



**SOUTHERN PLAINS**  
TRANSPORTATION CENTER

**Combined Effect of Sea-Level Rise and Coastal Land  
Subsidence – Identification of Critical Transportation  
Infrastructure At-Risk in Coastal SPTC Region**

**Part II – Coastal Texas**

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**SPTC17.1-10-2-F**

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## TECHNICAL REPORT DOCUMENTATION PAGE

1. REPORT NO. <b>SPTC 17.1-10-2</b>		2. GOVERNMENT ACCESSION NO.		3. RECIPIENTS CATALOG NO.	
4. TITLE AND SUBTITLE <b>Combined Effect of Sea-Level Rise and Coastal Land Subsidence – Identification of Critical Transportation Infrastructure At-Risk in Coastal SPTC Region: Part II - Texas</b>		5. REPORT DATE <b>November 30, 2019</b>		6. PERFORMING ORGANIZATION CODE	
		8. PERFORMING ORGANIZATION REPORT			
7. AUTHOR(S) <b>Sanjay Tewari</b>		10. WORK UNIT NO.			
9. PERFORMING ORGANIZATION NAME AND ADDRESS <b>College of Engineering Louisiana Tech University 600 Dan Reneau Dr., Ruston, LA 71272</b>		11. CONTRACT OR GRANT NO. <b>DTRT13-G-UTC36</b>			
		13. TYPE OF REPORT AND PERIOD COVERED <b>Final October 2017 – November 2019</b>			
12. SPONSORING AGENCY NAME AND ADDRESS <b>Southern Plains Transportation Center 201 Stephenson Pkwy, Suite 4200 The University of Oklahoma Norman, OK 73019</b>		14. SPONSORING AGENCY CODE			
		15. SUPPLEMENTARY NOTES <b>University Transportation Center</b>			
<p>Coastal Texas along with many other regions are facing numerous geologically, and climate change impacts jeopardizing their coast. Subsidence, which can occur naturally or be human-made, is chiefly the result of the extraction of both water and petroleum resources in coastal Texas. In many areas of the coast, the extraction of groundwater to support a large and increasing population is the most significant cause of subsidence. Within Texas, the highest rates of subsidence are in Harris and Galveston counties. Sea level rise is the result of climate change. Sea level rise is occurring across the globe. The combined impacts of sea-level rise and subsidence are jeopardizing not only the geography of coastal Texas but also its population. As land subsides and the sea level rises along coastal Texas not only will the population be in jeopardy but also the infrastructure in place to serve it. The transportation infrastructure in coastal Texas provides essential routes for daily tasks, logistical services, the mobility of community, and evacuation during natural disasters for estimated populations of 6 to nearly 8 million in this report's study area. This report provides estimates of the impacts that subsidence and sea-level rise would have on the transportation infrastructure in Coastal Texas. Open-source data made available by national-level agencies were processed using ArcGIS to develop surfaces and intersect those surfaces with transportation data. These processes and their results are detailed in the report. The processed data were used to identify trends that subsidence and sea-level rise will have on the transportation infrastructure.</p>					
17. KEY WORDS <b>sea-level rise, land subsidence, Texas, infrastructure, risk, ArcGIS</b>			18. DISTRIBUTION STATEMENT <b>No restrictions. This publication is available at <a href="http://www.sptc.org">www.sptc.org</a> and from the NTIS.</b>		
19. SECURITY CLASSIF. (OF THIS REPORT) <b>Unclassified</b>		20. SECURITY CLASSIF. (OF THIS PAGE) <b>Unclassified</b>		21. NO. OF PAGES <b>36 + Cover</b>	22. PRICE

# SI\* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
<b>LENGTH</b>				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	645.2	square millimeters	mm <sup>2</sup>
ft <sup>2</sup>	square feet	0.093	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yard	0.836	square meters	m <sup>2</sup>
ac	acres	0.405	hectares	ha
mi <sup>2</sup>	square miles	2.59	square kilometers	km <sup>2</sup>
<b>VOLUME</b>				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft <sup>3</sup>	cubic feet	0.028	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.765	cubic meters	m <sup>3</sup>
NOTE: volumes greater than 1000 L shall be shown in m <sup>3</sup>				
<b>MASS</b>				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
<b>TEMPERATURE (exact degrees)</b>				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
<b>ILLUMINATION</b>				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m <sup>2</sup>	cd/m <sup>2</sup>
<b>FORCE and PRESSURE or STRESS</b>				
lbf	poundforce	4.45	newtons	N
lbf/in <sup>2</sup>	poundforce per square inch	6.89	kilopascals	kPa

## APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
<b>LENGTH</b>				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
<b>AREA</b>				
mm <sup>2</sup>	square millimeters	0.0016	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	10.764	square feet	ft <sup>2</sup>
m <sup>2</sup>	square meters	1.195	square yards	yd <sup>2</sup>
ha	hectares	2.47	acres	ac
km <sup>2</sup>	square kilometers	0.386	square miles	mi <sup>2</sup>
<b>VOLUME</b>				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m <sup>3</sup>	cubic meters	35.314	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.307	cubic yards	yd <sup>3</sup>
<b>MASS</b>				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
<b>TEMPERATURE (exact degrees)</b>				
°C	Celsius	1.8C+32	Fahrenheit	°F
<b>ILLUMINATION</b>				
lx	lux	0.0929	foot-candles	fc
cd/m <sup>2</sup>	candela/m <sup>2</sup>	0.2919	foot-Lamberts	fl
<b>FORCE and PRESSURE or STRESS</b>				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in <sup>2</sup>

\*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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**Part 2 – Coastal Texas**

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November 2019

# Table of Contents

LIST OF ILLUSTRATIONS .....	vi
GLOSSARY .....	vii
EXECUTIVE SUMMARY .....	viii
INTRODUCTION .....	1
DATA .....	5
METHODOLOGY .....	12
RESULTS .....	19
REFERENCES .....	26

# List of Illustrations

## Figures

Figure 1. Study Area Extent.....	4
Figure 2. NOAA Office for Coastal Management Coastal Inundation Digital Elevation Model: Aggregate Record for Coastal Texas. ....	6
Figure 3. Example of the Extracted DEM for a Portion of Texas Coast. ....	7
Figure 4. Q 804 Current Survey Control .....	9
Figure 5. Q 804 Superseded Survey Control .....	9
Figure 6. NASA Sea-Level Rise Rates .....	10
Figure 7. Phases of Processing.....	13
Figure 8. Interpolation of NGS Data Phase .....	14
Figure 9. Calculation of Subsidence & Sea-level Rise Phase.....	14
Figure 10. Extraction, Conversion, & Classification Phase.....	16
Figure 11. Identification of Infrastructure Inundation Phase.....	18
Figure 12. Projected Inundation of Coastal Texas Map .....	21
Figure 13. Coastal Texas Callout of 100-Year Projected Inundation. ....	22
Figure 14. Map Book Cover Page.....	24
Figure 15. Map Series Sheet D4 .....	25

## Tables

Table 1. Estimated Parish Populations as of July 1, 2017 .....	2
Table 2. Estimated Metro Populations as of July 1, 2017 .....	2
Table 3. Timespan Values.....	8
Table 4. Projected Loss of Transportation Infrastructure .....	23

## Glossary

**Add Field:** ArcGIS Tool; Adds a new field to a table or the attribute table of a feature class.

**Calculate Field:** ArcGIS Tool; Calculates the values of a field in an attribute table.

**Clip:** ArcGIS Tool; Extracts larger input features that overlay the clip features.

**CORS:** Continuously Operating Reference Station.

**DEM:** Digital Elevation Model.

**Dissolve:** ArcGIS Tool; Aggregates features based on specified attributes.

**Erase:** ArcGIS Tool; Creates a feature class by overlaying the input features with the polygons of the erase features. Only those portions of the input feature falling outside the erase features outside boundaries are copied to the output feature class.

**Extract by Attributes:** ArcGIS Tool; Extracts the cells of a raster-based on a logical query.

**Extract by Mask:** ArcGIS Tool; Extracts the cells of a raster that correspond to the areas defined by a mask.

**GIS:** Geographic Information Systems.

**IDW:** ArcGIS Tool; Interpolates a raster surface from points using an inverse distance weighted (IDW) technique.

**Intersect:** ArcGIS Tool; Computes a geometric intersection of the input features. Features or portions of features which overlap in all layers and/or feature classes will be written to the output feature class.

**LiDAR:** Light Detection and Ranging.

**Merge:** ArcGIS Tool; Combines multiple input datasets into a single, new output dataset. This tool can combine point, line, or polygon feature classes or tables.

**Plus:** ArcGIS Tool; Adds the value of the second input raster to the value of the first input raster on a cell-by-cell basis.

**ModelBuilder:** A visual programming language for building geoprocessing workflows.

**NASA:** National Aeronautics and Space Administration.

**NGS:** National Geodetic Survey.

**NOAA:** National Oceanic and Atmospheric Administration.

**NSRS:** National Spatial Reference System.

**PID:** Identification code for benchmarks starting with two letters followed by four numerical values.

**Raster Calculator:** ArcGIS Tool; Builds and executes a single Map Algebra expression using Python syntax in a calculator-like interface.

**Raster to Polygon:** ArcGIS Tool; Converts a raster dataset to polygon features.

**TIGER:** Topologically Integrated Geographic Encoding and Referencing.



## **Executive Summary**

Geographic Information Systems (GIS) offer platforms and procedures in which numerous data formats can be integrated, manipulated, analyzed, and interpreted spatially. This allows researchers a greater understanding of the data such as its relationships or patterns present in geography that may not have been otherwise observed. The patterns or relationships present in the data can be projected offering insight on future geography. For the successful implementation of GIS, it must have the correct components. Two of these components are data and methods.

