COASTWIDE REFERENCE MONITORING SYSTEM (CRMS)

CRMS DATA SYNTHESIS – COASTWIDE TRENDS IN HYDROLOGY AND WETLAND SURFACE ELEVATION (2008-2023)

REPORT: VERSION 01
DATE: MAY 2026

PREPARED BY: LEIGH ANNE SHARP, BERNARD WOOD, ADAM CONSTANTIN, MARK MOULEDOUS, MELISSA HYMEL, DANIELLE RICHARDI, AND MARGARET DAIGLE

COASTAL PROTECTION AND
RESTORATION AUTHORITY
635 CAJUNDOME BLVD
LAFAYETTE, LA 70506
WWW.COASTAL.LA.GOV

COASTWIDE REFERENCE MONITORING SYSTEM (CRMS)

This document features data collected through Louisiana's Coastwide Reference Monitoring System (CRMS), a network of 390 coastal monitoring sites that provide comprehensive information on coastal trends necessary to plan, implement and assess coastal restoration projects and in support of CPRA's Coastal Master Plan. The CRMS network was established in 2005 to provide a complete suite of monitoring data for Coastal Wetland Planning, Protection and Restoration Act (CWPPRA) projects. CRMS monitoring is conducted by the Coastal Protection and Restoration Authority (CPRA) and the U.S. Geological Survey (USGS) and is currently funded by the CWPPRA program, the Louisiana Trustee Implementation Group for the Deepwater Horizon Natural Resource Damage Assessment (NRDA) Trustees, and the State of Louisiana. CRMS data are publicly available from CPRA's Coastal Information Management System (CIMS; link) and derived data are available through USGS's CRMS website (link).

CITATION

Sharp, L. A., Wood, W. B., Constantin, A. J., Mouledous, M., Hymel, M. K., Richardi, D.C., Daigle, M. L. (2026). CRMS Data Synthesis: Coastwide Trends in Hydrology and Surface Elevation (2008-2023). Lafayette, Louisiana: Coastal Protection and Restoration Authority.

ACKNOWLEDGEMENTS

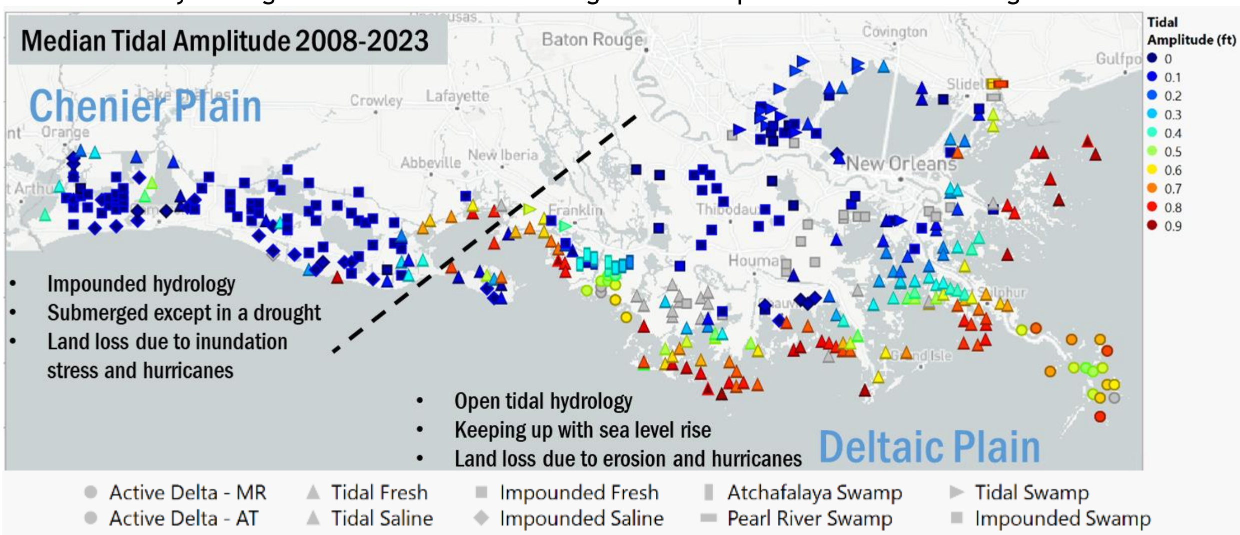
This document was prepared by the CRMS Analytical Team in CPRA's Lafayette Regional Office with support from US Geological Survey (USGS) scientists and other CPRA Regional Office staff. Work was reviewed and refined by CRMS funding partners including CWPPRA agencies (EPA, NOAA, USACE, NRCS, and USFWS) and members of the DWH LaTIG Monitoring and Adaptive Management Small Workgroup.

- Coastal Protection and Restoration Authority – Leigh Anne Sharp, Bernard Wood, Mark Mouledous, Adam Constantin, Margaret Daigle, Melissa Hymel, Danielle Richardi, Justin Homer, Elizabeth Jarrell, Kimberly Hamm, and Todd Folse
- U.S. Geological Survey – Dave Hewitt, Rachel Villani, Gregg Snedden, Brady Couvillion, Don Schoolmaster, and Camille Stagg

This work was funded, in part, by the Louisiana Trustee Implementation Group as part of the effort to restore natural resources injured by the 2010 *Deepwater Horizon* oil spill.

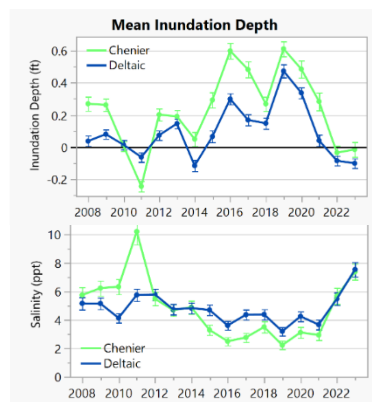
EXECUTIVE SUMMARY

Louisiana's coast is dynamic and complex with two distinct ecosystems, the open tidal Deltaic Plain and the structurally managed Chenier Plain. Each region has unique restoration challenges and solutions.

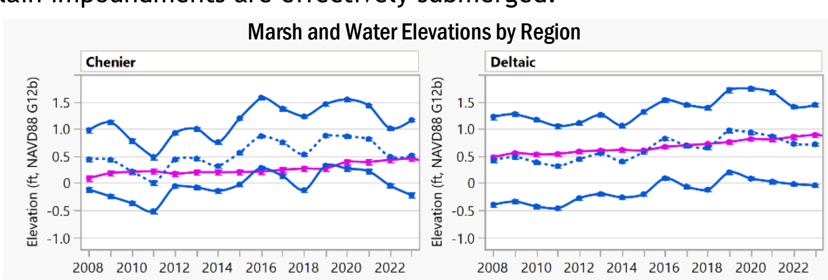


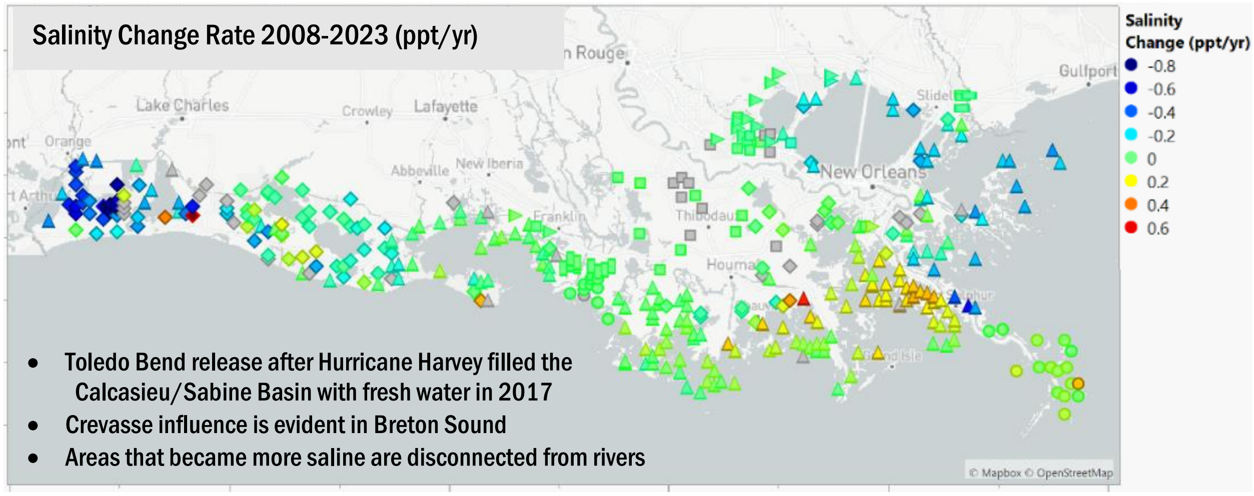
The CRMS monitoring timeframe captures ecosystem response as hydrologic conditions transitioned from drought (2005/2006) to flood (2016-2021) back to drought (2022 and 2023).

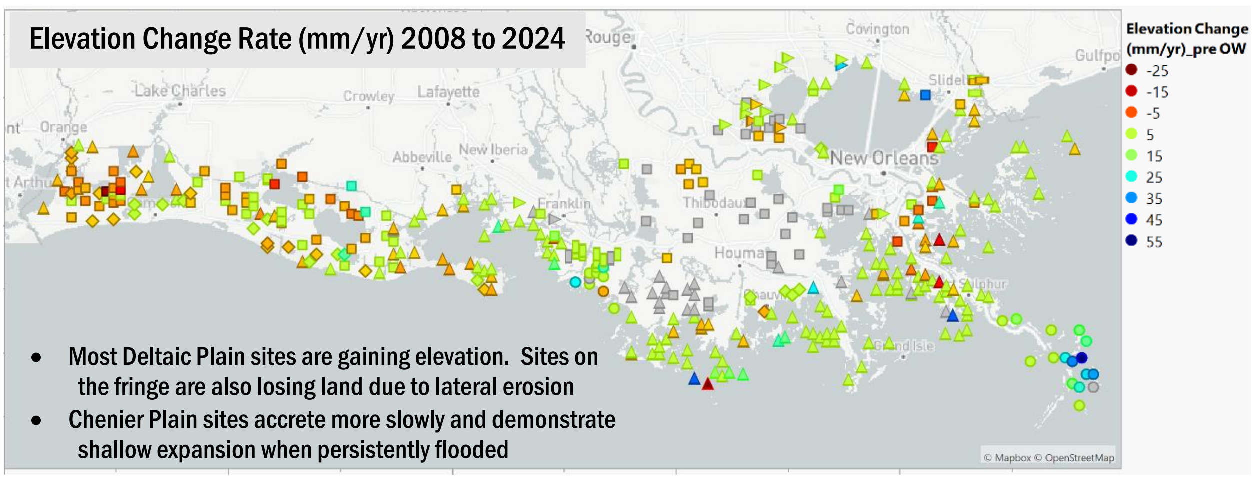
COASTWIDE TRENDS

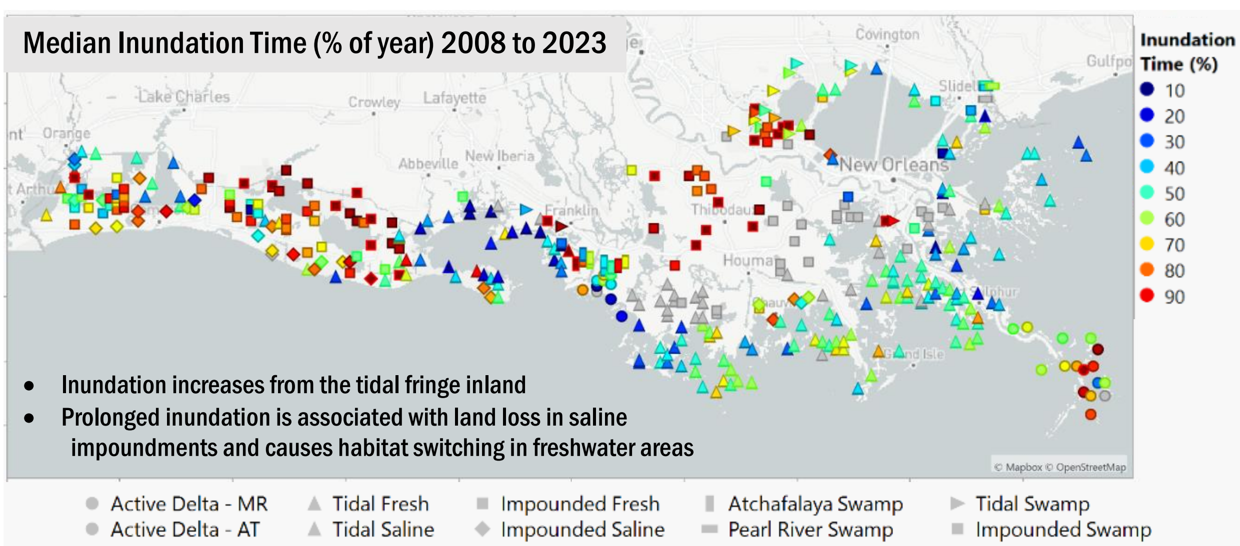


- Land loss continued driven by ongoing tidal erosion on the lower Deltaic Plain, hurricane impacts coastwide, and inundation stress on the Chenier Plain.
  - Land gain was observed in active deltas, recovering wetlands, and in marsh creation areas.
- Wetland inundation increased coastwide from late 2015 until 2021.
  - Most coastal areas freshened until the 2022/2023 drought reversed the trend.
  - Shallow expansion or floating marsh type behavior was observed in every marsh type during the high inundation time frame.
- Most CRMS sites are gaining elevation with the highest rates in active deltas and along eroding shorelines.
  - Vertical accretion is much higher in tidal marsh than in impoundments.
- In general, Deltaic Plain tidal wetland surfaces are found at or above mean water elevation while Chenier Plain impoundments are effectively submerged.









CRMS sites capture a full suite of coastal processes from emerging deltas to eroding salt marshes. CRMS data show that Louisiana coastal ecosystems are dynamic, exhibiting feedback mechanisms that prevent drowning in place. Ongoing land loss highlights the need for erosion control and sediment trapping in tidal areas and improved water management in impounded, non-tidal wetlands.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AT .... ATCHAFALAYA BASIN
BA .... BARATARIA BASIN
BS.......... BRETON SOUND BASIN
CIMS.......... COASTAL INFORMATION MANAGEMENT SYSTEM
CPRA .... COASTAL PROTECTION AND RESTORATION AUTHORITY
CS.......... CALCASIEU/SABINE BASIN
CWPPRA .... COASTAL WETLANDS PLANNING, PROTECTION, AND RESTORATION ACT
CRMS .... COASTWIDE REFERENCE MONITORING SYSTEM
DWH.......... DEEPWATER HORIZON
EPA .... ENVIRONMENTAL PROTECTION AGENCY
GIWW .... GULF INTRACOASTAL WATERWAY
LDWF.......... LOUISIANA DEPARTMENT OF WILDLIFE AND FISHERIES
NOAA.......... NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ME .... MERMENTAU BASIN
MR .... MISSISSIPPI RIVER DELTA BASIN
MRGO .... MISSISSIPPI RIVER GULF OUTLET
NRCS .... NATURAL RESOURCES CONSERVATION
NRDA.......... NATURAL RESOURCE DAMAGE ASSESSMENT
PO .... PONTCHARTRAIN BASIN
PS.......... PLOT SET
QA/QC .... QUALITY ASSURANCE AND QUALITY CONTROL
RESTORE .... RESOURCES AND ECOSYSTEMS SUSTAINABLITY, TOURIST OPPORTUNITIES, AND REVIVED ECONOMIES OF THE GULF COAST STATES
RSET .... ROD SURFACE ELEVATION TABLE
SEC .... SURFACE ELEVATION CHANGE
SSF .... SHALLOW SOIL FACTOR
SWAMP.......... SYSTEM-WIDE ASSESSMENT AND MONITORING PROGRAM
TIG .... TRUSTEE IMPLEMENTATION GROUP
TE .... TERREBONNE BASIN
TV .... TECHE/VERMILION BASIN
USACE.......... U.S. ARMY CORPS OF ENGINEERS
USFWS .... U. S. FISH AND WILDLIFE SERVICE
USGS .... U. S. GEOLOGICAL SURVEY SERVICE
VA .... VERTICAL ACCRETION

1.0 INTRODUCTION

1.1 ABOUT THE CRMS PROGRAM

The Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) of 1990 was enacted to restore, create, enhance and protect Louisiana's coastal wetlands. As required by the Act, a restoration plan was developed that specifically requires: (1) "an evaluation of the effectiveness of each coastal wetland restoration project in achieving long-term solutions to arresting coastal wetland loss in Louisiana;" and (2) "a scientific evaluation of the effectiveness of the coastal wetlands restoration projects carried out under the plan in creating, restoring, protecting and enhancing coastal wetlands in Louisiana."

The CWPPRA program initially addressed its monitoring mandate with a paired project/reference area approach. Monitoring data were collected in both a project area and a reference area for six months to a year pre-construction, and those data would be compared to twenty years of data collected from the same project and reference areas post-construction. Extremes in the pre-construction dataset (like a drought or a hurricane) or changes to reference areas over time (like being incorporated into a new project area) could easily confound project assessment. Further, any findings would only apply to the immediate project area and there was no opportunity to assess combined effects of restoration projects on the landscape.

In 2004, the CRMS design was developed and implemented to provide a network of reference sites, which would replace the paired project/reference monitoring approach and would provide information on landscape change at multiple spatial scales (Figure 1. Steyer et al., 2003). Because CRMS was designed to determine the ecological condition and trajectory of all of Louisiana's coastal wetlands (not just those assigned to project areas), CRMS also provides the opportunity to evaluate coastwide trends and restoration efforts at the ecosystem scale.

CRMS sites were randomly selected from thousands of LDWF transect points historically utilized for aerial wildlife surveys. Sites were proportionally allocated to basins and marsh types within basins, which allows for inference from the dataset at multiple scales including project, marsh type, basin, and coastwide scales. Each site is potentially a reference for any other site in the monitoring network. Each site effectively collects the same data at about the same time as every other site in the network each year (with exceptions in floating marshes and swamps).

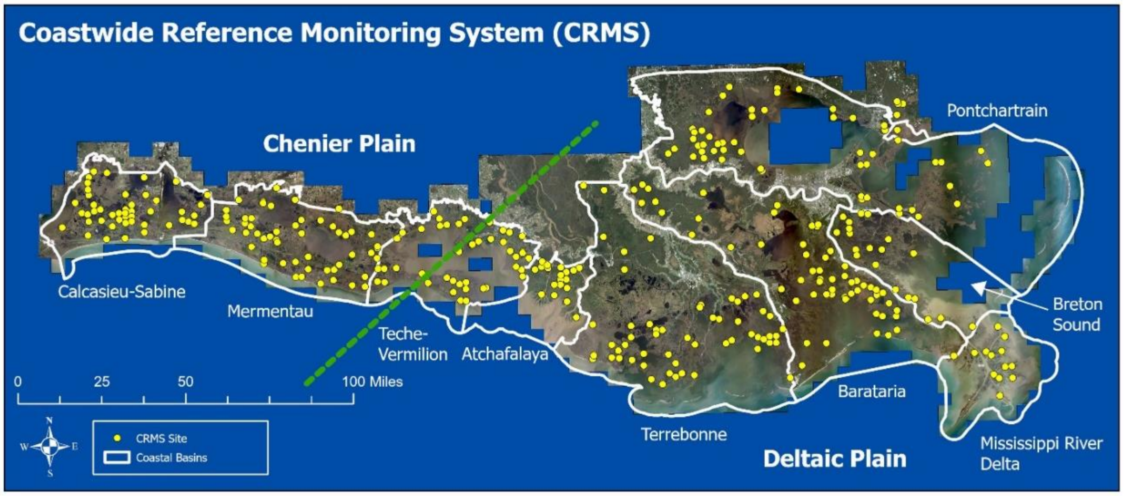


Figure 1. CRMS Sites, geomorphic provinces, and coastal basins

1.2 CRMS METRICS

Land loss is the primary issue in coastal Louisiana and as such, all CRMS variables measure processes associated with land loss (Couvillion et al., 2017). Inundation and saltwater intrusion cause land loss so CRMS provides trends in water elevation, inundation and salinity. Erosion and subsidence cause land loss so CRMS provides trends in vertical accretion and surface elevation that help assess elevation capital. Restoration projects target specific vegetation communities and marsh types so CRMS measures vegetation and classifies species data to communities and marsh types (Snedden et al., 2019; Visser and Sasser, 1998). The ultimate response variable is land and land change so CRMS measures land and land change at multiple spatial scales. Satellite derived estimates that capture historical trends (currently 1985-2020; Couvillion, 2021a) are paired with higher precision spatial analyses performed by USGS every three years (Couvillion, 2021b). Annual vegetation monitoring provides additional detail and context necessary to interpret restoration impacts on a changing coastal landscape. The CRMS data collection methodology is described in detail in the CRMS/SWAMP SOP (Folse et al., 2023).

1.3 ABOUT THE 2005 TO 2023 COASTWIDE DATA SYNTHESIS

This report is the second in a series of reports intended to highlight emerging trends and improve public utilization of the CRMS dataset. Detailed appendices with site level data used in each report are provided to help CRMS data users distill and utilize this valuable coastal resource generously made publicly available by the CWPPRA program to the benefit of Louisiana and its coastal citizens.

This report features CRMS hydrology, vertical accretion, and surface elevation change datasets and is intended to help interpret the recent 2005 to 2021 CRMS land change analysis (Wood et al., 2025). Future reports will feature trends in vegetation and drought impacts.

2.0 LAND CHANGE REVIEW

In a previous analysis, CRMS sites were separated into land change groups using hierarchical clustering of spatial datasets (Wood et al., 2025; link). The analysis produced seven distinct groups that captured a range of conditions from sites that continuously lose land and are now open water to sites that are 100% vegetated and have not changed over the CRMS monitoring timeframe (since 2005; Figures 2.1, 2.2 and 2.3).

LAND CHANGE EXECUTIVE SUMMARY

The entire network of 390 sites was classified into land change groups using hierarchical clustering in order to assess coastwide trends. CRMS sites fell into seven (7) groups that captured a range of conditions including:

- **Continuous, ongoing land loss** in saline marshes on the lower deltaic plain (15% of CRMS network) with all vegetation removed from 2% of sites.
    - Continuous land loss was isolated to fringe marshes in Barataria, Terrebonne, and Breton Sound Basins.
    - Loss appears to be due to erosion of otherwise healthy vegetation (*not* drowning in place).
- **Landscape stability** coastwide (66% of CRMS network).
    - No land change and nearly 100% land in swamps and inland freshwater marshes (19.2%).
    - No land change and around 70% land at sites in every basin and every marsh type, including salt marsh (46.7%).
- **Landscape variability** with three different outcomes (19.2%)
    - **Variable Land Gain** (5.6%) – episodic land gain found mostly in deltas and recovering marshes. Net land gain.
    - **Variable Land Loss** (5.4%) – episodic land loss, typically due to hurricanes but occasionally due to inundation stress or vegetation rafting. Net land loss.
    - **Variable Stable** (7.7%) – episodic loss with recovery. No net land change.

Notable Trends:

- There is an emerging land loss hot spot in the Calcasieu/Sabine Basin in an area that is thought to be geologically stable. Saline impoundments were observed to destabilize during the last high sea level timeframe (2015-2021) and the loss appears to be related to saline **inundation stress**.
    - Calcasieu/Sabine Basin land loss within CRMS sites between 2005 and 2021 was at the same scale as loss in Barataria and Terrebonne basins (around 8% lost).
- The only landscape collapse happening now is in the Calcasieu/Sabine Basin. Ongoing deltaic plain land loss appears to be due to tidal erosion and hurricanes.

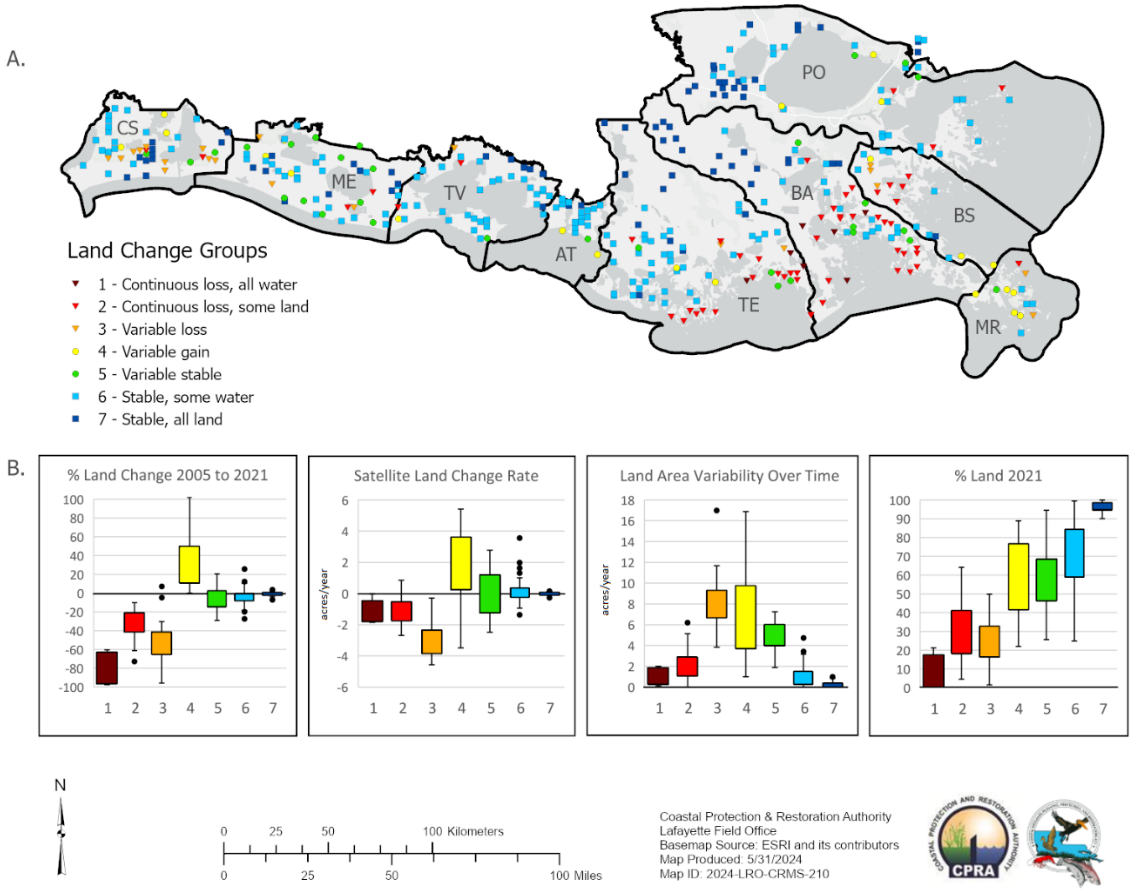


Figure 2.1. A) CRMS Land Change Groups and B) associated metrics. Box and whiskers indicate data range excluding outliers (black dots)

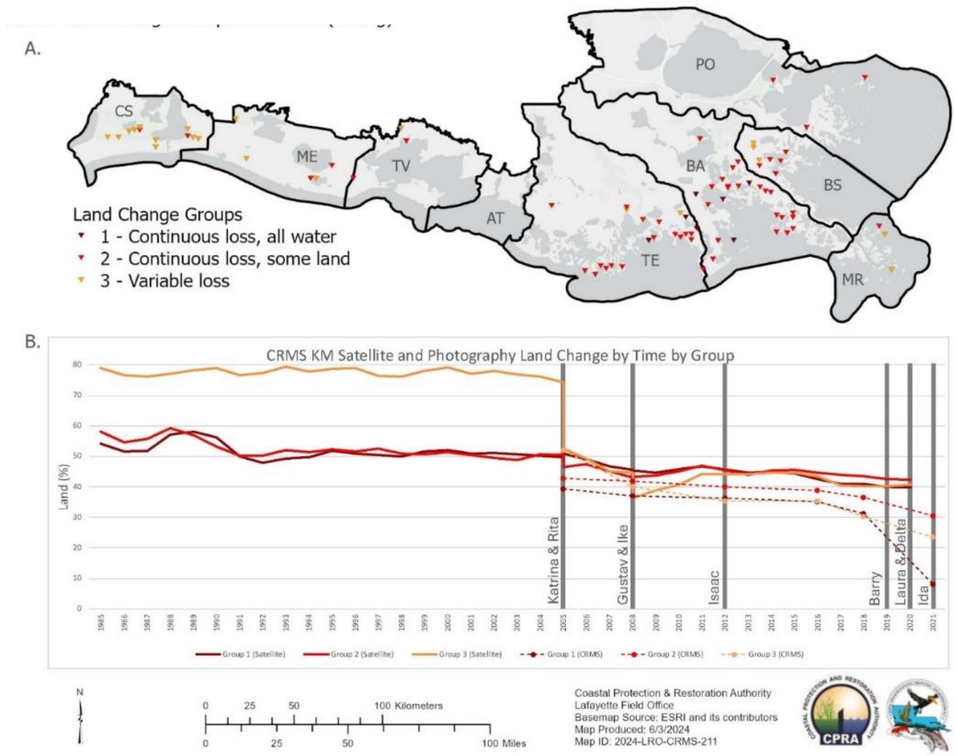


Figure 2.2. A) Location of CRMS sites allocated to groups that capture land loss and B) trends in land change by group (% land by year)

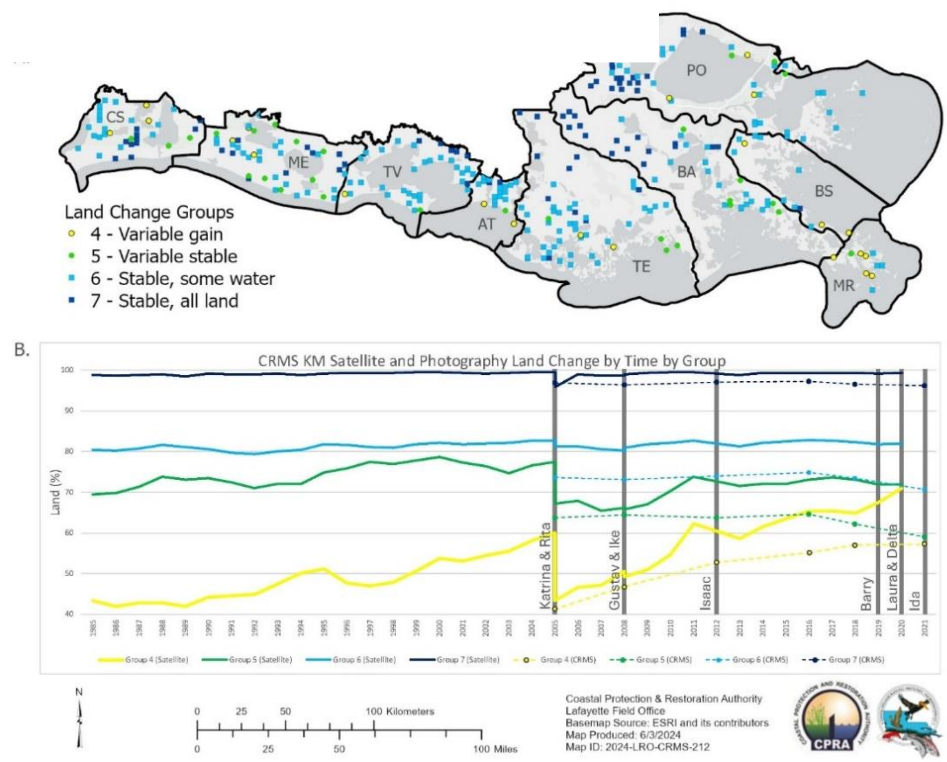


Figure 2.3. A) Location of CRMS sites allocated to groups that capture stability and land gain and B) trends in land change by group (% land by year)

3.0 HYDROLOGY

3.1 DATA PREPARATION

The CRMS monitoring network has produced a substantial amount of monitoring data over the last twenty years. Each of the 390 hydrology stations produces 8760 hourly readings each year so the hourly hydrology dataset now has over 50 million observations. Data summary and reporting tools on the CRMS website provide a full suite of summary statistics on each primary hydrology variable and those tools were utilized to compile this data summary.

