Flood Risk Analysis of Historical Locations along the Texas Gulf Coast Threatened by Storm Surge and Sea-Level Rise

by

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LIST OF ABBREVIATIONS

Abbreviations	Description
SLR	Sea-level rise
THC	Texas Historical Commission
FEMA	Federal Emergency Management Agency
FIRMS	Flood Insurance Rate Maps
NOAA	National Oceanic and Atmospheric Administration
UNESCO	United Nations Educational, Scientific, and Cultural Organization
GIS	Geographic Information Systems
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
MEOWs	Maximum Envelopes of Water
MOMs	Maximum of MEOWs
TCEQ	Texas Commission on Environmental Quality
USFWS	United States Fish and Wildlife Service
NFIP	National Flood Insurance Program
CRS	Community Rating System
SFHA	Special Flood Hazard Area
NSFHA	Non-Special Flood Hazard Area

1. Introduction and Problem Statement

Outside of the usual geographical and archaeological dialogue, historical site vulnerability to climate change is rarely mentioned or placed as a priority in urban and disaster planning. Communicating climate change and sea-level rise (SLR) and other coastal risks is not a simple task being that SLR is a phenomenon that is abstract for many individuals. SLR is a gradual and temporally distant process which makes this a nonissue for many. For those who live along coastlines, this is a much greater threat, not only for their homes, city centres, and transportation systems, but also their sensitive cultural heritage. The Texas coast is a sensitive region for hurricane disasters in particular. Hurricanes such as Ike, Harvey, Rita, and the 1900s Galveston flood have gone down in history as being some of the most destructive to the coastal cities and towns of Texas. SLR is a particularly important topic because of the low elevation of the region and the vast amount of cultural and historical sites that are located along the coastline. Brazoria County, an hour south of Houston, is one of the oldest counties in the state and this county alone has over 300 historical locations per the Texas Historical Commission (THC) database. To begin this study, a literature review was completed that introduces and discusses four themes within previous research: (1) risk and vulnerability, (2) multi-disciplinary collaboration, (3) public outreach and education, and (4) adaptation. The literature review will be concentrating on all World Heritage Sites on a global scale so that the full scope of what researchers are doing regarding site preservation and planning can be discussed.

2. Purpose of Study

There has been little to no published research on the projected damage from SLR on historic locations along the Texas Gulf Coast, to date. Coastal regions are extremely critical areas to study because of their steadily growing populations, especially the Texas Gulf Coast. Per the Texas Comptroller, the Texas Gulf Coast region has grown by 20% since the 2010 Census (more than 1.2 million people), compared to the 15.9% growth statewide (2022). Reeder states, "although habitable coastal zones comprise only 1.5% of the earth's land mass, 41% of the world's population and nine of the ten most densely populated cities occur within 100 km of a coastline" (2012). The dense population growth leads to urban development, which causes erosion, and with that, cultural heritage site degradation. The purpose of this study is to assess how previous research has analyzed the effects of sea-level rise and climate change at World Heritage Sites and aims to answer the question: Would identifying all historical sites along the Texas coastline and comparing them to current FEMA FIRMs (Flood Insurance Rate Maps) and the National Oceanic and Atmospheric Administration's (NOAAs) hurricane surge zone maps aid in hazard-risk management and historical preservation?

These threats along the coastline endanger important public infrastructure and entities such as the Federal Emergency Management Agency (FEMA) help communities who have been impacted by such disasters, so that they can prevent future impacts. FEMA offers risk management, such as visual aid risk maps, hazard mitigation planning, insurance, and educational opportunities to better prepare communities. For this research, I would like to primarily focus on the historical features within the coastal counties as to better understand which features are more prone to flooding and to look for any patterns in feature location along the coastline and compare these locations to FEMA 100- and 500-year floodplain maps and the NOAA hurricane surge zone maps. The point of this visual tool is to create a graphic and collaborative instrument for future research so that interested parties could answer more in-depth questions about how to better prevent and plan for protecting Texas historical locations along the sensitive coastline.

3. Literature Review

Theme 1: Risk and Vulnerability

Risk and vulnerability are two terms that are used often within conversations on climate change, especially conversations concentrating on global sea-level rise. For this discussion, we will be looking at the topic of risk and vulnerability in terms of how cultural and historical sites are affected by sea-level rise and how measuring both can aid in preparing researchers and urban planners in protecting these important locations. Within the twenty articles that were used for this literature review, there were five that primarily examined the importance of risk and vulnerability assessments and how important they are for proper planning and protection of World Heritage Sites. The literature reflects that most of the sites that are within one hundred meters of a shoreline and below thirty meters in elevation will be drastically affected by sea-level rise within the next one hundred years. If the current global mean temperature rise is sustained for the next two millennia, about 6% of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) sites will be affected and .7% of global land area will be below mean sea-level. At 3,000 years, three to twelve countries will experience a loss of more than half of their current land surface, twenty-five to thirty-six countries will lose at least 10% of their territory, and 7% of the global population currently lives in regions that will be below local sea-level (Marzeion et al. 2014). Creating a cultural resource vulnerability index of all these sites will allow for an assessment of which sites will be in harm's way first for hazard planning, conservation, and data recovery purposes. The literature also states that it is extremely important to measure changes of low-lying shorelines regularly for an up-to-date vulnerability assessment. Reeder's article stated that the Santa Barbara Channel has a lower vulnerability than those located along more open and sloped coastlines, such as the Texas Gulf Coast (2012). The Texas coastline being a larger sloped region makes this an extremely sensitive spot for SLR, which argues the need for an extensive risk assessment of all historical sites at risk along the coast. One study, from 1984 to 2016 within the boundaries of sixty-seven sites world-wide, showed that changes found in low-lying shorelines (at around <one meter elevation) and vegetated tidal deltas that consisted of unconsolidated sediments were the most vulnerable to sea-level rise and flooding and that sediment redistribution, whether directly or indirectly caused by humans, was the main cause of shoreline retreat (Sabour et al. 2020). Forrest Wilder (2021) of the Texas Observer stated that "almost 50% of Port Arthur and Galveston are less than one meter above sea level. Roughly 90% of those cities' land area is below two meters. Corpus Christi, the third most vulnerable Texas city, has about 15% of its area below one meter." A published study on the UNESCO Heritage site of Guimarães in Portugal showed that flood vulnerability must be assessed by combining an exposure and sensitivity component, such as wall orientation of buildings, heritage status, age, number of stories, condition, and material. The flood hazard score used in this study was calculated by analyzing the hydrologic–hydraulic modelling of peak flows with a 100-year return period, which provided flood extent, depth, and velocity. Momentum was calculated by using data on depth and velocity, which created the hazard score. Once a hazard score was created, it was compared to the vulnerability model which created a risk matrix (low, medium, high risk). This study concluded that wall orientation and condition were the most concerning aspects, with exposure being more relevant than sensitivity in terms of vulnerability (Ferreira et al. 2020). For the purpose of this research, we are limited to only the site information

that the THC has on record for each location in terms of exposure and sensitivity, such as age and heritage status. Although site descriptive information is not consistent for each site, we will be able to create a base model that can be built upon as more vulnerability data is gathered. Also, the literature reflects that cities should obtain radio-carbon dates for sites that have not yet been dated, so that evaluations and decisions can be made for data recovery. For this research, we are utilizing the sites that have been documented and protected by the THC, who has already thoroughly dated all sites within their registry. The THC has detailed site-specific information on the site location, listing date, area of significance (local, state, national), architectural style (if applicable), time period, whether the site is on private or public property, and any marker text that is available for the site. We will be using the information on site location, county, type, and the THC atlas number. The atlas number is the specific number assigned to each THC location for the online digital atlas database. Additional site information regarding marker text and dates is useful for further research but is not included in this study.

It is also crucial for all historical sites, especially cemeteries, to be properly dated so that mitigation planning can be done to survey, document, and inventory the most vulnerable sites. Cemeteries cannot be moved to other locations in a timely or cost-effective manner, so mitigation strategies to ensure no data is lost from SLR or storm surges are necessary. One study on Rainsford Island, Massachusetts concluded that 26% of the shoreline would be inundated if sea-level rose by one meter and 67% would be inundated if it rose by three meters based on past trends between 1944 and 2008. The Boston Harbor shoreline consists of unconsolidated sediment beaches and a low elevated plain. Rainsford Island is an area of great cultural and historical importance because of the numerous historical locations, one in particular, a Revolutionary War Era cemetery. Maio, et al. concluded that this cemetery would potentially begin to experience the effects of SLR within the next ten years of the study, which was completed in 2012 (2012). Colleen Cronin of ecoRI News stated “Though storm flooding could be a major threat to the integrity of historic cemeteries, general flooding and higher water tables will also have an impact on trees, which hold the ground together in many cemeteries. Falling trees, either weakened by disease, pests, or waterlogged roots, will have the potential to smash historic gravestones and reveal what is below them.” Cronin pointed out that in addition to the threat of cemetery degradation due to SLR in Rhode Island, there is also a threat of flooding due to rivers rising. Many of the historic cemeteries are located along rivers and are in extremely sensitive areas. Cronin also stated that because of limited resources for historical preservation within the state, the most attainable method of preservation would be to better document the graves before they are damaged (Cronin 2022). In conclusion, prior literature that discusses site vulnerability to flood and SLR recommends that a flood vulnerability risk assessment be completed, which allows stakeholders to properly begin steps in the preservation process.

Theme 2: Multi-disciplinary Collaboration

The second theme that repeats throughout the literature is the use of multi-disciplinary approaches along with worldwide collaboration. The three articles that discuss this topic make clear that worldwide cooperation is an important theme that allows different regions to communicate planning strategies and to allow for open-source data to be shared. The study by Cacciotti, et al, reviewed the necessary points to be addressed for strengthening existing management approaches within Central Europe. The discussion introduced solutions such as a GIS platform and a manual for cultural heritage site resilience for support in decision making. These tools resulted from the Interreg Central Europe project ProteCHt2save, which concentrates on risk assessment and sustainable protection of cultural heritage within evolving environments. The study showed that there were problems with collaborations due to funding, knowledge, and awareness of planning and policy. There were also divergences in technological frameworks across the region. Also, lack of funding or limited accessibility to financial resources for conservation are commonly reported together, with low budgets of private owners with little to no resources for the rescue of cultural heritage. Additionally, lengthy procedures along with low participation of public administration in co-financing worsened the problem (2021).