Coastal Texas along with many other regions are facing numerous geologically, and climate change impacts jeopardizing their coast. Subsidence, which can occur naturally or be human-made, is chiefly the result of the extraction of both water and petroleum resources in coastal Texas. In many areas of the coast, the extraction of groundwater to support a large and increasing population is the most significant cause of subsidence. Within Texas, the highest rates of subsidence are in Harris and Galveston counties. Sea level rise is the result of climate change. Sea level rise is occurring across the globe. The combined impacts of sea-level rise and subsidence are jeopardizing not only the geography of coastal Texas but also its population. As land subsides and the sea level rises along coastal Texas not only will the population be in jeopardy but also the infrastructure in place to serve it. The transportation infrastructure in coastal Texas provides essential routes for daily tasks, logistical services, the mobility of community, and evacuation during natural disasters for estimated populations of 6 to nearly 8 million in this report's study area.

This report provides estimates of the impacts that subsidence and sea-level rise would have on the transportation infrastructure in Coastal Texas. Open-source data made available by national-level agencies were processed using ArcGIS to develop surfaces and intersect those surfaces with transportation data. These processes and their results are detailed in the report. The processed data were used to identify trends that subsidence and sea-level rise will have on the transportation infrastructure.

## Introduction

The coastal ecosystems of Texas are just as diverse and complex as the neighboring coastal ecosystems of southwestern Louisiana or any other ecosystem within the United States. Coastal Texas and southwestern Louisiana share many of the same ecological traits. The region consists of vast coastal prairies and delicate marshes.<sup>1</sup> There are also barrier islands, floodplains, and low terraces.<sup>2</sup> There are also barrier islands, floodplains, and low terraces. The significant part of this region, which was dominated by coastal prairies, has lost much of this ecology due to human activity. The increase in large-scale agriculture, natural resource extraction, and extreme population growth in the 20<sup>th</sup> century and into the 21<sup>st</sup> century has dramatically changed and affected this region. Much of the region is low lying and vulnerable to small changes in elevation. Leading up to the last century much of coastal Texas naturally shifted under geological factors unhindered by external factors. Within the past century, coastal Texas boomed with extraction and refining of petroleum leading to dramatic increases in the population which altered its delicate ecosystem.

In 1917 Texas was the largest state geographically and had an estimated population of 4.5 million people.<sup>3</sup> According to estimations by the Census Bureau, the population exceeded 10 million in 1963 and 20 million in 1999.<sup>4</sup> The rate of change in population since 1917 is 520.3% with the most considerable amount of that change occurring in the past half-century. The growth in population is no different along coastal Texas. The population of the 14 counties covered in this report along coastal Texas had an estimated growth rate of 12.3% since the previous census in April of 2010. These counties also comprise approximately 22.5% of the population of Texas. One of these counties, Harris is home to Houston and adjunct to Galveston County has the highest population of any county in Texas and is the third most populated county in the United States. Harris also has a higher population than all the other counties in the study combined. Four major metropolitan areas are entirely contained within these counties or intersect it. All four of these areas share a similar trend with increasing populations. Tables 1 and 2 below display both the current census and estimates with growth rates of the counties and metropolitan areas. The increasing population and intense concentration of that population have led to the dramatic alteration of coastal Texas. Robust urbanization will inevitably lead to higher demands on geography, critical infrastructure, and resources. In fact, the coastal prairie region has been almost wholly modified for agriculture and development leaving only a fraction of 1% of its original area unobstructed.<sup>6</sup> This dynamic swift to alter geography to suite urbanization is not unique along coastal Texas with coastal development increasing across the nation.

**Table 1.** Estimated County Populations as of July 1, 2017.

**Source:** “County Population Totals and Components of Change: 2010-2017.” Data, U.S. Department of Commerce, U.S. Census Bureau, 8 May 2018, [www.census.gov/data/tables/2017/demo/popest/total-metro-and-micro-statistical-areas.html](http://www.census.gov/data/tables/2017/demo/popest/total-metro-and-micro-statistical-areas.html).

County	Census Population Totals April 2010	Population Estimates July 2017	Population Growth Rates
Aransas	23,158	25,572	10.4%
Brazoria	313,127	362,457	15.8%
Calhoun	21,381	21,744	1.7%
Chambers	35,099	41,441	18.1%
Galveston	291,303	335,036	15.0%
Harris	4,093,244	4,652,980	13.7%
Jackson	14,075	14,805	5.2%
Jefferson	252,277	256,299	1.6%
Matagorda	36,702	36,840	0.4%
Nueces	340,223	361,221	6.2%
Orange	81,837	85,047	3.9%
Refugio	7,383	7,224	-2.2%
San Patricio	64,807	67,215	3.7%
Victoria	86,793	92,084	6.1%
<b>Total</b>	<b>5,661,409</b>	<b>6,359,965</b>	<b>12.3%</b>

**Table 2.** Estimated Metro Populations as of July 1, 2017.

**Source:** “Metropolitan and Micropolitan Statistical Areas Totals: 2010-2017.” Data, U.S. Department of Commerce, U.S. Census Bureau, 8 May 2018, [www.census.gov/data/tables/2017/demo/popest/total-metro-and-micro-statistical-areas.html](http://www.census.gov/data/tables/2017/demo/popest/total-metro-and-micro-statistical-areas.html).

Metro Area - Texas	Census Population Totals April 2010	Population Estimates July 2017	Population Growth Rates
Beaumont-Port Arthur	403,190	412,437	2.3%
Corpus Christi	428,185	454,008	6.0%
Houston-The Woodlands-Sugarland	5,920,416	6,892,427	16.4%
Victoria	94,003	99,646	6.0%
<b>Total</b>	<b>6,845,794</b>	<b>7,858,518</b>	<b>14.8%</b>

The increased urbanization in coastal Texas also came with an increase in infrastructure, industry, and agriculture. Some of the most significant industries in coastal Texas are the production and refining of crude petroleum. These industries are of not only regional importance but also national importance. So significant is crude petroleum to the United States economy that the price per barrel is factored into and use to judge the state of the economy by economists. Texas leads in both the production and refining of crude petroleum in the nation. Production of crude oil alone has hit recorded highs in Texas with approximately 129,203,000 barrels being extracted in March of 2018.<sup>7</sup> At that level of production, Texas is producing more oil itself than many oil-producing nations. The refining capacity of Texas is no different averaging the refinement of 5,628,990 barrels per day in 2017.<sup>8</sup> Coastal Texas not only is a tremendous player

in this economic and industrial activity but also plays a significant role in the logistical needs for its success. Nearly  $\frac{2}{3}$  of the nation's crude petroleum importing occurred at ports in the Gulf states primarily Texas and Louisiana.<sup>9</sup> This activity is not only limited to importing but also the exporting. In 2016, the ports of Houston and Beaumont ranked in the top five for the total cargo tonnages.<sup>10</sup> Houston itself ranked second only to the Port of South Louisiana processing 247.99 tonnages in domestic and foreign cargo.<sup>11</sup> With a significant amount of economic activity taking place in coastal Texas, it is vital to understand how geological factors such as subsidence, erosion, and sea-level rise could impact the coast.

Geologically, parts of Texas suffer from extreme rates of subsidence. Subsidence, which can occur naturally or be human-made, is chiefly the result of the extraction of groundwater from a limited aquifer network in coastal Texas. Subsidence results in a loss of soil volume, which lead to decreases in elevation, and compaction of the soil. In a study published by the U.S. Geological Survey (USGS), it was found that parts of Houston suffer from rates of subsidence that average 15 to 40 millimeters per year.<sup>12</sup> As the elevations along coastal Texas decrease, the risk of inundation will increase. Intense rainfall and storm surges are all factors that can cause subsided surfaces to be temporarily inundated causing millions in damage to private and public assets. Subsidence can also cause compaction in soil, which can decrease the soil's ability for water retention, infiltration, and percolation. This can lead to runoff, erosion, prolong water accumulation on the surface, and increase the stresses on aquifers by decreasing their ability to recharge. While subsidence is one critical factor influencing Coastal Louisiana in a negative way, it is not the only factor.

Climate change is another factor that has negatively affected Coastal Texas. The National Aeronautics and Space Administration (NASA) monitors and investigates the impact of climate change. According to NASA, the current global rate of sea-level rise is 3.2 millimeters per year. It also estimates that the temperature in the top 700 meters of oceans has increased by 0.302 degrees in the past fifty years.<sup>13</sup> As sea-levels along the Gulf Coast are rising and the ocean temperatures are increasing, there is a more significant threat of coastal erosion and submergence along coastal Texas. The increasing temperature of the oceans can cause a higher strength and frequency of tropical storms leading to significant coastal erosion and flooding from storm surge. As the Texas coast comes under threat of submergence and erosion due to climate change the potential for saltwater intrusion into its marshes will continue to increase. Saltwater intrusion into the marshes, which serve as a natural barrier against storm surges, can cause significant losses to marshes. The negative consequences of climate change can potentially alter landscapes in a manner that inhabitation of the affected areas could become very expensive and unfavorable.

