Impacts of Sea Level Rise on the Houston, Texas Metroplex

A Professional Paper

by

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Introduction

Mankind has been drawn to live next to water since the dawn of time; whether that be a lake for drinking water, a river for transportation of goods, the oceans for their vast food resources, islands for military defense, or simply because we find the idea of living on the water's edge to be enjoyable. This ideology has led to nearly 2.4 billion people living within 100km of the coast and over 600 million people living in coastal areas with an elevation less than 10m (nearly 10% of the global population) (United Nations Ocean Conference 2017). In the United States of America, this coastal living phenomenon is even more established with 127 million, or 40% of the United States population living within the coastal zone (NOAA 2023).

The state of Texas is no exception to the above statements. With over 350 miles of beachfront (Webster and Linton 2013) Texas beaches are known for their natural beauty, natural resources, and importance to the maritime transportation industry; both domestically and globally. If you were to find a city in Texas that exemplified these three traits, it would be Houston. Located in the shallow relief of the southeast Texas coastal plains, Houston finds itself nestled between the bayous that flow into western Galveston Bay. When the Allen brothers first established Houston on the banks of Buffalo and White Oak bayou, they could have never dreamed how expansive the city would become in 187 years. What was originally a single league of property and a dozen families has become the Houston Metroplex, covering 9 counties and home to over 7 million people.

While the ocean has always provided for the people of Houston, it has also been known to take away. Typically, the natural disasters that plague the area stem from hurricanes or rain-based flooding events, however, sea level rise (SLR) will become a much more relevant issue for the people of the Houston metroplex in the coming years. Sea levels have varied greatly on Earth since the oceans first formed; currently we have been in a rising system since the fall of the last ice age about 20,000 years ago. With modern day climate change, SLR is projected to continue and likely accelerate for the foreseeable future. The proximity of residential areas and industrial centers to the coast puts the city of Houston at extreme risk to SLR induced impacts. This study will quantify the impacts of SLR on the Houston metroplex using GIS spatial analysis. The insights gained from this study are important for understanding how resiliency of the area will be impacted both in the near and distant future.

Literature Review

The level of the oceans on a global scale is dependent on two factors: the amount of water in the ocean basin and the shape/size of the ocean basin. Kominz (2001) reports that the latter of the two changes is based on tectonic drift and can be observed over a long-term scale, > 50 million years. The former is based off how much water is captured frozen in glaciers and occurs on a shorter scale of tens of thousands of years. The most recent example of SLR due to melting glaciers is the fall of the last ice age. During the last glacial maximum, about 20,000 years ago, the global climate was on average 5°C cooler than it is today. Sea levels during the ice age were low enough that much of the modern-day continental

shelves were dry ground. The warming period after the ice age and consequential thawing of much of the North American and European glaciers resulted in global sea levels rising by around 120m from 20,000 years ago to 11,000 years ago.

Widlansky et al. (2020) report that another important part of the SLR problem is the thermal expansion of sea water associated with a warmer modern-day climate. The authors note that while not a driver of SLR, the nonlinear thermal expansion of seawater could result in a great deal of variation in local sea level across the globe. Using a model based upon the CMIP5 climate model, the authors found that a 2°C increase in the upper portion of the ocean could correlate to an increase in sea levels anywhere from 4-10% on a global scale.

Harvey et al. (2021) note that while global mean sea level is an important metric for understanding large scale changes in sea level, regional relative sea level is much more important to city planners. The authors have found that two of the main variables that can change a local regions relative sea level compared to global mean sea level are glacial isostatic adjustment (GIA) and vertical land movement (VLM). GIA refers to the movement of land in response to the melting of glaciers. Land mass directly underneath ice age era ice sheets are experiencing a rising response, while adjacent areas experience a falling response. VLM can be a change in land mass elevation due to tectonic events, such as plate convergence or subduction, or land subsidence due to changes in groundwater pressure.

SLR in the Gulf of Mexico

A study looking into relative sea level rise (RSLR) rates in the Gulf of Mexico by Penland et al. (1988) reports that the highest rates of RSLR in the northwestern Gulf of Mexico. Galveston, TX; Eugene Island, LA; and Grand Isle, LA had the highest RSLR rates out of 8 tide gauges examined during the study at 0.63 cm/year, 1.19 cm/year, and 1.04 cm/year respectively. The authors noted that sediment compaction may be the most important variable in understanding changes in RSLR in the northern Gulf of Mexico. The areas with the highest RSLR in Louisiana are located over Holocene period sediment surrounding the Mississippi River delta. RSLR was found to increase as the depth of this sediment layer increased, and sharply decrease or even disappear if the sediment layer was not present.

On the Texas coast, tectonic movement is not generally considered a driver of changes in relative sea level. However, Kolker et al. (2011) note that subsidence is a significant driver that impacts variability of relative sea level across the northern Gulf of Mexico. The driver of subsidence in the northern Gulf of Mexico is generally considered to be sub-surface fluid withdrawal, whether that be ground water or oil reserves. The authors were able to accurately determine subsidence rates by subtracting the RSLR rate of Galveston from the rates found in Pensacola, because Pensacola is built upon a stable carbonate platform that experiences minimal vertical movement. Three distinct phases of subsidence were found in Galveston: phase 1 (1947-1958) at 2.55 ± 2.15 mm/year, phase 2 (1959-1991) at 6.18 ± 0.34 mm/year, and phase 3 (1992-2006) at -1.99 ± 1.41 mm/year.

Using tide gauge data from a NOAA at Pier 21 in Galveston Island, TX; Lui et al. (2020) have regressed and predicted RSLR rates for the Galveston area. The focus of this study was to primarily evaluate to what extent various types of subsidence contributed to RSLR. The authors found that there are at least four distinct subsidence phases in the Galveston area. Phase one from 1909-1937, phase two from 1937-1983, phase three from 1983-1992, and phase four from 1992 to current. Across those time periods, the authors saw the steepest RSLR rates in the second period, as well as the highest percent contribution of subsidence to RSLR. They warned to take into consideration that the variable distribution of hydraulic sediments and aquifers coverage across the Galveston Bay region may lead to widely variable subsidence based RSLR.

SLR and Resilience

Even the most minimal impacts of SLR will have extreme negative impacts upon coastal communities worldwide (Griggs et al. 2021). The risk of high tide floods due to seasonal storm systems such as El Niño pose extreme threats to coastal areas of low relief. SLR could get to a point where even daily high tides could cause chronic nuisance flooding. SLR puts coastal communities at an elevated risk for catastrophic weather events such as hurricanes. The projected increase in regional sea level would cause a storm surge that would be considered minor under today's circumstances to be extremely dangerous to life and property. Elevated sea level will also correspond to increased wave action, causing increased erosion to sediments and damages to hard coastal structures. In addition to structural damage to the built environment, SLR threatens the overall resilience of communities through damages, largely indirect, to other capitals.

Resilience theorists categorize the assets that communities have for adaptation into six types of 'capital': human, social and cultural, physical, financial, and natural (National Academies, 2019). Human capital refers to the resources that contribute to a productive and thriving population. Factors such as education, mental and physical health, and mobility are all critical for human capital (Callaghan et al. 2008). Social capital is based upon the relationships, communication, and trust that different groups have with each other. Typically, a higher degree of social capital can be correlated with a healthier community. However, Callaghan et al. (2008) remark that extreme social capital can lead to the exclusion of other groups of people on the basis of socio-demographic status, race, or gender. Cultural capital within an SES is made up of tangible and intangible forms (Callaghan et al. 2008). Some examples of objects that bolster the tangible cultural capital are historical landmarks, cemeteries, sacred grounds, and art. Intangible cultural capital consists of the different ideologies within a community and the beliefs, legends, practices, values, and traditions that these ideologies represent.

Physical capital refers to the built environment of a community, including its housing stock, infrastructure, and related supporting services (e.g., hospitals, schools) (National Academies, 2019). Financial capital consists of the various different livliehoods that are available in a community and the means that individuals have to be successful in a given livelihood. Ellis (2000) describes that by working towards a more diverse livliehood portfolio, individuals can bolster the financial capital of their households and community.

Finally, natural capital consists of the natural resources available in a given area, as well as the inherent ecosystem services that the surrounding environment provides back to the community. Provisioning, regulating, and cultural ecosystem services derived from natural capital support other capital domains. Resources such as fish, oil, and lumber all contribute to financial capital; while regulating services such as clean water, clean air, and a clean environemnt to live in all boost the human capital of an SES. Cultural services can include the recreational, aesthetic, and spiritual/religious values that are provided by the environemnt.

All of these capitals may be directly or indirectly affected by SLR. Elevated sea levels can damage physical capital directly and degrade natural capital resources. Such place-based impacts may threaten livelihoods, destroy historical sites, impeded recreation, and drive people to relocate. As a result of relocation, communities loose critical human and social capital (Navarra et al., 2013). With this framework in mind, this study will quantify the extent of SLR in the Houston metroplex to explore the impact of SLR on coastal communities' resilience.

Data and Methods

Sea Level Rise Projections

Several government entities have produced sea level rise projections. The NOAA 2022 Technical Sea Level Rise report (Sweet et al. 2022) is one of the more recent publications on concerning historical and projected sea level changes. This report encompasses several topics including global sea level projections, short-term and long-term projections, information on how SLR will impact local weather, and many other pertinent topics. However, for the sake of this paper I was only interested in their short-term (2020-2050) sea level projections for the western Gulf of Mexico (Table 1). The projections from the NOAA 2022 SLR Technical Report that I will be using in this study are the low (0.49m), median scenario (0.59m), and the high scenario (0.69m).

Table 1. NOAA Data

NOAA SLR Projections: Western Gulf of Mexico (2020-2050)						
Observation Extrapolations	Low	Intermediate Low	Intermediate	Intermediate High	High	Median Bounding Scenarios
Sea Level Rise (m)	0.49	0.53	0.57	0.63	0.69	Int-Int High
95% CI	[0.41, 0.57]	[0.44, 0.62]	[0.47, 0.67]	[0.51, 0.79]	[0.56, 0.87]	

The National Aeronautics and Space Administration (NASA) has produced similar records that increase confidence in the NOAA projections. These values were produced based off historical measurements taken from the NOAA tide Guage at Pier 21 in Galveston, TX (Table 2).

Table 2. NASA Data

NASA SLR Projections: Galveston Pier 21 (2020-2050)					
Observation Extrapolations	Low	Intermediate Low	Intermediate	Intermediate High	High
Sea Level Rise (m)	0.46	0.51	0.54	0.61	0.67
Likely Low/High range	[0.40, 0.53]	[0.44, 0.57]	[0.47, 0.63]	[0.51, 0.75]	[0.54, 0.83]

Digital Elevation Models

The digital elevation models (DEM) used for this project were produced by NOAA in conjunction with the Department of Commerce, National Ocean Service, and the Office for Coastal Management. This data, as well as other coastal management related geospatial data is available for public download. These DEMs were originally created by combining the most current LiDAR available to be used inside of NOAA's Sea Level Rise viewer and Coastal Flooding Impacts Viewer. The resulting DEMs have a high resolution of 2.85m. The particular dataset used in this project covers Brazoria, Chambers, Galveston, Harris, and Liberty counties; and was created by using (1) 2018 TNRIS Lidar: Upper Coastal Lidar, (2) 2017 TNRIS Lidar: Jefferson, Liberty, and Chambers, and (3) 2016 FEMA Region 6 TX - Neches Basin QL2 Lidar. One aspect of the NOAA SLR DEM is that they have removed all above-water crossings such as bridges and pipelines (Figure 1). This is desirable to answer the research questions asked in this paper as it helps improve connectivity of the water surface. If bridges were included in the DEM, they would essentially act like a Dam. An example of this would be the Fred Hartman Bridge that crosses the Houston Ship Channel. The inclusion of the Fred Hartman bridge would make it appear as though the southeastern side (open to Galveston Bay) and the northwestern side (open to the San Jacinto River and Houston Ship Channel) were separate bodies of water, and water could not flow between the two.

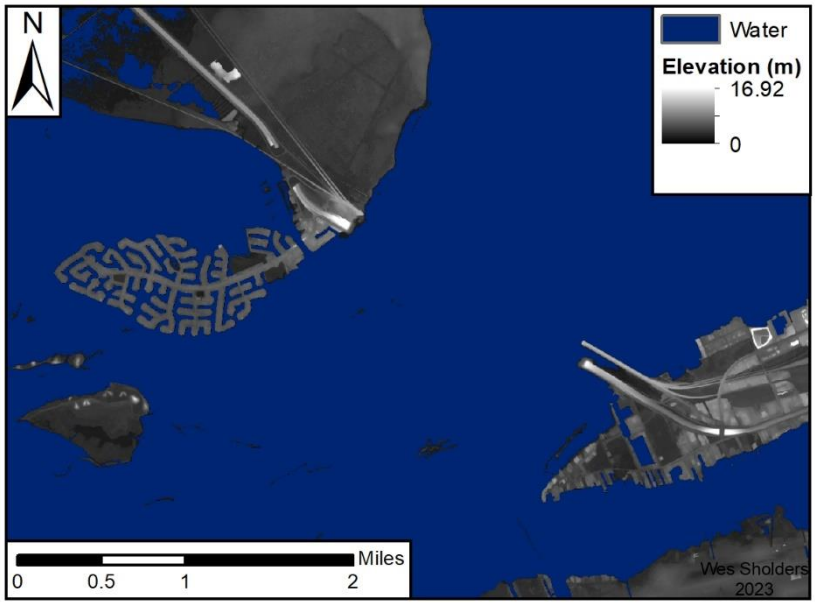

Figure 1). An example of above the surface water crossings being removed can be seen in this figure. The Galveston Island Causeway (I-45) and train bridge have been removed. This effectively connects Galveston Bay to the northeast, and West Bay to the southwest.