Annual mean values were compiled from all sites in the CRMS network for each hydrology variable including annual mean water elevation, inundation depth, inundation duration, tidal amplitude, and salinity. There is a datum shift in the CRMS dataset on 10/1/2013 and that was addressed, bringing original Geoid 99 observations into the most recent datum (NAVD88 Geoid 12b). Data were excluded from this summary for incomplete data records (<70% complete) or if station relocation prevented trend analysis. Details are included in Appendix D.

3.2 BOUNDARY CONDITIONS

Over the CRMS monitoring timeframe (since 2005), the coast of Louisiana has been impacted by hurricanes, drought, floods and an acceleration in sea level rise (Table 3.1). Boundary conditions effectively define and constrain the range of possible water level, salinity and inundation values captured in the CRMS hydrology dataset. The coastal landscape interacts with boundary conditions and coastal restoration efforts to produce the range of ecosystem responses that are observed in the CRMS dataset.

Over the CRMS timeframe, coastal Louisiana has been directly impacted by 17 hurricanes and tropical storms, six high river years, five extreme drought years, and several other exceptional events such as the 2016 flood, 2017 Toledo Bend release, and an acceleration in sea level rise that began around 2015 and increased through 2021.

PRECIPITATION

Local precipitation is an important driver of water level and salinity variability within the CRMS network, especially among interior basins and non-tidal sites. Precipitation values were calculated using available regional airport data along the Louisiana, Texas, and Mississippi coastlines (Figure 3.1a). Annual precipitation in the coastal zone (averaged across all data sources) is approximately 54 inches per year. In addition to interannual variability, rainfall varies by season with higher rainfall in the spring and summer months. Positive precipitation anomalies occurred coastwide from 2015-2021 and extreme droughts occurred in 2010-11 and 2022-23 (Figure 3.1b). The response to rainfall variability is captured in CRMS salinity, flooding, and vegetation change datasets.

Table 3.1. Major events that impacted Louisiana's coastal hydrology between 2005 and 2024. High River refers to years that the Mississippi River was high and the Bonnet Carre Spillway was opened.

Event	Begin Date	Event	Begin Date
Hurricane Katrina	8/29/2005	2018 Drought	6/1/2018
Hurricane Rita	9/24/2005	High River 2019	2/27/2019
High River 2008	4/11/2008	Hurricane Barry	7/13/2019
Hurricane Gustav	9/1/2008	Tropical Storm Olga	10/26/2019
Hurricane Ike	9/3/2008	High River 2020	4/3/2020
2010 Drought	8/1/2010	Tropical Storm Cristobal	6/7/2020
2011 Drought	8/1/2011	Hurricane Laura	8/27/2020
High River 2011	5/9/2011	Hurricane Sally	9/16/2020
Hurricane Isaac	8/28/2012	Tropical Storm Beta	9/21/2020
2015 Sea Level Acceleration	10/24/2015	Hurricane Delta	10/9/2020
High River 2016	1/10/2016	Hurricane Zeta	10/28/2020
2016 Flood	8/12/2016	Hurricane Ida	8/29/2021
Tropical Storm Cindy	6/22/2017	2022 Drought	8/1/2022
Hurricane Harvey	8/30/2017	2023 Drought	8/1/2023
Toledo Bend Release 2017	9/1/2017	Hurricane Francine	9/11/2024
High River 2018	3/8/2018		

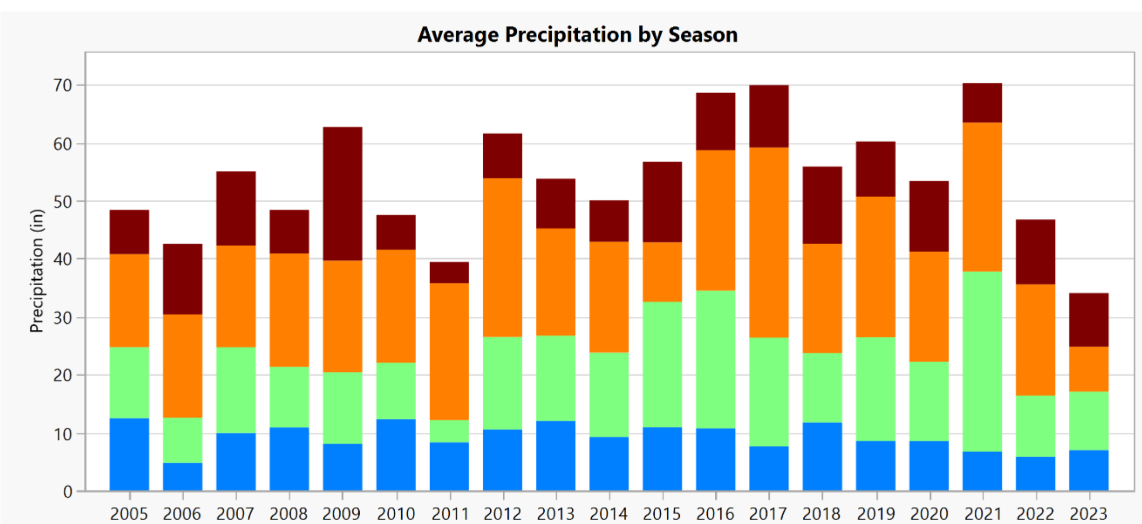


Figure 3.1a. Seasonal precipitation representing the Louisiana Coastal Zone for 2005-2023 averaged from Regional Airport Data (Lake Charles Regional Airport, KLCH, New Orleans Armstrong Intl Airport (MSY), Slidell Airport (ASD), Lafayette Airport (LFT), Boothville (ASOS), Gulfport-Biloxi Airport (GPT), Port Arthur Airport (BPT) and Boothville/Petro Heli (LNQ))

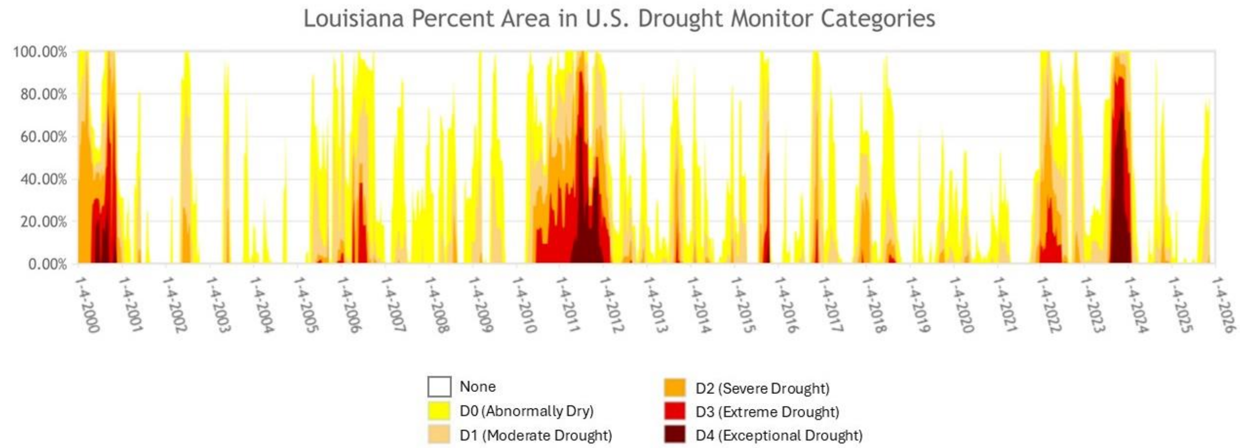


Figure 3.1b. Drought conditions over the last 25 years in Louisiana. The drought of 2010-2011 and 2023 were both historic events. The first due to its near three year duration and exceptional categorization, and the latter due its rapid onset and near state-wide exceptional category

SEA LEVEL

Relative sea level rise is a function of regional sea level rise and local subsidence. The Louisiana and Texas coasts experience some of the highest rates of relative sea level rise in the nation (NOAA Sea Level Trends), with NOAA's published rates ranging from 0.67 to 0.92 cm/yr (Galveston, TX to Grand Isle, LA).

While CRMS sites reflect similar sea level trends to long term NOAA tide gauges (Figure 3.2), CRMS data include seasonal variability and are more responsive to localized forces. Mean Gulf sea level is effectively minimum water level for CRMS sites across the coast and small increases at the Gulf are amplified in inland areas, particularly those that are non-tidal and rely on gravity drainage.

Sea level rise in the northern Gulf displays a long-term pattern of variation with decades of relatively high rates of sea level rise followed by decades of relatively low rates. This oscillation is related to an 18.6 year lunar cycle (Thompson et al., 2021) and Atlantic Basin scale processes (like the North Atlantic Oscillation; Zhang et al., 2024) that impact Jet Stream dynamics (Appendix B). NOAA's Galveston gauge has a continuous data record that begins in 1904 and has captured 2.18 ft (0.66 m) of sea level rise through multiple cycles of relatively high and relatively low sea level variation (Figure 3.3).

During the CRMS monitoring time frame, interannual sea level variation switched from well below the trend to well above the trend. This transition began around 2010 and the impacts were felt in late 2015 when Gulf coast sea level increased rapidly, driving increases across Louisiana coastal wetlands. Interannual variation is caused by irregular fluctuations in coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. The 2022/2023 drought and associated Gulf sea level conditions allowed water levels to drop back down to around the mean trend line but water level remained well above the previous 2011 minimum.

Global oscillations in both the Atlantic (North Atlantic Oscillation) and Pacific (El Nino Southern Oscillation) impact precipitation in the Mississippi River watershed (Hiatt et al., 2019). In coastal Louisiana we experience high rainfall and high Mississippi River levels together with high sea level and conversely, we also experience drought and low Mississippi River water levels together with low sea level (Figure 3.4). Flood and drought cycles align with the 18.6 year lunar cycle. It is important to understand where CRMS sites are located along the coastal zone and what boundary conditions will allow when interpreting CRMS hydrology trends as Gulf sea level at the coastal boundary is a limiting factor for drainage either tidally or gravity driven.

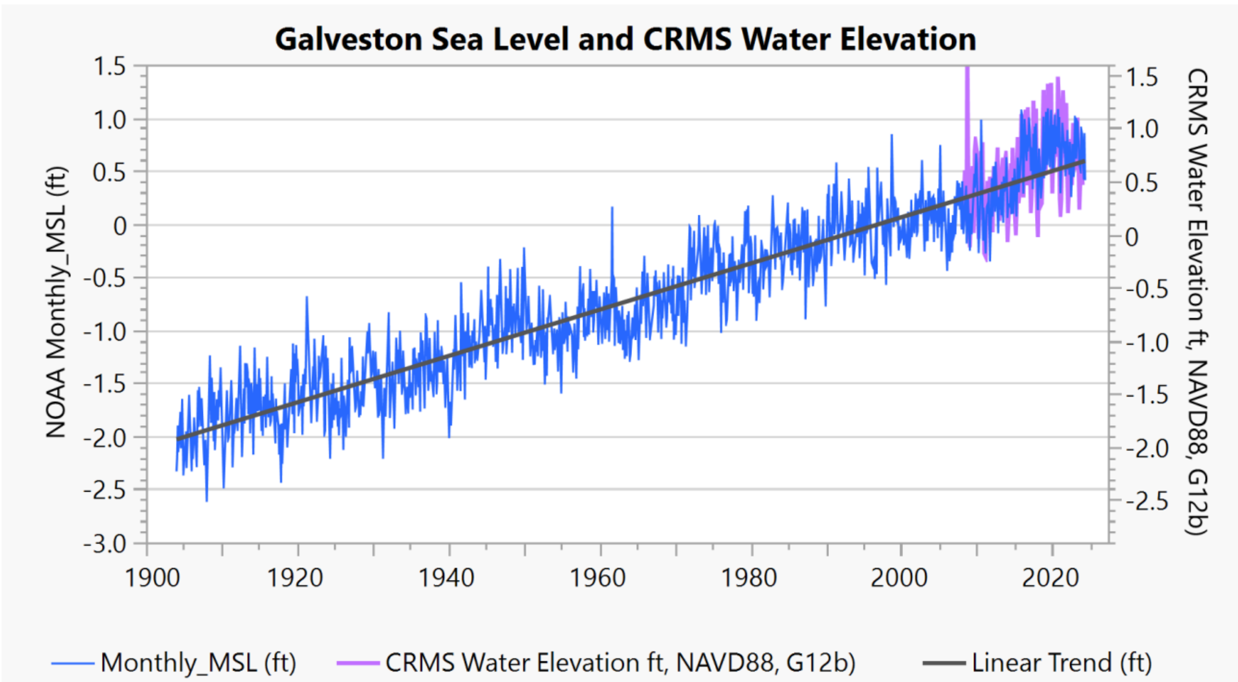


Figure 3.2. Monthly mean sea level (ft) at Galveston, TX's Pier 21 from 1904 through 2024 (Source: Center for Operational Oceanographic Products and Services (CO-OPS)), and CRMS monthly mean water elevation (ft, NAVD88 G12b). Note NOAA data have seasonality removed and CRMS data are as observed

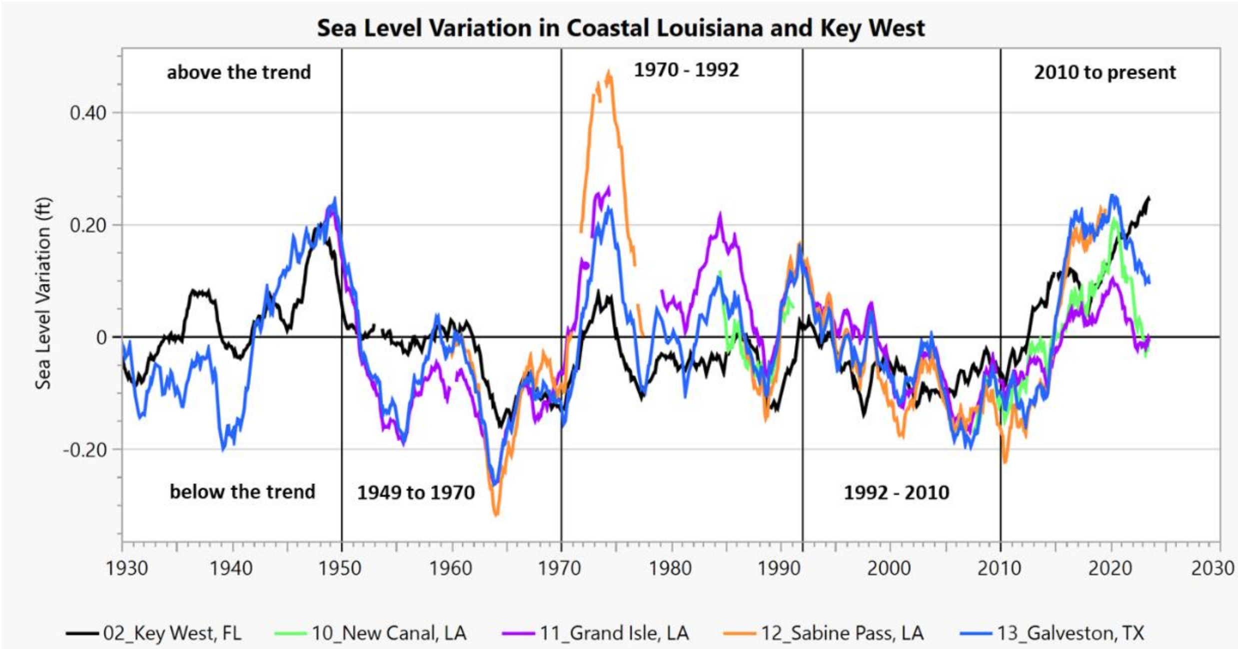


Figure 3.3. Sea level variation at Key West, New Canal, Grand Isle, Sabine Pass and Galveston gauges smoothed with a 36 month moving average. All stations were below the rising trend from the mid 90's until they began a transition to positive in 2010. A declining trend commenced in recent drought years but Key West gauge captures a continuous rise associated with larger scale Atlantic basin processes

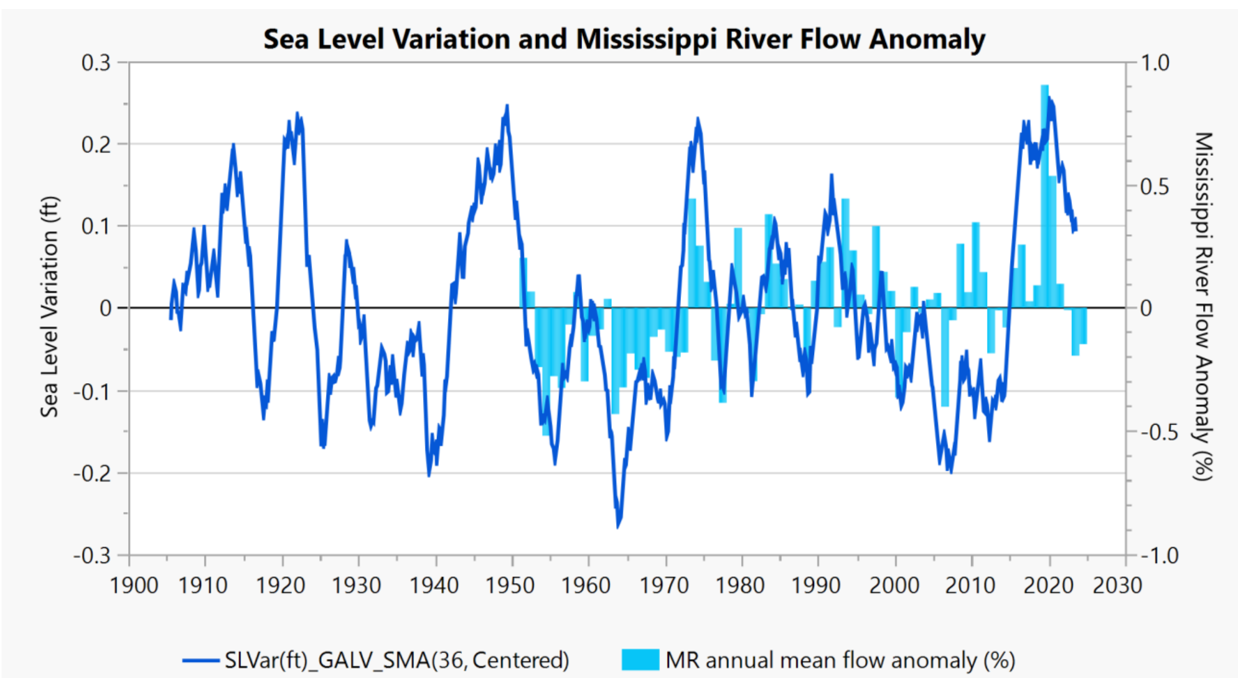


Figure 3.4. Galveston sea level variation (ft) and Mississippi River annual mean flow anomaly (%) from Tarbert's landing. Galveston is a good reference for coastal Louisiana because it captures the same trends as other regional Louisiana gauges and has the longest continuous record in the region

3.3 COASTWIDE HYDROLOGY TRENDS AND REGIONAL DIFFERENCES

Annual mean values were utilized to distill trends in primary hydrology variables including water elevation, wetland inundation depth, inundation time, and salinity. Sites that had more than 30% of the data record missing for the year were excluded from means and sites that had substantial changes related to station relocation were omitted from trend analyses.

COASTWIDE WATER ELEVATION

Practically all CRMS sites exhibited an increasing water level trend over the 2008 to 2023 data collection period (Figure 3.5). The rate of increase across the CRMS network during this period was 1.0 cm/yr (0.034 ft/yr), equating to 0.6 feet of higher average water level. Water levels decreased during the 2022-2023 drought, but did not reach the same minima they did during the previous deep exceptional drought in 2011. This is significant considering that record high temperatures in conjunction with primarily westerly winds and currents along with below average Mississippi River flow created ideal conditions for drainage in 2023. Water surface elevations in 2023 fell below the 2008-2023 trend line. It is reasonable to expect water surface elevations to increase again in coming years as cyclical regional weather patterns shift back to a wetter period (Thompson et al., 2021).

Regional water level is about the same on the Chenier and Deltaic Plains, except during period of drought conditions (Figure 3.6). Water levels within managed marshes that rely on gravity drainage can decrease well below Gulf sea level through evapotranspiration during a drought while those with high connectivity to the Gulf (i.e. tidal marshes) remain at Gulf sea level.

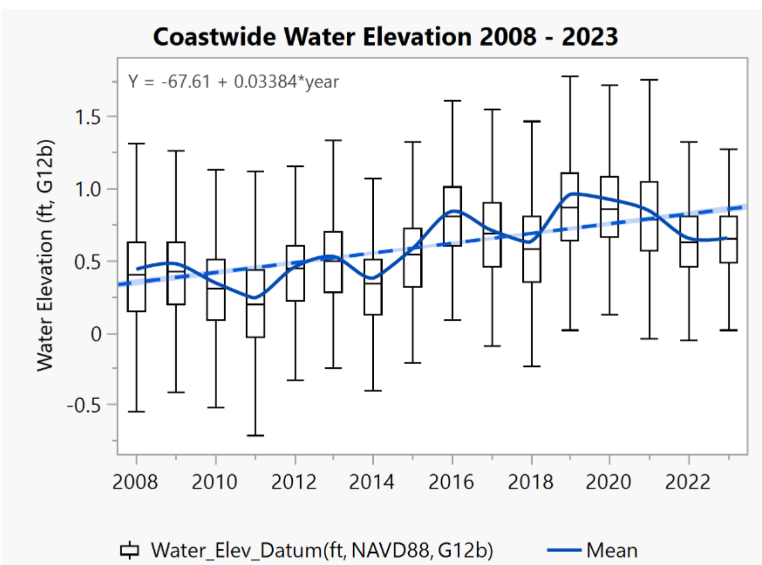


Figure 3.5. Distribution of annual mean water elevations (ft NAVD 88, G12b) with trend coastwide. Box plot indicates mean, quartiles, and range. The annual spread of these water elevations is truncated during drought years generally due to the reduction of flooding inland and in large impoundments

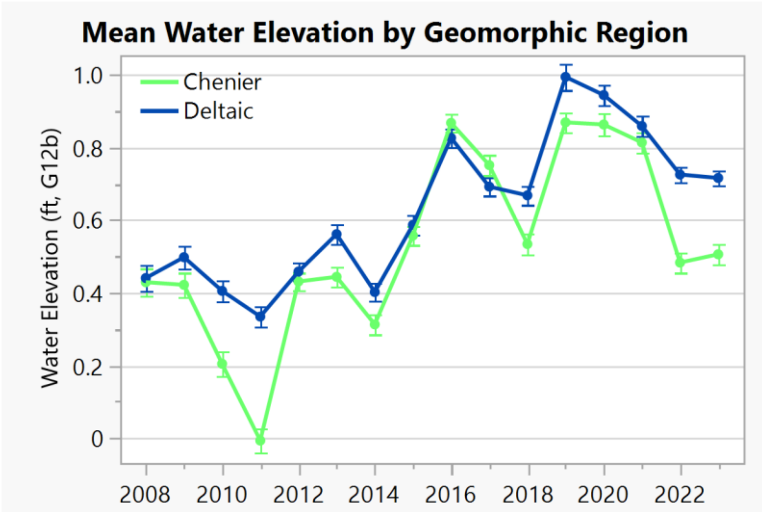


Figure 3.6. Annual mean water elevation by geomorphic region. The lack of localized rainfall allows the Chenier Plain marshes to drop meaningfully below Gulf sea level where direct hydrologic connections to the Gulf are lacking

COASTWIDE INUNDATION DEPTH AND DURATION

Prior to the most recent sea level rise acceleration that began in 2015, inundation depth at CRMS sites coastwide averaged near zero (Figure 3.7). From 2016 to 2020, high sea level, high Mississippi River discharge, and high precipitation caused higher inundation of tidal wetlands and persistent flooding in Chenier Plain impoundments. These trends reversed in 2022 and 2023 due to the deep exceptional drought both locally and regionally, combined with lower Gulf sea level and river discharge.

Inundation depths are higher within the managed marshes of the Chenier Plain and have become more pronounced with sea level rise (Figure 3.8). The only year that average inundation was higher in the Deltaic Plain was 2011, a significant Mississippi River flood year, which coincided with the 2011 drought in the western coastal areas. Even prior to the sea level acceleration of 2015, Chenier Plain marshes required a deep exceptional drought for average inundation to be below zero. Average inundation depth was over 0.5 ft in 2016 and 2019 within the Chenier Plain and decreased to just below marsh elevation during the deep exceptional drought and record breaking heat wave of 2022-23. The Deltaic Plain sites also experienced a significant increase in water levels and inundation levels between 2016 and 2020. This increased marsh inundation pattern is occurring even as local marsh elevations have increased, generally through ecogeomorphic processes to maintain a relationship at or near mean water level, via the complex interplay of trapping mineral sediments, increased pore space, redefining the root zone repeatedly through horizontal root growth and abandonment, and overall root mat buoyancy due to aerenchymas tissue.

Along with depth, inundation duration has increased coastwide during the CRMS monitoring period (Figure 3.9). Prior to 2015, the coast was inundated approximately half of the year roughly equating to tidal cycles in the Deltaic Plain and lower water seasonally in the Chenier Plain. These annual inundation durations increased after 2015 to 60-80% until 2021 with some non-tidal CRMS sites flooded almost 100% of the time for up to five consecutive years. Elevated flooding that preceded 2019-2021 hurricanes was likely a factor in the amount of wetland damage and removal observed in 2019-2021 storms. Floating marshes were removed by Hurricanes Barry (2019) and Ida (2021) and land loss in areas that had been persistently flooded was observed due to 2020 Hurricanes Laura and Delta.

As with inundation depth, inundation durations across the Chenier Plain sites exceeded those of the Deltaic Plain (Figure 3.10). Mean annual flood duration on the Chenier Plain was more than 50% in all years except 2011. The 2022/2023 drought brought average water levels back down to marsh level. Mean annual flood duration on the Deltaic Plain was less than 50% in 2011, 2014, and 2021-2023, as tidal connectivity promotes drainage at low tide and tidal egress is not possible along most of the Chenier Plain. Overall, increasing inundation can negatively impact vegetation, weaken marsh soils and interfere with the marsh's ability to act as a buffer against storms.