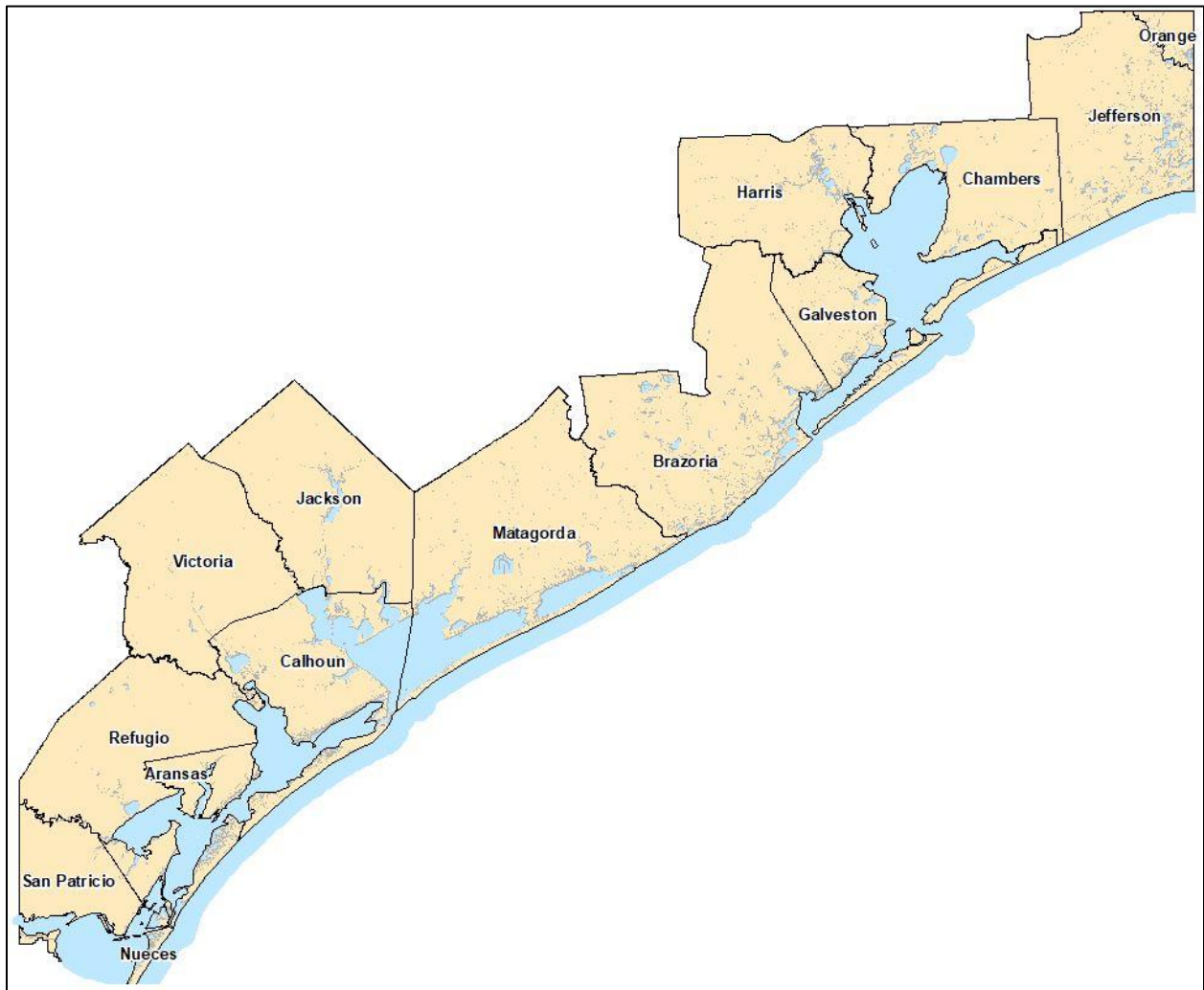
### **GIS Approach**

Geographic Information Systems (GIS) can be incredibly insightful and supportive in researching both subsidence and sea-level rise. It offers platforms in which numerous data formats can be integrated, manipulated, analyzed, and interpreted spatially. This allows researchers a greater understanding of geographic data such as relationships or patterns that could not be observed otherwise. The patterns or relationships present in the data can be projected in graphical manners offering a greater insight.

This research was conducted with ArcGIS and its Spatial Analysts extension to create shapefiles for the projected inundation and transportation infrastructure affected by the inundation. The datasets were generated by interpreting, analyzing, amending, and integrating various datasets from numerous federal agencies. The goal of these datasets is to assist in the planning for the design and policy-making of the infrastructure network by providing technical insight into the combined effects of subsidence and sea-level rise on coastal Texas's transportation infrastructure.

**Extent**

The study area is covered by 14 of Texas's northern coastal counties. These 14 counties are home to nearly a quarter of Texas's population, billions in monthly commerce at the national and state level, and thousands of miles in transportation infrastructure. The extent also includes some of Texas's numerous major metropolitan areas such as Houston-The Woodlands-Sugar Land, Corpus Christi, and Beaumont-Port Arthur. The extent of the study area is displayed below in Figure 1.



**Figure 1.** Study Area Extent.

## Data

An essential component and part of the foundation of GIS is the data. The data used to produce both the inundation shapefile and the inundation of transportation infrastructure shapefile originate from four federal agencies. These federal agencies along with many others provide incredibly sophisticated, current high-quality data for GIS analysis. The data is open-sourced, requiring in some cases that the user set up an account with a username, password, and valid email. The data is often the same data used in large-scale research and reports by the agencies releasing it to the public. These federal agencies have millions in taxpayer dollars invested in the collection, processing, and release of GIS data. Federal agencies such as the United States Geological Survey (USGS), National Oceanic and Atmospheric Agency (NOAA), United States Census Bureau, and many more are incredible assets and sources of GIS data. This research and resulting data outlined in this report is a direct result of using data from the four agencies listed below. The following sections detail the source, processing, and use of the data.

- National Oceanic and Atmospheric Agency (NOAA)
- National Geodetic Survey (NGS)
- National Aeronautics and Space Administration (NASA)
- United States Census Bureau

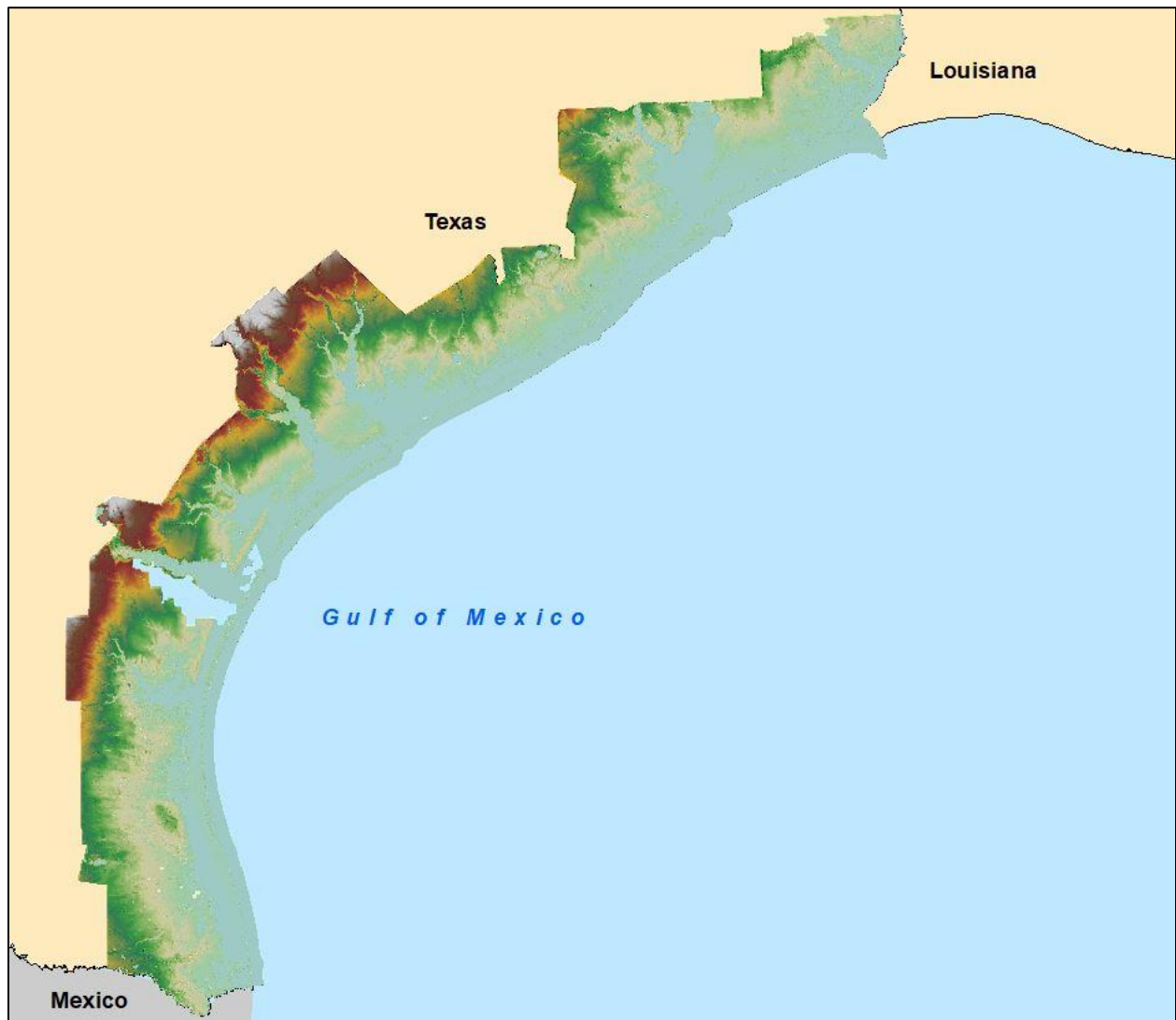
The data from all four agencies were projected from their sourced coordinate systems to *North America 1983 Lambert Conformal Conic* before any of the processing outlined below took place.