An important topic within this theme is the use of a multi-disciplinary approach for research and planning for SLR and climate change. A multi-disciplinary approach in SLR planning for historical sites could include individuals within fields such as archaeology, geology, chemistry, engineering, geography, and architecture. One of the studies that was done in Spain used a multi-disciplinary approach and because of this methodology, the authors were able to reach the conclusion that the historic city centre of Seville was at an extremely low risk of flooding due to the engineering works being undertaken to divert the river. However, due to the permeability of the subsoil and the presence of underground water, dampness within the historic buildings had caused damage (Ortiz et al. 2016). This conclusion was made possible because of the input of seven different experts from various fields of study that collaborated on their experiences and education to make a comprehensive analysis of the site. Another point made by the literature was that for successful collaboration to occur, it is important to consider team members backgrounds, experiences, and personal identifiers. Having a well-rounded team is important for successful collaboration. As stated by Hirsenberger, et al., heterogeneity of project teams is reflected in professional experiences, education levels, skills, cultural backgrounds, age, and gender, and all are important to consider for successful collaboration (2019). Previous studies revealed that inconsistent understanding of group tasks and knowledge create obstacles for research teams within historic preservation. Those obstacles may also inspire teams to communicate and boost team integration if proper planning and instruction is implemented. For an optimal vulnerability assessment to be completed, there needs to be a cross-collaborative approach from different parties and from individuals with varying expertise with a strong goal of educating stakeholders and the local government entities on the importance of these historical sites.

Theme 3: Public Outreach and Education

The third theme that is found throughout the literature is public outreach on potential community risks and the importance of education for all stakeholders involved. Public engagement and education are a crucial step in disaster and hazard training for the communities located near flood-sensitive areas and there should be collaboration across those communities concerned. In one of the studies done on Cape Hatteras National Seashore near Buxton, North Carolina, over 250 people attended a hurricane preparedness and safety open house in May of 2016 which consisted of displays, activities, and guest speakers that provided educational opportunities and community organization. The attendees learned about hurricanes, flooding, preparedness, response, recovery, and mitigation. Education and outreach are both critical components of hazard mitigation and the hope is that this education model will be replicated in other regions, especially those with historical sites (Allen 2017). Calil, et al. revealed that a powerful way to educate communities on the dangers of coastal hazards and climate change is through the use of virtual reality simulations. Virtual reality would enable users to learn key principles related to climate change along the coast in an immersive, collaborative, and secure environment and will allow for more environmental literacy within these communities. Calil, et al. recommends that interactive 'management flight simulators' be developed for policy makers and the public to support any decisions made in regard to risk. Virtual reality can simulate some impacts from climate change that are not immediate, such as coastal flooding which can communicate the dangers without putting the user in direct harm (2021). Micle, et al. stated that Geographic Information Systems (GIS) could be a practical solution for the online management of archaeological sites. Sites could be managed on a GIS interface such as Google Earth, accompanied by a spatial database which includes all information pertaining to the properties for decision making purposes. This database and digital map would be accessible to both researchers and to the public, whether it be for town halls and local councils, or to private individuals interested in the location of archaeological sites (2014).

Theme 4: Adaptation and Mitigation

The fourth theme that was prevalent throughout the literature on the effects of SLR on World Heritage Sites was the concept of adaptation. Adaptation under the umbrella of historical preservation is the way in which historical and cultural sites become better equipped for the environment that they are in, whether that be due to changes in temperature, humidity, SLR, or extreme weather conditions. The literature explains that architects and city planners should adapt to current climate and projected climate changes for proper risk mitigation, such as adapting older styles of architecture. This method would potentially create a more disaster resilient community. One of the studies completed in Turkey revealed that many vernacular sites in the region were not under threat compared to newer buildings. This was found because those buildings were built with the consideration of the local climate which made more disaster resilient architecture long-term. Builders in that region knew the environmental risks of the time and adapted their construction tactics to combat it (Aktürk et al. 2021). Another method that could be used for adaptation purposes would be to adapt historical interpretations of forts as a new defense against flood mitigation. Many forts, at least incidentally, provide the regulatory ecosystem service of flood control and soil protection by way of wetland/riparian restoration and protection of native vegetation (Julian 2019). Also, the global assessment done by Ciski, et al, detailed that structurally these sites were typically raised on embankments or hills and/or are accompanied by moats (2021). If this new interpretation were applied, this could help planners and preservationists manage the architecture and land to better protect the cultural resources that are within sensitive areas. The study of the sites in Lisbon explained that after the earthquake, tsunami, and fires of 1755, the city was rebuilt as a modern disaster resilient city. A few of the adaptations that were implemented to make it disaster resilient were wider street grids, a lifted stable base under the city for construction, building styles to match those that survived the disasters of the past, and more drains under the main streets for flood prevention (Martins, et al. 2017). The literature also recommends that all site assessments should include data on cultural significance, use potential, and cost for proper trade-off analysis to occur. For most agencies, funding and resources are limited, so using a trade-off analysis to consider which sites are most vulnerable and whether those sites can adapt their uses to be more time and cost effective can help in the protection of the sites. Site assessments should consider varying budget scenarios, and it is recommended by researchers that adaptative use of historical buildings (e.g., building occupancy) should be used to improve the resource values when budgets are controlled (Xiao et al. 2021). Public administration should also be involved in the planning process and a systematic method should be used to value each site so that allocation of funding can take place. Valuation of historic sites is a feasible method of spatial planning. Proper planning should include data on legislation, methodology, and a comprehensive spatial database so that proper steps are in place for mitigation decisions (Micle 2014). City planners should also be knowledgeable when it comes to planning for climate change and mitigation methods and should use techniques that aid in preservation. The results of the study done by Carroll et al., showed that climate change is still considered only in a limited way in urban planning. A recommendation for future planning was to make certain that city planners have thorough knowledge of the threats of SLR even if they cannot prioritize every site (2021). The qualitative categorization of the risks and the spatial distribution of sites can serve as a key tool for management. Prioritization and an organized allocation of resources are both extremely important for mitigation and preservation to take place effectively (Garrote et al. 2020).

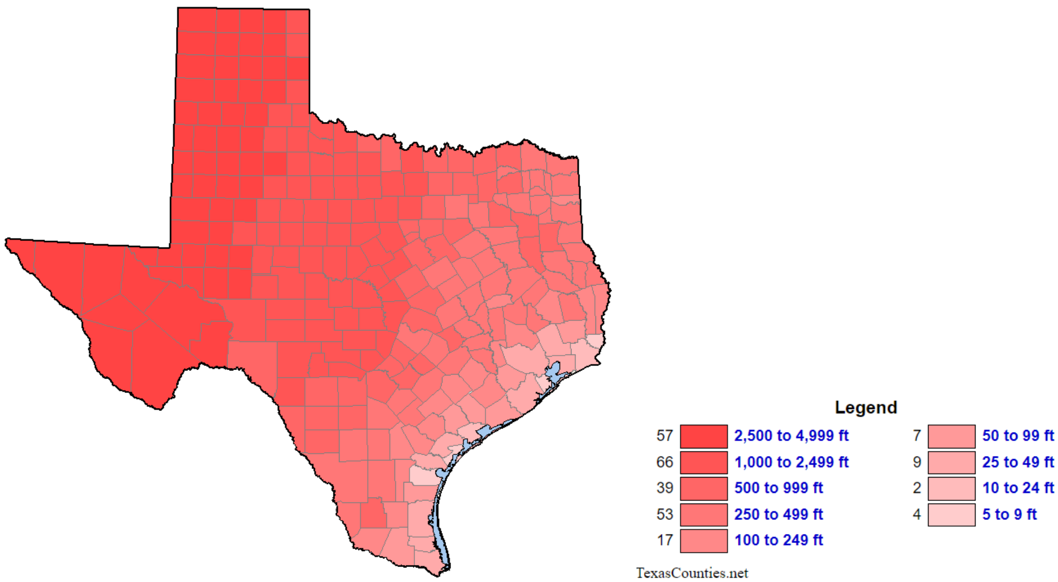
Buckley and Youngs' *The American Environment Revisited* delved deep into the concepts of environmental historical geography and how these concepts have evolved over time and have become more prominent, especially with the rise of digital technology. Digital cartography, GIS, GPS, and a range of other technologies shape how we gather, visualize, and analyze data. Technologies such as digital photography and GoPro cameras shape our ways of projecting that information out into the world. Historical environmental geographers are adapting and embracing these new methods in their mission to find new ways to digitally preserve and promote historically significant features, such as cemeteries, homes, forts, and landscapes (Buckley, Youngs 2018).

4. Research Methods

4.1 Site and Situation

The state of Texas has 254 counties but for the purpose of this research, we will be concentrating on the fifteen counties that border the Texas Gulf Coast. These counties include Aransas, Brazoria, Calhoun, Cameron, Chambers, Galveston, Harris, Jefferson, Kenedy, Kleberg, Matagorda, Nueces, Refugio, San Patricio, and Willacy. Per the U.S. Census Bureau 2023 county facts information, out of the 254 total Texas counties, the fifteen chosen for this study rank lowest in elevation ranging from fifty-nine feet in Kleberg County to seven feet in Galveston County. Future SLR projections along the Texas coast will be affected by the shifting currents and sea surface temperatures. In addition, the land itself is slowly sinking and in some areas even rising, which either increases or reduces local SLR. In the future, gravity will also affect the coast as ice diminishes and with that the gravitational force the ice exerts on the oceans will affect SLR along the coast. A vulnerability assessment of Texas was completed in 2014 by Climate Central, an organization who conducts scientific research on climate change and informs the public of key findings through peer-reviewed scientific papers. Climate Central stated that more than 1,000 square miles of land lie less than five feet above the high tide line in Texas, unprotected by levees or ridges. More than half of the $9.6 billion in property value in Texas is concentrated in Galveston and Nueces Counties alone. In this region, 45,000 people live in nearly 37,000 homes and nearly 40% of these homes are located in Galveston County. These totals leap to more than $33 billion and 320,000 people live in more than 175,000 homes on 2,400 square miles of land under ten feet of elevation. Texas has 1,619 miles of road on unprotected land below five feet, plus numerous museums, schools, houses of worship, power plants, and EPA listed sites such as hazardous waste dumps and sewage plants (Climate Central 2014).