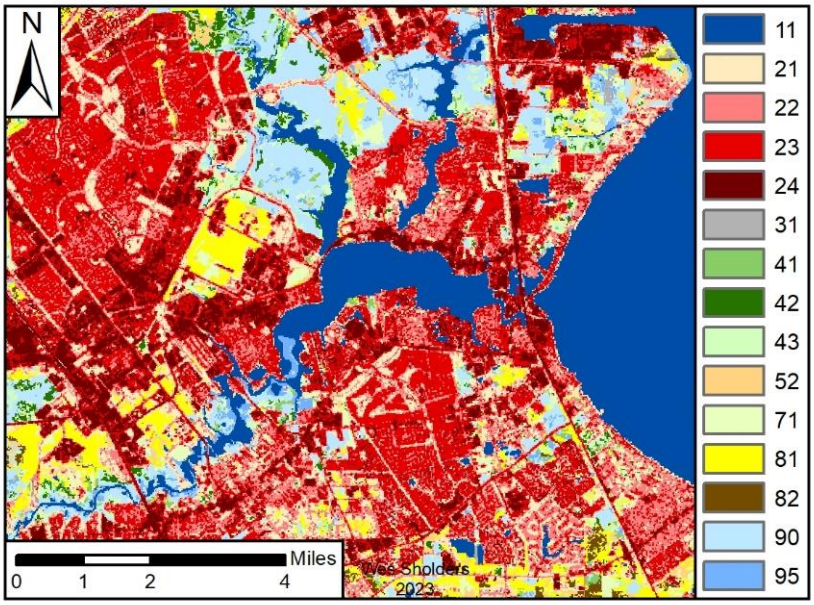

Figure 2). NLCD land use/land cover data surrounding Clear Lake, Houston, TX.

National Land Cover Dataset (NLCD)

The land use/land cover dataset that I will be using during this project is created by the NLCD (Dewitz and U.S.G.S. 2021) and is provided by the Multi Resolution Land Change Consortium (MRLC). This is a land cover data set that is updated every three years; the most recent available version (2019) is what I have used. The NLCD contains 20 different land cover classes, with 16 of them being relevant to the Galveston Bay area. It is important to note that this data set is of a much lower resolution (30m) and *does* include bridges and above water crossings (Figure 2). The land cover class associated with each code can be found in (Figure 3).

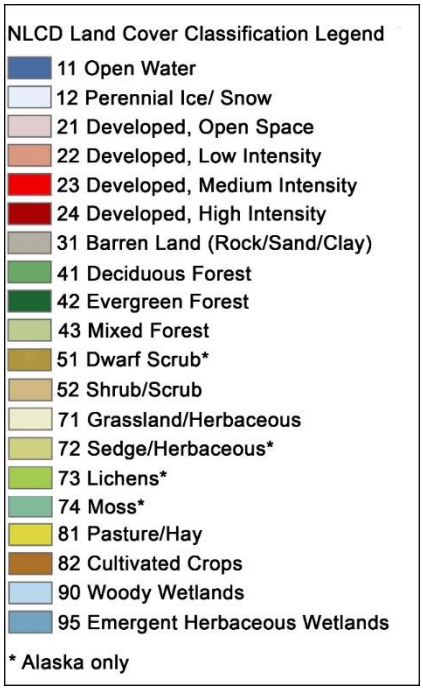

Figure 1). Legend of National Land Cover Dataset codes.

Methods

The study area for this project is the Galveston Bay system to include East Bay, Galveston Bay, Trinity Bay, and West Bay. The first step in preparing for SLR project surfaces was to clip the NOAA SLR DEM to the correct size. To do this, I used a modified shapefile of Brazoria, Chambers, Galveston, Harris, and Liberty counties. The first modification was to extend the beach front of Galveston and chambers counties so that SLR from the Gulf of Mexico could be assessed. The original shapefile did not go past the beach, so SLR impacts in these areas would have been missed. The next modification was to remove most of Brazoria County, as I was interested only in the far east portion that contains Chocolate Bayou and far-west West Bay. Once the study area was established, I then used the extract by mask tool to clip the NOAA SLR DEM and NLCD data to the right size. The clipped DEM and land cover data were then projected to UTM zone 15 (m).

Since I wanted to evaluate the impacts of SLR at three different projection values, I used a python script. The first step of this was to create a raster of the current modern day sea level that other sea levels could be compared to. This step, along with many of the following steps were created by using conditional functions within python. By specifying m=0, this could be accomplished. This current day water surface was then used in every following SLR projection.

I then created a temporary depth grid for the entirety of the study area by using conditional functions and called that raster the depth_x layer. The next step is in preparation for determining what areas are considered connected to tidal flow, i.e., water that is connected to the bay and areas that are unconnected, i.e., land locked areas near the coast that could be flooded. This layer was called the single_x layer. To do this, a single value is assigned to raster cells that fall within the inundated areas, -99999 in this case. Using the single_x raster as the input for the RegionGroup function, I created the clumped_x layer. This layer told me whether or not an inundated area was connected to the Bay by calculating how many cells were within each area. Essentially, if an area had less cells in it than Galveston Bay, I knew it was smaller unconnected body of water. In this case, Galveston Bay had about 230,909,000 cells in it. I could then use this value within two similar ExtractByAttributes functions to

define inundated areas connected to the bay, and unconnected low-lying areas near the coast. Essentially if an area had < 230,909,000 cells in it, I knew it was unconnected, and if an area had > 230,909,000 cells in it, I knew it was connected. These layers were called lowlying_x and connect_x respectively. The last code that I ran used the connect_x layer as a mask to extract the connected areas from the original depth_x layer.

I then used the SLR projection surfaces as a mask to extract the land cover types that were impacted by that particular SLR projection level. Knowing that each cell corresponds to a 30x30 m area, I determined how much acreage of each land cover type was impacted. Finally, broke those values down and calculated a SLR impact ratio (impacted acreage/total county acreage).

Results

First, we can evaluate SLR ratio to get a 'big picture' of the impact of SLR on each county in the study area. Table 3 reports the SLR ratio as the ratio of impacted land to total county area for low, intermediate, and high scenarios. At each SLR projection scenario, Chambers County experienced the highest ratio of inundated land to total County area. At the low (.49m) and intermediate (.59m) scenarios, the portion of Brazoria County that was tested had the second highest SLR ratio. However, under the high scenario (.69m) Galveston County had the second highest SLR ratio at 12.17%.

Table 3. SLR Ratios for Counties in the Study Area

	SLR Ratio		
SLR Scenario	LOW	INT	HIGH
Brazoria	7.52	9.71	10.91
Chambers	11.01	14.43	16.94
Galveston	6.71	9.57	12.17
Harris	0.19	0.21	0.24
Liberty	0.03	0.05	0.11

Next, the effect of SLR can be examined for its impact on land cover types. Of the 20 land cover classes in the NLCD, there were 15 different classifications that were impacted by SLR in the Galveston Bay area. The land class open water has been removed for analysis because tidally connected water cannot be distinguished from low-lying water sources. Table 4 presents the results. Under each SLR projection scenario (LOW, INT, and HIGH) the type of flooding is listed. LL corresponds to flooding of low-lying coastal areas, and CD represents flooding due to being tidally connected.

Table 4. SLR Impact on Land Cover Types by County

a.)

Brazoria County

	Impacted Area (ac)					
	LOW		INT		HIGH	
Land Cover	LL	CD	LL	CD	LL	CD
21	0.00	5.56	0.67	5.56	1.11	6.00
22	0.44	6.67	0.44	6.67	0.67	7.34
23	0.00	6.45	0.00	6.45	0.00	7.34
24	0.00	2.45	0.00	2.45	0.00	2.45
31	123.60	83.40	120.76	120.98	0.44	262.43
41	1.11	1.11	1.11	1.11	1.33	1.11
42	1.33	6.23	1.11	6.67	0.44	8.23
43	0.44	8.90	0.22	10.45	0.22	10.67
52	0.00	2.22	0.67	2.45	0.89	2.67
71	0.67	19.79	1.33	22.91	1.56	30.02
81	2.00	8.90	2.67	10.01	3.11	11.56
82	4.89	5.78	5.78	9.79	5.56	13.34
90	8.00	97.63	17.57	121.87	14.23	160.35
95	1,229.10	1,723.56	1,222.72	3,967.52	107.42	6,816.84
Total	1,371.59	1,978.64	1,375.07	4,294.88	137.00	7,340.35
Scenario Total	3,350.23		5,669.95		7,477.35	

b.)

Chambers County

	Impacted Area (ac)					
	LOW		INT		HIGH	
Land Cover	LL	CD	LL	CD	LL	CD
21	8.89	56.04	17.35	71.17	13.57	94.07
22	77.36	163.46	84.95	252.42	72.50	354.27
23	21.56	68.05	16.90	95.18	16.68	117.87
24	0.44	39.59	0.67	40.48	1.56	42.70
31	24.68	137.44	11.12	160.79	8.01	170.58
41	0.00	1.33	0.22	2.00	0.00	3.56
42	0.89	29.58	0.89	30.91	1.33	36.03
43	0.89	19.79	2.45	21.57	3.11	26.69
52	0.00	3.11	0.89	2.22	0.44	11.56
71	43.13	54.93	55.15	59.16	50.04	87.18
81	244.31	209.50	423.22	300.01	507.50	502.61
82	222.08	59.38	349.16	74.95	421.22	169.69
90	139.83	714.55	227.73	1,577.22	179.03	2,754.36
95	10,315.61	31,892.48	6,789.48	47,694.72	5,753.79	57,138.48
Total	11,099.66	33,449.24	7,980.18	50,382.81	7,028.78	61,509.65
Scenario Total	44,548.91		58,362.99		68,538.43	

c.)

Galveston County

	Impacted Area (ac)					
	LOW		INT		HIGH	
Land Cover	LL	CD	LL	CD	LL	CD
21	128.27	231.29	141.67	255.98	156.79	294.01
22	143.38	366.95	175.02	406.98	208.16	485.49
23	128.27	644.05	174.58	698.10	207.49	777.27
24	81.36	347.16	95.18	356.72	112.31	369.17
31	271.43	462.14	278.22	552.21	58.04	845.10
41	2.00	8.90	1.78	9.56	2.00	11.12
42	1.11	10.90	0.44	12.01	0.44	13.79
43	3.78	32.91	2.67	34.92	3.34	38.03
52	0.67	9.12	8.01	12.90	7.12	22.46
71	68.91	45.15	96.96	57.82	102.08	74.95
81	2.89	18.01	8.90	20.02	10.23	23.57
82	0.00	1.56	0.22	2.00	0.89	2.22
90	76.47	136.55	99.86	171.02	117.20	220.84
95	2,075.62	11,884.09	2,887.35	17,949.46	1,206.49	25,809.99
Total	2,984.16	14,198.78	3,970.85	20,539.69	2,192.59	28,988.01
Scenario Total	17,182.93		24,510.54		31,180.60	

d.)

Harris County

	Impacted Area (ac)					
	LOW		INT		HIGH	
Land Cover	LL	CD	LL	CD	LL	CD
21	31.34	215.28	30.25	225.73	34.69	246.41
22	33.35	316.24	37.81	331.81	42.25	356.50
23	30.01	359.39	40.48	380.52	44.26	401.64
24	27.79	244.41	42.70	249.08	48.93	257.31
31	15.56	67.16	15.12	68.94	15.57	70.94
41	0.22	15.12	1.33	16.68	2.67	18.46
42	1.78	35.36	1.11	38.25	1.56	41.81
43	2.22	57.38	3.11	61.38	2.89	68.28
52	2.00	5.34	2.89	6.23	3.11	6.67
71	12.89	47.15	16.46	49.82	16.68	57.38
81	5.11	26.91	6.67	28.02	9.56	30.69
82	0.00	0.00	0.00	0.00	0.00	0.00
90	12.23	179.92	23.35	210.39	30.91	253.97
95	71.36	320.69	90.29	374.07	115.87	486.60
Total	245.86	1,890.35	311.57	2,040.91	368.95	2,296.67
Scenario Total	2,136.22		2,352.49		2,665.62	

e.)

Liberty County

	Impacted Area (ac)					
	LOW		INT		HIGH	
Land Cover	LL	CD	LL	CD	LL	CD
21	0.00	3.78	0.00	4.45	0.00	4.45
22	0.00	6.00	0.00	8.01	0.00	8.01
23	0.00	0.67	0.00	0.67	0.00	0.67
24	0.00	0.00	0.00	0.00	0.00	0.00
31	0.00	0.00	0.00	0.22	0.00	0.22
41	0.00	0.00	0.00	0.00	0.00	0.00
42	0.00	0.67	0.44	1.11	0.44	1.11
43	0.00	0.00	0.67	0.22	1.33	0.22
52	0.00	0.00	0.00	0.00	0.00	0.00
71	0.67	0.67	0.00	0.67	0.00	0.67
81	0.00	0.89	0.00	0.89	0.00	0.89
82	0.00	0.00	0.00	0.00	0.00	0.00
90	20.67	145.67	42.92	296.23	48.70	665.18
95	5.11	43.59	5.78	50.48	12.68	67.39
Total	26.45	201.93	49.82	362.95	63.16	748.80
Scenario Total	228.39		412.76		811.96	

f.)