### **National Oceanic and Atmospheric Agency**

The *NOAA Office for Coastal Management Coastal Inundation Digital Elevation Model: Aggregate Record* LiDAR dataset's primary purpose was for its user to generate data to visualize the impacts of sea-level rise along the coastal United States.<sup>14</sup> The results of the processing can be viewed at NOAA's sea-level rise viewer webpage. The dataset has one of the most complete coverages of the entire coast of Texas. The dataset collections range from 1996 to 2016.<sup>15</sup> The resolution of the dataset is approximately 5 meters; some areas of the dataset have a higher resolution.<sup>16</sup> The dataset has also been hydro flatten so that the elevation of all water surface is either at 0 or below. The data is accessible through the NOAA data access viewer. The approximate download size is 6.18 gigabytes. The dataset in its original and unaltered state is displayed below in Figure 2.

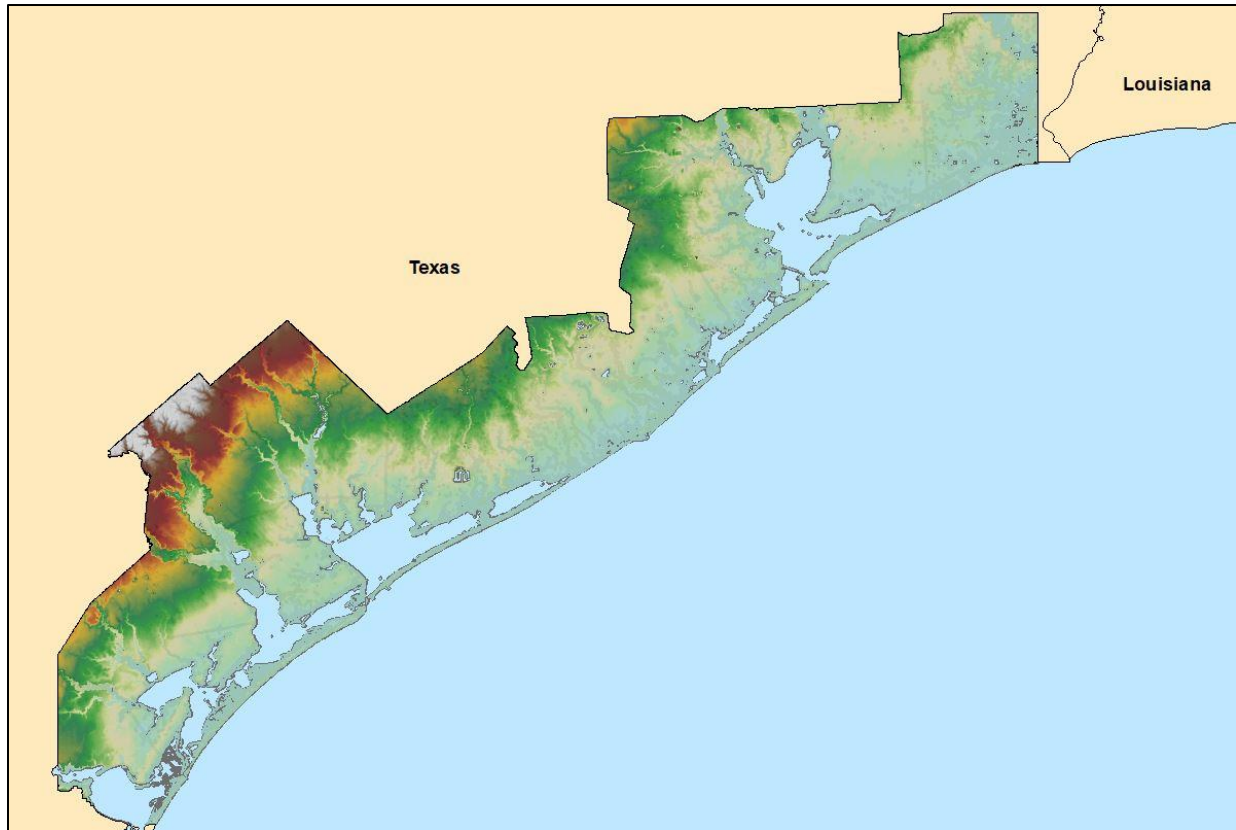
Before the processing for the development of the inundation shapefiles, the digital elevation model (DEM) had to be refined to match the extent of the applicable National Geodetic Survey (NGS) marks and to increase processing speed. Matching the DEM to the study area extent was performed by running the Extract by Mask tool using the processed Census Bureau TIGER/line county shapefile as the feature mask data. The Census Bureau Tiger/Line county shapefile was clipped to the extent of the interpolated raster of the NGS marks. The resulting DEM is displayed in Figure 3 below. Next, the DEM was resampled from a 19.4-foot to 30-foot resolution or 5-meters to 9.144 meters. The resampling along with the extraction decreased the storage size of the data. By reducing the storage size, processing speeds for many of the steps required to create the inundation shapefiles would improve significantly. The final step of preparation was the reprojection of the DEM. The DEM was projected to *North America 1983 Lambert Conformal*

*Conic* using the Project Raster tool. The purpose of this is to minimize the impact on geographic change resulting from the transition of the DEM across multiple State Plane references.



**Figure 2.** NOAA Office for Coastal Management Coastal Inundation Digital Elevation Model: Aggregate Record for Coastal Texas.

**Source:** Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Office for Coastal Management (OCM). "NOAA Office for Coastal Management Coastal Inundation Digital Elevation Model: Aggregate Record." NOAA Office for Coastal Management, 2016.



**Figure 3.** Example of the Extracted DEM for a Portion of Texas Coast.

Once the preparation of the DEM surface was completed, it was ready for the required processing to create the inundation shapefiles. This dataset is the zero-day elevation surface from which to project the impacts of subsidence and sea-level rise. The dates represented in the corresponding map symbolization are projected from the 2016 release date of the DEM. The mathematical calculations were conducted to estimate the effects of subsidence and sea-level rise for the next 100 years in ten-year intervals. The areas residing below 0-meter elevation were extracted and classified as areas of inundation.

### **National Geodetic Survey**

The survey marks datasheets and their corresponding shapefiles are surveyed grade collections of geodetic information over a benchmark. NGS tracks and maintains survey markers through the entire United States. NGS is an entity of NOAA whose purpose is to provide and maintain the framework for National Spatial Reference System, which both benchmarks and Continuously Operating Reference Station (CORS) help to establish.<sup>9</sup> They also offer GIS data and records that correlate with their mission such as survey marks and CORS shapefiles.

The survey marks shapefiles were downloaded from the NGS download page for the statewide achieve of Texas. This shapefile was projected to the same coordinate system as the DEM raster. Next, the shapefile was clipped to the study area extent using Census Bureau TIGER/line county shapefile displayed above in Figure 3. Following this, the shapefiles were edited so that the only attribute fields retained were the FID, Shape, PID, Designation, Latitude, and Longitude fields.



At this point, there were over 17,000 benchmarks. The shapefile was trim so that only attributes with elevation fields remained. This was accomplished by performing a select by attributes using the following query, "ELEVATION" <> '. The selected attributes were then exported into a new shapefile. The purpose of this small process assists in narrowing the benchmark shapefile to attributes with elevation values. By narrowing the attributes to only those that have elevation values, this helped to save time when researching those benchmark datasheets. At this point, there were over 7,000 benchmarks. Following this, the attribute fields were copied to excel.

Excel was used to record the differences in orthometric heights and to forecast those differences. Datasheets were pulled for each of the benchmark using their PIDs. To get the ten-year intervals of subsidence rates an annual rate had to be calculated first. The annual subsidence rate was determined by calculating the difference in the orthometric height readings for each benchmark using differences in survey controls and then dividing the difference by the elapsed time between the survey controls. Timespans were determined by converting all dates into a day-number format. The values of those day-numbers were divided by 365 (366 if the year was a leap year). The result is a percentage for the year in which the orthometric height was collected. The time span between the current and superseded survey control dates was summed using the day number percentages and a value of one for years that were between survey controls. An example of this can be found below in Table 3. The following is an example of the previously outlined processed using survey mark designation Q 804.

- The date of the current control survey is on the 179<sup>th</sup> day of 2012. The following formula is used to determine the percentage,  $179/366 = 0.49$ . The day number is divided by 366 since 2012 was a leap year.
- The date of the superseded survey control is on the 166<sup>th</sup> day of 1991. The following formula is used to determine the percentage,  $166/365 = 0.45$ ,  $1 - 0.45 = 0.55$ . The superseded survey control should only represent the reminding days in that year.
- The difference in years between the superseded and current surveys should just be represented in whole values meaning one year would be represented by a value of 1 or seven years would represent a value of 7.
- The total timespan for Q 804 is 21.04. This value was used to perform the division on the height difference.

**Table 3. Timespan Values.**

<b>Timespan for Survey Mark Designation Q804</b>		
	<b>Date</b>	<b>Day Number Percentage</b>
Current Survey Control	6/27/2012	0.49
Year Difference	1992-2011	20.00
Superseded Survey Control	6/15/1991	0.55
<b>Total</b>		<b>21.04</b>

The difference in orthometric height was determined by subtracting the superseded control survey from the current control survey. The totals for the timespans and orthometric heights then used division to get an annual rate of subsidence for each location by dividing the orthometric height difference by the timespan total. These differences were recorded in Excel as the annual rate of subsidence in meters. The values for the orthometric heights and dates all come from the datasheets for each of the survey marks. There are examples of a portion of the same datasheet for survey mark designation Q 804 as shown in Figure 4 and Figure 5. The difference between controls for A 193 would be  $26.3 - 26.54 = -0.24$ . The values used should be in meters since they were used to interpolate a surface that was subtracted from the elevation dataset whose vertical units are in meters. The resulting difference of  $-0.24$  in the case of Q 804 would then be divided by the timespan value 21.04 to calculate the rate of subsidence per year.