Figure 1. Average elevation of Texas. U.S. Census Bureau State and County Quick Facts



The county shapefiles will be acquired through the 2019 U.S. Census Bureau and the layer will only include the bordering coastal counties polygons as listed above. In regard to site-specific FEMA data, after further investigation of FEMA and contacting County Judge Charles Burns of Kenedy County, I was informed that the county does not have up to date FEMA FIRMS due to an ongoing city-wide drainage system project, but that more accurate maps will be made available in the future.

It is important for this study to acknowledge that FEMA offers a Community Rating System (CRS) which is a voluntary incentive program that recognizes and encourages community floodplain management practices that surpass the minimum requirements of the National Flood Insurance Program and would offer discounted insurance rates to the communities who acquire scores consistently. The purpose of this program is to create better prepared communities while also lowering the number of flood insurance claims each year. The CRS examines the level of participation within counties and cities within each state and each community is categorized as either a Special Flood Hazard Area (SFHA) or a Non-Special Flood Hazard Area (NSFHA) depending upon the flood risk level. Taking a look at Texas as a whole and the coastal counties, it should be noted that not all Texas coastal counties take part in the CRS program. From the report completed in July 2021, Brazoria County had 15,887 policies total but did not receive a class score due to non-participation in the CRS program. Galveston County, which had the lowest elevation on the Texas Coast and the highest number of historic features at risk of flooding, also did not receive a CRS class score due to lack of participation. Despite this result, both Brazoria and Galveston County offer outreach opportunities for CRS

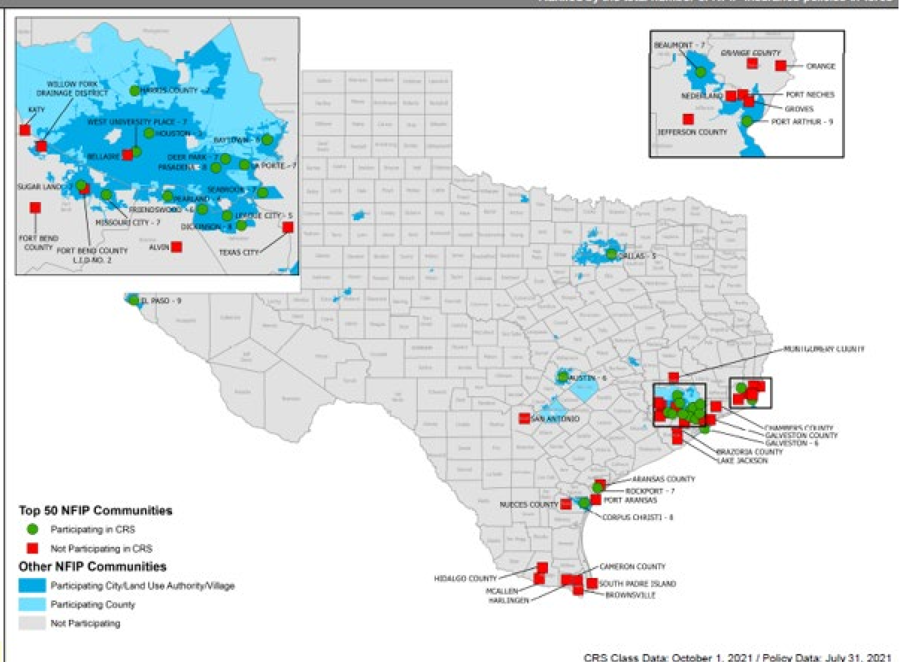
Figure 2.

Texas

Top 50 National Flood Insurance Program (NFIP) Policy Count Communities* and Community Rating System (CRS) Participation

*Ranked by the total number of NFIP insurance policies in-force

Rank	CID	Community Name	Policies	Class
1	480296	Houston	157,550	5
2	480287	Harris County	128,752	7
3	480228	Fort Bend County	32,706	--
4	480483	Montgomery County	30,909	--
5	485488	League City	20,340	5
6	485464	Corpus Christi	18,783	8
7	485469	Galveston	17,278	6
8	485458	Brazoria County	15,887	--
9	480077	Pearland	12,153	6
10	485457	Beaumont	11,392	7
11	480307	Pasadena	10,349	8
12	485468	Friendswood	8,482	6
13	480115	South Padre Island	8,142	--
14	480624	Austin	7,882	6
15	485499	Port Arthur	7,726	9
16	485470	Galveston County	7,652	--
17	480510	Orange County	7,612	--
18	480334	Hidalgo County	7,001	--
19	485498	Port Aransas	5,438	--
20	485514	Texas City	5,261	--
21	480289	Bellaire	5,132	--
22	485494	Nueces County	5,077	--
23	485487	La Porte	4,977	7
24	481603	Willow Fork Drainage District	4,971	--
25	480171	Dallas	4,951	5
26	480304	Missouri City	4,671	7
27	485456	Baytown	4,621	6
28	480385	Jefferson County	4,557	--
29	480045	San Antonio	4,541	--
30	480291	Deer Park	4,347	7
31	480234	Sugar Land	4,100	7
32	481569	Dickinson	3,918	8
33	480119	Chambers County	3,732	--
34	485484	Lake Jackson	3,468	--
35	485507	Seabrook	3,454	7
36	480318	West University Place	3,431	7
37	481485	Fort Bend County L.I.D. #2	3,377	--
38	480103	Brownsville	3,326	--
39	485477	Harlingen	3,091	--
40	485504	Rockport	2,972	7
41	480214	El Paso	2,935	9
42	485475	Groves	2,883	--
43	485452	Aransas County	2,834	--
44	485492	Nederland	2,770	--
45	480101	Cameron County	2,585	--
46	480512	Orange	2,470	--
47	485451	Alvin	2,449	--
48	485500	Port Neches	2,397	--
49	480343	Mcallen	2,363	--
50	480301	Katy	2,255	--



For a full list of CRS communities, visit https://www.fema.gov/flood-insurance/rules-legislation/community-rating-system

As of July 2021, 1260 communities in Texas participate in the National Flood Insurance Program (NFIP).
Of these communities, 66 (or 5%) participate in the Community Rating System (CRS).
Of the top 50 Texas communities (in terms of flood insurance policies-in-force), 22 participate in the CRS.
The remaining 28 communities present an outreach opportunity for encouraging participation in the CRS.

FEMA

NFIP/CRS

Benefits of Joining the CRS

- *Activities credited by the CRS provide direct benefits to the community, including enhanced public safety, reduction in flood damage, and environmental protection.*
- *Residents know the community is working to protect them from flood losses.*
- *Public information activities will build a knowledgeable constituency interested in supporting and improving flood protection measures.*
- *Money stays in the community instead of being spent on insurance premiums.*

participation. CRS program administrations may need to do additional outreach, education, and technical assistance in these areas. The CRS program is an effective way to plan and mitigate flood damage and would subsequently aid in the preservation of the historical features within those counties.

4.2 Data and Methodology

The historical locations chosen for this research were acquired through the THC online database and include features such as historical markers, cemeteries and individual graves, county courthouses, registered properties within the National Register of Historic Places, state historic sites, and museums. Most of the museum locations were determined by address geocoding and the cemeteries were chosen based on those that have received the Historic Texas Cemetery designation or have been located during surveys by Texas Historical Commission staff. While organizing the data, I categorized them in more specific groupings because many of the locations were within the historical markers, historic sites, or registered properties data and were too broad. A more specific set of locations were created based on museums, registered properties, forts, historical markers, religious establishments, cemeteries, and courthouses. Once the new site categories were created, a merged layer was created, and the Select by Attribute tool was used where "Type" was equal to each new category to create a new set of map layers based on the reorganized types. I also included data on historic districts but did not include them with the point data because the historic district polygons were made up of a majority of the historic site points and would be redundant for this research. While cleaning the data, it was noticed that some of the points were in counties outside of the research area and some were also in incorrect counties all-together, especially around the counties of Brazoria, Harris, and Chambers. These locations were deleted if they were outside of the research area and the locations in incorrect counties were corrected. After cleaning the data, the chosen projected coordinate system for all of the point data was NAD 1983 Texas Statewide with a Lambert Conformal Conic projection. The columns "OBJECTID," "Shape," "Atlas_Num" (Atlas Number), "Name," and "County" were kept for each feature layer. While organizing the attribute tables two new columns were created to better organize each group of points, point "Type" and "Notes." The column for "Notes" was added for any additional information describing the location such as potential duplicate names or whether the location is a historic marker representing the location. "Notes" could also be an appropriate location for any historical marker text information.

A counties layer was acquired through the U.S. Census Bureau 2019 Census. This shapefile included all counties within the United States and so the Select by Attribute tool where the "STATEFP" was equal to "48" (which represents Texas) was used to create a new layer from the selection. After this new layer was created, Select by Attribute was used for the counties in this study as listed above and a new polygon feature was created for the study area. These counties were chosen because of their shared border with the Texas Gulf and their low elevation. After looking over the metadata, I only retained the layer columns of "Shape," "FID," and "Name" for the county data. A shapefile depicting the surface water of Texas as line segments was acquired through the Texas Commission on Environmental Quality (TCEQ). These line segments represent the freshwater and tidal streams that have been defined by the TCEQ. This data has been added to the database for the purpose of analyzing the distance of all historical locations within this research and their proximity, specifically within a half mile, to any surface water inside the study area.

In addition, FIRMS (flood insurance rate maps) were acquired through ArcGIS Online for the 100- and 500- year flood zones. The 100-year flood zone represents the land that is predicted to flood during a 100-year storm, which has a 1% chance of occurring in any given year. The 500-year flood zone represents the land that is predicted to flood during a 500-year storm, which has a .2% chance of occurring in any given year. An example of this is Hurricane Harvey, which was a category four hurricane which flooded 500-year flood zones along the Texas and Louisiana coasts in 2017. The FEMA flood zone types of AH, A, AE, VE, AO, and X were retained for this research. A, AH, AE, AO, and VE are considered to be within the Special Flood Hazard Area which requires flood insurance per FEMA. X, or the area that is within the 500-year flood zone is considered to be in the low-moderate risk category and does not require flood insurance, although after severe events like Hurricane Harvey, insurance is desirable. The table below describes what each zone represents per the FEMA definitions.

Table 1. FEMA Flood Zone Area Types.