Bay Area Total

	Impacted Area (ac)					
	LOW		INT		HIGH	
Land Cover	LL	CD	LL	CD	LL	CD
21	168.50	511.95	189.92	562.88	206.16	644.94
22	254.53	859.33	298.23	1,005.89	323.58	1,211.61
23	179.84	1,078.61	231.96	1,180.91	268.43	1,304.79
24	109.59	633.60	138.55	648.72	162.79	671.63
31	435.26	750.14	425.22	903.14	82.06	1,349.27
41	3.33	26.46	4.45	29.36	6.00	34.25
42	5.11	82.73	4.00	88.96	4.23	100.97
43	7.34	118.98	9.12	128.54	10.90	143.89
52	2.67	19.79	12.45	23.80	11.56	43.37
71	126.27	167.69	169.91	190.37	170.35	250.19
81	254.31	264.20	441.45	358.94	530.41	569.33
82	226.97	66.72	355.16	86.73	427.66	185.25
90	257.20	1,274.32	411.43	2,376.73	390.08	4,054.70
95	13,696.79	45,864.42	10,995.63	70,036.25	7,196.24	90,319.30
Total	15,727.73	51,718.95	13,687.49	77,621.24	9,790.47	100,883.48
Scenario Total	67,446.68		91,308.73		110,673.96	

In Brazoria County (Table 4.a.), the most impacted land cover type was emergent herbaceous wetlands. The portion of Brazoria County used in this study was mostly rural, leading to relatively low impacts to developed land cover classes such as developed open space, developed low intensity, developed medium intensity, and developed high intensity. With this being a primarily coastal area, most impacts to deciduous, evergreen, and mixed forest areas were also minimal. Across the different SLR projection scenarios, tidally connected flooding was responsible for up to 98% of inundation on Brazoria County.

In Chambers County, the most impacted land cover class was also emergent herbaceous wetlands by a margin of over 200%. The least impacted land cover classes in Chambers County were deciduous forests and shrub/scrub (Table 4.b). Chambers County is relatively rural compared to others such as Harris and Galveston County. However, there were increased impacts to each level of developed land when compared to Brazoria County. Tidally connected flooding contributed to up to 92% of all inundated areas in Chambers County.

In Galveston County, the most impacted land cover class is also emergent herbaceous wetlands, however, the impact to developed land cover classes such as developed open space, developed low intensity, developed medium intensity, and developed high intensity are much higher than in Brazoria or Chambers County (Table 4.c). The least impacted land cover class was consistently deciduous forests. Across the different SLR projections scenarios, tidally connected flooding was responsible for up to 92% of inundated areas in Galveston County.

Harris County did not have a consistent most impacted land cover type. What type of areas depended greatly upon SLR projection scenario and if they were tidally connected or low-lying areas. Emergent herbaceous wetlands were still one of the most impacted land class types, however, developed low intensity and developed medium intensity were consistently heavily impacted as well (Table 4.d). Harris county had no cultivated cropland areas that were inundated at any SLR projection scenario. Across the different SLR projection scenarios, tidally connected flooding was responsible for up to 88% of the inundated areas in Harris County.

Liberty County's most impacted land cover class, across both different SLR projection scenarios and flood type were woody wetlands (Table 4.e). Most of the other land cover classes that were impacted in other counties saw little to no impact in Liberty County. Tidally connected flooding was responsible for up to 92% of the inundated areas in Liberty County.

Across the entirety of the Galveston Bay system, the most impacted land class type by far was emergent herbaceous wetland. They made up nearly 89% of impacted acreage across the different SLR projection scenarios (Table 4.f). Th least impacted land classes were deciduous forests and shrub/scrub areas at roughly 0.04% and 0.05% respectively. Tidally connected flooding was responsible for up to 91% of inundation across the Galveston Bay System.

Discussion: County Level Impacts to Resiliency

Brazoria County

It is important to note that while the study area does not include all of Brazoria County, the eastern portion included in this study is characteristic of coastal Brazoria County as a whole. That being said, this is the smallest sub-area analyzed so its impacts appear to be relatively minor compared to other counties. Most of the imapcted areas in Brazoria County are of three different environment classes: emergent herbaceous wetland, mixed forest, and woody wetland. This results in most of the losses in community capital to be attributed to loss of important ecosystem services. Brazoria County has one of the highest SLR ratios ranging from 7.52% - 10.91% of land impacted by SLR. Refer to figure 4 for impacted areas in Brazoria County.

The biggest threats to human capital as a result of SLR in Brazoria County is decreased over all health. On the eastern bank of Chocolate Bayou, there is a chemical industrial complex, primarily owned and opperated by INEOS. There are currently three active Environmental Protection Agency (EPA) clean up sites in this complex that are within 1 mile of areas that may become inundated with SLR. 2 of them are Resource Conservation and Recovery act (RCRA) corrective action sites and the last is a Non-National Priority List (NPL) Superfund site. At this time each of the RCRA sites have had high-priority Clean Air Act (CAA) violations at every quarter of the last three years and Clean Water Act (CWA) violations throughout the last three years. SLR in these areas could lead to increased risk of leaching contaminents into groundwater, as well as increasing the risk that these areas could be damaged durring catastrophic flood events such as storm surge, which would impact health and human capital.

The developed areas in this part of Brazoria County owe much of their protection from storm surge to the marshes and bayous of West Bay and Cholocalte Bayou. Rising sea levels will inundate these marshes causing either the decrease or destruction of these essential protective areas. Without the marshes, this areas stands little chance against a strong storm surge. This elevated risk of catastrophic flooding reduces the health and human capital of those that have to work and live in this area.

The impact to social and cultural capital due to SLR in Brazoria County is relatively minimal compared to others. There are no National Register of Historic Places (NRHP) listings impacted by SLR in this area. The majority of areas that hold cultural value are small rural communities along the banks of Chocolate Bayou and any of their culturally signififcant areas such as curches and cemeteries are not going to be immediately impacted by SLR.

The greatest impact to the physical capital of Brazoria County along West Bay will be to the infrastructure around Chocolate Bay. When crossing Chocolate Bay, Farm to Market (FM) 2004 single lane, two-way steel stringer/beam bridge. Considerations on how elevated wave action under standard weather and hurricanes impact this bridge should be made. This road is a major traffic corridor for plant workers and people commuting between Brazoria and Galveston County and the next available crossing

is over 7 miles away as the crow flies. The shores of Chocolate Bayou are covered in several boat ramps, which flooding due to SLR could render useless.

Brazoria County stands to suffer great losses to their financial capital in the event of SLR. Among the outermost marshes of Chocolate Bay, there are several oil rigs that will become totally submereged even under minor flooding. SLR will impact the operations of the INEOS plant as they store a great deal of product underground.

The natural capital of Brazoria County would likely be the most heavily impacted form of capital. Impacts to all coastal provisioning resources in the are can be expected. There will be impacts to the recreational and commercial bait/shrimp industry of Chocolate Bay, as well as reduced access to current oil and gas collection sites. Inundation of the marsh removes a great deal of finfish and crustacean nursery habitat from the area. Regulating services that the marsh provides such as erosion prevention, soil stabilization, storm water buffering, nutrient cycling, and carbon cycling will all be negatively impacted. The cultural services provided by Chocolate Bay, such as aesthetic value recreational/ecotourism generated value will be negativley impacted by SLR.

Chambers County

Chambers County can be split into two sides that have different attributes. On the eastern side of the Trinity river the county is relatively rural, with most of it being comprised of Anahuac National Wildlife Refuge. West of the Trinity river, Chambers County is more developed and has more residential areas and indutry. That being said, most of the flooding in Chambers County will occur in the low lying areas of the Trinity river delta and Anahuac National Wildlife Refuge. Chambers County has the highest SLR ratio of all Counties ranging from 11.01% - 16.94% of land being impacted by SLR. Refer to figures 5-7 for impacted areas in Chambers County.

Impacts to human capital in this area will be largely due to increased risk of catatstrophic storm damage. Most of the resdiential areas on Trinity Bay are right up against the coast, i.e., they have never had protection from storm surge provided by a marsh. The cities of Anahuac and Barbers hill will be losing storm surge protection as the marsh that makes up the Trinity river delta will become mostly inundated under all SLR projection scenarios.

Chambers County is home to 6 sites that have been placed in the NRHP. Four of these that are important to Chambers County and Texas history as a whole are located right up against the edge of the Trinity river in Anahuac and Wallisville. These include the Chambers County Courthouse, the old Wallisville Townsite, Fort Anahuac, and the home of the County's namesake: Thomas Jefferson Chambers. The last two sites are of importance to native american heritage and are archaeologial sites found to be trading hubs and settlements of the Akokisa and Bidai tribes that once inhabited the area. These are located in the low lying areas of Wallisville and Cove, TX. SLR increases the already high risk that these important cultural sites will be lost to storm surge flooding in the event of a hurricane.

Impacts to the physical capital of Chambers county include important bridges, roadways, the Lake Anahuac levee, schools, and hospitals. On the border of Chambers and Galveston Counties there is a fixed bridge crossing the Intracoastal Waterway (ICW). This is the only roadway crossing the ICW on the Bolivar peninsula until the Sabine lake area to the east. Destruction of this due to erosion or increased wave action could leave residents of the Bolivar Peninsula stranded. In the Smith point area, there a re a great deal of small roads used as access to remote areas of the wildlife refuges and marsh in general. A great deal of this are is slated to become inundated by SLR and will reduce the ability for access to remote oil rigs, park access, or travel between small towns and the rest of Chmabers County. Lake Anahuac is located directly to the north of the town of Anahuac. This is a freshwater body of water that the town uses for many municipal and agricutural purposes such as in their treatment plant and irrigation. There is a 10' tall levee that was implemented in 1953 to increase the volume of the lake as well as act as a barrier to salt water intrusion (TWDB 2006). In the event of a stromg hurricane, elevated sea levels due to SLR could put this levee at an increased risk of leaking or being destroyed. This would not only reduce the freshwater supply of the area but could destroy the town of Anahuac. In the town of Anahuac there are four schools that cover ages pre-kindergarten to High School. Any negative impacts to these structures could spell disaster for families in Anahuac, resulting in the loss of physical, as well as human, and social capital. There is the OmniPoint Hospital that is located in Anahuac against the eastern bank of the Trinity river. There are not many hospitals in this County, and the loss of function there would decrease the physical capital of Anahuac and Chambers County as a whole.

A great deal of the finanical capital in Chambers county can be attributed to its petrochemical industry, natural resources, and ecotourism. Impacts from SLR to the petrochemical industry will be relativel minimal as there will be a small amount of flooding in lowlying areas near oil rigs and chemical plants/storage areas. There are several duck hunting clubs in the Smith Point/Anahuac area that will be negatively impacted by the loss of marshes. These duck clubs provide seasonal work for locals and can be crucial second jobs for some. Similarly, the loss of marshes in Anahuac National Wildlife Refuge and McFaddin National Wildlfie Refuge could impact the amount of ecostourism the area sees. Reduced tourist numbers could correspond to a reduction in funding for the refuge and its rangers.

The marshes of Chambers County provide the area with a great deal of natural capital. SLR will greatly impact this capital and the resilience of the County and SES's at a much greater scale. The coastline of the Gulf of Mexico provides critically important wintering habitat for a wide range of waterfowl, shore birds, and song birds. Chambers county is home to two of the most important refuges for these endemic and migrating species in Texas: Anahuac National Wildlife Refuge and part of McFaddin National Wildlife Refuge. Between the two refuges, there is nearly 40,000 acres of coastal plains that many native species and wintering migratory birds use. Even under the low SLR projection scenario, more than half of Anahuac National Wildlife Refuge and most of Mcfaddin National Wildlife Refuge within Chambers County would become inundated. The loss of this habitat would be detrimental to local natural capital and resileincy, but since this is critical habitat for migrating species, the loss of this habitat would be detrimental to SES's involving migratory birds all across North America.

Besides the loss of marshes within the national wildlife refuges, Chambers County can be expected to lose anywhere from 42,000 ac to 62,000 ac of emergent herbaceous wetland depending on the SLR projection scenario. These marshes provide the area with a variety of regulating services such as water purification, sediment stabilization, flood control, and carbon cycling. These services bolter the natural capital of the County and the loss of them would cause a steep decrease in the County's resilience.

Galveston County

Galveston county is composed of mainland Galveston County, Galveston Island to the south, and the Bolivar Peninsula to the east across the Houston ship channel. With nearly 400 miles of coastline, the County is known as a destination for its beaches. However, the County also has significant agricultural, maritime shipping, and petrochemical industries. The high population, industry, and proximity to the coast all lead to Galveston County being at severe risk of SLR. Galveston County has one of the highest SLR ratios ranging from 6.71 % - 12.17% of total land being impacted by SLR. Refer to figures 8-14 for impacted areas in Galveston County.

SLR will impact the human capital of Galveston Bay largely by putting residents at increased risk of health due to hurricanes. The Gulf Coast, especially Galveston is known to be a hot spot for tropical sotrm activity. Trepanier et al. (2015) note that from 1900-2008 there were 27 hurricanes that impacted Galveston in some shape or form. The most notable storm surge event in recent history was hurricane Ike in 2008. Ike brought a 3-4m storm surge to Galveston Island, caused $29.5 billion in damage to the area, and destroyed over 550 multi-family residential units on Galveston Island alone (Hamideh and Rongerude 2018). Elevation of sea levels under the low SLR projection scenario would cause catastrophic flooding during much weaker storms than the area currently floods under.