HT_MOD	-	This is a Height Modernization Survey Station.				
DESIGNATION	-	Q 804				
PID	-	AW2137				
STATE/COUNTY	-	TX/FORT BEND				
COUNTRY	-	US				
USGS QUAD	-	ALIEF (1995)				
*CURRENT SURVEY CONTROL						
NAD 83(2011) POSITION	-	29 39 42.57642(N)	095 37 09.41826(W)	ADJUSTED		
NAD 83(2011) ELLIP HT	-	-1.060 (meters)	(06/27/12)	ADJUSTED		
NAD 83(2011) EPOCH	-	2010.00				
NAVD 88 ORTHO HEIGHT	-	26.30 (meters)	86.3 (feet)	GPS OBS		

**Figure 4. Q 804 Current Survey Control.**

**Source:** National Geodetic Survey (NGS). "BY PIDS-Q 804." Survey Marks and Datasheets, US Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), 1 May 2018, [https://www.ngs.noaa.gov/cgi-bin/ds\\_pid.prl](https://www.ngs.noaa.gov/cgi-bin/ds_pid.prl).

SUPERSEDED SURVEY CONTROL						
NAD 83(2007)	-	29 39 42.57592(N)	095 37 09.41925(W)	AD(2002.00)	0	
ELLIP H (02/10/07)		-1.041 (m)		GP(2002.00)		
ELLIP H (10/25/00)		-0.989 (m)		GP( )	4 1	
NAD 83(1993)	-	29 39 42.57580(N)	095 37 09.41850(W)	AD( )	1	
ELLIP H (10/17/96)		-0.862 (m)		GP( )	3 1	
NAVD 88 (06/15/91)		26.541 (m)	87.08 (f)	ADJUSTED	1 2	
NGVD 29 (12/23/87)		26.535 (m)	87.06 (f)	ADJUSTED	1 2	
NGVD 29 (04/06/79)		26.908 (m)	88.28 (f)	SUPERSEDED	1 2	

**Figure 5. Q 804 Superseded Survey Control.**

**Source:** National Geodetic Survey (NGS). "BY PIDS-Q 804." Survey Marks and Datasheets, US Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), 1 May 2018, [https://www.ngs.noaa.gov/cgi-bin/ds\\_pid.prl](https://www.ngs.noaa.gov/cgi-bin/ds_pid.prl).

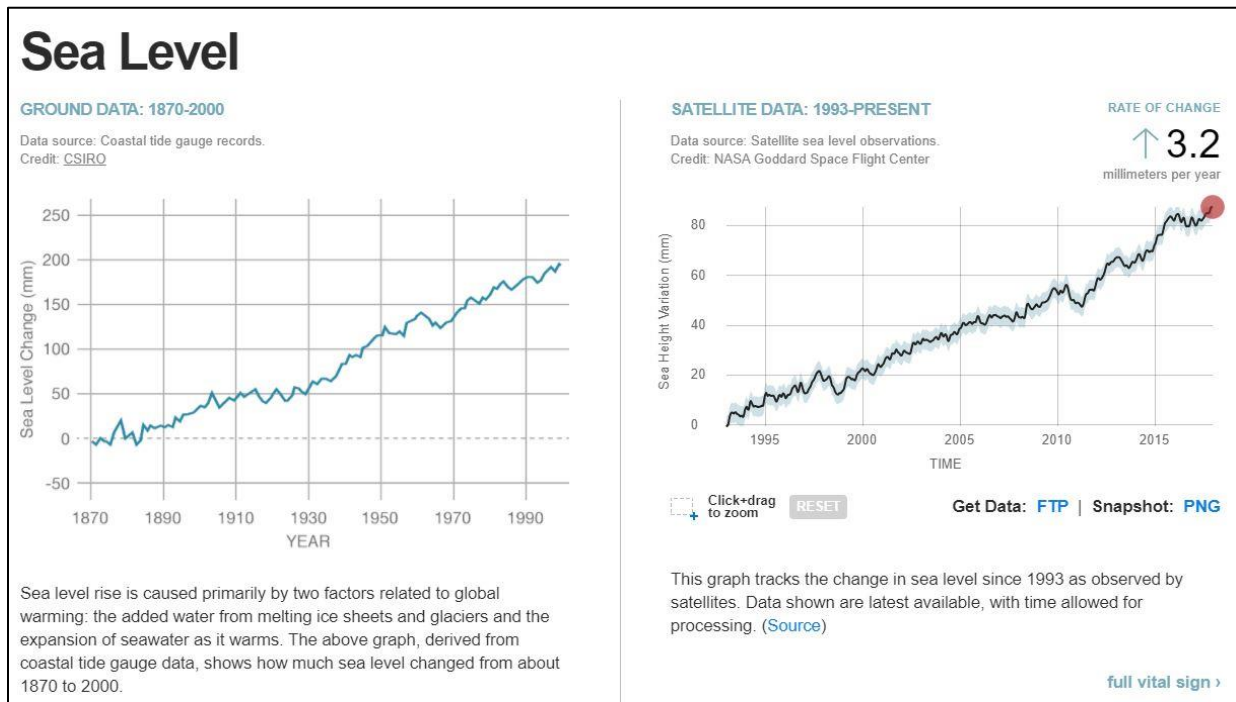
The subsidence per year rates was recorded in excel and then multiplied out by ten-year intervals up to a hundred years for each location. The excel file was then saved out separately in a CSV or comma delineated format. The CSV file was joined to the edited NGS shapefile using the PID fields. The joined shapefile was then exported to a separate shapefile retaining all the information of both the NGS shapefile and the excel table.

Once the preparation of the NGS survey marks was completed, each location retained information for its rates of subsidence. These rates were used to interpolate ten raster surfaces reflecting the rate of subsidence for each ten-year interval. Those raster surfaces were then applied to the DEM surface which resulted in ten separate DEM surfaces impacted by forecasted subsidence. Those surfaces then had the ten-year interval predicted impacts of sea-level rise applied to them.

### National Aeronautics and Space Administration

NASA has three strategic goals that provide the framework for all operations and essential initiatives. One of the three strategic goals is to advance the understanding of Earth and develop technologies that will advance the quality of life on Earth.<sup>17</sup> This strategic goal outlines NASA’s mission to monitor, study, and provide scientific insight into the impacts of climate change.<sup>18</sup>

Anyone can access NASA’s global climate change page to determine the rate at which global sea-level rise is occurring. Global sea-level rise rates are observed based on satellite sea level observations compiled at the NASA Goddard Space Flight Center.<sup>19</sup> The current rate of sea-level rise and the one used for this system is displayed below in Figure 6. The rate is provided in millimeters per year. To obtain sea level rise rates, the NASA observation were recorded in excel, converted to meters, and then multiplied out based on 10-year intervals up to 100 years.



**Figure 6.** NASA Sea-Level Rise Rates.

**Source:** “Sea-Level Rise.” Global Climate Change Vital Signs of the Planet, The National Aeronautics and Space Administration, 1 June 2018, [climate.nasa.gov/evidence/](https://climate.nasa.gov/evidence/).

During processing for the inundation datasets, the recorded sea-level rise values are applied to the subsided LiDAR surfaces using the Raster Calculator. The resulting LiDAR surface will then have the combined impacts of both subsidence and sea-level rise.

## **United States Census Bureau**

The United States Census Bureau maintains large geographic datasets that range from congressional districts to water boundaries. The wide range of GIS data offered by the Census Bureau makes it an excellent asset for conducting all forms of research, geocoding addresses, statistical analysis, and a source of current data. Within their GIS data warehouse is Topologically Integrated Geographic Encoding and Referencing (TIGER) GIS data. There are multiple TIGER datasets and formats. The most comprehensive TIGER GIS data offered is the TIGER/Line shapefiles.<sup>20</sup> The Census Bureau has a web interface under its geography section for downloading GIS data. One point to remember when using TIGER data is that the data itself needs considering when choosing which year data to use. TIGER data is continuously updated or checked each year for accuracy. All census related data is most accurate from the year of the census which may not be the most current year. Data that reflects geographic boundaries or lines are accurate within reason for the most current year.

Three shapefiles were used for both the preparation and processing of the inundation and the inundation of transportation infrastructure shapefiles that derived from the Census Bureau. These shapefiles were the counties, water boundaries, and the primary and secondary roads. The counties shapefile was one of the first datasets of this project to be refined due to its use in data preparation and processing. First, the shapefile was projected to match the coordinate system of the DEM raster. The TIGER water area was then erased from the counties area using the Erase Tool in the Analysis Toolbox. The final step was to clip the county shapefile to the extent of the study area which required that the following additional steps be performed. First, a field was added to the applicable NGS shapefile which stored a simple numerical value, in the case of this project it was one. The NGS shapefile was then interpolated using the IDW interpolation tool. Only two parameters are required for this simple interpolation. The mask under raster analysis in the environments tab was set to the processed TIGER/Lines counties shapefile post erase. The output cell size should also match the resampled DEM or 30-foot resolution. The raster output was then converted to a polygon using the Raster to Polygon tool. The polygon output was then used to clip the TIGER county shapefile to match the extent of the study area as defined by the extent of relevant NGS benchmarks.

The water boundaries and primary and secondary roads required minimum preparation for this project. First, both shapefiles were reprojected to match the DEM raster. Next, both shapefiles were clipped to the process county shapefile to match the extent of the study area. Once the Clip had completed the shapefiles needed no additional refinement. The primary and secondary could be dissolved based on the route name to improve processing, analysis, and/or storage size but it is not a requirement at this step of the project.

