hurricane Nicholas of 2021, to evaluate the model’s ability to reproduce the long-shore transport. Hurricane Nicholas formed in the southwestern Gulf as a tropical storm; it briefly intensified on September 14 to reach hurricane status before making landfall west of Sargent Beach at around 10 UTC (4 am CDT) with maximum sustained wind of 75 mph (Figs. 6-4 and 6-5). The storm produced surge and wind damage across Matagorda and Brazoria Counties. As shown in Fig. 6-5, the wind was predominantly southwesterly at its landfall, and shifted to northwesterly once the storm center moved east.

We performed simulations of wave, current and sediment using the coupled model over the period of September 1-18, which is further divided into two sub-periods: 1) September 1-12, where the wind conditions in the Gulf was considered “normal”, and 2) September 12-16, right during the passage of Hurricane Nicholas. A brief description of the model configuration is provided below:

- Boundary conditions over land:
 - Observed discharge at USGS stations along San Bernard River at Sweeny and Brazos River near West Columbia.
 - Sediment fluxes along channels assumed zero.
- Forcing: Wind and pressure from ERA-5 Reanalysis

- Lateral boundary in the Gulf: ERA-5 wave analysis; variables include significant wave height and dominant directions.
- Initial condition: water in the Gulf is still at mean sea level

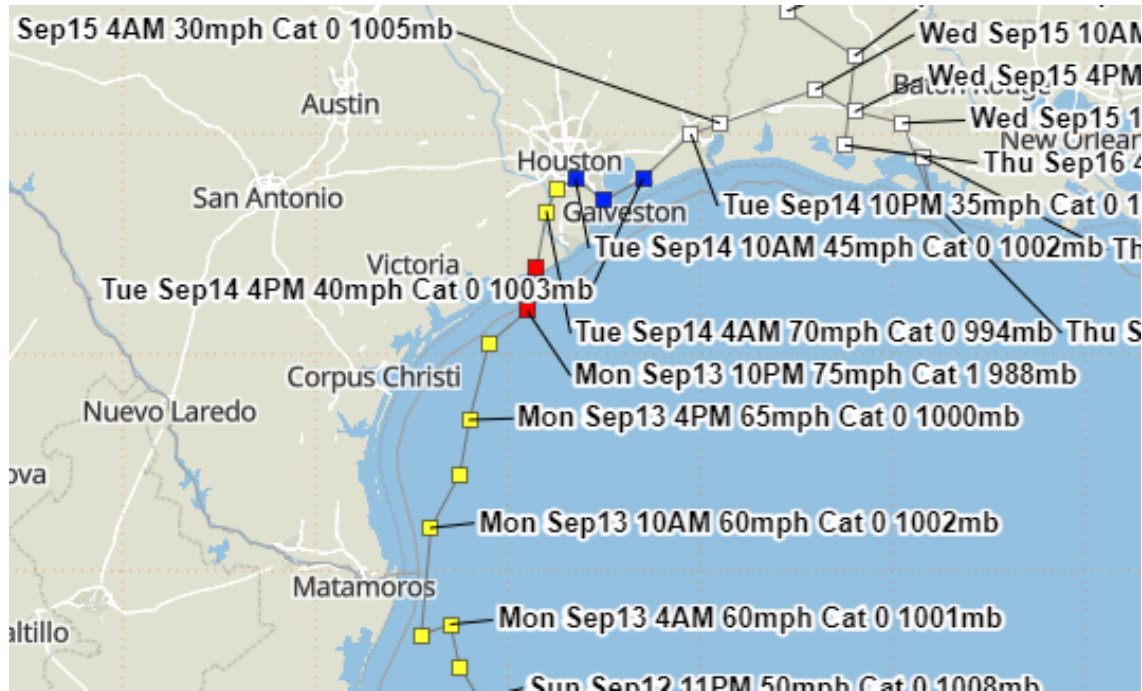


Figure 6-4: Time History of Hurricane Nicholas. Source: NOAA.

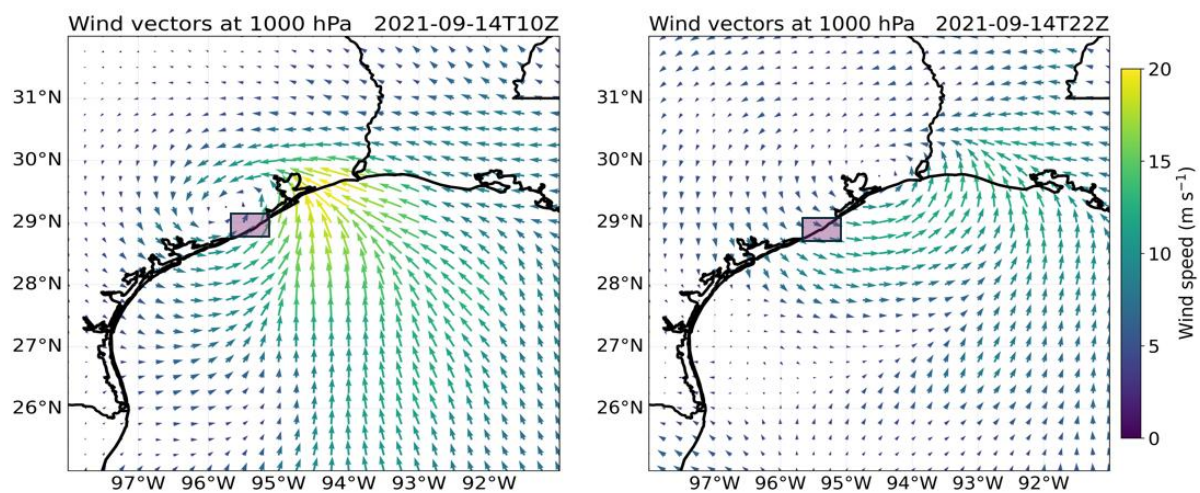


Figure 6-5: Wind fields at and after landfall of Hurricane Nicholas. Source: ECMWF.

The model simulated velocity fields are shown in Fig. 6-6. One day ahead of the landfall of Nicholas, the current was clearly influenced by the tidal boundary condition, exhibiting reversals within each day as a result of the semi-diurnal tidal cycle. At 2:30 CDT on September 14 right before the landfall, the flow was predominately offshore. At 22:00 CDT, the storm center had moved east and the current was pointing southwestward, despite the prevailing northwesterly wind.

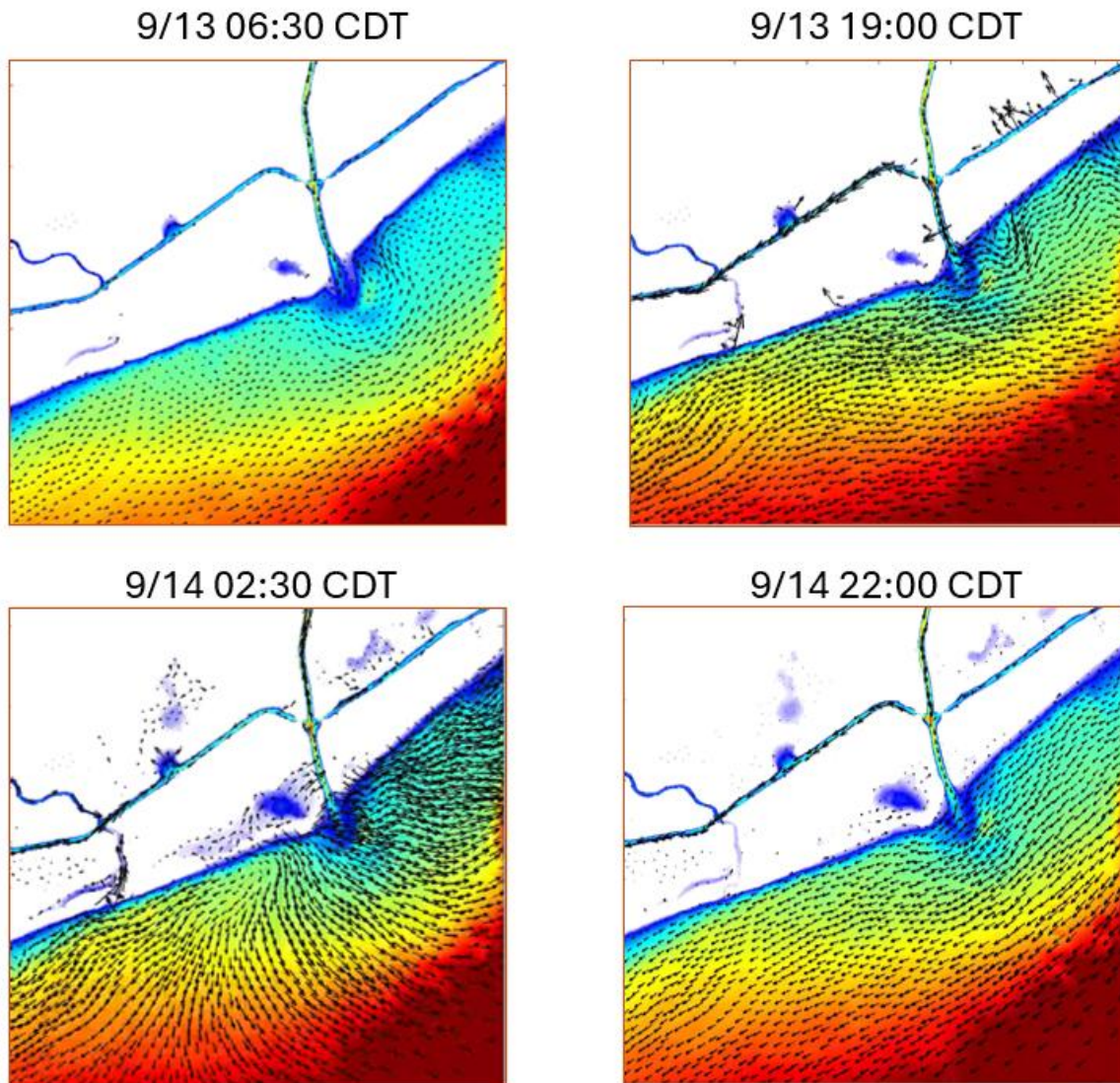


Figure 6-6: Velocity fields simulated by Delft-3D at four snapshots around the landfall of Hurricane Nicholas.

The model computed morphological changes along the San Bernard inlet and the shoreline adjacent to it during this period. Fig. 6-7 shows the flow and cumulative erosion/deposition on September 6 and 16. The following observations are evident:

- Alternating erosion/deposition is seen along the shoreline.
- Net deposition of sediments along both sides of the San Bernard River mouth.
- Net erosion in the surf zone right outside of the San Bernard River mouth.
- Net deposition within the inlet and along the old channel

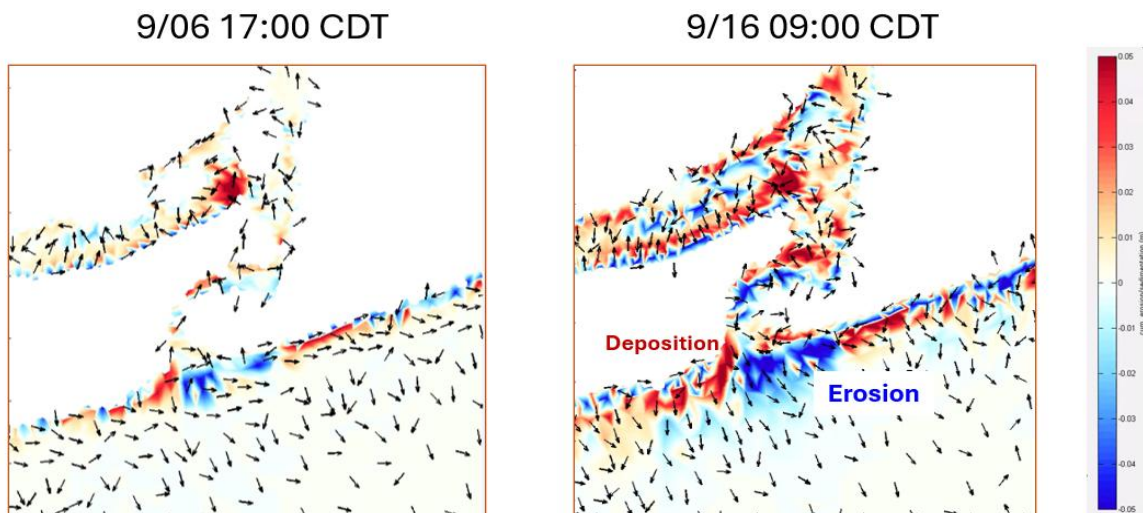


Figure 6-7: Flow vector and cumulative erosion/deposition along the shoreline and San Bernard inlet.

The littoral transport prior to and during the Hurricane is further illustrated in Figs. 6-8 and 6-9, where the cumulative sediment flux along five cross-sections along the shoreline is shown. These cross-sections extend to the littoral zone (500-1000m offshore). For the earlier sub-period, the direction of sediment flux varies among cross-sections and over time. To the east of Brazos River mouth, the sediments were transported primarily eastward until September 9. To the west, the flux is mostly westward, with the cross-section immediately west of the Brazos River mouth exhibiting the largest magnitude of flux. In addition, it should be noted that the sediment flux accelerates drastically after September 9 at all cross-sections, and becomes predominantly westward even at the eastmost one (east of Brazos River mouth). Among the cross-sections, the sediment flux appears consistently higher/lower to the east/west of San Bernard River mouth up to September 9, suggesting net accretion of sediment during that time window. After September 11, however, the flux to the west of San Bernard River mouth overtook that over the east, likely resulting in net erosion right in front of the mouth.

The later sub-period (September 13-15) saw much greater sediment fluxes at all cross-sections. At the cross-section in the middle, the cumulative flux attained its peak beyond 2500 m³ on September 14, whereas during the earlier, quiescent conditions, the flux at the same cross-section was less

than 40 m³ by September 13. Among the cross-sections, the eastmost one (east of Brazos) again featured the low amount of sediment flux, whereas all other four experienced an abrupt, explosive increase in flux right before the landfall of Nicholas. It is worth noting that the intensity of flux appears to increase towards the west, in stark contrast to the earlier, quiescent window where flux peaked immediately west of the Brazos River mouth and declined further east.

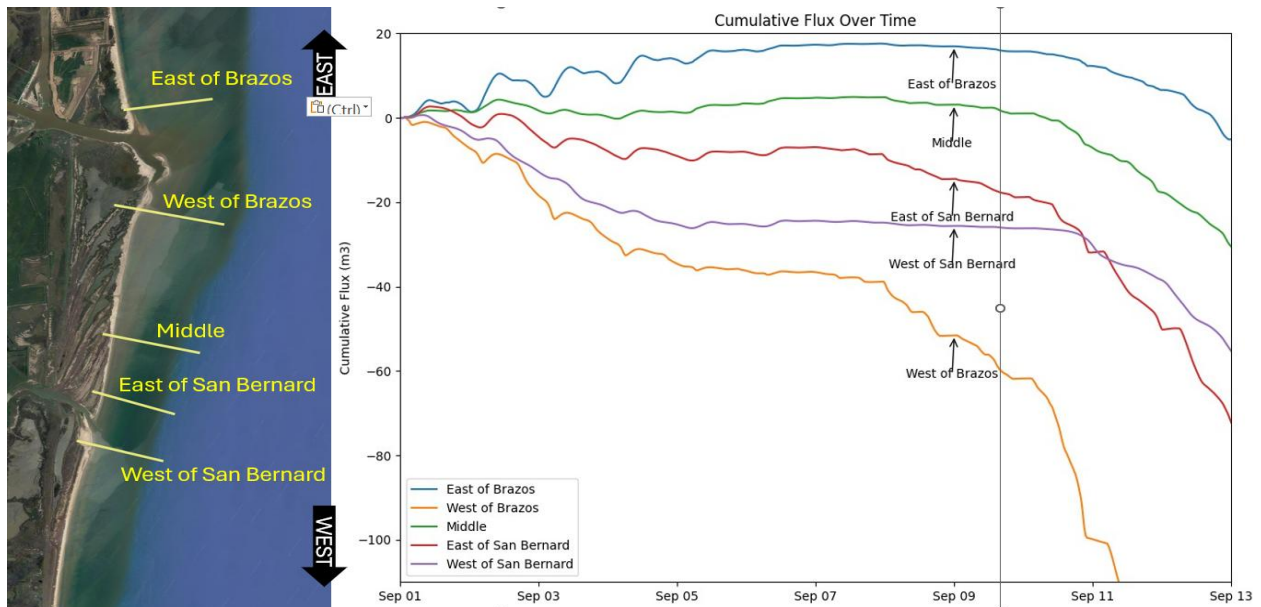


Figure 6-8: Cumulative sediment flux in the littoral zone along five cross-sections between September 1 and 13.

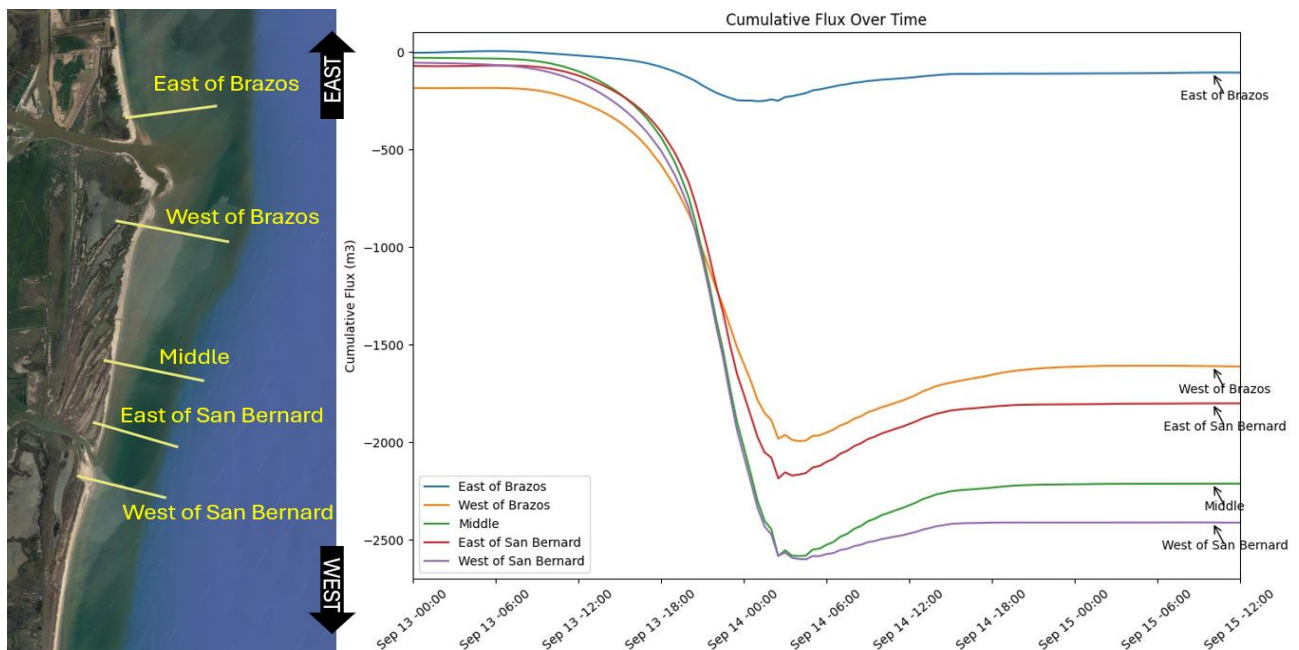


Figure 6-9: Cumulative sediment flux in the littoral zone along five cross-sections between September 13 and 15.

The comparison highlights the ability of tropical storms to mobilize sediments and drastically alter the erosion/deposition regimes. Despite the prevailing westerly wind after landfall of Nicholas, it produced strong westward currents that sharply increased the magnitude of sediment flux and propelled the sediment plume further west. This led to net erosion offshore of San Bernard River mouth, which, however, did not appear to alleviate the net accumulation of sediment within the inlet. It must be noted that these findings are based entirely on model simulations, and much needs to be done to corroborate the findings through empirical observations.

The modeling systems have been shared with staff of Texas Water Development who oversaw the development of Texas Integrated Flood Framework (TIFF).

7. Scenario Analysis

In the current project, we applied the hydrodynamic model to perform scenario analysis on three historical episodes, namely: 1) Hurricane Harvey of 2017; 2) Closure of San Bernard River mouth after the dredging project completed in 2022; and 3) 2) Hurricane Nicolas in 2021. These analyses serve to illuminate the impacts from the closure of the San Bernard River mouth on inland flooding, offshore littoral transport by a major storm and under prevailing wave regimes.

Hurricane Harvey

Hurricane Harvey produced heavy rainfall in the lower portions of San Bernard River and Brazos River Basins, and near record discharge along the two rivers. As shown in Fig. 7-1, most of the rainfall fell on August 28 with a northeastward gradient in the region. The USGS gauge on San Bernard River near Sweeny (USGS ID: 08117705) recorded peak discharge of 46,000 cfs on September 2, whereas the gauge on Brazos River near West Columbia (USGS ID: 08116850) recorded a peak of 129,000 cfs on September 3. At the latter site, the discharge appears to reach a quasi-steady phase between September 1 and 5, suggesting intensive channel-floodplain interactions during the event.

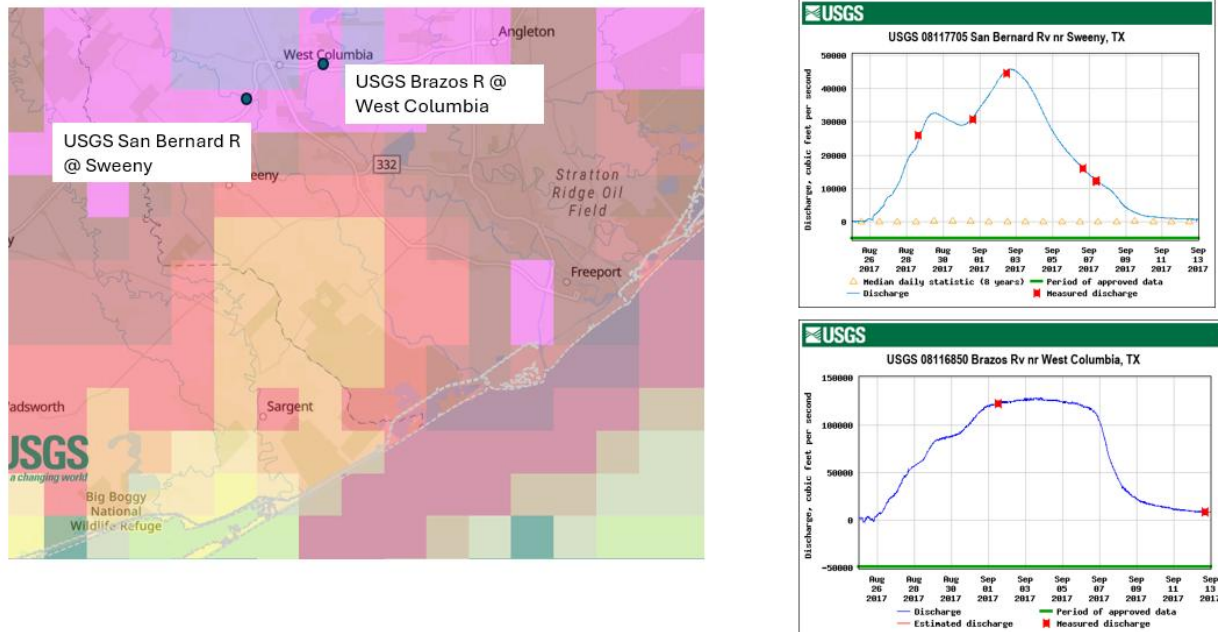


Figure 7-1: Left: Rainfall map on August 29, 2017 during Hurricane Harvey. Right: hydrographs observed at two USGS gauges, namely San Bernard River near Sweeny, and Brazos River near West Columbia.

The Delft-3D model was configured for the subdomain shown in Fig. 6-2 to examine the contribution from the closure of San Bernard River mouth to the flooding experienced upstream. To this end, we created scenarios. The first, or the scenario of closure, and it uses the topobathymetry data collected in 2016 when the mouth was closed. The second has the mouth artificially open by artificially opening the mouth to mimic the conditions after dredging done in 2022. The elevation maps for the two scenarios are shown in Fig. 7-2.

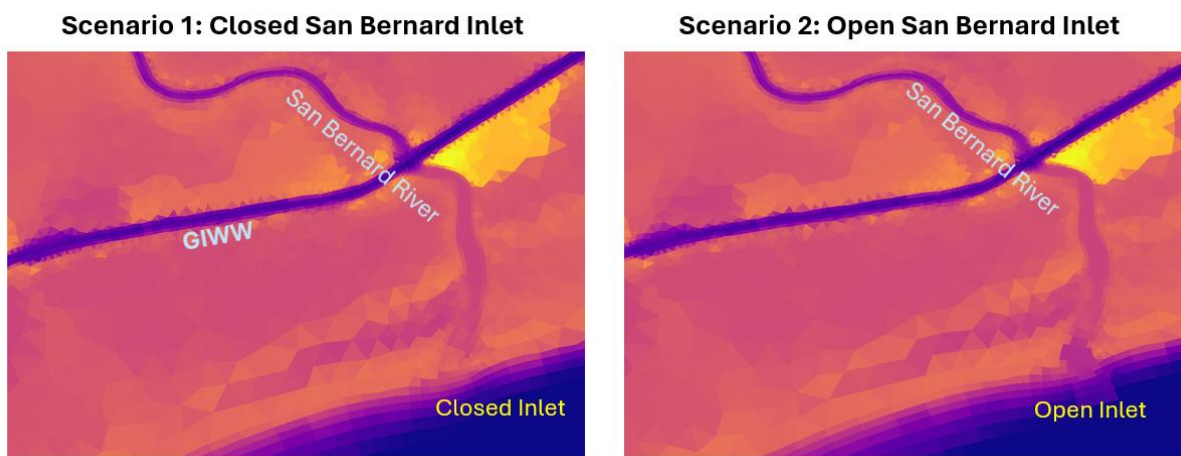


Figure 7-2: Elevation maps for the two scenarios: 1) with San Bernard Inlet closed and 2) with San Bernard Inlet open.

The model configurations for the two scenarios are summarized in Table 7-1. For both scenarios, the model ingested observed discharge series at the USGS gauges in Sweeny and West Columbia (Fig. 7-1), and simulated water level and velocity at the Gulf boundary. Though Delft-3D offers the rain-on-grid options to account for local rainfall, we chose not to activate this option, and only employed wind as the forcing. The first (closure) scenario also incorporated morphological simulations using the D-Morphology module to determine if the model is able to reproduce the dynamic opening of the San Bernard River mouth during Harvey.

Table 7-1: Scenarios for Hurricane Harvey

Scenario	Topo-bathy	Riverine Boundary	Gulf Boundary	Forcing	D-Morphology
SB inlet closed	2016	Discharge	Riemann	Wind, pressure	Yes
SB inlet open	2016 with altered elevation at mouth	Discharge	Riemann		No

The model configured for each scenario was run from August 25, 2017 for 11 days. The maps of simulated inundation depth at 18z on August 28 are shown in Fig. 7-3.

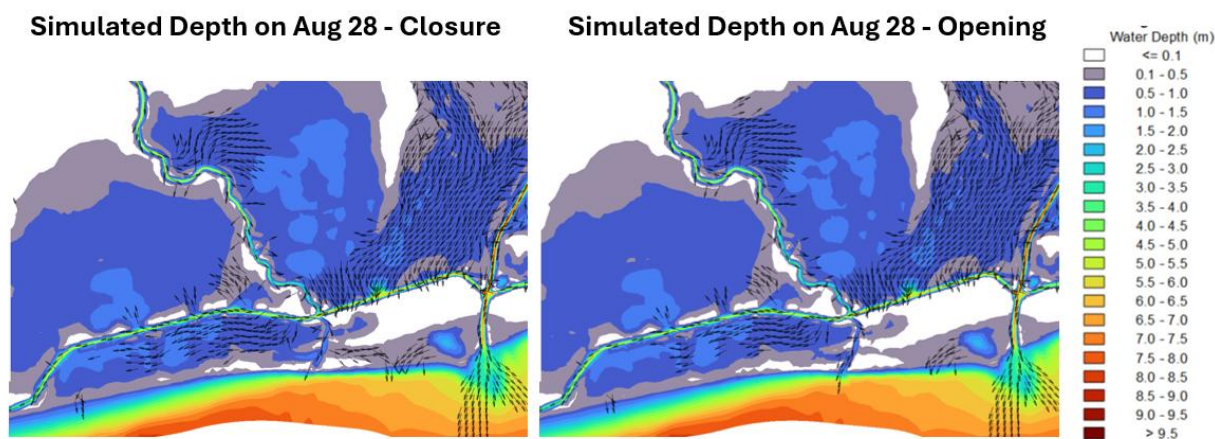


Figure 7-3: Simulated water depth on August 28 for the scenarios with San Bernard River inlet closed (left) and opening (right).

To further depict the impacts of impact of San Bernard mouth closure on intensity of flooding, we compared the time series of water level at six locations along the San Bernard River (Fig. 7-4). Broadly speaking, the inundation maps and time series are quite similar between the two scenarios with the closure and opening of the San Bernard River inlet. The most discernible differences are seen along the lower segment of the San Benard River between the coast and GIWW, where the water level rose at a faster rate when the inlet is closed. Above the intersection with GIWW, the water level series for the two scenarios rapidly converge.

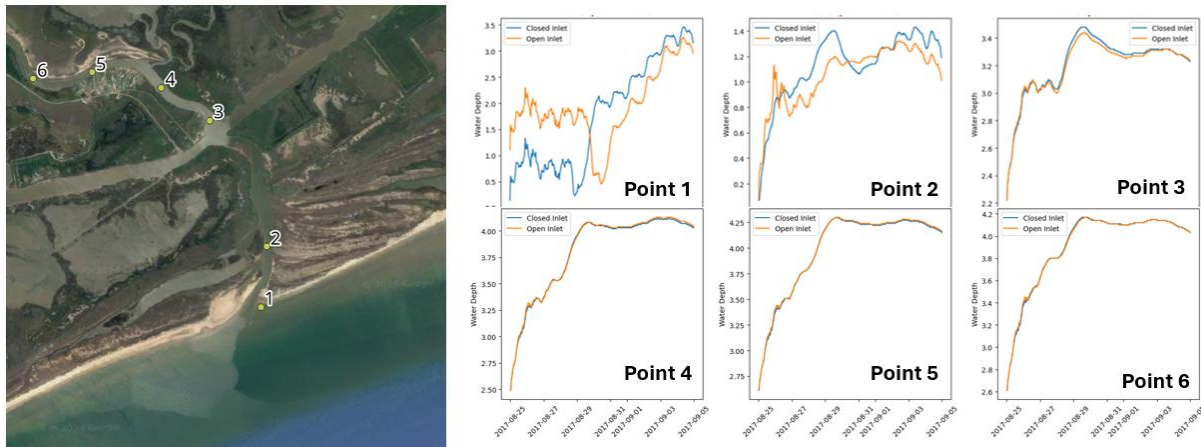


Figure 7-4: Time series of simulated water level at selected locations along the San Bernard River for the two scenarios.

The rather muted impacts from the mouth closure were scrutinized by reviewing the flow directions at the lower San Bernard River for the closure scenario. As shown in Fig. 7-5, it appears that much of the flow is propagated towards the west after encountering GIWW.

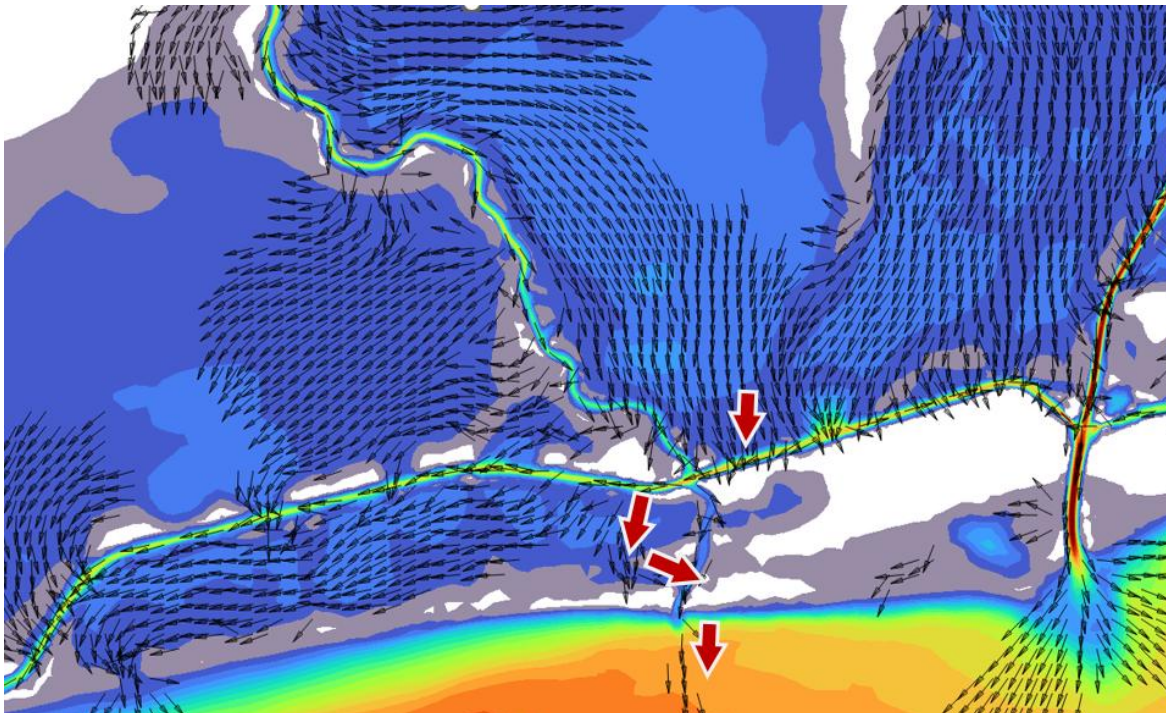


Figure 7-5: Schematic of flow directions along the GIWW and lower San Bernard River during Harvey.

The presence of the deep water pool along the GIWW served to attenuate the flood wave from the San Bernard. In addition, the floodwater was propagated westward, and some spilled out and

flowed into the Cedar Lakes before returning to the San Bernard River near its mouth. As such, though the littoral deposits at the San Bernard inlet served as a dam that induced backwater effects, these effects were confined to the lower portion of the river below the crossing with GIWW. Upstream of this crossing, the effects diminished as the GIWW itself served as the major barrier that dampened the flood wave and redirected the flow, overshadowing the impacts from the closure of the inlet.

Mouth Closure 2022-2023

As described in Section 1, the dredging project carried out between July 2021 and April 2022 successfully opened the San Bernard River mouth, but the sediment infilling went on unabated and eventually led to its closure by 2023. Our second case study aims to determine if the widening of BRFG would enhance the effectiveness of dredging. The idea is that the removal of the west gate and widening of the opening would 1) facilitate the flow of Brazos River into the lower portion of the San Bernard River that would help flush out littoral deposits; and 2) expand tidal prism that would help enhance scouring and thereby push back the littoral deposits to the Gulf during ebb tides. Past studies suggest that deepening or widening the channel would increase tidal prism and that facilitates scouring (O'Brien 1969; O'Brien and Dean, 1972), but if such measures may also increase sediment infilling to flood-dominant inlets, i.e., inlets where landward velocity is greater than the ebb velocity.

In order to assess the possibility that widening of GIWW upstream could impact the stability of San Bernard inlet, we performed long-term simulations of flow and shoreline evolution from April 2022 to July of 2023 using the two modeling systems, 1) the X-beach model, and 2) the Delft-3D model. Note that the former is limited in its ability to account for flow processes in channels and GIWW, and therefore it was used only to construct the baseline scenario (current BRFG configuration), whereas the latter model was used to simulate flow fields for both scenarios: namely a) status quo and b) with modified BRFG. For the latter scenario, we used the modified changes proposed by the USACE Galveston District, which include:

- Removal of the west gate
- Widening the channel from 75 ft to 125 ft.
- Deepening channel by 16 ft

These changes can be found in Fig. 7-6, which contrasts in the model bathymetries for the baseline and future scenarios.

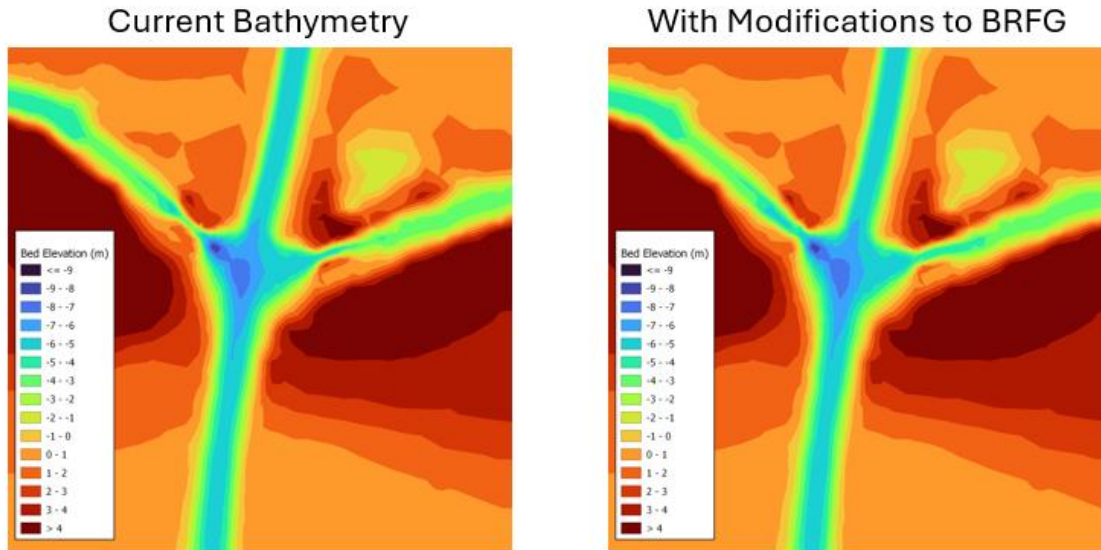


Figure 7-6: Topo-bathy data at the intersection between Brazos River and GIWW before (left) and after the modification of BRFG (right).

To perform the X-beach simulations, we collected wave data from the Wave Information Study managed by USACE ERDC ([Wave Information Study Webpage](#)). The project produces wave direction and heights by hindcast using wave models such as SWAN forced by European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 reanalysis. These are available at selected virtual stations online. Fig. 7-7 shows the locations of virtual stations in the region, and the distribution of wave height at station 73060 that is the closest to the San Bernard River mouth.

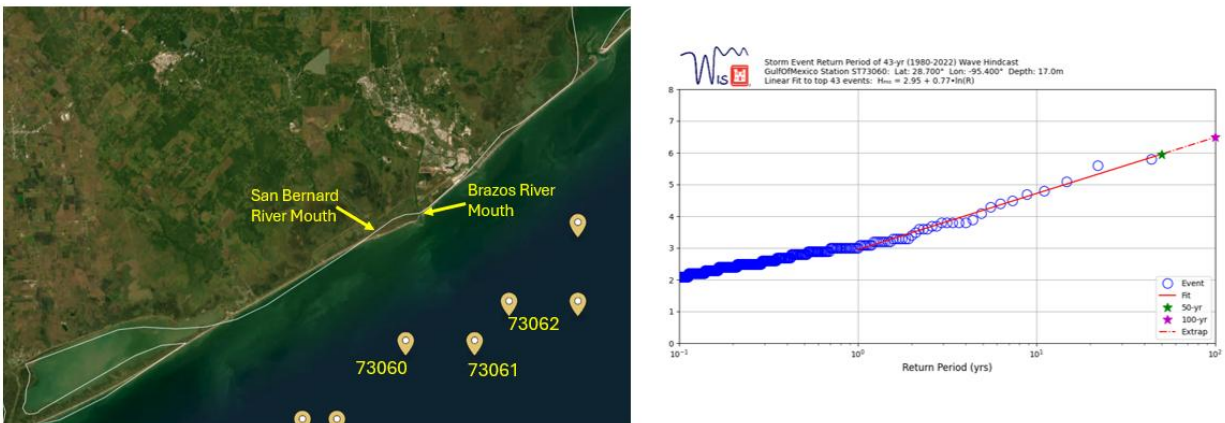


Figure 7-7: Locations of WIS virtual stations in the region (left) and the distribution of wave height characterized by average return period (right).

We retrieved the wave patterns at station 73060 for 2022 and 2023, and these are summarized in Fig. 7-8. Apparently, despite some differences, the wave patterns were broadly similar, with prevailing propagation direction towards the northwest.

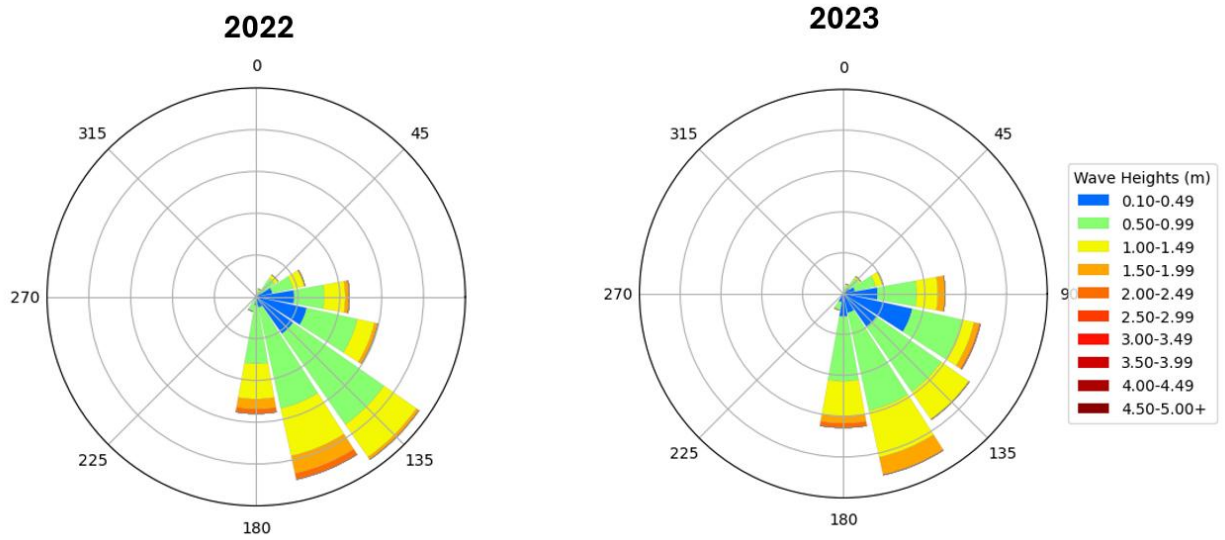


Figure 7-8: Wave patterns for 2022 and 2023 based on ERDC Wave Information Study.

We chose the X-beach model for reproducing the morphological evolution along this segment of coast over the 2022-2023 period, and for examining the potential impact of modifications of the BRFG. To this end, we chose the wave pattern at station 73060 as the representative wave pattern in the X-beach simulation. Rather than running the model for the entire time window, we performed simulations for each dominant wave regime, i.e., a combination of wave height/direction, and projected the changes over the entire period by employing *morphological acceleration*, a strategy that entails aggregating the impact of different wave regimes based on number of days each occurred. This strategy allows for computationally efficient simulations of shoreline changes as results of erosion and deposition over a long period of time.

2022

Class	Wave Height (m)	Period (s)	Direction (°)	Occurance (days)
Case 1	0.7	5.8	135.00° 	86.9
Case 2	1.0	5.9	157.50° 	81.8
Case 3	0.6	5.9	112.50° 	54.4
Case 4	1.0	5.6	180.00° 	51.1
Case 5	0.7	5.9	90.00° 	40.9
Case 6	0.7	5.3	67.50° 	21.9
Case 7	0.7	4.8	45.00° 	11.7
Case 8	0.7	4.7	202.50° 	6.6
Case 9	0.9	4.3	22.50° 	3.6
Case 10	0.8	4.7	225.00° 	1.1

2023

Class	Wave Height (m)	Period (s)	Direction (°)	Occurance (days)
Case 1	0.9	5.8	157.50° 	83.2
Case 2	0.7	5.9	135.00° 	68.6
Case 3	0.6	6.1	112.50° 	62.8
Case 4	0.9	5.4	180.00° 	60.2
Case 5	0.8	6.0	90.00° 	45.6
Case 6	0.7	5.4	67.50° 	18.2
Case 7	0.6	4.4	45.00° 	9.5
Case 8	0.5	4.3	202.50° 	7.7
Case 9	0.8	4.0	22.50° 	4.4
Case 10	0.2	3.9	225.00° 	1.1

Figure 7-9: Dominant wave regimes in 2022 and 2023.

The dominant wave regimes used in the morphodynamic simulations are further summarized in Fig. 7-9.

X-beach simulations of sedimentation/erosion for 2022 and 2023 are shown in Figs. 7-10 and 7-11. Apparently, in both years, deposition dominates over erosion at the San Bernard River mouth, though erosion is seen slightly away from the shoreline. This net deposition is a result of predominantly northwestward propagating waves, which tend to deposit sediments to the two sides of the mouth, consistent with observed changes during the period (Fig. 1-4).