With the area's long history, Galveston County has extremely strong social and cultural capital. Galveston County has 81 properties that are currently listed on the NRHP. 74 of those are located on Galveston Island alone. Galveston Island has over 50 churches, some of which are included in the NRHP listings. The area is also known for over 80 festivals throughout the year such as Mardi Gras, Oktoberfest, and others. As was discussed earlier, the county and especially the island are already at extreme risk to hurricane damage. Elevated sea levels could lead to the destruction of these signififcant cultural and historical sites, reducing the social and cultural capital of the County.

Galveston County stands to suffer greta losses to their physical capital in the event of SLR. This is due to the great quantity of coastal roads, but also higher population counts and large numbers of schools and hospitals. The most notable roads that should be discussed here include the Galveston Island Causeway, Galveston Island train bridge, San Luis Pass Toll Bridge, Pelican Island Causeway, and the bridge crossing Dickinson Bayou on FM 146. All of these bridges, as countless other smaller ones provide daily transportation for tens of thousands of commuters and tourists within Galveston County. Another water crossing that may be impacted is the Galveston-Bolivar Ferry. Elevated wave action and erosion may impact the docking areas for the ferrys, influencing how people travel from Galveston Island to the Bolivar Peninsula. On mainland Galveston County, there are dozens of schools along the FM 146 corridor

that are close enough to the coast to see elevated risk of flooding in a hurricane situation. The Bolivar Peninsula has relatively few schools compared to the rest of the County, however these schools are already at extreme risk of damage during hurricanes. On Galveston Island there around 20 different schools that are both private and public, ranging from pre-kindergarten age to the college and post graduate level. These schools and universities on Galveston Island will be put at elevated risk for storm surge flooding during a hurricane. Hospitals that are et risk of negative impact from SLR in Galveston County include the University of Texas Medical Branch (UTMB) complex in Galveston and a variety of smaller clinics on the Bolivar Peninsula and in the Texas City area. UTMB provides services such as life-flight to areas far outside of Galveston Island so any negative impact to this system would cause a steep drop in the physical and human capital of the surrounding area.

Galveston County has a diverse variety of livelihoods that bolster the financial capital of the County. There is a healthy maritime industry in Galveston and Texas City, including three cruise terminals in Galveston. There are several chemical production companies such as DOW, British Petroleum, and INEOS that produce over 30 different chemical products in Texas City. Additionaly, there is a strong tourism sector on Galveston Island. This sector generated nearly $1 billion dollars for the Island with over 6.5 million visitors in 2021 (GEDP 2022). Flooding from hurricanes, rain, and high tides are already shutting businesses down. The increased flooding from SLR will negatively impact the tourism and retail sector, causing a reduction in financial capital in Galveston County.

Galveston County has a great deal of natural capital that can be attributed to its proximity to the Gulf of Mexico and nearly 400 miles of coastline. The inshore waters of West Bay and East Bay to the north of Galveston Island and the Bolivar peninsula supply the area with plentiful waters for recreational and commercial fishing alike. Shrimp, crabs, and oysters make up roughly 95% of the commercial fishing take and the remaining 5% consists of Southern Flounder, Black Drum, Sheepshead, and Striped Mullet (TexasDigitalLibrary). The marshes of Galveston County help to stabilise sediment, cycle nutrients, and improve air quality. The ecosustem in Galveston County also provides cultural ecosystem services such as recreation and ecotourism. In the event of SLR, all of these ecosystem services will be negatively impacted. The flooding of the marshes will lead to less habitat for important commercial species, less soil stabilization, and less recraetional value; which in turn lead to a less resilient County.

Harris County

Located on the northwest side of Galveston Bay, Harris County is the most populated and developed County in this study. It has a relatively small coastline that is heavily bulkheaded, however the Houston Ship channel and its ties to the Gulf make SLR in Harris County a relevant issue. Harris County has a very low SLR ratio ranging from 0.19% - 0.24% of all land in the County being impacted by SLR. Refer to figures 15 and 16 for impacted areas in Harris County.

Due to the Counties relatively high population density, this area will see strong negative impacts to its human capital due to SLR. From Harris County's borders with Galveston County to the south and Chambers County to the north, there are minimal marshes left to protect inland development. Many of

these areas have some sort of man made structure such as a bulkhead or sea wall implemented to protect the coast from flooding, wave action, and erosion. These structures can be effective under standard conditions, however elevated sea levls will decrease their efficacy during a hurricane.

Harris County has dozens of EPA clean up sites, and most of them are concentrated around the Houston Ship channel and Buffalo Bayou. While many of them are far enough inland that they will not be impacted by day to day flooding, there are four superfund sites in the proximity of the Houston Ship channel that could pose an increased risk to human health if flooded. This includes two NPL superfund sites and two non-NPL superfund sites. The inundation of these sites due to SLR could lead to the spread of dangerous chemical to Harris County and surrounding areas.

Harris County as whole has nearly 300 listings, however there are only five that remain in close proximity to the coast. The Walker House, Sterling S. Ross House, and Morgan's Point Historic Distrcit are all at an elevated risk to be lost due to storm surge flooding. The San Jacinto Battlefield and Sylvan Beach Pavilion however will experience inundation from SLR due to these sites being low lying areas. These sites are a part of Houston's identity, and the loss of them would cause the social and cultural capital of the County to decrease.

Possible physical capital in Harris County that could be negatovely impacted by SLR include major water crossings, residential areas, industrial areas, schools, and healthcare groups. The two major water corssings that should be considered for increased stress due to SLR are the Fred Hartman Bridge crossing the Houston ship channel and the bridge where highway 146 crosses Clear Lake. Both of these bridges serve as travel routes for thousands of commuters daily. The loss of functionality in either of these bridges would create massive traffic problems as there are not many other options for crossing these bodies of water. Along Galveston Bay, the communities of Shoreacres, Bayshore, La Porte, and Baytown will be put at an elevated risk for storm surge damage. These areas have been damaged in past storms, and current sea walls and bulkheads may not be effective in preventing damage in elevated sea levels due to SLR. Similarly, these communities all have schools ranging from pre-kindergarten age to High School that will see an equal increase in risk of storm surge flooding. This area does not have any hospitals in the immediate vicinity of the coastm however there are several smaller practices and emergency clinincs that will be at increased risk of flooding due to SLR.

Due to its strategic location and natural resources, Houston has grown to be an economic powerhouse. It has a wide range of industries including energy, transportation, manufacturing, and more. According to the Port of Houston, the revenue driven by maritime transportation produces over $300 billion or about 20% of the State of Texas' entired GDP. One of the only positive impacts that can be seen as a result of SLR would be increased depth of the Houston Ship channel. If the port wanted to bring in bigger ships this means less dredging would be required across the entirety of the Ship channel. Of course, this also means that there will be less clearance under bridges and other above water crossings. Despite this one benefit, SLR will increase the risk of flooding due to storm surge. If the Houston Ship channel were to get damaged during a flooding event, the economy of the state would be crippled, and

the global economy would feel the impact. Over all, SLR will lead to a general decrease in the financial capital of Harris County.

Being so developed, Harris County does not boast as many natural resources as it would have historically. This is especially true for the mostly industrialized coastline. Many of the fish that inhabit the waters near Harris County have been placed under a no-consumption order by the Texas Parks and Wildlife Department. There are hundreds of oil and gas drilling rigs in Harris county, however very few of them are close enough to the coastline to impacted directly by SLR. The biggest negative impact to natural capital in Harris County will likely be to the bayous. The bayous in Harris County help to disperse storm water from heavy rainfall events. These bayous are already at reduced capacity due to development and impervious surface creep around them. The marshes at the end of these bayous help maintain sediments and prevent excessive erosion. Inundation of the marshes from SLR will reduce their ability to control these sediments, causing further reduction in marsh/bayou size. This will in turn cause flooding of properties along the banks of these bayous to become even more frequent.

Liberty County

Liberty County is the second largest County by acreage in this study, but has one of the smaller populations. Out of the five Counties examined in this study, Liberty County is the only one that does not border Galveston Bay. Because of this, flooding here is minimal, however the county still experiences impacts to resiliency from tidally connected flooding and flooding of low lying areas. Liberty County has the lowest SLR ratio of all Counties ranging from 0.03% - 0.11% of all land in the County being impacted by SLR. Refer to figure 17 for impacted areas in Liberty County.

Impacts to human capital due to SLR in Liberty County will be minimal. Across all SLR projection scenarios, there was less than one acre of developed land impacted. Where residents may be put into risk however is the loss of wetlands alongside the Trinity river. Most of the land to be inundated in Liberty County are woody wetlands, which are not necessarily as important for protecting against storm surge, but they are crucial in protecting the surrounding area from dangerous rain based storm waters. These areas allow storm water to flow above and filter through the porous surface layer (Raspati et al. 2017)), ultimately leading to a swifter reduction in high water due to heavy rainfall. The flooding of these wetlands due to SLR could lead to erosion, habitat transformation, and a largely unhealthy wetland system that cannot process as much storm water. This would cause a decrease in the human capital and overall resiliency of Liberty County, as well as areas that are downstream of Liberty County.

The social and cultural capital of Liberty County is not in great risk of being reduced by SLR. The County has 6 current listings in the NRHP and all of them are safely out of the way of projected inundated areas. No native american archaeological sites have been established in the flooded areas, however there is a strong presence of Orcoquisac villages in the area. These unknown native sites may be at risk of being lost if in the event of SLR.

Liberty County is relatively unlikely to see many aspects of its physical capital put at risk by SLR. There are no structures crossing the Trinity river in the area that will be impacted by flooding, and very little development in general. The most likely damage to physical capital in increased erosion in the town of Moss Bluff and the loss of functionality the boat ramps along the river.

Similaly, the financial capital of Liberty County is not in extreme risk of loss of resiliency due to SLR. The areas that will be impacted are largely rural/wilderness that do not have any business within them. The lower portion of the Trinity River National Wildlife Refuge will see some flooding and that may impact tourism rates of that area.

Liberty County is afforded a multitude of different ecosystems services that lend to the County's natural capital. Much of this is due to the Trinity river and the fertile soils along it. Residents utilize the area for lumber, fish, and drinking water among other provisioning services. The area around the river also supplies various regulating and supporting services such as improving air quality, removing pollutants from the water, and cycling nutrients. However, SLR may cause the habitat types that supply these resources to change via salt water intrusion. The Trinity river at Wallisville has a salinity of 0 ppt under standard circumstances (USGS 2022). However, even under the Low SLR projection scenario, water levels are expected to intrude over 28 kilometers up stream of this gauge. This could impact the standard salinty of the water there, in turn impacting the surrounding ecosystem and the natural capital it is able to afford the County.

Policy Implications

The issue of SLR poses a complicated puzzle for policy makers worldwide, let alone in the Galveston Bay area. The legislation that they produce regarding future sea levels will greatly impact how communities function, and how residents of the Galveston Bay area live. If the frequency of floods continues to increase as it is projected to, we may see a shift in legislating flood mitigation programs to more and more local governments. Brody et al. (2010) describe how coastal communities are becoming increasingly self-reliant when it comes to the decision-making process and legislation of flood mitigation measures. These entail structural flood mitigation measures such as levees, seawalls, and channels as well as non-structural flood mitigation approaches such as risk distribution focused insurance plans, buy backs, and direction away from hazardous areas. Policy makers may see greater pressures to implement climate change friendly policy in response to SLR. Nichols (2011) describes the need for climate change mitigation policy to be implemented. As greenhouse gas emissions and climate change in general are a global issue, he argues that international cooperation between heavy polluters to greatly reduce emissions is crucial in mitigating the impacts of SLR. Building in areas that are likely to be impacted by flooding has always been more strict than in other areas. Moser (2005) found when interviewing households that had experienced flooding from the ocean that simply having a home be built on stilts was not a satisfactory mitigation technique. Policy makers can expect to see increased desire in safer building codes in response to SLR.

Conclusion

Simply because the coastline is becoming a more dangerous place to live does not necessarily mean that people will stop wanting to live there. In the Galveston Bay area, the Counties that stand to lose the most from SLR are Galveston and Chambers Counties. The risk to Galveston County's people, social and cultural values, economy, and natural resources is extreme. Chambers County and its vast expanses of National Wildlife Refuges of international importance are likely to see losses of nearly 50%. This is followed by Harris County and its maritime industry. Although it has a relatively small coastline, any losses to the County's maritime transportation potential would be felt worldwide. While the portion of Brazoria County that borders the Galveston Bay system does not stand to lose as much important industry or safety from hurricanes, the same cannot be said for the nearby areas of Surfside and Freeport. Ultimately, Liberty County will be the least impacted county in the area, aside from loss of important woody wetlands. Policy makers in the area need to learn all that they can as to how SLR may impact the area, its people, and its natural resources.