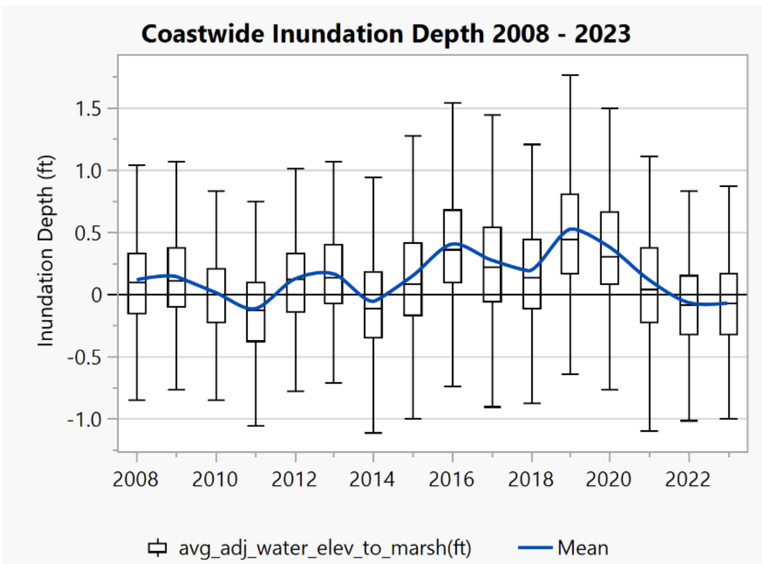


Figure 3.7. Distribution of annual mean inundation depth (ft) at CRMS sites coastwide. Box plot indicates mean, quartiles, and range

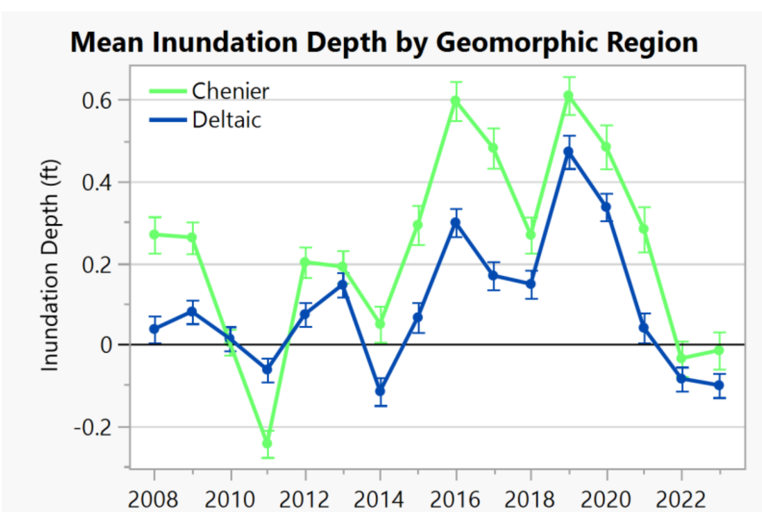


Figure 3.8. Annual mean inundation depth (ft) of CRMS sites by geomorphic region relative to marsh surface elevation. The Chenier Plain is general more deeply flooded than the Deltaic region, by approximately 0.25 (ft), except during prolonged exceptional drought conditions

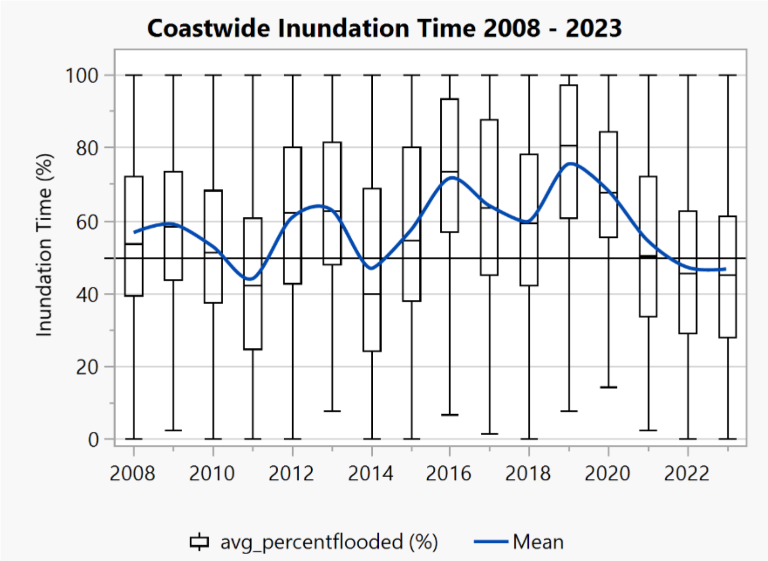


Figure 3.9. Distribution of annual mean inundation time (%) at CRMS sites coastwide. Box plot indicates mean, quartiles, and range. Average annual flooding hovers around 50% under most conditions except extensive regional high water events, generally in the form of regional precipitation trapped by an elevated Gulf

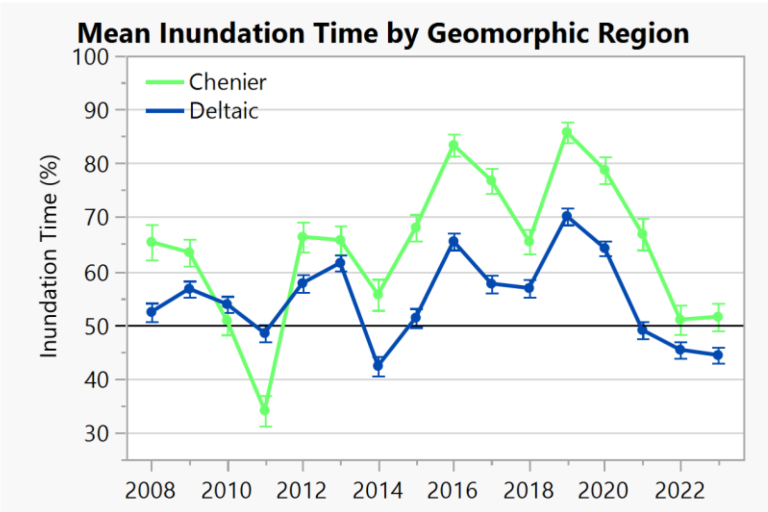


Figure 3.10. Annual mean inundation time (%) of CRMS sites by geomorphic region. The Chenier Plain, as a region was flooded 85% of the year in 2016 and 2020, leading to wide spread marsh mat detachment

COASTWIDE SALINITY

Salinity is a defining factor of coastal wetland ecotones, varying with proximity and connectivity to marine boundaries and riverine inputs, especially along Louisiana's complex coastal basins. Historically, as waterways were dredged for navigation, commerce, and drainage, saltwater intrusion intensified, further stressing fresh and oligohaline interior wetlands. This brought about infrastructure improvements to control and abate saltwater intrusion at multiple spatial scales, from the individual land owner to the sub-basin. Some of the largest projects like the Mermentau Basin locks and the Davis Pond and Caernarvon Freshwater Diversions are intended to control salinity at a sub-basin scale. Salinity variability at CRMS sites is driven by local rainfall, river discharge, and interconnections to the Gulf. The coast is so varied from east to west that there can be rainfall deficits in local precipitation in one region and simultaneous surpluses throughout the greater Mississippi River drainage basin as was seen in 2011. The most recent drought (2022-2023) caused a salinity spike that continues to impact vegetation communities into 2025.

The 2011 drought caused a large spike in salinity on the Chenier Plain which was not observed on the Deltaic Plain due to a prolonged Mississippi River flood pulse that persisted through August of the same year (Figures 3.11 and 3.12). The freshening effects from 2015 to 2021 were more pronounced at CRMS sites within the Chenier Plain. The isolating effect of impoundments within the Chenier Plain trapped fresh rainwater and provided minimal opportunities to drain against higher sea levels. Tidally connected areas of the Deltaic Plain were able to drain and mix more efficiently in this more open estuary, but CRMS sites in this region still displayed lower salinities related to increased precipitation during this time frame. Higher sea levels also increased the retention time of riverine inputs to the coastal marshes, especially during the historic flood of 2019. Salinities rose equally across both regions in 2022 and 2023, as low river discharge combined with acute drought conditions coastwide for the first time within the CRMS monitoring timeframe.

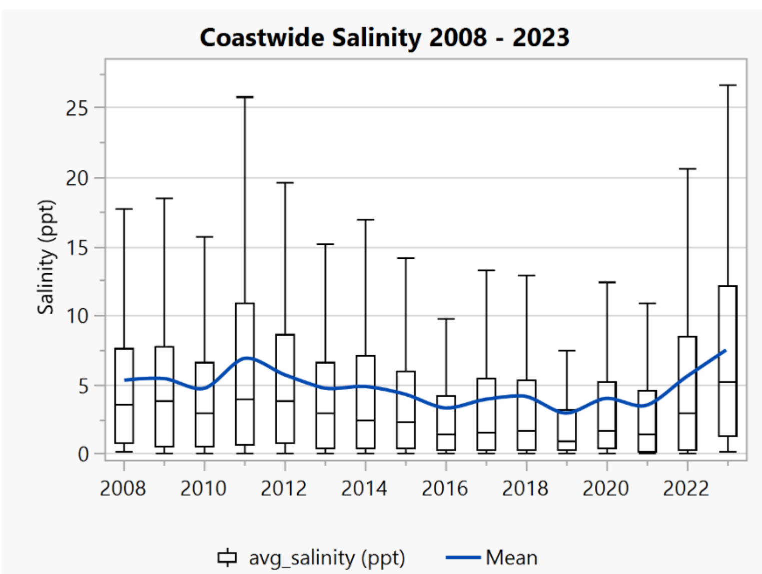


Figure 3.11. Distribution of CRMS annual mean salinity (ppt) with trend coastwide. Box plot indicates mean, quartiles, and range

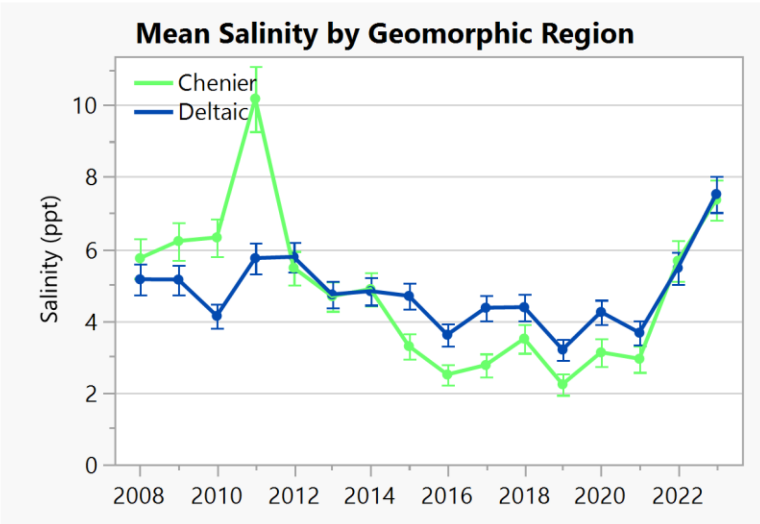


Figure 3.12. CRMS annual mean salinity (ppt) by geomorphic region. The drought of 2022-2023 increased regional salinity in concert due to below average Mississippi River flow in both years

3.4 SPATIAL PATTERNS AND TRENDS AMONG HYDROLOGY GROUPS

Hydrology in coastal Louisiana varies over small spatial scales with a wide range of hydrologic conditions found across the coast. The interaction between riverine, deltaic processes and open tidal hydrology produces a wide diversity of estuarine habitat types on the Deltaic Plain. Impounded, managed hydrology on the Chenier Plain adds to the diversity of ecosystems found in coastal Louisiana adding with it a unique set of hydrologic regimes.

For visualization, sites were separated into ten groups that capture whether a site is tidal or impounded (non-tidal), and fresh or saline, swamp or marsh, and or within an active delta (Figure 3.13). Herbaceous marshes were separated from swamps and active deltas were separated from other tidal fresh marshes. Meaningful differences between Louisiana's two active deltas required the separation of the Atchafalaya and Mississippi River deltas into two distinct groups. To further reduce the number of groups, fresh and intermediate marshes were combined into Fresh groups and brackish and salt marshes were combined into Saline groups. The Pearl River tidal swamp sites were separated out of tidal swamp due to their unique hydrology in the CRMS network.

For this analysis, impounded (non-tidal) is defined as tidal amplitude <0.1 ft which was shown to be a meaningful threshold in previous analyses. CPRA scientists reviewing CRMS data in the Calcasieu Sabine basin found that any tidal connectivity improved site conditions by reducing inundation stress (McGinnis et al., 2019). Sites may be physically impounded for water and or wildlife management as frequently occurs on the Chenier Plain or they may be functionally impounded if they are far enough inland to be beyond the reach of the tide as occurs in interior Deltaic Plain freshwater wetlands and backwater swamps.

Examining the total number of sites in each group by basin, the most common group is Tidal Saline marsh (33%; Table 3.2). Chenier Plain sites are mostly impounded fresh, managed marshes with tidal saline marshes on the perimeter of coastal lakes and bays. Deltaic Plain sites are mostly tidal saline marshes, particularly along the lower fringes, with floating fresh marshes transitioning toward impounded and tidal swamps within the upland boundaries. The Mississippi River and Atchafalaya active deltaic sites along with the Atchafalaya and Pearl River swamps combine to only account for 10.5% of the network but are some of the more dynamic locations due to the interplay of alluvial processes and the marine boundary of the Gulf. These distinctions in hydrology are directly evident in other data types and can be used in a practical application for restoration groupings, as site-specific hydrology drives most all other wetland processes. These functional groups, while intentionally broad, provide a solid framework to discuss the major hydrologic influences coastwide regardless of basin or geomorphic unit.

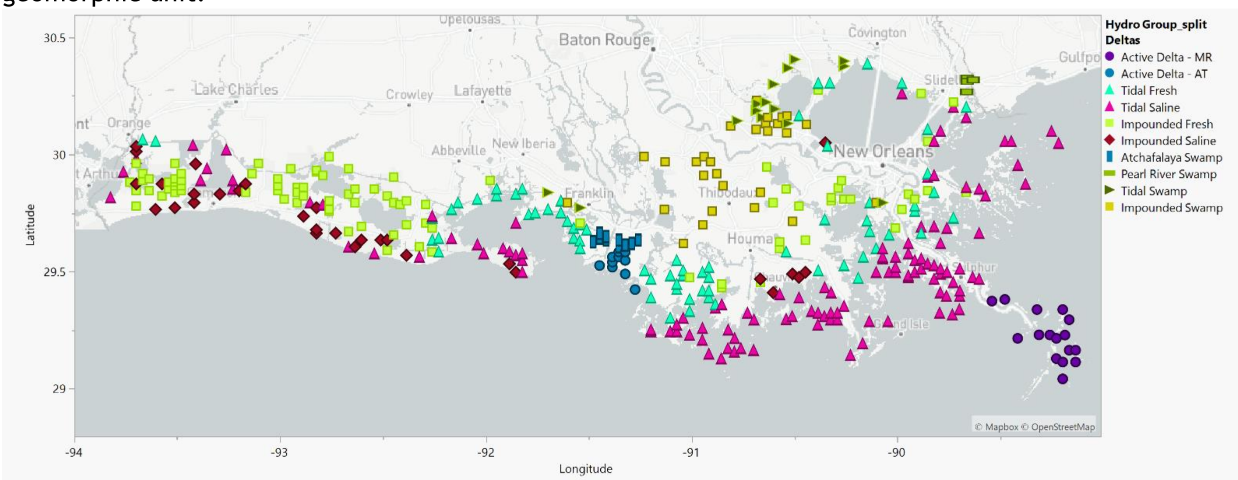


Figure 3.13. CRMS hydrology groups assignments defined by tidal connectivity and community type

Table 3.2. The number of CRMS site per hydrology group and basin

HYDRO GROUP	CS	ME	TV	AT	TE	BA	MR	BS	PO	TOTAL	% OF NETWORK
ACTIVE DELTA - MR	.	.	.	.	.	.	13	3	.	16	4.1
ACTIVE DELTA - AT	.	.	.	10	.	.	.	.	.	10	2.6
TIDAL FRESH	2	1	22	.	21	9	.	5	9	69	17.7
TIDAL SALINE	9	6	10	.	37	33	.	8	16	119	30.5
IMPOUNDED FRESH	23	36	3	.	6	12	.	4	5	89	22.8
IMPOUNDED SALINE	12	10	2	.	5	.	.	.	1	30	7.7
ATCHAFALAYA SWAMP	.	.	.	10	.	.	.	.	.	10	2.6
PEARL RIVER SWAMP	.	.	.	.	.	.	.	.	4	4	1.0
TIDAL SWAMP	.	.	2	.	.	1	.	.	12	15	3.8
IMPOUNDED SWAMP	.	.	1	.	6	10	.	.	11	28	7.2

TIDAL AMPLITUDE

Tidal amplitude (half of the tide range) has emerged as one of the more important CRMS variables, as tidal connectivity helps explain differences in regional water level, flooding and salinity trends (Figure 3.14). Tidal influence is a defining factor of coastal dynamics, orchestrating vegetation communities, patterns of land change via erosion and deposition, and flooding through drainage potential. Some parts of the coast, like the upper Deltaic Plain are non-tidal due to distance from the Gulf whereas much of the Chenier Plain was purposefully impounded for vegetation, wildlife and water management purposes.

Impoundments limit tidal deposition while management activities like extended and or repeated drawdowns further reduce marsh elevation. The benefit of impoundments is salinity and erosion control along with the ability to manage for specific vegetation and wildlife (LDWF 2011). Impoundment management is much more challenging at higher sea levels and can lead to unintended consequences related to persistent saltwater inundation and vegetation loss as seen in Calcasieu Sabine interior marshes (Wood et al 2025). This permanent saline flooding was, in most cases, the very thing the impoundment infrastructure was constructed to prevent.

Tidal marsh benefits from daily sediment deposition and drainage opportunities which produces relatively high elevation marsh platforms with robust attached wetland vegetation. However, these same marshes remain susceptible to daily tidal erosion and more direct bed shear stress during storm surge events (Howes et al 2010). This has led to a continuous reduction in marsh area while simultaneously maintaining relatively high resilient marsh platforms with healthy, robust vegetation (Wood et al 2025).

Sites with tidal connectivity drain more efficiently than non-tidal (impounded) sites, and as such they often exhibit lower inundation depths and higher salinities. CRMS sites with the largest tidal amplitudes occur in the lower Deltaic Plain and along the Vermilion Bay rim; these sites all exhibit high tidal connectivity with tidal amplitudes up to 0.9 ft. Sites within the upper Deltaic Plain and most of the western Chenier Plain exhibit very low tidal amplitudes (0.2 ft or less). Exceptions include sites along the rim of Calcasieu and Sabine Lakes, and sites in the lower Mermentau Basin that have some tidal connectivity, but do not have a direct connection to the Gulf. Intermediate tidal amplitudes occur throughout the Atchafalaya Delta, Mississippi River Delta and mid basin along the Deltaic Plain.

Groups were defined by tidal amplitude and marsh type (Figures 3.15). Trends in groups do vary through time with an increase in tidal amplitude after 2015 in all tidal groups. There is a notable increase in tidal amplitude in both active deltas where tidal amplitude nearly doubled between 2019 and 2023. Here it would appear that lower river discharge in 2021-2023 allowed marshes to become more tidally influenced.

Among swamps, Pearl River is much more tidal than other swamps with tidal amplitude values as high as tidal salt marsh and active delta sites. Atchafalaya swamp sites capture the same trend as active deltas with increasing tidal amplitude occurring in drought years. High river flow mutes the tide and low river flow allows for more tidal ingress into deltas. Swamps in the Pearl River and the Atchafalaya Delta can occur in closer proximity to the more tidal and more saline open bays and coastal lakes due to their regular fresh water deliveries from upstream, thus having higher tidal signature in an obligate fresh water habitat.

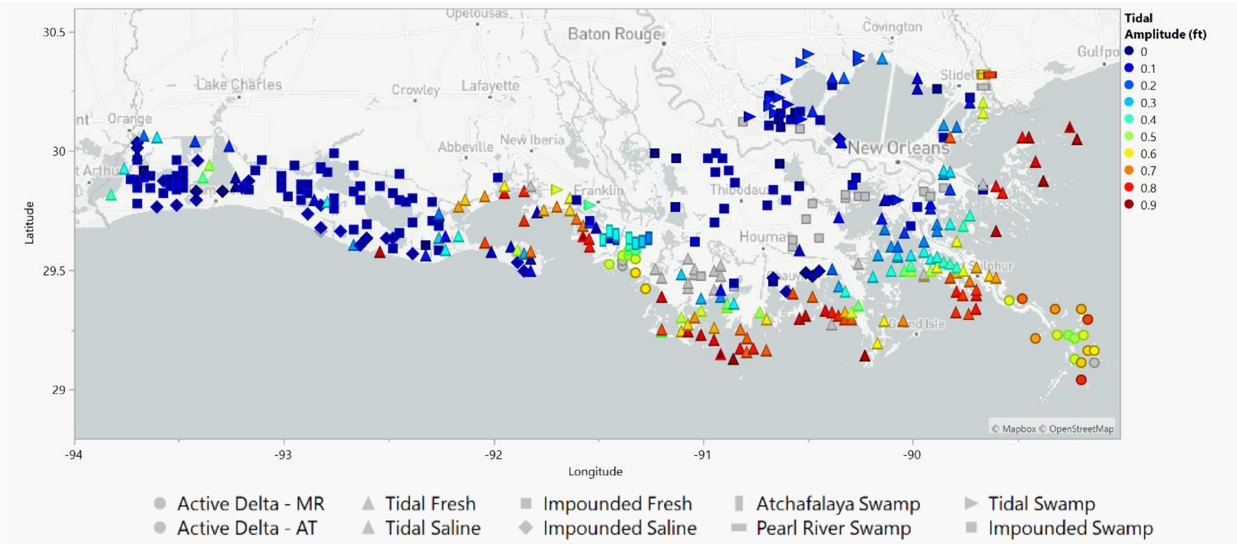


Figure 3.14. Median of annual tidal amplitude values from 2008 to 2023 by CRMS site

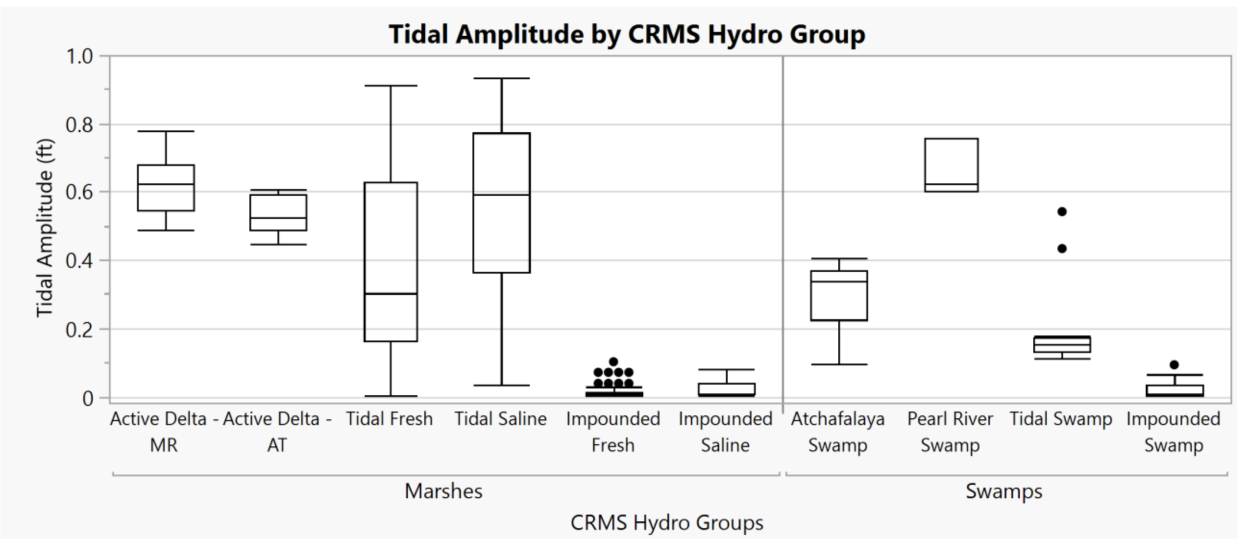


Figure 3.15. Distribution of median tidal amplitude (ft) values by CRMS Hydro Group. Median values for each CRMS site included in distribution were derived from annual means (2008 and 2023). Box plot indicates mean, quartiles, range, and outliers

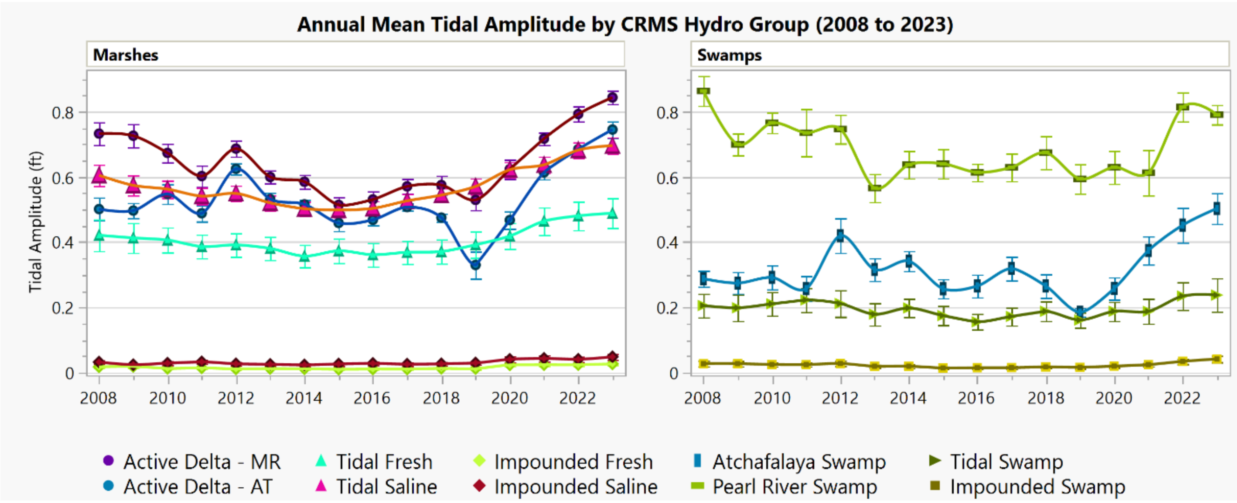


Figure 3.16. Annual mean tidal amplitude (ft) by CRMS Hydro Group from 2008 to 2023. Interestingly the tidal saline and tidal fresh groups do not see the same acceleration in tidal amplitude as the deltas under low river flow as they shift from riverine to marine dominated processes

WATER SURFACE ELEVATION

Water surface elevation generally increases from the edge of the coastal boundary inland. The lowest water observed coastwide is on the fringe of the lower Deltaic Plain where tidal exchange is open and water movement is relatively unrestricted (Figure 3.17). Water surface elevations in managed areas across coastal Louisiana can also reach relatively low levels if they are actively managed to reduce water level and/or have a direct outlet to the Gulf, as is seen in the Mermentau Basin south of Catfish Locks and on the Orleans Landbridge in Bayou Sauvage NWR (Appendix A). Inland areas, including coastal swamps and most Chenier Plain impoundments, have higher water elevations than tidal areas except during periods of intense drought. Evapotranspiration during drought can draw down impoundments to levels below Gulf sea level for months at a time.

Water surface elevations have displayed a consistently rising trend across all CRMS groups since 2015 (Figures 3.18 and 3.19), with the lowest water elevations within the Mississippi River delta and tidal salt marshes. The highest water elevations consistently occur in the Atchafalaya delta. The highest water surface elevations occurred in 2019 coastwide, followed closely by 2020. By 2023, water elevations had receded to levels comparable to 2017 but still higher than they were at program inception capturing about 0.5’ (15 cm) of sea level rise since 2008.