ZONE	DESCRIPTION
0.2%	Areas of moderate flood hazard, usually the area between the limits of the 100-year and 500-year floods. Are also used to designate base floodplains of lesser hazards, such as areas protected by levees from 100-year flood, or shallow flooding areas with average depths of less than one foot or drainage areas less than 1 square mile.
A	Areas with 1% annual chance of flooding and 26% chance of flooding over the life of a 30-year mortgage. Because detailed analyses are not performed for such areas; no depths or BFEs are shown within these zones.
AE	The base floodplain where base flood elevations are provided.
AH	Areas with a 1% annual chance of shallow flooding, usually in the form of a pond, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Average flood depths derived from detailed analyses are shown at selected intervals within these zones.
AO	River or stream flood hazard areas, and areas with a 1% or greater chance of shallow flooding each year, usually in the form of sheet flow, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Average flood depths derived from detailed analyses are shown within these zones.
VE	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. BFEs derived from detailed analyses are shown at selected intervals within these zones.

FEMA has this data available by individual county only and for the purpose of this research a full map layer of all the counties combined was preferred. The only counties that were not available were Jefferson and Kenedy. A separate map layer was added via FEMA directly from their County Level data for Jefferson County and a new layer was created that included Jefferson. Kenedy County was not included due to the data not being available.

A Category 1 to 5 hurricane surge zone raster layer was acquired through NOAA. NOAA, specifically the National Weather Service's National Hurricane Center, utilizes the hydrodynamic Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model to simulate storm surge from tropical cyclones. The storm surge composites used in the SLOSH model are the Maximum Envelopes of Water (MEOWs) and Maximum of MEOWs (MOMs) and are created to assess and visualize storm surge risk under varying conditions. SLOSH MOMs are available for mean tide and high tide scenarios and represent the worst-case scenario of flooding under ideal storm conditions.

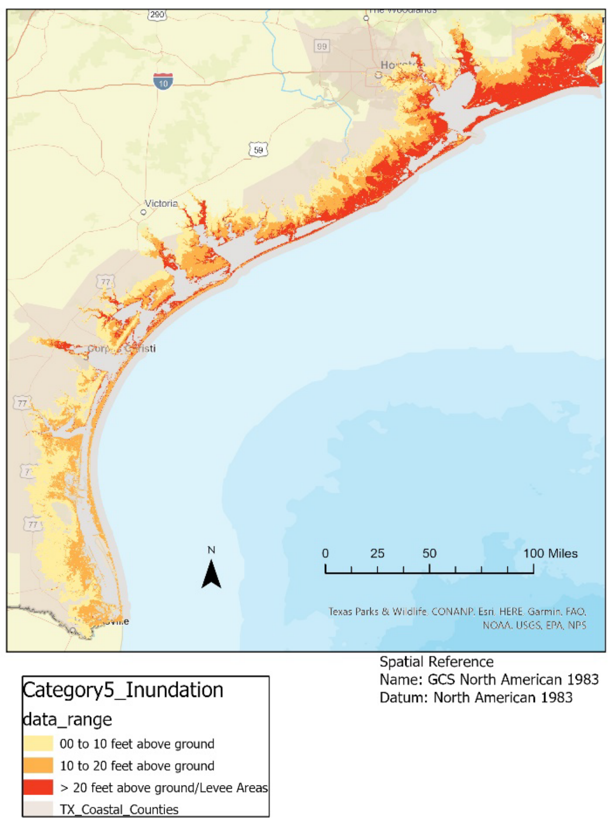
Table 2. NOAA's Saffir-Simpson Hurricane Wind Scale for Category One to Five hurricanes.

Category	Sustained Winds	Types of Damage Due to Hurricane Winds
1	74-95 mph 64-82 kt 119-153 km/h	**Dangerous winds will produce some damage:** Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap, and shallowly rooted trees may be toppled. Extensive damage to power lines and poles will result in power outages that could last a few to several days.
2	96-110 mph 83-95 kt 154-177 km/h	**Extremely dangerous winds will cause extensive damage:** Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3 (major)	111-129 mph 96-112 kt 178-208 km/h	**Devastating damage will occur:** Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4 (major)	130-156 mph 113-136 kt 209-251 km/h	**Catastrophic damage will occur:** Well-built framed homes can sustain severe damage with the loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted, and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to months. Most of the area will be uninhabitable for weeks or months.

Category	Sustained Winds	Types of Damage Due to Hurricane Winds
5 (major)	157 mph or higher 137 kt or higher 252 km/h or higher	**Catastrophic damage will occur:** A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to months. Most of the area will be uninhabitable for weeks or months.

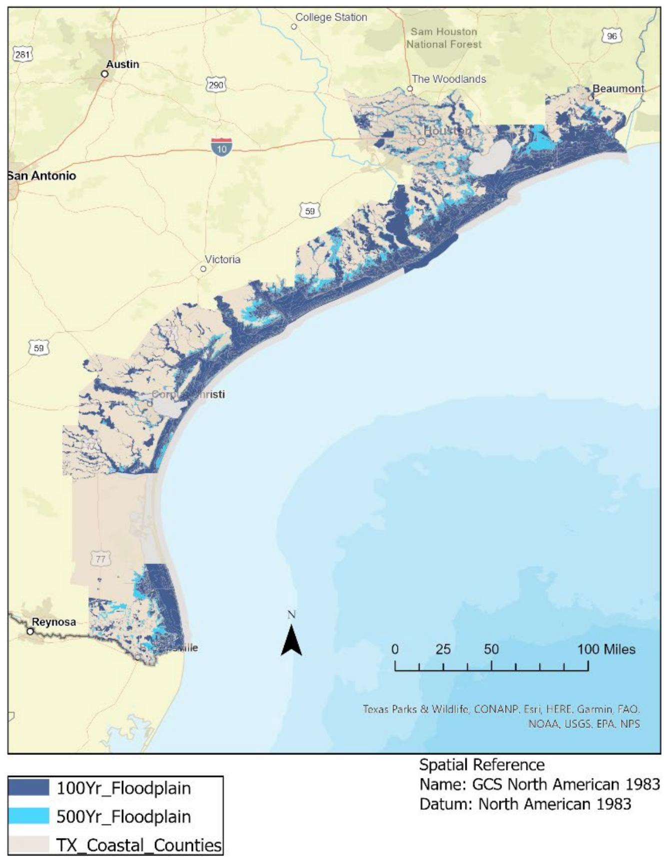
Data for the MOMs surge zones from Texas to Maine were available and a new layer was clipped to only include the research area along the coast. The surge zones were originally divided into twenty-two ranges from “00 to 01 foot” above ground to the highest range of levee areas. The Reclass tool was used to narrow the data range into three categories, “00 to 10 feet”, “10 to 20 feet”, and “greater than 20 feet/levee areas” and was completed for all five surge zones. Figure 3 depicts the extent of the Category 5 surge zone which is the category chosen for this research because of the high magnitude and potential for surge damage. Figure 4 depicts the

Figure 3. NOAA Category 5 Surge Zone along the Texas Coast



extent of both the FEMA 100- and 500-year floodplains within the study area, not including Kenedy County.

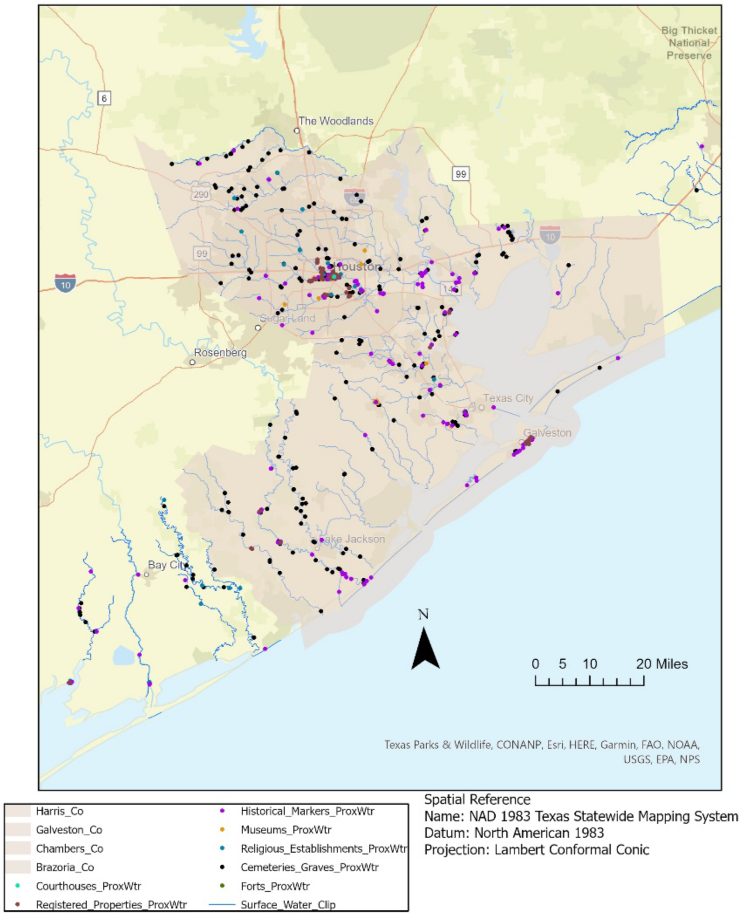
Figure 4. FEMA 100- 500-year Floodplains along the Texas Coast



4.3 Results

Before analyzing the results of the FEMA and NOAA flood areas, it is important to take into consideration the location of any surface water along the coastline that may be affected by storm surges or flooding events. The surface water data from TCEQ identified all freshwater and tidal streams, recreational beaches, bays, estuaries, in addition to which basins they are located within. These locations are situated along and near the FEMA floodplains used in this study and are related to each other. Select by Location was used to calculate the total historical points for each feature type that were within a half mile (2,640 feet) of the TCEQ surface water line segments. This close proximity to surface water relates to the risk of flooding during a 100- and 500-year flood event or to water inundation during a hurricane surge. The previous discussion on rivers flooding near historical cemeteries in Rhode Island is an extremely significant topic for this study and it is important to include surface water data to have a comprehensive risk analysis. In total, there were six courthouses, 423 historical markers, 113 registered properties, fifty-six museums, eighty-three religious' establishments, 474 cemeteries, and seven forts that were within a half mile of surface water.