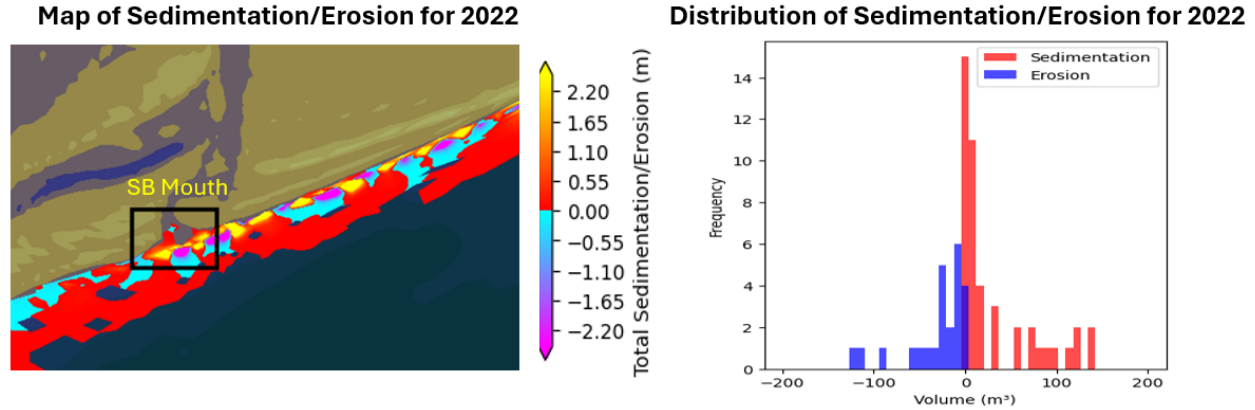


Figure 7-10: X-beach simulated sedimentation/erosion along the shoreline during the year of 2022: map of cumulative deposition/erosion (left), and distribution (right).

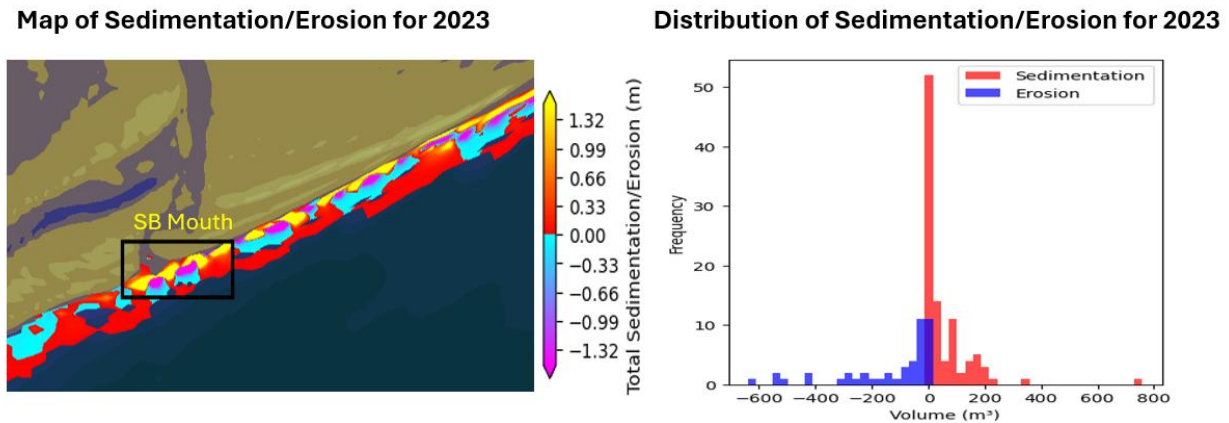


Figure 7-11: As Fig. 7-9, except for the year of 2023.

The outcomes from the X-beach simulations appear to echo the findings of Kraus and Lin (2002), i.e., the dominant wind and wave directions in the region favor net deposition at the mouth that will inevitably lead to mouth closure. Though our analysis covered only 2022 and 2023, we have found that wind and wave patterns are quite similar across years. As shown in Fig. 7-12, for a majority of years, onshore, southerly or southeasterly winds are a persistent feature through the spring and summer. Only in December and January are strong offshore flows seen that are likely a result of a cooler land mass. From September to November, the prevailing wind is easterly, which tends to amplify longshore transport of sediment from the Brazos River Delta, whereas the onshore wind during spring/summer tends to push the sediments northward to deposit within the mouth. Absent strong flushing by freshwater pulses coming down the lower reach of San Benard ebb tides, the wind pattern determines that persistent infilling is a near certain outcome.

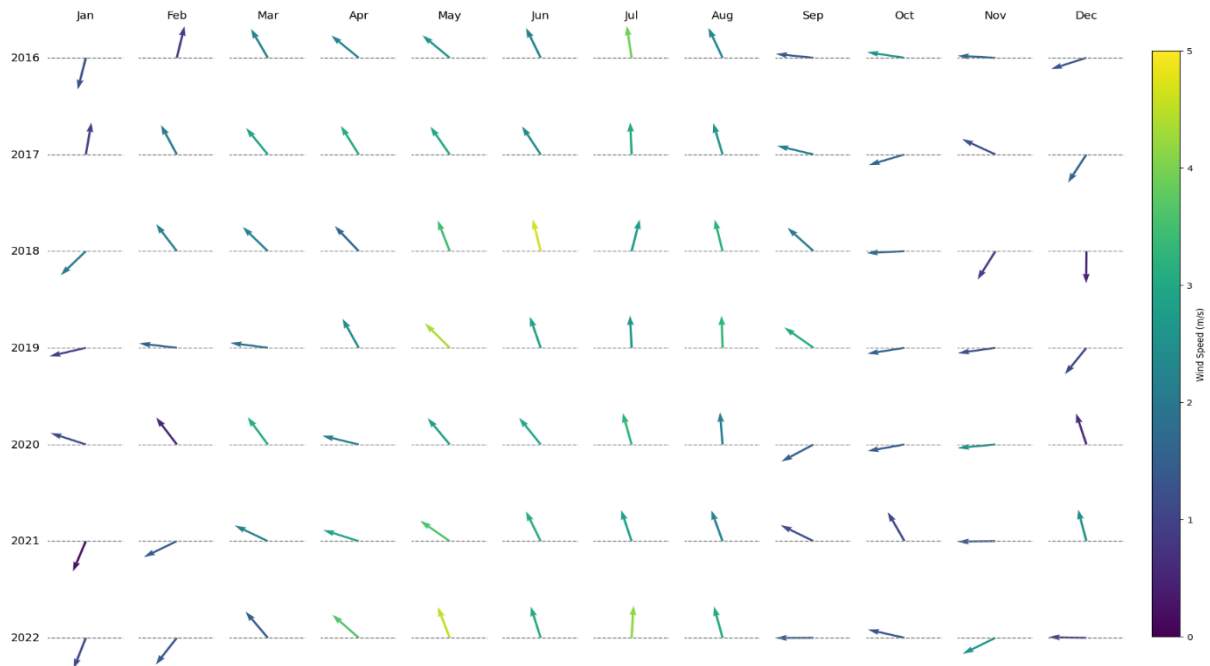


Figure 7-12: Averaged monthly wind direction and intensity at the San Bernard River mouth.

To further, quantitatively assess the potential impacts from modifying the BRFG on stability of San Bernard inlet, we performed Delft-3D simulations using the integrated flow-wave-sediment model with the current and modified BRFC configurations as described earlier over a 20-day window from November 17 to December 7, 2022. The time window features high flow pulses along both the Brazos River and San Bernard River, with peak discharge near 15,000 cfs reported at the USGS station near West Columbia and exceeding 6000 cfs at Sweeny (Fig. 7-13).

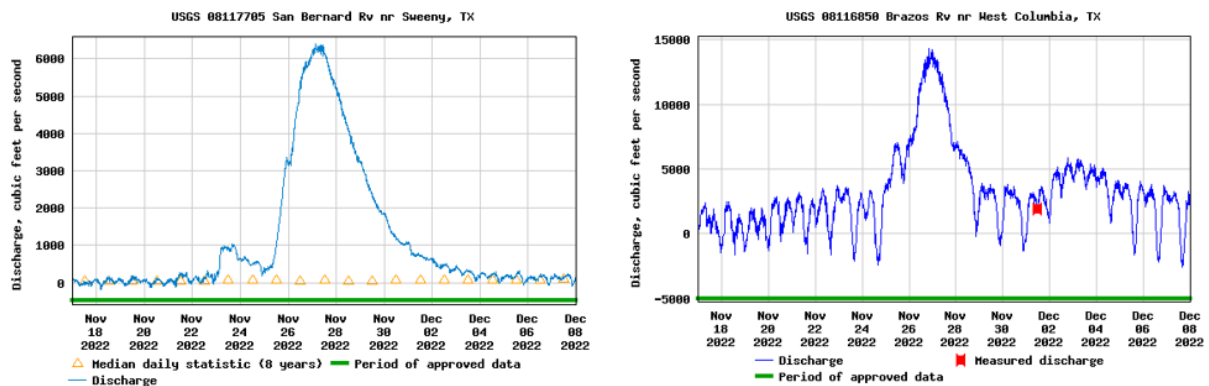


Figure 7-13: Observed discharge between November 17 and December 7 at USGS stations near Sweeny along the San Bernard River (left) and West Columbia on the Brazos River (right).

This event was chosen as it occurred prior to the complete closure of the San Bernard River mouth in early 2023 and because it produced moderately high flow before reverting to quiescent conditions where sediment balance at the mouth was determined by tide and wave. The model with the current and modified BRFG was run for this time window to produce cumulative discharge and sediment fluxes at six cross-sections shown in Fig. 7-14, which are then contrasted to determine the impacts of BRFG widening on freshwater and sediment flux. The first cross-section is located immediately west of BRFG along the GIWW; cross-sections 2-5 are located on the intersection between the San Bernard River and the GIWW, cross-section 6 is at the mouth of the San Bernard River.



Figure 7-14: Cross-sections where cumulative flow and sediment flux are computed.

The time series of cumulative water flux for the 20-day window at each of the cross-sections is shown in Figs 7-15 – 7-20. At cross-section 1 to the west of BRFG, it appears that the predominant flow direction was eastward with the current BRFG configuration, possibly driven by the high flow pulse from the San Bernard River. After BRFG removal and channel widening, the eastward flux only experienced minor changes at cross-section 1 (Fig. 7-15). The eastward flow along the GIWW was also present at cross-section 2 to the east of the intersection with San Bernard River. The BRFG removal again had marginal impacts on the cumulative discharge. At cross-section 3 west of the intersection, the discharge exhibited oscillations, likely a result of tidal influence. The impact from opening the flood gate was again rather minor. At cross-section 4, situated on San Bernard River above the intersection, the flow mimics the USGS discharge prescribed as upstream

boundary condition. At cross-section 5, located immediately downstream of the intersection on the San Bernard River and at the mouth of the river, the flow was again oscillatory, but the net discharge was pointing northward (landward). With BRFG removed, there was a small, but appreciable increase in the seaward flow. At cross-section 6, the net discharge pointed seaward, and removal of BRFG had no discernible impact.

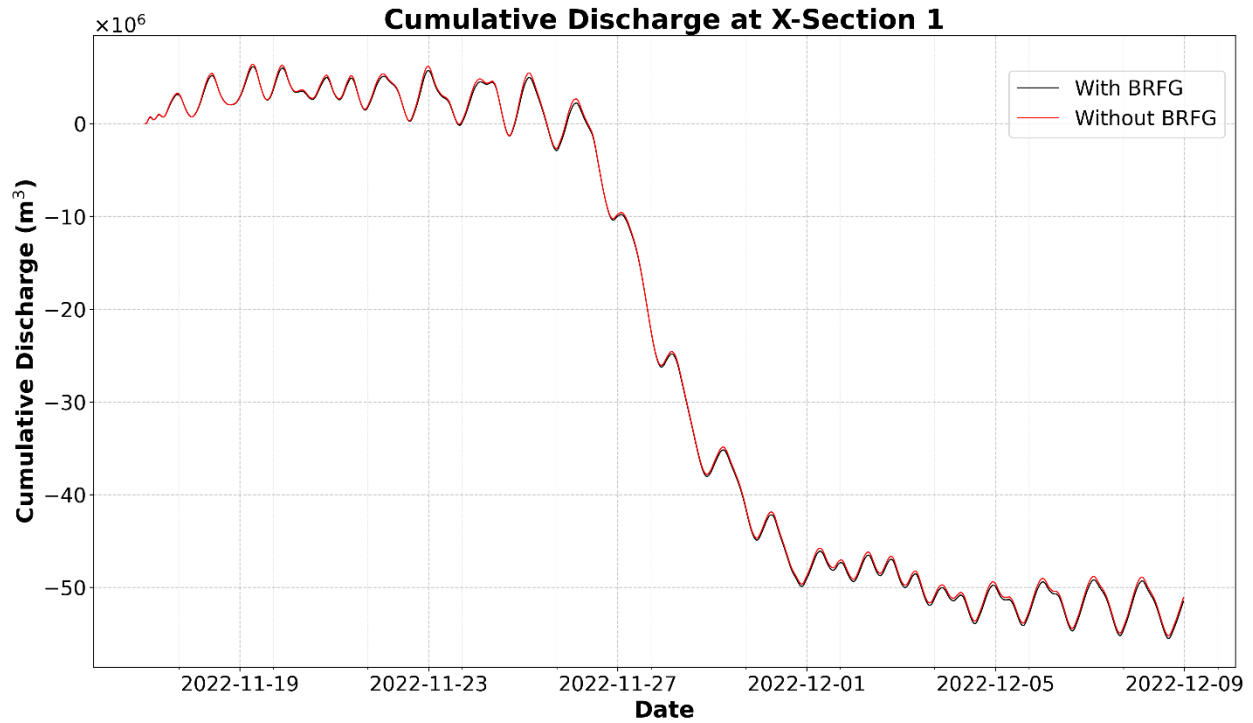


Figure 7-15: Time series of cumulative water flux at X-section 1.

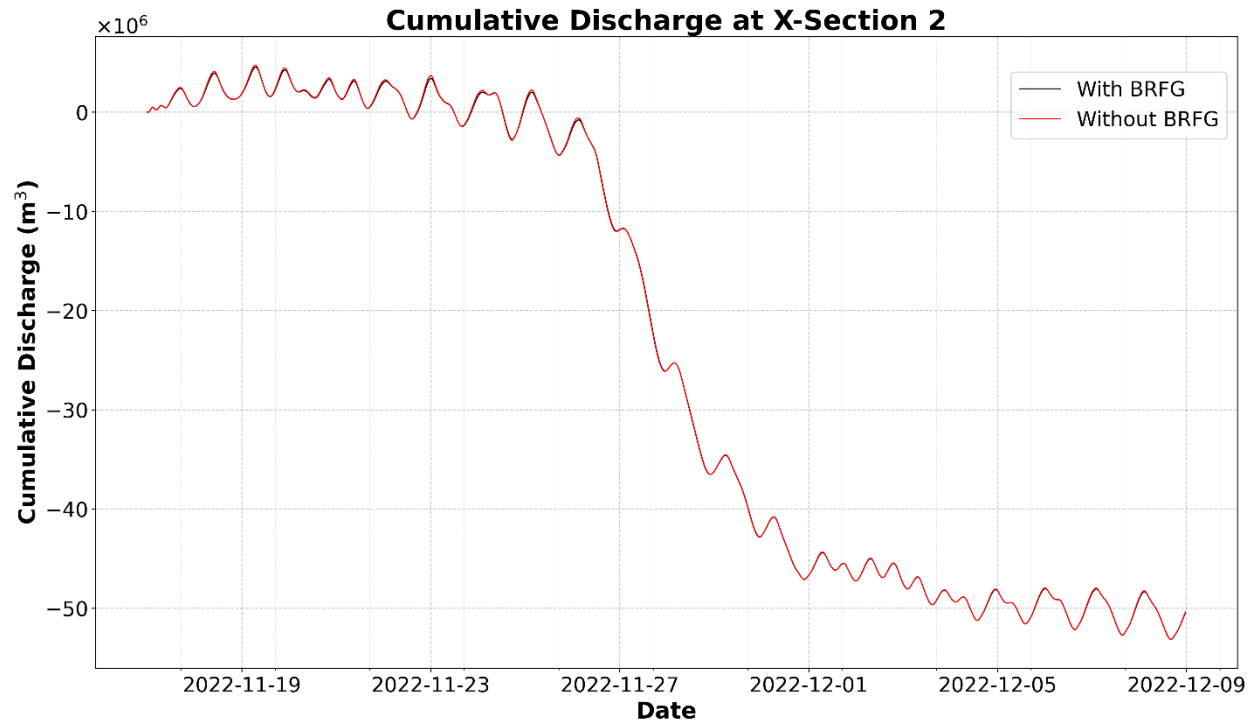


Figure 7-16: As Fig. 7-15, except at X-section 2.

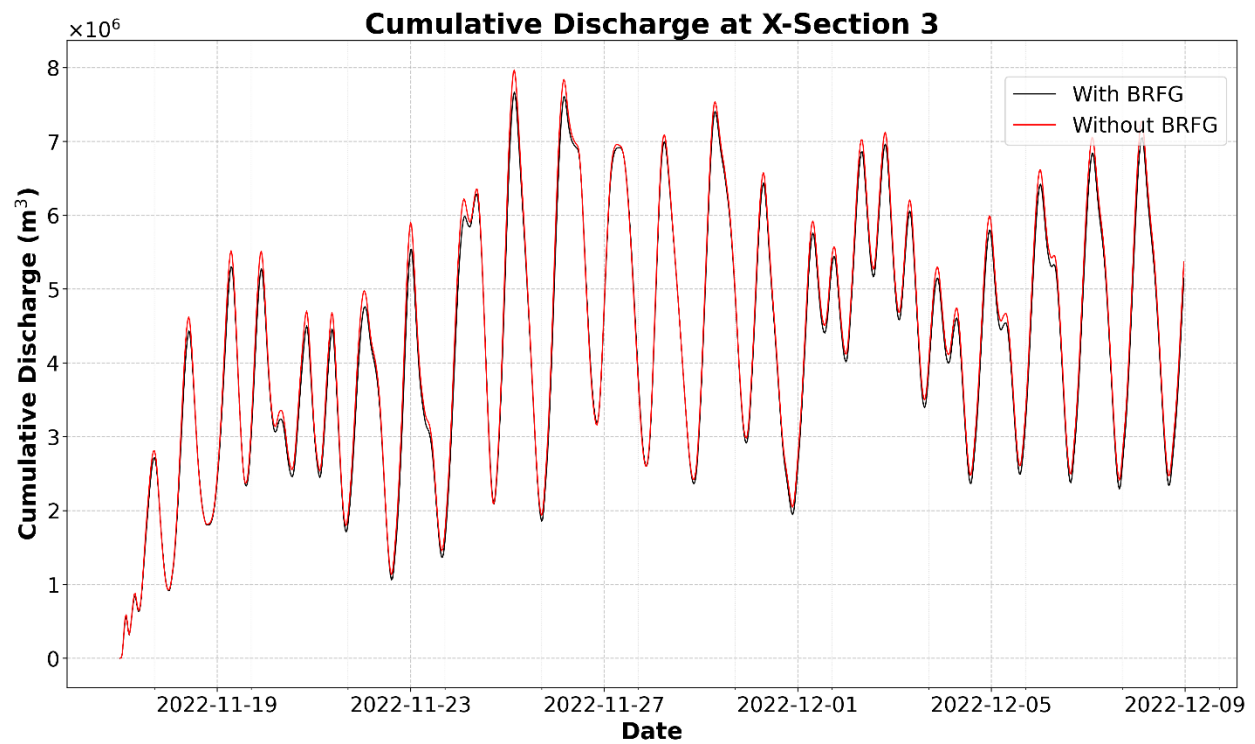


Figure 7-17: As Fig. 7-15, except at X-section 3.

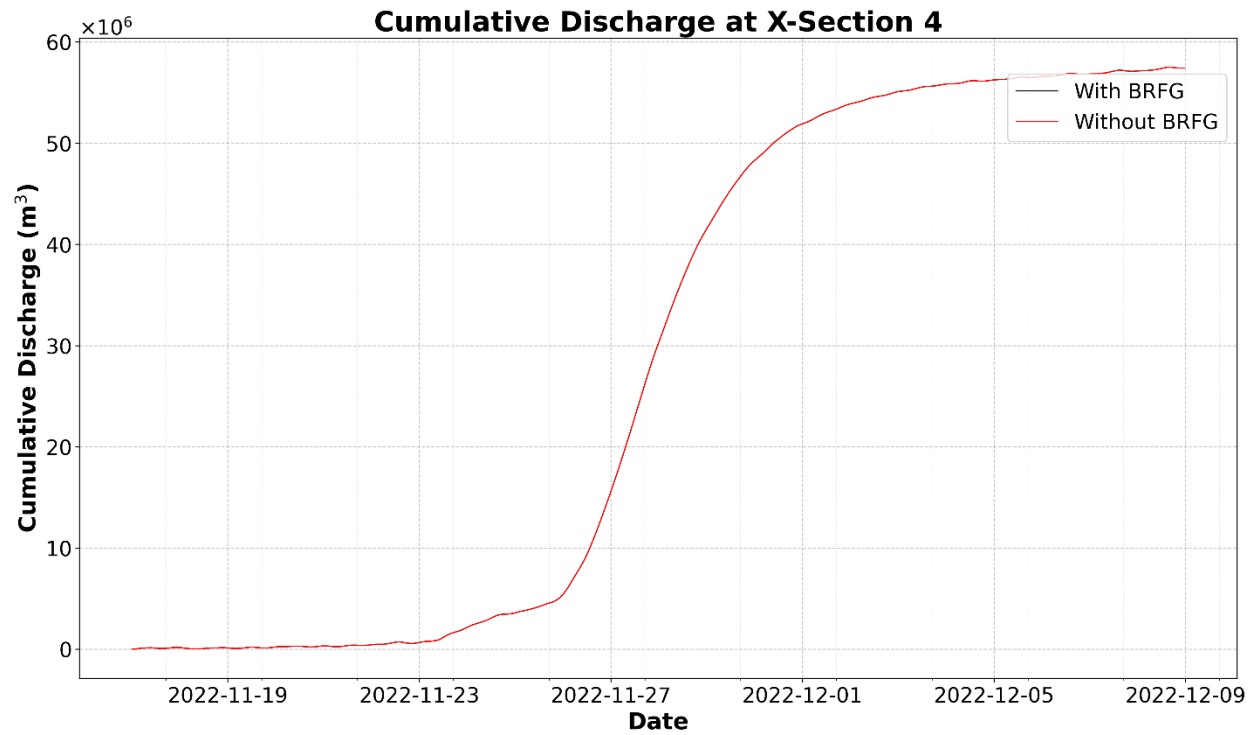


Figure 7-18: As Fig. 7-17, except at X-section 4.

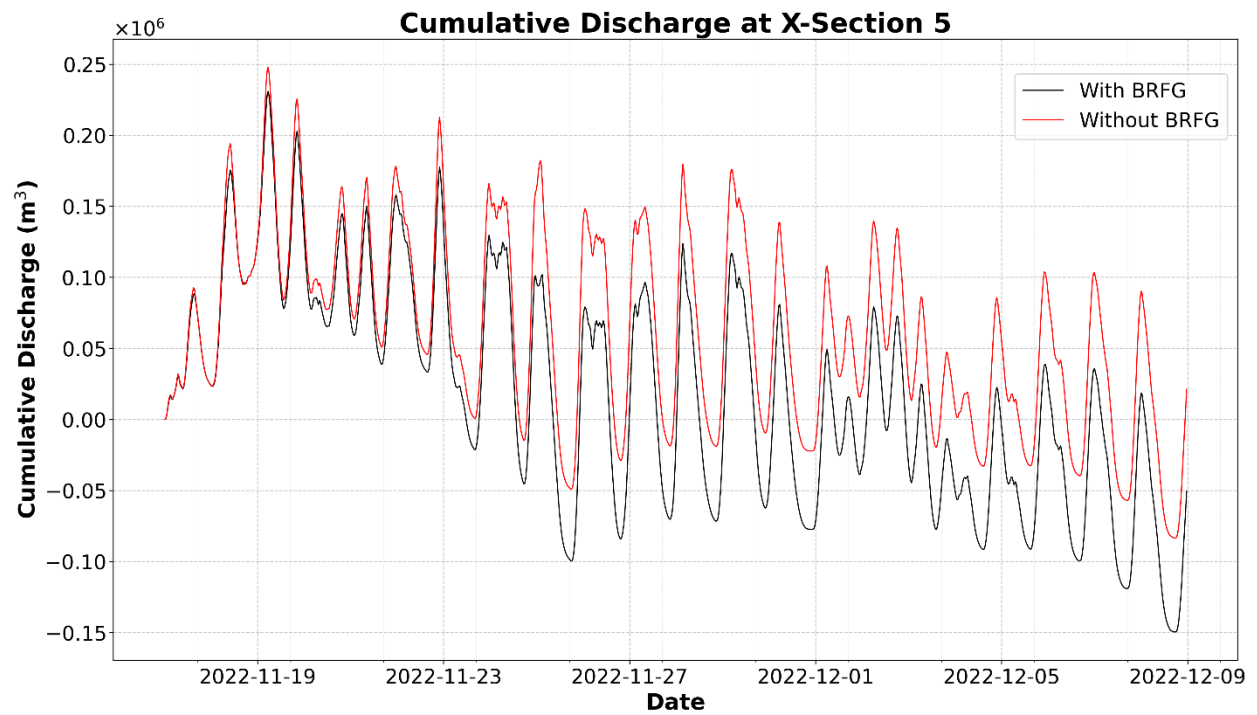


Figure 7-19: As Fig. 7-17, except at X-section 5.

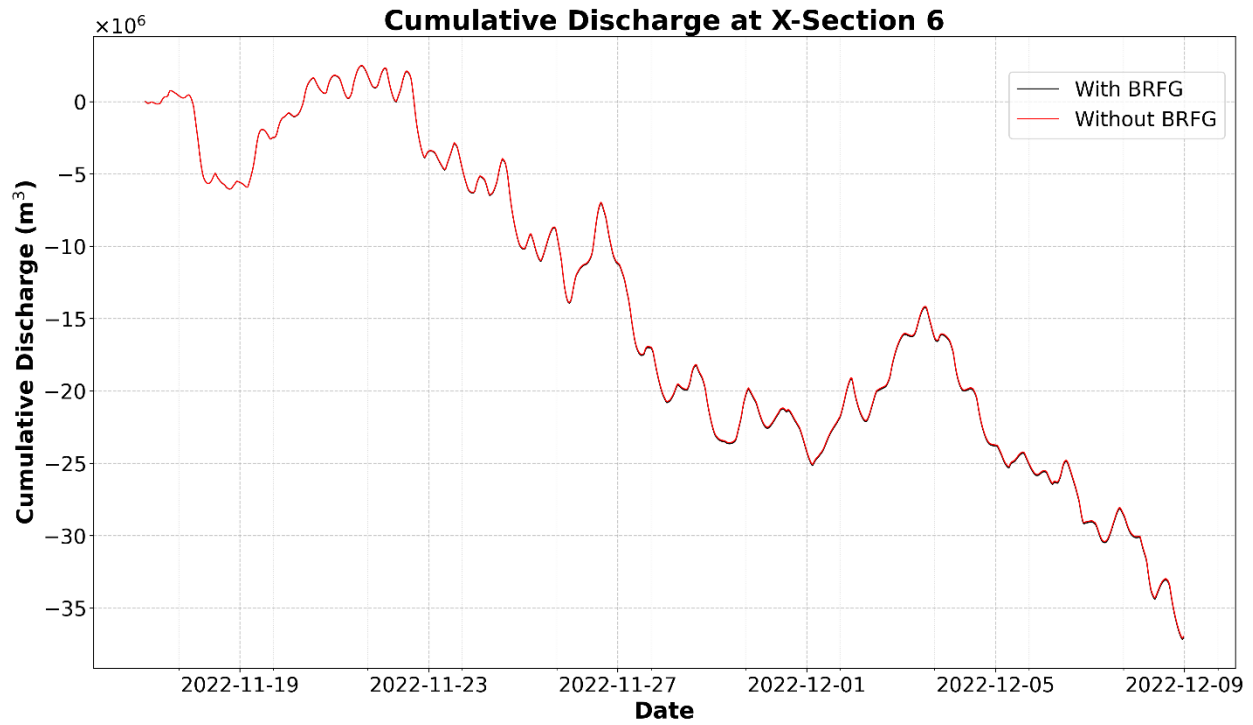


Figure 7-20: As Fig. 7-15, except at X-section 6.

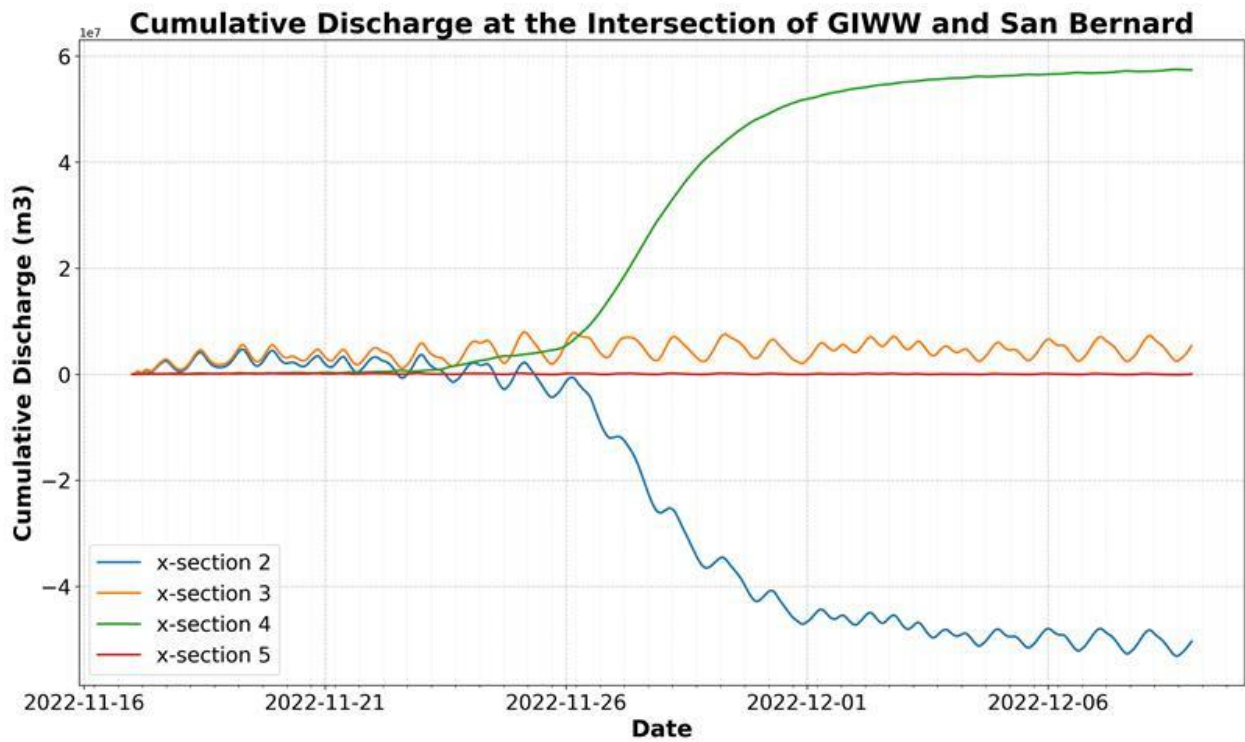


Figure 7-21: Discharge time series at the four cross-sections (2-5) at the intersection between GIWW and San Bernard River.

The cumulative discharge series along the four cross-sections at the intersection between GIWW and San Bernard River for the future scenario are contrasted in Fig. 7-21. It is quite clear that much of the upstream flow was diverted towards the east along the GIWW, and the impact of the pulse on the flow in the downstream portion of San Bernard River was negligible.

The impacts from BRFG removal on cumulative sediment flux, which combines both flux of bedload and suspended load, largely mirror those for water flux (Figs. 7-22 – 7-27). At X-section 1 to the west of BRFG, removal of BRFG led to a decrease in eastward sediment flux. By contrast, the impacts were rather muted at X-sections 2-4. At X-section 5, BRFG removal led to an increase in southward sediment load, whereas at X-section 6 (San Bernard River mouth), the impacts were again muted. The contrast between X-sections 5 and 6 may be a result of attenuation of the freshwater pulse when it approaches the Gulf.

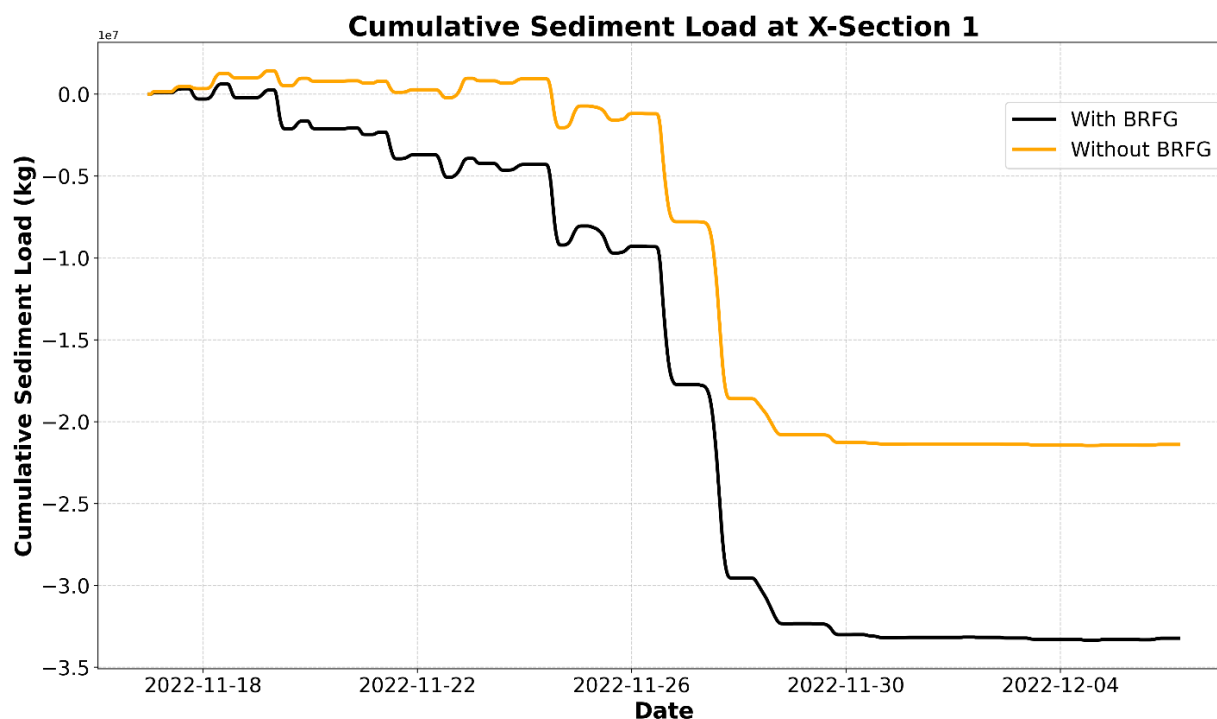


Figure 7-22: Cumulative sediment transport at X-section 1.

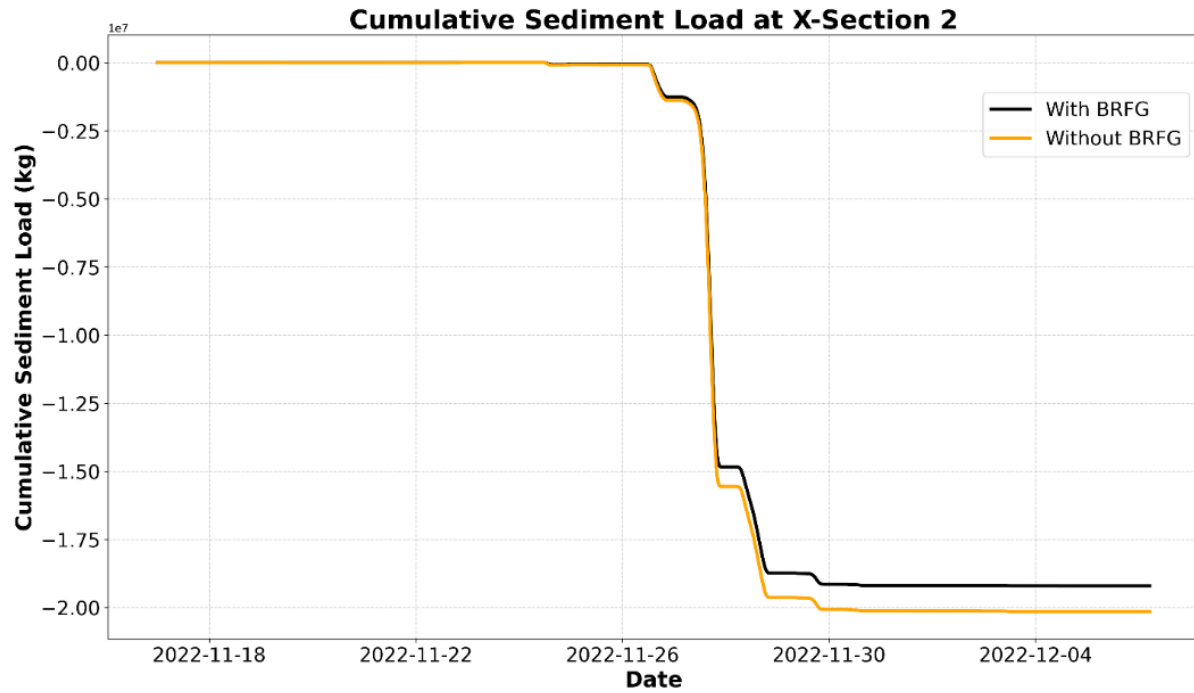


Figure 7-23: As Fig. 7-21, except at X-section 2.

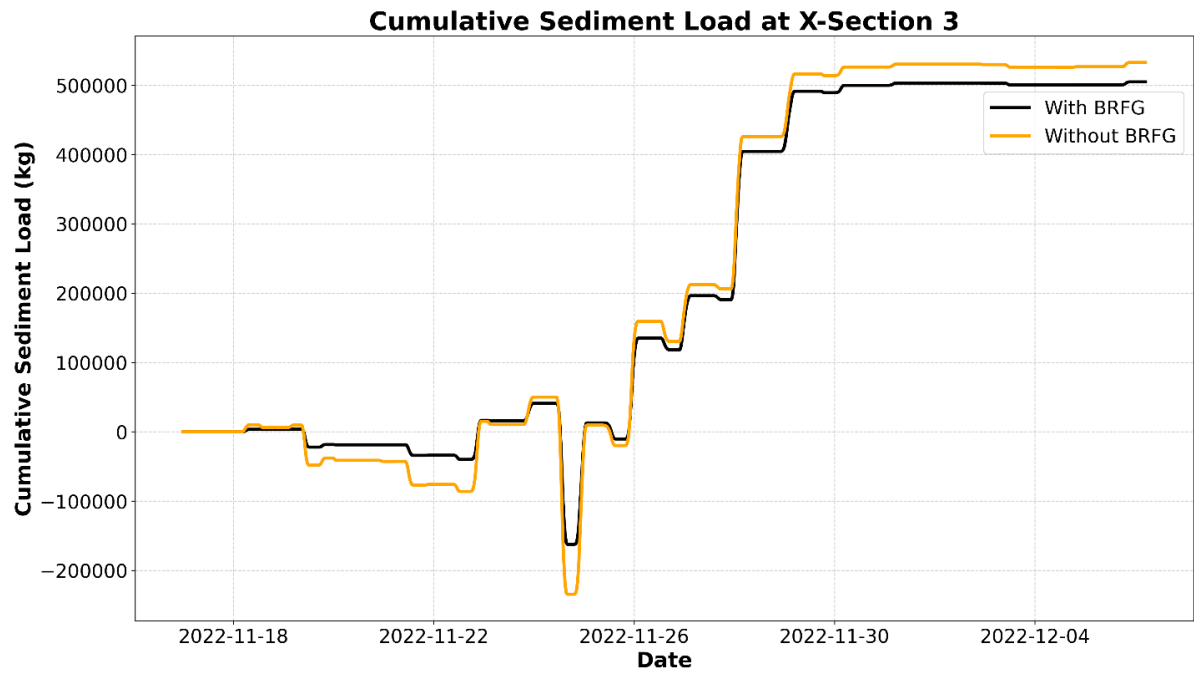


Figure 7-24: As Fig. 7-21, except at X-section 3.

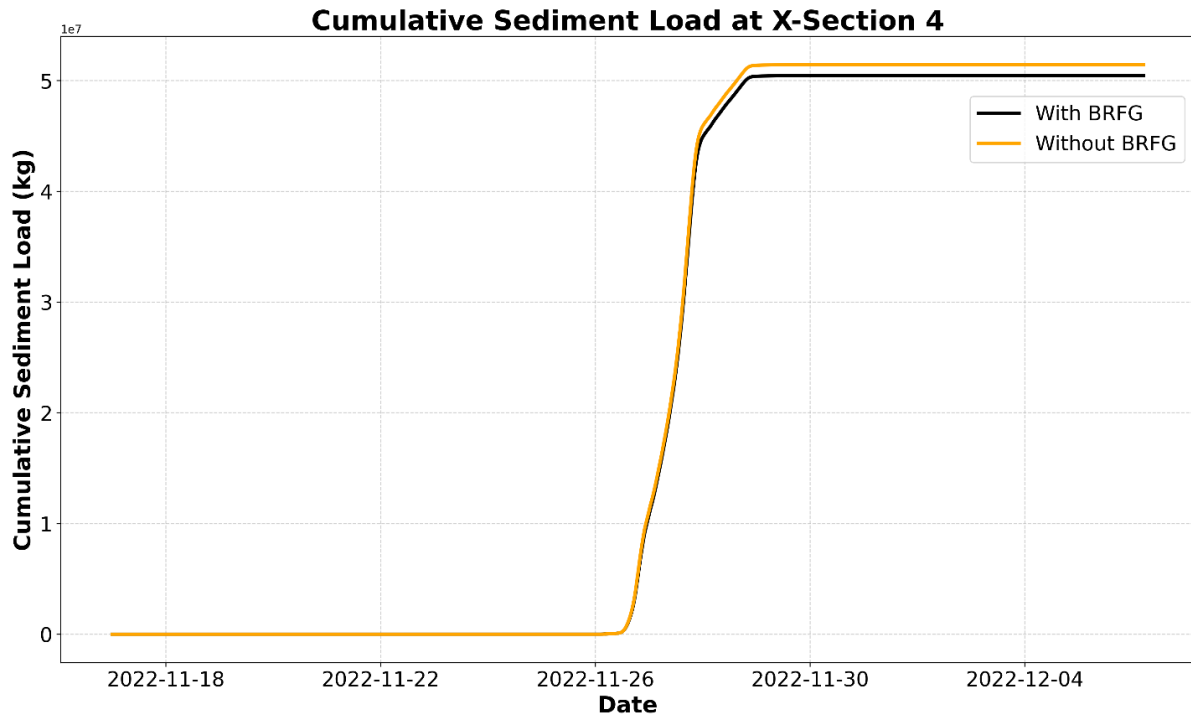


Figure 7-25: As Fig. 7-21, except at X-section 4.

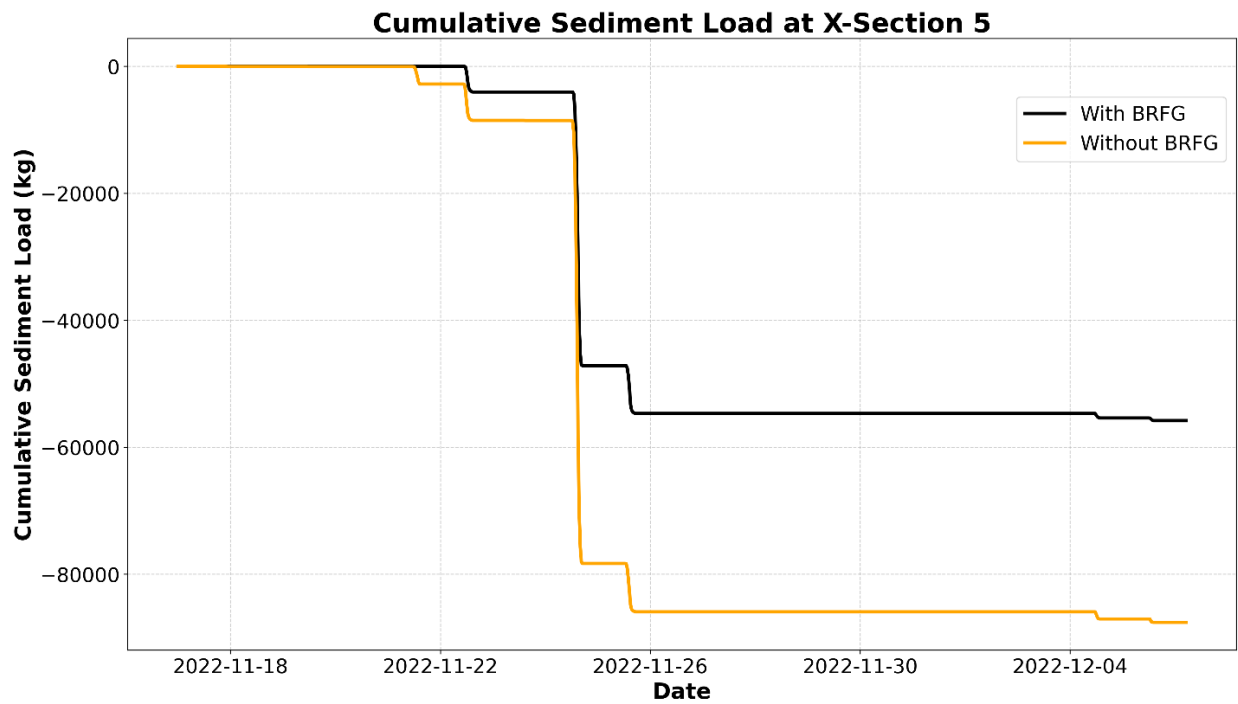


Figure 7-26: As Fig. 7-21, except at X-section 5.