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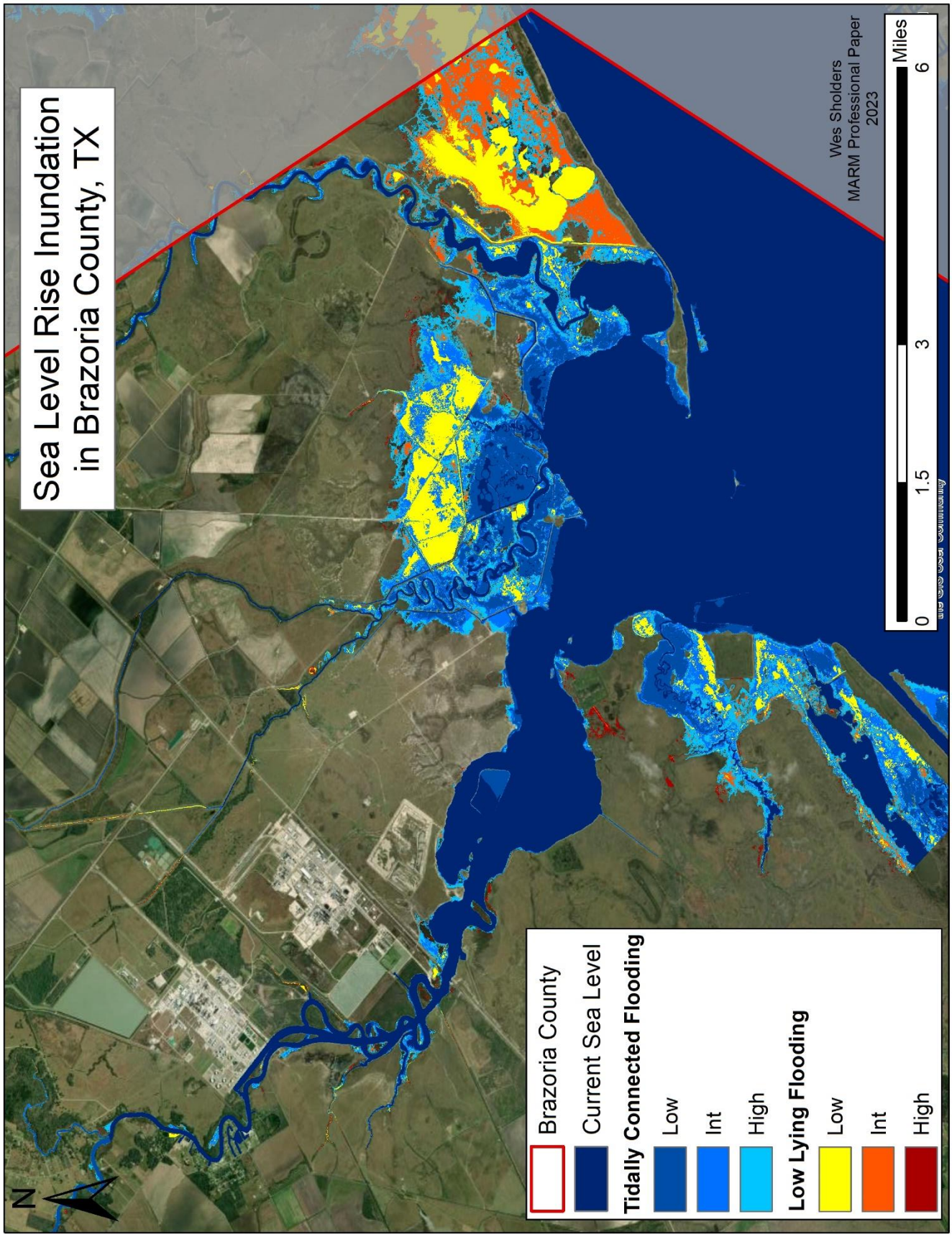

Figure 4.) Brazoria County will experience most of the impacts of SLR along the Chocolate Bay corridor, with most of it occurring around New Bayou.

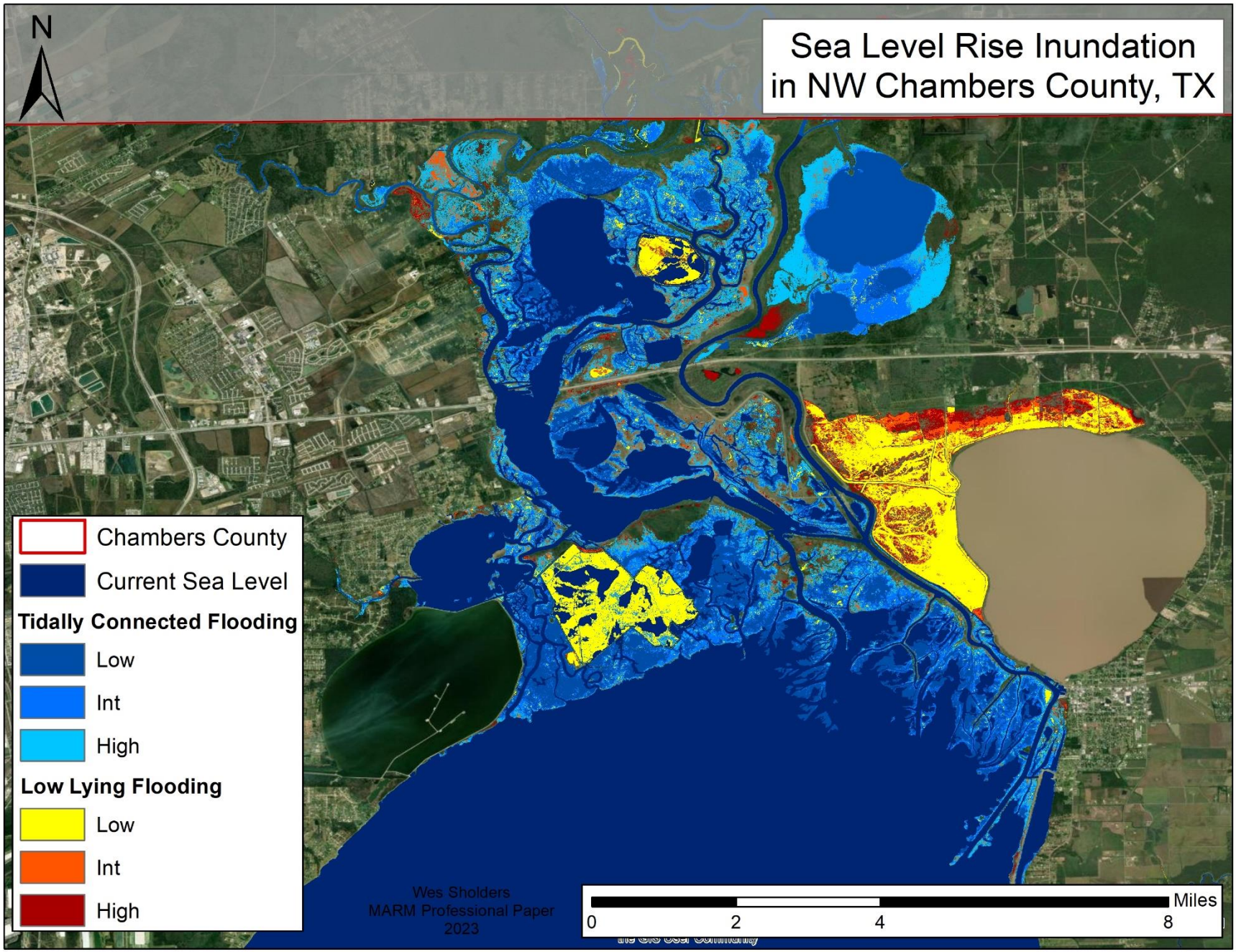

Figure 5.) The NW portion of Chambers County will see a heavy loss of marshes due to both tidally connected and low lying flooding. Note how the area around Lake Anahuac will be heavily impacted.

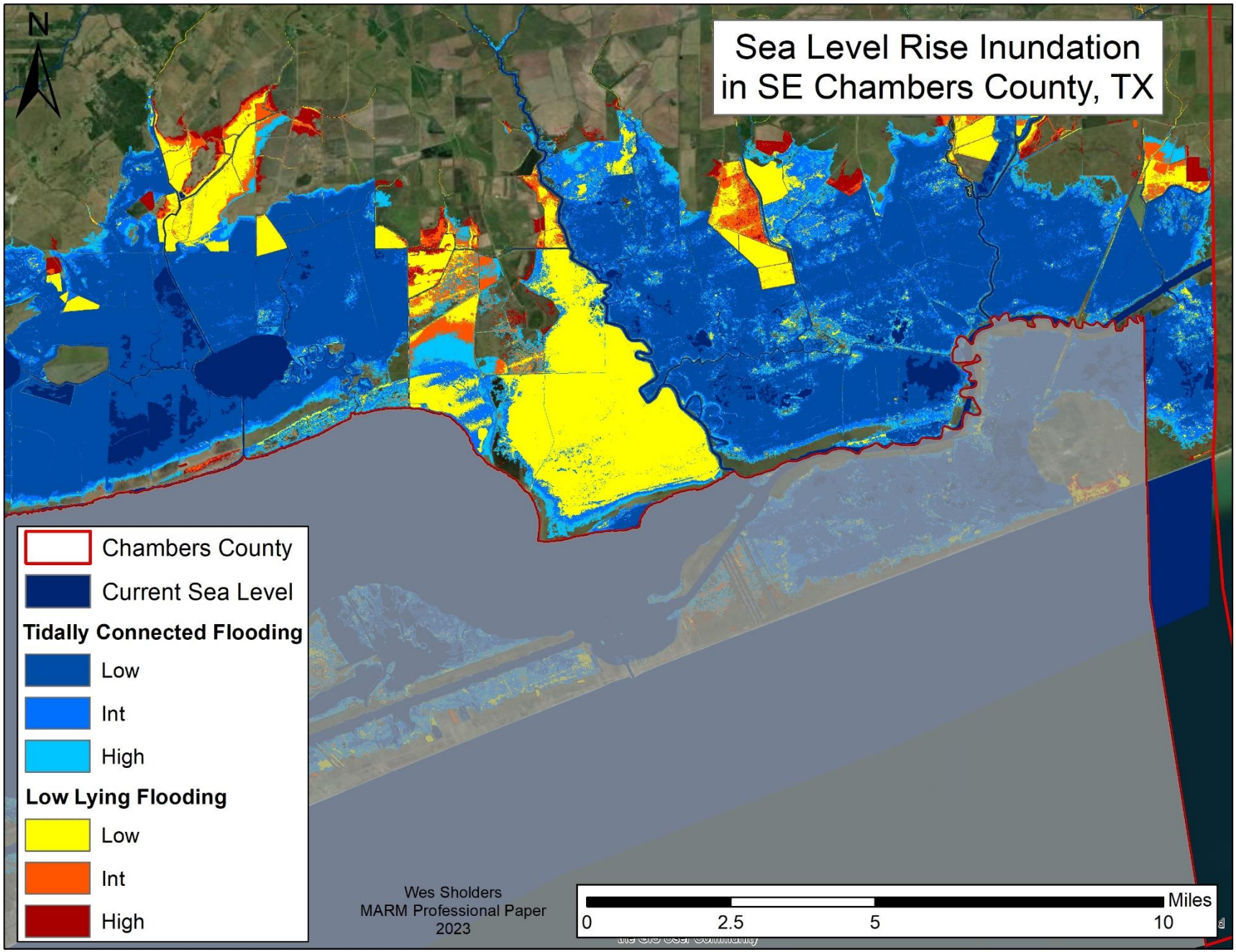

Figure 6.) The SE portion of Chambers County will see some of the heaviest loss of land cover due to inundation in the study.

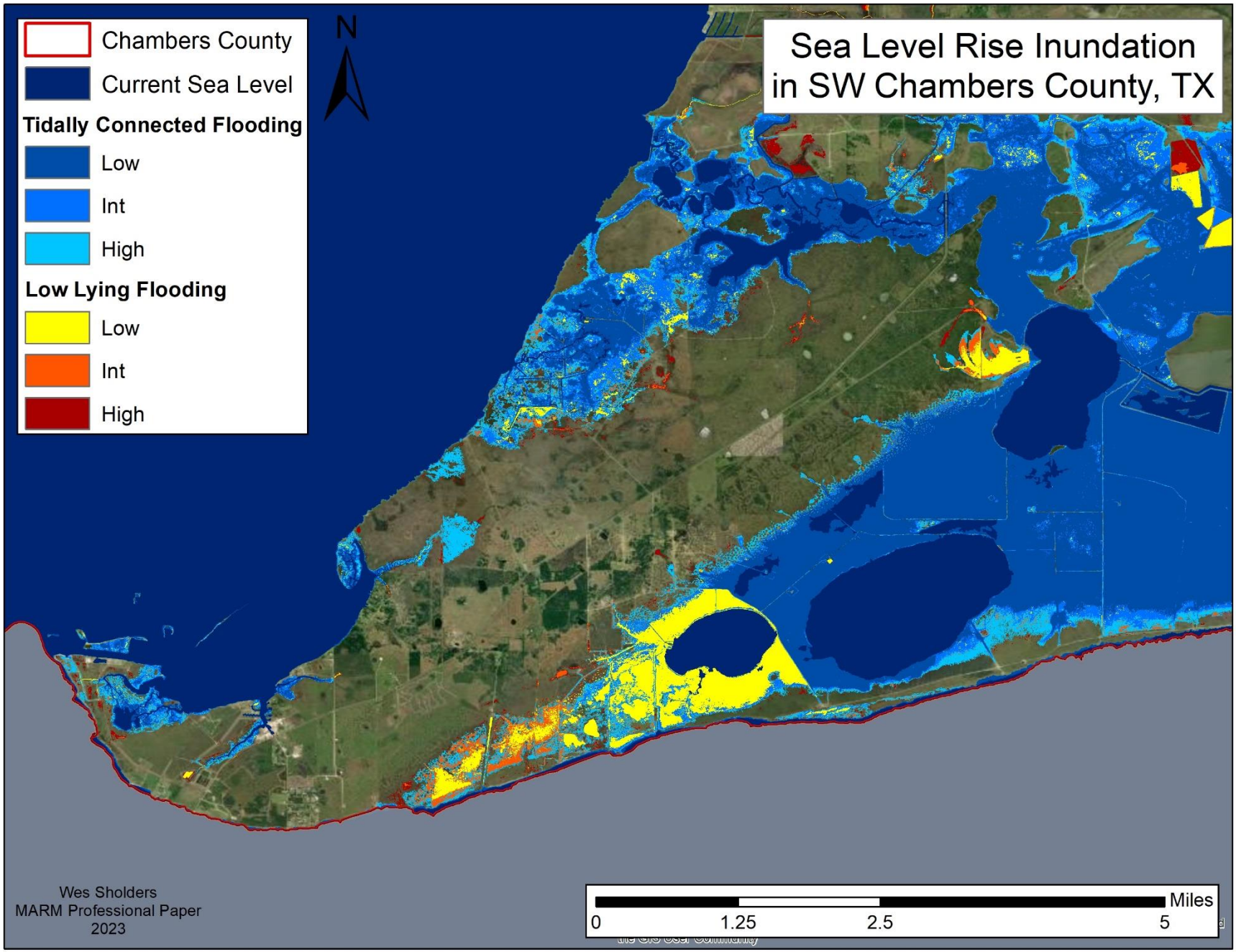

Figure 7.) The SW portion of Chambers County will see a heavy loss of marshes due to both tidally connected and low lying flooding.