Figure 5. Texas Historical locations in Harris, Galveston, Chambers, and Brazoria County within a half mile of TCEQ defined surface water



Using the outcomes from the proximity of surface water to the historical features helped support the results from the floodplains and surge zone proximity. The counties were ranked from low, medium, and high risk of historic site inundation based on which sites were within both the FEMA floodplains and NOAA Category 5 surge zone. The risk scale was grouped from (0-14%), (15-29%), and (30-90%) being that the lowest percentage is 0% and the highest out of the fifteen counties is 88%. In Table 3 below, the first column describes the number of historical sites that are present in one or both of the FEMA 100- and 500- year floodplains and also present within the NOAA hurricane surge zones. The total number of sites within the county are provided along with the number of sites that do not fall within these zones, which are shown within the null column. The average county elevation in feet is provided for context purposes and uses the county seat average elevation as a measurement. Being that these counties border the gulf coast, all fifteen counties are ranked the lowest in elevation in the state with Kleberg County being the highest average elevation in Kingsville to Galveston County being the lowest average elevation in the City of Galveston.

Table 3. Results- Number of Sites Vulnerable to Inundation by County.

County Name	# of Locations w/in FEMA & Surge Layers	# of Locations in neither zone	Total w/in County	% of Locations w/in Both	Av. County Seat Elevation in ft.
Kleberg	0	0	44	0%	59
Refugio	1	45	46	2%	46
Willacy	1	37	38	3%	30
Cameron	17	226	243	7%	33
San Patricio	7	57	64	11%	49
Harris	109	824	933	12%	43
Kenedy	2	8	10	20%	36
Jefferson	39	151	190	21%	16
Matagorda	39	125	164	24%	52
Chambers	27	72	99	27%	30

Nueces	49	132	181	27%	7
Brazoria	93	221	314	30%	30
Calhoun	38	52	90	42%	16
Aransas	43	28	71	61%	7
Galveston	370	49	419	88%	7

Figure 6. Counties Ranked from Lowest to Highest Risk of Historic Site Flooding Due to Sea-Level Rise & Hurricane Surge Inundation

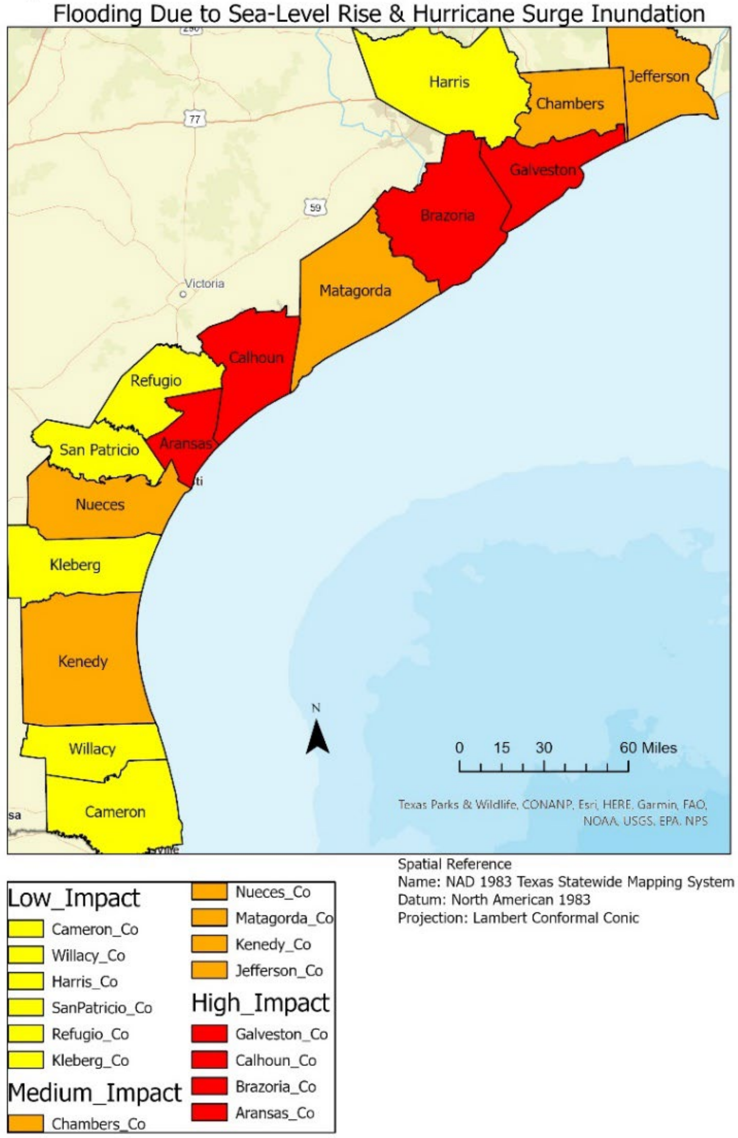


Table 4. Results- Number of historic locations within the 100- and 500- year floodplains.

100 Year	**# of Locations within Flood Zone**	**# of Locations Not in Flood Zone**	**Percentage of Locations Within Zone**	**500 Year**	**# of Locations within Flood Zone**	**# of Locations Not in Flood Zone**	**Percentage of Locations Within Zone**	**Total within Dataset**
Courthouses	2	13	13%	***Courthouses***	2	13	13%	**15**
Registered Properties	77	272	22%	***Registered Properties***	26	323	7%	**349**
Historical Markers	370	726	34%	***Historical Markers***	123	973	11%	**1096**
Museums	29	94	24%	***Museums***	10	113	8%	**123**
Religious Establishments	48	203	19%	***Religious Establishments***	27	224	11%	**251**
Forts	8	11	42%	***Forts***	0	19	0%	**19**
Cemetery/Graves	283	770	27%	***Cemetery/Graves***	101	952	10%	**1053**

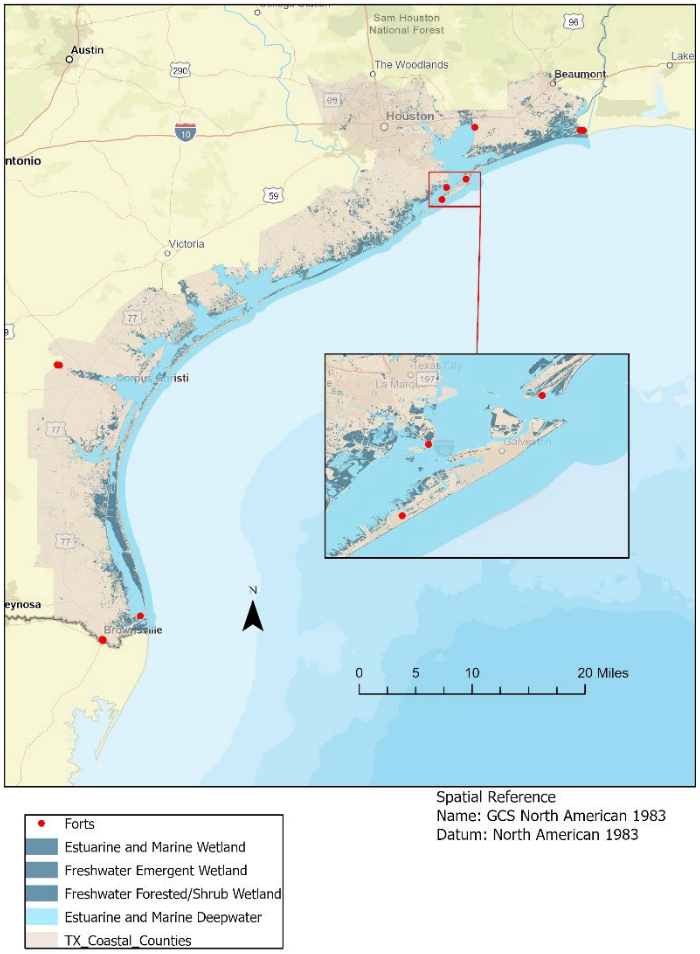
The final results of how many of each type of historic feature are within the 100- and 500-year floodplain shows that overall, a small percentage of sites are within the flood hazard areas, with the highest percentage being the forts at 42% within the 100-year floodplain. Despite the high percentage in the 100-year floodplain, 0% of the forts fall within the 500-year floodplain. The high number of forts within the 100-year floodplain corroborates with previous research on the Southern Plains forts within Texas and Oklahoma (Julian 2019).

Table 5. Forts within the FEMA floodplains and NOAA Surge Zone.

Forts within both layers	**100 Yr**	**Null w/in both layers**	**500 Yr**	**Total # of Fort**
Category 1 Hurricane	7	12	0	19
Category 2 Hurricane	8	11	0	19
Category 3 Hurricane	8	11	0	19
Category 4 Hurricane	8	11	0	19
Category 5 Hurricane	8	11	0	19

Julian stated that "Three quarters of the forts are located within active floodplains, and therefore incidentally mitigate downstream flooding and filter water pollutants, at least during floods, which are frequent in the Southern Plains" (2019). When considering the flood regulating service that forts typically provide, their proximity to floodplains is in fact beneficial for the surrounding areas. Many forts within Julian's research were located near riparian corridors and nine of the thirty-three purposefully provided flood control while sixteen of the thirty-three incidentally provided flood control. The forts were divided into three categories: protected forts that purposefully provided the service (P), forts that incidentally provided the service (I), and forts where the service was nonexistent (N). An additional inquiry that could be answered with further research could be whether the forts within this study are purposefully or incidentally providing flood control or are any of the forts not providing any flood control services.