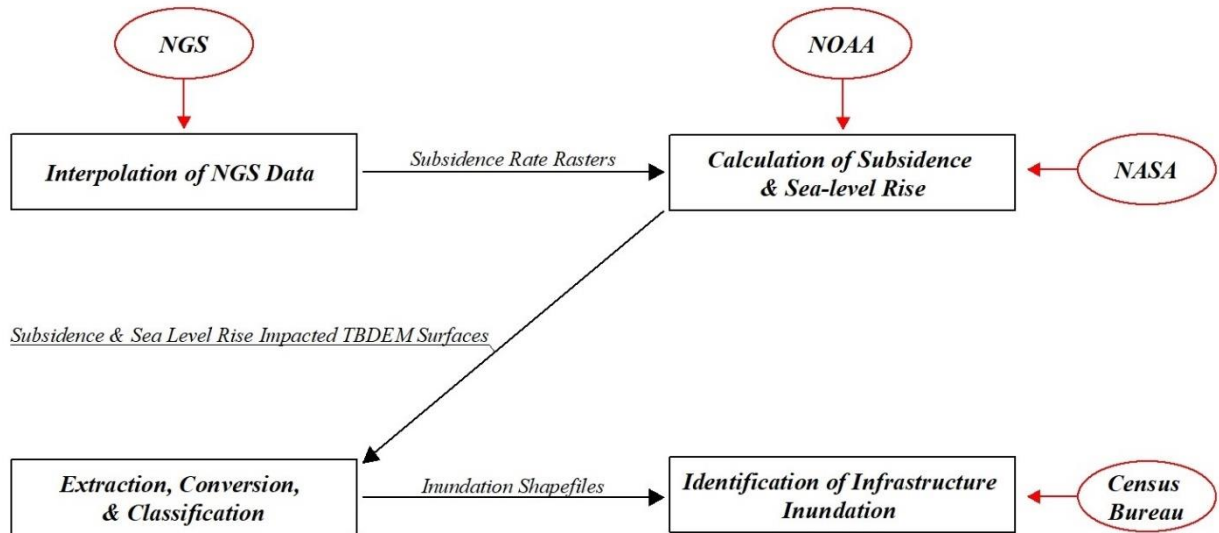
The counties shapefile was used for masking any processing such as the clips or interpolations required in the preparation of data and processing for the inundation shapefiles. The dataset was also used as the feature mask data for all the Extract by Mask processes ran on the raster surfaces. The primary and secondary roads were intersected with the inundation shapefile to create the inundation of transportation infrastructure shapefile. All the shapefiles were used for cartography purposes.

## Methodology

Once the data was prepared, the groundwork was set for the development of both the inundation shapefile and the inundation of transportation infrastructure shapefile. The goal was to develop an accurate inundation shapefile which would be used to modify the TIGER/Lines primary and secondary roads shapefile to create a single inundation transportation shapefile. The goal of inundation transportation infrastructure dataset was to reflect and categorize segments of essential routes in coastal Texas that may be jeopardized by the combined effect of subsidence and sea-level rise. As in the case of the preparation of the data, there were also many processes required to accomplish the above goals.

The processing was organized into four separate phases. The separation aided in monitoring progress, addressing errors as they happened, and data storage. Having the ability to resolve errors saved substantial time when processing large datasets such as the *NOAA Office for Coastal Management Coastal Inundation Digital Elevation Model: Aggregate Record* LiDAR DEM and its multiple outputs. Each phase resulted in a minimum of ten outputs that may have only been critical to the next process or phase. That means that there was a significant amount of data both in storage size and quantity to keep organized and achieved as the processing proceeded. The data storage was structured within folders corresponding to phases with subfolders corresponding to the processes of those phases.

The methodology phases correspond to their principal purpose or purposes. The first phase was the interpolation of the amended National Geodetic Survey (NGS) data. During this phase, raster surfaces were created with values reflecting predicted rates of subsidence that would occur at specific intervals and locations. The second phase was the calculation of subsidence and sea-level rise. During this phase, the impacts of both subsidence and sea-level rise were applied to the LiDAR surface. The third phase was extraction, conversion, and classification. During this phase, the areas impacted within the raster surfaces were extracted, converted to shapefile, and classified by their predicted year of inundation. The fourth phase integrated values from the inundation shapefiles with the TIGER/Lines primary and secondary roads shapefile to identify inundation within the infrastructure. During this phase and only during this phase, all processes were not duplicated ten times. The result of this phase would be only one shapefile. The procedures for each phase were constructed in ArcMap ModelBuilder for visual reference for the reading. The phases of processing are depicted in Figure 7 below.

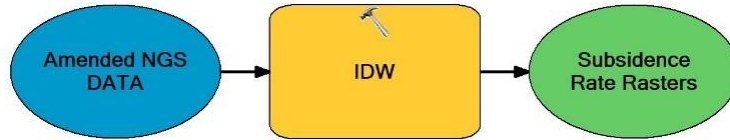


**Figure 7.** Phases of Processing.

### Interpolation of NGS Data

The first phase of processing is the interpolation of the amended NGS data. The process was duplicated ten times with different parameters and run once in ModelBuilder to produce the ten subsided raster surfaces. The data interpolation, which occurred ten times, made use of ten separate attributes using the Inverse Distance Weighted (IDW) tool in the Spatial Analyst toolbox. The interpolation was executed for each 10-year interval attribute by changing the Z value field in the tool. The Z value field controls, which attribute of the feature to interpolate, for the amended NGS data it was the subsidence values for each 10-year interval. The only parameter outside of the environments that did not remain default was the number of points in the search radius, which was decreased from 12 to 6. IDW performs two critical functions during the interpolation of data. First, it uses the weighted averages of surrounding values to determine values at non-sampled locations. Second, the influence of each sampled location decreases as the distance from that location increases. Keeping in mind these two points and understanding that subsidence is highly localized IDW was the best choice for interpolation. To further increase, the tool's localization the number of points of the search radius was limited to 6. The reminding paraments were set in the model properties menu under environments.

The model had three parameters with its environments set. The output coordinate system was set to *North America 1983 Lambert Conformal Conic*. The next two parameters set were both set under raster analysis. The cell size was set to the DEM surface (30 foot) to maintain that there would be no variance, and the mask was set to the processed TIGER/Lines counties shapefile. An example of the model used is displayed in the model in Figure 8.

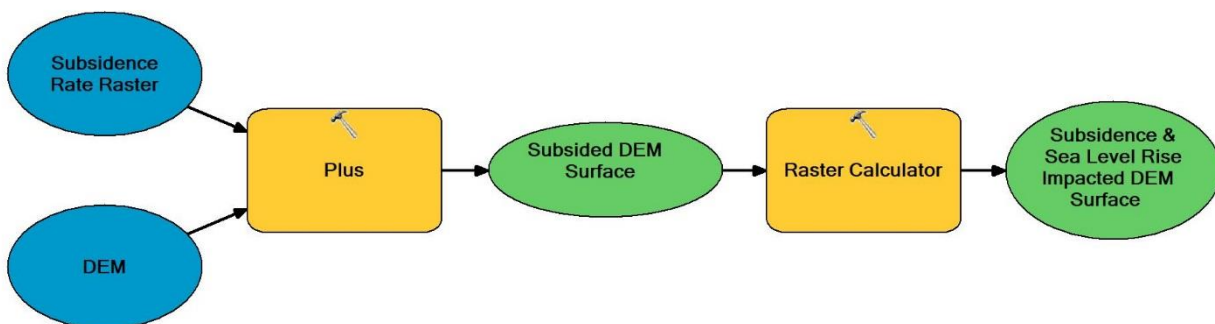


**Figure 8.** Interpolation of NGS Data Phase.

### Calculation of Subsidence & Sea-level Rise

The second phase of processing, within ModelBuilder, applies the impacts of subsidence and sea-level rise on the DEM surface by incorporating the subsidence rate rasters and the NOAA sea level rise information. First, the subsidence rate rasters were added to the DEM surface ten times creating ten subsided DEM surfaces. The addition of the negative valued subsided surfaces to the DEM surface will result in a loss. This process was accomplished using the Plus tool in the Spatial Analysts toolbox. The Plus tool adds the values of one raster to another raster. The “constant value 1” raster was set to the DEM surface for each of the ten processes. Later, the addition was performed on this raster. The “constant value 2” raster was set to one of the ten different subsidence rate rasters for each process. The “constant value 2” raster was the value added to the “constant value 1” raster or in this case, it was subtracted since the addition of a negative will be a loss. Next, the rates of sea-level rise were applied to each of the ten subsided TBDEM surfaces. These processes were accomplished using the Raster Calculator tool in the Spatial Analysts toolbox. In the map algebra expression box of the Raster Calculator, the NASA sea level rise rates were subtracted from each correlating subsided DEM surface. For example, subsided DEM surfaces of 40 years should have 0.128 subtracted from it, 0.128 being the 40-year projected global sea-level rise in meters. The resulting TBDEM surfaces from both processes had both impacts of subsidence and sea-level rise applied to them. The reminding parameters for both processes were set in the model properties menu under environments.

The model had two parameters set within the environments. The output coordinate system was set to *North America 1983 Lambert Conformal Conic*. The next was setting the cell size to the DEM surface (30 foot) under raster analysis. An example of this model is displayed below in Figure 9.