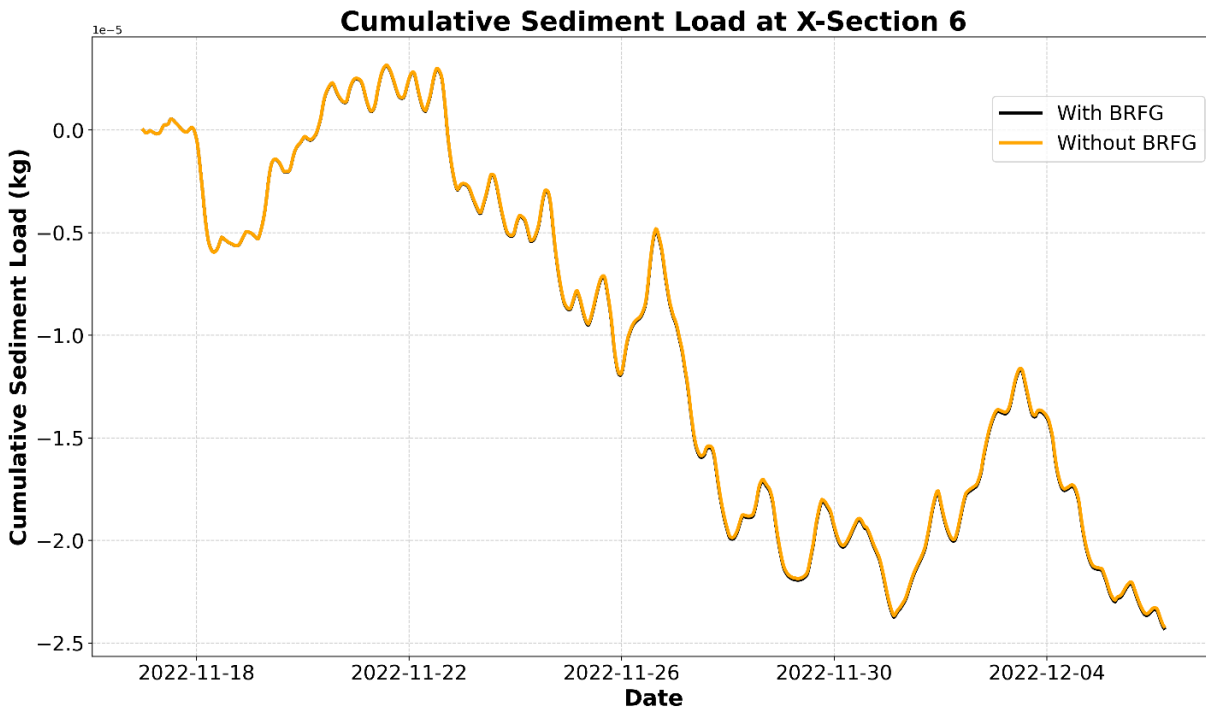


Figure 7-27: As Fig. 7-21, except at X-section 6.

Overall, the simulation experiments produced the following insights.

- Even though Brazos River carried higher discharge than San Bernard River during the 2022 event, the predominant flow direction along the GIWW was eastward, apparently driven by the high flow pulse from the San Bernard River.
- The configuration of BRFG, which features a sharp angle between the GIWW and Brazos River, makes it easier for water to flow from GIWW into the lower portion of the BRFG. By contrast, the high flow pulse along the Brazos River had to overcome a sharp turn to enter GIWW, and this limited the spillover of the floodwater westward into the GIWW.
- GIWW, with its deep channel, serves as a barrier that drastically attenuates the flow along the San Bernard River. For the 2022 event, much of the flow from the San Benard River was diverted to the east, and little reached the coastal segment. Opening the BRFG most likely has marginal impacts on the discharge and sediment flux in the lower portion of San Bernard River, and therefore is unlikely to improve or degrade the stability of the mouth.

It must be cautioned that these insights were based on a single event where San Bernard River featured a moderately large flow pulse that is not negligible relative to that along the Brazos River. For this particular event, the movement of flow and sediments along the GIWW was primarily eastward, pointing to the hindrance of Brazos River flow by the configuration of intersection between the river and GIWW. However, in several historical events, westward propagation of sediments from the Brazos River was evident from satellite imagery. It is possible that flow would be predominately westward if the imbalance of discharge along the two streams reached a certain

threshold. In addition, it is also worth noting that the flow episode featured a moderate pulse from San Benard River that was too low to overcome the deepwater barrier along the GIWW. Larger flow pulses were able to do so, as was observed during Hurricane Harvey when the flood wave caused a breach in the mouth.

8. Summary of Stakeholder Engagement, Findings and Recommendations

This project marks the first step to establish foundational modeling tools and data sets that will serve as the basis to formulate long-term strategies to address the myriads of challenges faced by the coastal zone that stretches from Freeport to East Matagorda Bay, including coastline erosion, siltation, flooding, ecological degradation. It featured concurrent modeling efforts and field campaigns, and contributed to ongoing efforts including TxSed, Texas longshore transport study, and TIFF. Moreover, the project team involved a broad range of stakeholders in the execution of the project, which include counties, citizen groups, non-for-profit organizations, state agencies, and federal agencies. The stakeholder engagement involved the following activities:

- Annual on-site workshops held at Brazoria County and boat tours
- Quarterly stakeholder meetings
- Stakeholder survey on regional priorities in 2024
- One-on-one meetings with core partners

Notably, the project team organized on-site workshops in the fall of 2022, 2023, 2024, and 2025. Three of the workshops were held in the meeting room of Precinct 4 in Brazoria County; and one at the county courthouse. In these workshops, the team members were able to interact with Commissioners of Precinct 3 and 4, and partners from Friends of San Bernard River and Fish and Wildlife Service. These workshops and subsequent field trips allowed the project team to deepen understanding of the concerns of regional partners, visualize flow and sediment processes along the lower Brazos, GIWW, Cedar Lakes, and San Benard River, corroborate results of modeling analysis with anecdotal observations by stakeholders, and adjust the scope of case studies.

The 2024 stakeholder survey unveiled a large number of concurrent and future management activities and plans in the region that this particular project may contribute to or leverage. These include:

- Brazoria Sand Management Plan
- Brazos Basin and Bay Stakeholder Committee, Steering committee for Brazos Texas Clean Rivers Program
- Coastal Program Strategic Management Plan
- Gulf Of Mexico Fisheries Management Plans
- Local and regional flood plan within the San Bernard River
- Mid-coast Refuge Comprehensive Management Plan
- Multiple listed species recovery outlines and plans
- Regional Flood Planning, Regional Water Plans,

- The stakeholder survey further highlighted potential project priorities based on stakeholder input and interests from each core stakeholder. These are summarized in Tables 8-1 and 8-2. These results helped the project team determine the focus areas in the next phase of project.

[illegible]

Table 8-2: Results from Stakeholder Survey: Breakdown of Interests from Stakeholders

	Refine geology of Sargent Beach's inner shelf to inform counter-measures to beach erosion	Model offshore sediment plumes and Brazos Delta growth after Hurricane Harvey	Delineate sediment dynamics along GIW after opening of Brazos River Flood Gates	Estimate flooding risks along the lower SBR after the next round of dredging	Model interbasin flow b/t SBR and Caney Creek and estimate downstream flood risk impacts	Investigate sediment budgets for East Matagorda Bay	Reassess saltwater intrusion along the Brazos River during drought and evaluate salt-water barrier
<i>Brazoria County</i>							
<i>Brazos River Authority</i>							
<i>Fort Bend County Drainage District</i>							
<i>Freese and Nichols Inc.</i>							
<i>Friends of the River San Bernard</i>							
<i>Individual San Bernard River Resident</i>							
<i>Lower Brazos Riverwatch</i>							
<i>Texas Department of Transportation</i>							
<i>Texas General Land Office</i>							
<i>Texas Water Development Board</i>							
<i>Tx General Land Office</i>							
<i>U.S. Fish and Wildlife Service</i>							
<i>US Army Corps of Engineers - Galveston District</i>							

LEGEND High Medium Low

The key findings from the Phase-I project are summarized below.

Finding 1: The backwater effects during Hurricane Harvey induced by the closure of San Bernard River mouth were felt mostly in the vicinity of the mouth, whereas the impacts rapidly diminished upstream of the intersection between the GIWW and San Bernard River due to spillover of floodwater, which likely reached the Gulf through the Cider Lakes and bypassed the San Bernard inlet. For moderate flooding,

Finding 2: Prevailing regional wind and wave patterns favor net deposition of littoral material at the San Bernard River mouth, consistent with observations and earlier analysis performed by the US Army Corps of Engineers. In absence of freshwater pulses with sufficient intensity and frequency capable of dislodging the littoral sediments at the lower portion of San Benard River, this net deposition Closure of mouth inevitably leads to mouth closure, as it did after the completion of the 2022-2023 dredging project.

Finding 3: Impacts from opening of west gate of BRFG are most likely muted on stability of San Bernard River mouth. The case study of the high flow episode in 2022 suggests that the configuration of BRFG limits the ability of high flow from Brazos River to enter the GIWW towards west. Perhaps more importantly, the GIWW serves as a barrier that inhibits the flow pulses along the San Bernard River from reaching the downstream portion. In the 2022 episode, the high flow pulse was diverted mostly to the east along the GIWW. Barring historical floods such as Harvey, moderately high pulses from the San Bernard are mostly unable to enter the inlet

to flash out the littoral deposits. This highlights the critical role GIWW plays to disrupt the flow connectivity along the San Bernard and contributes to the repeated closure.

Finding 4: Prior to the completion of GIWW in 1948, Cedar Lakes received its majority of sediments from the Gulf of America through storm surge, and from Colorado River floodwater that crossed into San Bernard River. After 1948, Brazos River contributed to a major share of sediments deposited in the lakes south of the canal, whereas Colorado River sediments are still an important source for lakes north of the canal.

Finding 5: The bathymetry of lower Brazos underwent rapid changes between 2022-2024 due to accumulation of sediments brought by flood pulses. About a million cubic yards of sediment deposited near Brazos mouth between 2023 and 2024, comprising mainly sand that can be potentially harvested for beach nourishment.

Finding 6: Contributions of runoff from coastal watersheds to streamflow along lower Brazos River and San Bernard River remain uncertain as extant model simulations depart widely from gauge observations. Much remains to be done to refine the estimates of runoff volumes for major flow events.

On the basis of these findings, we make the following recommendations for the future phase of the TCRMP:

Recommendation 1: Determine possible complementary strategies to sustain the opening of San Bernard River mouth after the future dredging effort. Several options emerged through the Phase-1 project, including installation of a jetty to the east of the mouth, placing a flood gate on the GIWW west of San Benard River crossing to allow high flow pulses to reach the inlet, dredging the lower Brazos River to show the growth of Brazos River Delta, and creating a canal bypassing the sharp elbow between GIWW and San Bernard River.

Recommendation 2: Attain a more in-depth, qualitative understanding of flow connectivity among coastal streams including lower Brazos River, San Bernard River, Caney Creek, and GIWW by collecting flow observations and comparing these with runoff simulations. In particular, the direction and rates of flow along the GIWW impact flow along the tidal streams and have important implications for transportation (barge traffic), bank erosion and sedimentation. These variables should be monitored and analyzed.

Recommendation 3: Create a regional modeling framework that would encompass tidal portions of major streams and the coastal zone extending from Brazos River mouth to East Matagorda Bay, and account for interactions between wave, current, and sediment. This framework will combine the functions of X-beach morphodynamic model and Delft-3D hydrodynamic model to account for freshwater and sediment pulses in projecting coastline changes in response to modifications such as dredging, establishment of jetty, and installation of floodgates.

Recommendation 4: Conduct offshore data collection to determine the impacts from long-shore and cross-shore currents on the offshore sediment regime near the coast from Brazos River mouth

to Sargent Beach. Use the data to refine the regional modeling framework for projecting shoreline changes.

Recommendation 5: Expand data collection to along the GIWW and Cedar Lakes, and possibly perform sediment tracing, to quantify the volumetric fluxes of sediments from Brazos River that reached the Cedar Lakes and further west at Mitchell's Cut under different flow conditions

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<https://www.swg.usace.army.mil/Portals/26/GIWW%20BRFG-CRL%20DIFR-EIS%20Main%20Report.pdf>"

USACE: San Bernard River Dashboard. <https://www.swg-wc.usace.army.mil/sanbernardRiverDb/>

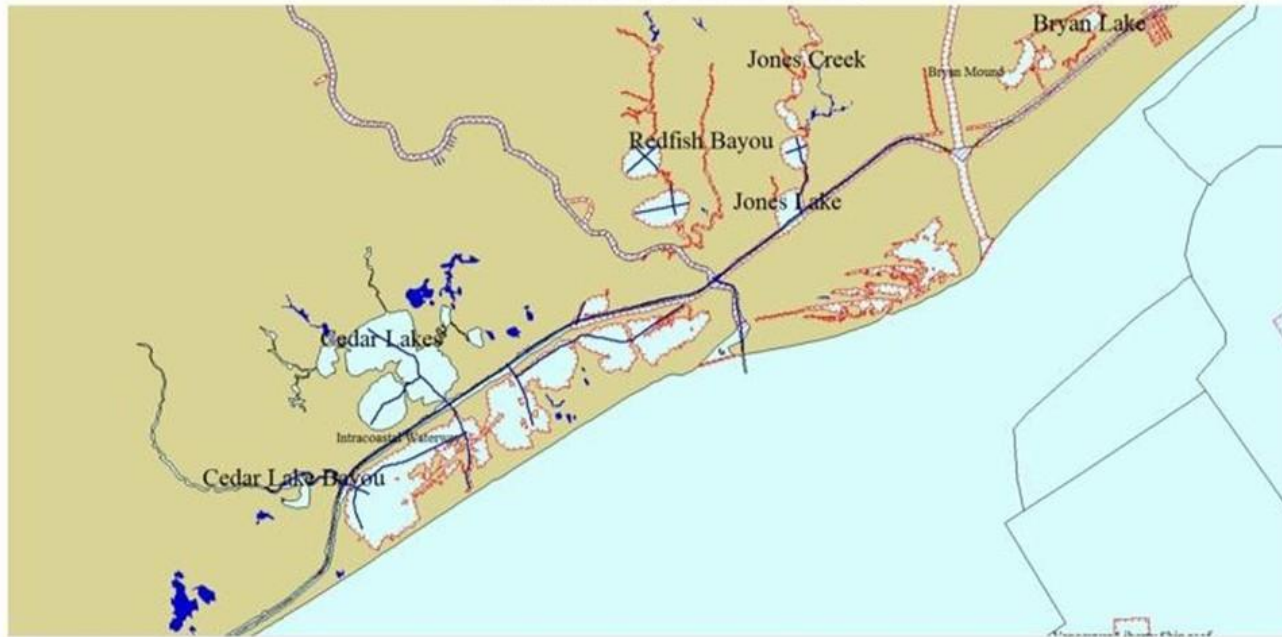
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Appendix A: Coring Locations

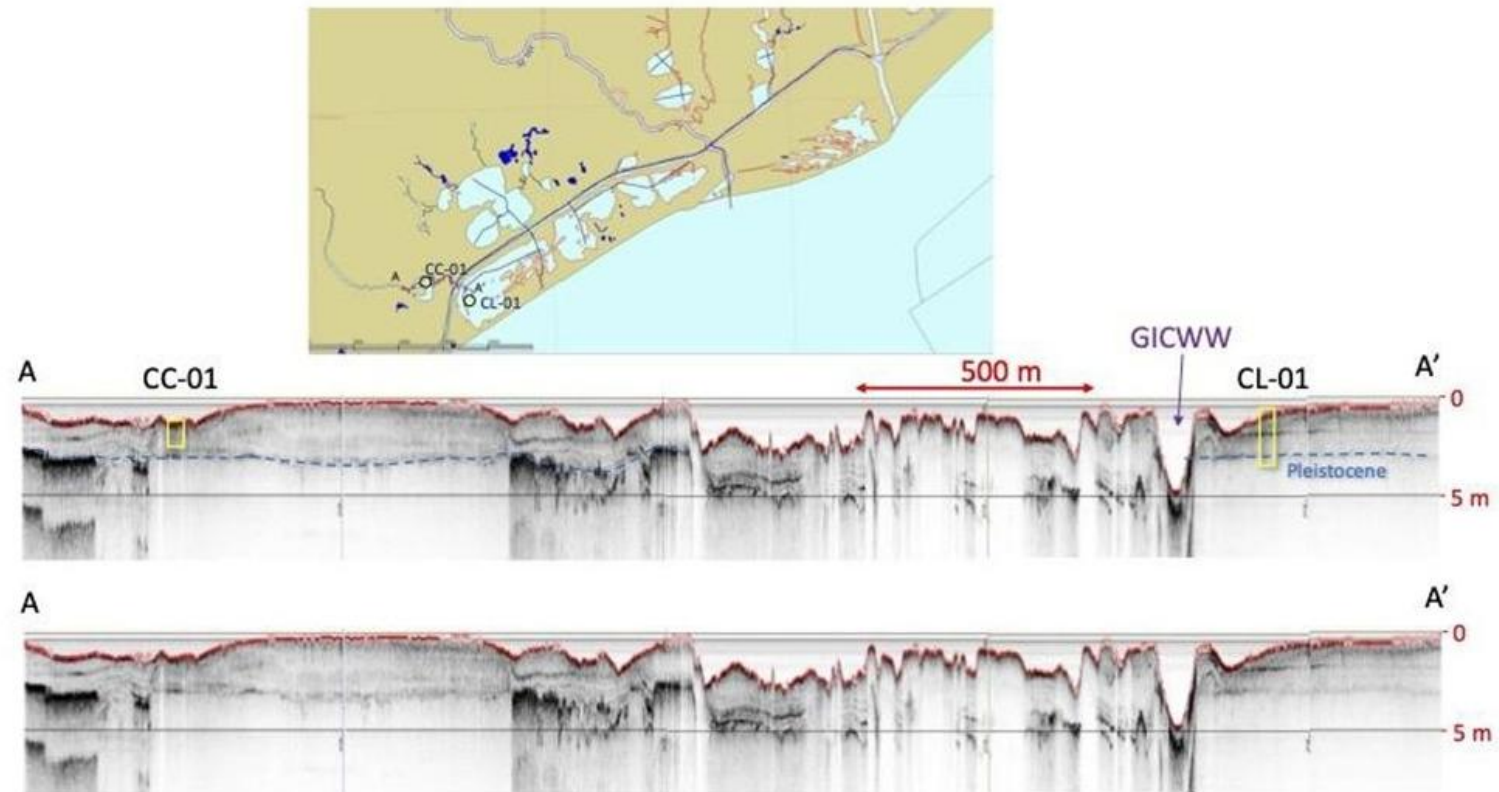
Core	Date of collection	Time (utc)	Latitude	Longitude	Water Depth (ft, MLLW)	Penetration	Recovery	Percent
CC01	12-Apr-23	16:43	28.8311393	-95.5441889	0.4	9.1	6.9	76%
CL01	12-Apr-23	17:51	28.8262230	-95.5316785	1.2	9.0	6.9	77%
CL02	12-Apr-23	18:48	28.8337256	-95.5210690	0.7	9.5	7.2	76%
CL03	13-Apr-23	19:17	28.8377724	-95.5121821	0.9	10.0	7.6	76%
CL04	14-Apr-23	16:36	28.8440325	-95.4909031	0.6	9.5	6.2	65%
CL05	14-Apr-23	17:52	28.8498909	-95.4956266	0.8	6.0	5.6	93%
CL06	14-Apr-23	15:30	28.8548170	-95.4856330	0.7	8.6	4.8	56%
CL07	14-Apr-23	14:10	28.8574098	-95.4659081	0.8	9.2	4.5	49%
CL08	14-Apr-23	13:12	28.8591401	-95.4612924	0.3	8.5	6.8	80%
CL09	13-Apr-23	20:46	28.8666530	-95.4754422	0.6	6.9	5.6	81%
CW01	13-Apr-23	16:50	28.8465546	-95.5237652	0.9	10.0	7.6	76%
CW02	13-Apr-23	18:16	28.8510658	-95.5152017	0.4	8.4	6.9	82%
CW03	13-Apr-23	15:39	28.8599946	-95.5229843	1.7	9.9	7.6	77%
ML01	24-Apr-23	15:35	28.8964330	-95.4603830	1.6	7.8	3.9	50%
ML02	24-Apr-23	16:07	28.8963660	-95.4605000	1.5	4.2	3.6	86%
PL01	24-Apr-23	17:28	28.8864330	-95.4515000	0.7	8.6	6.5	76%
BR01	26-Apr-23	15:38	28.8807170	-95.3913500	0.7	5.1	4.2	82%
JC01	26-Apr-23	17:31	28.8880170	-95.3913500	0.9	8.2	5.8	71%
JC02	26-Apr-23	18:41	28.8972500	-95.4246330	0.9	5.2	4.2	81%

Appendix B: Cedar Lake Sub-bottom

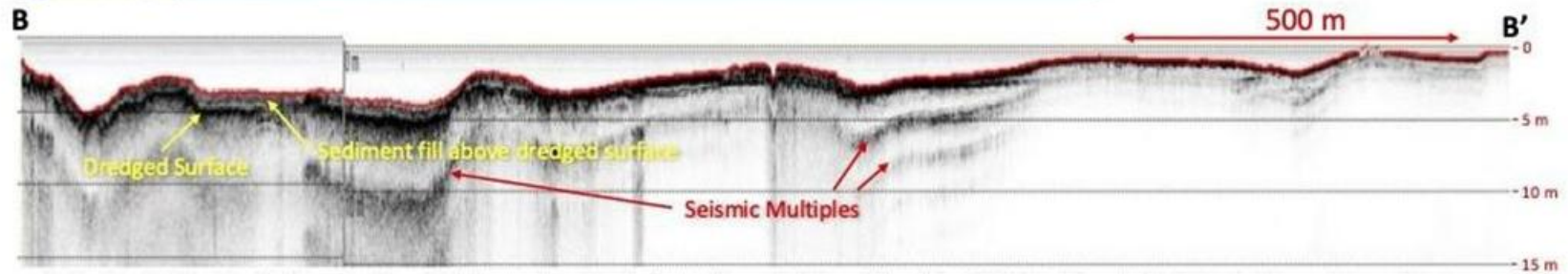
Seismic Survey Line Base Map



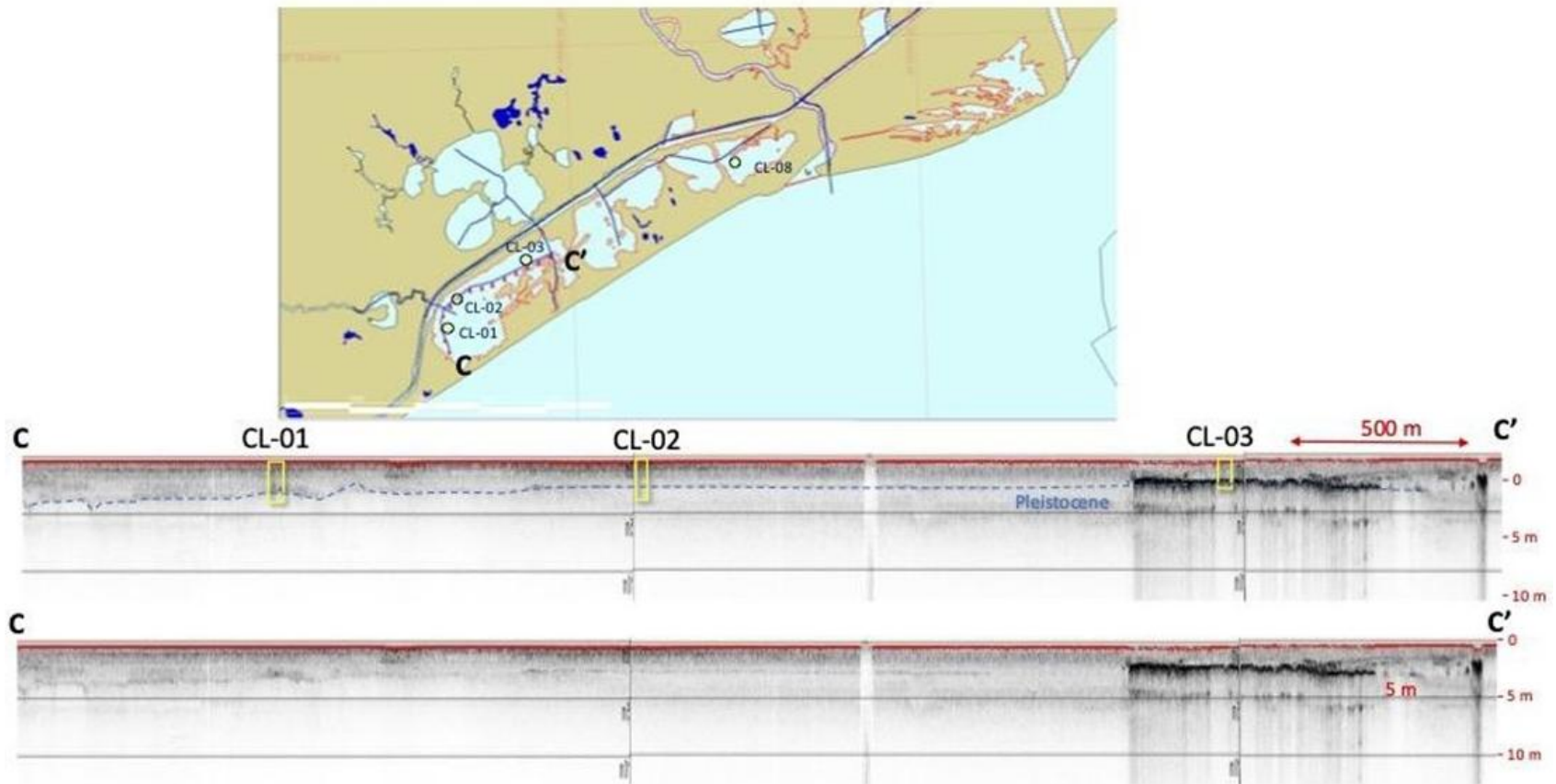
Base Map showing the locations of all the Seismic Lines shown in this Appendices as blue traces.



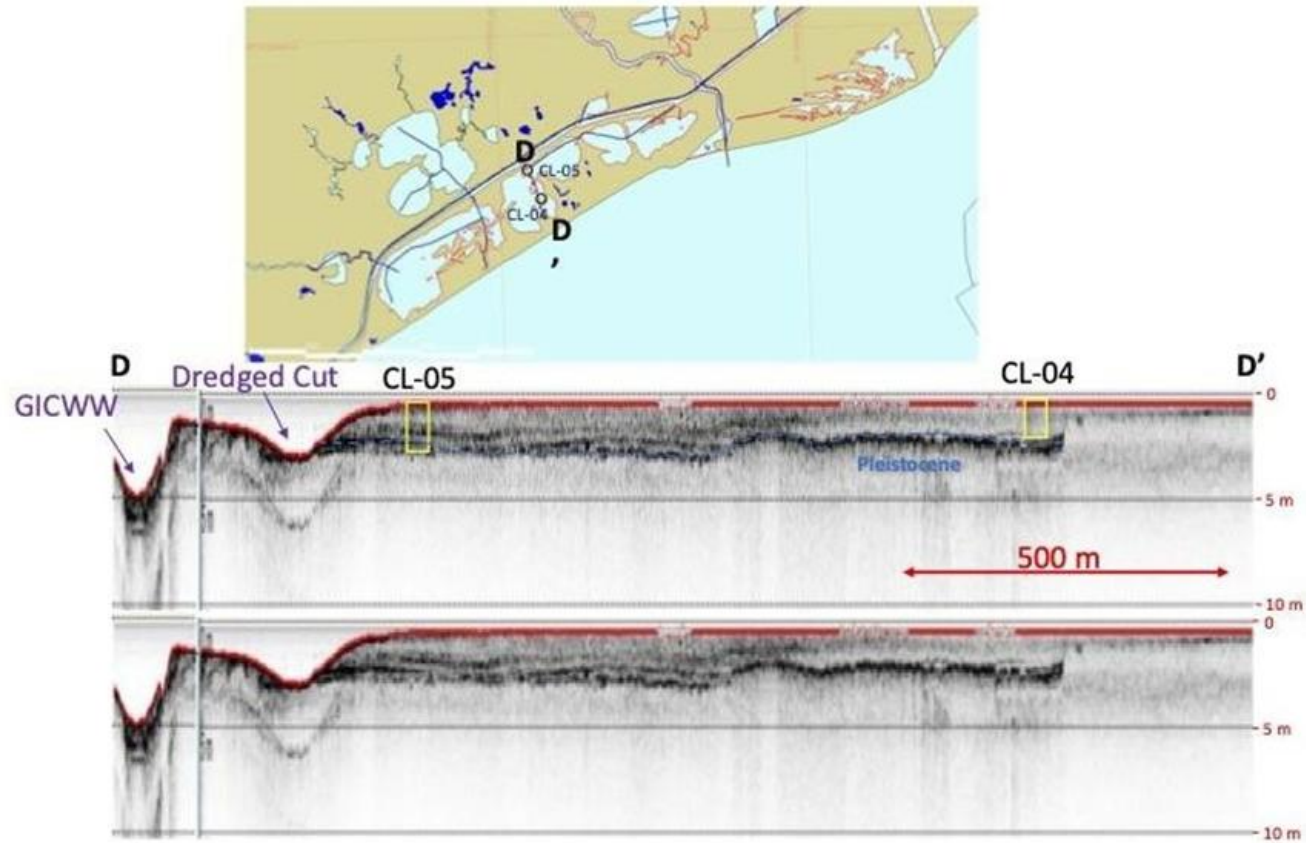
Subbottom Profiler Line A-A' showing the subbottom profiler data for transect from Cedar Lake Creek to the north across the GICWW and into the western end of Cedar Lake. The lower panel shows uninterpreted lines. The red dashed line shows the surface of the seabed in both panels. The Pleistocene surface is shown as a dashed blue line, shown in the upper panel. Core locations are labeled and shown as yellow rectangles. Note, where identified, the Pleistocene surface is relatively flat and underlies the entire survey area, except under the GICWW where it was removed by dredging.



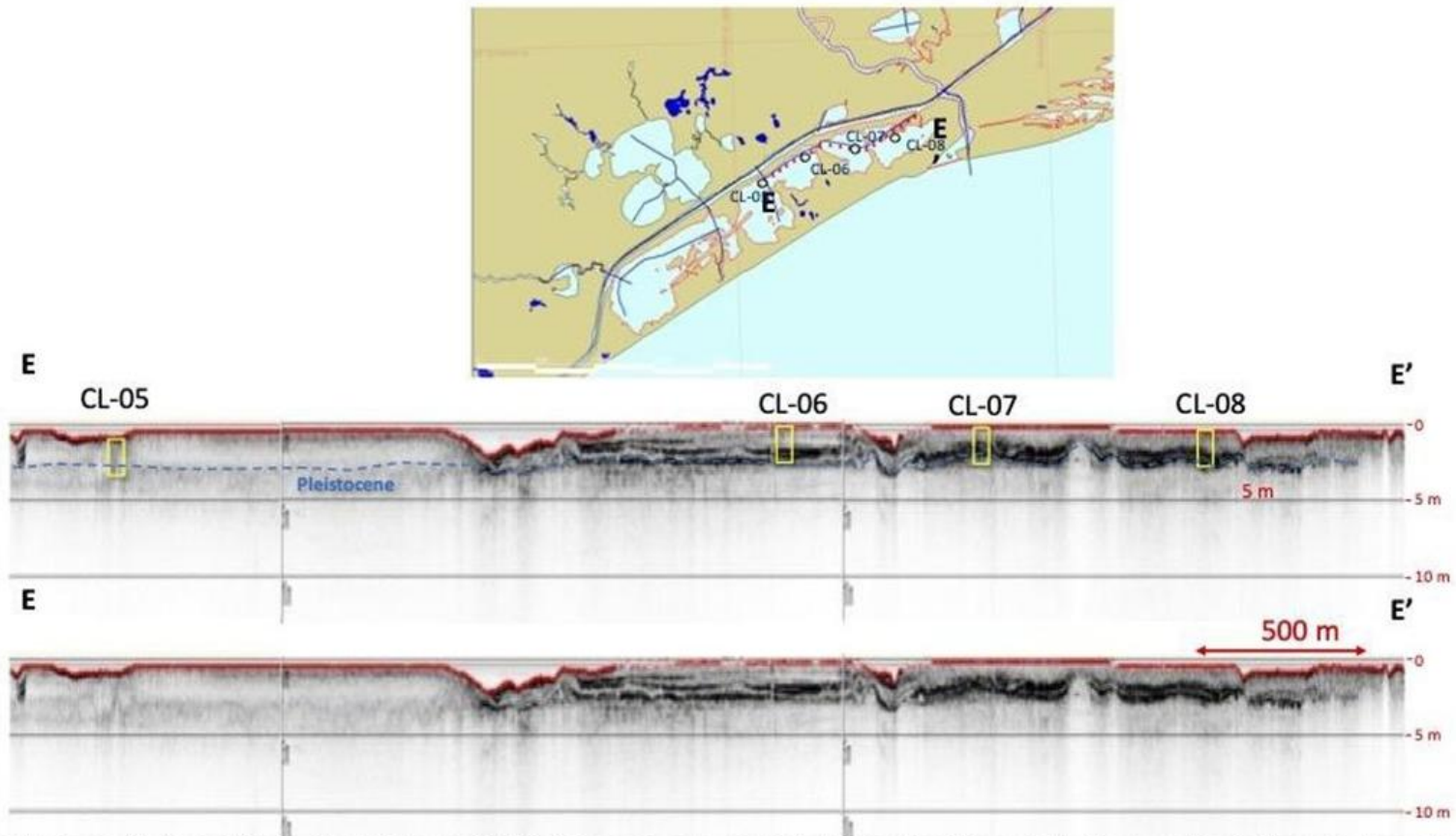
Subbottom Profiler Line B-B' showing the subbottom profiler data for transect from the intersection of the GICWW southward within the San Bernard Channel to where it is blocked at its mouth. The red dashed line shows the surface of the seabed in both panels. The dark reflector below the Red line is the dredged surface. The lighter toned area between these two lines is the sediment fill above the dredged surface. Any horizons shown below these are "seismic multiples, i.e., sonar echos rather than real data.



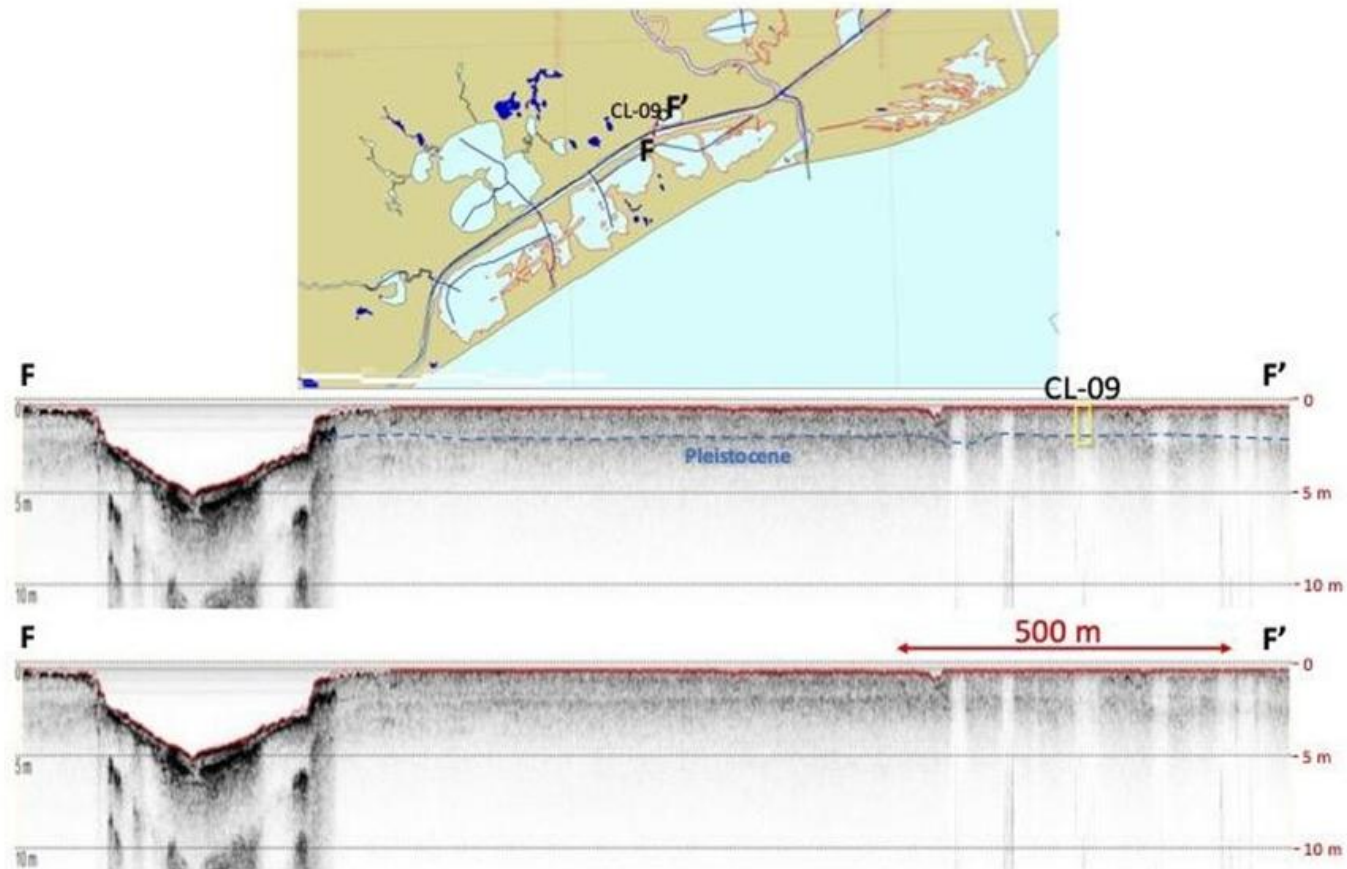
Subbottom Profiler Line C-C' showing the subbottom profiler data for transect across western Cedar Lake Creek west to east. The lower panel shows uninterpreted lines. The red dashed line shows the surface of the seabed in both panels. The Pleistocene surface is shown as a dashed blue line, shown in the upper panel. Core locations are labeled and shown as yellow rectangles. Note, where identified, the Pleistocene surface is relatively flat and underlies the entire survey area.



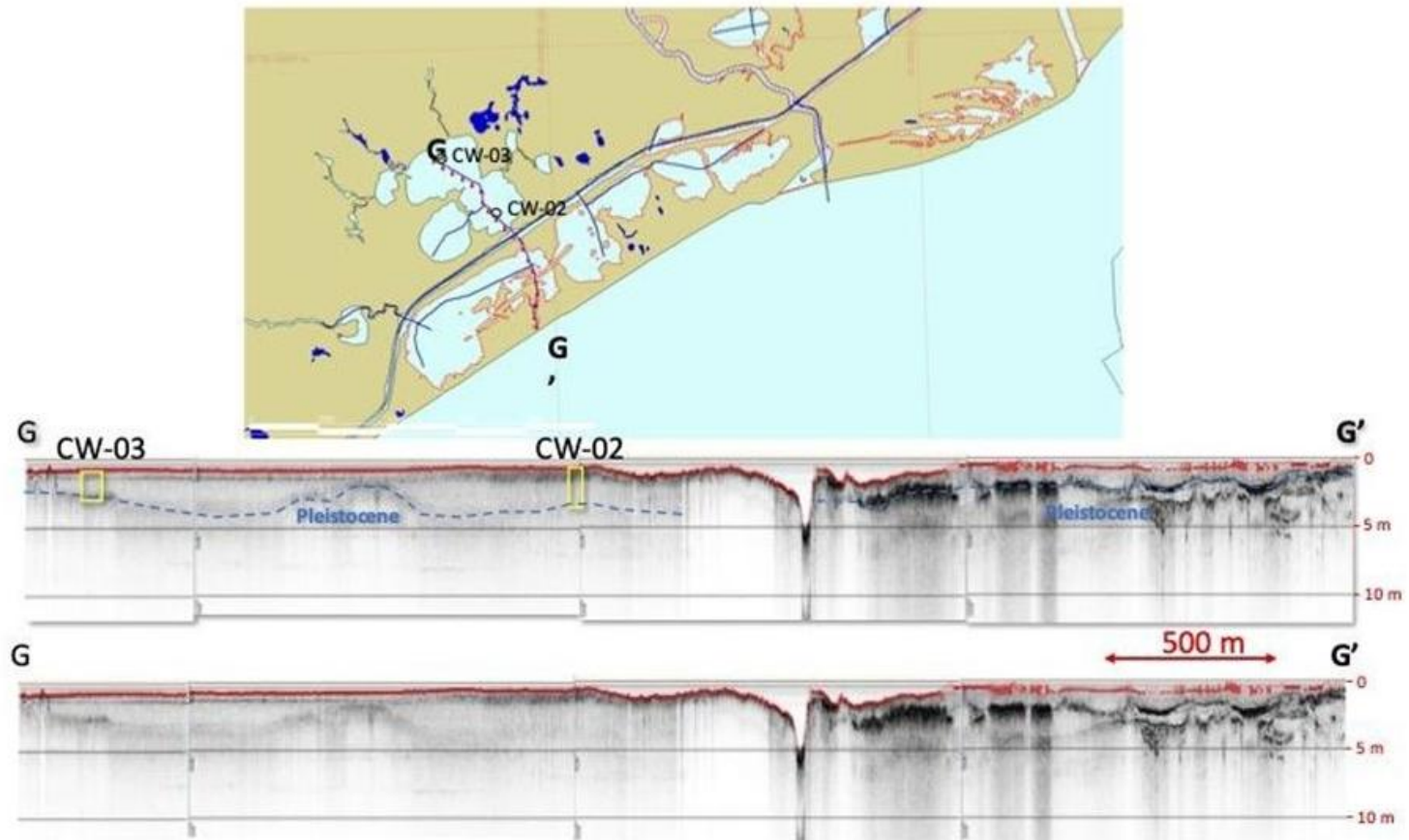
Subbottom Profiler Line D-D' showing the subbottom profiler data for transect across central Cedar Lake Creek north to south. The lower panel shows uninterpreted lines. The red dashed line shows the surface of the seabed in both panels. The Pleistocene surface is shown as a dashed blue line, shown in the upper panel. Core locations are labeled and shown as yellow rectangles. Note, where identified, the Pleistocene surface is relatively flat and underlies the entire survey area. The northern end of the transect includes both a dredged cut as well as the GICWW, both noted in purple.