Figure 7. Forts within a quarter mile of a USFWS defined wetland habitat



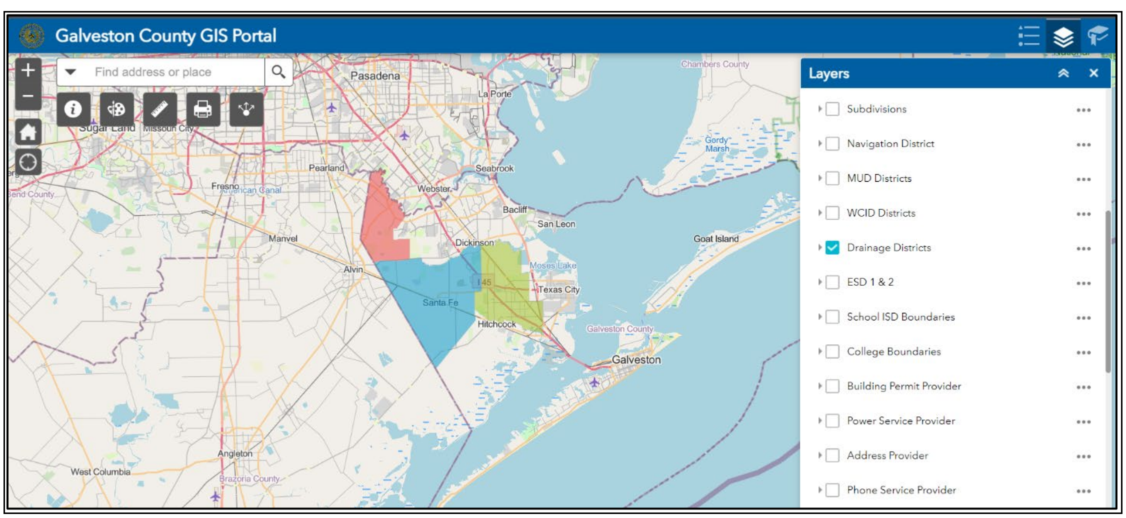
Considering the benefits of having a fort near a wetland/riparian corridor, a map was made using the U.S. Fish and Wildlife Service (USFWS) Wetlands GIS data showing areas along the Texas coast that contain estuarine and marine deepwater and wetlands, freshwater emergent wetlands, and freshwater forested/shrub wetlands. The layers were originally split into east and central Texas but were clipped to the study area and merged into a single polygon layer.

Of the nineteen total forts within the study area, all nineteen were within a quarter mile of a wetland habitat.

After examining the results by county, some significant figures were observed. The first being that Galveston County has the highest percentage of historical sites that are vulnerable to inundation at 88%. This figure is not a huge surprise being that the county was formed in 1838 under the republic from Harrisburg, Liberty, and Brazoria counties and organized in 1839. The county was made a port of entry prior to this in 1837. Per the Texas Historical Commission, the area was also where numerous Native American groups lived, dating back as early as 10,000 B.P. (10,000 years before 1950). An Atakapan burial site was dated 5,000 years old near Caplen on Bolivar Peninsula. There are also numerous historic sites and markers within the county that represent and educate on the counties rampant problem of slavery. Slavery began in the county before 1820 when the pirates Jean Laffite and Louis Michel Aury pursued the slave trade by seizing slave ships headed for the West Indies and by 1850 the slave markets openly operated in Galveston County (Kleiner 2021). With this historical context, the sheer number of historic sites (courthouses, registered properties, markers, cemeteries, historical churches, forts, and museums) sitting at 419 for this research, is not a surprise. Based on the data from the hurricane surge zones from NOAA and the 100- and 500-year floodplains from FEMA, 370 of those sites are within both map layers. The high vulnerability is potentially attributed to the low average elevation of Galveston County, which is seven feet above sea-level based on the county seat of the City of Galveston. There are also only two drainage districts within the county, one east of I-45 and one west of I-45, and neither on Galveston Island where the majority of the historic sites are located. Despite the far location of the drainage districts, the City of Galveston has established the South Shore Drainage project which aims to fortify the city against future flooding events. The City of

Galveston is collaborating with Stantec, which is a company that provides professional consulting services in planning, engineering, architecture, surveying, project management, and environmental sustainability. The South Shore Drainage project will be supporting $55 million in infrastructure improvement by creating a more expansive drainage system and enhancing evacuation routes throughout the county. Project construction is expected to be launched in 2024. As part of the project, the Stantec team will design an enhanced storm sewer system spanning approximately 9,000 feet with the capacity to manage water drainage from a twenty-five-year flood event. The system will also be designed to retain stormwater from a 100-year flood event through the addition of an outfall pump station on English Bayou. To help protect the pump station, resilient design measures will include a floor elevation above the 500-year flood level and there will be mechanisms for remote monitoring. The project will also address "sunny-day flooding" from high tide flooding events (Meluzio 2022). In conclusion, Galveston County has an extremely vulnerable population of historic sites due to the location of the drainage districts and the low average elevation but has an active project in place that will positively impact the City of Galveston and create a more resilient city infrastructure.

Figure 8. Galveston County Drainage Districts No. 1 (blue), No. 2 (green), and Consolidated Drainage (red).



Another significant figure to discuss is the low site vulnerability of Harris County compared to the substantial number of historic sites within the area. There are 933 total sites within Harris County used in this research and only 109 of them are within the FEMA floodplains and hurricane surge zones. Harris County successfully has 824 sites that are outside of the floodplains and surge zones, and this may be attributed to the average elevation which is forty-three feet at the county seat of Houston. Harris County is one of the largest and most populated counties in Texas and also one of the oldest, dating back to 1836. Per the Texas Historical Commission, archeological sites in Harris County reveal the presence of human beings dated back to 6,000 years ago. The Harris County Flood Control District website states that along with the natural streams and manufactured systems, Harris County now has about 2,500 miles of channels, which is significantly higher than the 800 miles of natural channels that initially existed in the county. Also, only 6% of those channels are concrete-lined, most are grass-lined which aids stormwater runoff more effectively. However, under extreme rainfall conditions when rainfall exceeds several inches per hour for several hours, many sections of the county are vulnerable to flooding. An example of this is Hurricane Harvey which hit the coast of Louisiana and Texas and developed into a Category 4 hurricane. Harvey had significant rainfall patterns and it sat directly over Harris County for an extended period of time which caused catastrophic drainage issues and made rivers rise drastically. In conclusion, Harris County has created a mostly successful infrastructure that supports the protection of their historic sites in regard to the FEMA floodplains and NOAA hurricane surge zones.

Another county that has significant figures is Kleberg County, which has the lowest percentage of historical site vulnerability to inundation in both the FEMA and NOAA layers at 0%. There are forty-four total historic sites from the THC database, which is the third lowest number of sites within the study area. The county seat of Kingsville has an average elevation of fifty-nine feet which is the highest average elevation within the study area. Out of the forty-four total historic sites within the county, only four historical markers and one cemetery are within the 100-year floodplain, and none are within the 500-year floodplain or the hurricane surge zone. One notable historic feature that is within the county is the King Ranch which is considered a historic district within the THC. The King Ranch is cumulatively within the boundaries of Kleberg, Kenedy, Nueces, and Willacy Counties within the study area and falls within the FEMA 100- and 500-year floodplains and the NOAA surge zones. Despite the small number of historic point data that fall within the flood zones within Kleberg County, it is still important to consider the historic districts that are within these zones and to consider them when planning and preparing for future flooding events. These locations typically include registered properties, historical markers, etc.

Figure 9. Areas of the King Ranch within Kleberg, Kenedy, and Willacy Counties within the Category 5 Surge Zone

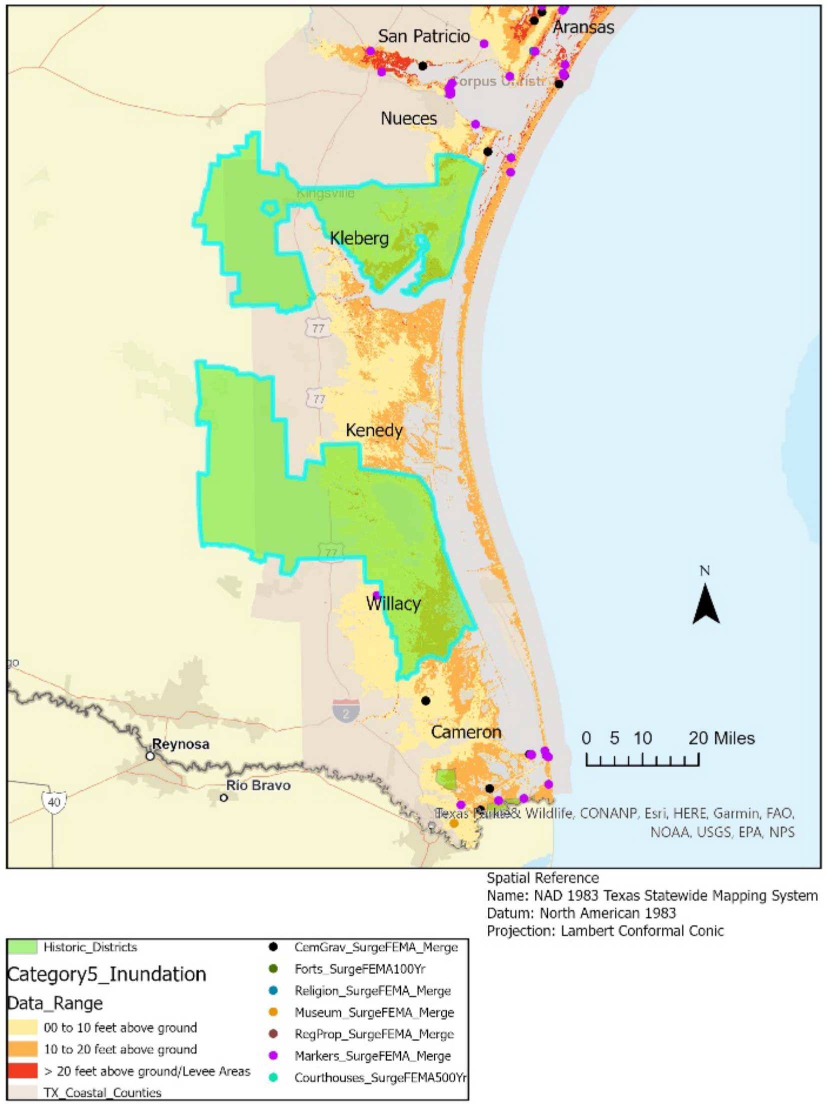
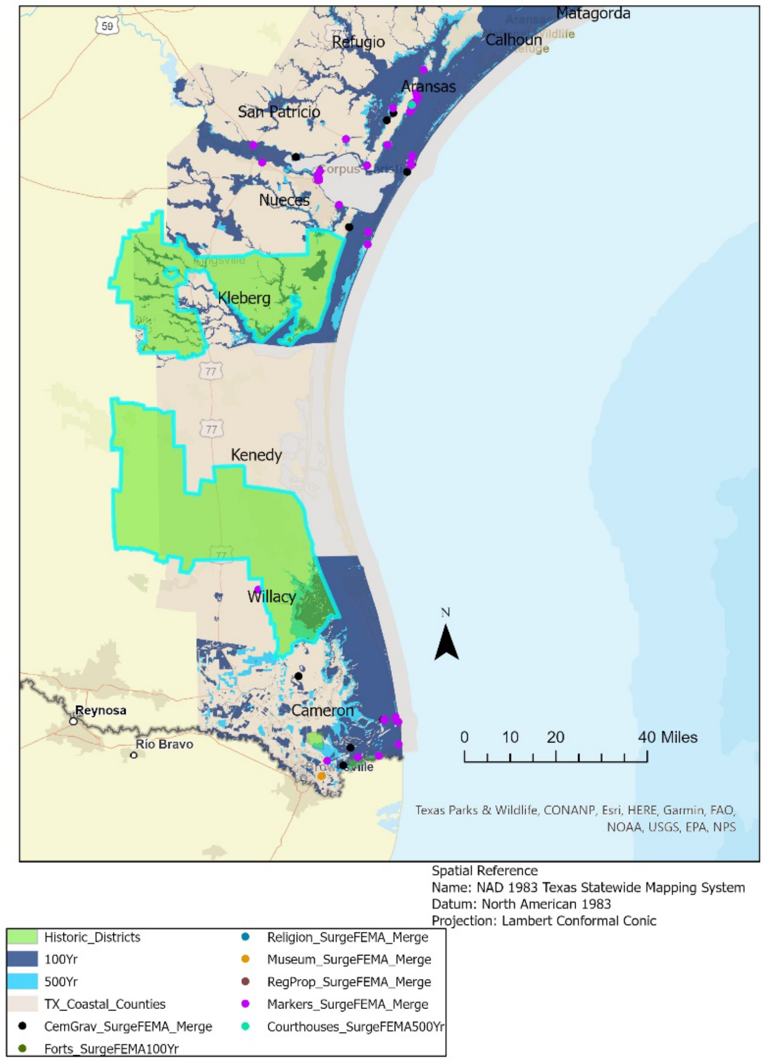