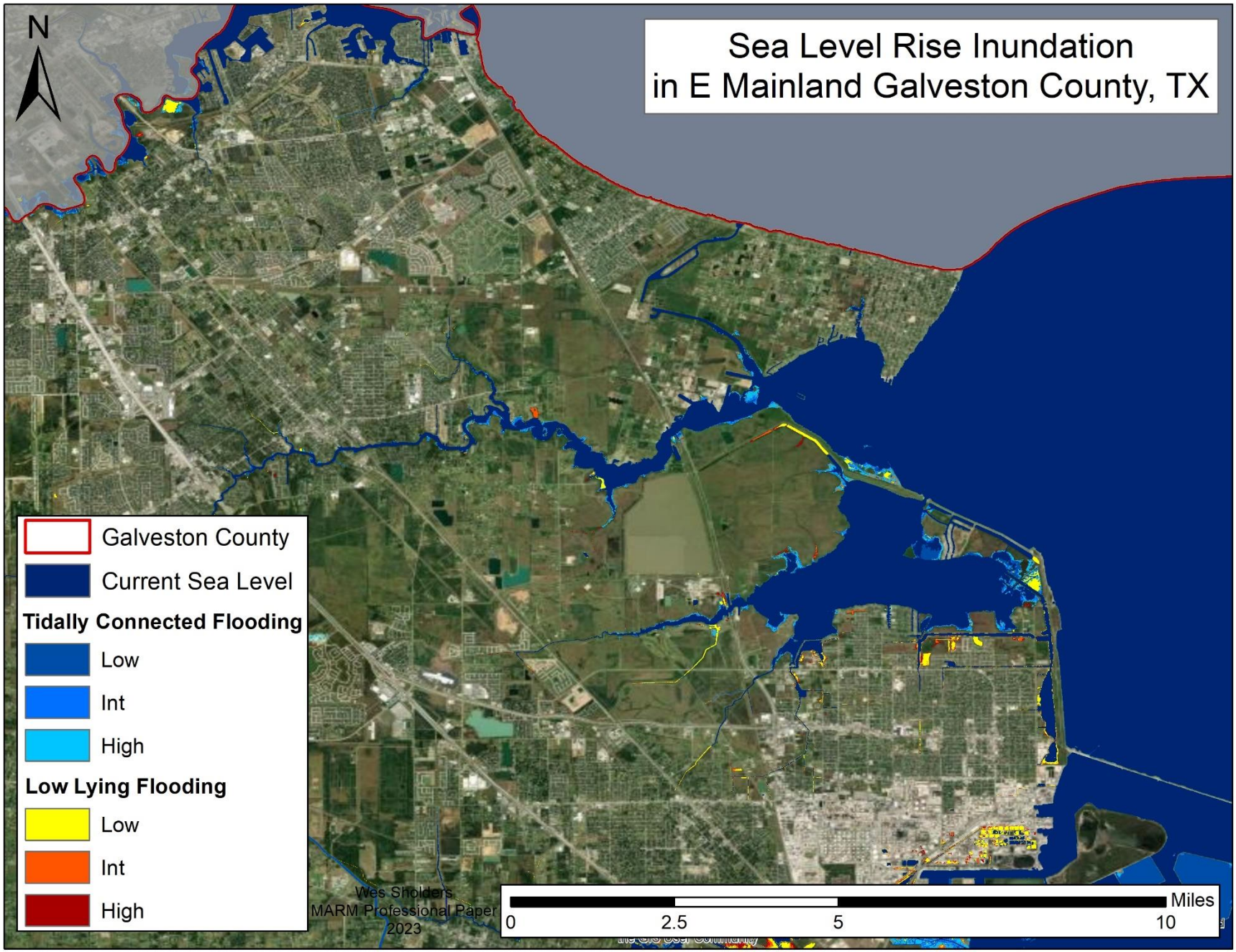

Figure 8.) The eastern area of Galveston County will see relatively minor flooding. However, it will be in highly polluted industrial areas.

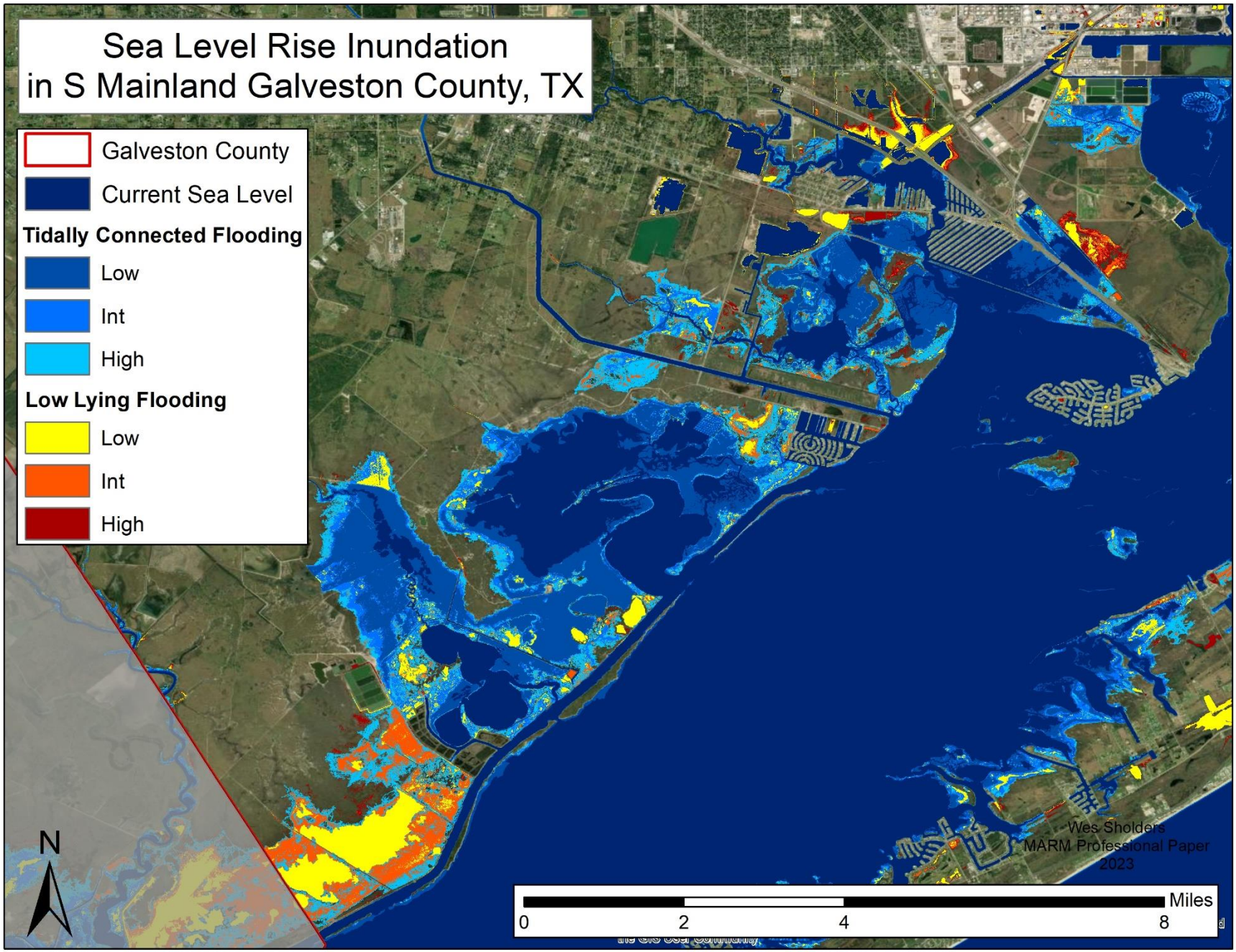

Figure 9.) South Galveston County will see extreme inundation and loss of protective wetlands along Greens and Carancahua Lake.

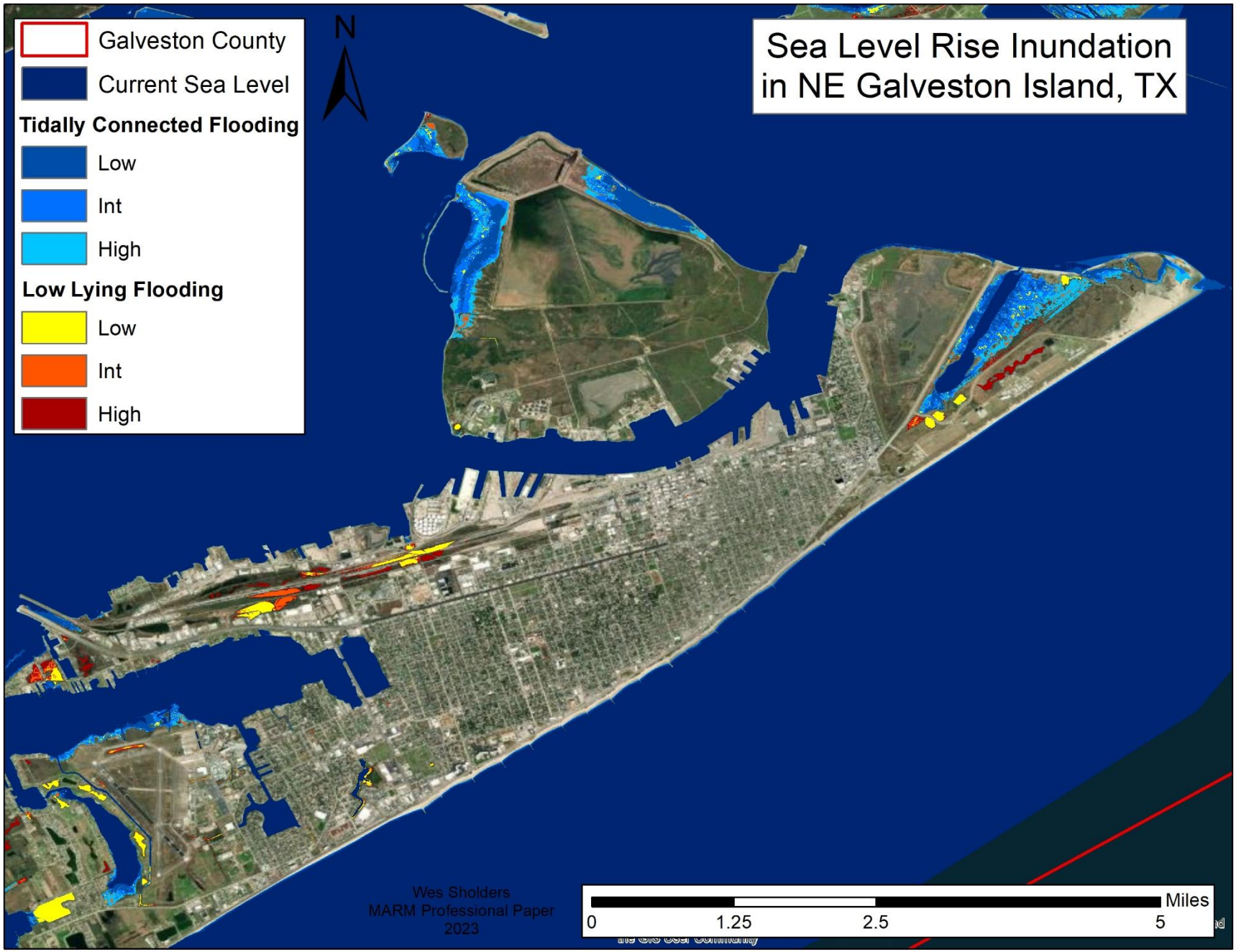

Figure 10.) The NE portion of the Galveston Island in Galveston County will see flooding at the East End Lagoon and Pelican Island, as well as flooding of low lying areas near the harborside.