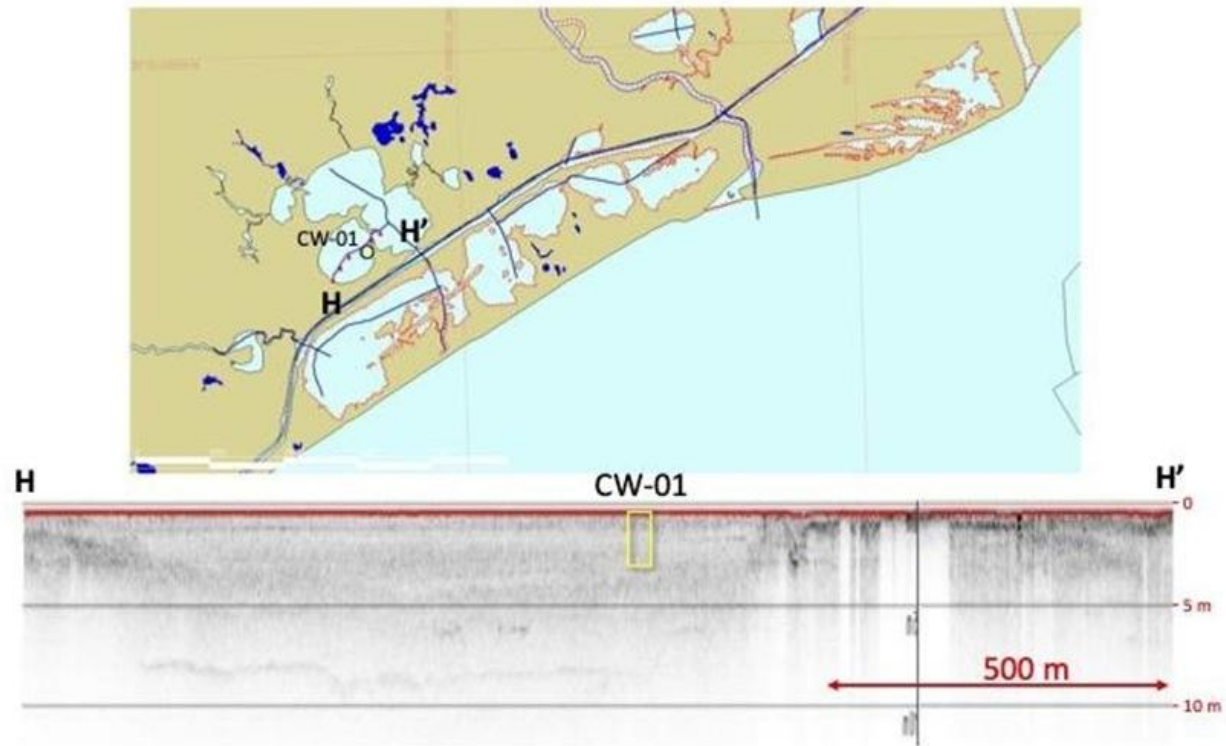
Subbottom Profiler Line E-E' showing the subbottom profiler data for transect across central Cedar Lake Creek north to south. The lower panel shows uninterpreted lines. The red dashed line shows the surface of the seabed in both panels. The Pleistocene surface is shown as a dashed blue line, shown in the upper panel. Core locations are labeled and shown as yellow rectangles. Note, where identified, the Pleistocene surface is relatively flat and underlies the entire survey area.



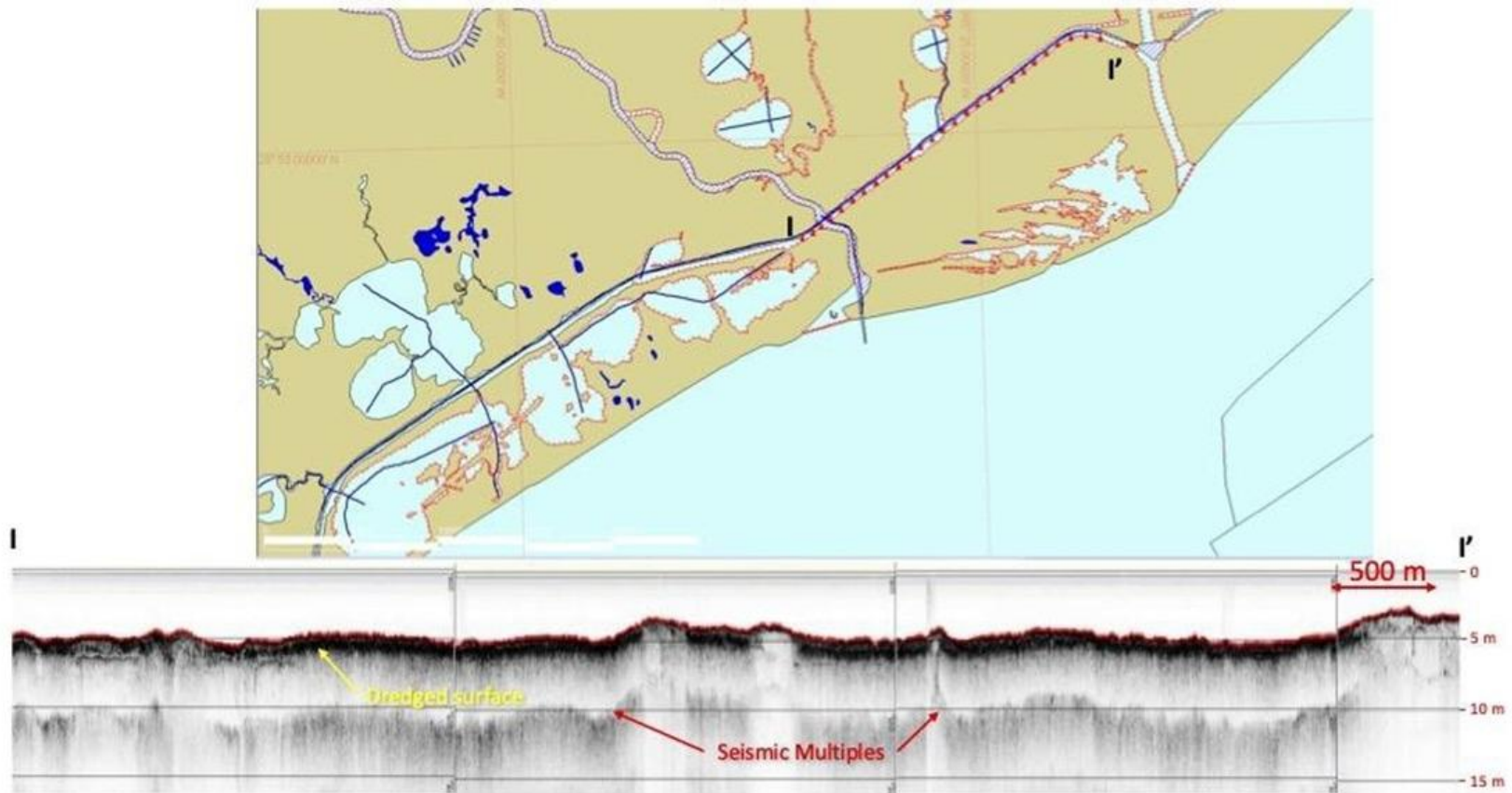
Subbottom Profiler Line F-F' showing the subbottom profiler data for transect from south to north from the outlet of eastern Cedar Lake, across the GICWW and across an unnamed embayment along the northern shore of the GICWW where core CL-09 is located. The lower panel shows uninterpreted lines. The red dashed line shows the surface of the seabed in both panels. The Pleistocene surface is shown as a dashed blue line, shown in the upper panel. Core locations are labeled and shown as yellow rectangles. Note, where identified, the Pleistocene surface is relatively flat and underlies the entire survey area.



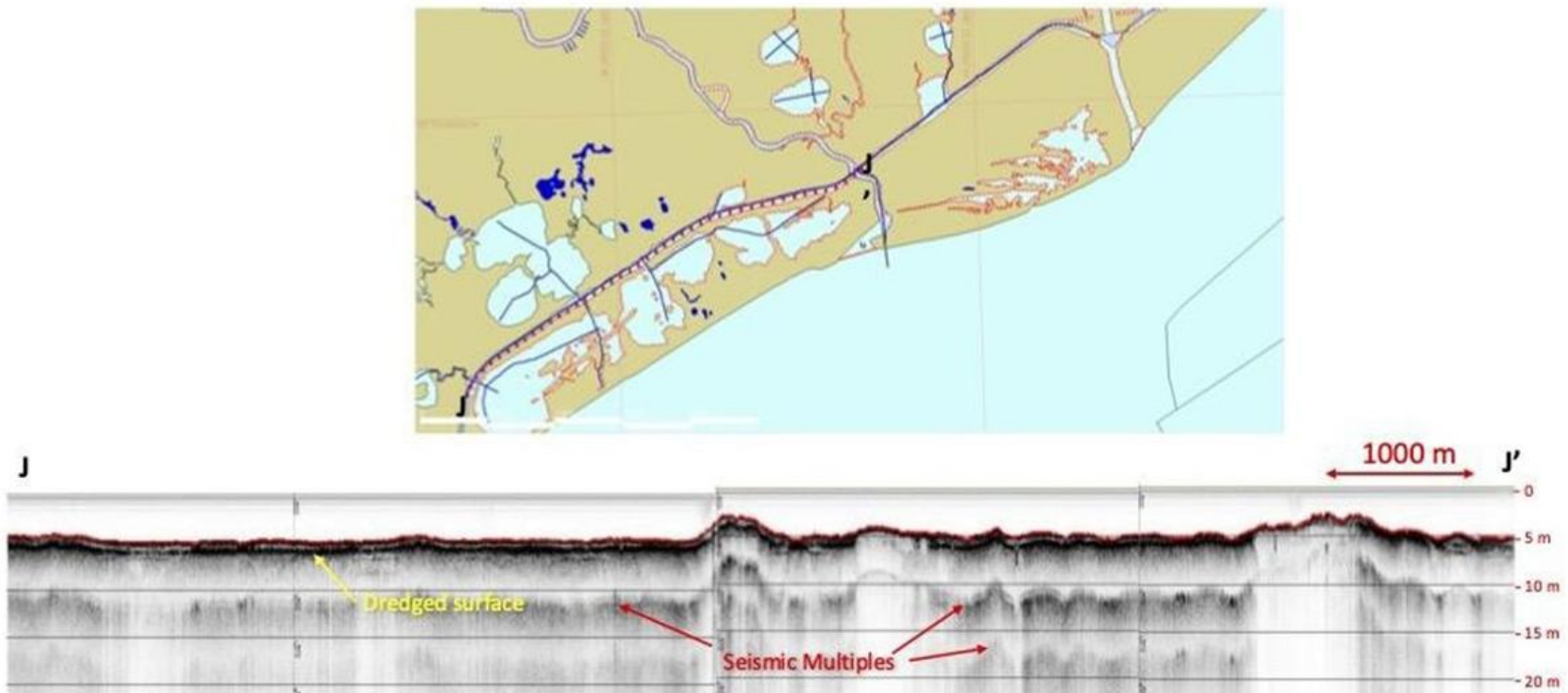
Subbottom Profiler Line G-G' showing the subbottom profiler data for transect from south to north from the southern end of West Cedar Lake, across the GICWW and north through Cowtrap Lake, past core locations CW-02 and CW-03. The lower panel shows uninterpreted lines. The red dashed line shows the surface of the seabed in both panels. The Pleistocene surface is shown as a dashed blue line, shown in the upper panel. Core locations are labeled and shown as yellow rectangles. Note, where identified, the Pleistocene surface is relatively flat and underlies the entire survey area.



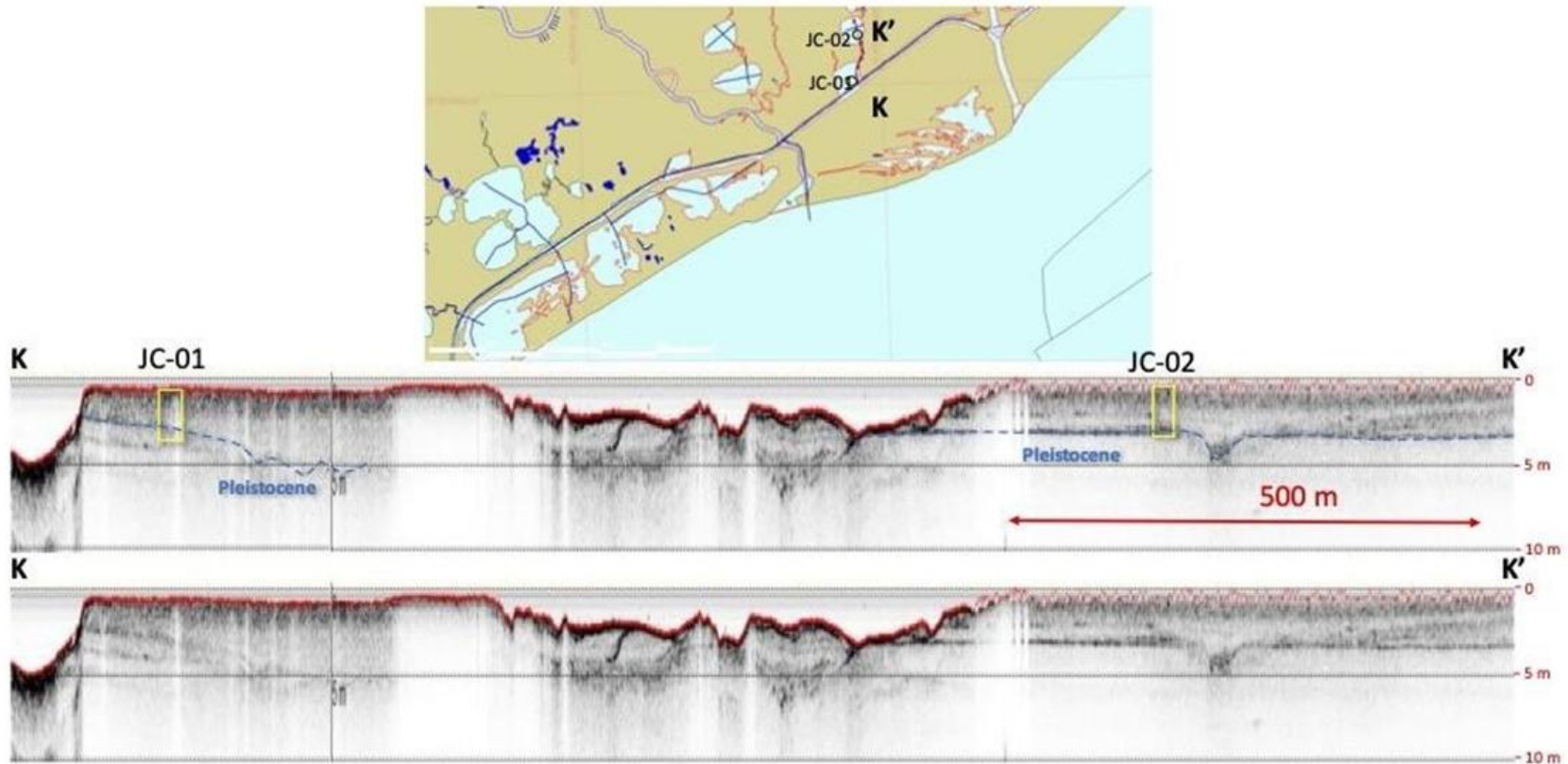
Subbottom Profiler Line H-H' showing the subbottom profiler data for transect from west to east across Cowtrap Lake, past core location CW-01. The Pleistocene surface was not observable in this line, so no interpretation panel is offered.



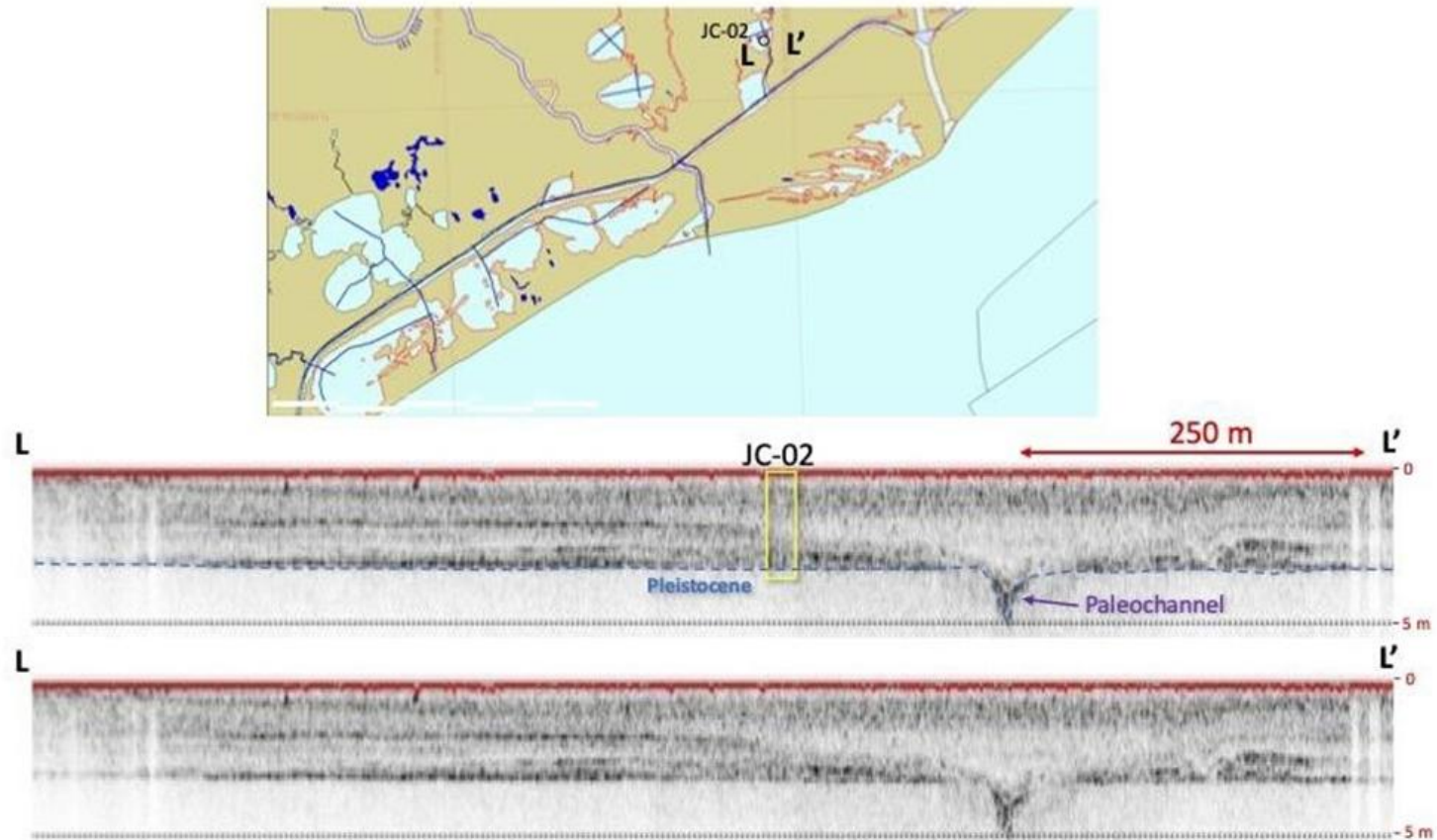
Subbottom Profiler Line I-I' showing the subbottom profiler data for transect from west to east along the GICWW from west of the intersection with the San Bernard River to the West Flood Gate of the Brazos River. The red trace shows the surface of the seabed. The dark reflector below the Red line is the dredged surface. The lighter toned area between these two lines is the sediment fill above the dredged surface. Any horizons shown below these are "seismic multiples, i.e., sonar echos rather than real data.



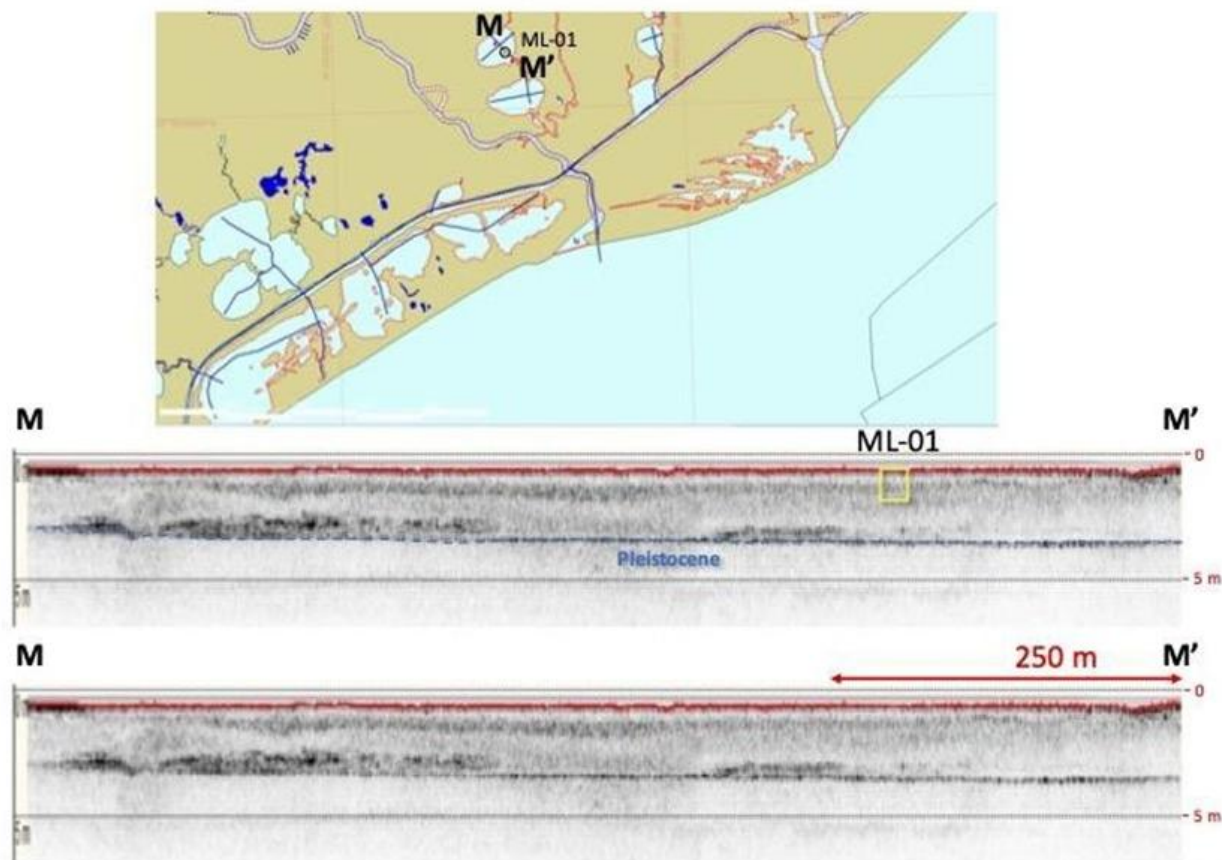
Subbottom Profiler Line J-J' showing the subbottom profiler data for transect from west to east along the GICWW from west end of the survey area to the intersection with the San Bernard River. The red trace shows the surface of the seabed. The dark reflector below the Red line is the dredged surface. The lighter toned area between these two lines is the sediment fill above the dredged surface. Any horizons shown below these are "seismic multiples, i.e., sonar echos rather than real data.



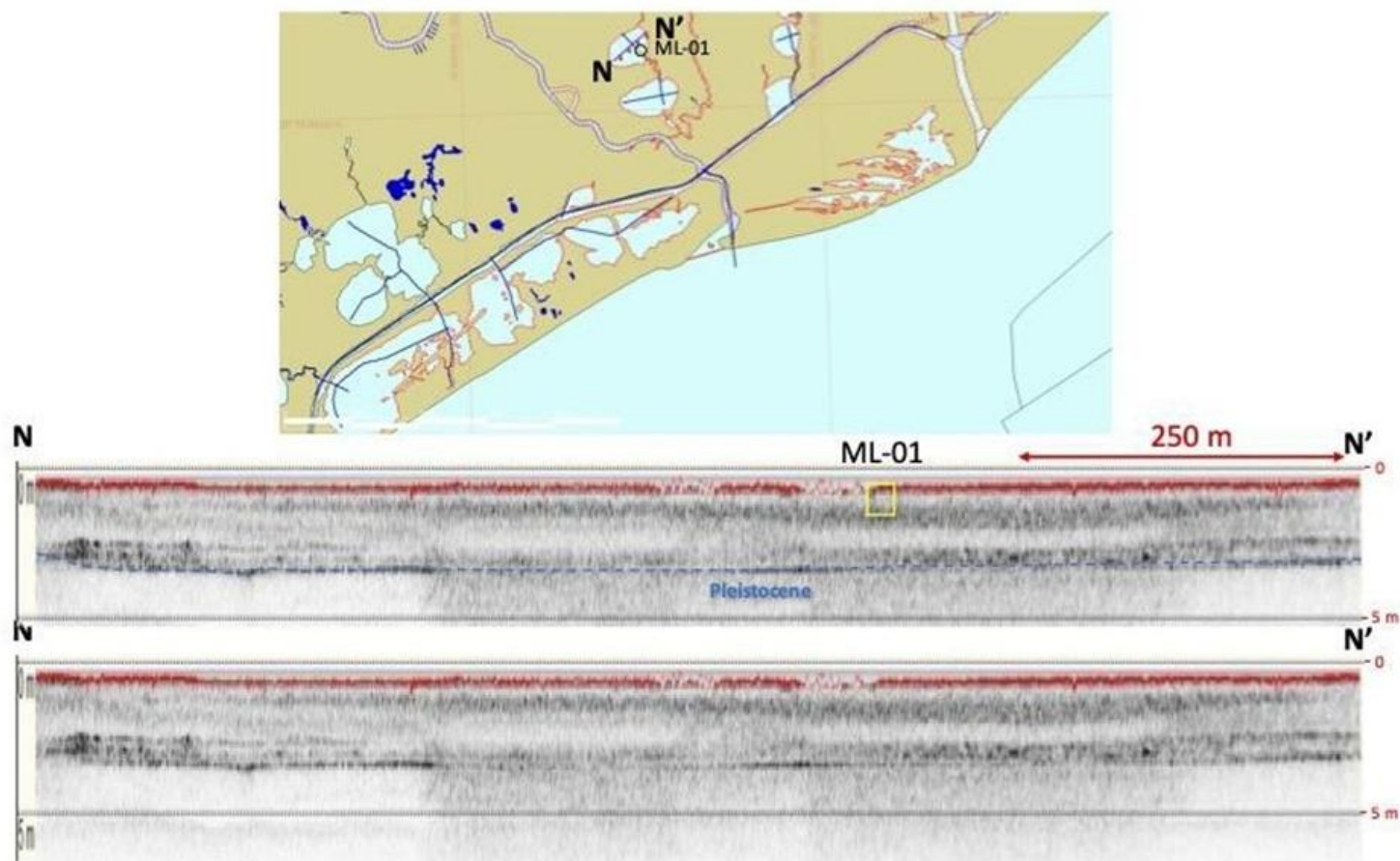
Subbottom Profiler Line K-K' showing the subbottom profiler data for transect from south to north from the southern end Jones Lake and up Jones Creek, past core locations JC-01 and JC-02. The lower panel shows uninterpreted lines. The red dashed line shows the surface of the seabed in both panels. The Pleistocene surface is shown as a dashed blue line, shown in the upper panel. Core locations are labeled and shown as yellow rectangles. Note, where identified, the Pleistocene surface is generally relatively flat, underlies the entire survey area, but does contain a few paleochannels.



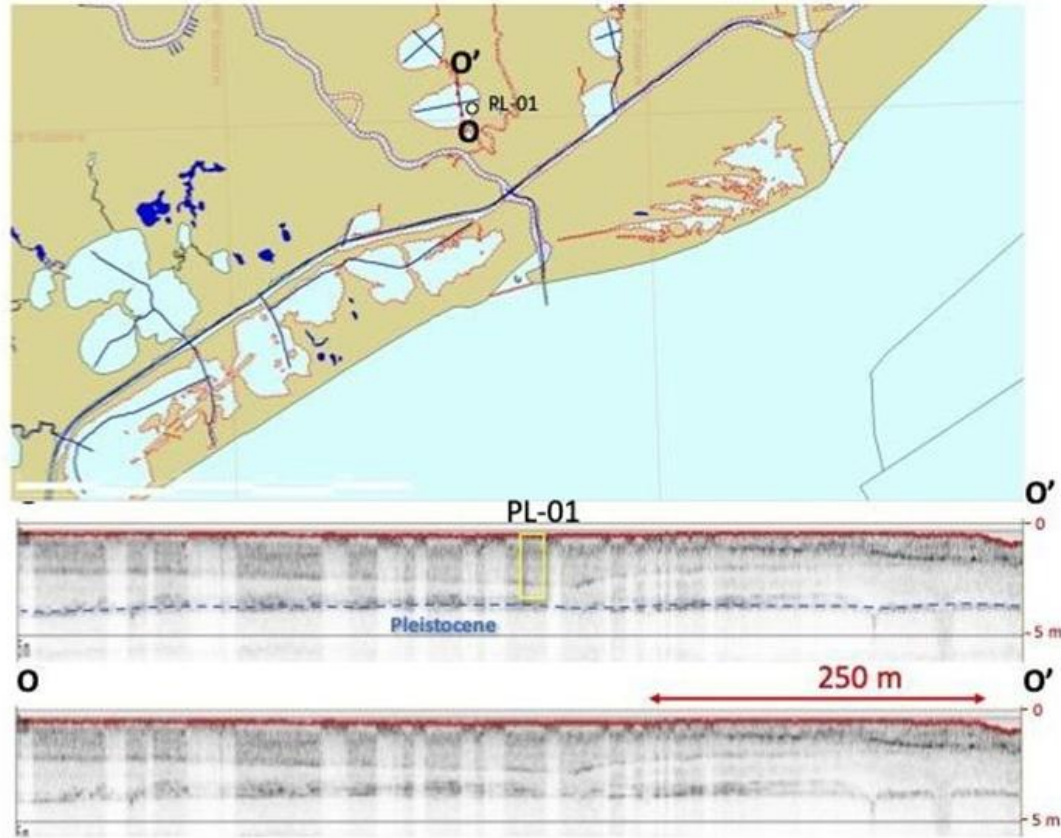
Subbottom Profiler Line L-L' showing the subbottom profiler data for transect from west to east across Northern Jones Lake, past core location JC-02. The lower panel shows uninterpreted lines. The red dashed line shows the surface of the seabed in both panels. The Pleistocene surface is shown as a dashed blue line, shown in the upper panel. Core locations are labeled and shown as yellow rectangles. Note, where identified, the Pleistocene surface is generally relatively flat, underlies the entire survey area, but does contain a small paleochannel.



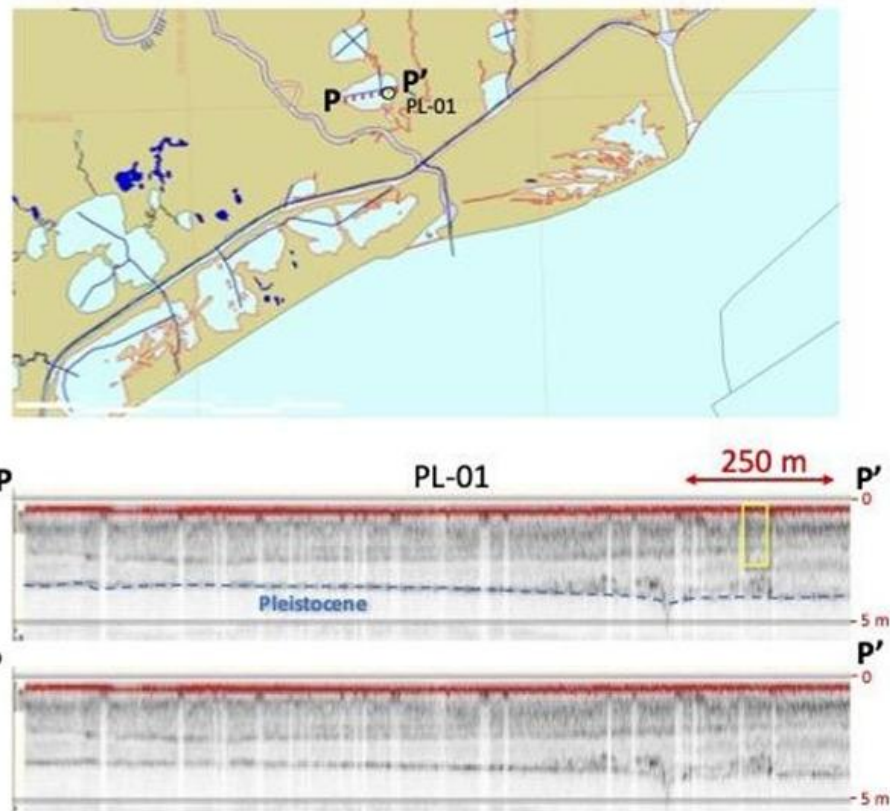
Subbottom Profiler Line M-M' showing the subbottom profiler data for transect from north to south across McNeal Lake, past core location ML-01. The lower panel shows uninterpreted lines. The red dashed line shows the surface of the seabed in both panels. The Pleistocene surface is shown as a dashed blue line, shown in the upper panel. Core locations are labeled and shown as yellow rectangles. Note, where identified, the Pleistocene surface is generally relatively flat and underlies the entire survey area.



Subbottom Profiler Line N-N' showing the subbottom profiler data for transect from west to east across McNeal Lake, past core location ML-01. The lower panel shows uninterpreted lines. The red dashed line shows the surface of the seabed in both panels. The Pleistocene surface is shown as a dashed blue line, shown in the upper panel. Core locations are labeled and shown as yellow rectangles. Note, where identified, the Pleistocene surface is generally relatively flat and underlies the entire survey area.



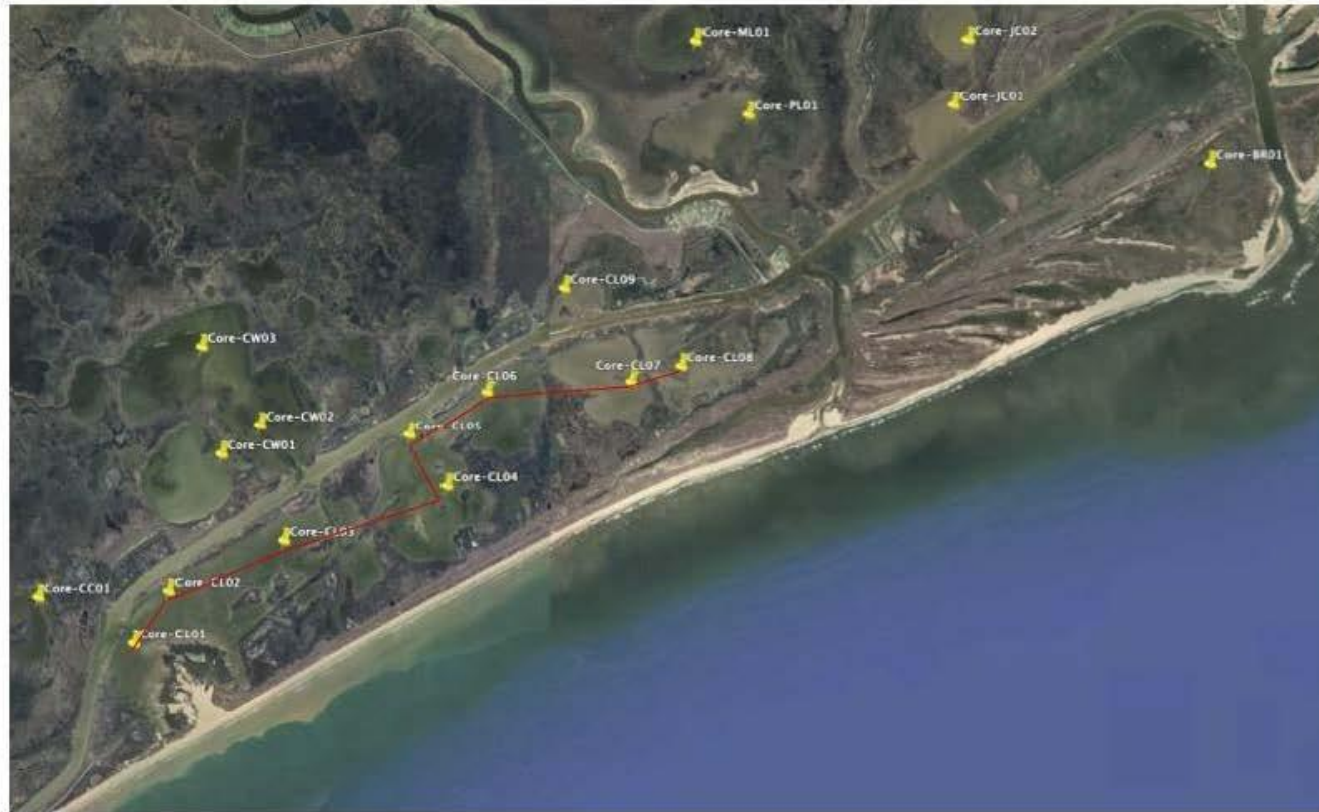
Subbottom Profiler Line O-O' showing the subbottom profiler data for transect from south to north across Pelican Lake, past core location PL-01. The lower panel shows uninterpreted lines. The red dashed line shows the surface of the seabed in both panels. The Pleistocene surface is shown as a dashed blue line, shown in the upper panel. Core locations are labeled and shown as yellow rectangles. Note, where identified, the Pleistocene surface is generally relatively flat and underlies the entire survey area.



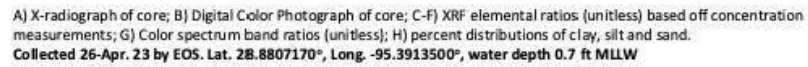
Subbottom Profiler Line P-P' showing the subbottom profiler data for transect from west to east across Pelican Lake, past core location PL-01. The lower panel shows uninterpreted lines. The red dashed line shows the surface of the seabed in both panels. The Pleistocene surface is shown as a dashed blue line, shown in the upper panel. Core locations are labeled and shown as yellow rectangles. Note, where identified, the Pleistocene surface is generally relatively flat and underlies the entire survey area.

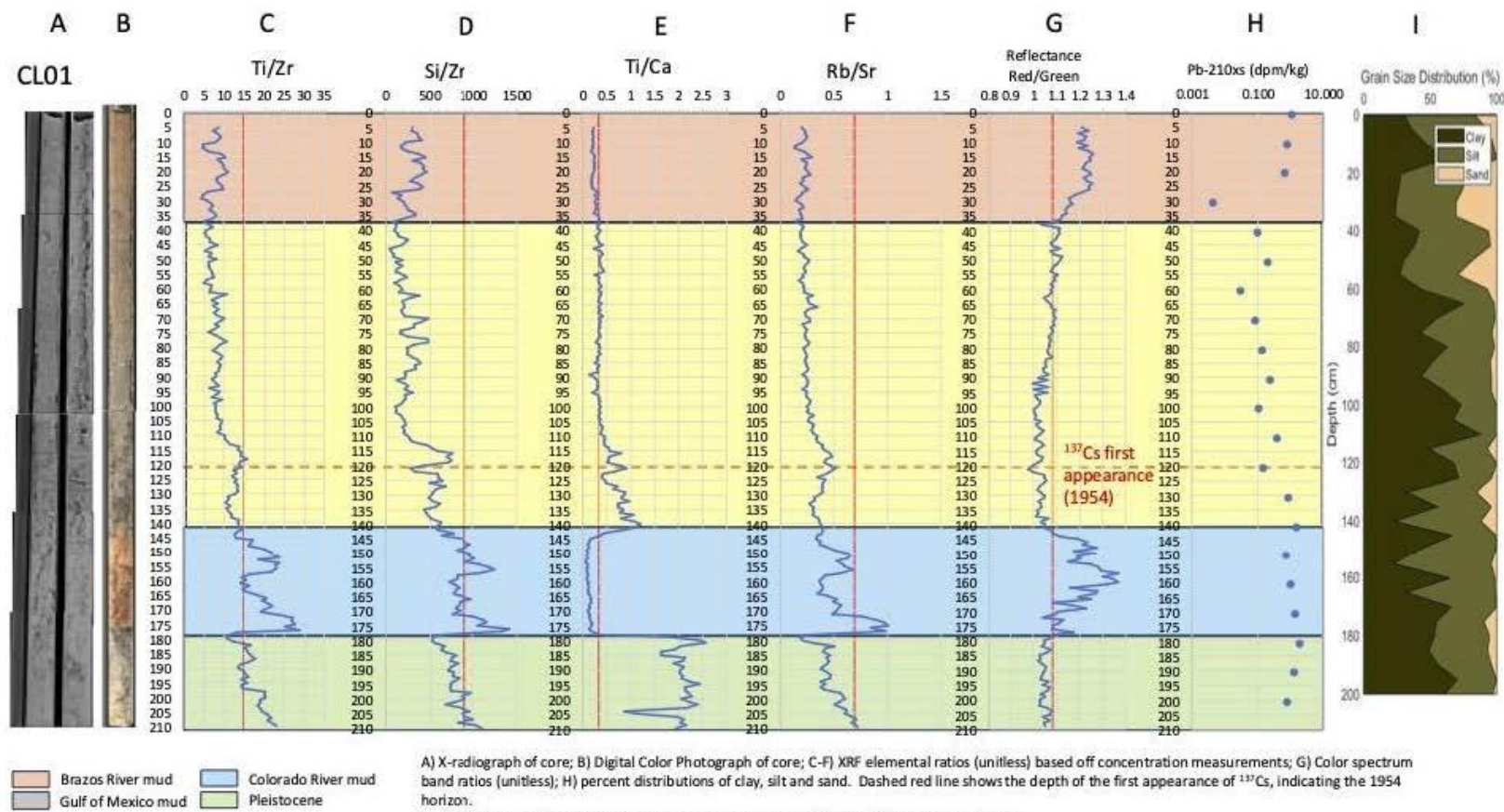
Appendix C: Core Sheets

Base Map of Appendix C showing location of cores and cross section



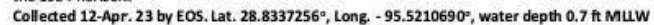
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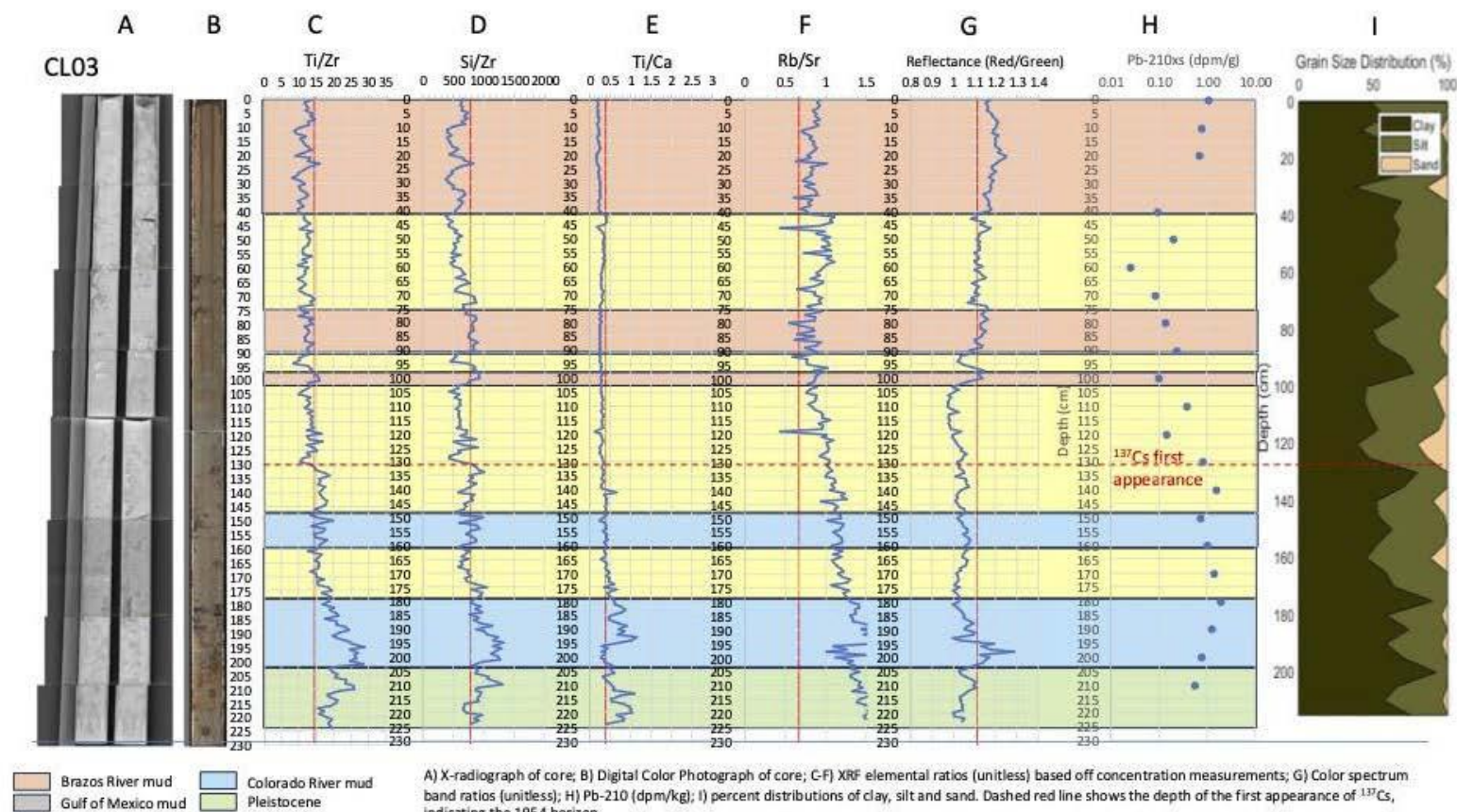