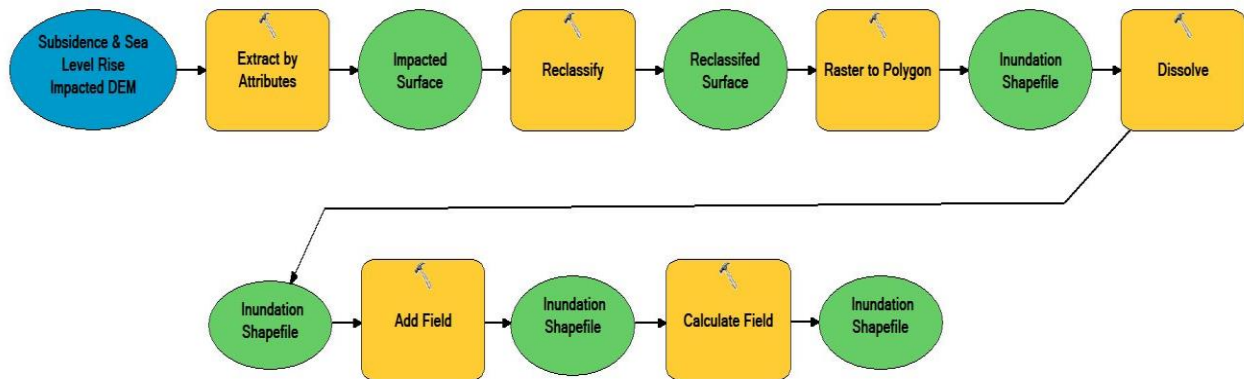
**Figure 9.** Calculation of Subsidence & Sea-level Rise Phase.

### **Extraction, Conversion, & Classification**

The third phase of processing extracted the areas threatened by inundation from the subsidence and sea-level rise impacted DEM surfaces converted those rasters to shapefile, and added an identification attribute to the shapefiles. This phase was run from ModelBuilder with the exception of the Add Field and Calculate Field tools. These tools can be incorporated into ModelBuilder or can be completed from the attributes table menu of the shapefiles. The processes for this phase were ran for each 10-year interval. The first process was to extract the areas that would be threatened by inundation due to residing below 0-meter of elevation for each of the subsidence and sea-level rise impacted DEM surfaces. The DEM surface processed for this research classifies the water surface elevation in the wetland and marshes along the coast as 0-meter or less in elevation. This process was accomplished using the Extract by Attributes tool in the Spatial Analyst toolbox. The Extract by Attributes tool uses a logical expression to extract values of a raster. The where clause expression box of the tool is where the logical expression is placed. The expression used to extract the values below 0-meter of elevation was “VALUE” < 0.000001. The next process was to reclassify the data. The elevation of the extracted surfaces inherited the extensive values range of the DEM surface, which would generally slow or stop any processing of the inundation shapefiles. This process was accomplished using the Reclassify tool in the Spatial Analyst toolbox. The Reclassify tool will change any values of a raster. The reclass field was set to values. In the reclassification table, the old values column was set a low value that would not be surpassed during any of the previous processing to the limit set in the logical expression used for the Extract by Attributes tool (-50 - 0.000001). The new value was set to 0. This will reclassify all the elevation values of the extracted surfaces to 0. The change missing values to NoData parameter was checked to assure that all values below 0.000001 are classified as 0 or no data. The next process was to convert the reclassified raster to a shapefile. This process was accomplished using the Raster to Polygon tool in the Conversion toolbox. The only parameter set for this tool was checking the simplify polygons box. The next process was to dissolve the newly created inundation shapefiles. The dissolve aids in decreasing the storage space and limiting attributes of the inundation shapefiles, which helps, minimize the shapefiles rendering time. The only parameter used was unchecking the “create multipart features” box. The next two processes were to create an identification attribute for each inundation shapefile. The addition of a specific identification attribute is necessary for the creation of the inundation of transportation infrastructure shapefile in the next phase. This was accomplished outside of ModelBuilder by using the add field command in the attribute table menu of the shapefiles. The field name was labeled *IId* for inundation identification and the long for the field type. When the field was added to the attribute table the field was calculated by right-clicking it and selecting calculate field. Each field was calculated based on the year interval value of the shapefile. To complete this in ModelBuilder the steps would work. First, a field was added to the attribute table of each inundation shapefile using the Add Field tool in the Data Management toolbox. The field name and field type tool parameters were set to the following. The field name label was *IId* for inundation identification and the long for the field type. Next, the newly created field was calculated using the Calculate Field tool in the Data Management toolbox. To calculate the field, the field name used for was set to *IId* for each inundation shapefile. In the expression box, the numerical value is set to the interval year of shapefile being identified. An example of this would be the 50-year interval inundation shapefile with the numerical value 50 in the expression box. The reminding paraments were set in the model properties menu under environments.



The model had two parameters set. The parameters remained the same if including the Add Field and Calculate Field tools. The output coordinate system was set to *North America 1983 Lambert Conformal Conic*. The next was setting the cell size to the DEM surface (30 foot) under raster analysis. An example of this model including the Add Field and Calculate Field tools is displayed below in Figure 10.



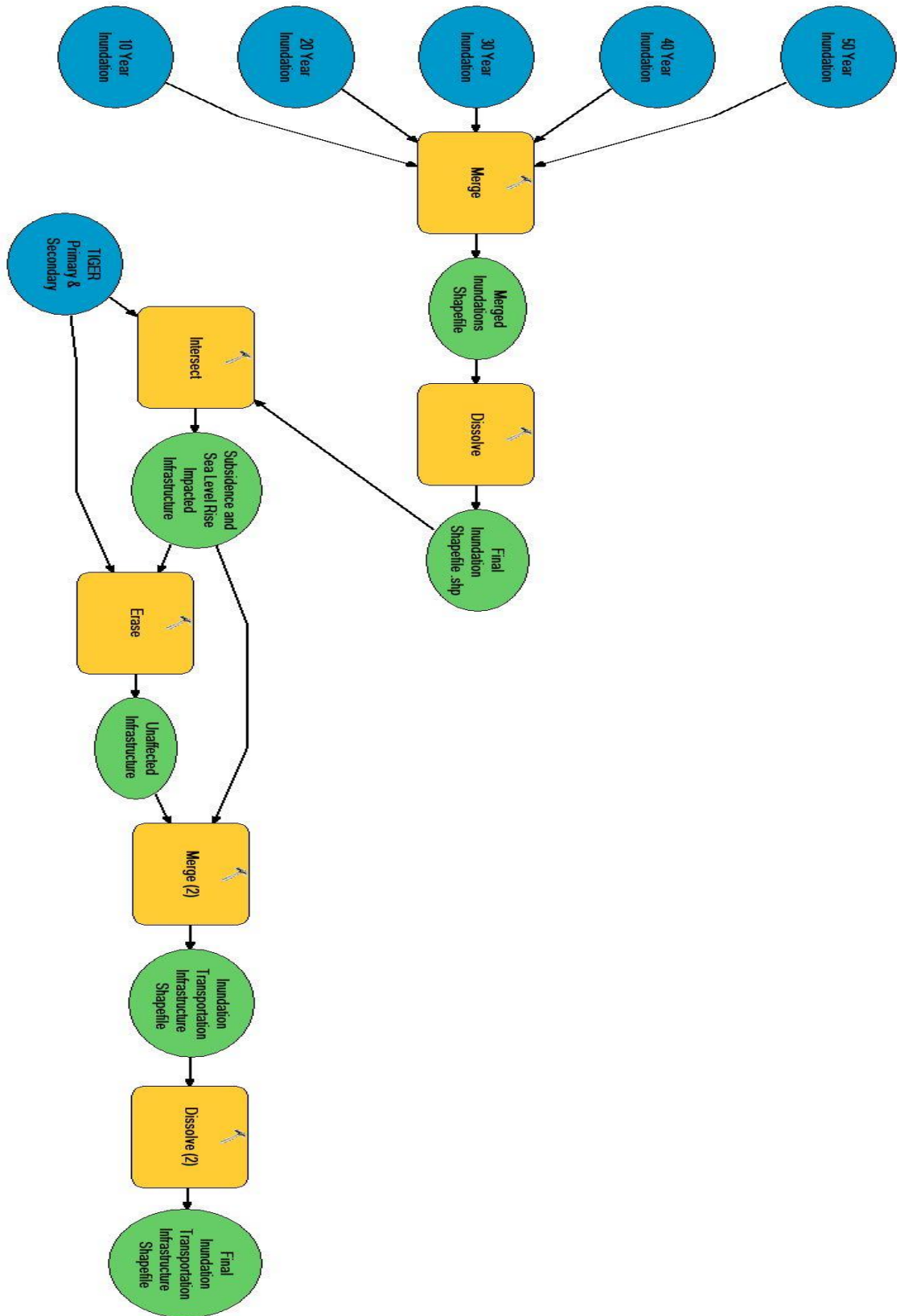
**Figure 10.** Extraction, Conversion, & Classification Phase.

### Identification of Infrastructure Inundation

The final phase of processing was to identify segments within the transportation infrastructure that intersect with one single inundation shapefile. The phase was run using a model. The model listed below is a visualization of the steps and tools used. The model only displays the processing of the first 50 years of inundation to be better visualized in the report. The complete model required all 100 years or 10 inundation shapefiles. The consideration of the Intersect and Spatial Join tools should also be noted. The Intersect tool which is found under the Analysis toolbox calculates the geometric intersection of multiple shapefiles producing one shapefile with whose attributes contain this relationship. The Spatial Join tool is in the same toolbox directly next to the Intersect. The Spatial Join tool will join the attributes of one shapefile to another based on their shared spatial relationship. The two tools which may share results in some cases that are similar do not share the same functions. The Intersect is processing geometric relationships while the Spatial Join is processing spatial relationships. The Intersect can only produce shapefiles of the lowest geometric function value of the inputs. This means that if the inputs are a polygon and line the resulting shapefile can be a line or point shapefile. This geometric relationship is not required for the Spatial Join. The output of a polygon or line input can be either a polygon or line when using the Spatial Join tool. The Intersect tool was used for processing in this research due to its functional use in developing and maintaining the geometric relationship of the TIGER/Line primary and secondary roads shapefile. This allows for the addition of accurate geometric attributes such as length, bearing, height, and other geometric characteristics to the attribute fields of the inundation of transportation infrastructure shapefile. If the output does not require this geometric relationship and only needs to contain spatially shared attributes either tool will work.