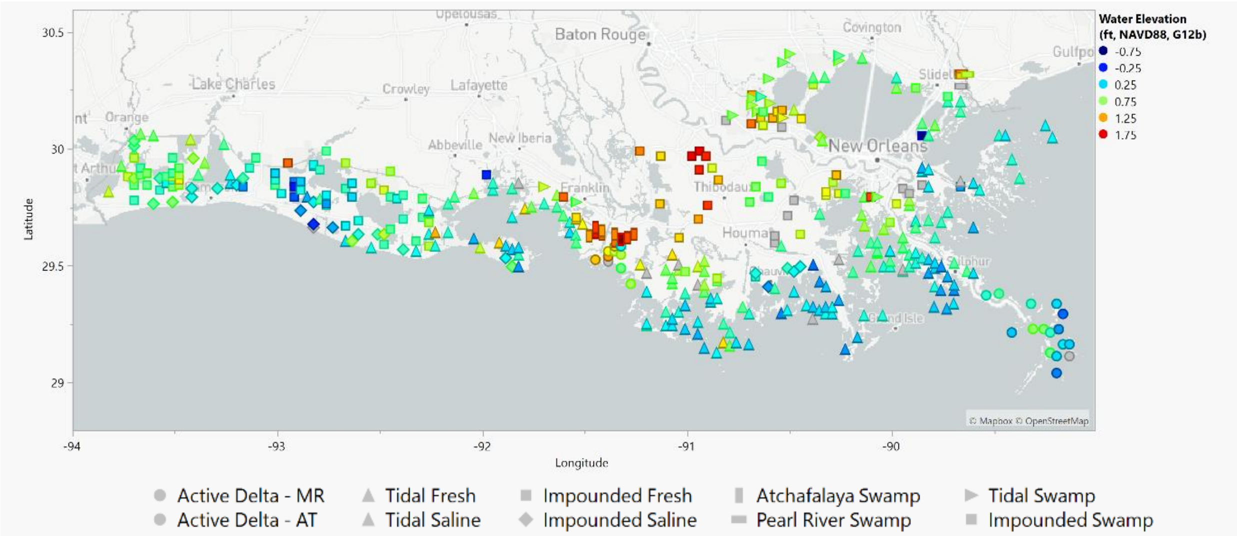


Figure 3.17. Median of annual water elevation (2008 to 2023) by CRMS site. The Atchafalaya Basin sites are consistently the highest water elevation along with impounded swamps, while sparsely distributed actively managed impoundments maintain the lowest water coastwide. Some of these impoundments employ pumps while others take advantage of their proximity to the relatively low waters of the Gulf

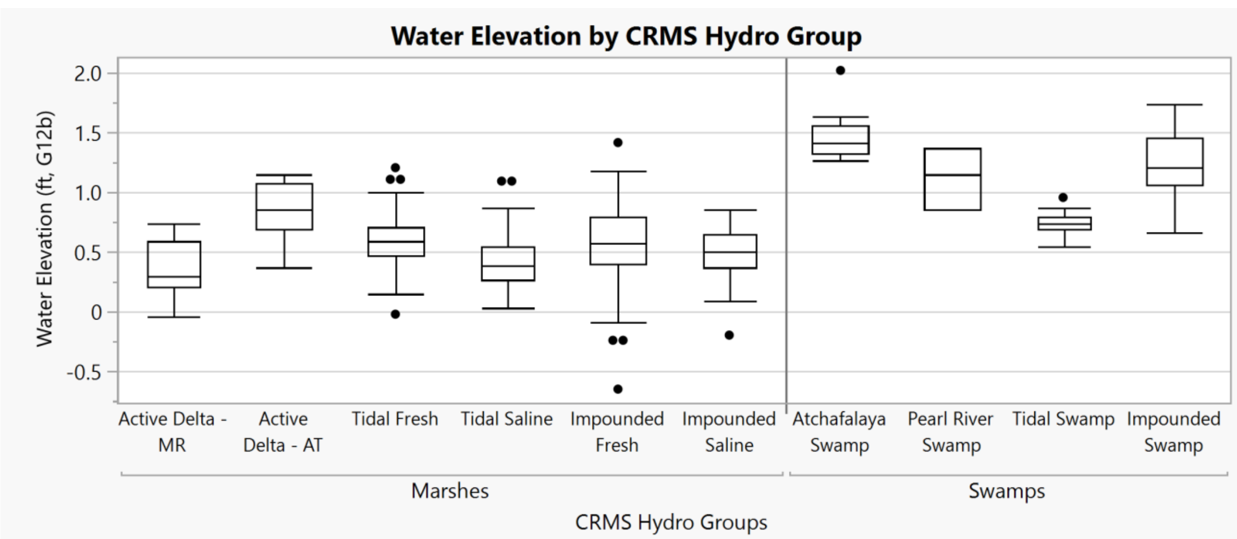


Figure 3.18. Distribution of median water elevation (ft, NAVD 88, Geoid 12b) values by CRMS Hydro Group. Median values for each CRMS site included in distribution were derived from annual means (2008 and 2023). Box plot indicates mean, quartiles, range, and outliers

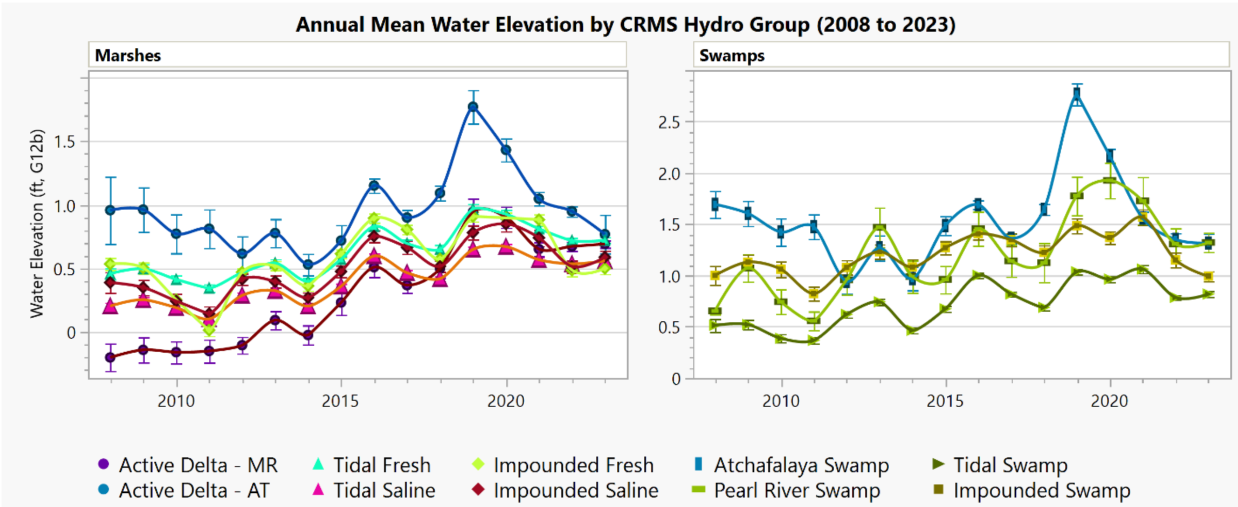


Figure 3.19. Water elevation trend by CRMS Hydro Group from 2008 to 2023. These hydro groups vary independently through time but as water elevation increases across the coast their behavior tends to become more homogenized. The one notable exception is the extreme high water event associated with the 2019 historic river flooding

WETLAND INUNDATION DEPTH AND DURATION

Flood depth and duration patterns integrate water and marsh elevations and reflect the interaction between the landscape, emerging deltas, receiving basins, and other impoundment effects (Figures 3.20 and 3.23). On the Deltaic Plain, sites east of the Mississippi River within Breton Sound are tidal and have relatively high marsh elevations; therefore, inundation depth and duration values are relatively low. Marsh elevations at sites across the emerging Mississippi River birdsfoot delta are relatively low and as such these sites are frequently inundated, especially during high river discharge years. The mid and lower Barataria and Terrebonne basins display moderate flood depths and durations compared to impounded and inland areas. Sites influenced by the Atchafalaya River, including Atchafalaya basin and parts of Terrebonne and Teche-Vermilion basins, have the highest marsh elevations and very low flood depth and flood time values as a result. These marshes are effectively subaerial and generally reside in the upper portion of the tidal frame. Chenier Plain sites south of Hwy 82 and those with some degree of tidal connectivity experience less flooding compared to impounded sites further inland. Finally, sites across the inland portions of the Mermentau and Calcasieu-Sabine basins experience greater flood depths with longer flood durations than any other marsh habitat coastwide. The Mermentau lakes sub-basin and the Maurepas swamp are epicenters of permanent freshwater flooding, albeit due to different mechanisms. The Mermentau Lakes sub-basin is an anthropogenic freshwater reservoir managed by USACE to provide a stable source of fresh water for agriculture. The Maurepas swamp fresh water impoundment is a naturally occurring geographically isolated backwater swamp of the Mississippi River, which is fed through local upland runoff and influenced by weak tidal forces but often results in unintentional non-tidal impoundments. This natural impoundment is further exacerbated by legacy infrastructure from logging, oil and gas extraction, and the Mississippi River levees.

Inundation depths increased with sea level rise within all groups after 2015 with only the Atchafalaya delta marshes, Tidal Fresh and Tidal Saline groups maintaining negative inundation values, even in recent drought years (Figures 3.21 and 3.22). Inundation values are highest in the Mississippi River delta and impounded marshes. Swamps are practically always inundated, with the exception of the Pearl River which is most similar in flood regime to saline marshes. The effect of the high Mississippi/Atchafalaya discharge during 2019 was particularly noticeable within the active deltas. As sea level rise plateaued and rainfall decreased in 2021, all groups showed a decrease in inundation through the end of the monitoring period. This took place in concert with several intense heat domes over the southeastern U.S., which induced westerly winds and reduced continental shelf sea level through Ekman divergence. The Tidal Fresh, Tidal Saline and Atchafalaya Delta groups exhibited negative inundation depths through the drought of 2022-2023. Even with the rapid decrease in water surface elevations through the drought, the impounded groups, which exhibited lower marsh elevations, were still submerged on average. This indicates that flooding in these groups is chronic and would require significant modifications to alter these hydrologic regimes.

Flood duration increased within all groups after 2014 with all impounded, Mississippi River delta groups being inundated more than 60% of the year until they began to decrease in 2021 (Figures 3.24 and 3.25). The AT delta marshes were the most dynamic with inundation reducing from 80% in 2019 to 20% in 2021. The Pearl River swamp was inundated >80% of the time until levels began to drop in 2020. Water elevation to datum has remained higher post 2022-2023 drought than it was prior to the 2015-2016 acceleration. However flood depth and flood duration are near the lowest in the CRMS record, this is a result of marsh surface elevation gain during the prolonged flooding. Much of this surface elevation gain was retained even after water level dropped and has resulted in lower flood statistics coastwide with still above average water elevations.

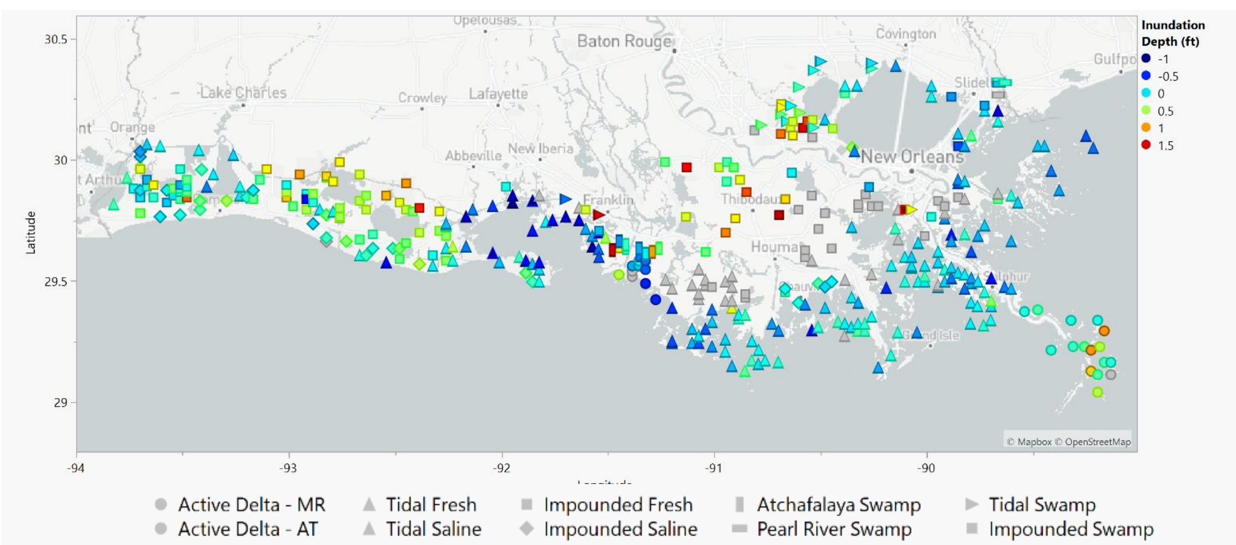


Figure 3.20. Median annual inundation depth (ft) (2008 to 2023) by CRMS site. The Mermentau Lakes Sub-basin and the interior swamps are flooded over 0.5 ft on average, while water is well below surface elevation in the AT and TV basins

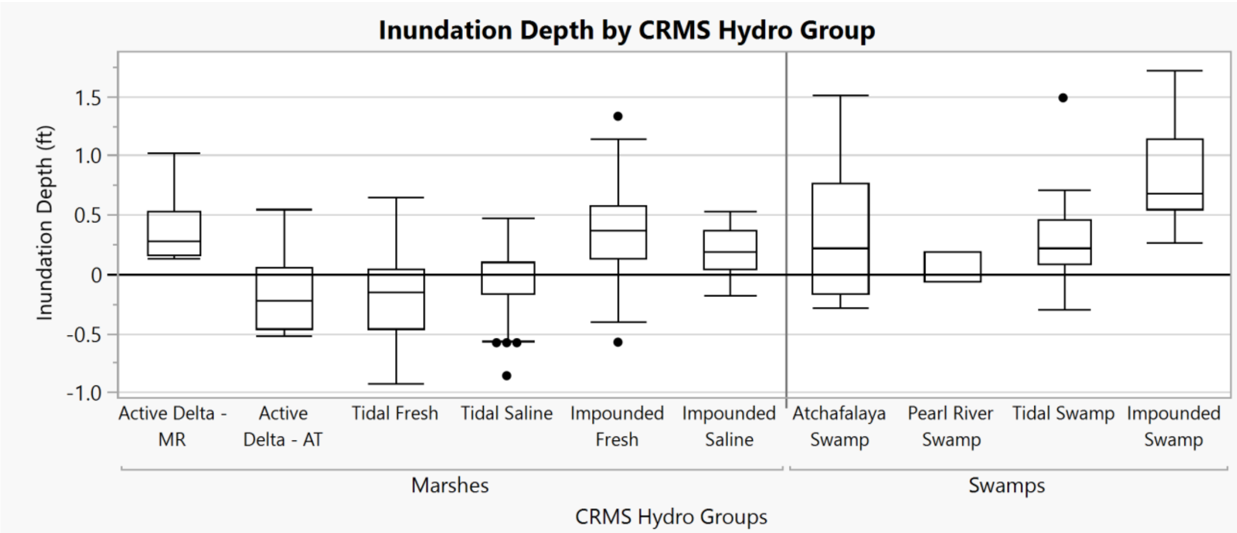


Figure 3.21. Distribution of median inundation depth (ft) values by CRMS Hydro Group. Median values for each CRMS site included in distribution were derived from annual means (2008 and 2023). Box plot indicates mean, quartiles, range, and outliers. The Mississippi River birdsfoot delta and the impounded swamps are the only groups with inundation depths over the soil surface at all sites

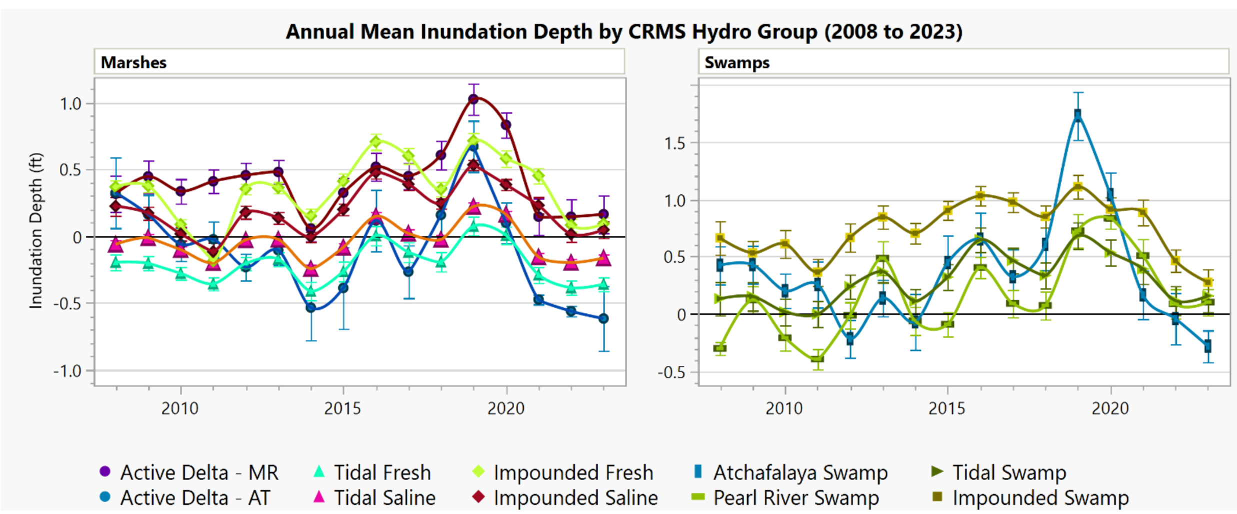


Figure 3.22. Trends in annual inundation depth (ft) by CRMS Hydro Group from 2008 to 2023. Inundation depth has reverted back to pre-2016-2021 levels as drought and low riverine inputs have manifested in recent years

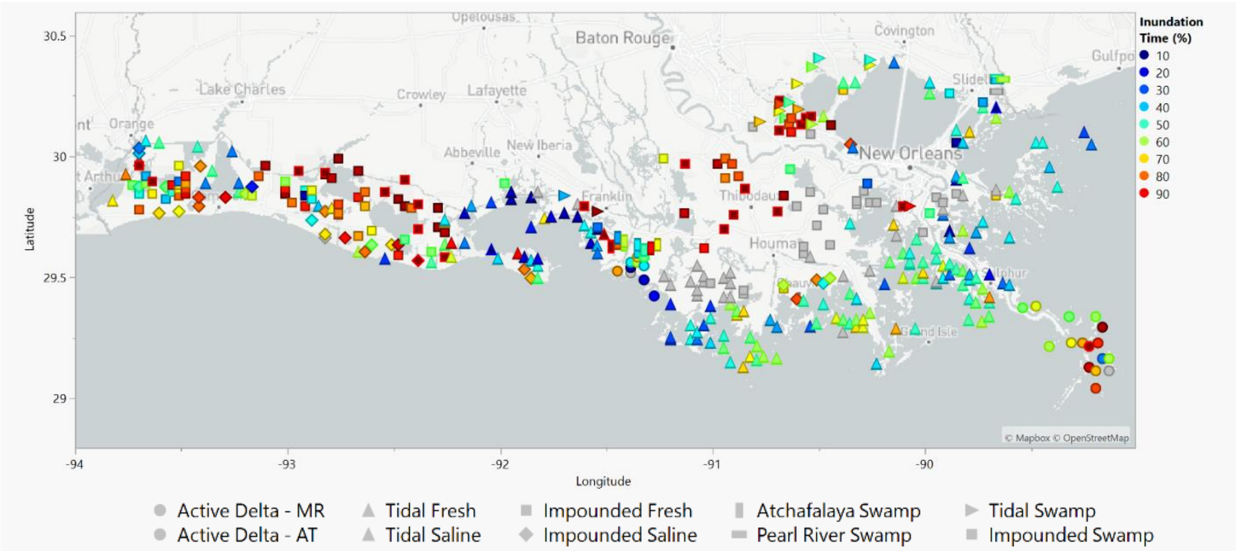


Figure 3.23. Median annual inundation time (% time flooded) (2008 to 2023) by CRMS site. Many Chenier plain, MRD, and interior sites are flooded nearly year round

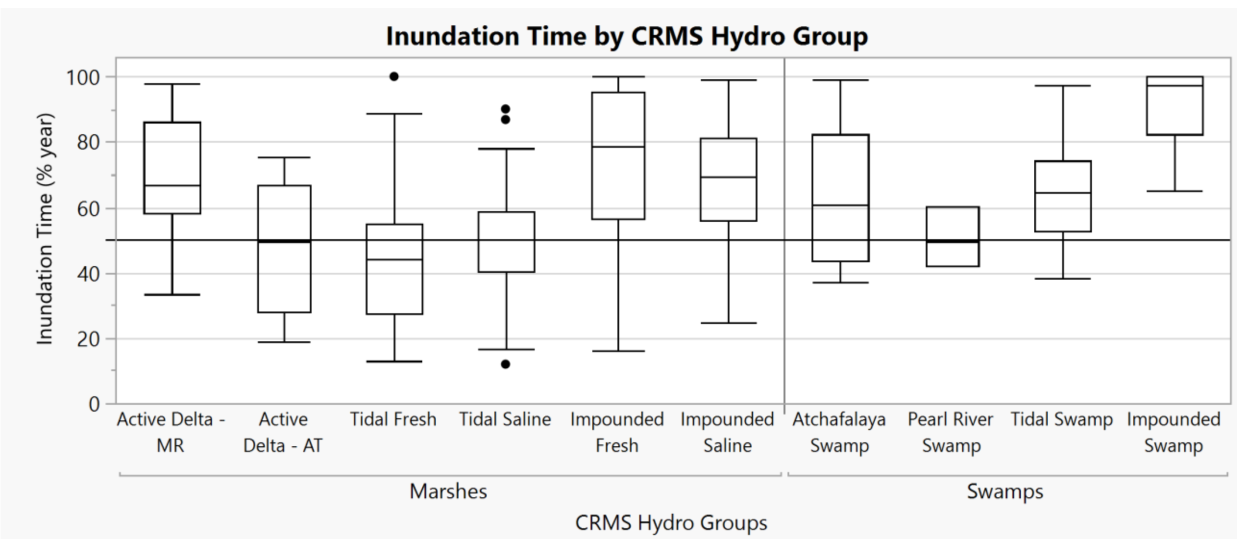


Figure 3.24. Distribution of median inundation time (% of year) values by CRMS Hydro Group. Median values for each CRMS site included in distribution were derived from annual means (2008 and 2023). Box plot indicates mean, quartiles, range, and outliers

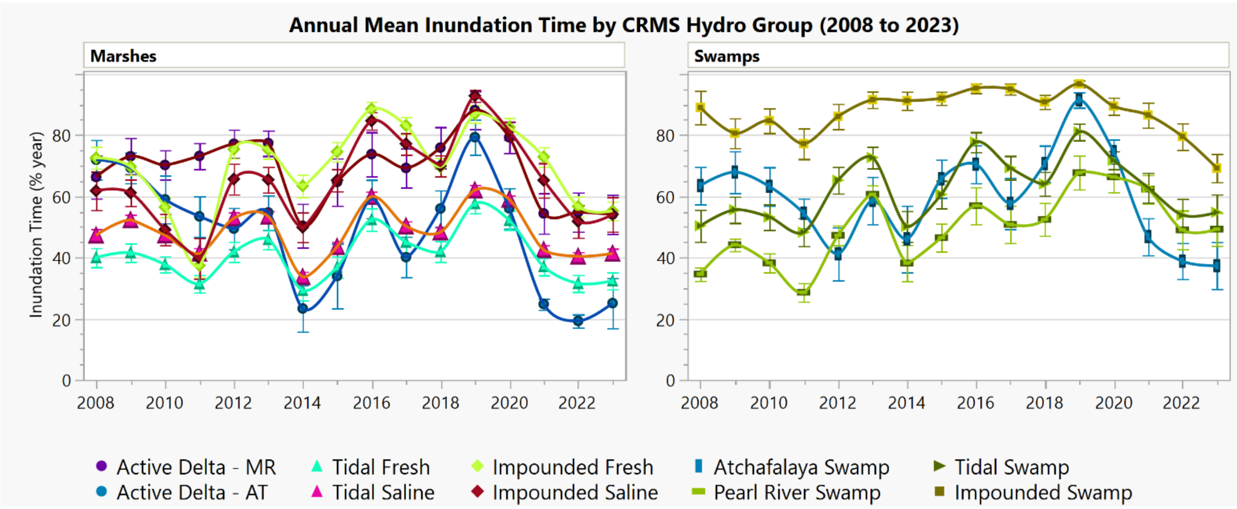


Figure 3.25. Trends in annual inundation time by CRMS Hydro Group from 2008 to 2023. Current inundation time is similar to 2014 levels as drought and low riverine inputs have reduced water level but the soil surface elevation gained from the response to the multiyear flood event of 2015-2021 was retained

SALINITY

Saltwater migrates into Louisiana's coastal wetlands inland from the Gulf through a myriad of waterways, many of which have been anthropogenically modified in ways that exacerbate saltwater intrusion. Examples include the Calcasieu Ship channel, Houma Navigation Canal, Barataria Waterway, and the now closed Mississippi River Gulf Outlet (MRGO). Tidally influenced CRMS sites on the lower Deltaic Plain that are not also influenced by the Mississippi or Atchafalaya Rivers display the highest average annual salinity values, ranging from 12-23 ppt (Figure 3.26). Brackish sites inland of the salt marsh sites and in managed areas on the Chenier Plain, as well as tidally connected sites on the perimeter of Calcasieu Lake and Vermilion Bay, display salinities ranging from 7-10 ppt. Beyond these exceptions, most CRMS sites are relatively fresh, averaging below 5 ppt in the interior regions of the coast (Figure 3.26). Average salinities are lowest and often near zero within the swamps of the upper Terrebonne, Barataria and Pontchartrain Basins, the Mermentau lakes sub-basin, and active deltas associated with the Mississippi and Atchafalaya rivers. The salinity gradient along coastal Louisiana is substantially truncated compared to other coastal areas on the northern Gulf coast and Atlantic seaboard due to the large freshwater discharge from the Mississippi/Atchafalaya River complex conveyed to the west along the Louisiana continental shelf as a longshore current.

Salinity levels declined within all non-fresh CRMS hydro groups following the 2010-2011 drought until the 2022-23 drought (Figures 3.28 and 3.29). The lowest salinities were observed within the Tidal Swamp, Impounded Swamp, and Active Delta groups (Figure 3.27). The highest salinities occurred in the Tidal Saline and Impounded Saline marshes. Coastwide, the highest salinities occurred during the extended exceptional droughts of 2010-2011 and 2022-23. Large salinity increases in 2011 which co-occurred with near record Mississippi River discharge, were restricted to the Tidal Saline, Impounded Saline, and Impounded Fresh groups. Effects of the 2022-2023 drought were seen within all groups except for the Atchafalaya delta, with salinities increasing far inland. Mean annual salinity in salt marsh increased from around 8 ppt to 15 ppt and fresh tidal marshes increased by several ppt. These changes are expected to cause changes in vegetation community composition in post drought years.

Prior to the 2022 drought, the coast was freshening due in large part to elevated sea levels trapping river and rain discharge within the coastal zone, so information about how increasing salinity affects wetland vegetation is only now emerging in the CRMS dataset. Trends after 2021 include the effect of increasing salinity.

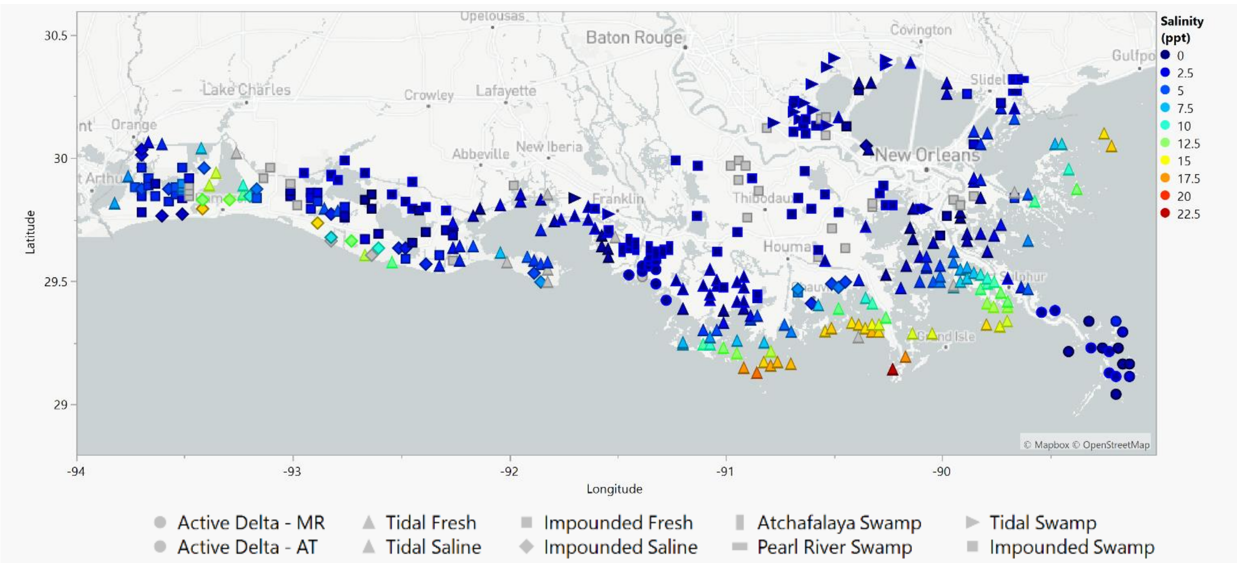


Figure 3.26. Median annual salinity (2008 to 2023) by CRMS site. The area from Port Sulphur through the Caminada headland stretching west to Caillou Bay contains the majority of non-fresh coastal wetlands

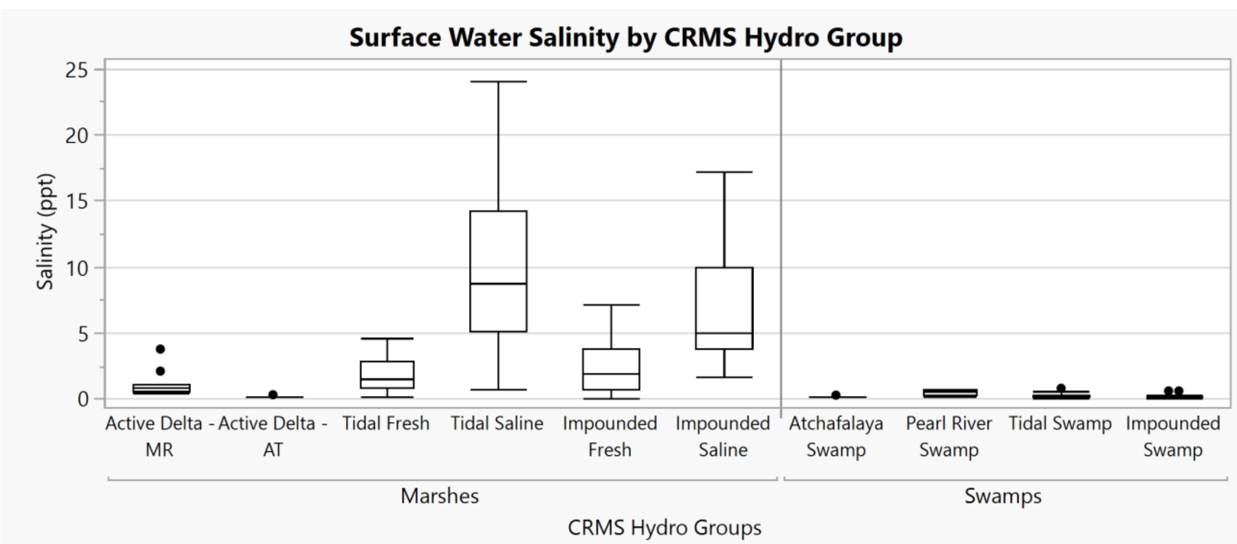


Figure 3.27. Distribution of median salinity (ppt) values by CRMS Hydro Group. Median values for each CRMS site included in distribution were derived from annual means (2008 and 2023). Box plot indicates mean, quartiles, range, and outliers. Impounded Fresh sites have a broader salinity range than the Tidal Fresh group which is somewhat counter intuitive. This is mostly a result of salinity concentration during exceptional drought conditions. Even Tidal Saline marshes experience periods of fresh water inundation due to river and upland flooding conditions