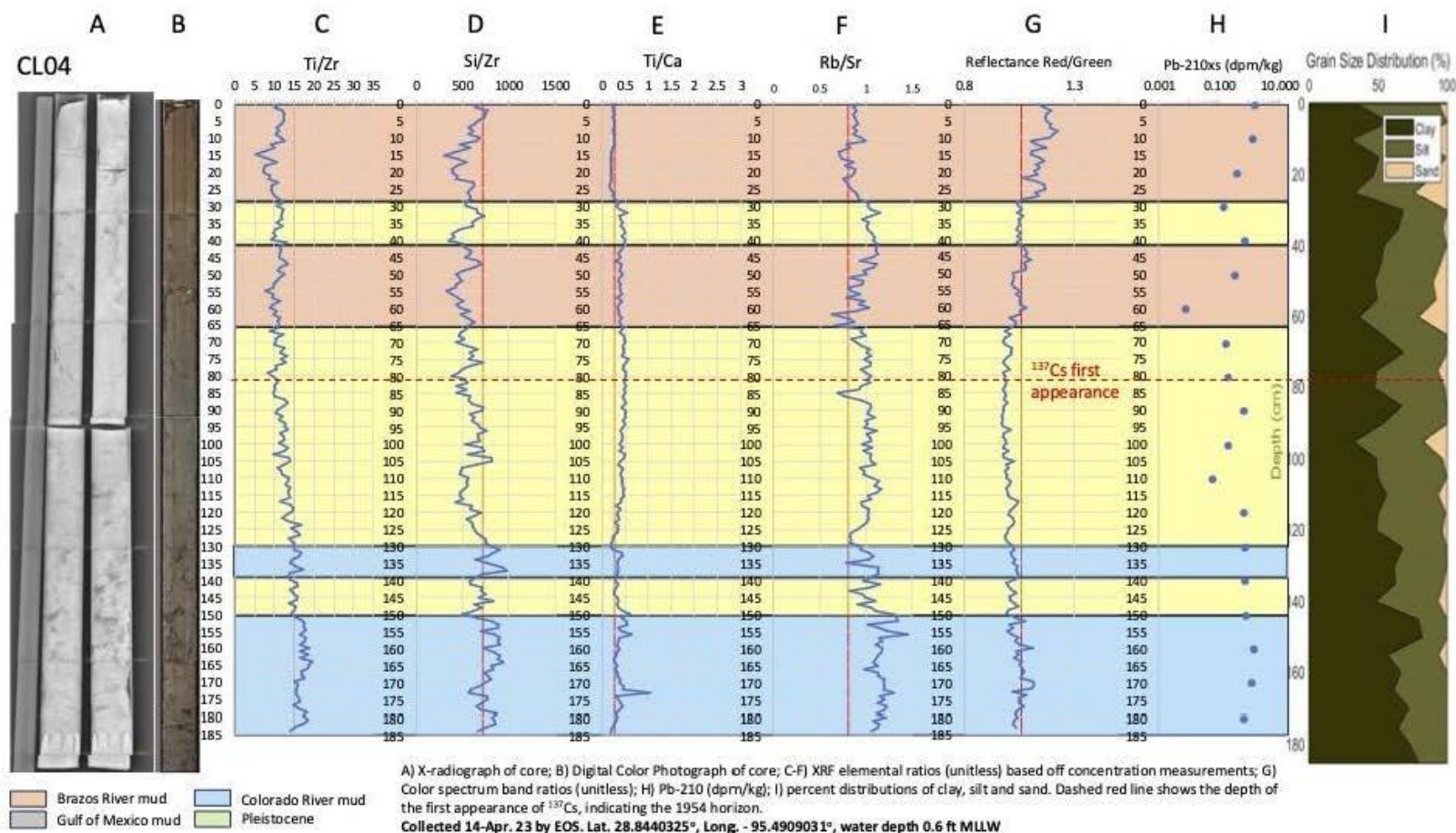


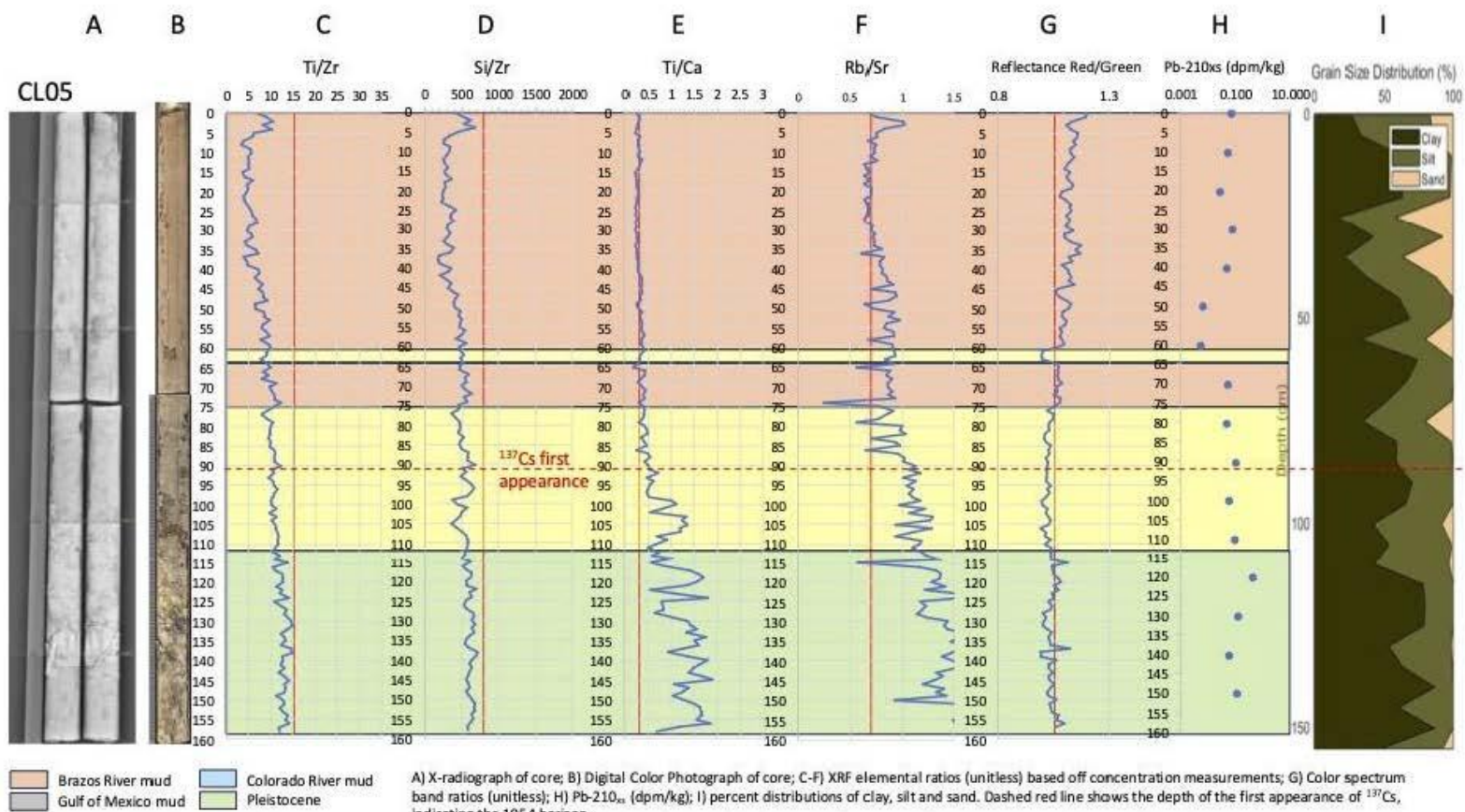
A) X-radiograph of core; B) Digital Color Photograph of core; C-F) XRF elemental ratios (unitless) based off concentration measurements; G) Color spectrum band ratios (unitless); H) percent distributions of clay, silt and sand. Dashed red line shows the depth of the first appearance of ^{137}Cs , indicating the 1954 horizon.

Collected 12-Apr. 23 by EOS. Lat. 28.826223°, Long. -95.5316785°, water depth 1.2 ft MLW



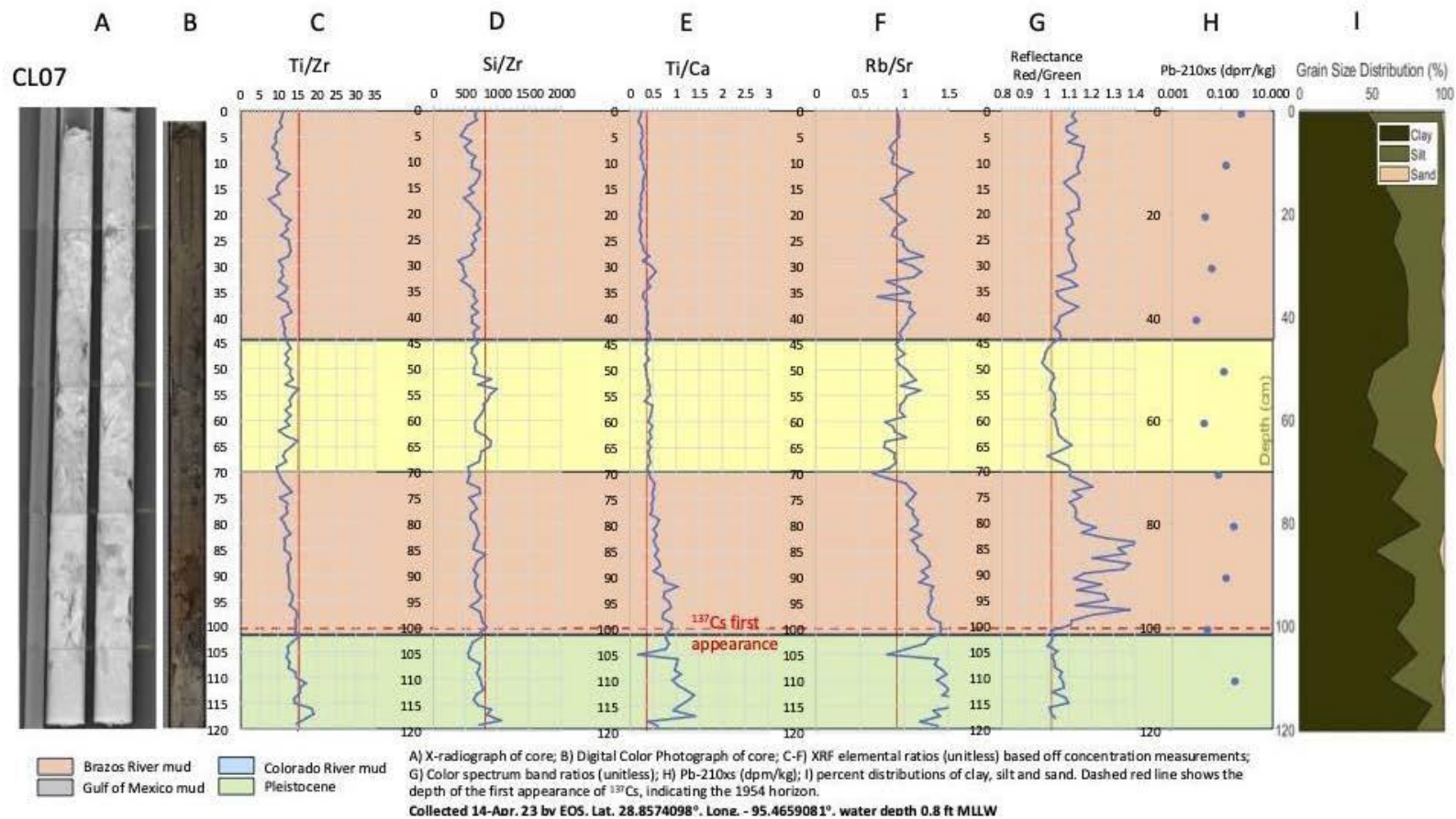


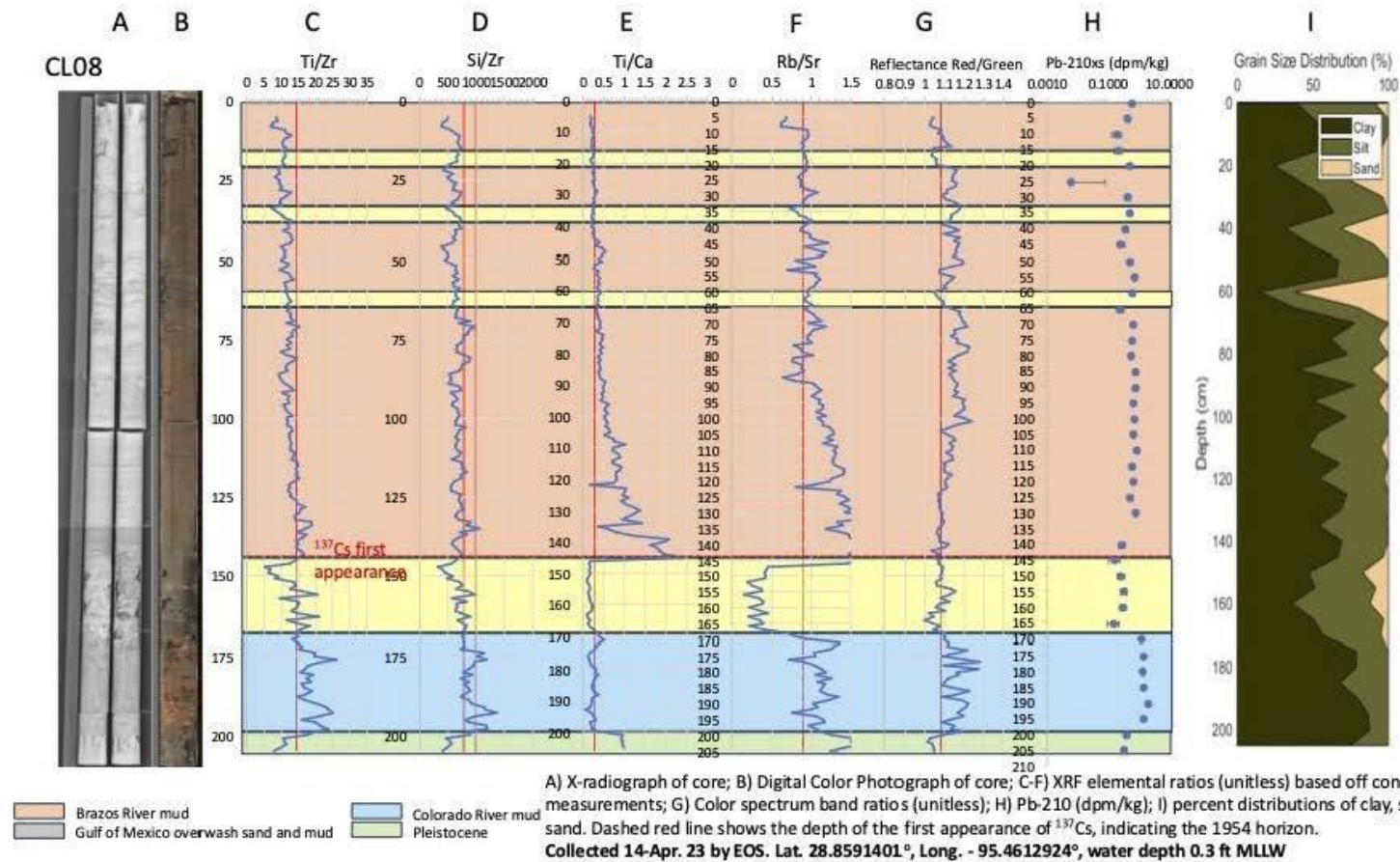


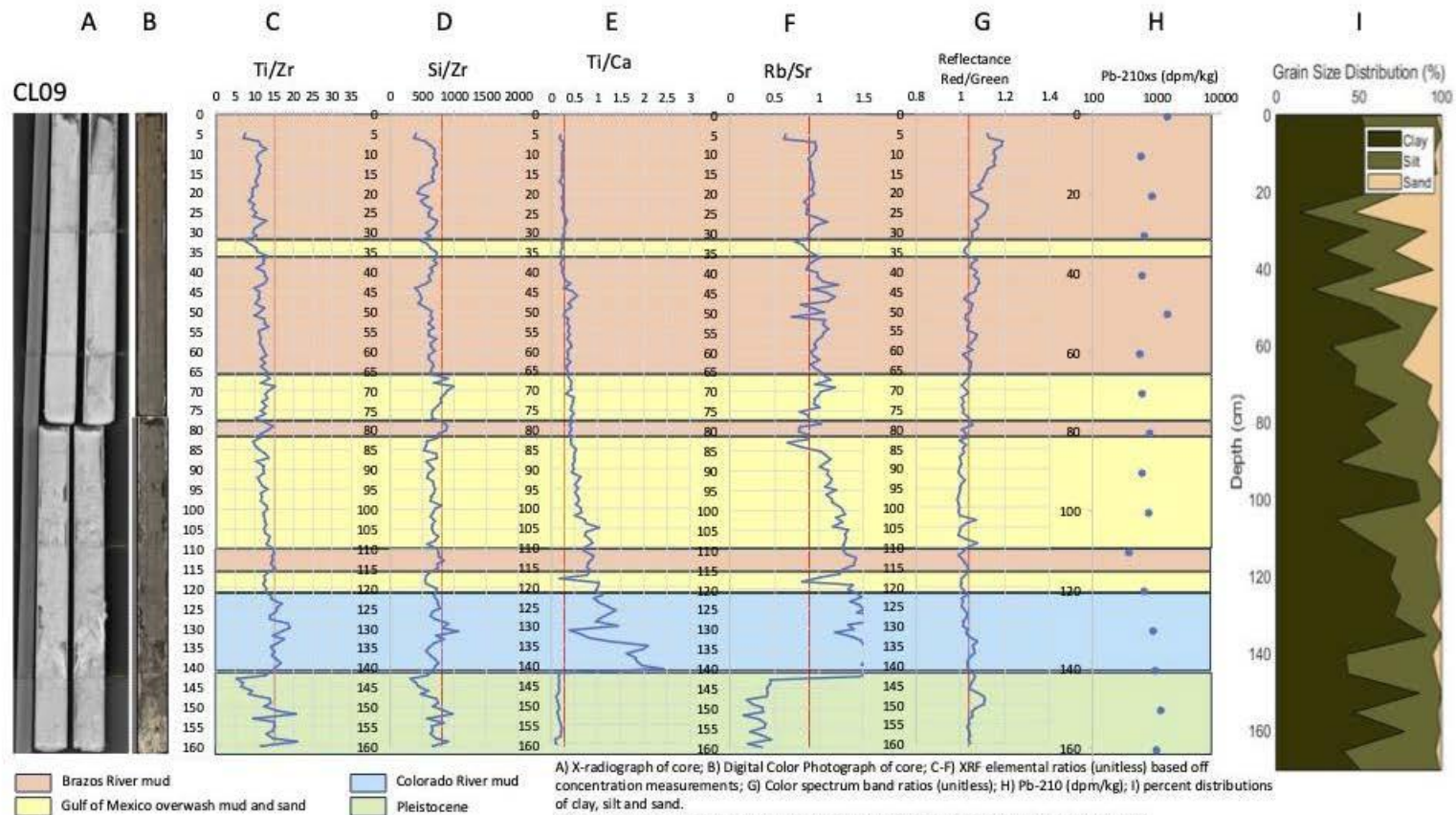


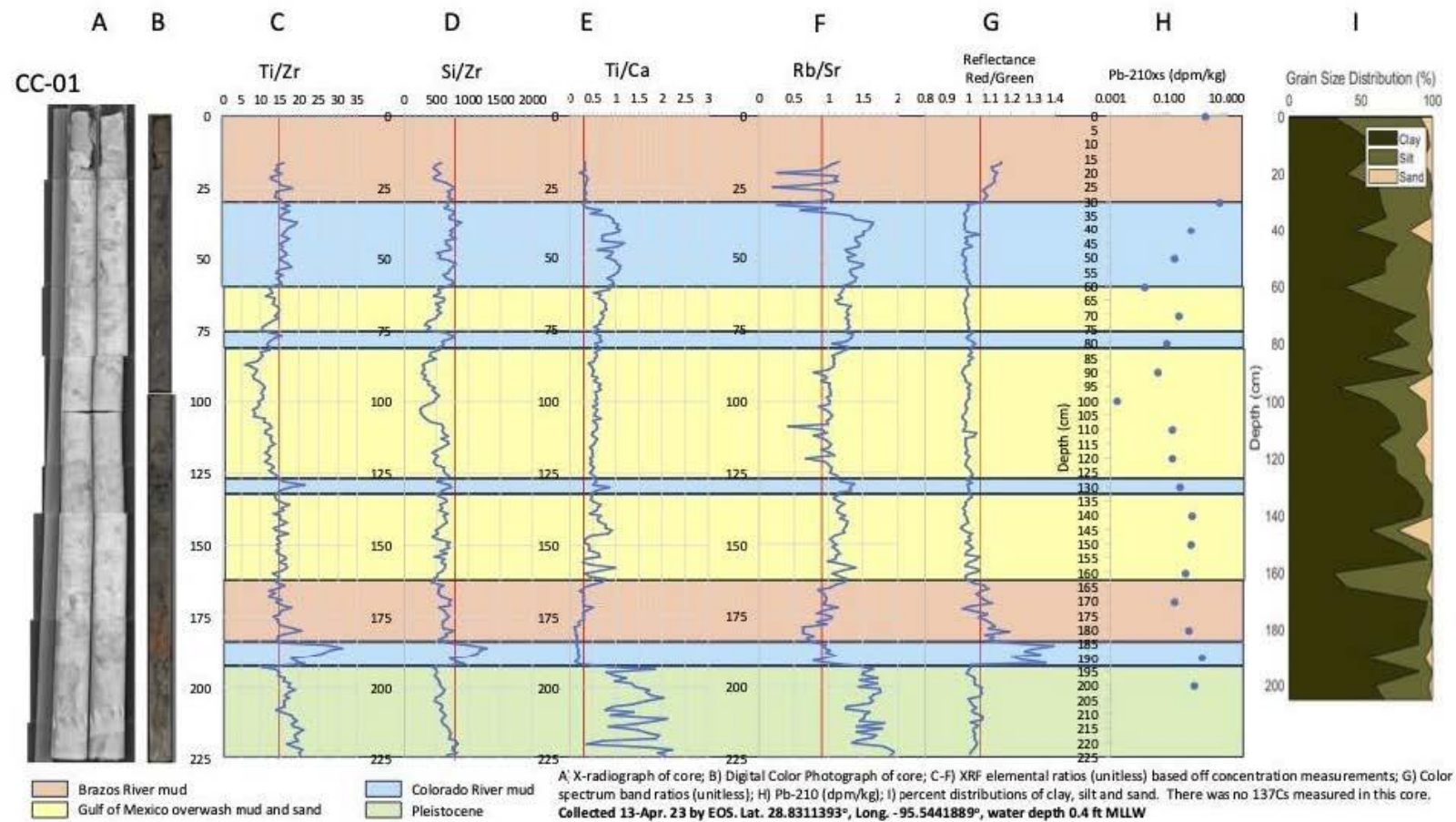
A) X-radiograph of core; B) Digital Color Photograph of core; C-F) XRF elemental ratios (unitless) based off concentration measurements; G) Color spectrum band ratios (unitless); H) Pb-210_{ex} (dpm/kg); I) percent distributions of clay, silt and sand. Dashed red line shows the depth of the first appearance of ¹³⁷Cs, indicating the 1954 horizon.

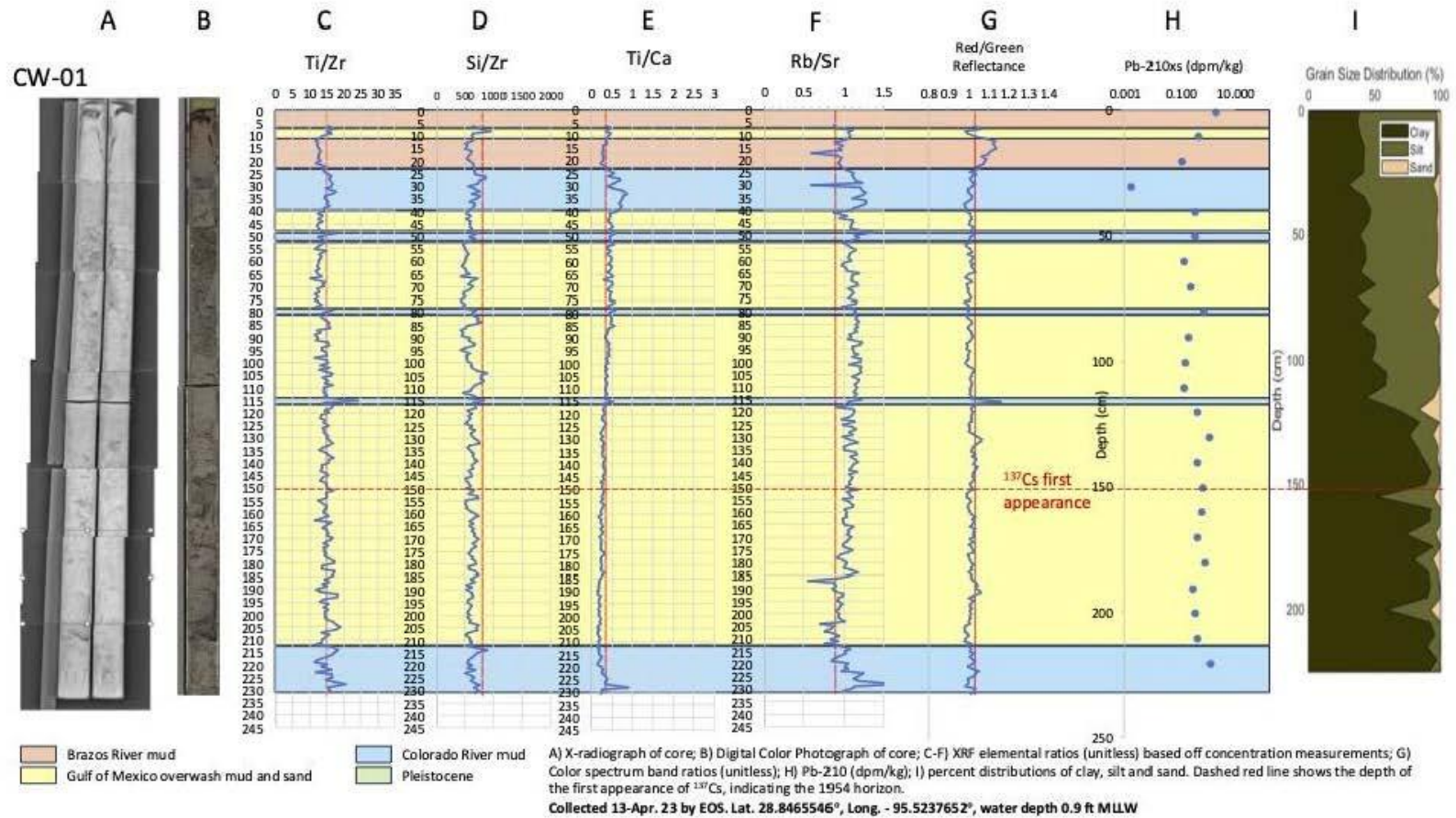
Collected 14-Apr. 23 by EOS. Lat. 28.8498909°, Long. -95.4956266°, water depth 0.8 ft MLLW