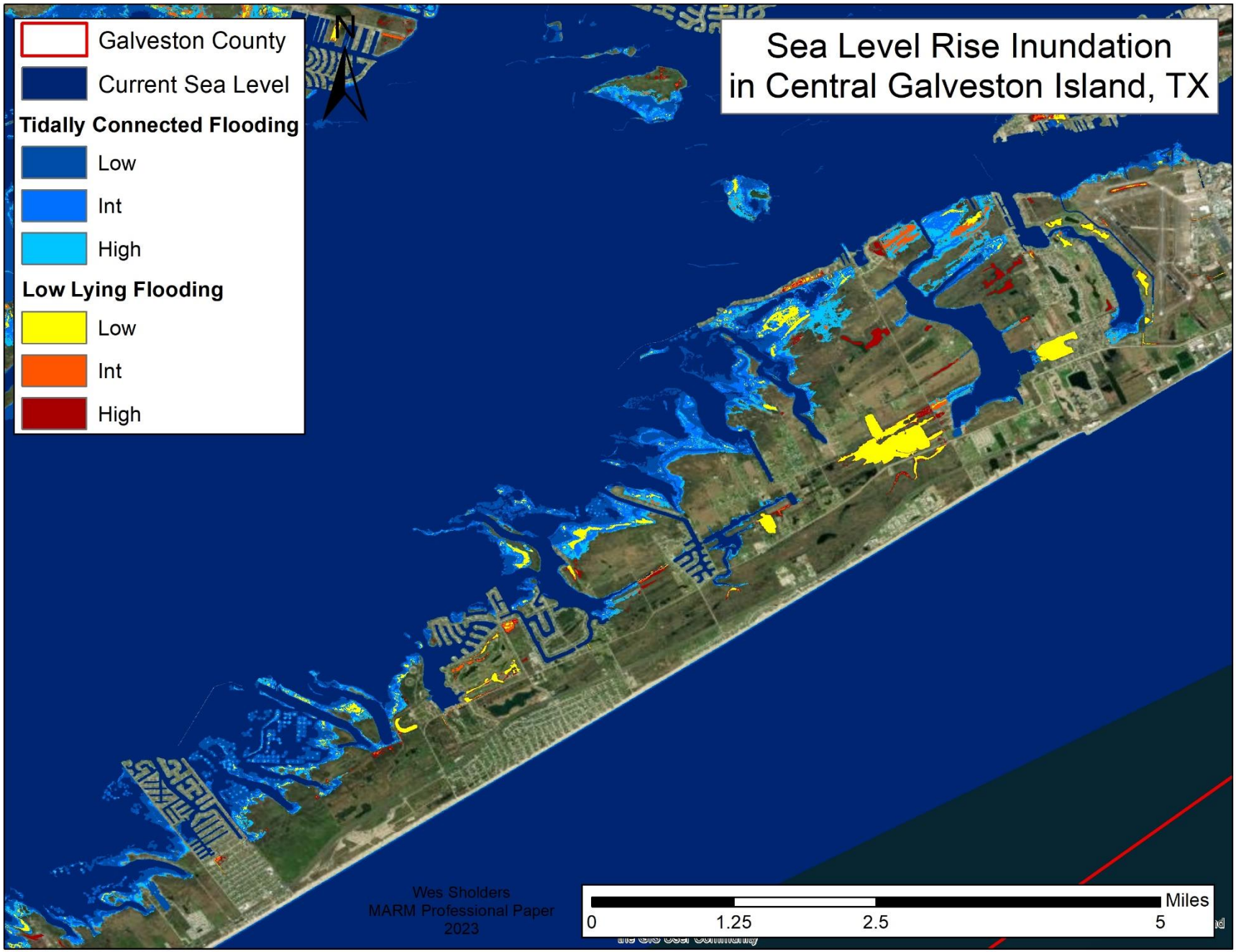

Figure 11.) The central portion of the Galveston Island in Galveston County will he heavy inundation of productive/protective marshes along the northern shoreline, as well as the near total inundation of important rookery islands in West Bay.

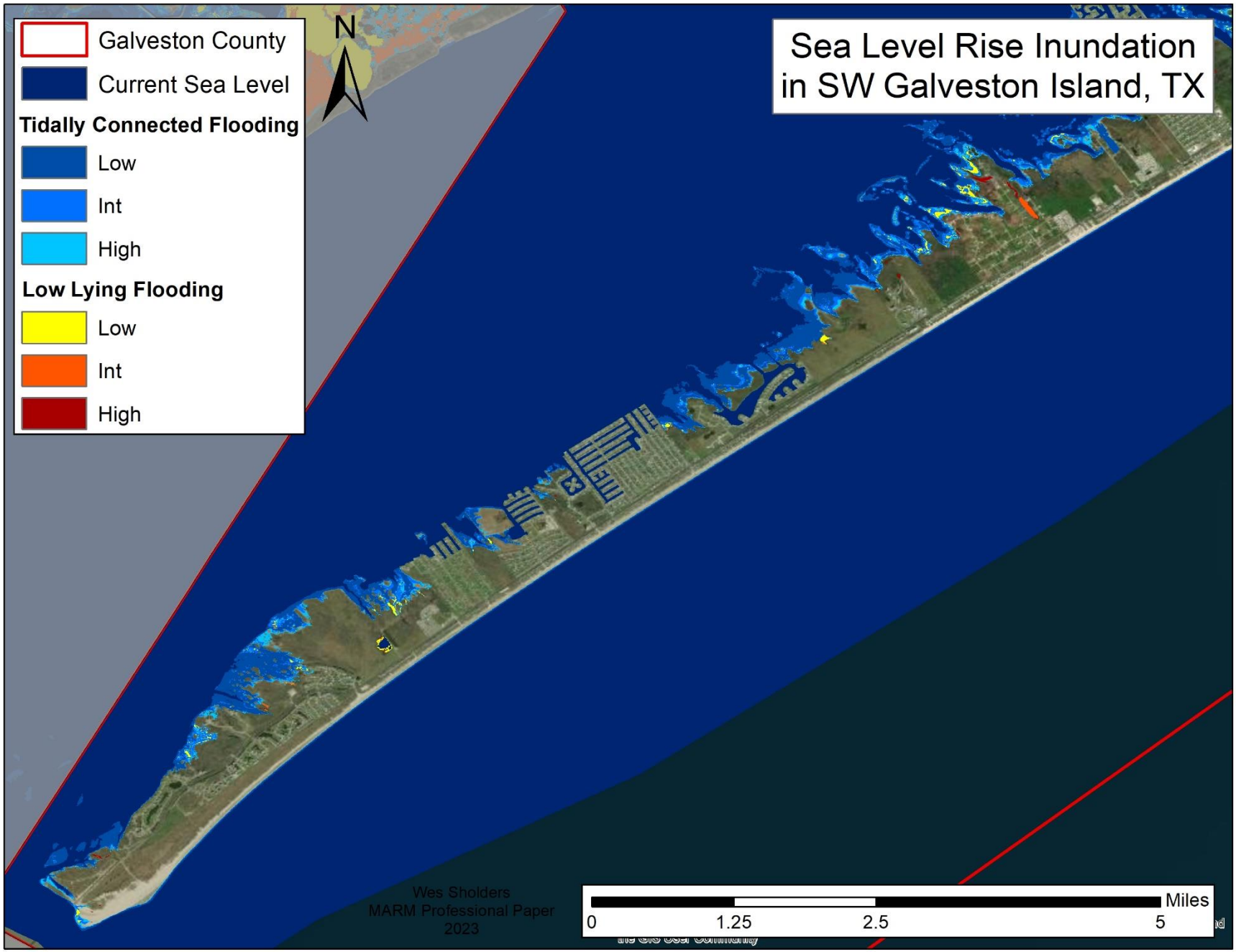

Figure 12.) The SW portion of the Galveston Island in Galveston County will he heavy inundation of productive/protective

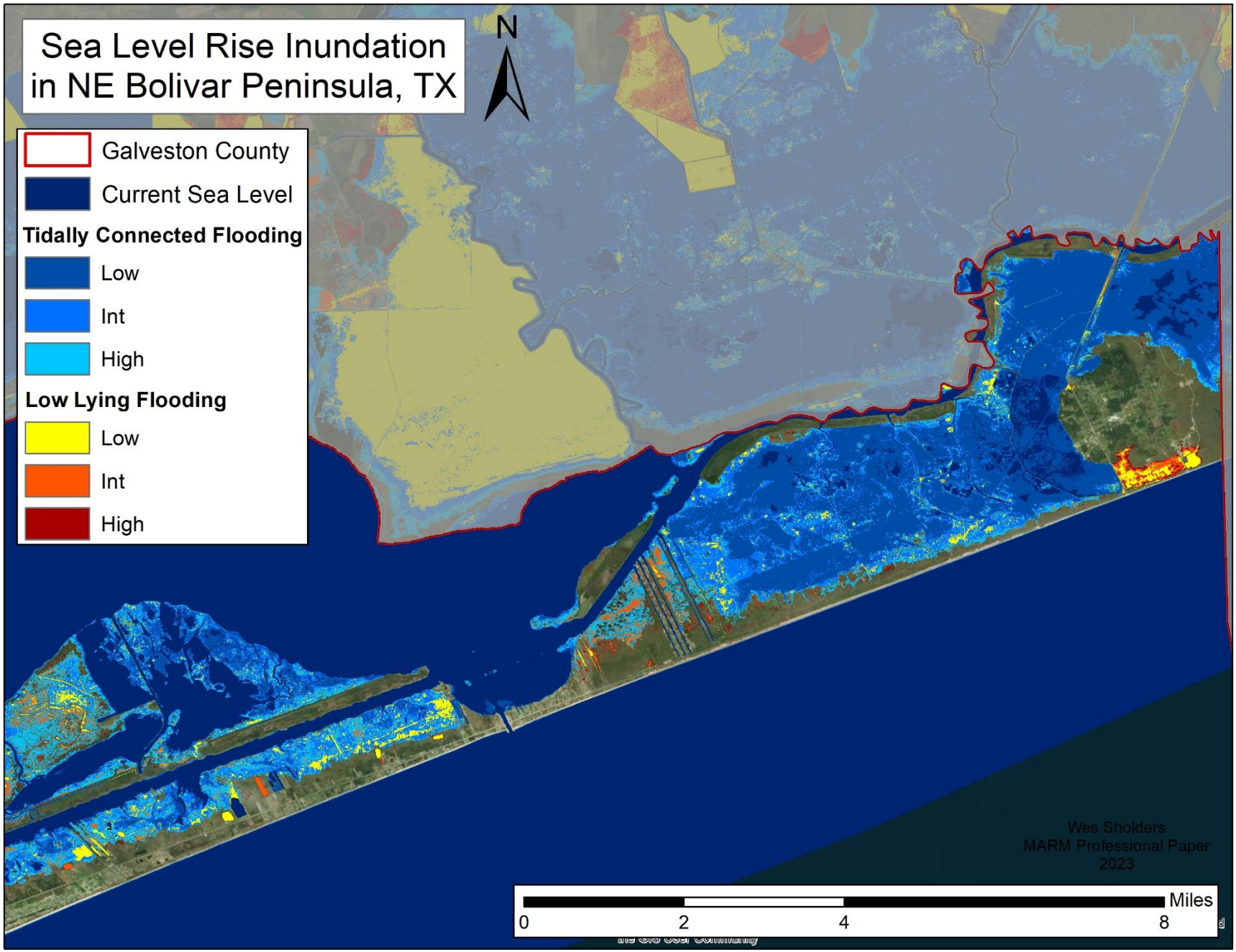

Figure 13.) The NW portion of the Bolivar Peninsula in Galveston County can expect near total inundation west of the High Island

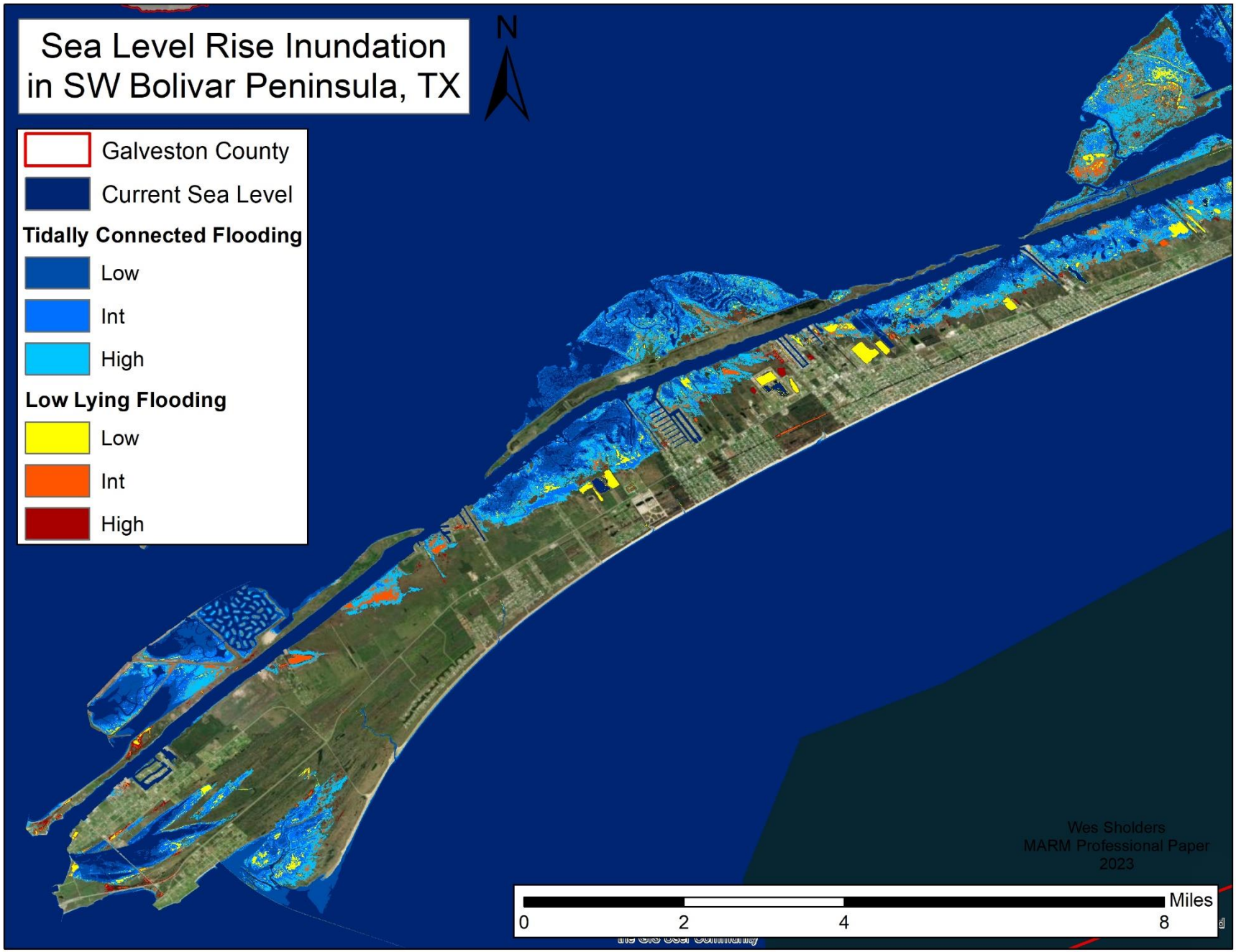

Figure 14.) The SW portion of the Bolivar Peninsula in Galveston County will see heavy inundation along its northern shoreline.