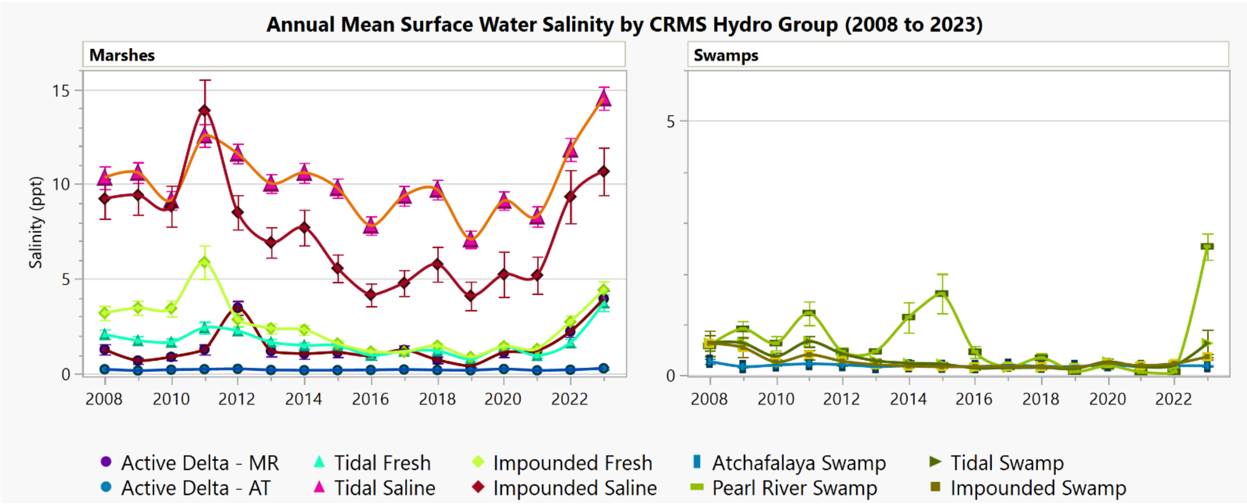


Figure 3.28. Salinity trend by Hydro Group from 2008 to 2023. The Pearl River swamp is the only swamp site to experience meaningful salinity spikes in the CRMS record, yet remains forested due to natural riverine inputs flushing the system. Tidal Fresh and Impounded Fresh groups started with higher than average salinities in 2008 likely due to Hurricane Gustav and Ike

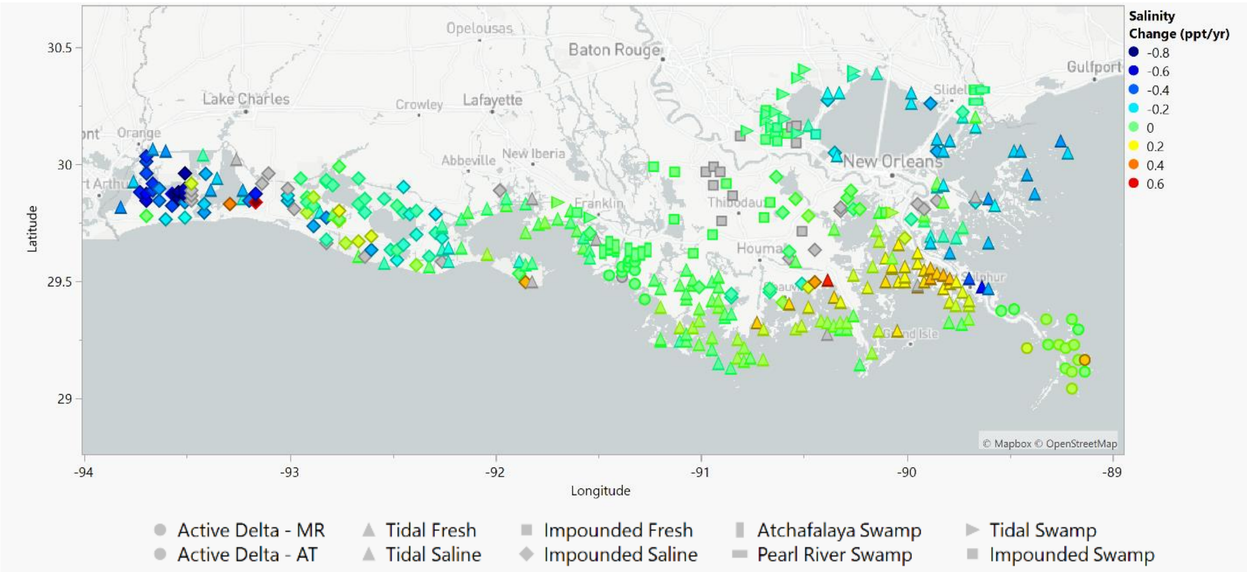


Figure 3.29. Salinity change rate (ppt/yr) calculated as linear regression through annual mean salinity values from 2008 to 2023

4.0 WETLAND ELEVATION DYNAMICS

4.1 MONITORING APPROACH

Surface elevation change and accretion are measured concurrently at 90% of sites in the CRMS network, which includes all sites except floating marsh and perpetually flooded swamp sites where the method cannot be precisely applied. Surface elevation change (SEC) is measured with a Rod Surface Elevation Table (RSET) leveling arm relative to a rod driven to refusal as described in Lynch et al., 2015 (Figures 4.1 and 4.2). Vertical accretion (VA) is measured concurrently in nearby accretion plots using the feldspar marker horizon method (Lynch et al., 2015).

RSET rods and vertical accretion stations were established coastwide between 2006 and 2008. Station establishment protocols required that the stations be established within living vegetation and at least 10 m from the water's edge. No sites were constructed in open water though several have converted to open water over the CRMS monitoring timeframe (Folse et al., 2023).

SURFACE ELEVATION CHANGE (SEC)

Surface elevation data is measured and stored as pin height relative to the instrument which provides a precise dataset for calculating elevation change and comparing to vertical accretion. Elevation change is calculated as the difference between the most recent observation and the baseline observation. SEC rates served on the CRMS website use the first observation as the baseline (typically between 2006 and 2008). For this analysis, the baseline was standardized to the Spring 2008 pin height measurement.

Pin height data can be converted to marsh elevation to datum and interpreted relative to changing water elevation using a set of conversion factors maintained by CPRA (Figure 4.3; Data Appendix). As of 2025, ten sites have seen deposition so high that RSET rods had to be extended to account for elevation gain so that monitoring could continue (Figure 4.4). Nineteen sites have seen so much elevation loss that longer pins had to be used to continue monitoring. Pin height to elevation to datum conversion values incorporate all equipment adjustments to date. Future adjustments to equipment deviations would change conversion values in successive analysis.

Station elevations were established during site construction (2006 to 2008) and the entire network was re-surveyed using a comprehensive network solution in 2014 and 2021 (CPRA 2019). Elevations are maintained between surveys through QA/QC, data review and maintenance surveys as needed. The next CRMS coastwide elevation update will take place in 2027.

Surface elevation change rates (SEC) were calculated with linear regression from 2008 to 2024. Where sites have converted to open water, rates were calculated from 2008 through the last vegetated date (excluding observations after all vegetation removed). Rates that include open water observations are available in the data appendix.

VERTICAL ACCRETION (VA)

The CRMS accretion sampling design provides accretion data from different aged plots, established systematically throughout the CRMS sampling time frame. Eight sets of three 0.5m x 0.5m plots have been established through 2025 (Table 4.1). The oldest plots (Plot Set 1; PS1) are over 16 years old and the youngest plots (PS8) were established in 2023 (Table 4.1). Accretion stations are cored more frequently after initial establishment and are regularly re-sampled through time (Figure 4.5).

The CRMS accretion sampling design lends itself to multiple types of inquiry. If one were looking for an estimate of how much material was deposited by a particular storm, newer plot sets would be most valuable. If one were looking for a long-term estimate of accretion to compare to surface elevation change, data from older plot sets would be more appropriate as more time and consolidation is included in the measurement. Averaging across different aged plot sets is not recommended.

For this analysis, accretion rates were derived from all available data and were calculated across plot sets as a regression of accretion (mm) versus time since plot set establishment. The accretion rate derived from this method is about the same as the rate from PS1 and PS2 (length of record 16 and 14 years respectively (see Appendix).

RELATIONSHIP BETWEEN SURFACE ELEVATION CHANGE AND VERTICAL ACCRETION

Surface elevation change integrates soil formation processes from the bottom of the RSET rod to the wetland surface. The SEC trend expresses the combined effect of surface deposition, organic accumulation, root growth, shallow expansion, decomposition, compaction, and subsidence. Vertical accretion captures sediment accumulation at the soil's surface above a feldspar marker horizons and helps interpret the efficiency and origin of soil formation indicated by the RSET. Vertical accretion is incorporated into Surface Elevation Change measurements.

Accretion rates are expected to be higher than SEC rates in attached wetlands keeping up with sea level rise. Wetlands were believed to be attached in all locations where the SEC/VA method was applied. There are instances where there is more elevation change than accretion can explain. At these times and locations, the wetland surface had expanded via pore space expansion, root formation, and/or water filled voids and potentially detached from the substrate allowing for elevation gain without surface deposition.

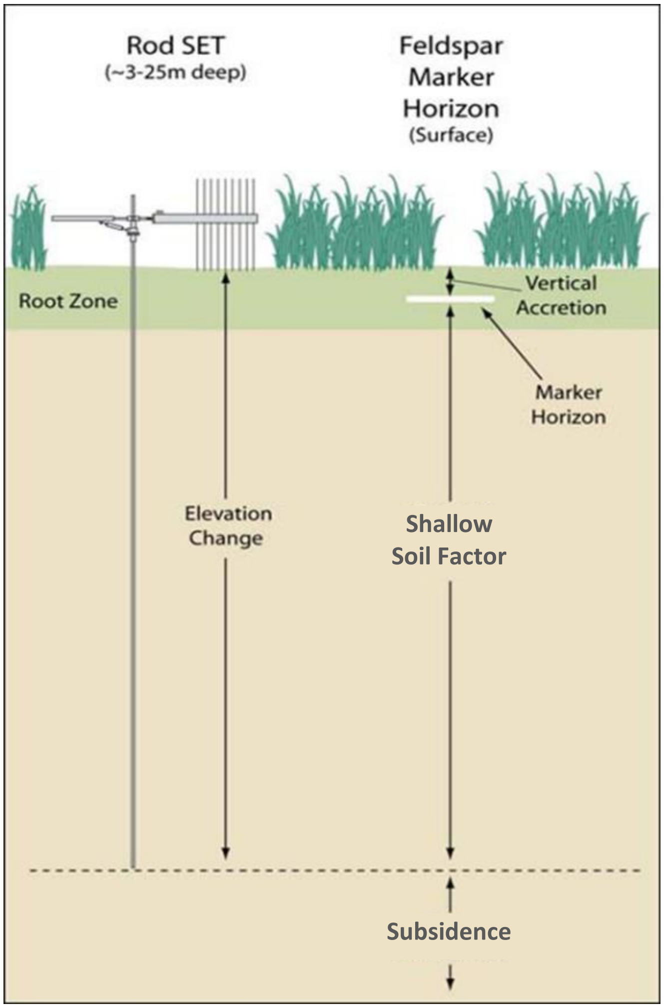


Figure 4.1. Surface elevation and accretion sampling diagram modified from Lynch et al, 2015 to match current CPRA terminology (CPRA 2025)

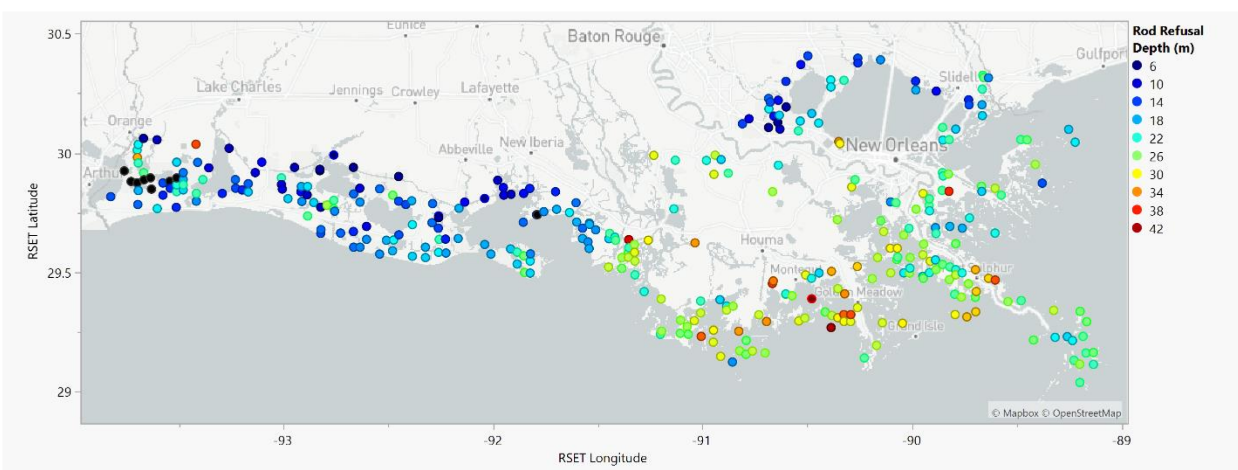


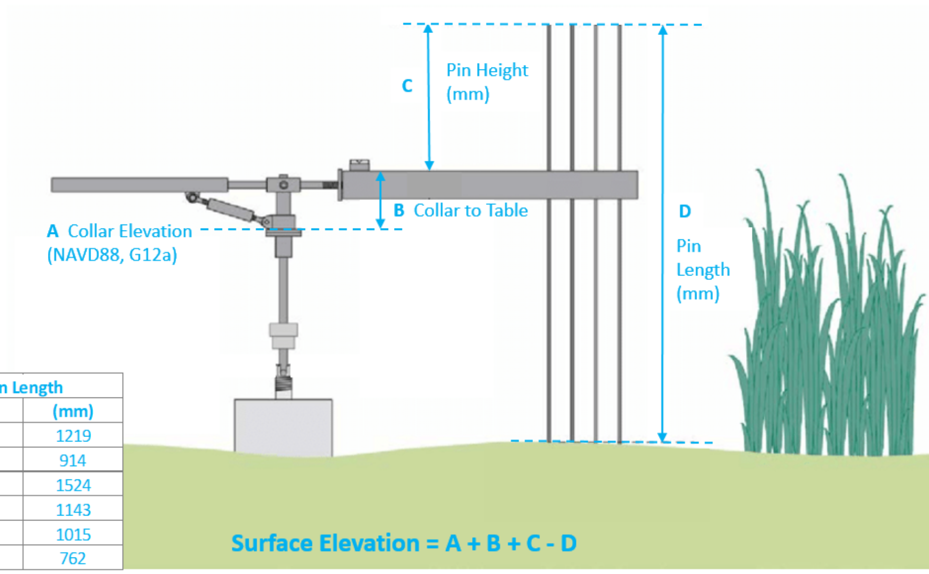
Figure 4.2. RSET Rod refusal depths, this generally translates to the depth of the Holocene over the Pleistocene epoch with deeper rod depth in the southern portions of the deltaic plain

CRMS Surface Elevation (NAVD88, G12b)

A – Some sites have been extended due to high deposition since the last survey. Extension length must be added to collar elevation.

B - Constant 110 mm measured from CRMS RSETs

D - Pin Length varies by Organization



Organization	Pin Length (ft)	Pin Length (mm)
Contractor Long Pins	4.0	1219
Contractor Regular Pins	3.0	914
CPRA Long Pins	5.0	1524
CPRA Regular Pins	3.75	1143
USGS Long Pins	3.33	1015
USGS Regular Pins	2.5	762

Figure 4.3. Diagram of values needed to convert CRMS pin heights served in CIMS into the vertical datum to compare to CRMS water elevations

Figure 4.4. Photograph of CRMS rod extension with new collar at Mississippi River Delta site CRMS0156 in 2016

Table 4.1. CRMS Accretion Plot Set Age Summary

CRMS Accretion Plot Set	PS Establishment Season	Median Establishment Date	Last Sample Season	PS Age as of 4/1/2024 (yrs)
PS1	Spring 2008	1/22/2008	Spring 2022	16.2
PS2	Spring 2010	3/17/2010	Spring 2023	14.1
PS3	Spring 2012	3/20/2012	Spring 2024	12.0
PS4	Spring 2014	4/1/2014	Spring 2022	10.0
PS5	Fall 2016	10/6/2016	Spring 2023	7.5
PS6	Spring 2018	4/3/2018	Spring 2024	6.0
PS7	Spring 2020	4/1/2020	Spring 2023	4.0
PS8	Spring 2023	2/28/2023	Spring 2024	1.1

	Plot Set (PS)									
Field Season	PS 1	PS 2	PS 3	PS 4	PS 5	PS 6	PS 7	PS 8	PS 9	PS 10
Sp 08*	E									
Fa 08	x									
Sp 09	x									
Fa 09	x									
Sp 10	x	E								
Fa 10		x								
Sp 11	x	x								
Fa 11		x								
Sp 12		x	E							
Fa 12	x		x							
Sp 13		x	x							
Fa 13			x							
Sp 14	x		x	E						
Fa 14		x		x						
Sp 15			x	x						
Fa 15	x			x						
Sp 16		x		x						
Fa 16			x		E*					
Sp 17	x			x	x					
Fa 17		x			x					
Sp 18			x		x	E				
Fa 18	x			x		x				
Sp 19		x			x	x				
Fa 19			x			x				
Sp 20	x			x		x	E			
Fa 20		x			x		x			
Sp 21			x			x	x			
Sp 22	x			x			x			
Sp 23		x			x		x	E		
Sp 24			x			x		x		
Sp 25	x			x			x	x		
Sp 26		x			x			x		
Sp 27			x			x		x	E	
Sp 28	x			x			x		x	
Sp 29		x			x			x	x	
Sp 30			x			x			x	
Sp 31	x			x			x		x	E
Sp 32		x			x			x		x
Sp 33			x			x			x	x
Sp 34	x			x			x			x
Sp 35		x			x			x		x
Sp 36			x			x			x	

E = Establish Plot Set (n=3)
x = sample Plot Set (n=3)

Figure 4.5. Feldspar marker horizon establishment and sampling design for CRMS accretion Plot Sets. Plot Set 1 was established as sites were constructed. Plot Set 2 was established in Spring of 2010. SEC and VA were measured twice a year in spring and fall from inception to 2020 and then once a year in the spring thereafter. SP=Spring, FA=Fall, PS=Pot Set, E=Establishment. E*= PS 5 was established in Fall 2016 due to high water in Spring 2016.

4.2 SURFACE ELEVATION DYNAMICS (RSET DATA)

INITIAL ELEVATION

CRMS monitoring began just after Hurricanes Katrina and Rita caused both land loss and storm surge deposition coastwide in 2005 (Turner et al., 2006). Sea level was relatively low (Figure 3.3) and the recent deposition placed marshes high in the tidal frame (McKee and Cherry, 2009). Initial marsh elevation was highest in the central coast including the Atchafalaya and Teche-Vermilion basins (Figure 4.6). Sites along the Mississippi River were also high, particularly east of the river in Breton Sound and elevation was relatively high in some swamps. Initial elevations were lowest in the emerging birdsfoot delta and in Chenier Plain impoundments.

By Hydro Group, MR delta marshes were lowest while AT delta marshes were a foot higher (Figure 4.7). Impounded marsh groups are lower elevation than tidal marsh groups. Tidal Salt is lower than Tidal Fresh. Tidal fresh marsh is as high as AT delta marsh and is higher than the Tidal Salt marsh group.

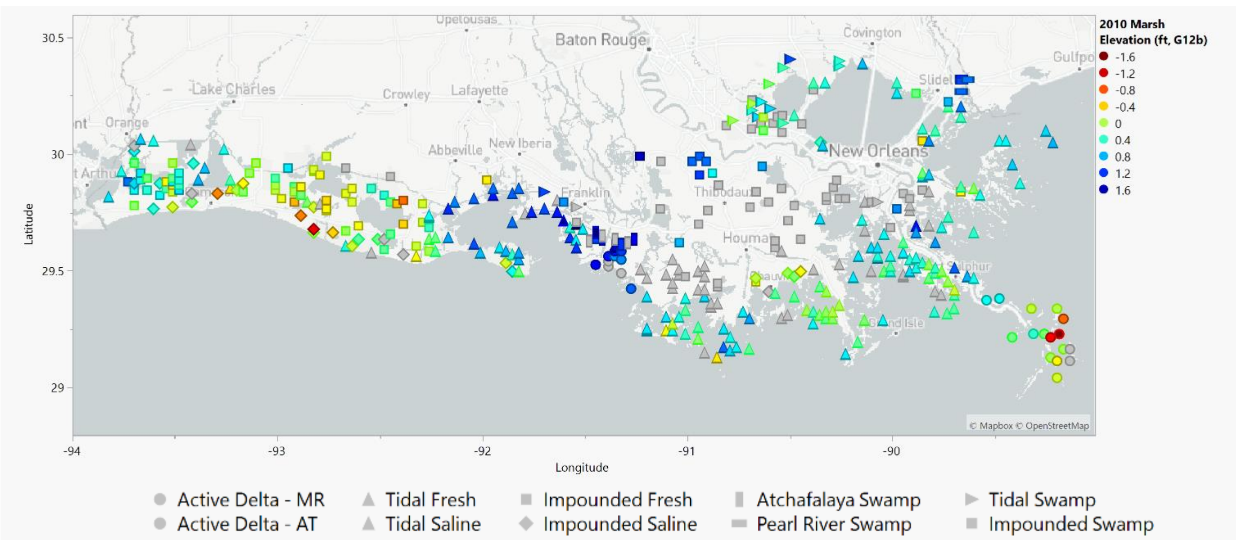


Figure 4.6. Initial wetland surface elevation at CRMS sites derived from RSET data

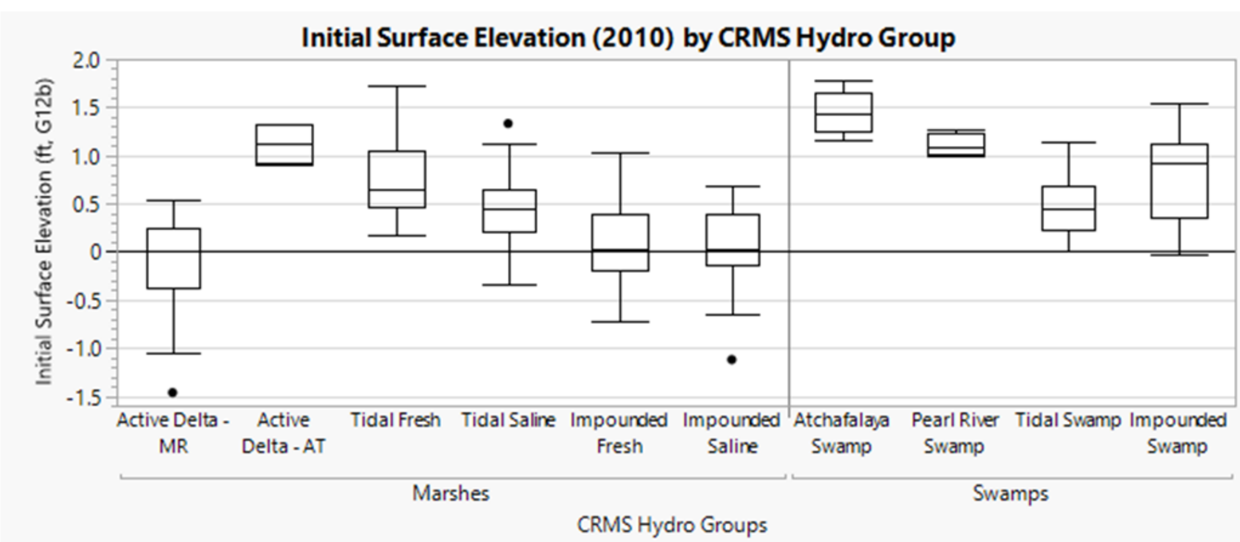


Figure 4.7. Distribution of initial wetland surface elevation by Hydro Group. Box plot

indicates mean, quartiles, range, and outliers

ELEVATION CHANGE

Throughout the CRMS monitoring timeframe, surface elevation of marshes on the Deltaic Plain have generally increased with rising water levels while Chenier Plain sites increased more slowly (Figure 4.8). Both regions experienced the same sea level rise (Figure 3.6). Deltaic plain sites effectively kept up with sea level (marsh elevation tracks mean water level) while Chenier Plain sites became submerged. Hurricane deposition from Hurricanes Barry, Laura, Delta and Ida between 2019 and 2021 (Table 1) combined with the drop in water level in 2022 and 2023 effectively raised Chenier Plain sites back up to mean water level and placed Deltaic Plain sites above mean water which is similar to conditions in 2005 post Katrina and Rita. Some of this elevation gain come at the expense of lost wetland area as the marsh platform captures sediment from eroding wetlands.

CRMS surface elevation trajectories have been positive since program inception. Deltaic plain wetlands are gaining elevation at 8 mm/yr while Chenier Plain gains 5 mm/yr (Figure 4.9). Elevation of the wetland surface is higher on the Deltaic Plain, in part due to inland swamp elevations. By hydro group, swamps and AT delta marshes are highest (Figure 4.10). Tidal fresh marsh is higher than tidal salt marsh. The MR delta has emerged from the lowest elevation to the height of other saline tidal marsh in recent years. High deposition during floods in 2016, 2019 and 2020 contributed to elevation gain. Impounded marsh types are the lowest elevation on the coast as the only mechanism for elevation gain is through peat formation which is also reduced via flooding and nutrient limitations.

When compared to observed water elevations, it is clear that wetland surfaces track mean water elevation in most of Louisiana's coastal wetlands (Figure 4.11). The MR delta has been the most dynamic and has kept on track with mean water since program inception. The AT delta marshes are above mean water as are Tidal Fresh wetlands. Tidal Saline are effectively at mean water. Impounded wetlands are at the bottom of the tidal frame and only approach mean water elevation in a drought.

The highest surface elevation gain rates occur in the active deltas with a maximum rate of 55 mm/yr occurring in the birdsfoot delta of the Mississippi River (CRMS2627, Appendix C). Very high elevation gain is common in active deltas (Figure 4.12). When the same occurs outside of active deltas, the sediment source has been either tidal erosion (Stagg et al., 2024; Marrioti and Carr, 2014; CRMS0174, Appendix C), storm surge deposition (Tweel and Turner 2012; CRMS0225 and CRMS0600 Appendix C), marsh creation with dredged material (CRMS3667, Appendix C), or water hyacinth rafting (CRMS0161, Appendix C). In some areas, like the interior Mermentau basin, rapid elevation gain due to shallow expansion or floating marsh type behavior was observed (Mouledous et al., 2016; CRMS1100, Appendix C).

Elevation loss is rare on the deltaic plain prior to site erosion, though there are a few sites along both banks of the Mississippi River that capture elevation loss. West of the Mississippi River in the Barataria basin, elevation loss appears to be storm related (CRMS0258/0260 Appendix C). East of the river in the Breton Sound basin, elevation loss appears due to be settling of Katrina deposited sediments (CRMS0128, Appendix C) or erosion from the edge. Elevation loss is common on the Chenier Plain where impounded marshes do not receive regular tidal deposition and are also impacted by water management, inundation stress (McGinnis et al., 2019; CRMS0635, Appendix C) and drawdown effects (Cahoon 1994).

All hydro groups have positive elevation change rates with the highest elevation gain in the MR delta (Figure 4.13). Negative elevation change is found only in a small subset of impounded fresh marshes and eroding salt marshes.