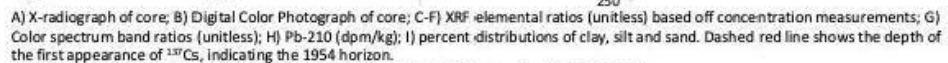


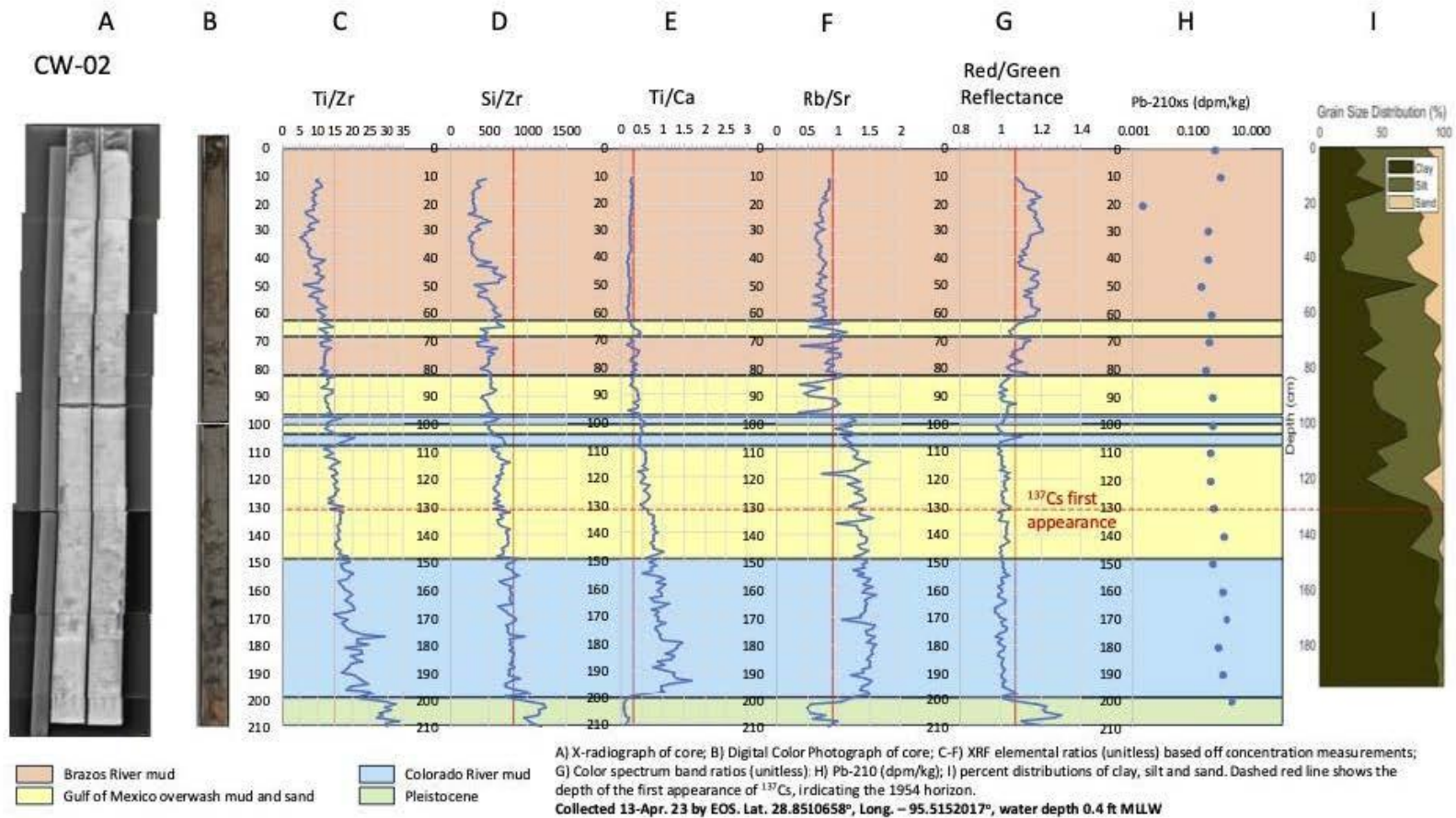


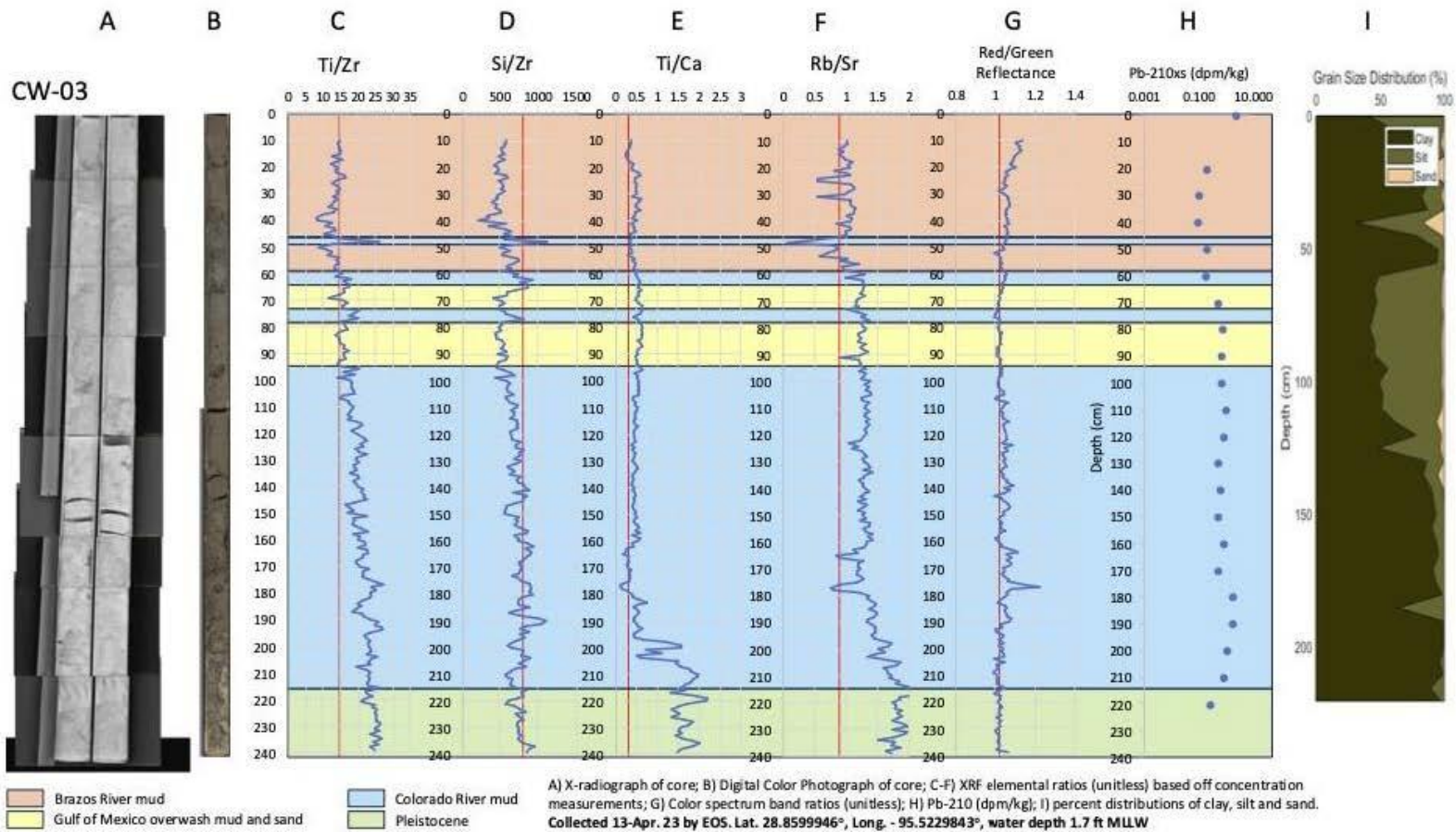


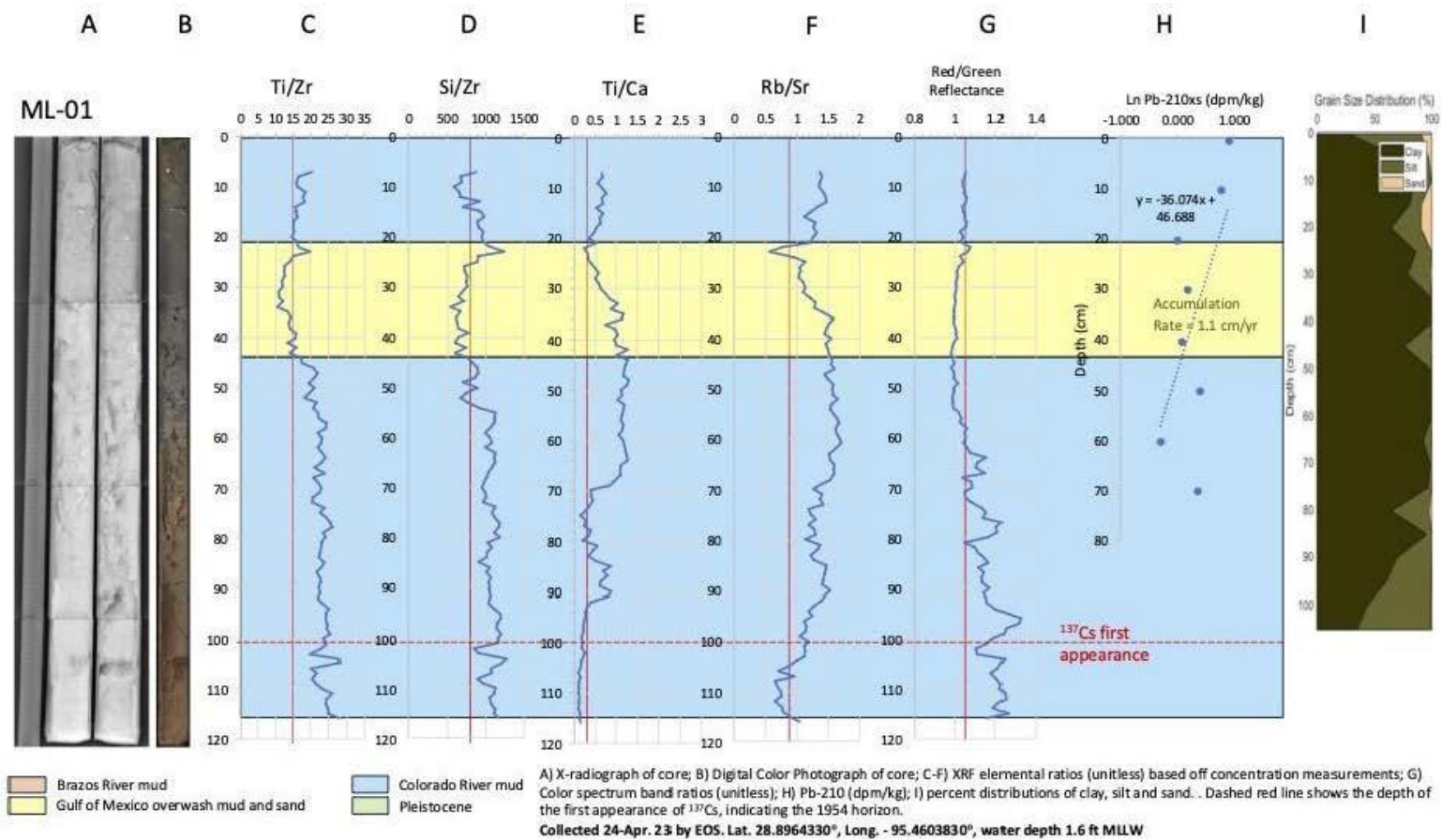


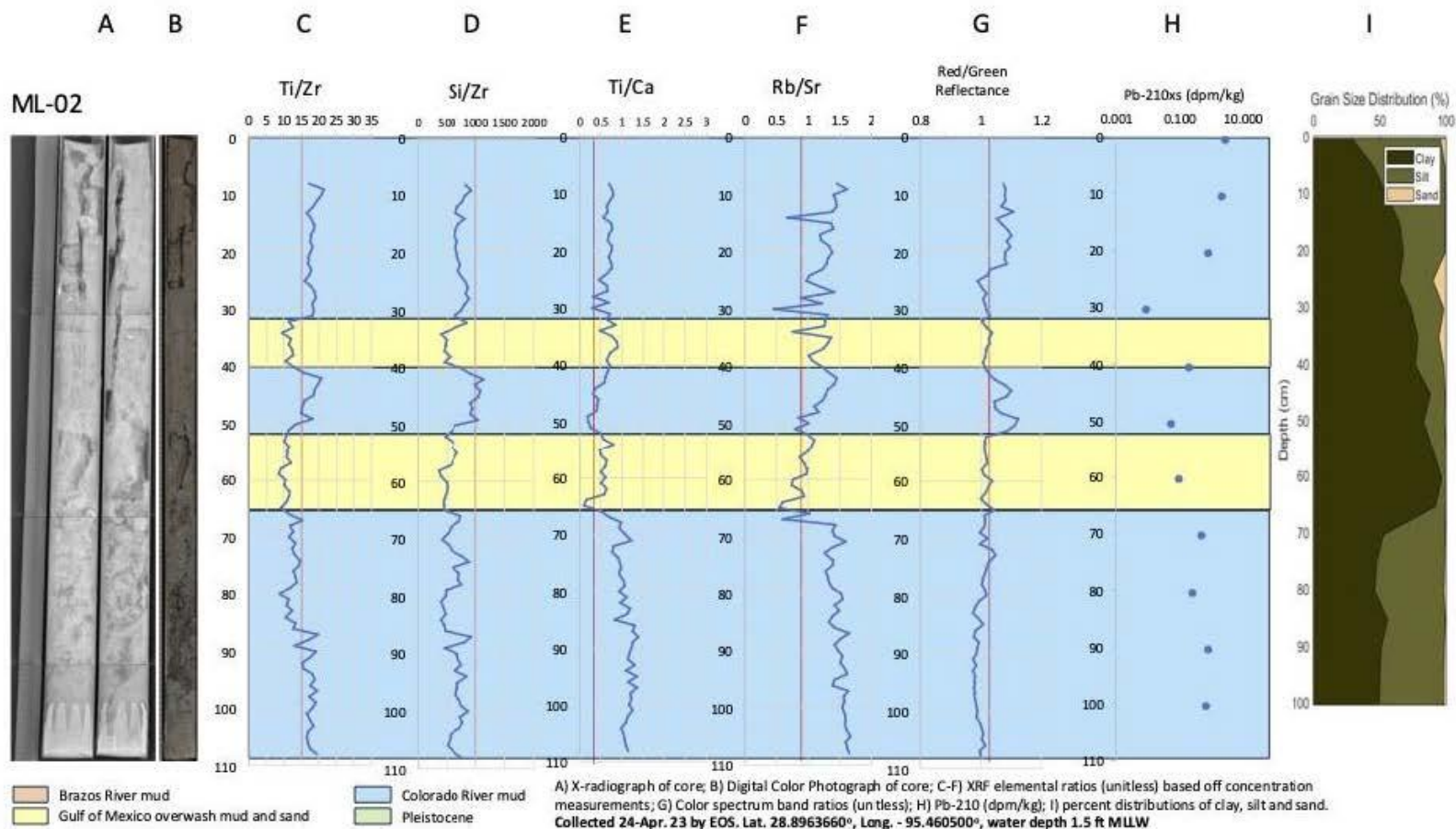


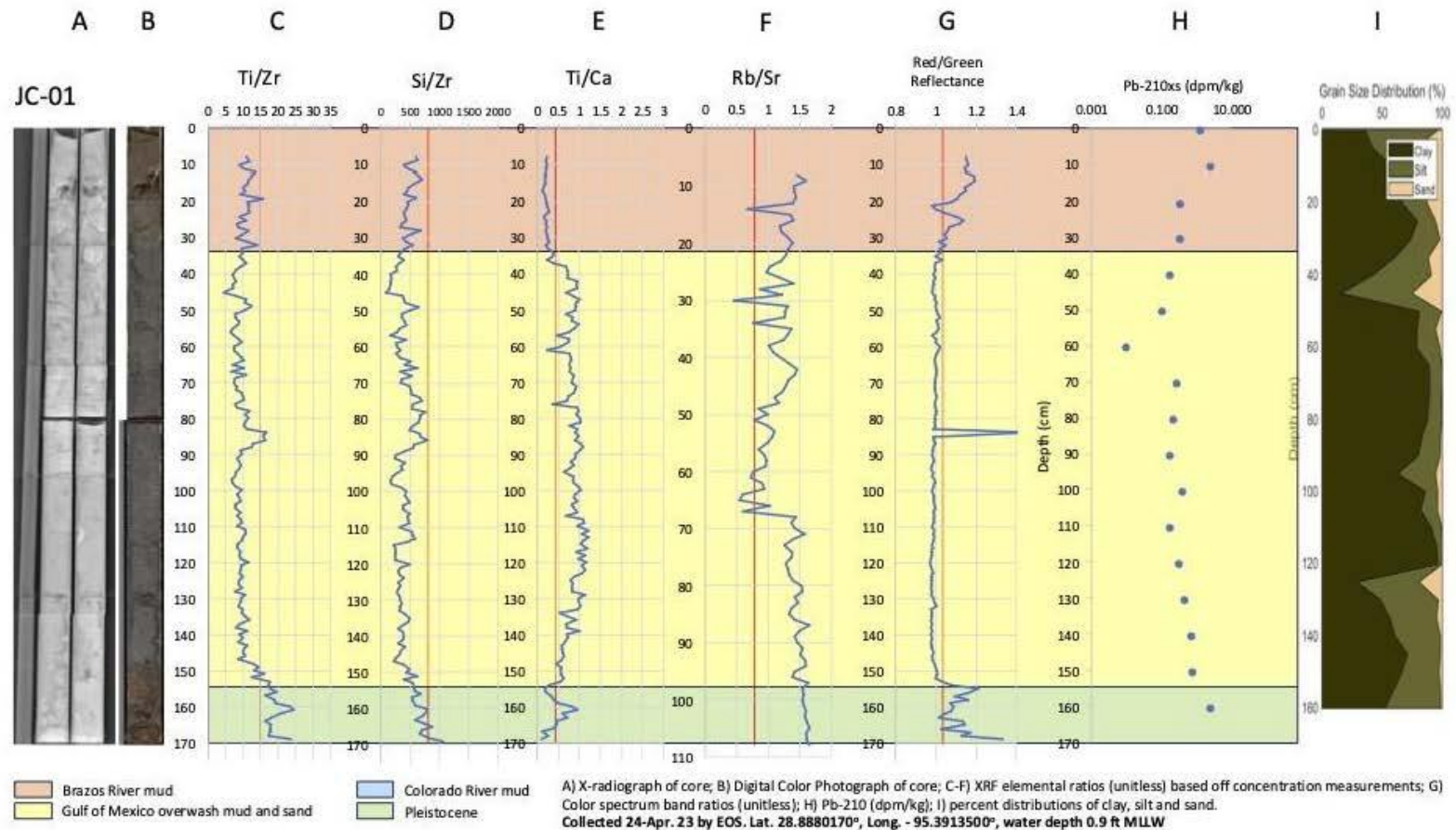


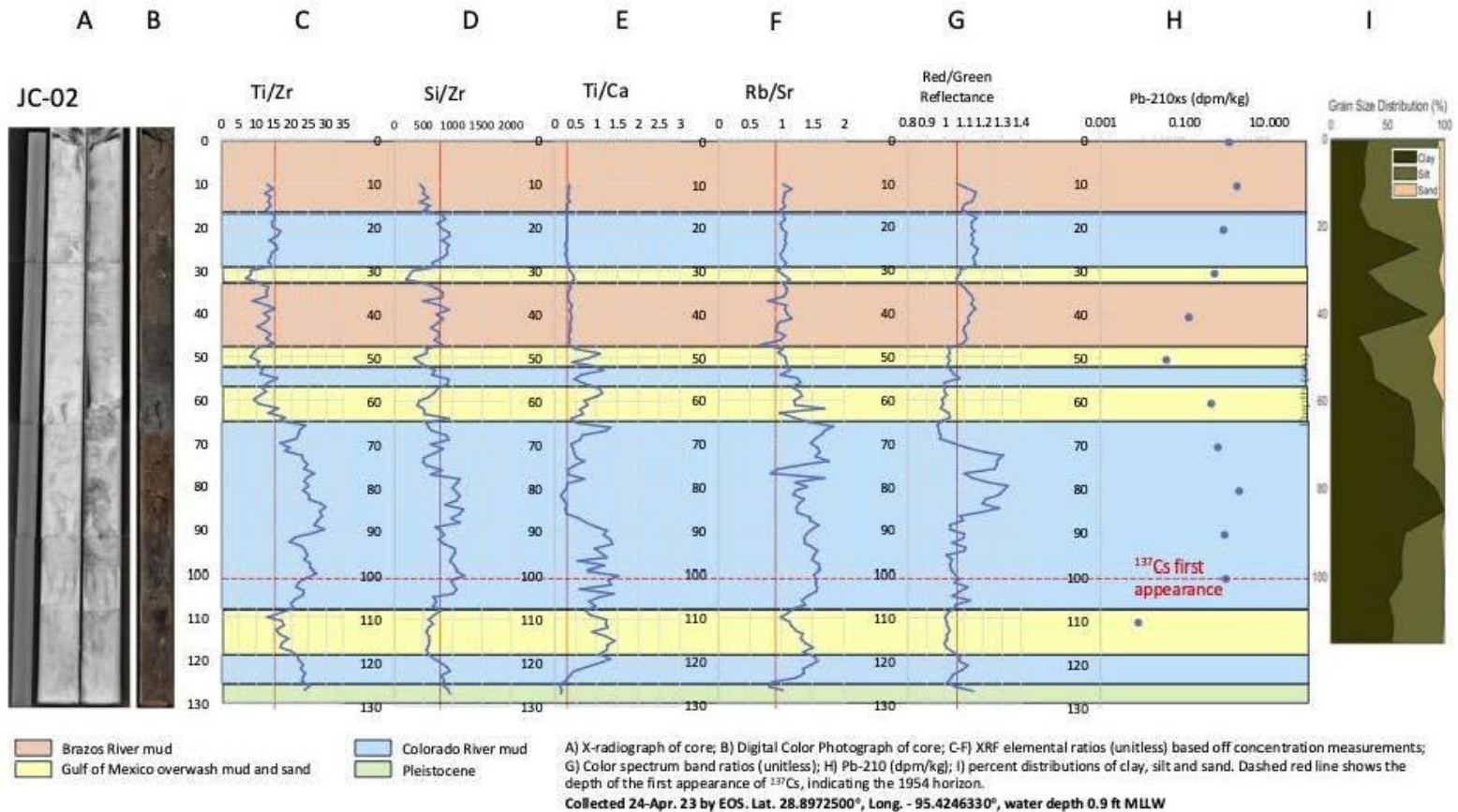


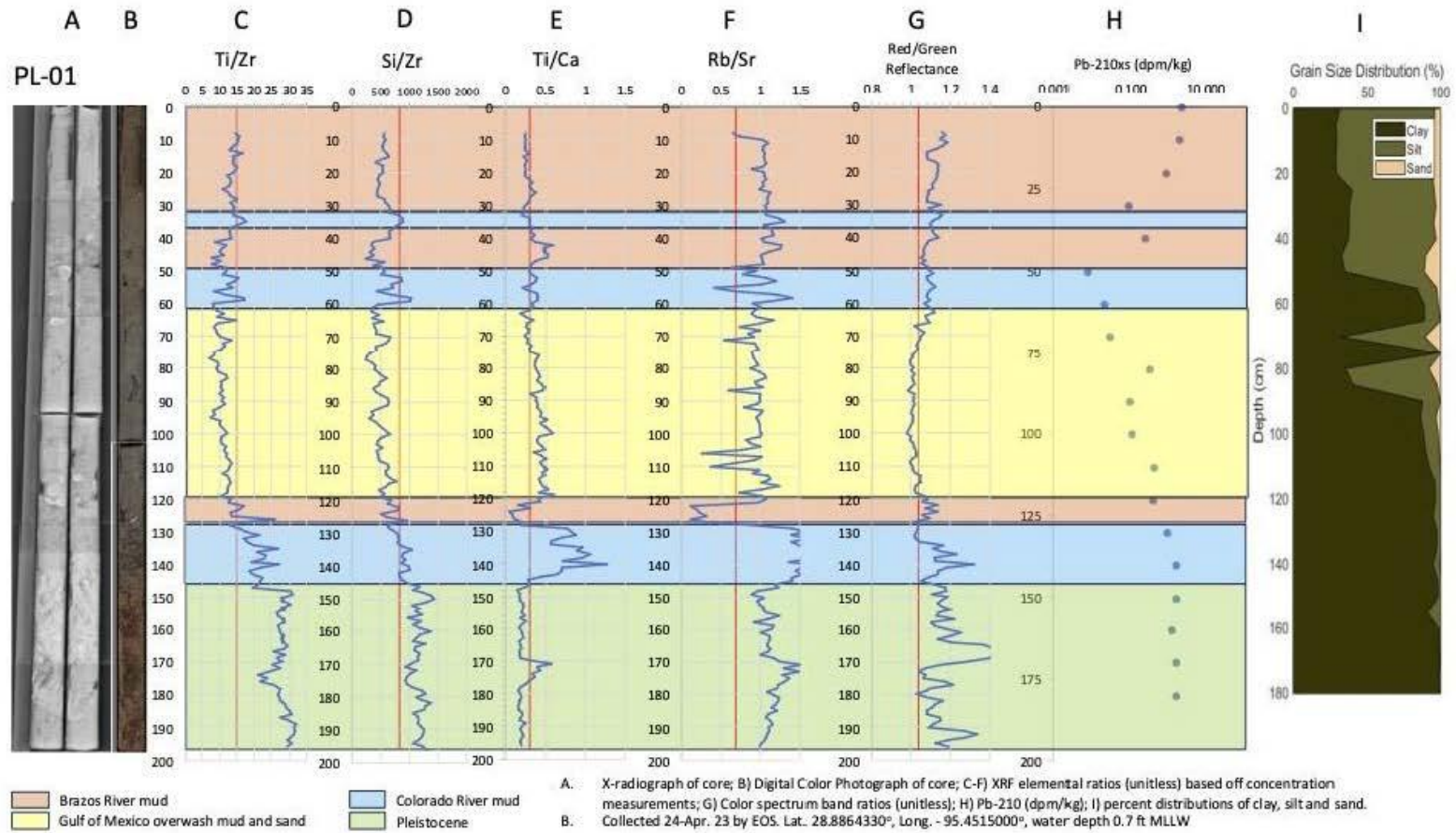




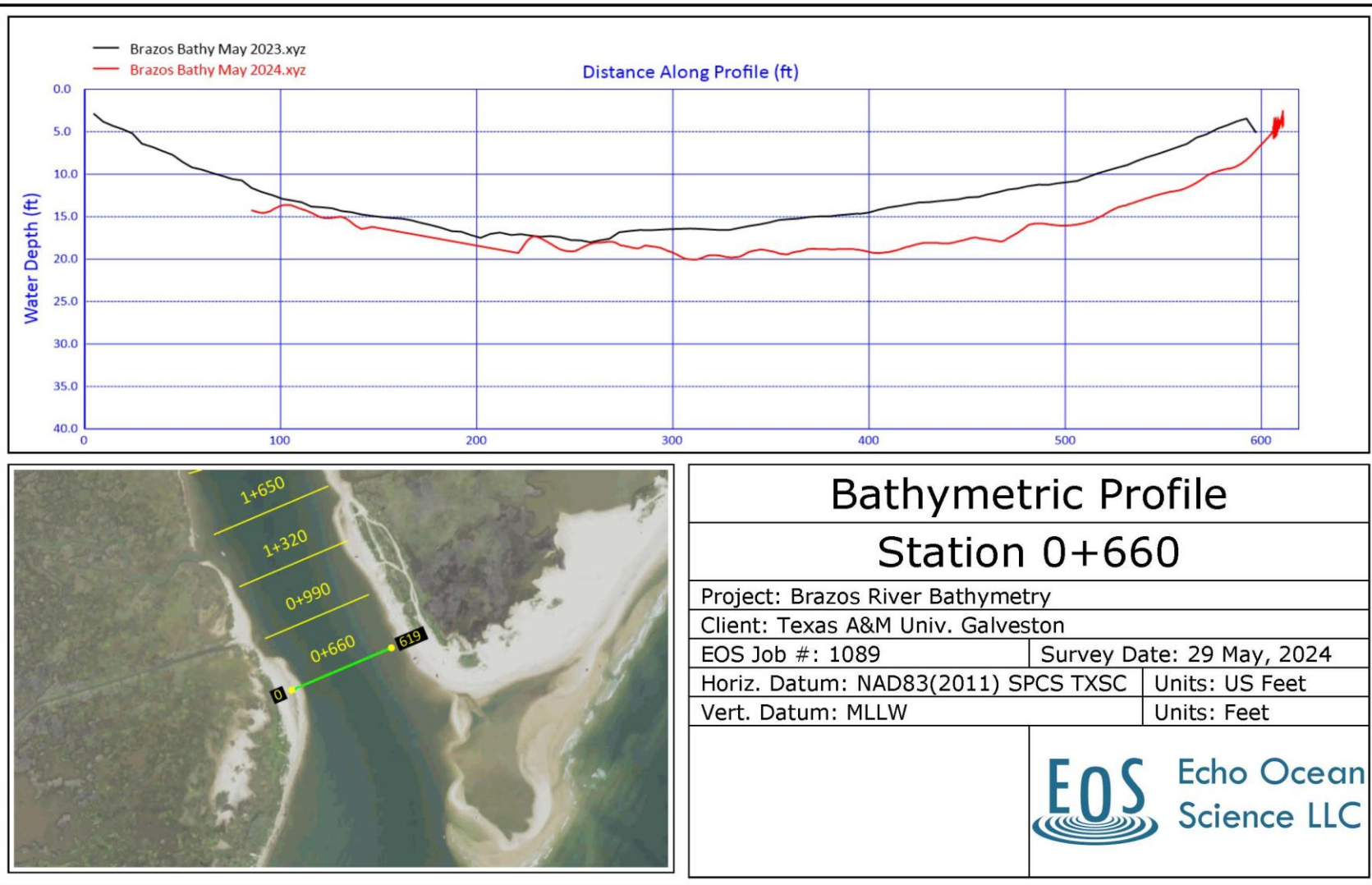


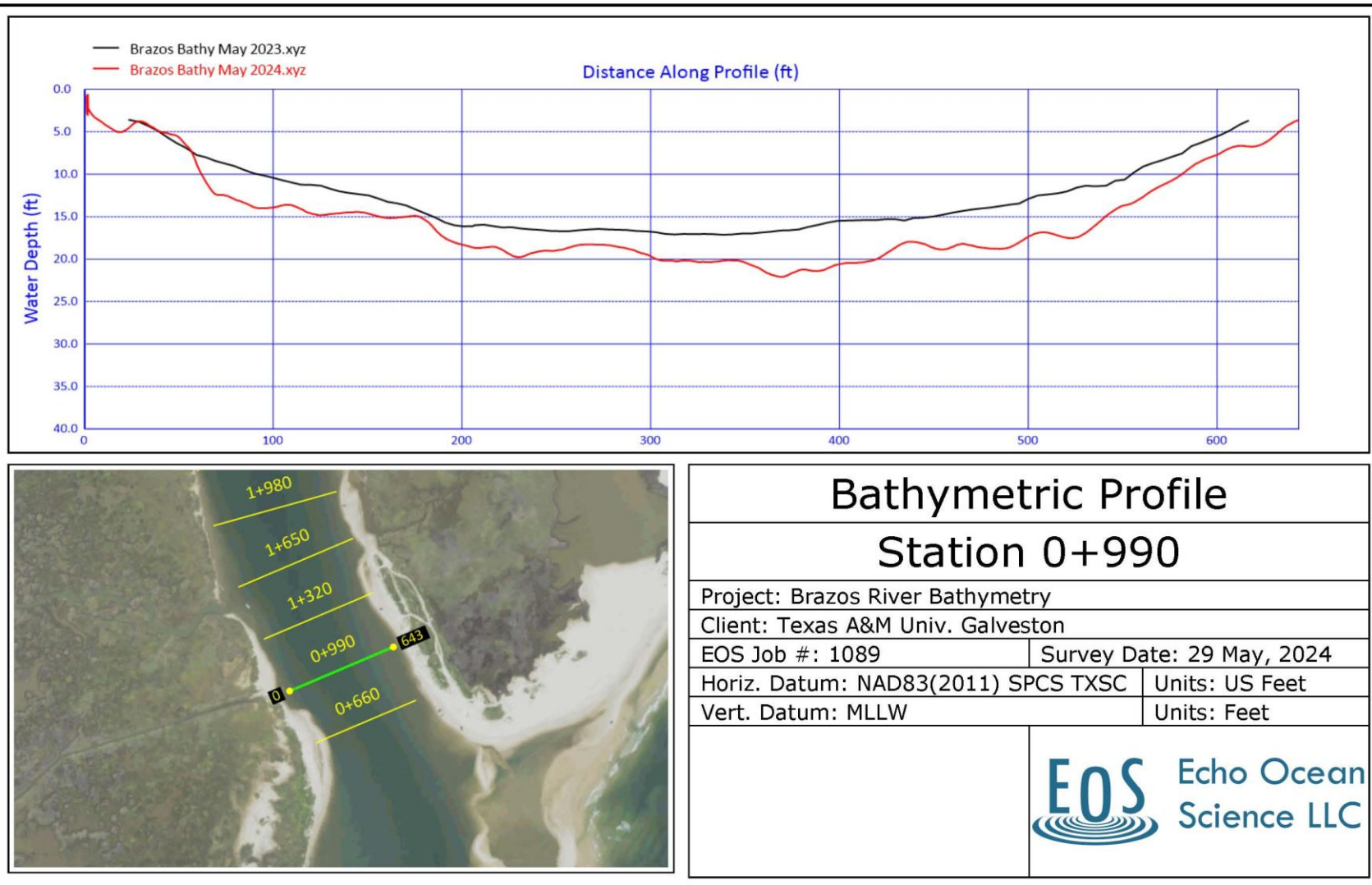


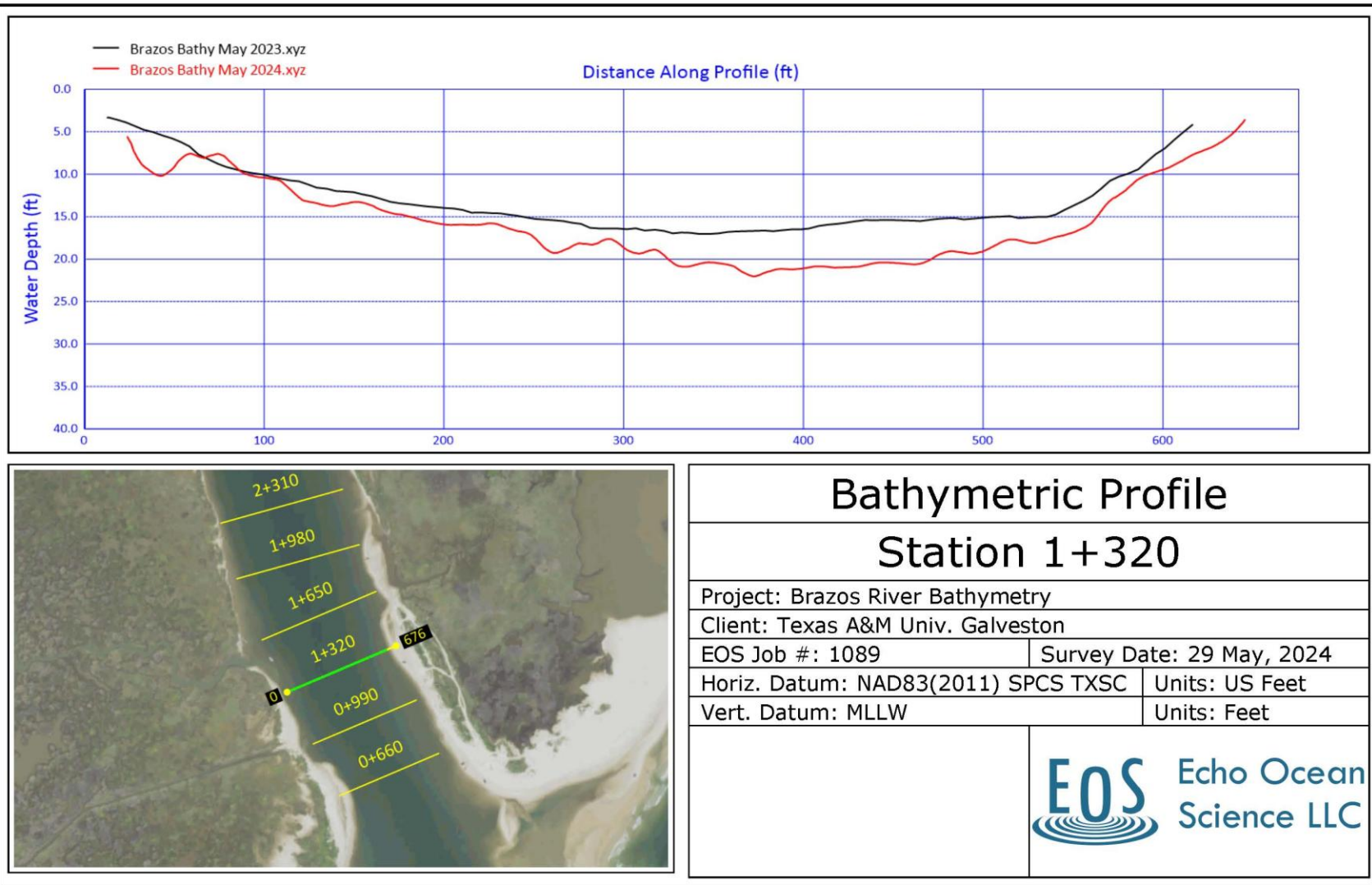


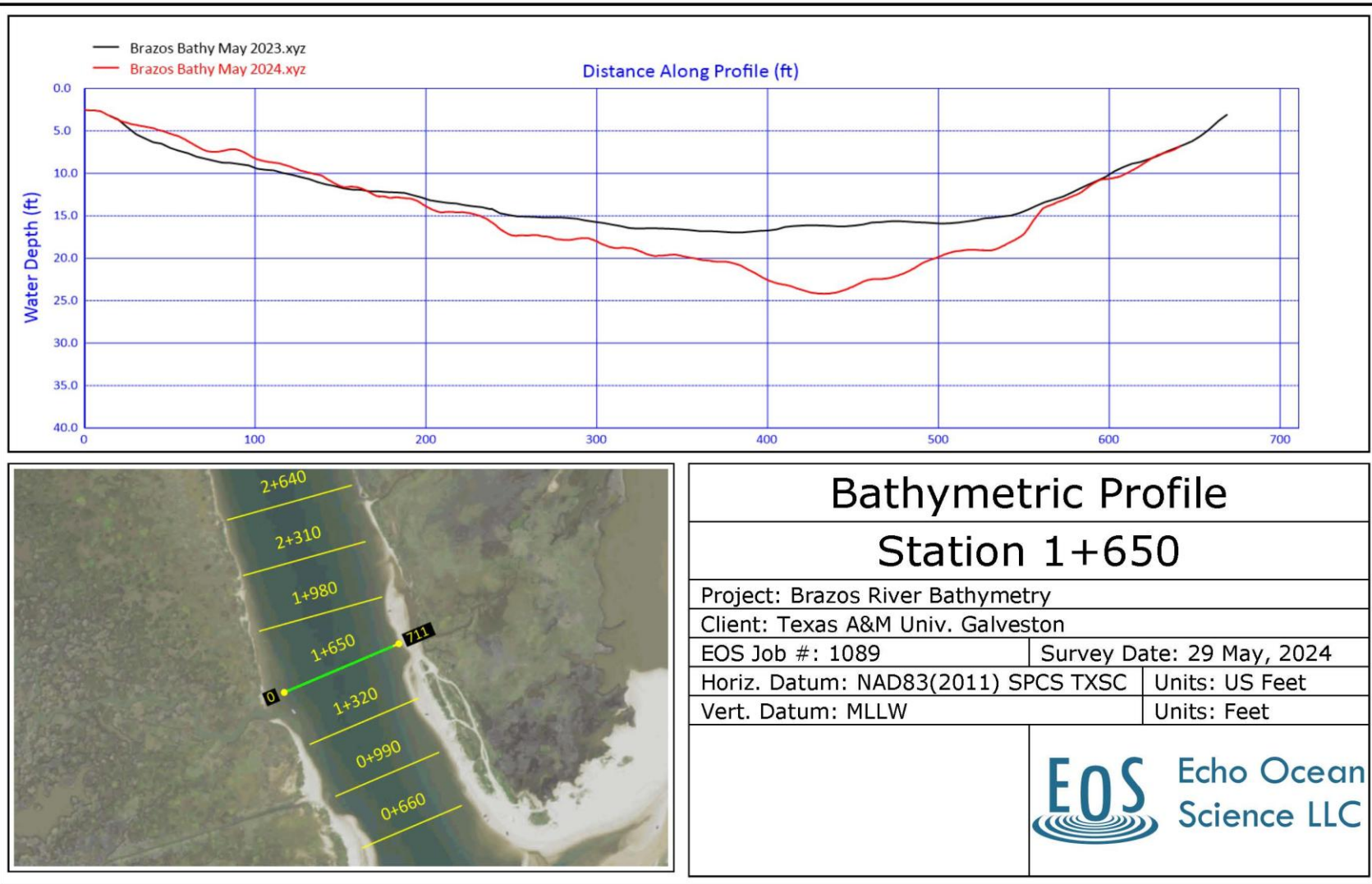


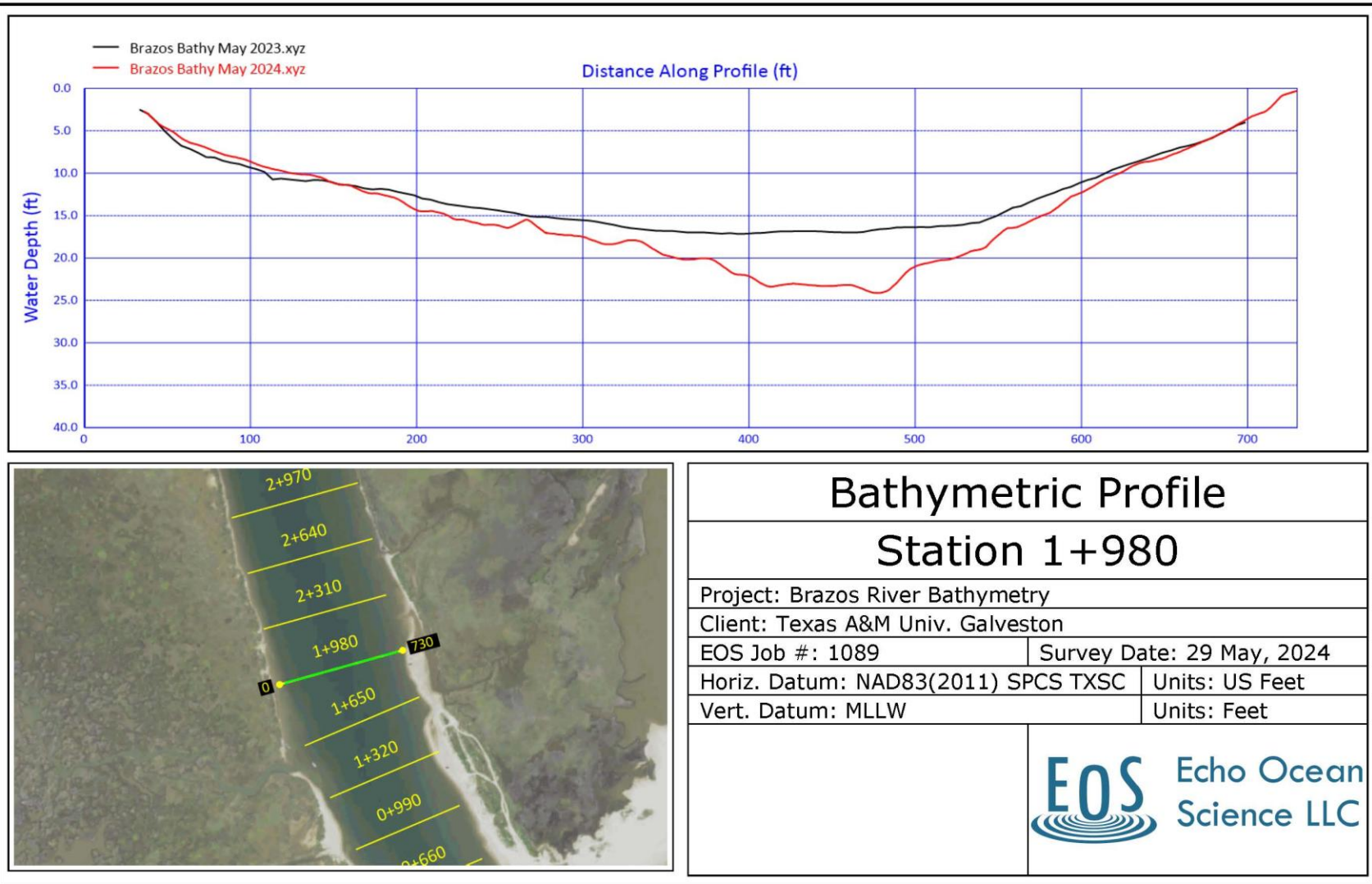
Appendix D: Brazos River Bathymetry

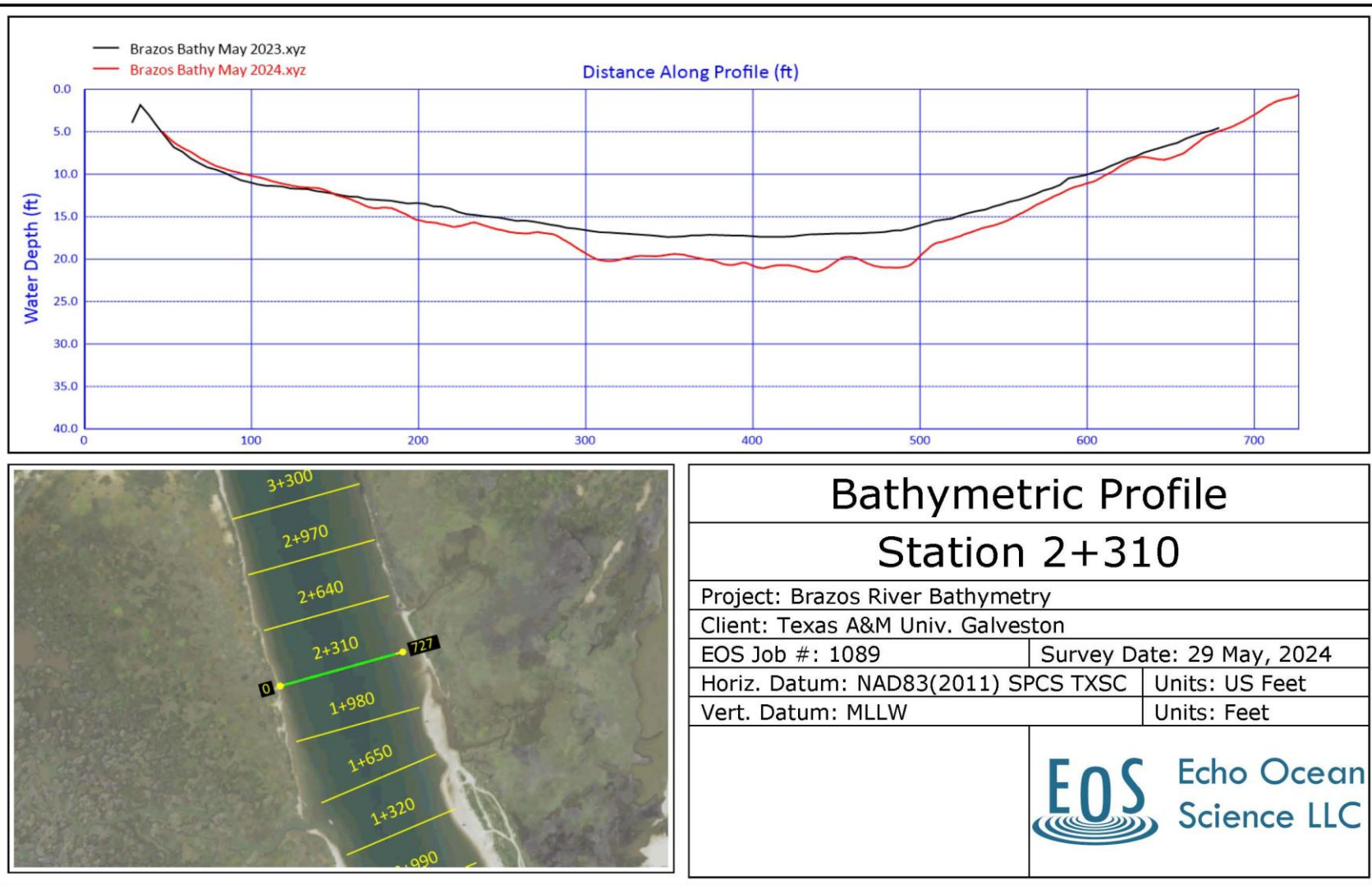


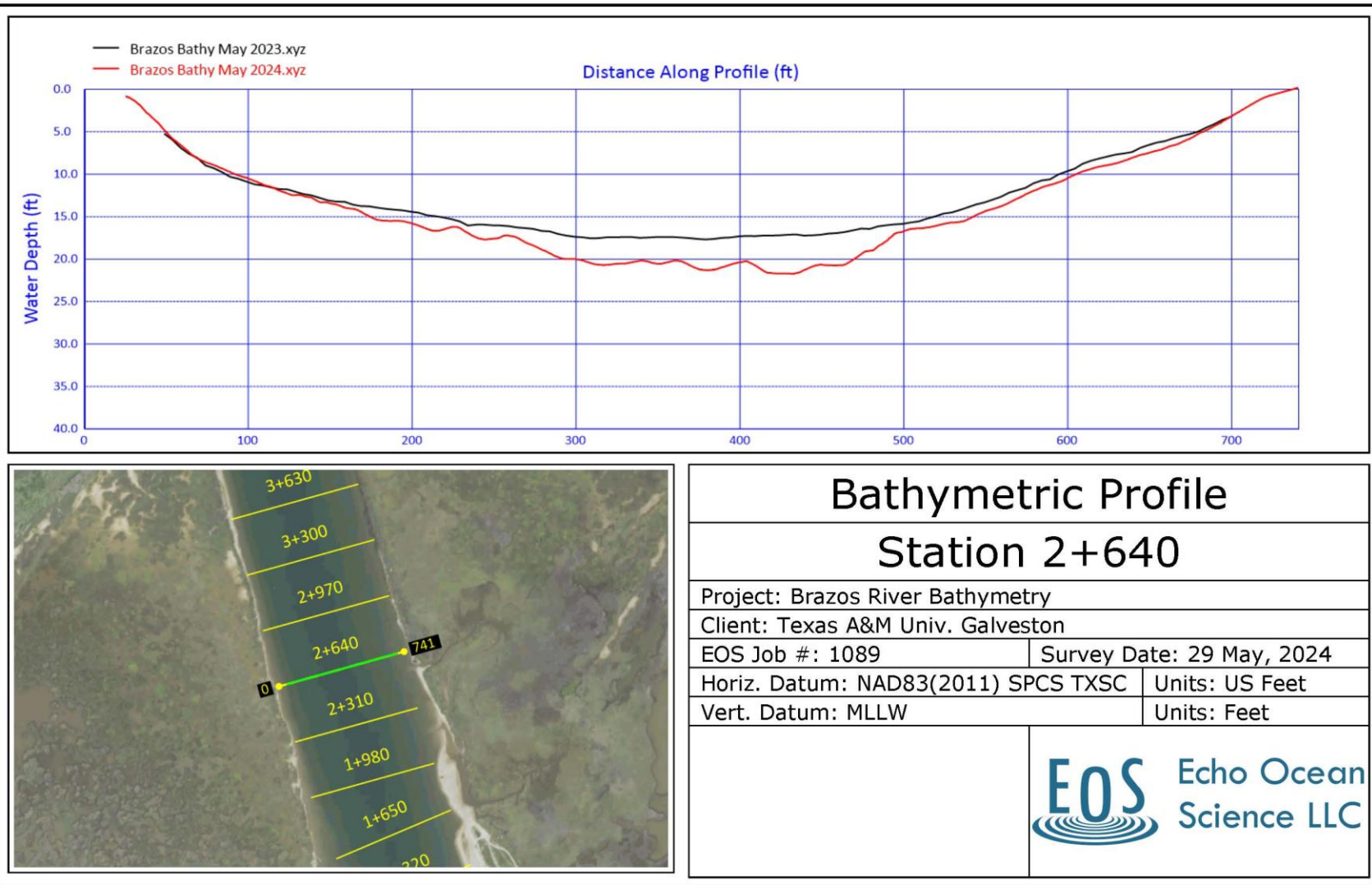


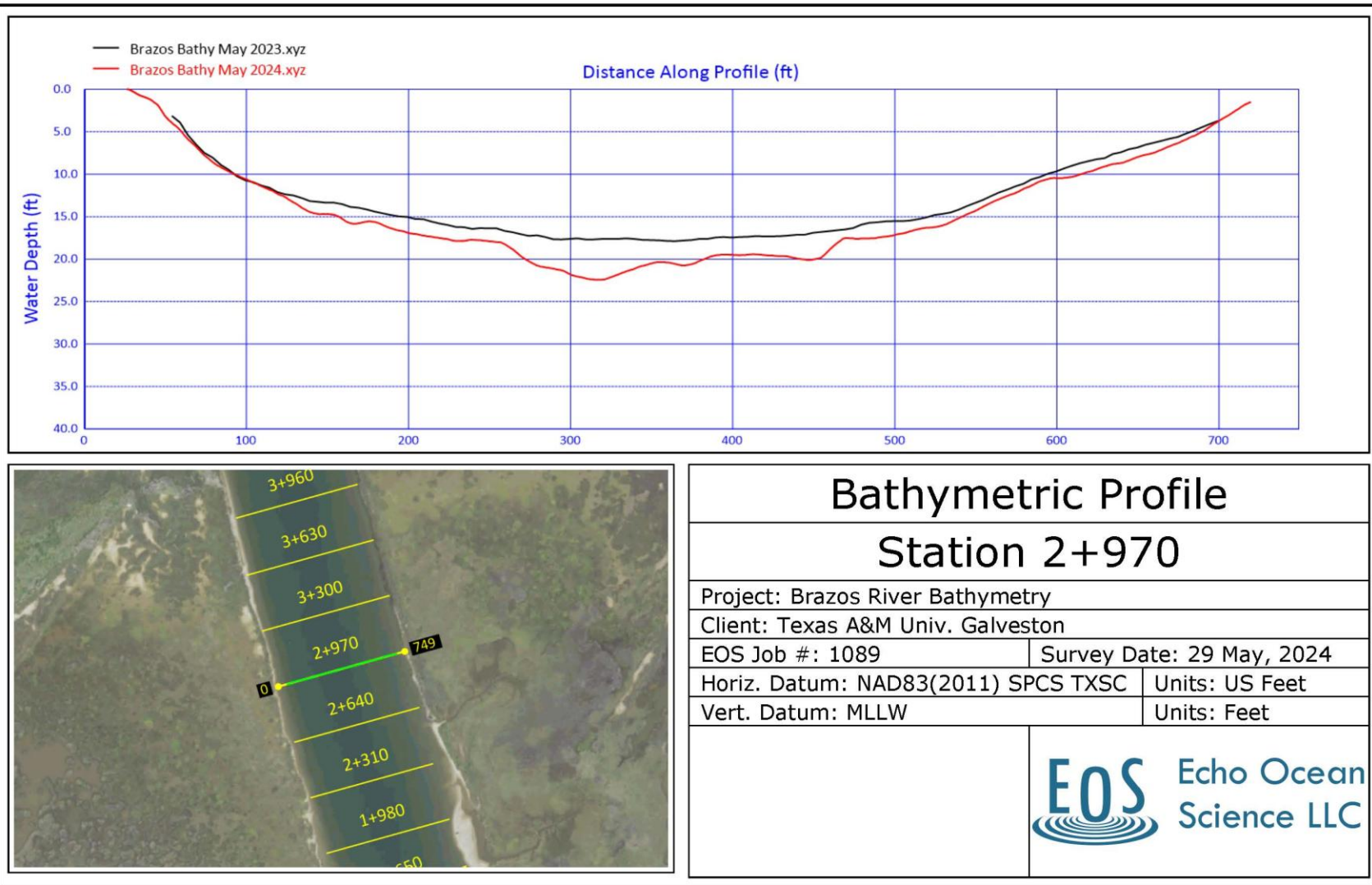


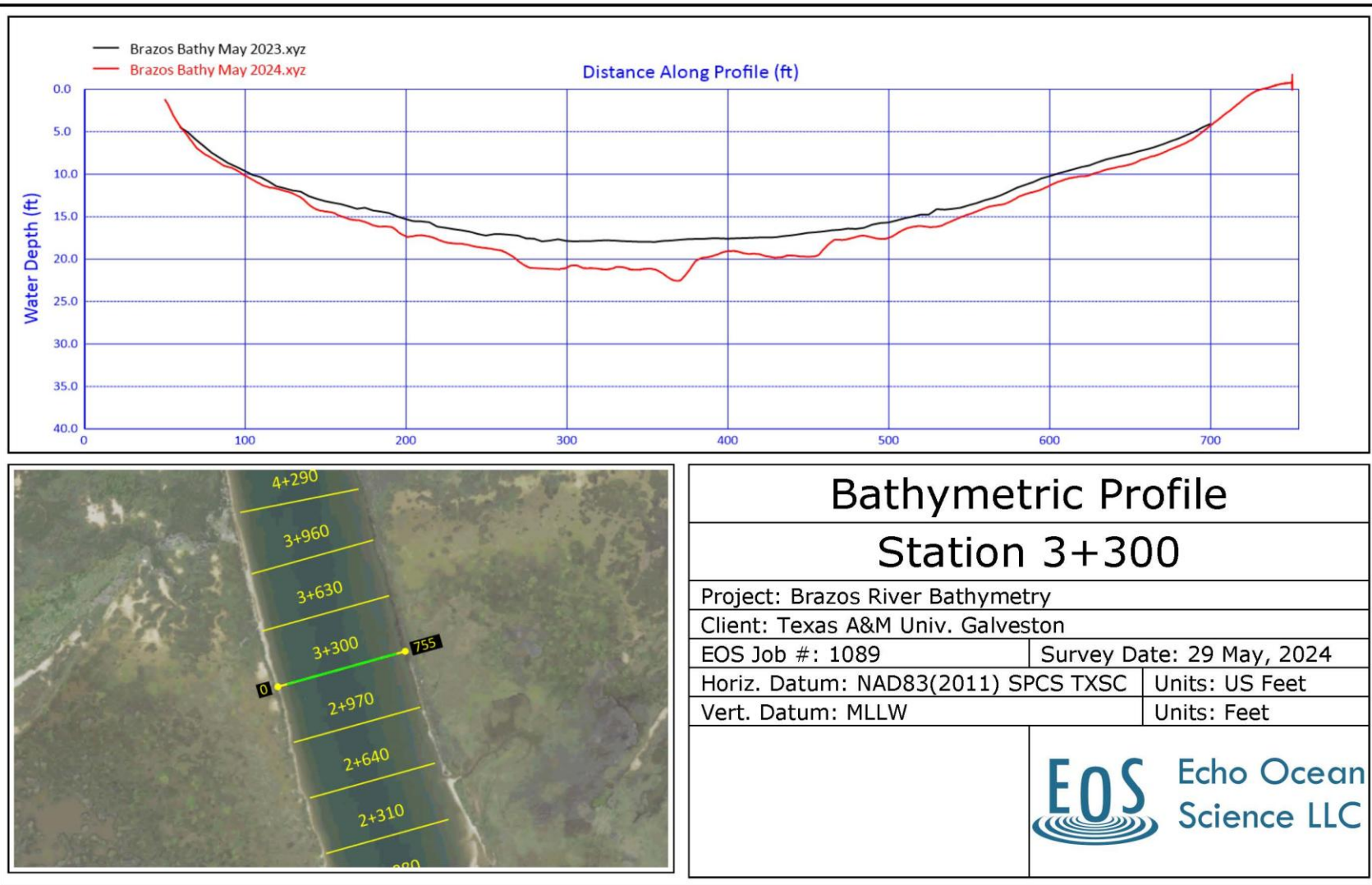