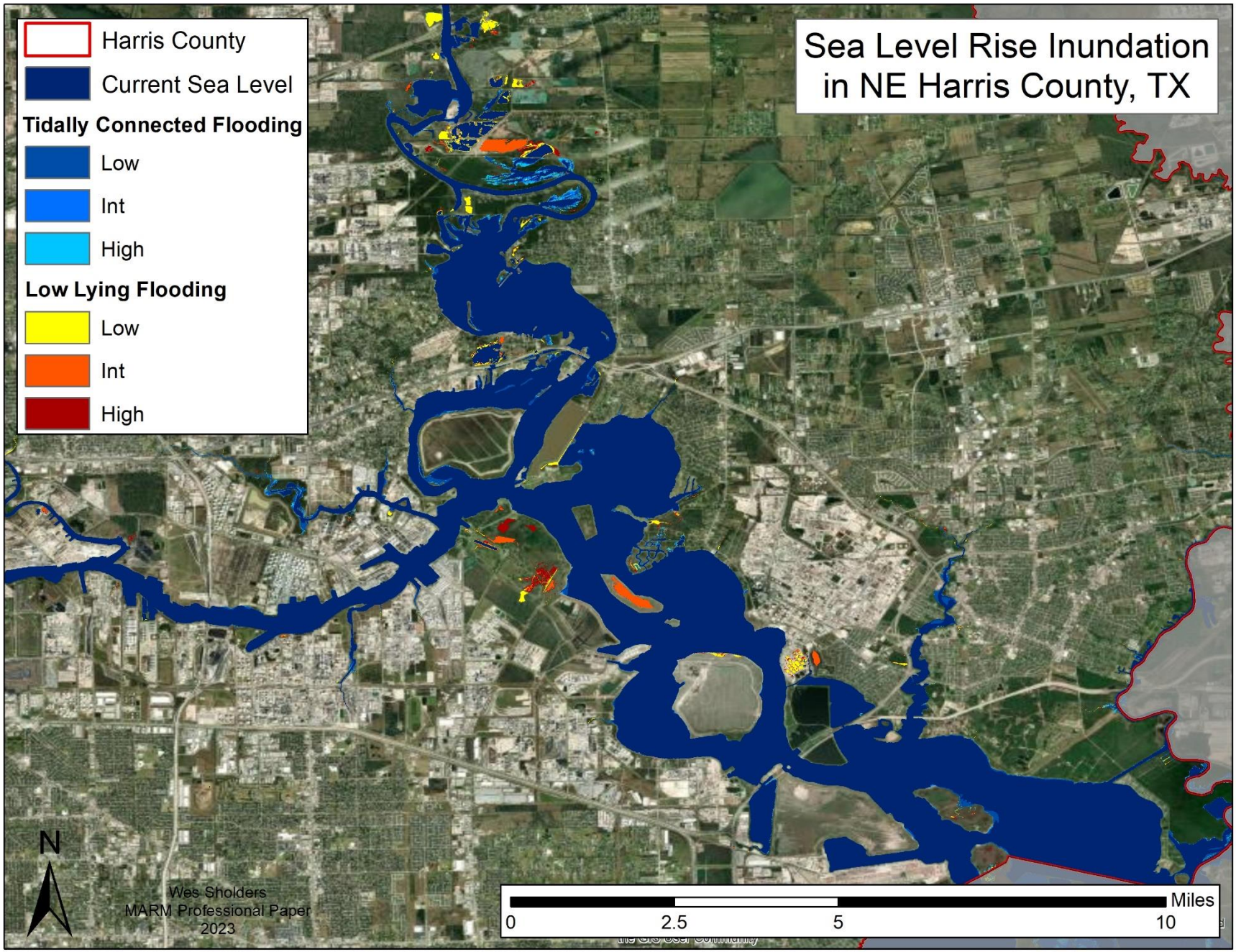

Figure 15.) Most of the areas that will become directly inundated by SLR can be found along the San Jacinto

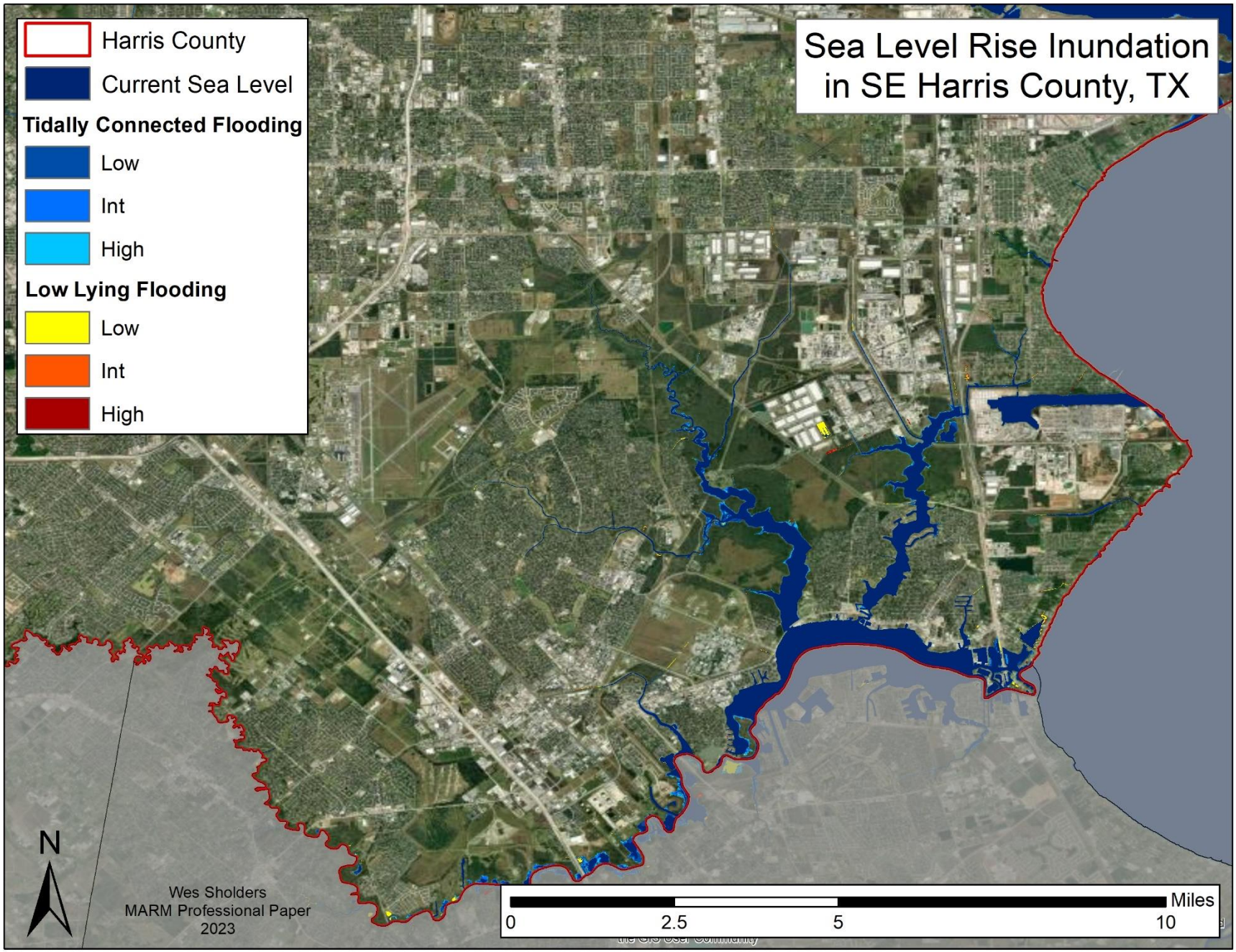

Figure 16.) The majority of the inundation experienced in SE Harris County can be found along the natural portions of Clear Lake.

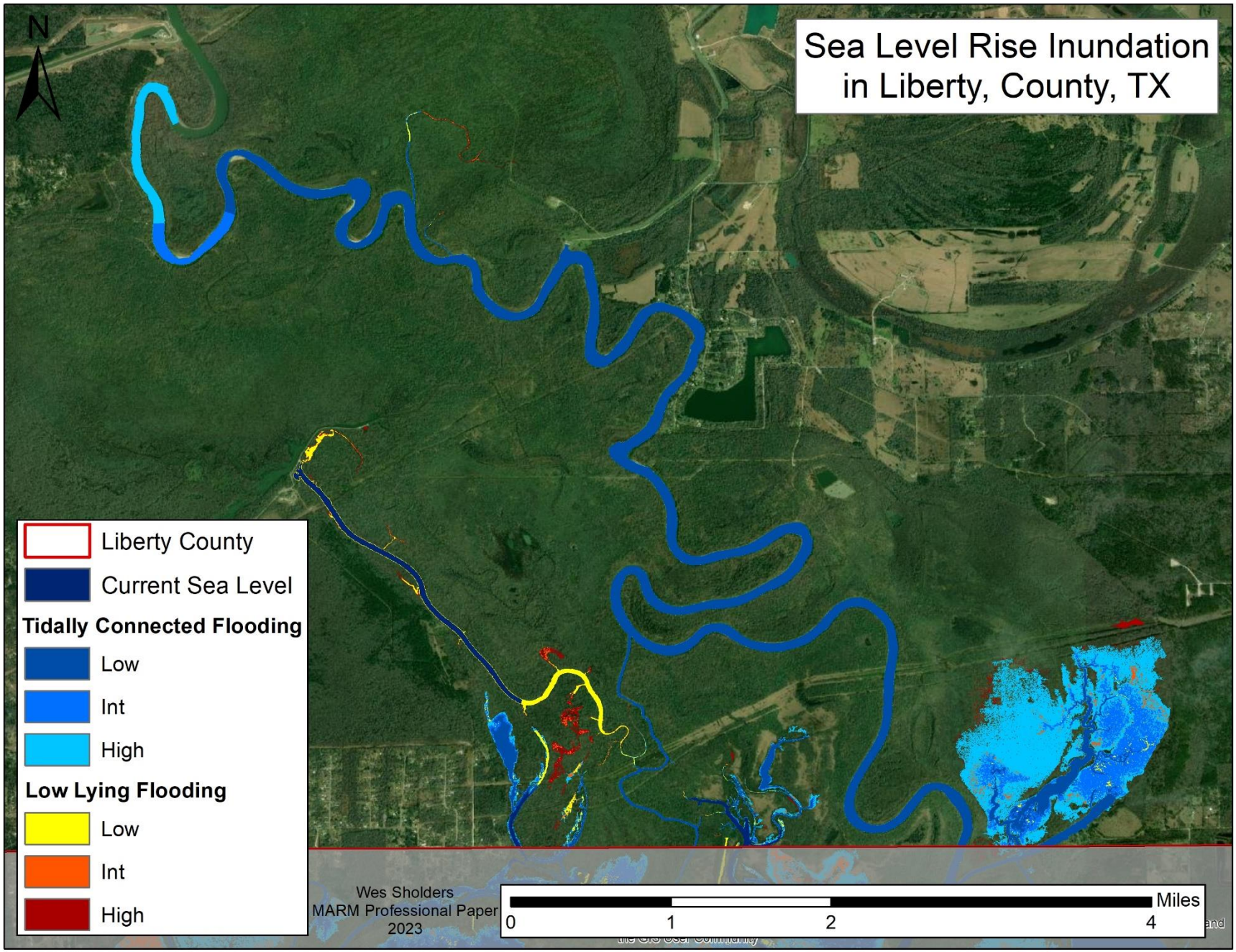

Figure 17.) Most of the inundation experienced in Liberty County is along the Trinity