Figure 10. Areas of the King Ranch within Kleberg, Kenedy, and Willacy Counties within the FEMA 100- and 500-year floodplain



To conclude the results, the counties were analyzed individually in order to see how each historic feature faired in regard to flood risk. The results showed that eleven of the fifteen counties had the highest risk with historical markers and the remaining four counties had the highest risk within the historic cemeteries. The high risk of the historical markers may be attributed to the sheer number of them within the dataset while also considering that many of the historical markers were located near other features that are already in the dataset. The complete set of markers was kept for this research because each marker represents an accessible object near each location that has valuable historic data describing each site. Also, many historical markers introduce information about historic locations that no longer have any visible elements, for example those no longer standing due to hurricane damage. A historical marker is a smaller feature that is typically built using aluminum, which is resistant to weather damage. It must be noted that because of the decision to keep all historical markers for this research, there are markers that represent the same location for features such as registered properties, cemeteries, courthouses, museums, religious establishments, and forts. Appendix A shows the final results for each county based on the historical features that are within the FEMA floodplains, the NOAA surge zones, those within both layers simultaneously, and features that are in neither risk zone.

5. Limitations of Study

The dataset provided by the THC had detailed information about each historical location including information such as marker text and dates but did not include this information on the shapefile dataset that is downloadable to the public. This information would provide even more context to the site being analyzed and could provide context on the sensitivity of the site to flood damage. It would also be helpful to have site-specific information on the number of stories in the buildings, wall orientation, current condition, and materials used for construction. All of these details would be valuable exposure and sensitivity components that are not currently available through the THC database. The Texas Historical Commission also states on their GIS database that it makes no guarantee or warranty to the accuracy or completeness of the data depicted on the website or the data from which it was produced. The THC instructs any individuals who find locational errors to report them to the Atlas team using the error reporting tool via the website.

An additional limitation within this study is the lack of FEMA flood data for Kenedy County. It was established that one would be available in the future but there was no known date. With this lack of information, there could only be a visual analysis using the NOAA surge zones within Kenedy, which is useful but not consistent with the remainder of the county results.

These historic locations are being analyzed based on a 100- and 500- year flood event and a Category 5 hurricane surge. With these chosen zones, a worst-case scenario is being used as the measure for how many sites are in a risk zone and because of this, it is not measuring for low-scale flood impacts which happen more often. With this limitation in mind, this study is meant as a baseline for the worst-case flooding events along the Texas Coast.

6. Conclusion

Across the board, all the literature concludes that many historical and cultural sites along coastal regions will eventually be submerged if the SLR increase continues, especially those in lower elevation regions with permeable grounds. The Texas Coast has the lowest elevation in the state and because of this, many historical sites within the coastal counties have a higher risk of flood damage. Coastal cities are also growing in population which leads to urban development which causes coastal erosion. Sites that are within hurricane surge zones and areas where flash flooding due to rivers rising are also at a major risk of degradation.

There is a resounding plea for a cross-national collaboration amongst multi-disciplinary stakeholders to create a common language for risk assessments and mitigation planning. There is either a lack of legislation or inconsistencies within information which creates obstacles for all involved. Prior to this study, no research has been conducted on SLR risk of historical sites along the Texas coastline and the purpose of this research is to set a foundation for future investigation.

The ultimate goal for this research is that it can be used for future public outreach for agencies such as the Texas Historical Commission to aid in decision making and to assist in proper allocation of funding for preservation efforts.

In conclusion, there are some recommendations for future research beyond this study that should be considered for a more comprehensive analysis. In terms of updated spatial flood GIS data, a second study should be completed once Galveston County completes their South Shore Drainage project and has a more accurate FEMA FIRM available. In addition, more accurate GIS data should be collected and integrated into this study once Kenedy County completes their county-wide drainage project and updates their FEMA FIRMs. It would also be interesting to include information on whether the forts included in this study have purposefully or incidentally provided flood management services with their proximity to the flood zones and surface waters.

It is also recommended that the THC includes more robust and consistent site-specific information for open-access. The THC Atlas database has descriptive information for each location but does not include this information in the GIS shapefile download. Unless an updated open-source GIS shapefile is created, any further research would require manual transcription from the Atlas to the current study's database. It is understood that not all information is available for every location and so incomplete data may be the end result, which only highlights the ongoing problems with data recovery for historic locations. Information pertaining to exposure and sensitivity to the elements would be valuable for the database such as, the number of floors within the buildings, building/site materials, the current condition of the site, and wall orientation. This information would support the currently listed information on architectural style, the time periods of each site, and the local/state/national significance. This information would aid in local administrations and preservationist's decision-making on which sites are more sensitive to future flooding events and where to allocate funding and resources first.

To conclude, it is recommended that the counties with little to no participation in the FEMA flood insurance program's CRS program should do more community outreach, education, and technical assistance. For the counties within this study, Brazoria, Galveston, Nueces, Jefferson, Chambers, Cameron, and Aransas all have a zero CRS score as of July 2021. These communities have outreach programs in place, but each county's outreach varies from community to community and has resulted in a score of zero. It is recommended that each county offers more community meetings such as the county-wide event near the Cape Hatteras National Seashore near Buxton, North Carolina. A hurricane preparedness and safety open house would be extremely beneficial to these counties and could offer displays, activities, and guest speakers that provide educational opportunities and community organization. Educating the public and creating consistent information on the risk of SLR and storm surges are two of the most important concerns that should be considered for local administrations and stakeholders to support in protecting Texas' most sensitive historical landmarks.

Works Cited

Aktürk, Gül, and S.J. Hauser. 2021. "Detection of Disaster-Prone Vernacular Heritage Sites at District Scale: The Case of Fındıklı in Rize, Turkey." *International Journal of Disaster Risk Reduction* 58 (May): 102238. https://doi.org/10.1016/j.ijdrr.2021.102238.

Allen, Thomas. 2017. "Identify Cultural Resources Sites Affected by Sea Level Rise at Cape Hatteras National Seashore." PDF File. *Coastal Review*, January 11, 2017. Accessed November 27, 2021. https://coastalreview.org/wp-content/uploads/2018/08/SLRISE_REPORT_NPS_CAHA_11Jan2017.pdf.

Buckley, Geoffrey L., and Yolonda Youngs. 2018. *The American Environment Revisited: Environmental Historical Geographies of the United States*. Rowman & Littlefield.

Cacciotti, Riccardo, Anna Kaiser, Alessandro Sardella, Paola De Nuntiis, Miloš Drdácký, Christian Hanus, and Alessandra Bonazza. 2021. "Climate Change-Induced Disasters and Cultural Heritage: Optimizing Management Strategies in Central Europe." *Climate Risk Management* 32 (January): 100301. https://doi.org/10.1016/j.crm.2021.100301.

Calil, Juliano, Géraldine Fauville, Anna Carolina Muller Queiroz, Kelly L. Leo, Alyssa Newton Mann, Tiffany Wise-West, Paulo Salvatore, and Jeremy N. Bailenson. 2021. "Using Virtual Reality in Sea Level Rise Planning and Community Engagement—An Overview." *Water* 13 (9): 1142. https://doi.org/10.3390/w13091142.

Carroll, Paul V., and Eeva Aarrevaara. 2021. "The Awareness of and Input into Cultural Heritage Preservation by Urban Planners and Other Municipal Actors in Light of Climate Change." *Atmosphere* 12 (6): 726. https://doi.org/10.3390/atmos12060726.

Carson, David. *Texas Counties: Elevation*. Last modified 2023. Accessed March 28, 2023. https://www.texascounties.net/statistics/elevation.htm.

Ciski, Mateusz, and Krzysztof Rząsa. 2021. "Threats to Cultural Heritage Caused by the Global Sea Level Rise as a Result of the Global Warming." *Water* 13 (18): 2577. https://doi.org/10.3390/w13182577.

Cronin, Colleen. 2022. "Historic Cemeteries Could See Grave Impacts of Climate Change in the Ocean State." *EcoRI News*, October 3, 2022. Accessed February 26, 2023. https://ecori.org/rhode-islands-historic-cemeteries-could-see-grave-impacts-of-climate-change/.

Ferreira, Tiago Miguel, and Pedro A. Santos. 2020. "An Integrated Approach for Assessing Flood Risk in Historic City Centres." *Water* 12 (6): 1648. https://doi.org/10.3390/w12061648.