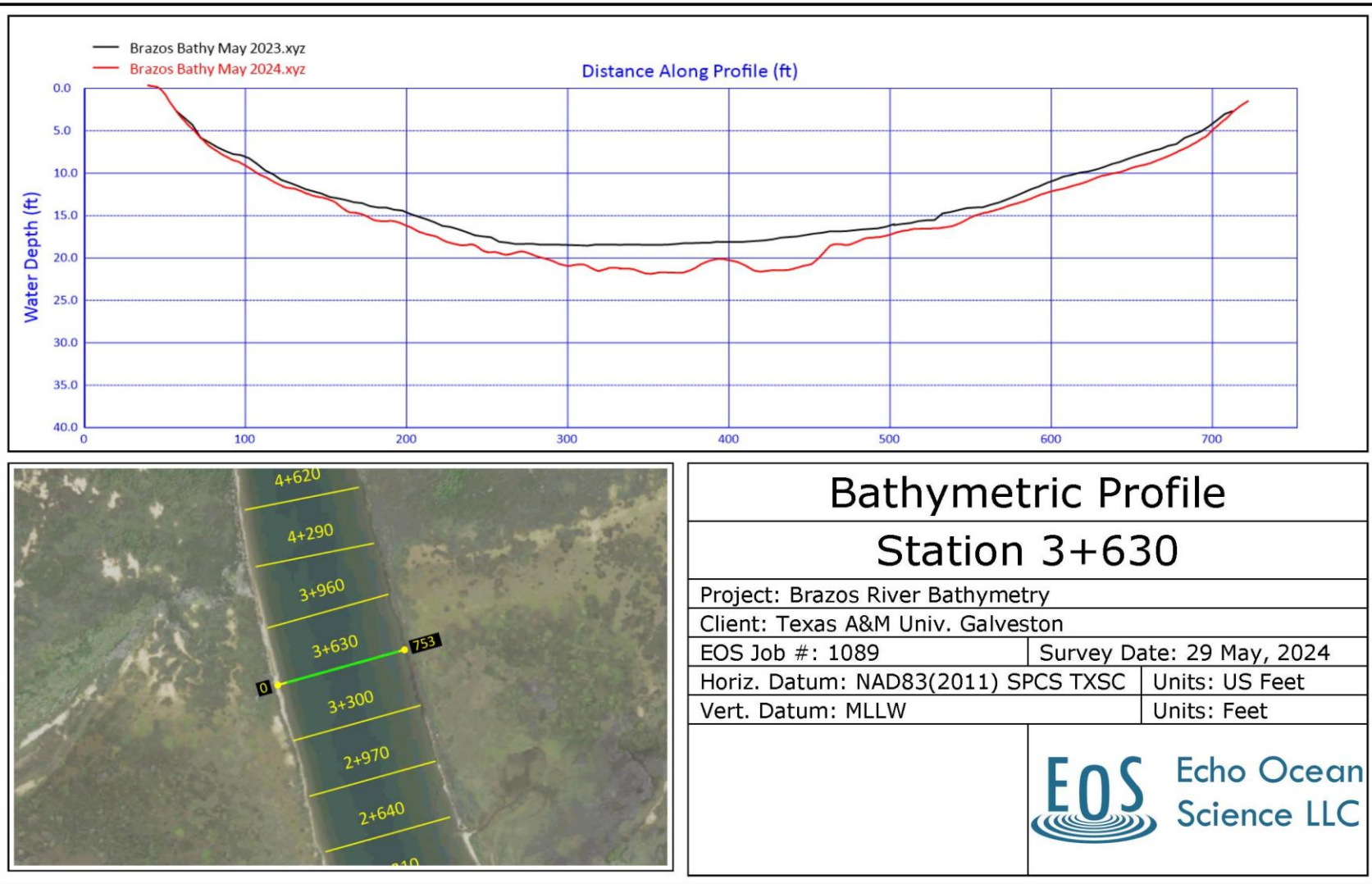


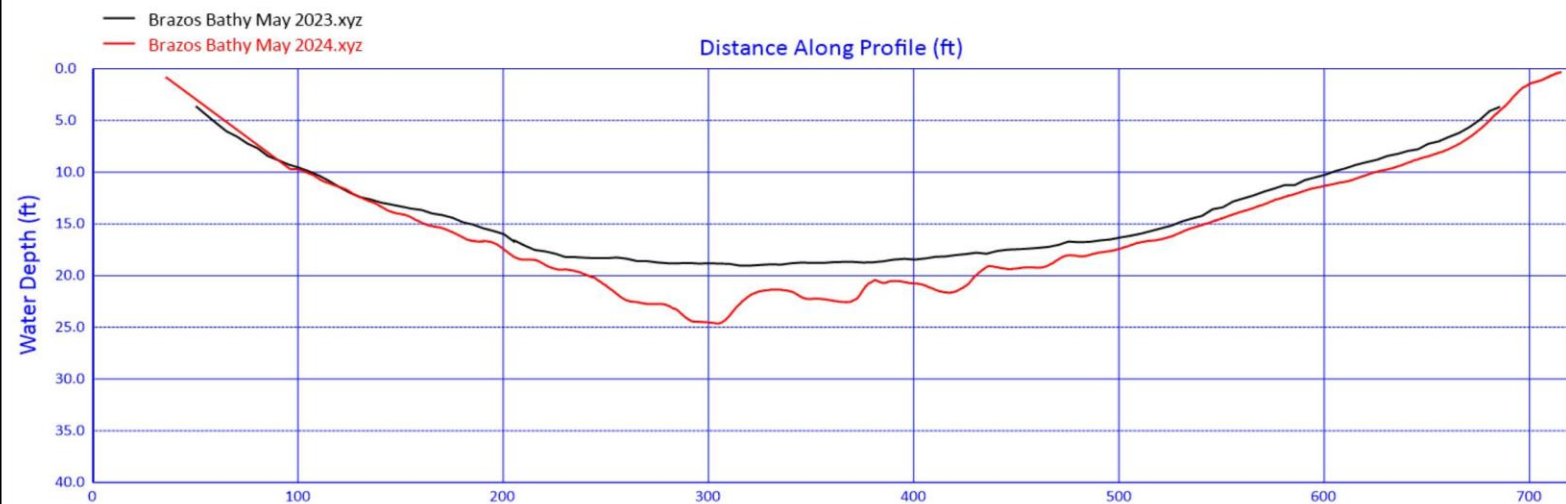












Bathymetric Profile

Station 3+960

Project: Brazos River Bathymetry

Client: Texas A&M Univ. Galveston

EOS Job #: 1089

Survey Date: 29 May, 2024

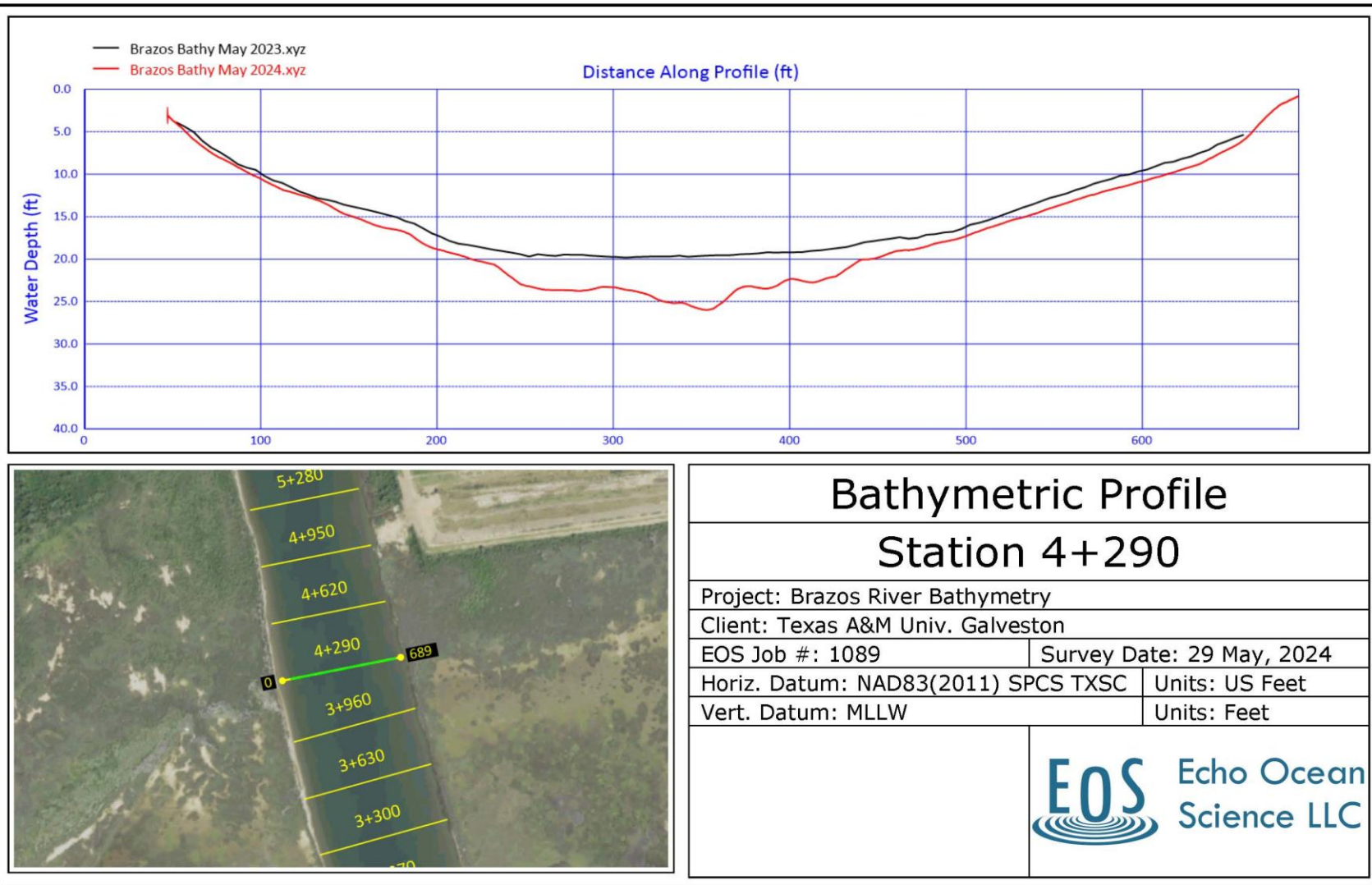
Horiz. Datum: NAD83(2011) SPCS TXSC

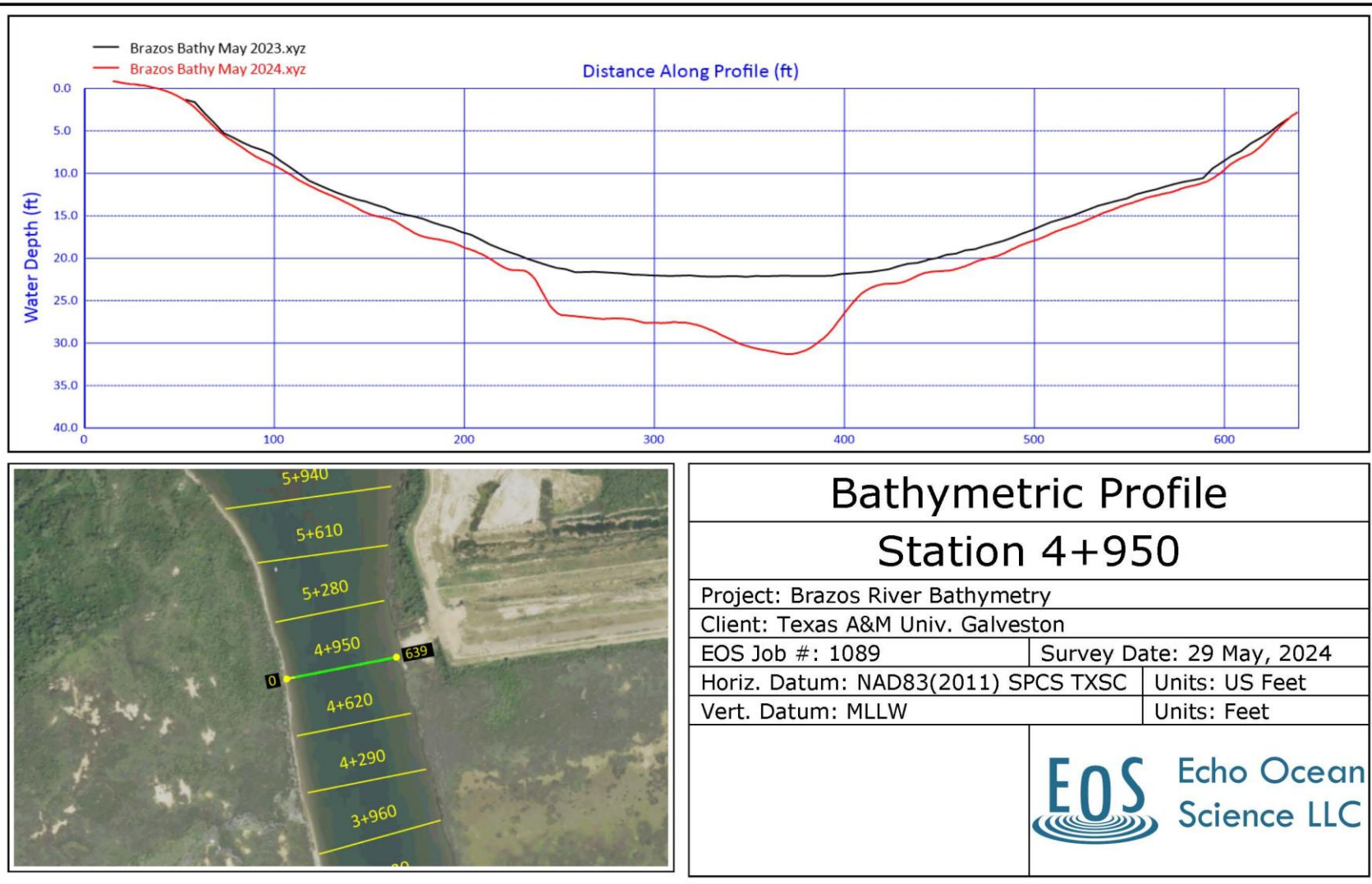
Units: US Feet

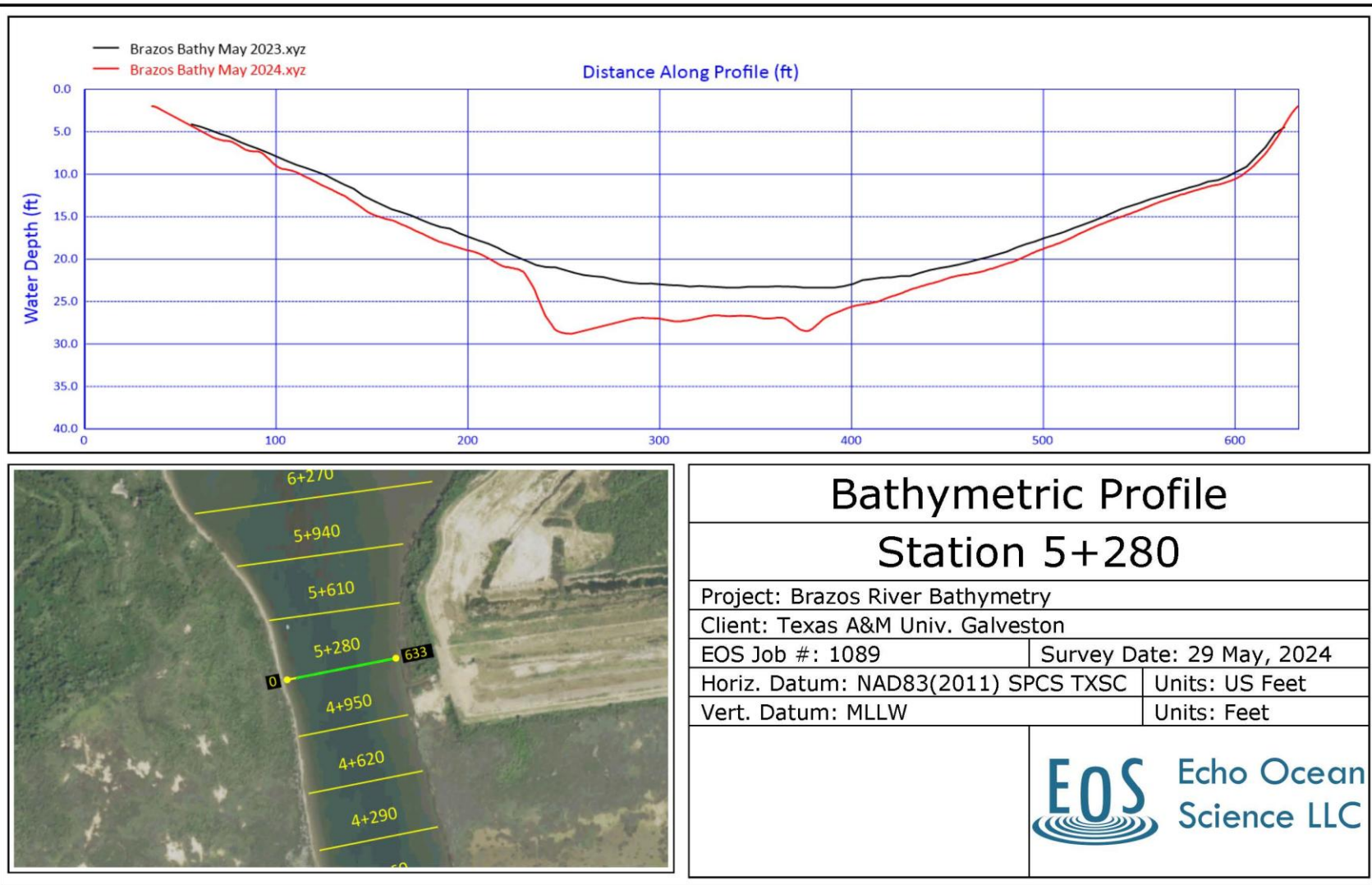
Vert. Datum: MLLW

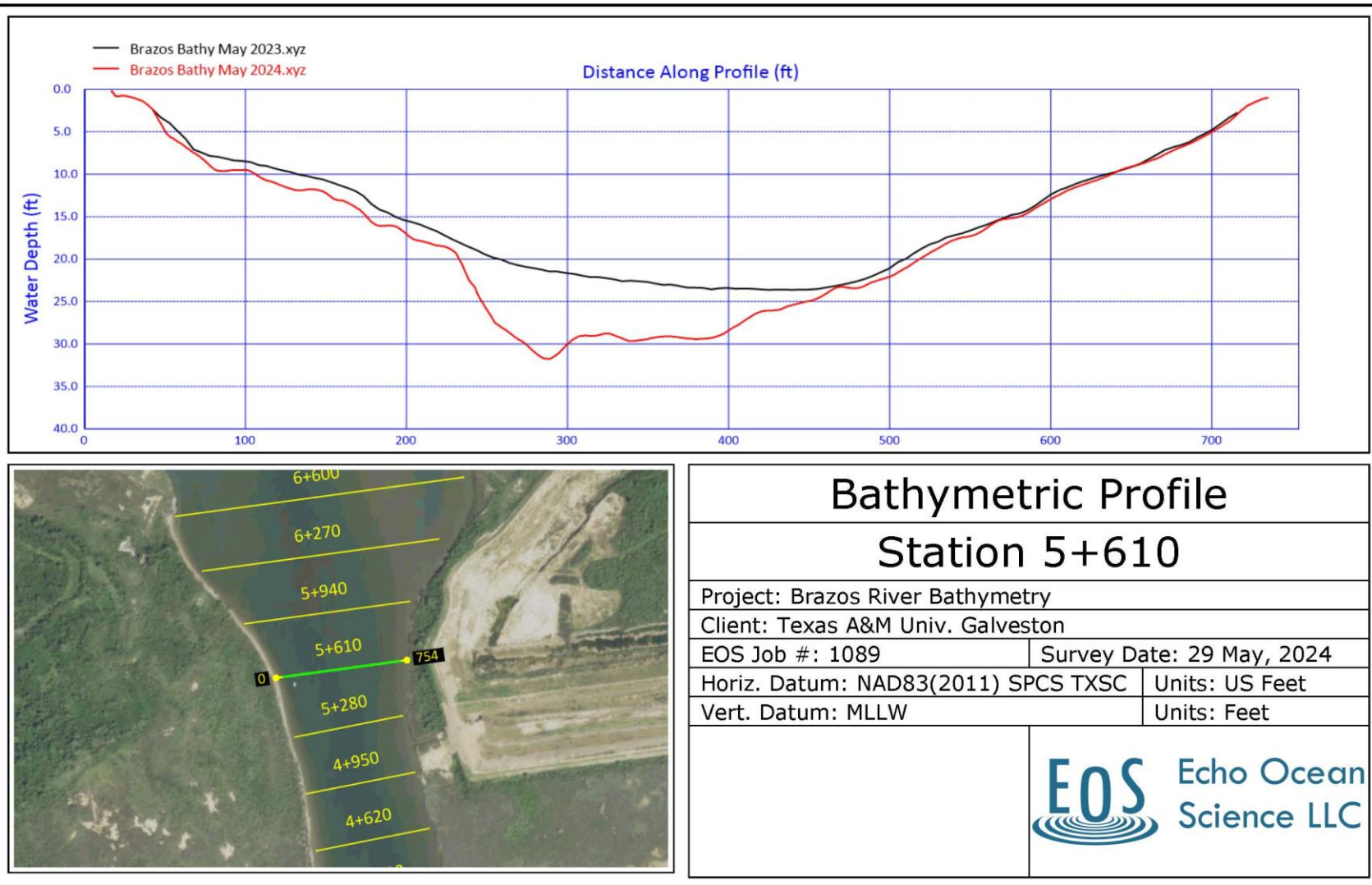
Units: Feet

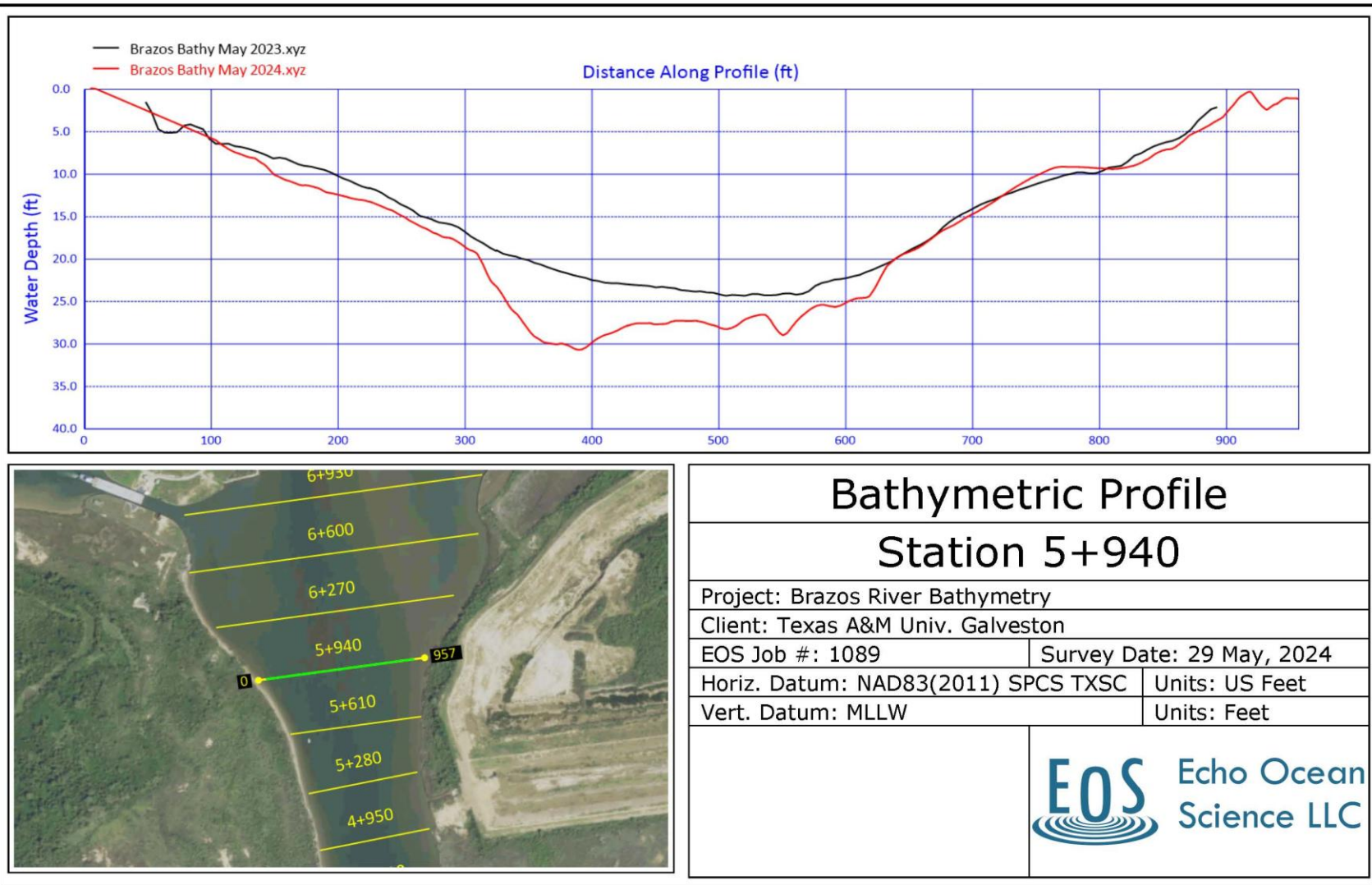


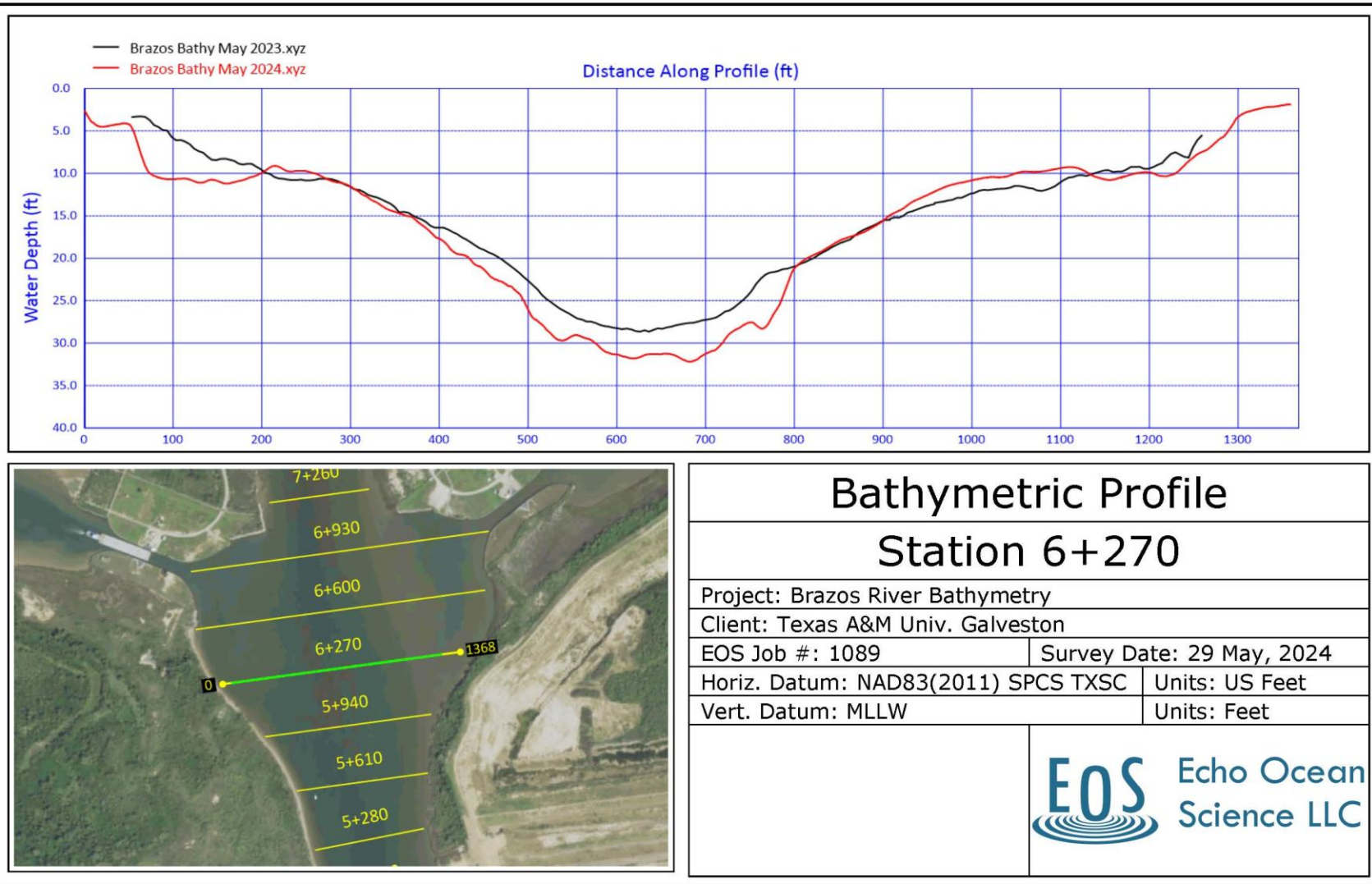


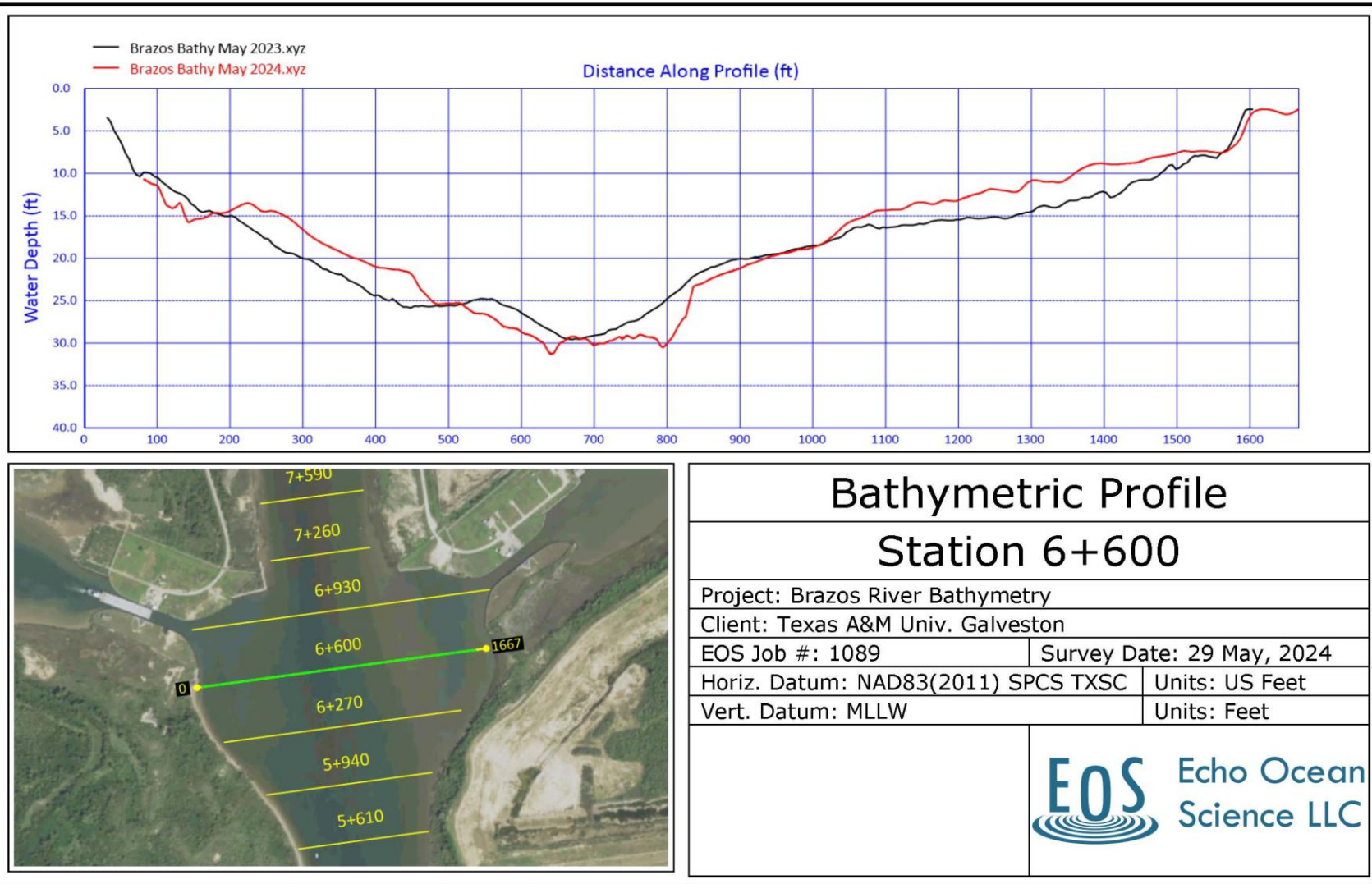


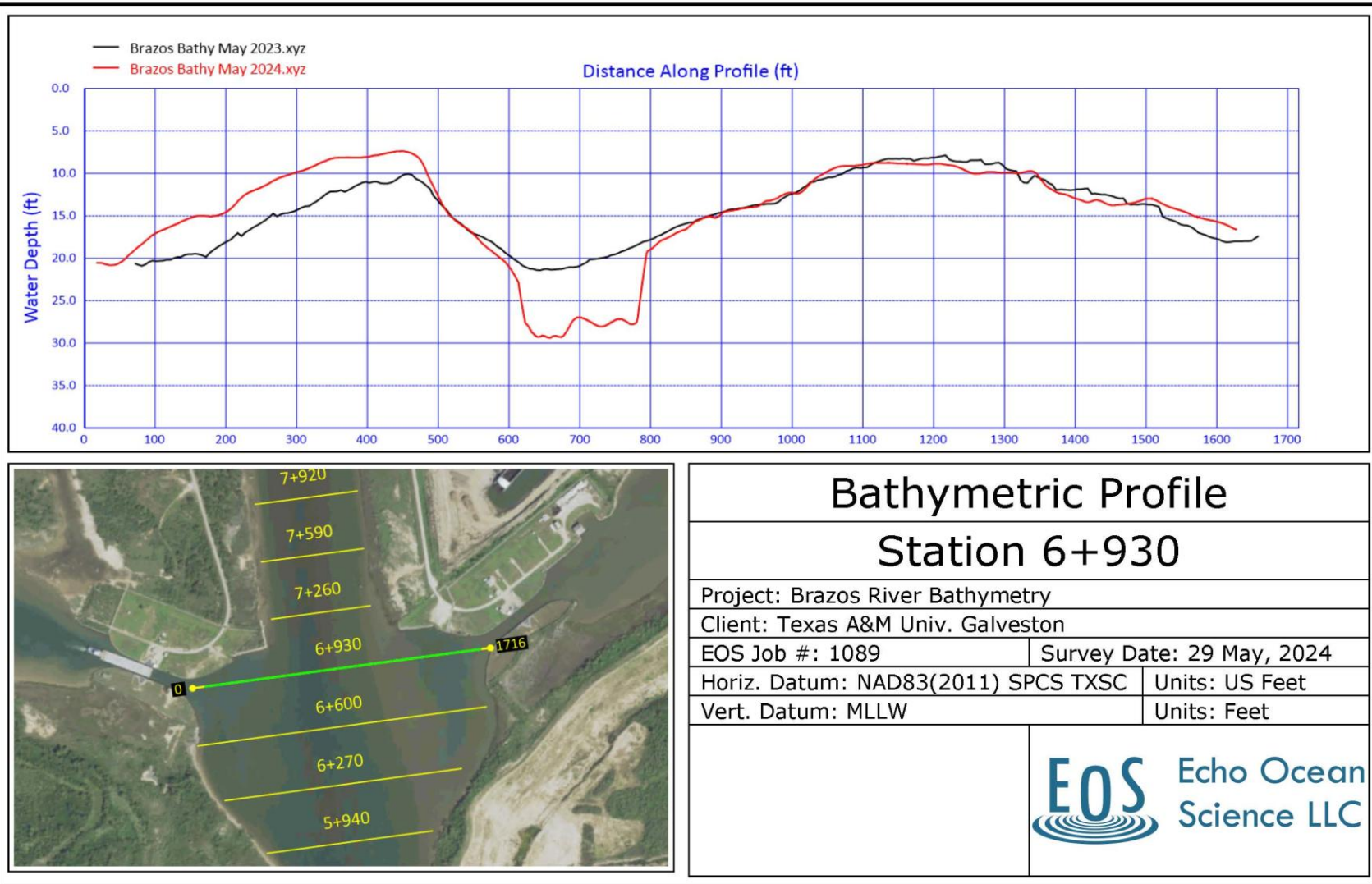


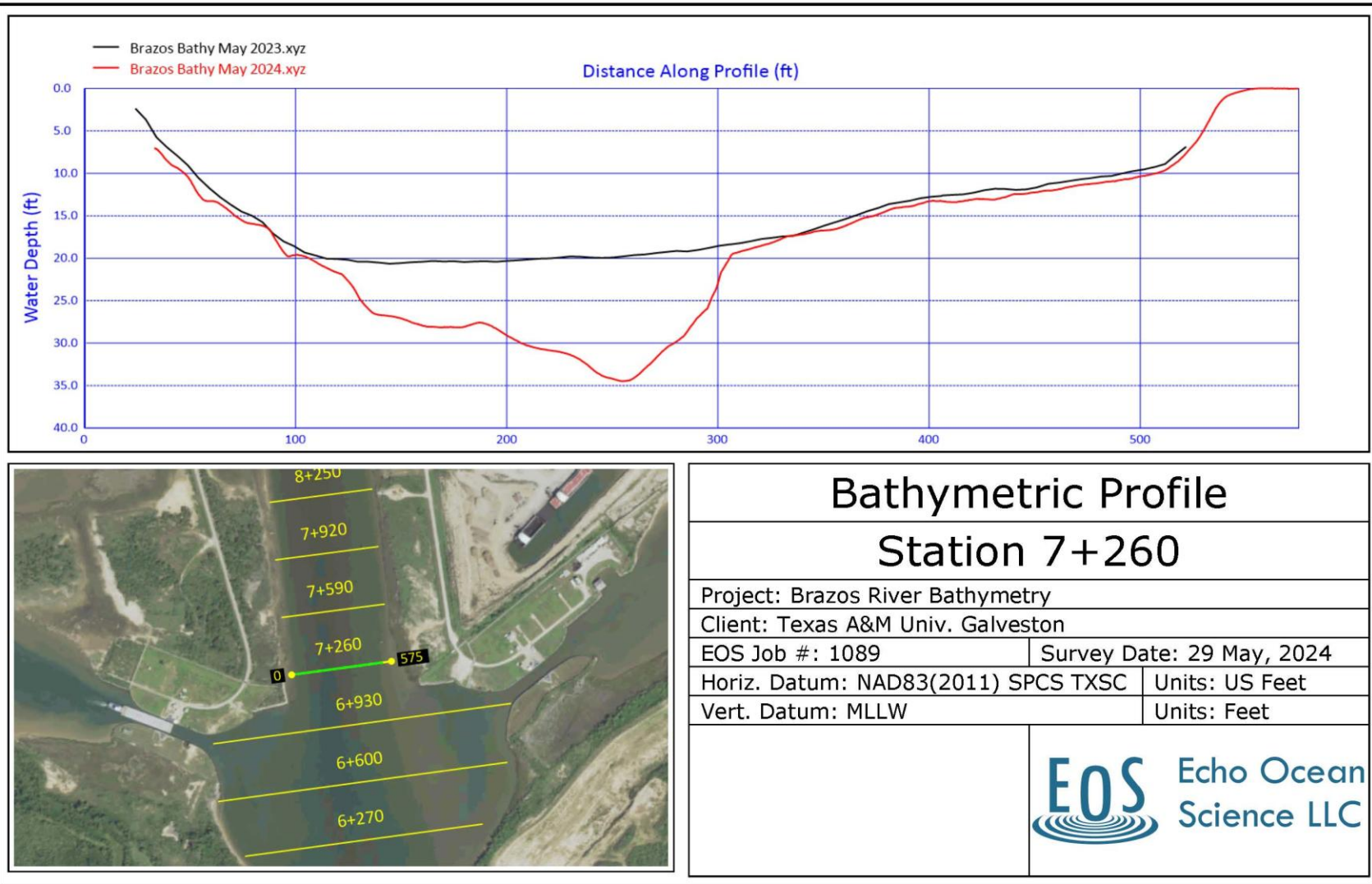


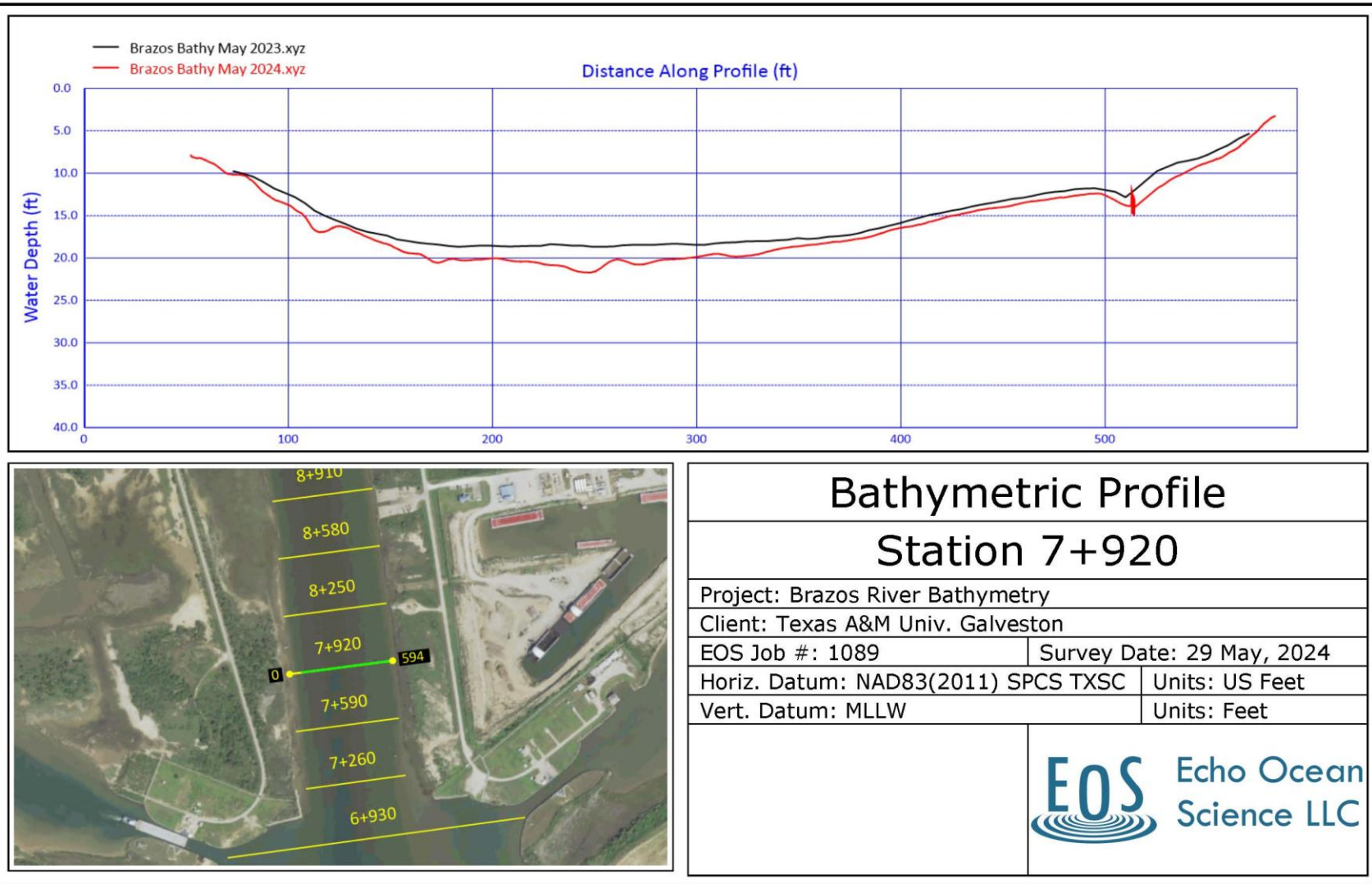


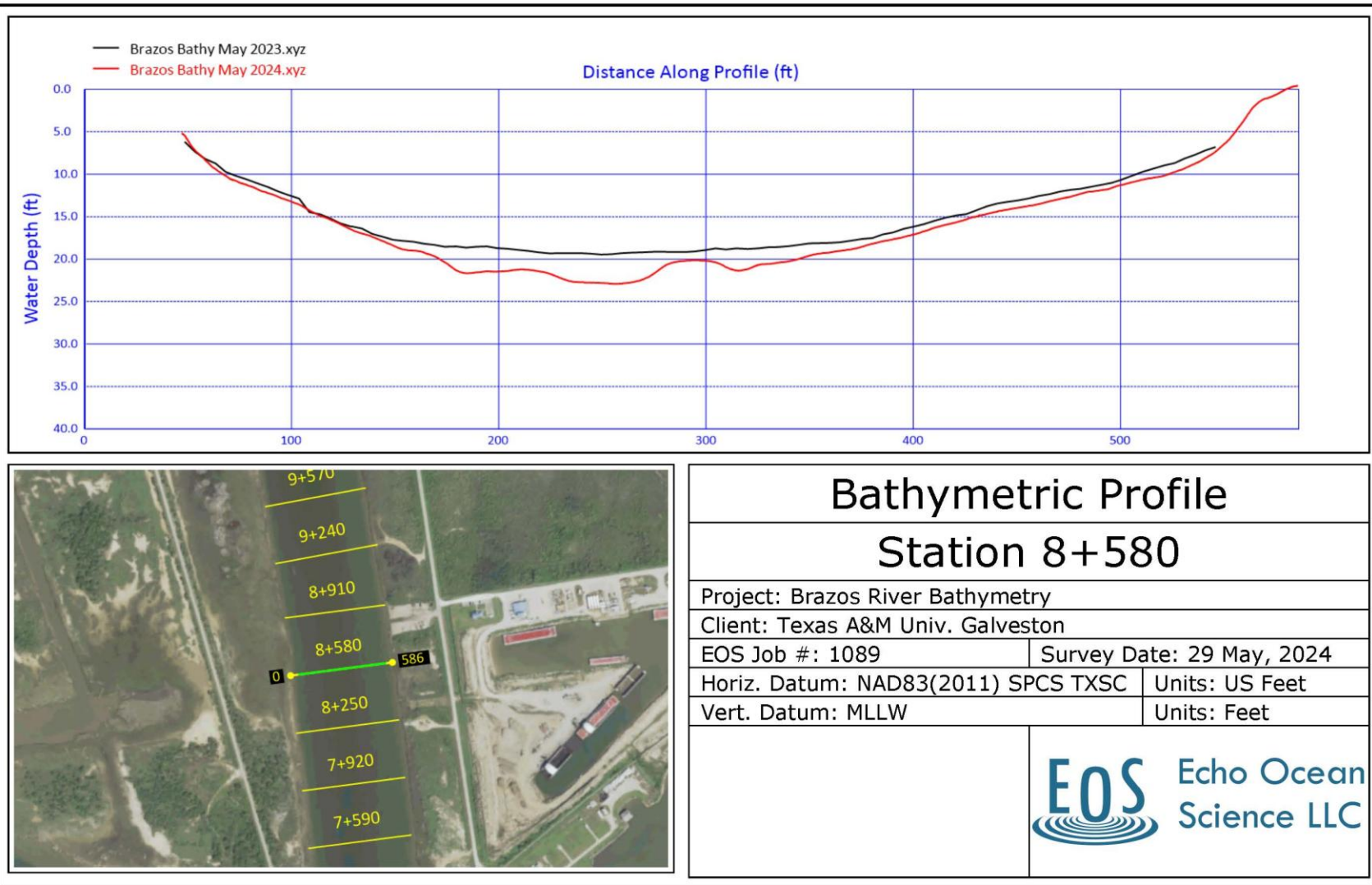