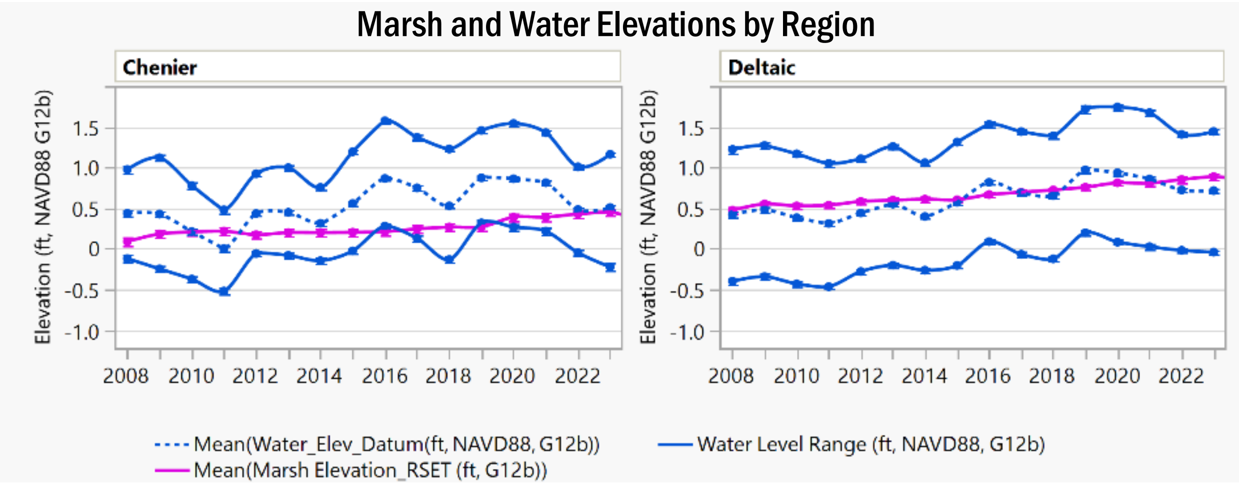


Figure 4.8. Regional water elevation with marsh elevation (ft, NAVD88, Geoid 12b). Range defined by 10th and 90th quantile of annual water elevation distribution. Marsh elevation is annual mean derived from RSET data (Mean ± Std Err)

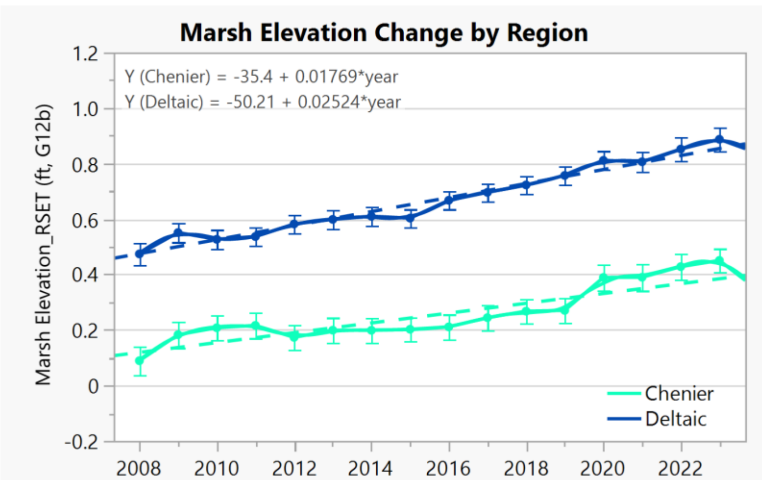


Figure 4.9. Annual mean wetland surface elevation derived from RSET data by region with linear regression (ft, NAVD88, Geoid 12b; Mean ± Std Err). Chenier Plain 5.4 mm/yr; Deltaic Plain 7.7 mm/yr

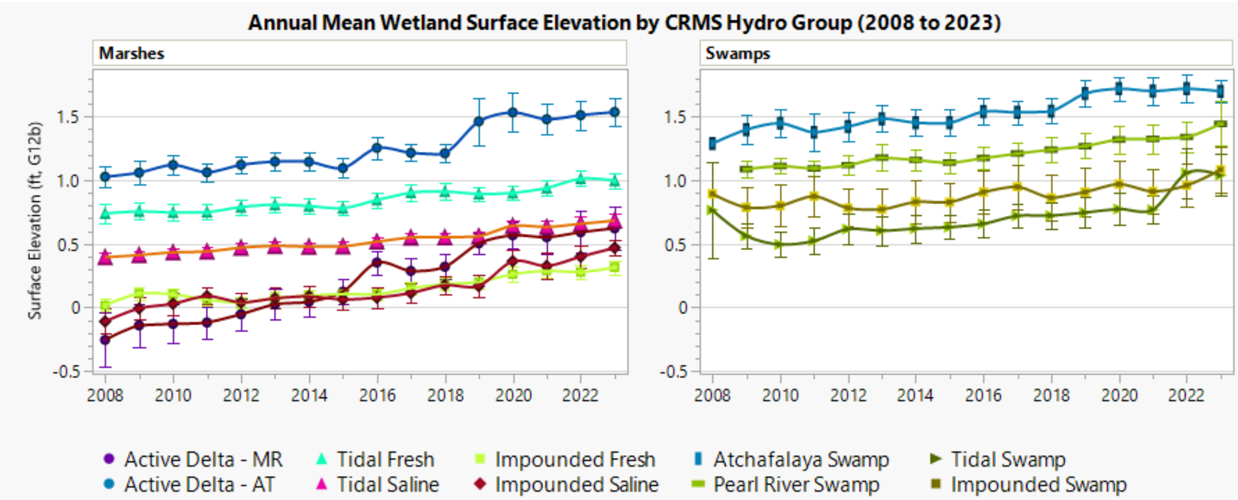


Figure 4.10. Annual mean wetland surface elevation derived from RSET data by hydro group (ft, NAVD88, Geoid 12b; Mean ± Std Err)

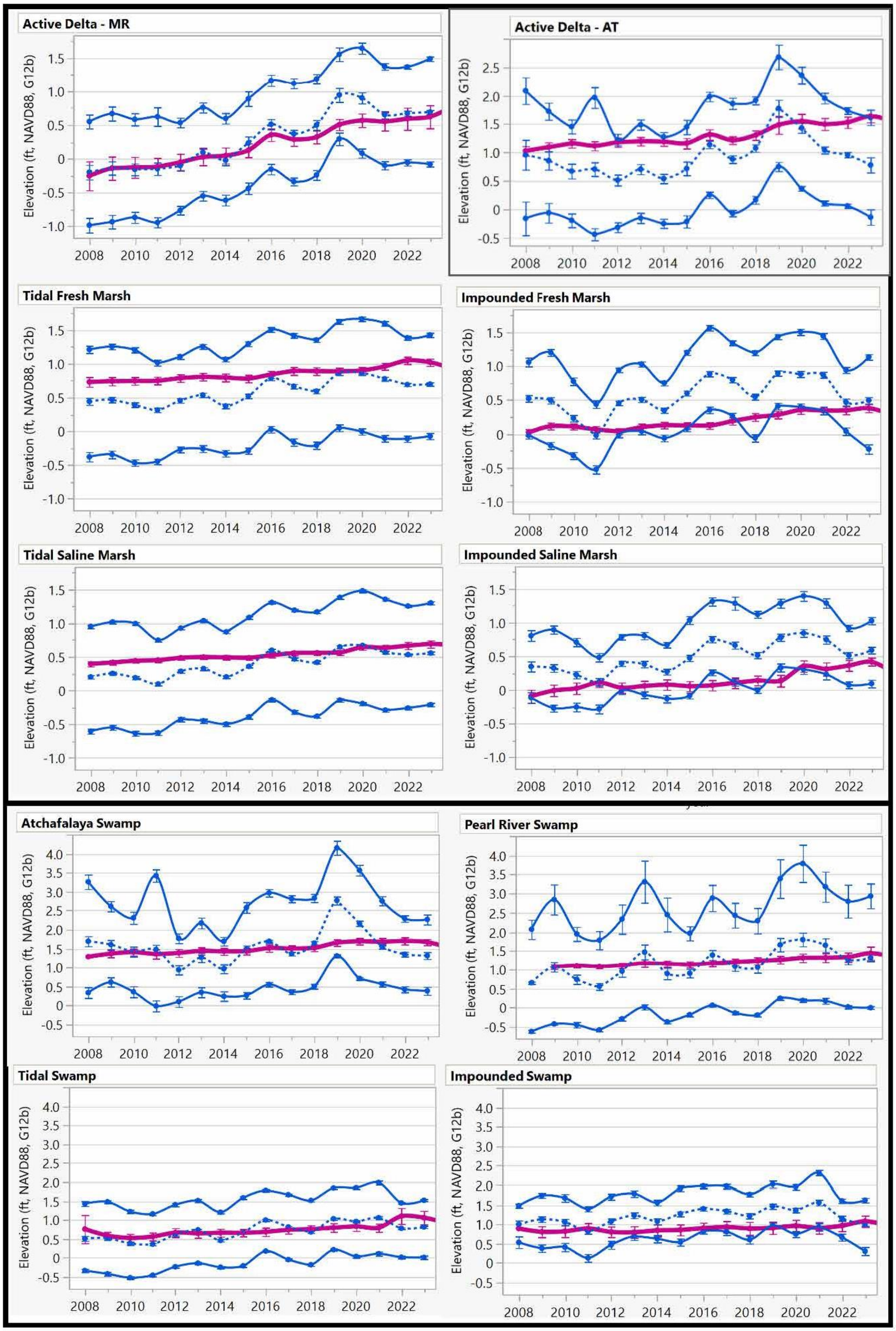


Figure 4.11. Water elevation with marsh elevation by Hydro Group (ft, NAVD88, Geoid 12b). Range defined by 10th and 90th quantile of annual water elevation distribution. Marsh elevation is annual mean derived from RSET data (Mean ± Std Err). Marsh groups and swamp groups are plotted on different scales with AT delta marsh on it's own scale

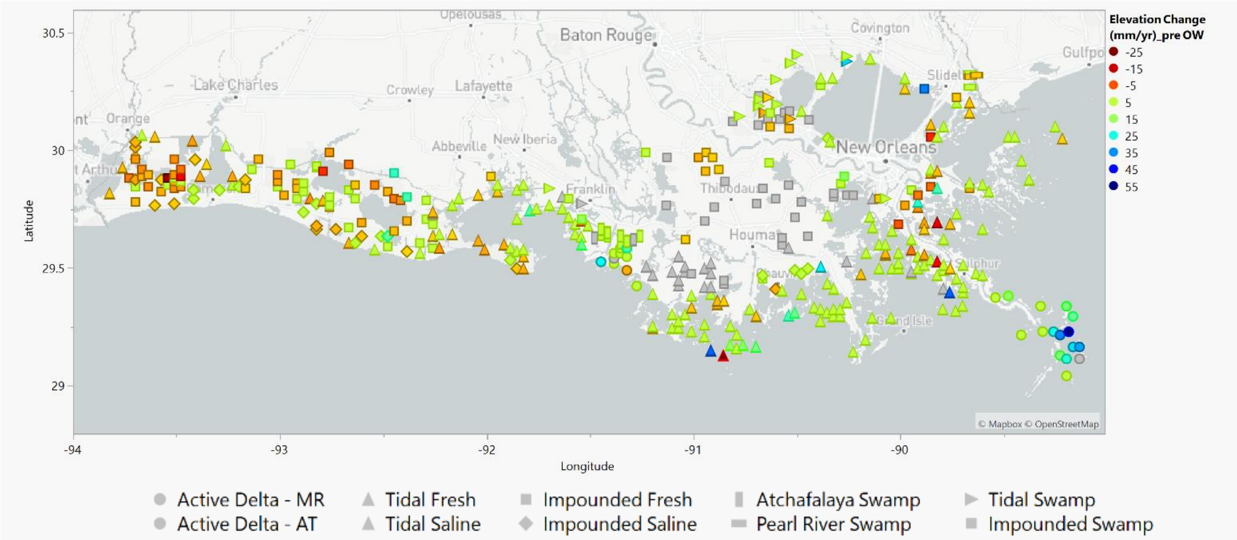


Figure 4.12. Surface Elevation Change Rates 2008 to 2024. Open water observations from after all vegetation is removed at the boardwalk are excluded from these rates

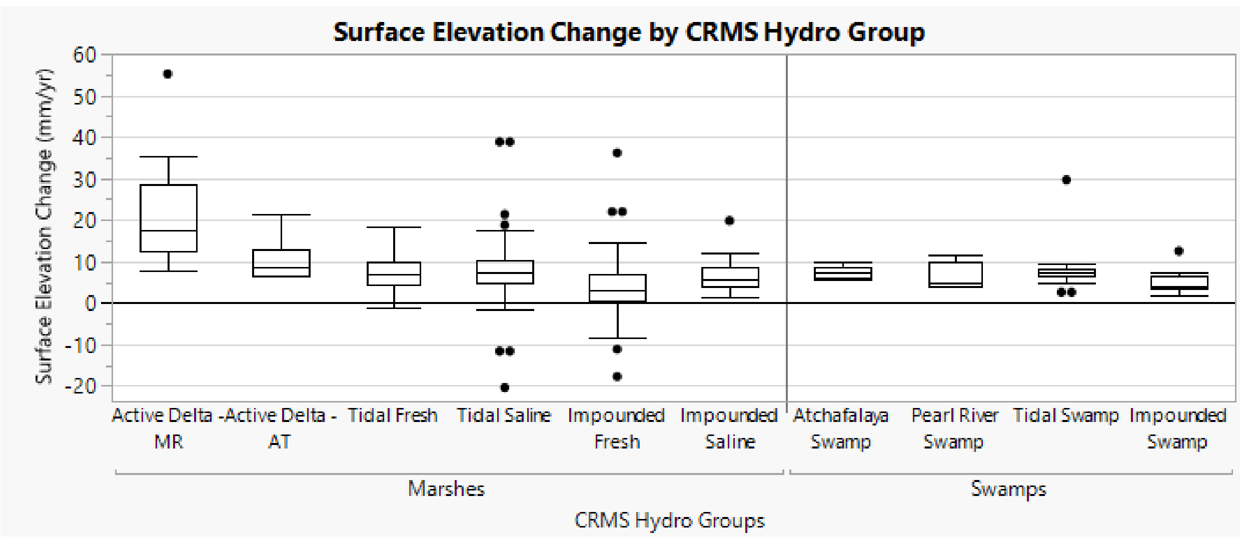


Figure 4.13. Distribution of Elevation Change Rates within CRMS Hydro Groups. Box plot indicates mean, quartiles, range, and outliers

ELEVATION CAPITAL

Elevation capital is defined here as the difference between mean surface elevation and mean water elevation where positive values indicate emerged wetlands. Annual marsh elevation is derived from the RSET dataset which incorporates annual changes in elevation at the boardwalk. These values are effectively the inverse of inundation depth except the marsh elevation used for inundation depth is the site value which is derived from mean vegetation station elevation during the last professional land survey, currently from 2021. Rates of elevation capital change calculated as a linear regression through annual values may provide more information than elevation change rates alone as they integrate marsh and water elevation.

Most of the Deltaic Plain sites have positive elevation capital values. The highest values are found in the Atchafalaya swamp and along the Acadiana Bays complex where fresh, tidal marshes receive sediment from the Atchafalaya River via the GIWW (Figures 4.14 and 4.15). Chenier Plain impoundments and swamps have the lowest elevation capital as they are effectively submerged except during a drought (Figure 4.16).

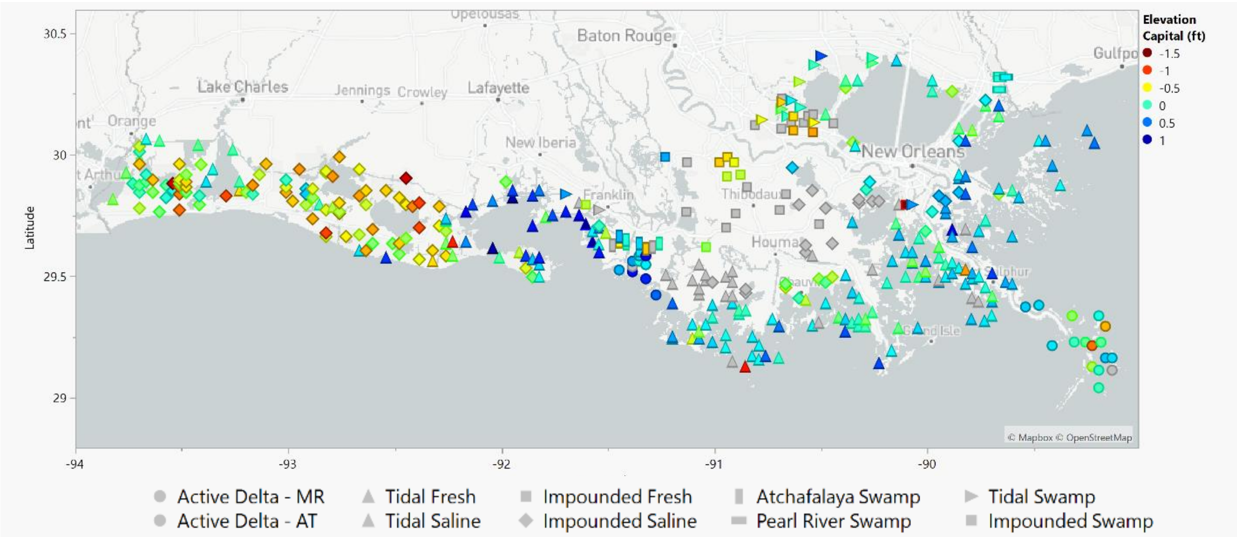


Figure 4.14. Median Elevation Capital (2008 to 2023) by CRMS site

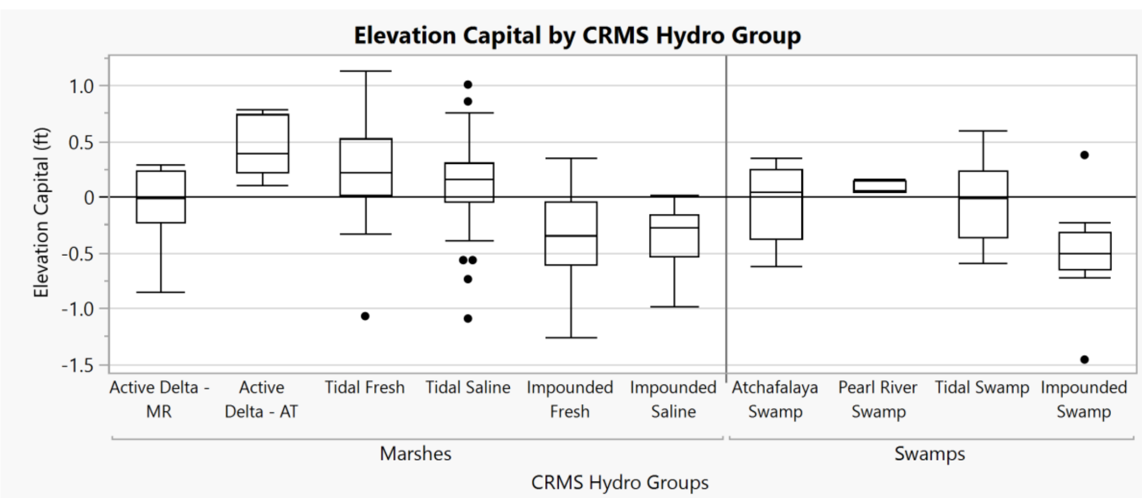


Figure 4.15. Distribution of median elevation capital values (ft) by CRMS Hydro Group. Median values for each CRMS site included in distribution were derived from annual means (2008 and 2023). Box plot indicates mean, quartiles, range, and outliers

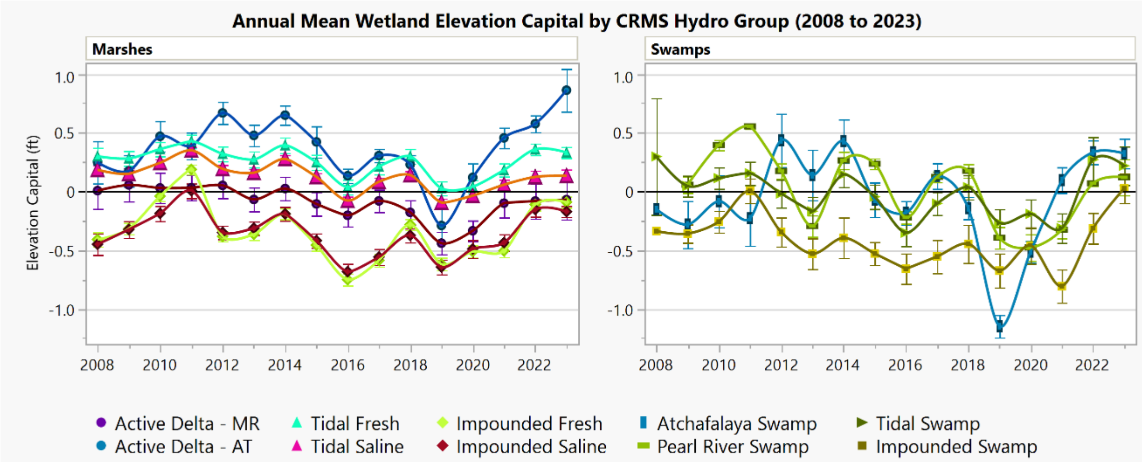


Figure 4.16. Elevation capital trend by CRMS Hydro Group from 2008 to 2023

4.3 VERTICAL ACCRETION (VA)

Vertical accretion captures the surface deposition component of elevation change. Surface elevation change rates integrate surface and subsurface processes between the bottom of the RSET rod and the wetland surface while accretion plots capture the unconsolidated deposition on top of the marker horizon (Figure 4.1). Accretion rates are positive by definition and are 60% higher than elevation change rates (Figure 4.17). Newly deposited sediments are less consolidated than older soil layers and as such rates from younger plots are higher than rates that have had more time to settle and compact (Appendix A).

The highest accretion rate (83 mm/yr) was observed on an eroding Barataria basin shoreline (Figure 4.18; CRMS0174 Appendix C). By hydro group, the highest accretion values are found in the MR delta and eroding salt marsh shorelines (Figure 4.19). Accretion is lowest in swamps and impoundments where there is little to no mineral deposition (Cahoon, 1994) and lower productivity due to flood stress and nutrient limitations (McGinnis et al., 2019).

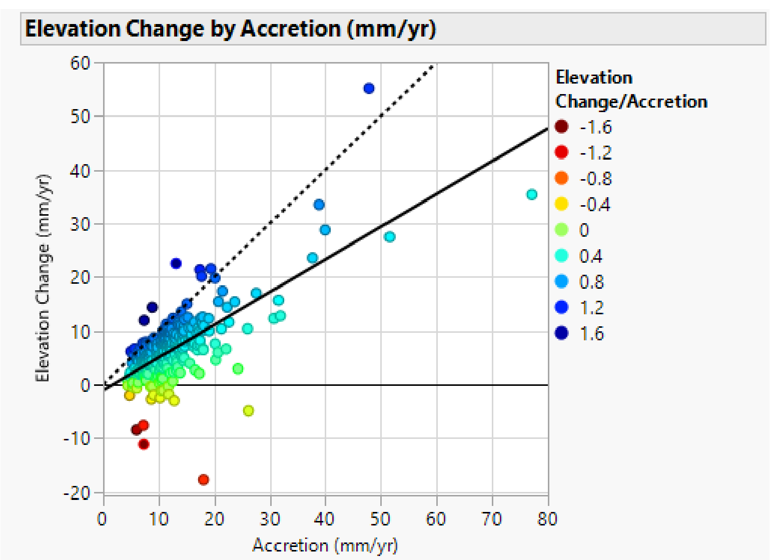


Figure 4.17. Elevation Change rates by Accretion rates. Dashed line is 1:1 Elevation

Change:Accretion solid line is linear regression unconstrained. This captures the fractional nature of the relationship of elevation gain and accretion.

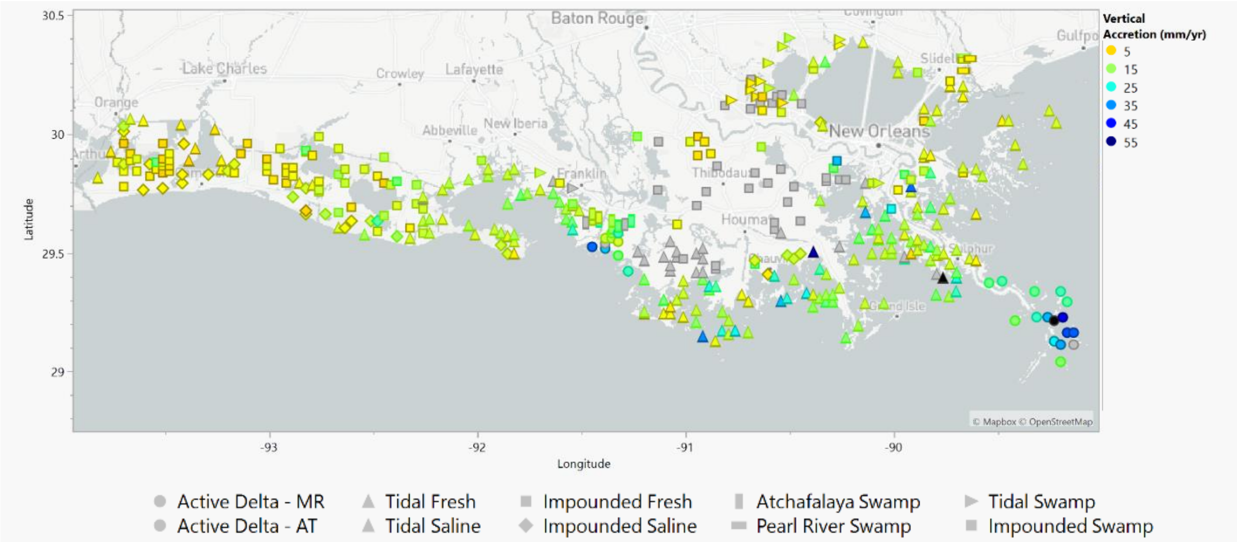


Figure 4.18. Vertical accretion rates at CRMS sites

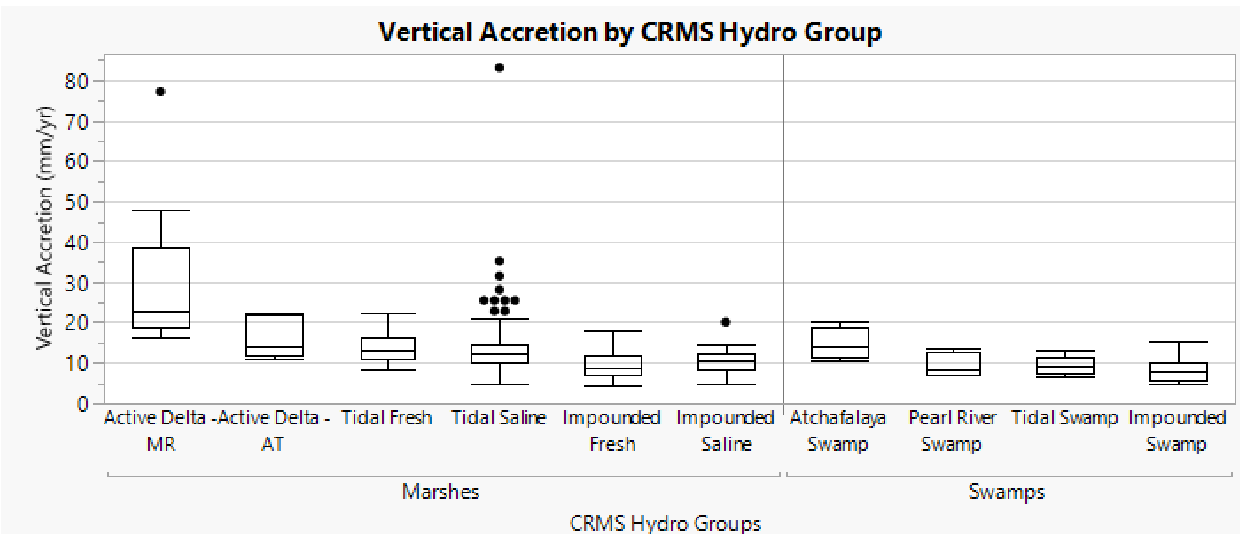


Figure 4.19. Distribution of Accretion Rates within CRMS Hydro Groups. Box plot indicates mean, quartiles, range, and outliers. Delta formation and shoreline transgression are responsible for high vertical accretion rates

4.4 SHALLOW SOIL FACTOR (SSF)

CPRA's planning team has clarified terminology for Vertical Land Motion as part of the 2029 Coastal Master Planning process (CPRA 2025). The term "Shallow Subsidence", defined as VA - SEC has been replaced with "Shallow Soil Factor (SSF)" defined as SEC - VA. The change was necessary because there are a whole suite of variables that influence sediment accumulation in addition to geologic subsidence and because there was emerging evidence from CRMS data that shallow expansion is common during periods of high inundation in Louisiana's coastal wetlands (Cahoon, 2024).

Shallow soil expansion was somewhat unexpected when CRMS monitoring began. The phenomenon emerged in 2012 when the 2010/2011 drought ended and the marsh platforms that had dried out became submerged. At that time, data collectors began to notice void spaces in the accretion cores and captured notes like “water pocket at 10 cm; 1 cm diameter”. Notes in vegetation data also captured transitions in the vegetated platform to floating and quaking marshes along the Teche-Vermilion basin and in the interior of the Mermentau Lakes sub-basin. After 2015 when sea level rise and inundation increased, shallow expansion was observed more frequently and was found across the coastal landscape, far from the known floating wetlands in the central coast around Houma (Figures 3.6, 3.8 and 3.10). The spatial distribution of sites that “feel like they are floating” to CRMS vegetation data collectors standing on the marsh surface increased from 21 sites in 2009 to 67 sites in 2016 (Figure 4.20). Dominant species in wetlands that “feel like they are floating” come from every salinity regime including salt marsh (Table 4.2). This process captures the sponge effect in living wetland soils as gas in the plants tissue and released below ground via respiration causes uplift on the submerged root and soil matrix.

This process captures a type of ecosystem feedback that would help explain wetland persistence across a wide range of sea levels. Living vegetation adapts to inundation stress by gaining elevation without peat formation or mineral input, likely at the expense of weakened shear strength before it drowns. Understanding this feedback process would help improve coastal restoration planning.