Galveston County GIS Portal: ArcGIS Web Application. Accessed March 28, 2023. https://galvcountymaps.maps.arcgis.com/apps/webappviewer/index.html?id=d619c89878cd4c399b376b51996a7541.

Garrote, Julio, Andrés Díez-Herrero, Cristina Escudero, and I. García. 2020. "A Framework Proposal for Regional-Scale Flood-Risk Assessment of Cultural Heritage Sites and Application to the Castile and León Region (Central Spain)." *Water* 12 (2): 329. https://doi.org/10.3390/w12020329.

Hirsenberger, Helena, Jonjaua Ranogajec, Snežana Vučetić, Bojan Lalic, and Danijela Gracanin. 2019. "Collaborative Projects in Cultural Heritage Conservation – Management Challenges and Risks." *Journal of Cultural Heritage* 37 (May): 215–24. https://doi.org/10.1016/j.culher.2018.10.006.

Julian, Jason P. 2019. "Old Forts and New Amenities in the Southern Plains." In: *Collateral Values: The Natural Capital Created by Landscapes of War.* Edited by Lookingbill, T., Smallwood, P.*, 77-109. Landscape Series*, vol 25. Cham, Springer.

Kleiner, Diana J. "Galveston County." *Texas State Historical Association*. Last modified April 7, 2021. Accessed March 29, 2023. https://www.tshaonline.org/handbook/entries/galveston-county#:~:text=Congress%20made%20Galveston%20a%20port,county%20was%20organized%20in%201839.

Maio, Christopher V., Allen Gontz, David J. Tenenbaum, and Ellen P. Berkland. 2012. "Coastal Hazard Vulnerability Assessment of Sensitive Historical Sites on Rainsford Island, Boston Harbor, Massachusetts." *Journal of Coastal Research* 278 (January): 20–33. https://doi.org/10.2112/jcoastres-d-10-00104.1.

Martins, Alfredo, Catherine S. Forbes, Andreia Pereira, and Daniela Matos. 2018. "The Changing City: Risk and Built Heritage. The Case of Lisbon Downtown." *Procedia Engineering* 212 (January): 921–28. https://doi.org/10.1016/j.proeng.2018.01.119.

Marzeion, Ben, and Anders Levermann. 2014. "Loss of Cultural World Heritage and Currently Inhabited Places to Sea-Level Rise." *Environmental Research Letters* 9 (3): 034001. https://doi.org/10.1088/1748-9326/9/3/034001.

Meluzio, Maggie. "City of Galveston Fortifies Flood Protection Network, Selecting Stantec for South Shore Drainage Project Design." Last modified August 3, 2022. Accessed April 7, 2023. https://www.stantec.com/en/news/2022/city-of-galveston-fortifies-flood-protection-network-selecting-stantec-south-shore-drainage-project.

Micle, Dorel. 2014. "Archaeological Heritage Between Natural Hazard and Anthropic Destruction: The Negative Impact of Social Non-Involvement in the Protection of Archaeological Sites." *Procedia - Social and Behavioral Sciences* 163 (December): 269–78. https://doi.org/10.1016/j.sbspro.2014.12.316.

Ortiz, Rocío Ponce, Pilar Ortiz, José Martín, and María José Domínguez Vázquez. 2016. "A New Approach to the Assessment of Flooding and Dampness Hazards in Cultural Heritage, Applied to the Historic Centre of Seville (Spain)." *Science of the Total Environment* 551–552 (May): 546–55. https://doi.org/10.1016/j.scitotenv.2016.01.207.

Reeder, Leslie A., Torben C. Rick, and Jon M. Erlandson. 2012. "Our Disappearing Past: A GIS Analysis of the Vulnerability of Coastal Archaeological Resources in California's Santa Barbara Channel Region." *Journal of Coastal Conservation* 16 (2): 187–97. https://doi.org/10.1007/s11852-010-0131-2.

RI Coastal Resources Management Council. *RI CRMC Beach Samp Coastal Property Guide*. Accessed March 28, 2023. http://www.crmc.ri.gov/samp_beach/cpg_floodzones.html.

Sabour, Salma, Sally Brown, Robert J. Nicholls, Ivan D. Haigh, and Arjen Luijendijk. 2020. "Multi-Decadal Shoreline Change in Coastal Natural World Heritage Sites – a Global Assessment." *Environmental Research Letters* 15 (10): 104047. https://doi.org/10.1088/1748-9326/ab968f.

Saffir-Simpson Hurricane Wind Scale. National Oceanic and Atmospheric Administration, n.d. Accessed March 28, 2023. https://www.nhc.noaa.gov/aboutsshws.php.

Strauss, Ben, Claudia Tebaldi, Scott Kulp, Susan Cutter, Chris Emrich, Daniel Rizza, and Daniel Yawitz. "Texas and the Surging Sea - Climate Central." PDF File. *Climate Central*. Last modified 2014. Accessed March 16, 2023. https://sealevel.climatecentral.org/uploads/ssrf/TX-Report.pdf.

Texas Comptroller of Public Accounts. 2022. "The Gulf Coast Region 2022 Regional Report," 2022. Accessed January 16, 2023. https://. https://comptroller.texas.gov/economy/economic-data/regions/2022/gulf-coast.php#:~:text=The%20region's%20population%20has%20grown,to%2015.9%20percent%20growth%20statewide.

"Texas CRS Map." PDF File. *CRS Resources*. Last modified October 2021. Accessed March 28, 2023. https://crsresources.org/files/100/maps/states/texas_crs_map_october_2021.pdf.

Wilder, Forrest. 2021. "Rising Seas Could Swamp Some Texas Cities By 2100." *The Texas Observer*, September 24, 2021. https://www.texasobserver.org/new-research-rising-seas-could-swamp-some-texas-cities-by-2100/.

Xiao, Xiao, Erin Seekamp, Junyu Lu, Mitchell J. Eaton, and Max Post Van Der Burg. 2021. "Optimizing Preservation for Multiple Types of Historic Structures under Climate Change." *Landscape and Urban Planning* 214 (October): 104165. https://doi.org/10.1016/j.landurbplan.2021.104165.

Appendix

Appendix A. Study totals by county.

Willacy	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	2	0	3	10	1
Registered Prop	0	0	0	1	0
Museums	0	0	0	0	0
Religion	1	0	0	2	0
Forts	0	0	0	0	0
Cem/Graves	1	0	13	24	0
Courthouses	1	1	0	1	0
San Patricio	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	4	10	8	26	5
Registered Prop	0	1	0	2	0
Museums	0	0	1	2	0
Religion	2	1	2	7	1
Forts	0	0	0	0	0
Cem/Graves	5	3	4	26	1
Courthouses	1	0	0	1	0
Refugio	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	2	0	5	20	1
Registered Prop	0	0	1	3	0
Museums	0	0	0	1	0
Religion	0	0	0	1	0
Forts	0	0	0	0	0
Cem/Graves	3	2	2	20	0
Courthouses	0	0	0	1	0
Nueces	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	40	6	49	96	36
Registered Prop	6	0	5	8	5
Museums	5	0	4	7	4
Religion	3	1	1	19	0
Forts	0	0	0	3	0
Cem/Graves	6	3	13	47	4
Courthouses	0	0	0	1	0

Matagorda	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	9	22	31	69	19
Registered Prop	1	4	3	9	3
Museums	0	2	1	2	1
Religion	2	9	15	30	7
Forts	0	0	0	0	0
Cem/Graves	8	9	26	53	9
Courthouses	0	0	0	1	0
Kleberg	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	4	0	0	21	0
Registered Prop	0	0	0	2	0
Museums	0	0	0	3	0
Religion	0	0	0	5	0
Forts	0	0	0	0	0
Cem/Graves	1	0	0	12	0
Courthouses	0	0	0	1	0
Kenedy	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	N/A	N/A	0	4	N/A
Registered Prop	N/A	N/A	0	0	N/A
Museums	N/A	N/A	0	1	N/A
Religion	N/A	N/A	0	0	N/A
Forts	N/A	N/A	0	0	N/A
Cem/Graves	N/A	N/A	2	4	N/A
Courthouses	N/A	N/A	0	1	N/A
Jefferson	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	13	3	84	88	16
Registered Prop	0	0	12	12	0
Museums	0	0	13	15	0
Religion	1	2	18	20	3
Forts	4	0	4	4	4
Cem/Graves	9	7	38	50	16
Courthouses	0	0	0	1	0
Harris	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	38	37	83	265	46
Registered Prop	16	16	16	231	12
Museums	5	3	6	37	3
Religion	5	3	7	75	3
Forts	0	0	0	0	0
Cem/Graves	59	35	74	324	45

Courthouses	0	0	0	1	0
Galveston	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	183	12	213	214	194
Registered Prop	48	0	49	51	47
Museums	16	2	20	21	17
Religion	31	5	43	43	36
Forts	3	0	3	3	3
Cem/Graves	65	7	86	86	72
Courthouses	0	1	1	1	1
Chambers	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	6	1	24	26	7
Registered Prop	0	0	1	1	0
Museums	1	0	1	2	1
Religion	2	1	4	5	3
Forts	1	0	2	2	1
Cem/Graves	9	6	53	62	15
Courthouses	0	0	1	1	0
Cameron	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	9	7	18	101	11
Registered Prop	0	2	0	18	0
Museums	1	1	4	12	2
Religion	0	1	0	15	0
Forts	0	0	1	7	0
Cem/Graves	5	4	18	89	4
Courthouses	0	0	0	1	0
Calhoun	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	11	5	37	38	16
Registered Prop	2	0	2	2	2
Museums	0	0	1	1	0
Religion	0	0	10	11	0
Forts	0	0	0	0	0
Cem/Graves	9	11	37	37	20
Courthouses	0	0	1	1	0
Brazoria	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	33	5	44	75	26
Registered Prop	4	0	4	6	2
Museums	1	0	11	16	1
Religion	1	0	6	11	0
Forts	0	0	0	0	0

Cem/Graves	103	12	98	205	64
Courthouses	0	0	1	1	0
Aransas	**W/ in 100 Yr**	**W/ in 500 Yr**	**W/ in Surge Zones**	**Total Count w/ in County**	**# w/in both**
Markers	16	15	43	43	31
Registered Prop	0	3	3	3	3
Museums	0	2	3	3	2
Religion	0	4	7	7	4
Forts	0	0	0	0	0
Cem/Graves	0	2	13	14	2
Courthouses	0	1	1	1	1