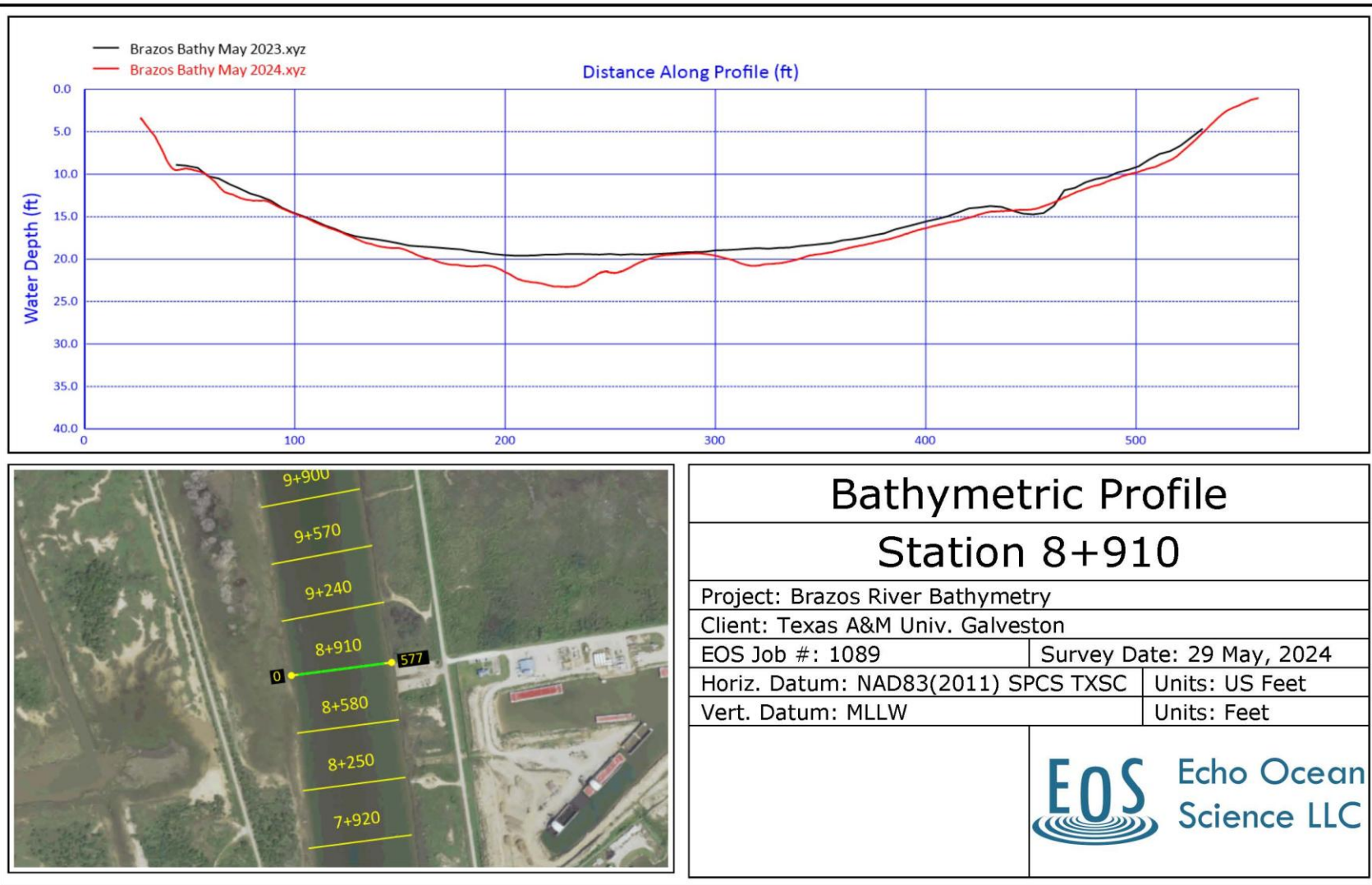


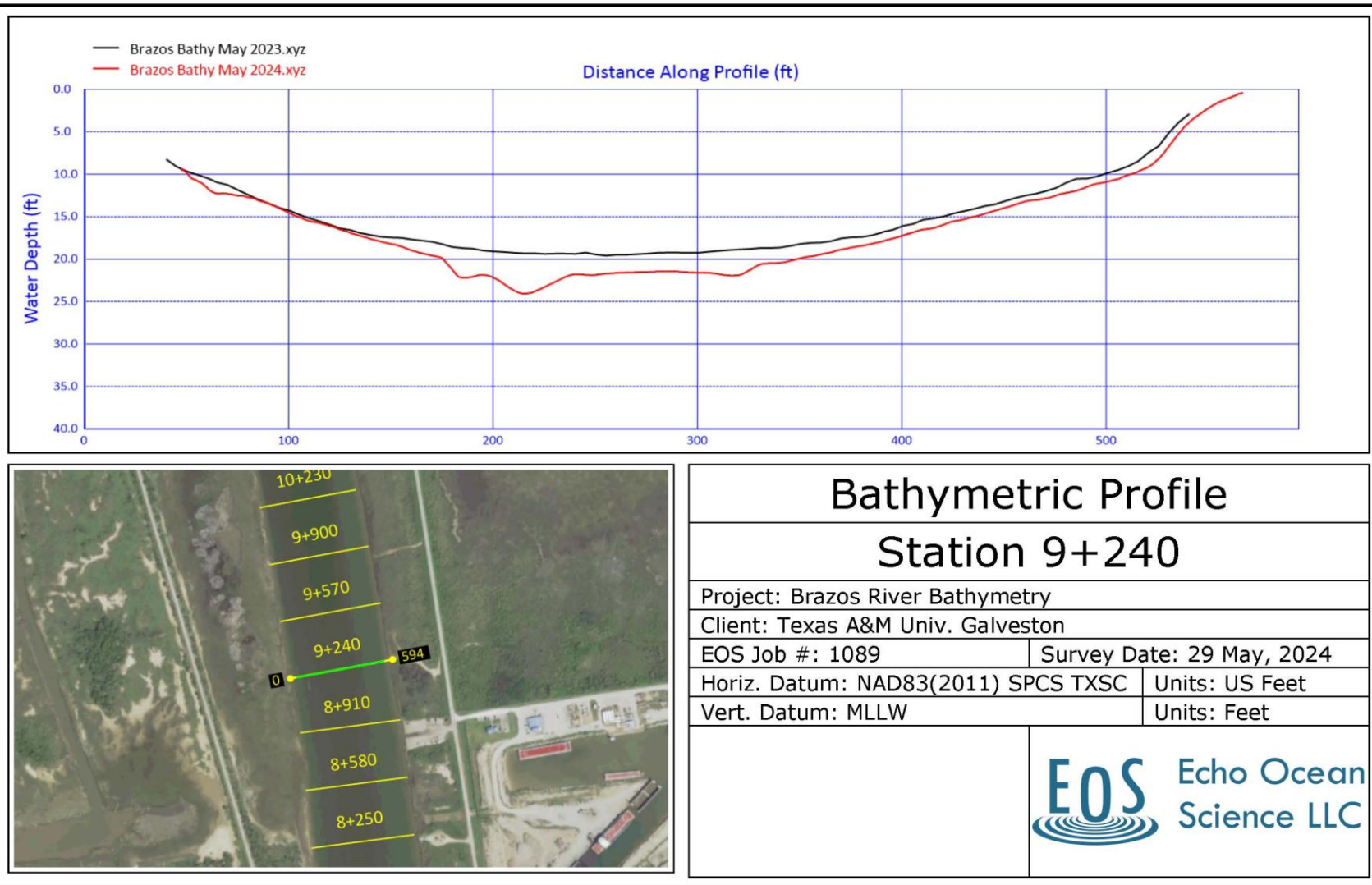


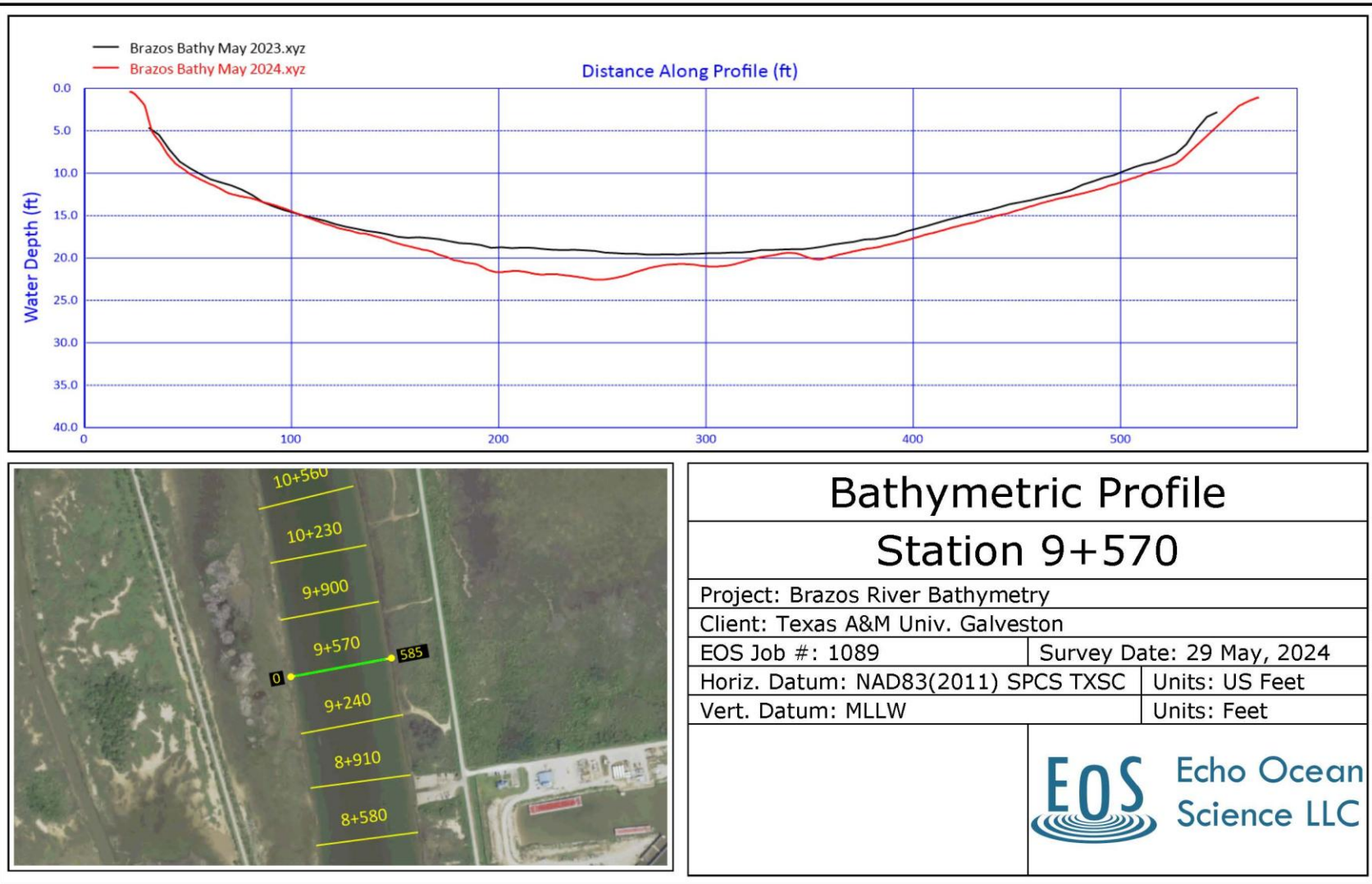


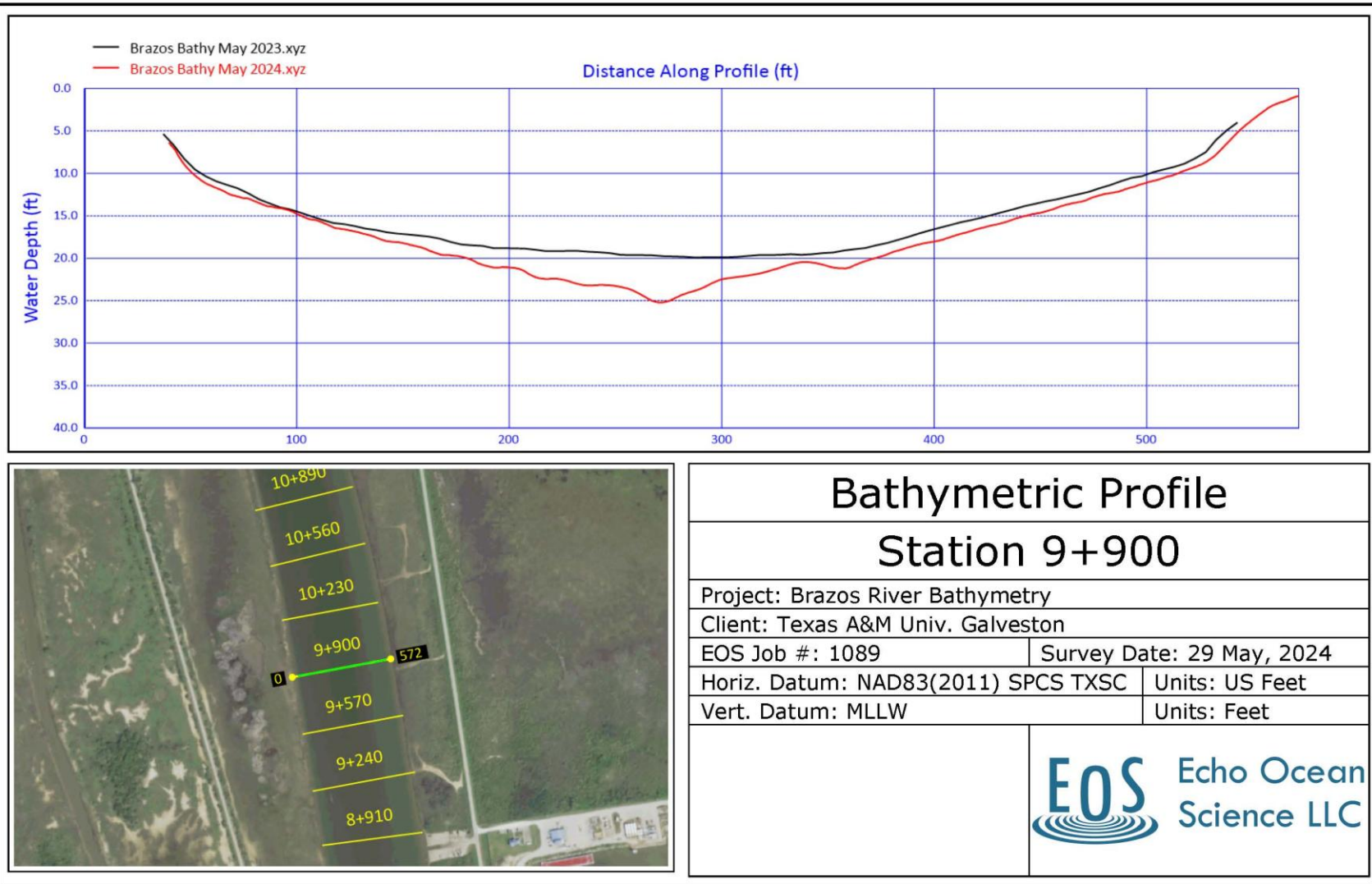


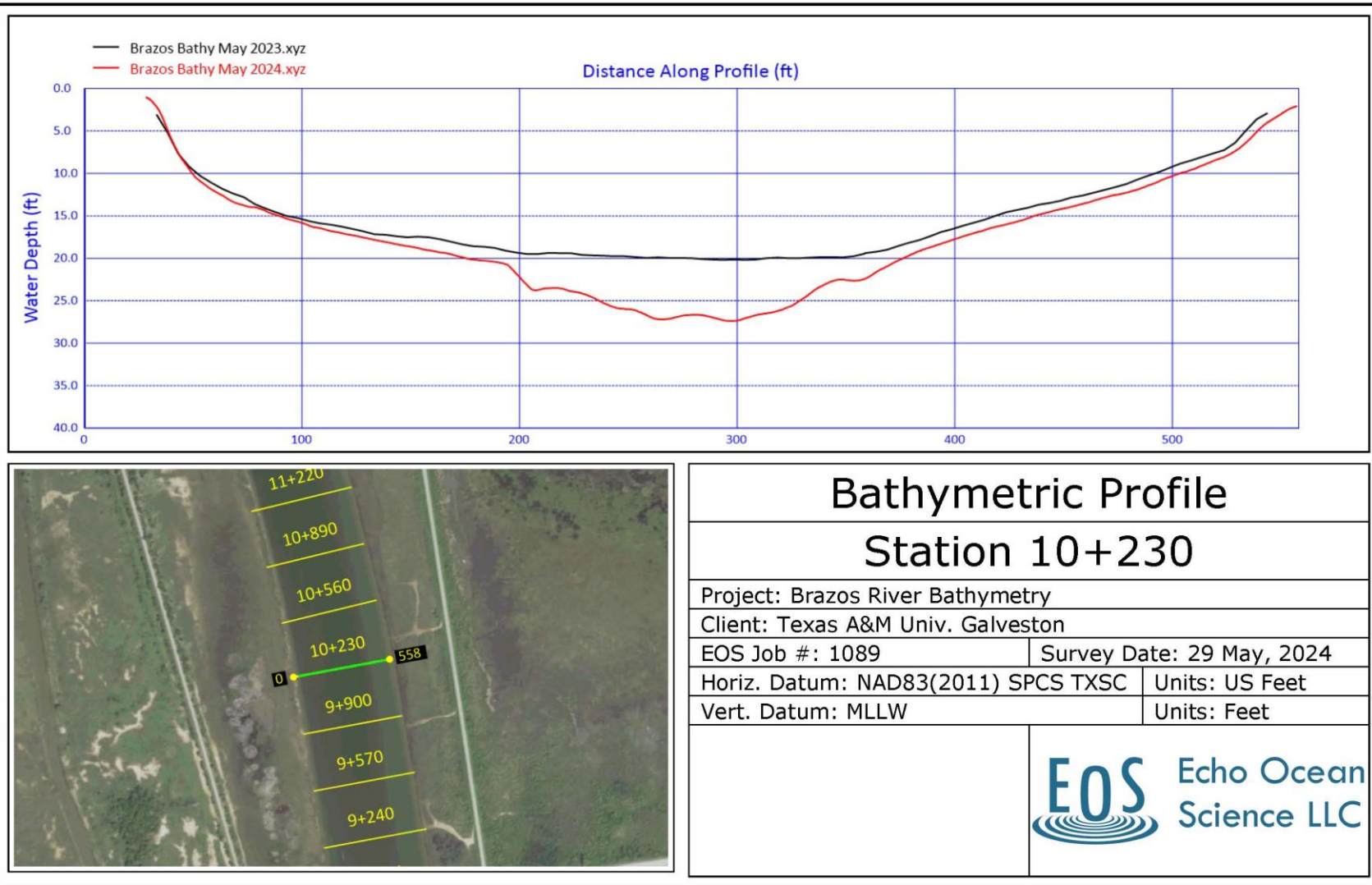


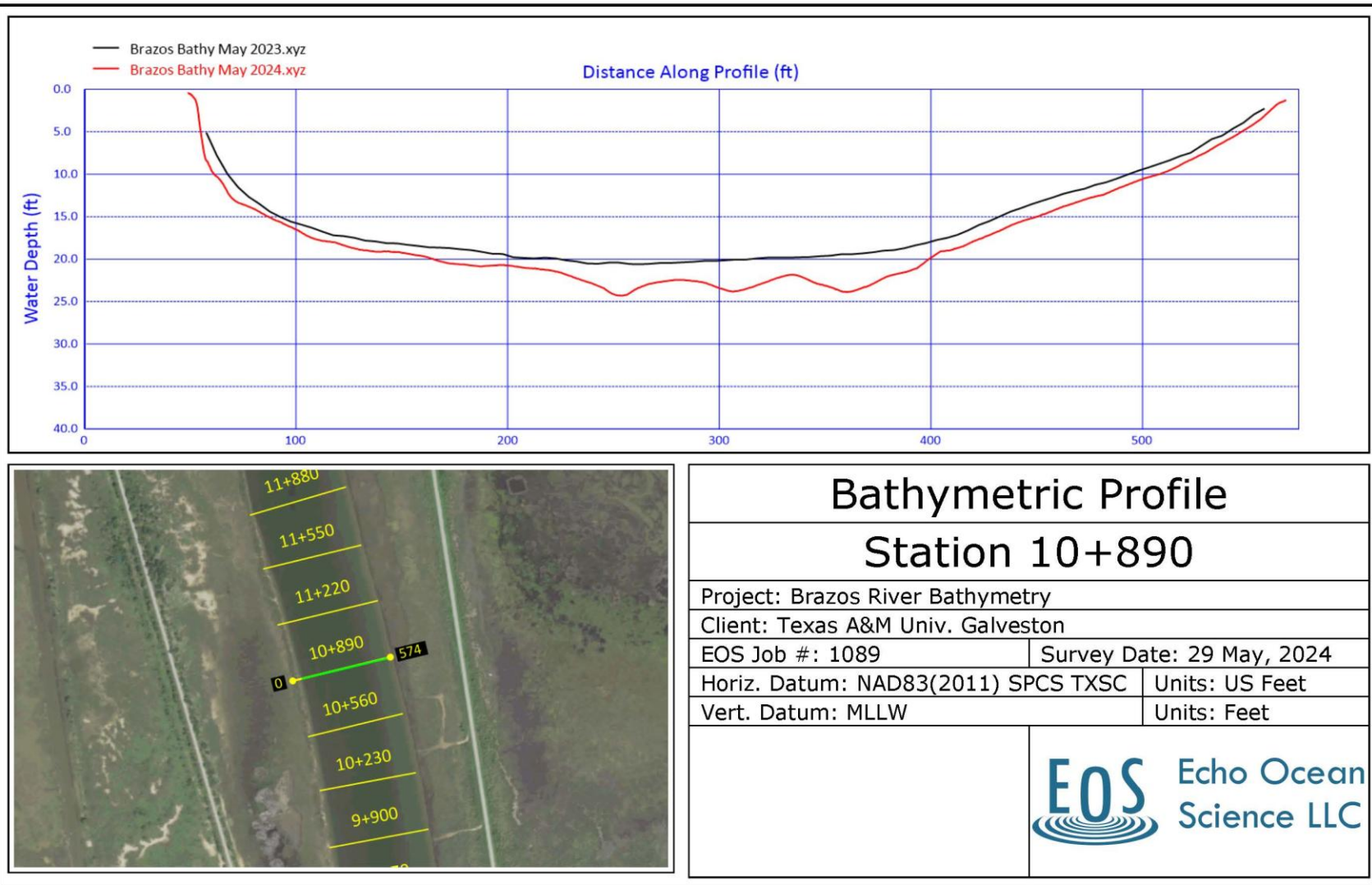


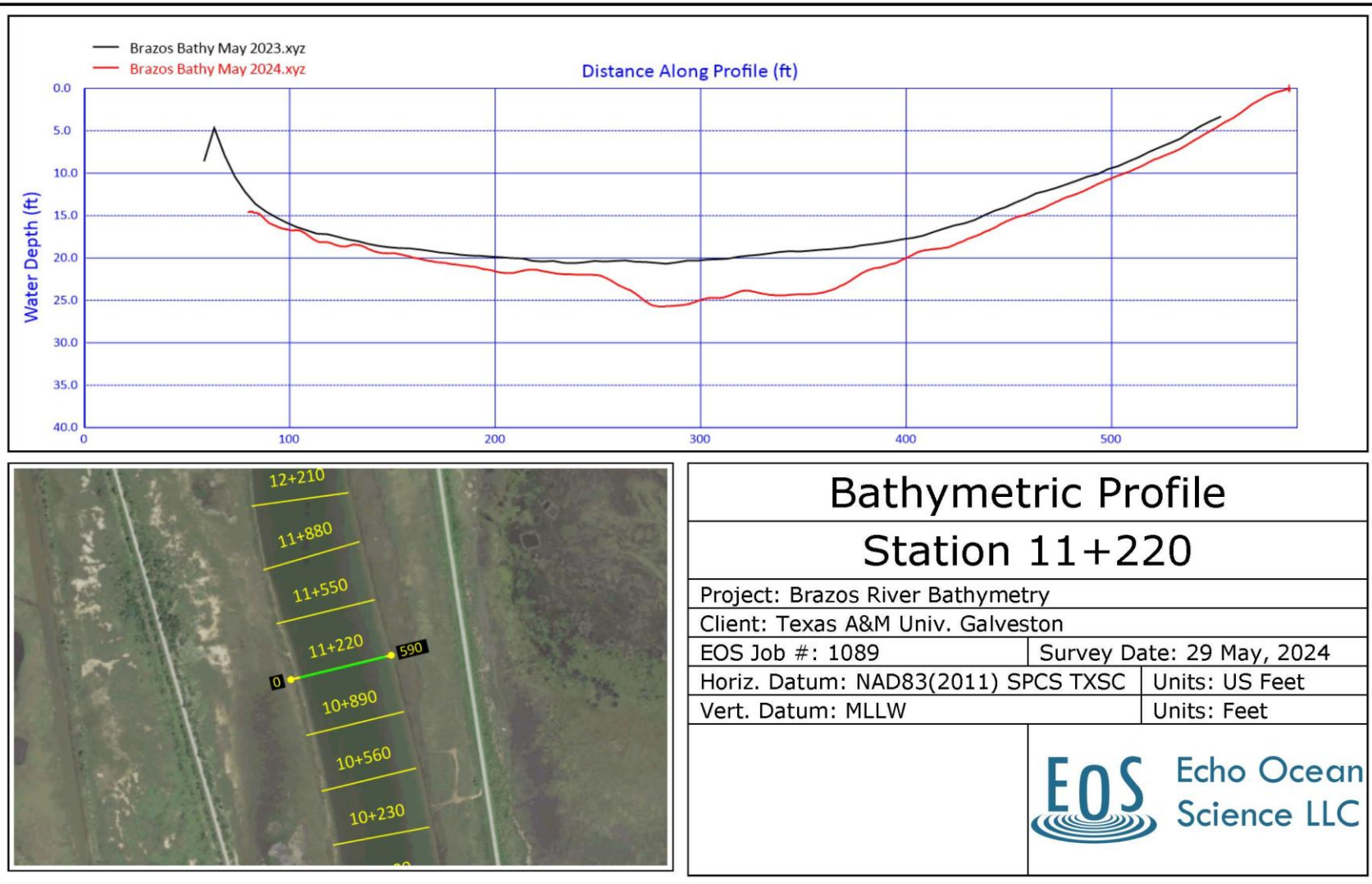


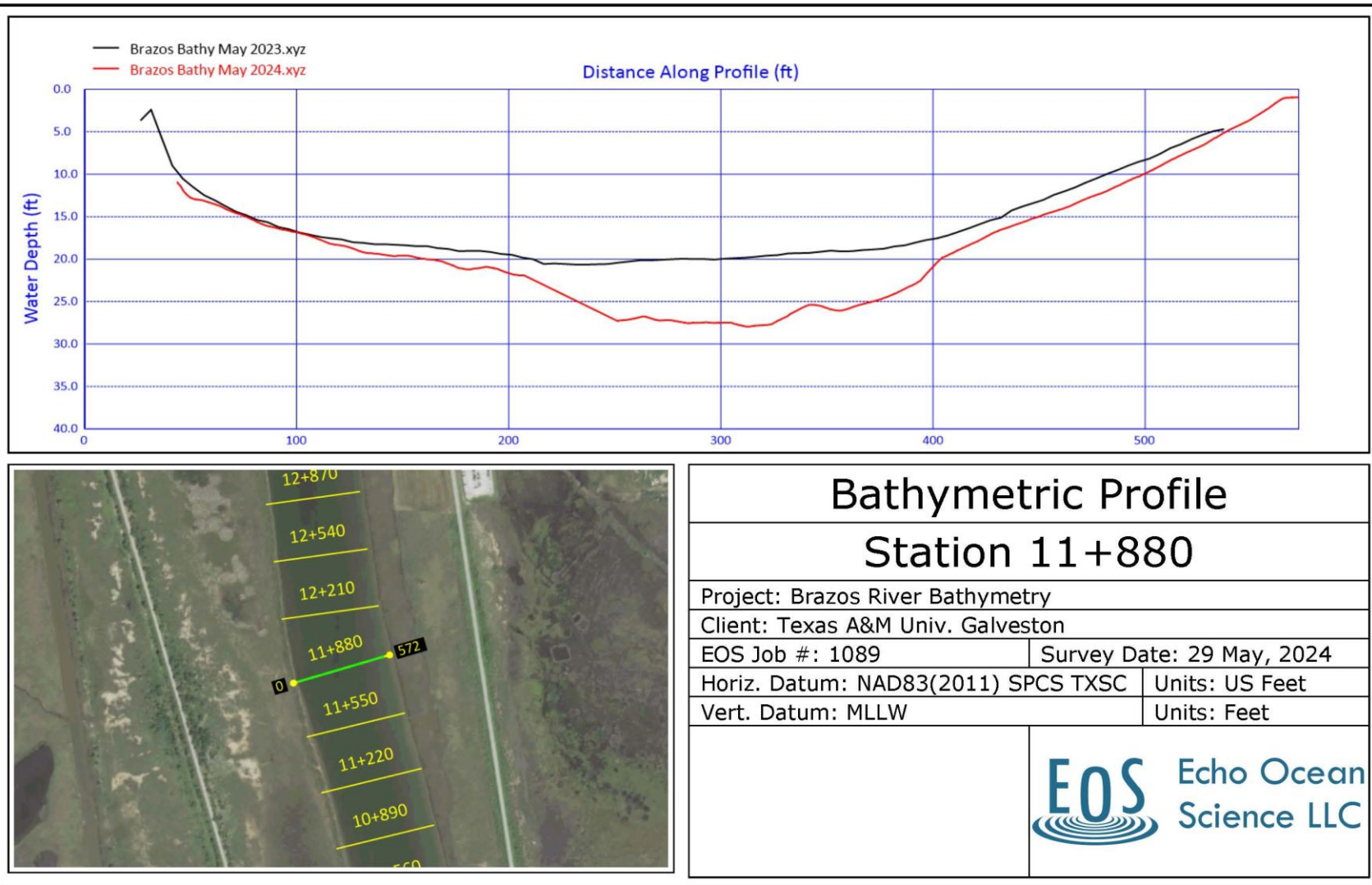


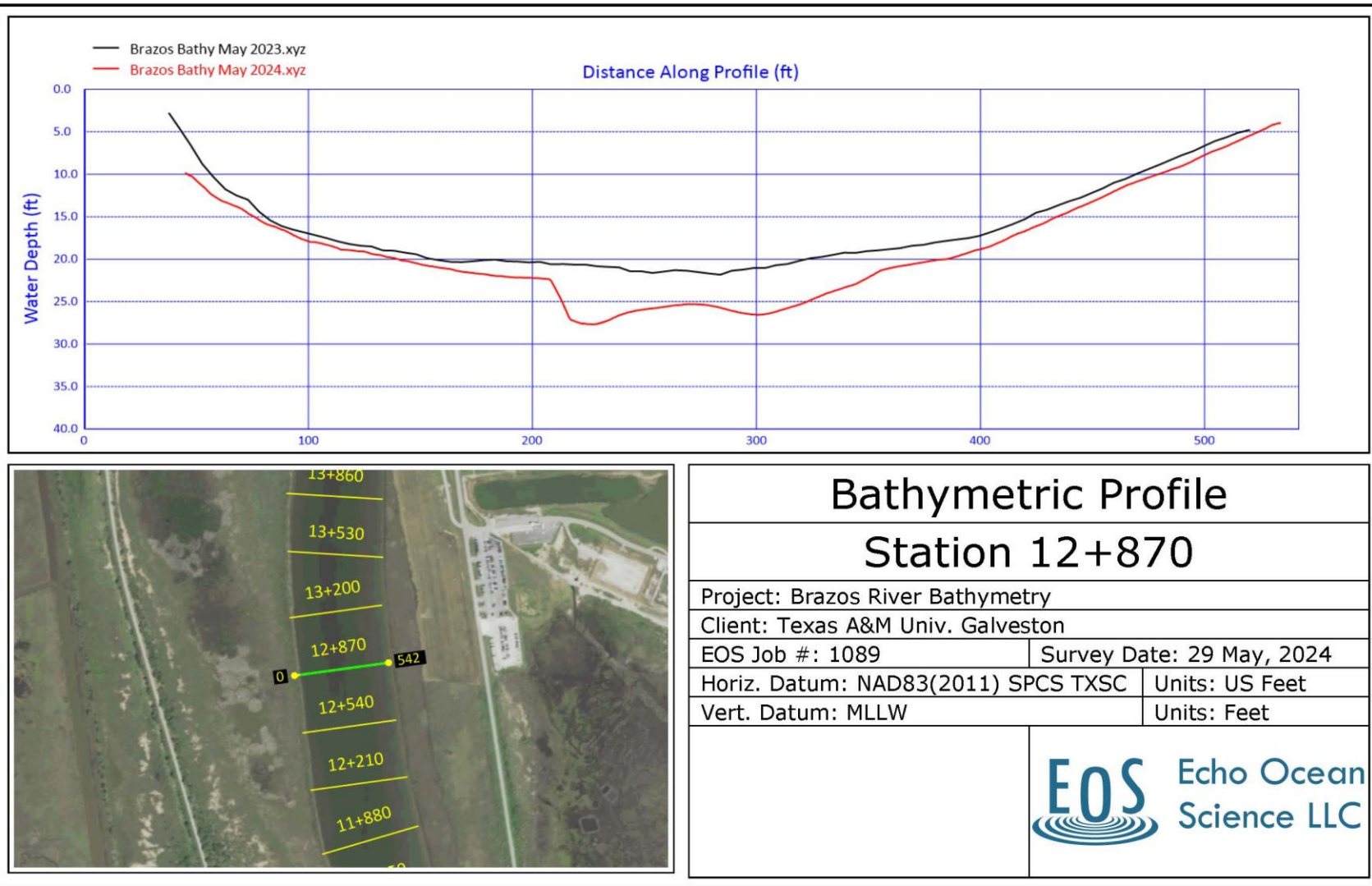


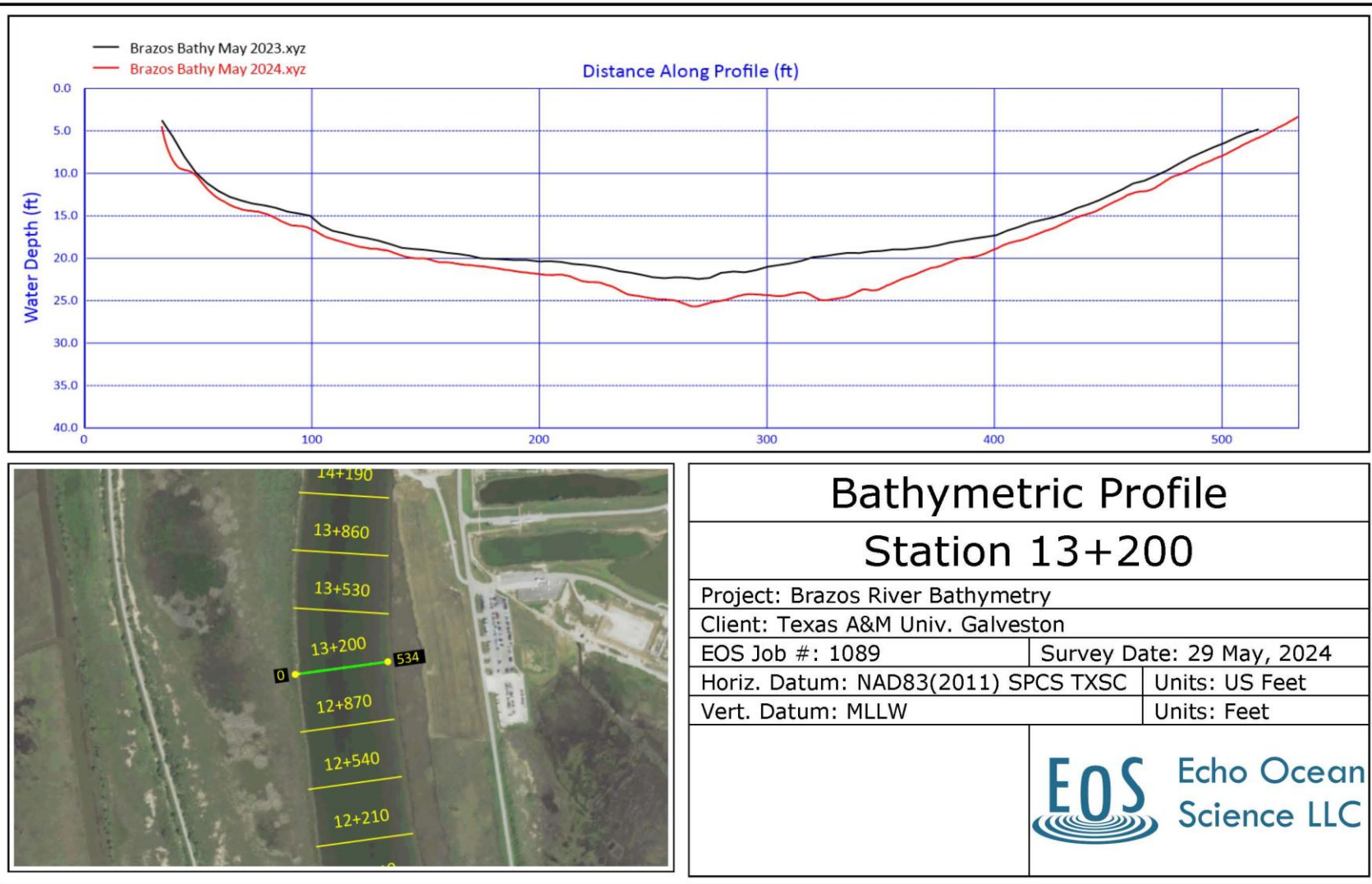


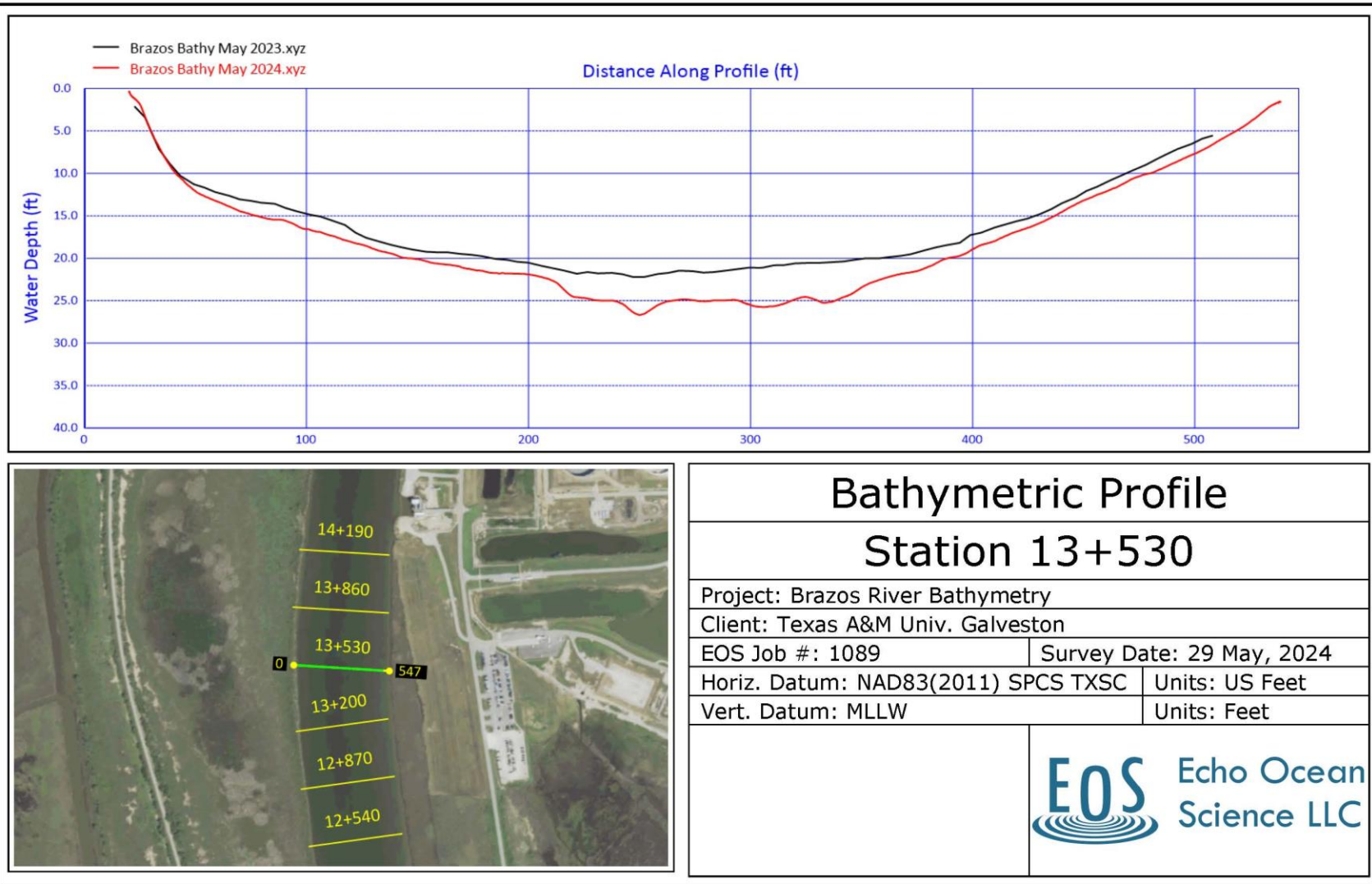


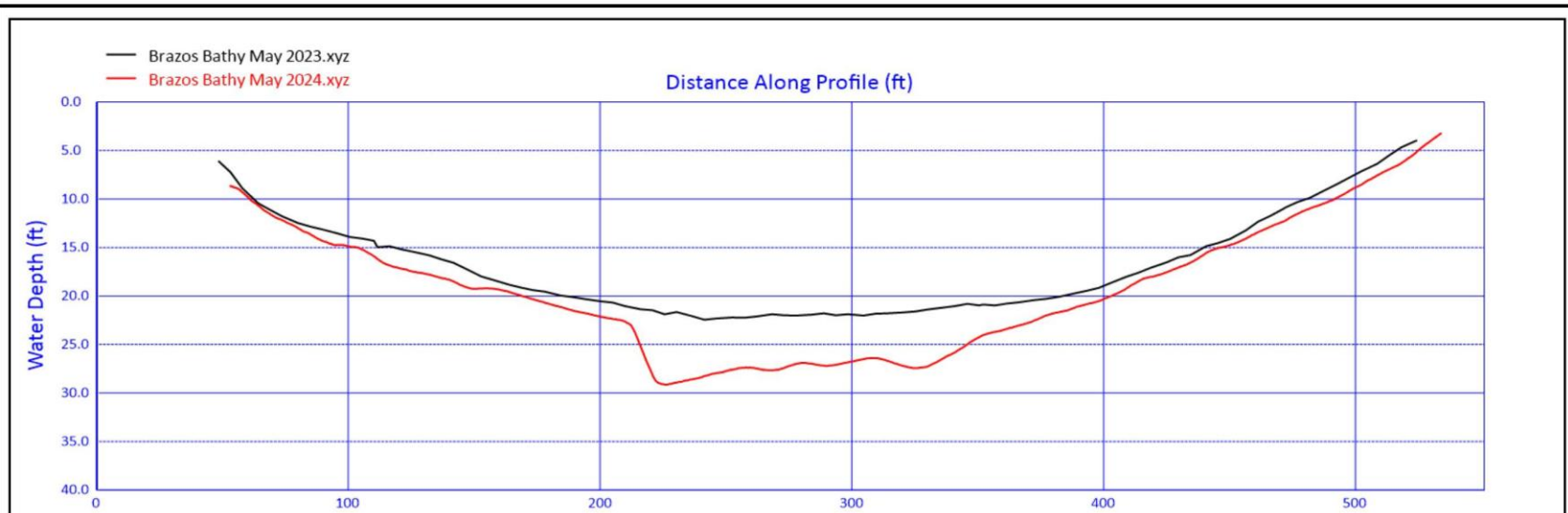












Bathymetric Profile

Station 13+860

Project: Brazos River Bathymetry

Client: Texas A&M Univ. Galveston

EOS Job #: 1089

Survey Date: 29 May, 2024

Horiz. Datum: NAD83(2011) SPCS TXSC

Units: US Feet

Vert. Datum: MLLW

Units: Feet