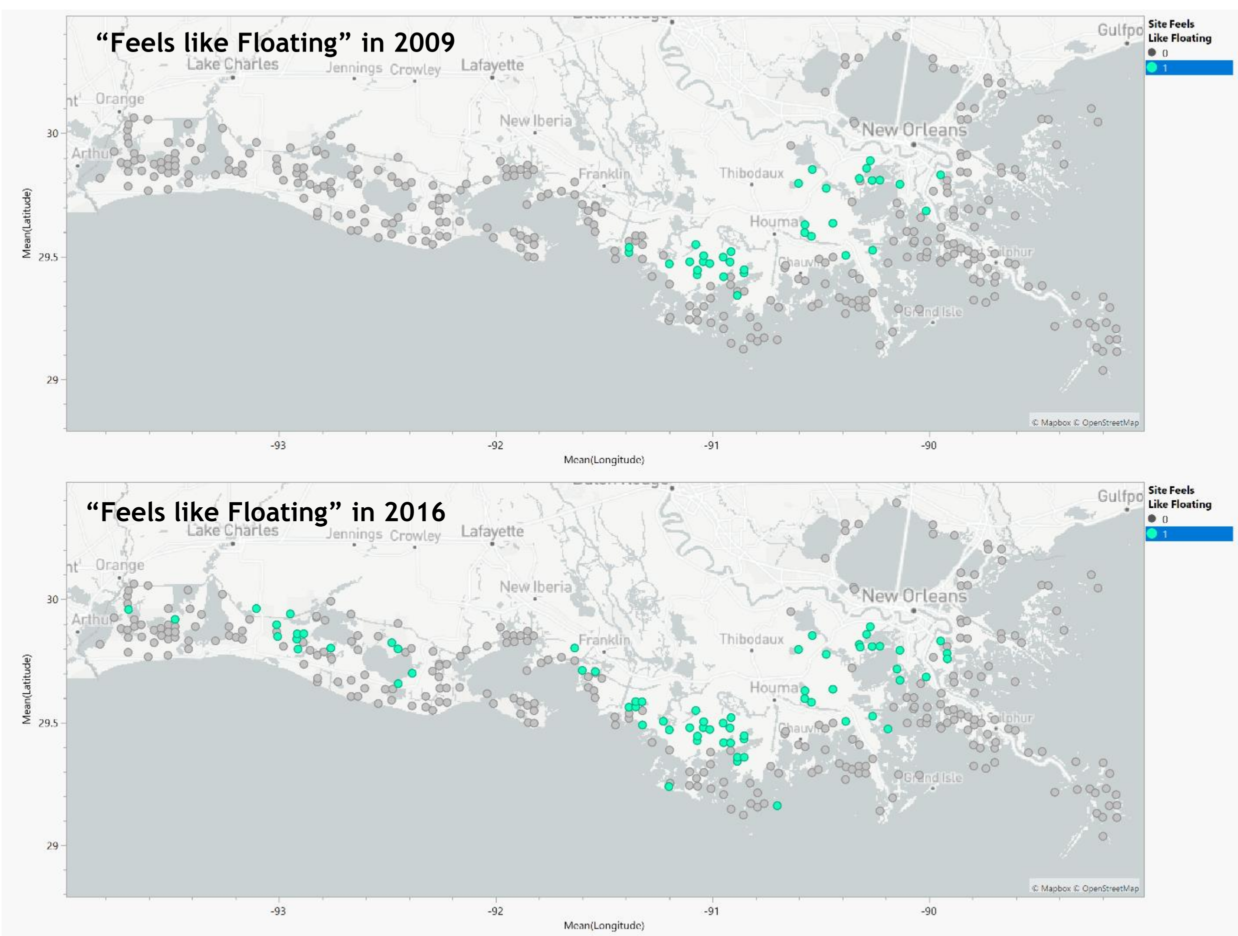


Figure 4.20. Location of wetlands that "feel like floating marsh" according to data collectors standing on the surface during vegetation data collection. 2009 was the first year of standardized "feels like floating" data collection. 2016 had the most sites classified as such

Table 4.2. Dominant species and N vegetation stations when vegetation data collectors indicated that the wetland "feels like floating"

Dominant species	**N Vegetation Stations "feels like floating"**	**Dominant species**	**N Vegetation Stations "feels like floating"**
Panicum hemitomon	1195	*Hydrocotyle umbellata*	27
Sagittaria lancifolia	858	*Ipomoea sagittata*	25
Spartina patens	364	*Oxycaryum cubense*	22
Thelypteris palustris	361	*Salix nigra*	22
Eleocharis sp.	322	*Schoenoplectus californicus*	21
Ludwigia grandiflora	298	*Mikania scandens*	20
Leersia hexandra	200	*Spartina alterniflora*	16
Morella cerifera	199	*Ludwigia leptocarpa*	15
Vigna luteola	183	*Luziola peruviana*	15
Polygonum punctatum	174	*Panicum repens*	14
Typha latifolia	168	*Lythrum lineare*	12
Schoenoplectus americanus	120	*Echinochloa walteri*	11
Eleocharis montana	111	*Taxodium distichum*	11
Typha domingensis	111	*Eleocharis baldwinii*	10
Zizaniopsis miliacea	104	*Kosteletzkya virginica*	10
Alternanthera philoxeroides	87	*Panicum dichotomiflorum*	10
Sagittaria latifolia	82	*Distichlis spicata*	9
Sacciolepis striata	73	*Eleocharis olivacea*	8
Eleocharis macrostachya	71	*Ludwigia peploides*	8
Typha sp.	65	*Phyla lanceolata*	8

Bidens laevis	56	*Cicuta maculata*	7
Eleocharis rostellata	53	*Hydrocotyle ranunculoides*	7
Phragmites australis	52	*Polygonum setaceum*	7
Paspalum vaginatum	45	*Pontederia cordata*	7
Baccharis halimifolia	43	*Cyperus odoratus*	6
Cladium mariscus	42	*Acer rubrum*	5
Decodon verticillatus	40	*Apios americana*	5
Eleocharis cellulosa	37	*Bacopa monnieri*	5
Colocasia esculenta	31	*Sesbania drummondii*	5

SHALLOW SOIL FACTOR (SSF) REVIEW

SSF was calculated for every paired VA/SEC observation. Sites were filtered to remove any potential disturbance that would influence VA/SEC relationships. Sites were excluded if they were actively eroding (having some VA and SEC stations in open water and others within vegetation), if they had substantial animal disturbance (typically hogs), or sites where all of the apparent disturbance is after a large storm surge deposition event. Ultimately, 277 sites were utilized to examine the SEC and VA relationships. Note, sites that were thought to be floating marsh when the CRMS program began do not have VA/SEC measurements. VA/SEC data were only collected in wetlands thought to be attached in 2005.

For this analysis, shallow expansion was defined as > 15 mm of elevation gain not accounted for by accretion over a given interval (SSF>15 mm). If there was only one observation of SSF > 15 mm at a site, it was ignored.

Of the 277 sites utilized, 141 sites (51% of network) have data indicating shallow expansion at some point, with an increasing frequency of shallow expansion observations as water levels increased through time (Figure 4.21). The protracted 2022-2023 drought effectively reset this process by causing very low water levels. Giving the expanded soils an opportunity to dewater thus contracting and floating marshes the opportunity to settle and re-attach to the substrate.

Within the CRMS network there are no direct observations of when and where the shallow expansion produced mat detachment and when it's just mat stretching and swelling. We tallied the number of intervals with SSF> 15 mm and reviewed maximum SSF value information (Figure 4.22). There are sites that behave like floating marshes where we find repeat observations of shallow expansion and very high maximum SSF values (>200 mm). Those sites are most likely detached at times. We used that information to classify sites as 1-all surface deposition (no evidence of shallow expansion), 2-some evidence of shallow expansion, 3- frequent shallow expansion with potential mat detachment, and noted where we've seen 4-both expansion and subsequent elevation loss, which may capture collapse in saline impoundments (Chenier Plain; Figure 4.23).

Shallow expansion appears to contribute to coastwide elevation gain. There is some evidence to suggest that it increases vulnerability to removal by hurricanes. Additional research and analysis is needed in order to understand the implications of shallow expansion on different parts of the landscape.

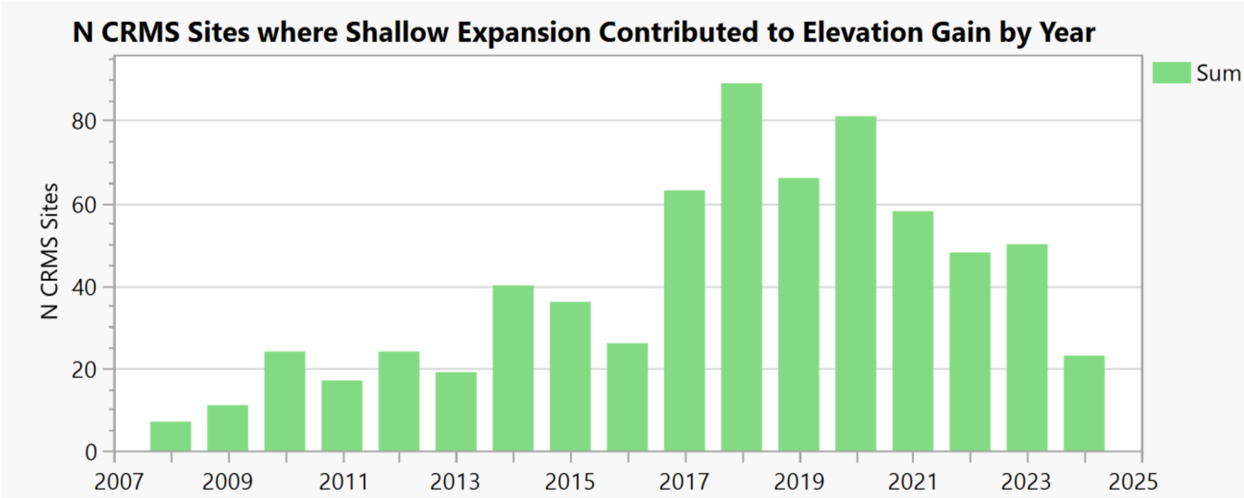


Figure 4.21. N sites with elevation gain from shallow expansion through time. Note the increasing frequency in high water years that reduces during the drought conditions

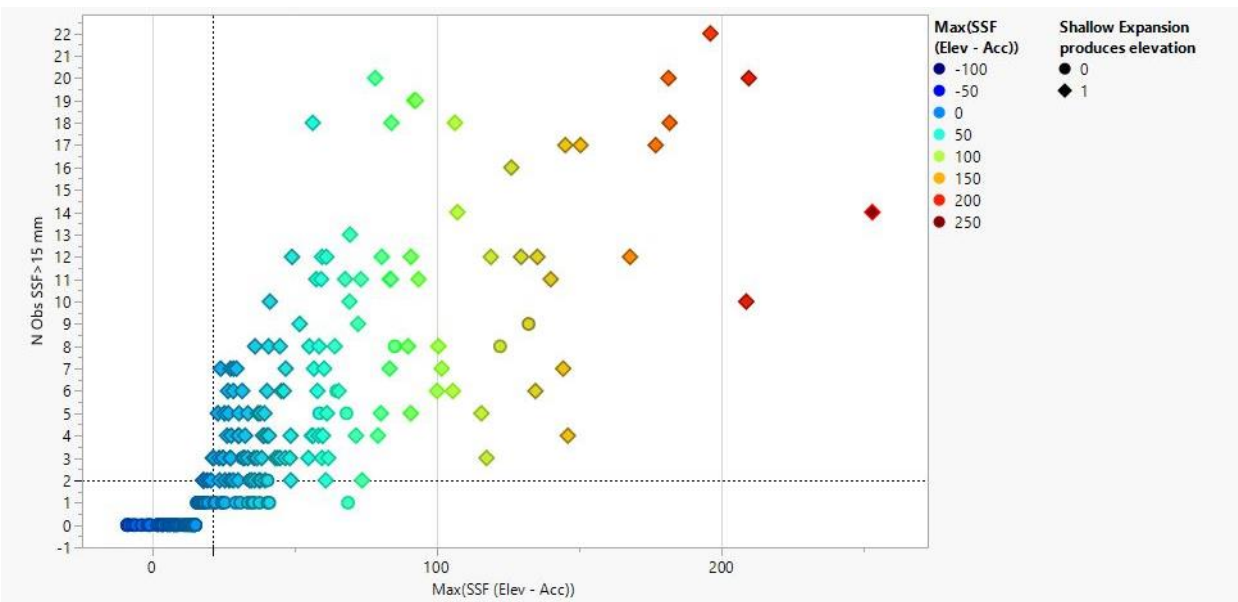


Figure 4.22. N observations of SSF>15 mm vs Maximum SSF value. Sites that gain elevation through shallow expansion indicated by diamonds

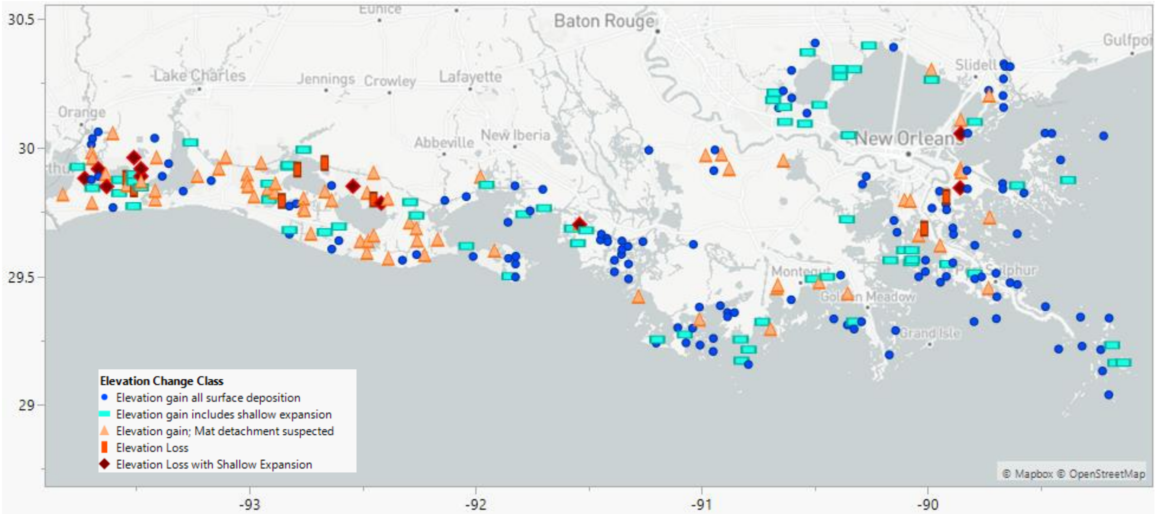


Figure 4.23. SSF classes indicating where sites gain elevation with shallow expansion, where there is repeated shallow expansion and potential mat detachment, and where elevation loss and expansion co-occur at the same site (collapse)

4.5 DISCUSSION AND CONCLUSIONS

RELATIONSHIP BETWEEN WATER AND SURFACE ELEVATION TRENDS AND LAND CHANGE GROUPS

We can juxtapose the CRMS land change groups with the hydrology groups analyzed above to gain insight on mechanisms causing land loss and stability as it relates to flooding and salinity influences. Continuous land loss has occurred primarily in the tidal marsh on the lower Deltaic Plain due to lateral erosion with landward transgression (Figures 4.24 and 4.25). All of the sites that have been completely lost are found within the Tidal Fresh and Tidal Saline groups. Those same salt marshes that are continuously losing land are also gaining elevation, becoming supratidal with very high deposition occurring as the eroding edge moves through the site with high-energy waves resulting in shallow open water (Figure 4.11; Stagg et al., 2024). There is no evidence of drowning in place associated with continuous land loss in Tidal Fresh and Tidal Salt marshes (Figures 3.20 to 3.25). Elevation gain in these fringe marsh sites along the Gulf/wetland interface comes from erosive forces that displace sediment from the shoreline and redeposited some fraction back onto the marsh platform, giving the appearance of a ‘healthy’ accreting marsh prior to erosion and subsequent removal of sediment and vegetation and resulting land loss (Figure 4.26). Erosion is also causing extensive land loss along the Chenier Plain, specifically along the Gulf shoreline from Southwest Pass, west of Marsh Island, to Calcasieu Pass (Berlinghoff et al., 2025). The Acadiana Bays shoreline from just west of the Wax Lake Delta to Southwest Pass including Marsh Island are retreating at various rates, with some such as Bayou Sale, Weeks Bay, and the north and east shore of Marsh Island being alarmingly rapid.

The CRMS sites falling within the Variable Loss category are primarily found within Chenier Plain impoundments where flood stress has weakened below ground vegetative structure in interior marshes. Persistent inundation, especially in the presence of salinity, limits peat formation via a lack of belowground biomass production. Tidal sediment and nutrient deposition is limited to storm surge deposition and beach over wash events resulting in low bulk density and weakening of marsh soils in most interior impounded wetlands. Together, these impacts foster conditions that cause vegetative stress and land loss with specific venerability to storm surge removal.

CRMS sites falling within the Variable Gain land change group are quite diverse in the mechanisms of land gain and hydrology, as they are spread throughout the coast and land gain is both natural and restoration driven. Most of the gain is occurring in active deltas. The hydrology of these sites is conducive to the natural land building process which created coastal Louisiana over the last 10,000 years, with sites experience spring alluvial flooding with nutrient and sediment rich water followed by fall and winter low water cycles. Periodic tropical cyclones damage and destroy wetlands, but this damage is repairable through progressive seasonal floods, mineral soil addition, and vigorous vegetation growth. Land gain outside of deltas is either due to recovery from previous hurricane induced land loss, as in central coast and Breton Sound, redistribution of sediments by storms, or it is due to marsh creation and beneficial use projects as is the case in the Calcasieu Sabine and Pontchartrain basins (Figures 4.24 and 4.25).

The Variable Stable land change group includes sites that experience land loss followed by recovery to pre-storm conditions with little net land change. The bulk of these CRMS sites are in the Mermentau basin but are also scattered along the coastal zone and capture a range of processes. Deltaic Plain tidal marsh recovery is possible as evidenced by site membership in this group across basins. In the Mermentau lakes sub-basin, elevations are very low and flooding is near constant; however, due to the USACE lock system, salinity and tidal action in this region is near zero. This area also drains a vast upland agricultural network and its nonpoint sources of nutrients. All of these factors allow for recovery and expansion of marsh vegetation despite extensive flood stress. Similar flooding conditions exist in the Calcasieu Sabine basin but we find land loss. The difference appears to be salinity. Fresh wetlands recover from storm damage much better than non-fresh wetlands.

CRMS sites falling within the Stable land change groups are the most ubiquitous sites coastwide representing more than 60% of the network. These sites and their representative hydrology have successfully weathered some of the most intense hurricanes in Louisiana’s recent history, including Katrina, Rita, Laura, and Ida. These sites are usually located further inland near the upland/wetland boundary, and are fresher, frequently flooded, and possess an attenuated tidal signature. Notable exceptions to these generalizations include stable assemblages in tidally exposed Biloxi marsh, near Bay Batiste, southwestern Terrebonne basin, throughout the Teche-Vermilion basin, and along the southwest coastline of the Chenier Plain. These sites have high soil bulk density, soil elevation and elevation capital, high belowground biomass, and low flood depth and duration. These persistent exposed tidal marshes are good examples of what conditions restoration efforts should attempt to replicate.

Overall, the driving force of landscape loss across the coast during the CRMS monitoring epoch is lateral erosion driven by tidal and meteorological forces. Wind, wave, and wake energy combined with tidal reworking of sediments is contributing to coastal fringe marsh destabilization, especially in the inactive deltaic plain. Portions of the Chenier plain are also undergoing destabilization but permanent saline inundation is denuding the soil of live vegetation and either making these marshes susceptible to removal during storm events or drowning in place with increased sea levels.

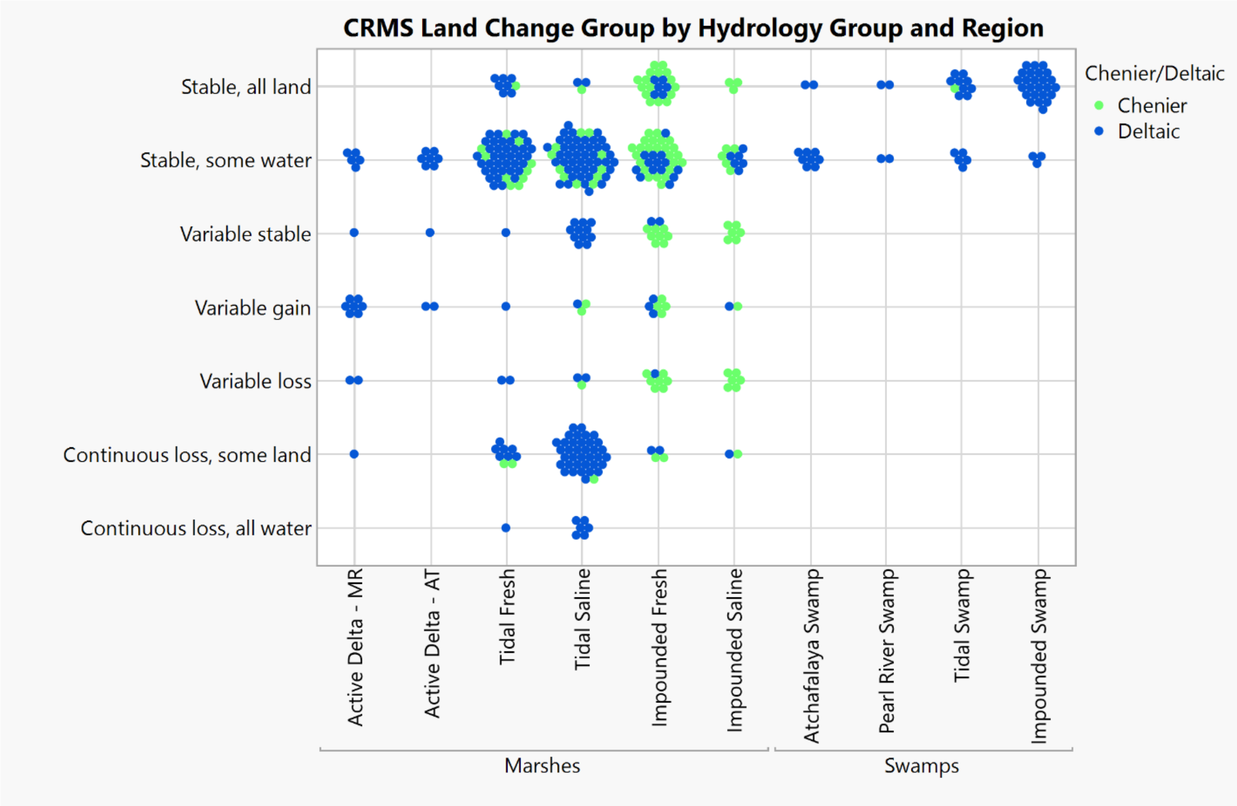


Figure 4.24. CRMS Hydro Groups and Land Change Groups with Geomorphic Region indicated

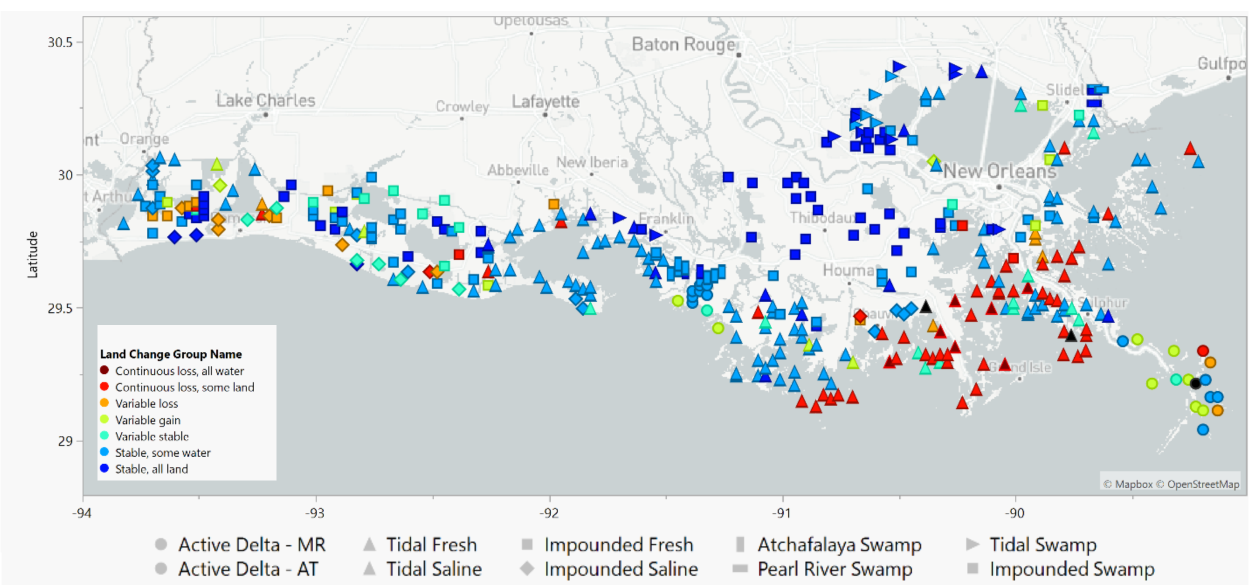


Figure 4.25. CRMS Hydrology Group symbols colored by Land Change Group

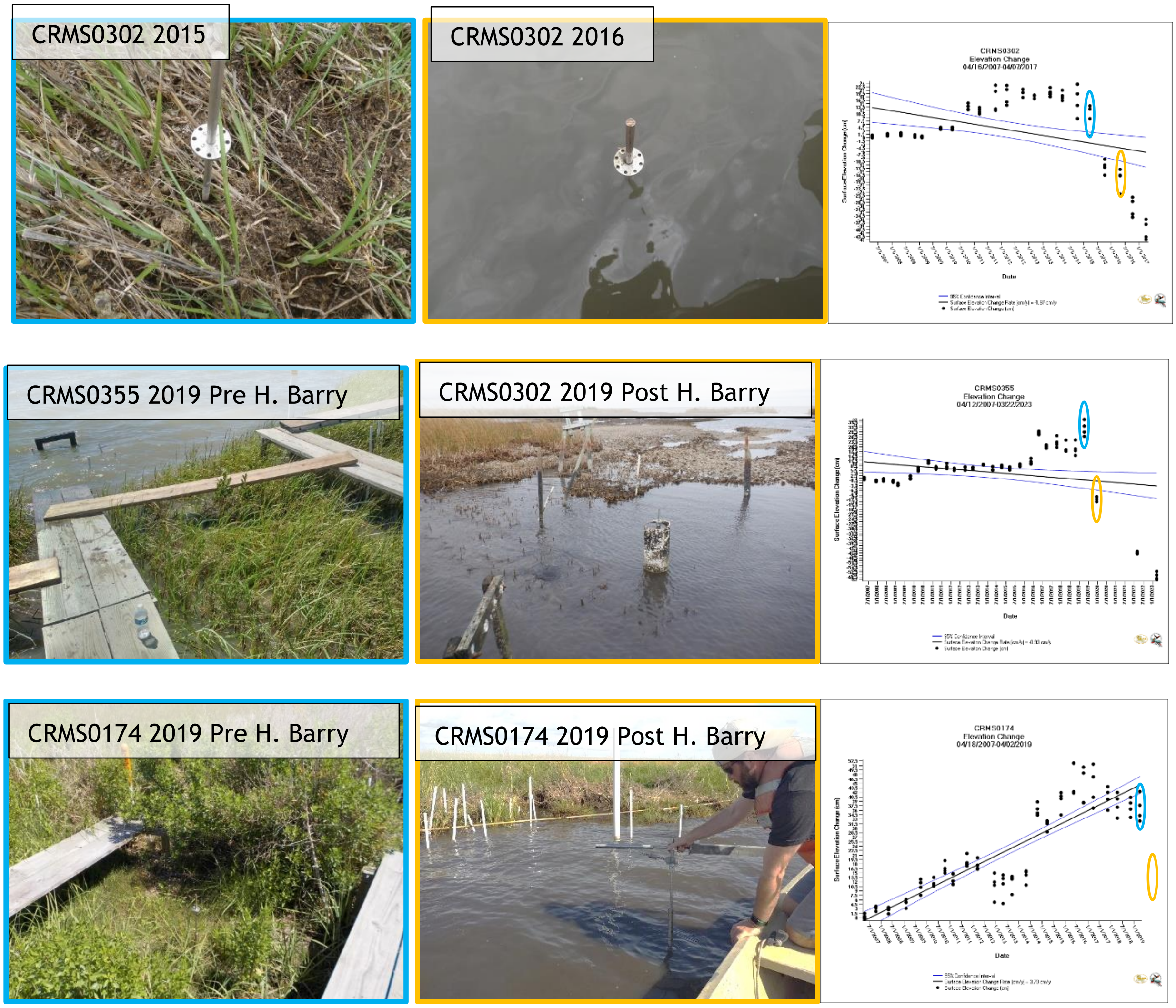


Figure 4.26. Photographs of sites where the vegetation was ultimately removed along with Surface Elevation Change chart. Left photos capture the last time vegetation was present at the site. Center photos capture conversion to open water on a subsequent trip. Right charts are CRMS Surface Elevation Change charts with observations from the day of the photos highlighted (blue circles = left photo; orange circles = right photo). Note vegetation is healthy and difficult to remove by hand in it's last year. Substrate is firm with shell hash beneath eroding vegetation. Note CRMS0174 RSET rod was destabilized and did not allow for post H. Barry measurements

FUTURE PLANS

This was the second report in a series of CRMS data synthesis reports. It is intended to be a starting point for data exploration and should facilitate CRMS data utilization in planning and designing restoration projects and when interpreting trends at multiple scales. This report will be updated approximately once per Coastal Master Plan cycle with the next planned report to be published in 2030. The next report in this series will cover CRMS Vegetation data and will incorporate changes observed through 2025, including drought response and recovery.

5.0 REFERENCES

Berlinghoff, J.L., B.S. Beasley, M.R. Byrnes, and G.P. Curole, 2025. Louisiana Barrier Island Comprehensive Monitoring Program (BICM): Phase 3 – Updated Shoreline Compilation and Change Assessment, 1880s to 2021. Prepared for Louisiana Coastal Protection and Restoration Authority (CPRA) by Applied Coastal Research Associates, Mashpee, MA and Nashville, TN, 47 p. plus appendices.

Cahoon, D. R. (1994). Recent Accretion in Two Managed Marsh Impoundments in Coastal Louisiana. Ecological Applications, 4(1), 166–176. https://doi.org/10.2307/1942126

Cahoon, D.R. (2024). Measuring and Interpreting the Surface and Shallow Subsurface Process Influences on Coastal Wetland Elevation: A Review. Estuaries and Coasts 47, 1708-1734. https://doi.org/10.1007/s12237-024-01332-z

Coastal Protection and Restoration Authority (CPRA). 2019. A contractor's guide to the standards of practice: for CPRA contractors performing GPS surveys and determining GPS derived orthometric heights within the Louisiana Coastal Zone. Coastal Protection and Restoration Authority, Operations Division, Baton Rouge, LA. 41 pp.

Coastal Protection and Restoration Authority (CPRA). 2025. Glossary of Terms to Describe Vertical Land Motion in Louisiana Coastal Wetlands. Baton Rouge, Louisiana: Coastal Protection and Restoration Authority of Louisiana, 9p.

Couvillion, B. R., Beck, H., Schoolmaster, D., & Fischer, M. (2017). Land area change in coastal Louisiana (1932–2016). Scientific Investigations Map 3381. https://doi.org/10.3133/sim3381

Couvillion, B.R., (2021a), Coastal wetland area change in the Gulf of Mexico, 1985-2020: U.S. Geological Survey data release, https://doi.org/10.5066/P9ZQI7ZW.

Couvillion, B. (2021b). Gulf of Mexico Land Area Change in Wetland Possible Zone by Hydrologic Unit Code (HUC) Graphs: U.S. Geological Survey data release, https://doi.org/10.5066/P9ZQI7ZW.

Todd M. Folse, Thomas E. McGinnis, Leigh A. Sharp, Jonathan L. West, Melissa K. Hymel, John P. Troutman, Dona Weifenbach, William M. Boshart, Laurie B. Rodrigue, Danielle C. Richardi, W. Bernard Wood, C. Mike Miller, Elizabeth M. Robinson, Angelina M. Freeman, Camille L. Stagg, Brady R. Couvillion, and Holly J. Beck. (2023). A Standard Operating Procedures Manual for the Coastwide Reference Monitoring System-*Wetlands* and the System-Wide Assessment and Monitoring Program: Methods for Site Establishment, Data Collection, and Quality Assurance/Quality Control. Louisiana Coastal Protection and Restoration Authority. Baton Rouge, LA. 255 pp.

Hiatt, M., Snedden, G., Day, J. W., Rohli, R. V., Nyman, J. A., Lane, R., Sharp, L. A. (2019). Drivers and impacts of water level fluctuations in the Mississippi River delta: Implications for delta restoration. Estuarine, Coastal, and Shelf Science. https://doi.org/10.1016/j.ecss.2019.04.020

Howes NC, FitzGerald DM, Hughes ZJ, et al (2010) Hurricane-induced failure of low salinity 323 wetlands. Proceedings of the National Academy of Sciences 107:14014–14019. doi: 324 10.1073/pnas.0914582107

Louisiana Department of Wildlife and Fisheries, Coastal and Non-game Resources Division. Rockefeller Wildlife Refuge Management Plan. Final Draft, Aug. 2011. Prepared by Rockefeller Wildlife Refuge Biological Staff: Guthrie Perry, Tom Hess, Brac Salyers, Carrie Salyers, Will Selman, PhD., Sara Zimorski, Ruth Elsey, and Phillip Trosclair III. https://www.wlf.louisiana.gov/assets/Conservation/WMAs_Refuges_Conservation_Areas/Files/Rockefeller/Final-RWR-Management-Plan_8-24-11.pdf

Lynch, J. C., Hensel, P., & Cahoon, D. R. (2015). The surface elevation table and marker horizon technique: A protocol for monitoring wetland elevation dynamics (No. NPS/NCBN/NRR—2015/1078). National Park Service.

Mariotti, G., & Carr, J. (2014). Dual role of salt marsh retreat: Long-term loss and short-term resilience. Water Resources Research, 50(4), 2963-2974.

McGinnis, T.E., W.B. Wood, M. Luent, M. Mouledous, M. Miller, and L.A. Sharp. 2019. *2019 Basin Summary Report for the Calcasieu-Sabine Basin*. Coastal Protection and Restoration Authority of Louisiana, Lafayette, Louisiana. 59 pp plus Appendix.

McKee, K.L., Cherry, J.A. (2009) Hurricane Katrina sediment slowed elevation loss in subsiding brackish marshes of the Mississippi River delta. Wetlands 29, 2–15 (2009). https://doi.org/10.1672/08-32.1

Mouledous, M, Wood, W.B. and Sharp, L.A. (2016) 2016 Basin Summary Report for the Mermentau Basin, Coastal Protection and Restoration Authority of Louisiana, Lafayette, Louisiana. 57 pp

Stagg, C.L., Sharp, L.A., Fromenthal, E., Couvillion, B., Woltz, V. and Piazza, S., 2024. Accelerating elevation gain indicates land loss associated with erosion in Mississippi River deltaic plain tidal wetlands. Estuaries and Coasts, pp.1-13.

Steyer, G.D., C.E. Sasser, J.M. Visser, E.M. Swensen, J.A. Nyman, and RC. Raynie. (2003). A proposed coast-wide reference monitoring system for evaluating wetland restoration trajectories in Louisiana. Environmental Monitoring and Assessment 81:107–117.

Thompson, P.R., Widlansky, M.J., Hamlington, B.D. *et al.* Rapid increases and extreme months in projections of United States high-tide flooding. *Nat. Clim. Chang.* **11**, 584–590 (2021). https://doi.org/10.1038/s41558-021-01077-

Turner RE, Baustian JJ, Swenson EM, Spicer JS (2006) Wetland sedimentation from Hurricanes Katrina and Rita. Science 314: 449–452.

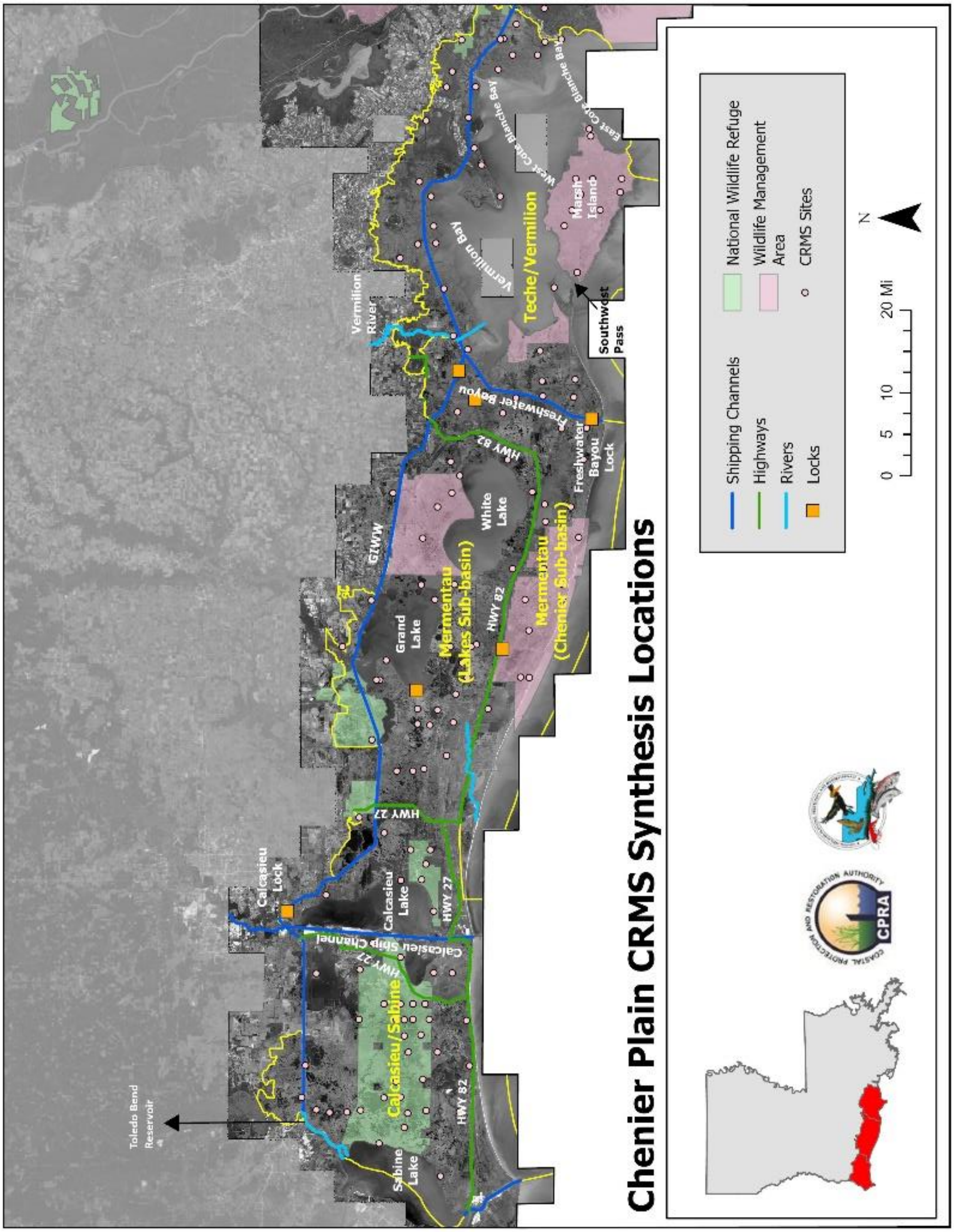
Tweel AW, Turner RE (2012) Landscape-Scale Analysis of Wetland Sediment Deposition from Four Tropical Cyclone Events. PLoS ONE 7(11): e50528. https://doi.org/10.1371/journal.pone.0050528

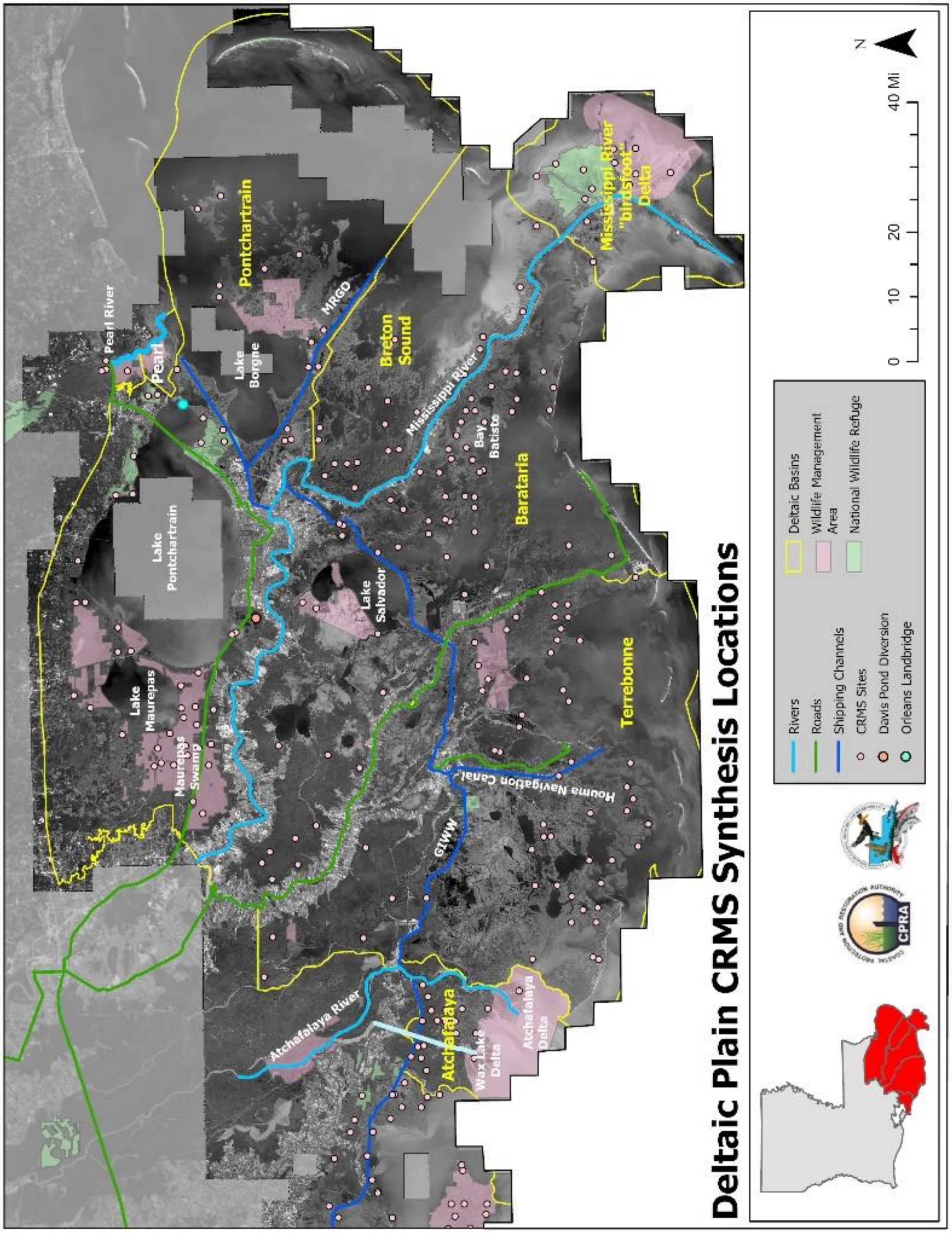
Visser, J.M. and C.E. Sasser. (1998) 1997 Coastal vegetation analysis. Louisiana State University: Coastal Ecology Institute. Baton Rouge, LA.

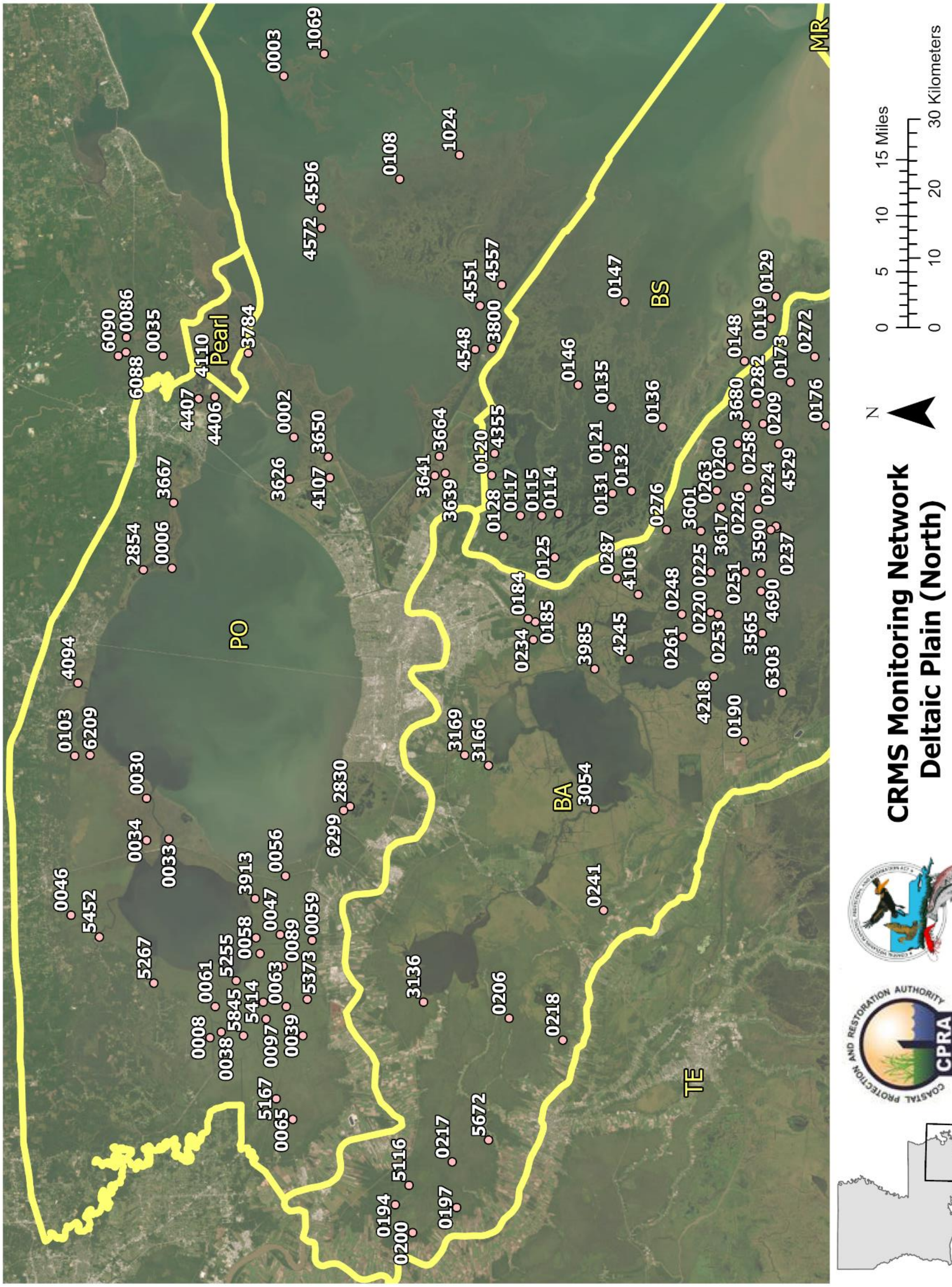
Wood, W. B., Constantin, A. J., Sharp, L. A., & Daigle, M. L. (2025). CRMS Data Synthesis – Coastwide Land Change 1985 to 2021 (p 29). Lafayette, Louisiana: Coastal Protection and Restoration Authority

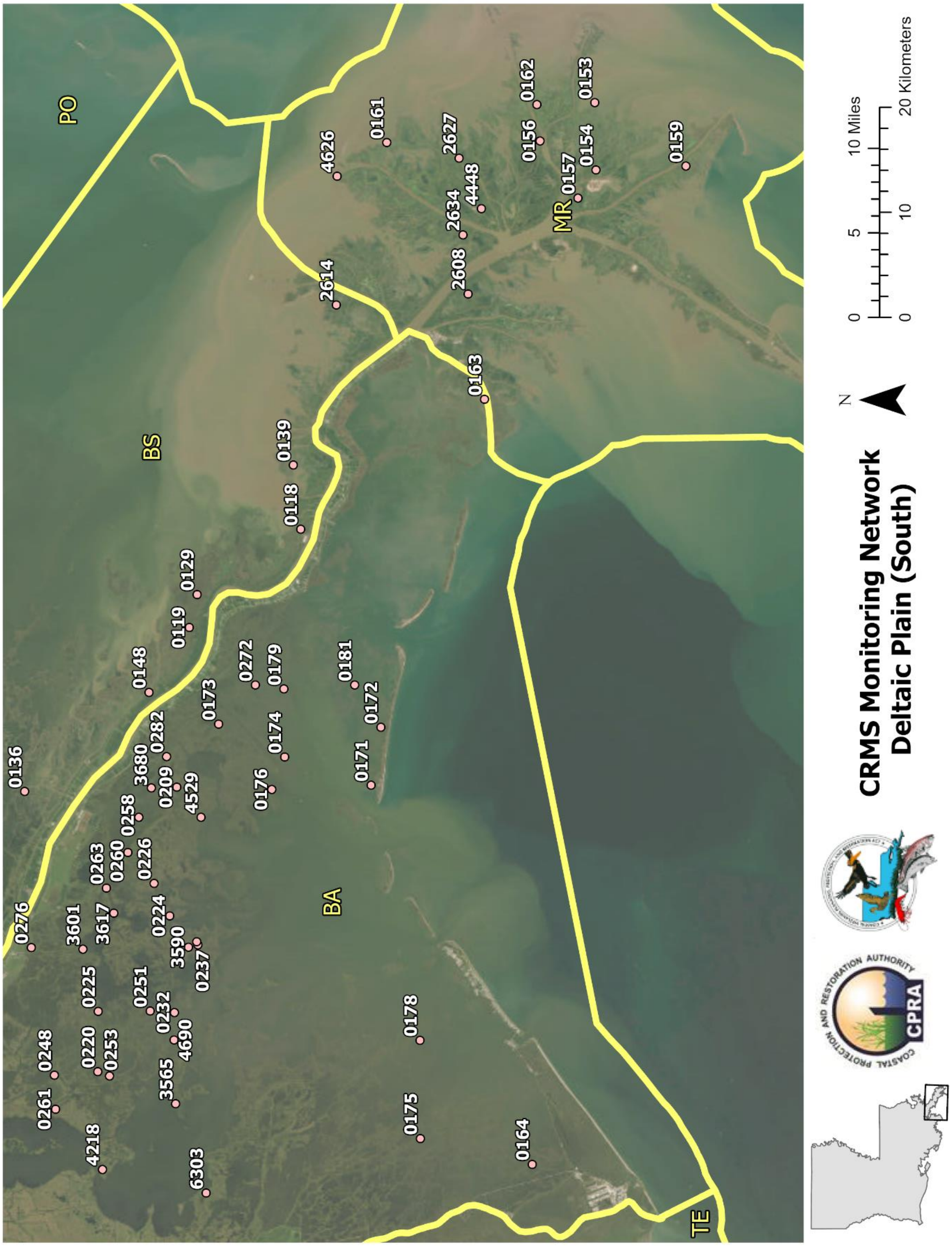
L. Zhang, Thomas L. Delworth, Xiaosong Yang, Fanrong Zeng et al. 2024: Causes and multiyear predictability of the rapid acceleration of U.S. Southeast Sea level rise after 2010. npj Climate and Atmospheric Science. 7, 113.

6.0 APPENDIX A - MAPS

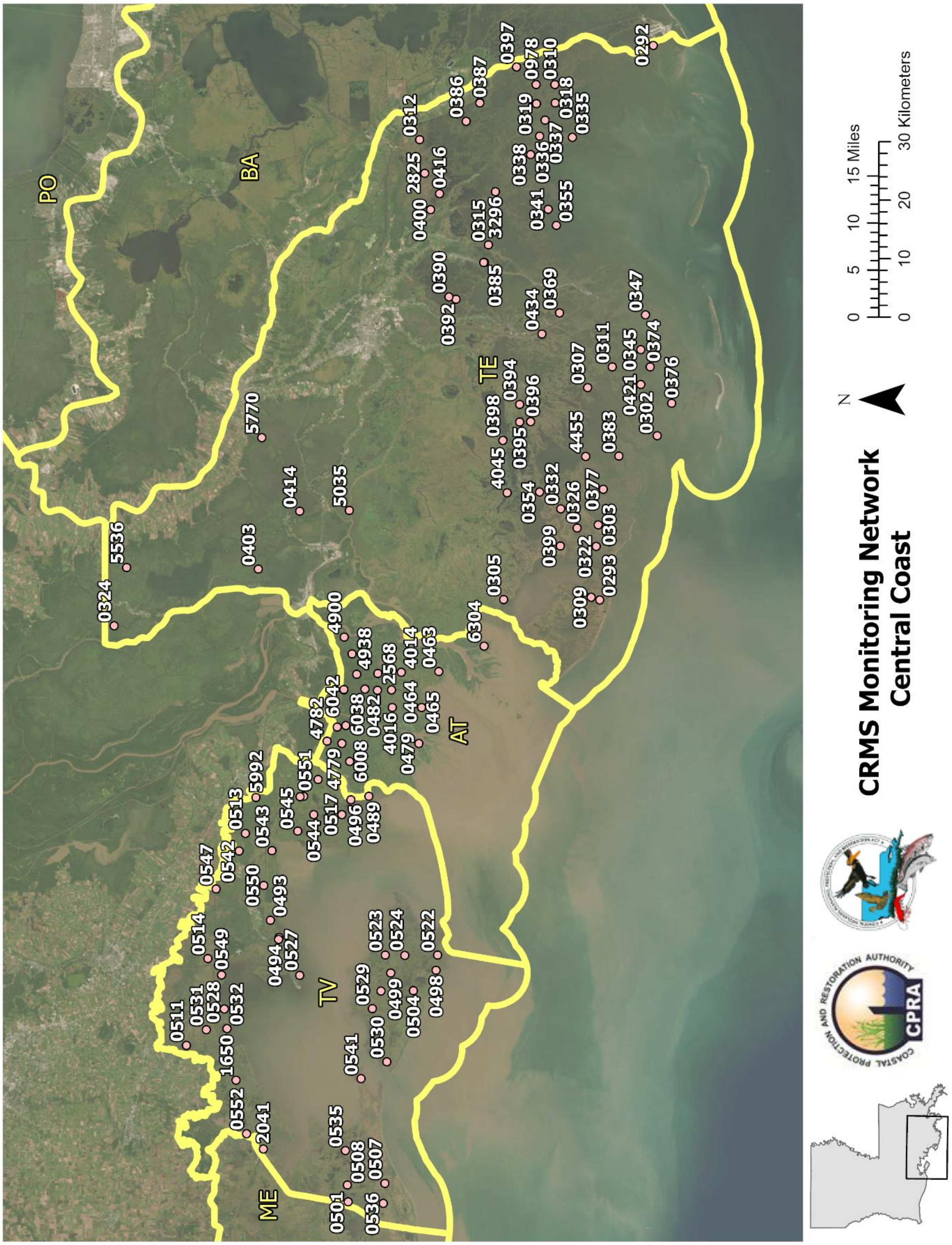


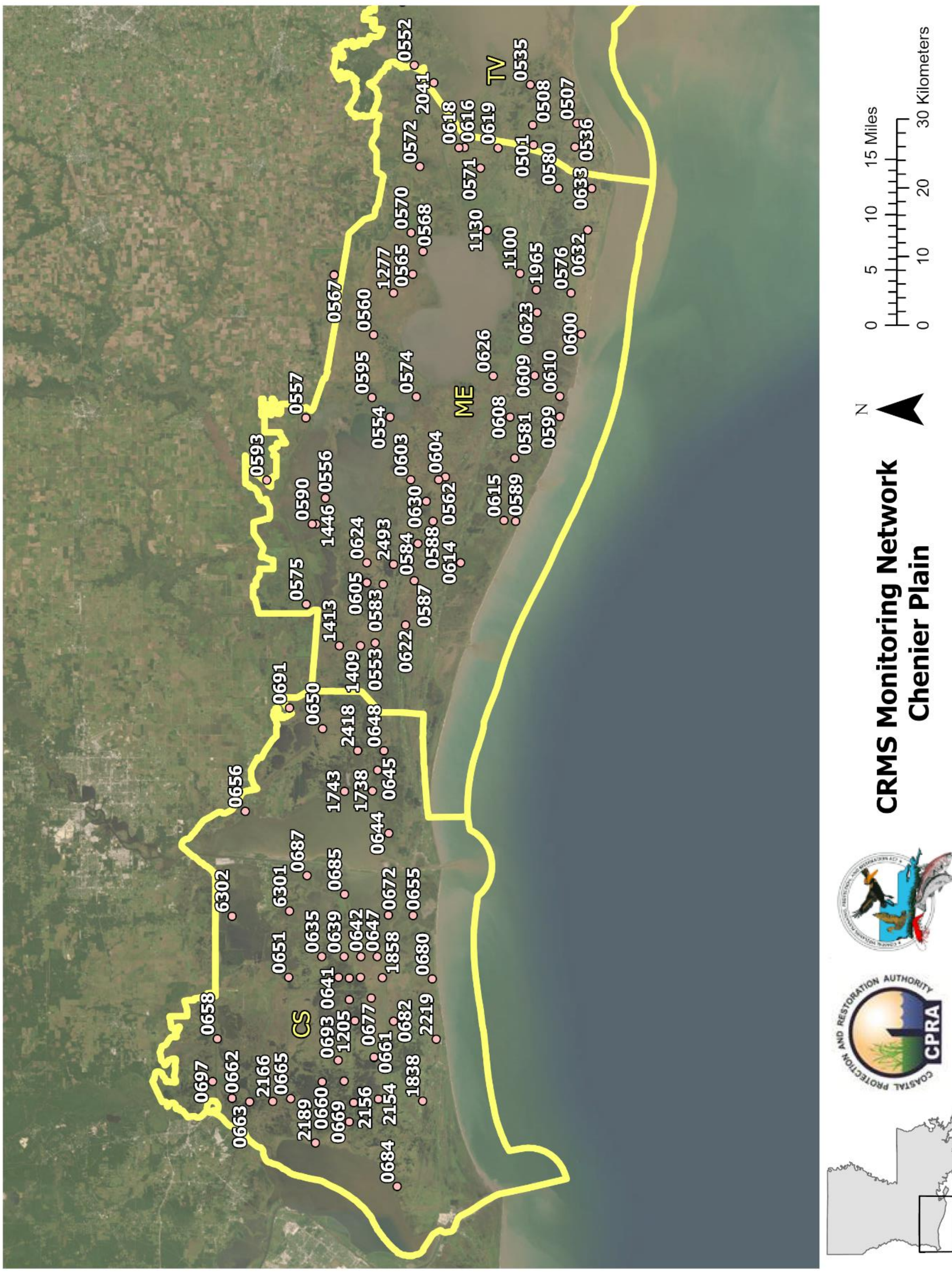

Deltaic Plain CRMS Synthesis Locations
Pearl River
Pearl
Pontchartrain
MRGO
Lake Borgne
Breton Sound
Mississippi River "birdsfoot" Delta
Mississippi River
Bay Batiste
Barataria
Lake Pontchartrain
Lake Salvador
Lake Maurepas
Maurepas Swamp
Terrebonne
Houma Navigation Canal
GIWW
Atchafalaya River
Atchafalaya
Wax Lake Delta
Atchafalaya Delta
Rivers
Roads
Shipping Channels
CRMS Sites
Davis Pond Diversion
Orleans Landbridge
Deltaic Basins
Wildlife Management Area
National Wildlife Refuge
0 10 20 40 Mi
N
CPRA


CRMS Monitoring Network
Deltaic Plain (North)
PO
Pearl
BA
BS
TE
MR
N
0 5 10 15 Miles
0 10 20 30 Kilometers
CPRA
COASTAL PROTECTION AND RESTORATION AUTHORITY



CRMS Monitoring Network
Deltaic Plain (South)
PO
BS
BA
MR
TE
0276
0136
3601
3617
0263
0260
0258
3680
0282
0148
0119
0129
0118
0139
0226
0209
4529
0224
3590
0237
0225
0251
0232
4690
0220
0253
0248
0261
3565
4218
6303
0173
0272
0179
0174
0176
0181
0172
0171
0178
0175
0164
2614
4626
0161
2627
2634
4448
2608
0163
0156
0162
0157
0154
0153
0159
N
0 5 10 Miles
0 10 20 Kilometers


CRMS Monitoring Network
Central Coast
PO
BA
TE
AT
TV
ME
N
0 5 10 15 Miles
0 10 20 30 Kilometers


CRMS Monitoring Network
Chenier Plain
CS
ME
TV
N
0 5 10 15 Miles
0 10 20 30 Kilometers
CPRA
COASTAL PROTECTION AND RESTORATION AUTHORITY