The processing for this phase begins with the use of the Merge tool found in the Data Management toolbox. The input datasets were all ten of the inundation shapefiles. The resulting shapefile is the final inundation shapefile that has the attributes of 100 years in 10-year intervals of inundation. The next step was running a dissolve to square away the attribute table of the shapefile. This step is not required but it will dissolve hundreds of attributes to ten based on the *Iid* field. The Dissolve tool in the Data Management toolbox was used. The *Iid* field was checked in the Dissolve Field parameter of the tool. The next process was to intersect the TIGER primary and secondary roads with the newly created inundation shapefile using the Intersect tool. The only parameter changed from the tool's default was the join attributes field which was changed to No FID. The result of the tool was only the roads intersecting the inundation shapefile. The road segments were also attributed the year interval of which they intersected. This shapefile was then used to erase the inundated segments of roads from the TIGER/Line primary and secondary shapefile. This was achieved by using the Erase tool in the Analysis toolbox. The input feature for this tool was the TIGER primary and secondary roads and the erase feature was the inundated roads. The output of this process is a shapefile containing all roads that were not jeopardized to inundation due to subsidence and sea-level rise. At this point during the processing, there was a shapefile depicting roads that are potentially impacted by subsidence and sea-level rise and roads which are not. The next process was to combine these two shapefiles into one shapefile which will provide a complete picture of the future state of the transportation infrastructure. The Merge tool was used for the second time during this process to attain the final inundation of transportation infrastructure shapefile. The resulting shapefile will also contain the *Iid* field retaining all the impacted attributes but also attributing nonimpacted road segments to a value of zero. The final step was to dissolve the newly created shapefile by both the road name and its inundation identification. The *Iid* and *Name* fields were both checked in the Dissolve Field parameter of the tool. The resulting shapefile is the inundation transportation infrastructure shapefile. Again, the Dissolve processes listed above and displayed in the model below are not required but they will square away the organization of the attribute table for the final shapefile.

The model is displayed below in Figure 11. The model only required one parameter to be set. The parameter is “setting the output coordinate system to *North America 1983 Lambert Conformal Conic*”.



**Figure 11.** Identification of Infrastructure Inundation Phase.

## Results

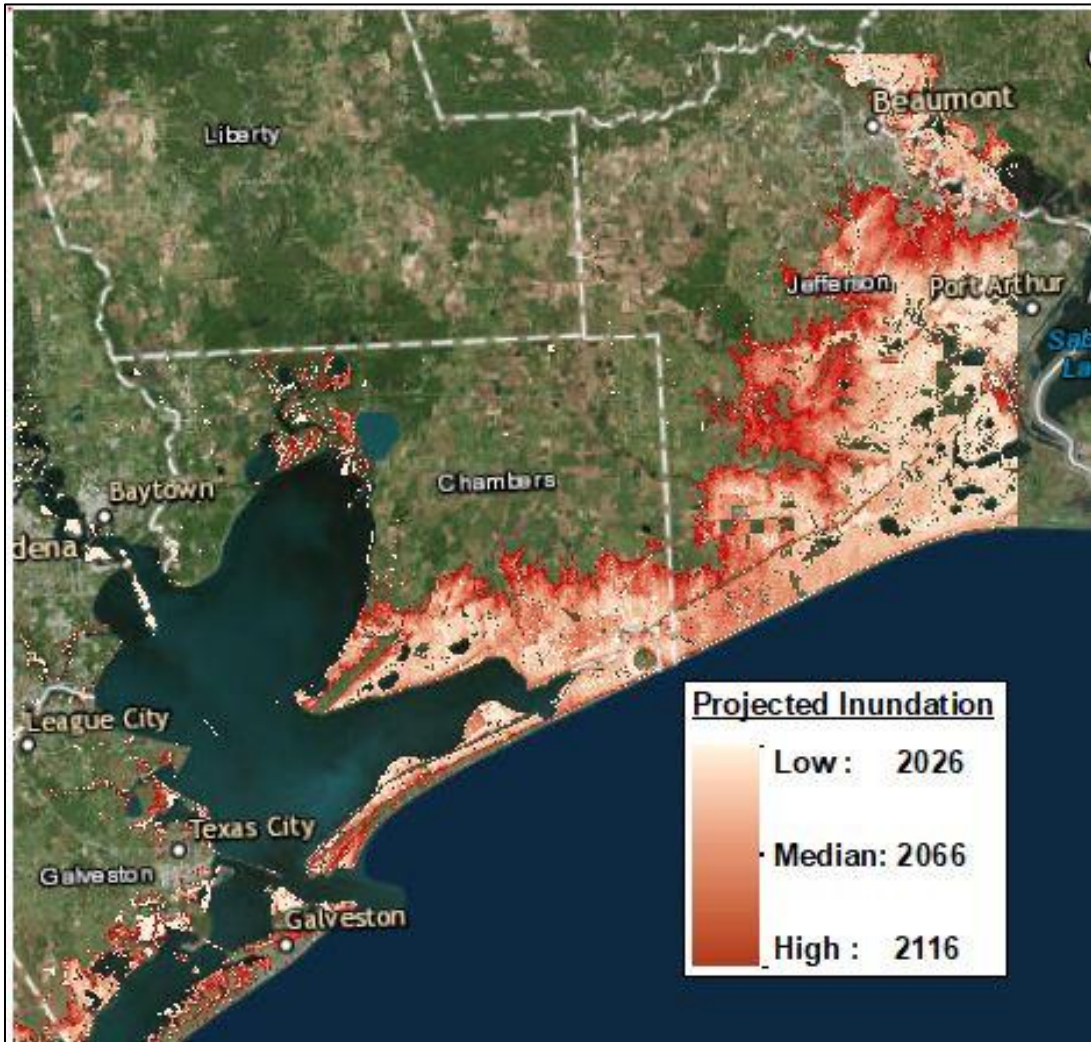
The results of the various conversions and processing phases were the inundation and inundated transportation infrastructure shapefiles. These two shapefiles assist in the analysis and visualization of the potential inundation of transportation infrastructure along the Coastal Texas due to subsidence and sea-level rise. The determination measurements such as length and area of the original data and the resulting processed data allowed for assessments of the newly created datasets. First, the total length of the TIGER/Line primary and secondary roads in coastal Texas was 4,052.36 miles. This data again only accounts for major federal and state highways. Next, the total area of the TIGER/Line county shapefile that had both been clipped to the study area and had the water bodies erased from it was 8,307.88 square miles. The measurements of the length and area of these shapefiles are precise, but it is important to remember that these shapefiles are approximating the geography and transportation infrastructure. The data is also reflective of the date at which it was collected. These means that it is only an assessment of the possible base on geographic conditions of the time of data collection and will not account for any future changes, positive or negative.

The inundation shapefiles revealed that there is a moderate trend of land loss due to subsidence and sea-level rise along coastal Texas. Subsidence accounts for a significant amount of volume loss across a large part of coastal Texas, but due to a rapid increase in elevation away from the coast, these areas were not classified as having the potential for permanent inundation. When assessing the potential for permanent inundation both subsidence and sea-level rise had an almost equal impact with subsidence having a slightly stronger influence over the entire study area. In the Houston area, expanding east to Galveston the rates of subsidence were far more significant than the rest of coastal Texas. The first 10 years of inundation reveal a total land loss of 146.04 square miles which is 1.8% of the original geography. The only major metro area with any significant inundation was fragments of the Beaumont-Port Arthur metro area, which has elevations near 0-meter and is similar in geography to south-west Louisiana that is also significantly affected by subsidence and sea-level rise. Projecting out 100 years from 2016 the date of the source surface elevation to 2116 the land loss is far more significant. The cumulative 100 years of inundation reveal a total land loss of 1049.39 square miles, which is 12.6% of the study area. The potential for permanent inundation extends into large areas of the Beaumont-Port Arthur metro area and portions of the Houston and Corpus Christi metro areas. The extent of the study area does not cover all the Beaumont-Port Arthur metro area and only includes a small part of the Corpus Christi metro area. The potential for permanent inundation could be far higher in these areas. The Houston metro area is also not wholly covered by the extent. However, the northeast Houston metro area should not be considered under threat of inundation due to the higher elevations of that area. Most of Galveston Island and Beaumont-Port Arthur metro area are at danger of higher inundation during each of the ten-year inundation intervals. The inundation shapefiles were used to create both shapefiles - a map of the 10-year intervals projecting out from 2016 and the inundated transportation infrastructure. In the map, the graduated red regions symbolize potential inundation based on their unique values. The inundation projection map and a call-out can be viewed in Figures 12 and 13 below.

The inundated transportation infrastructure shapefile was the result of intersecting major road networks along coastal Texas with the inundation shapefile. During analysis, it was determined

that the trend of transportation infrastructure loss due to subsidence and sea-level rise to permanent inundation was minor. The first 10 years of inundation reveal a total loss of 6.68 miles of infrastructure which is 0.2% of the original transportation infrastructure. The total loss of transportation infrastructure because of the projected inundation over 100 years was 239.65 miles or 5.9% of the original infrastructure. The addition of the new loss of transportation infrastructure was never more significant than 1% for any 10-year interval period. The percentages of loss range from 0.2% to 0.8% over the 100-year time span. Table 4 outlines the mileage and rates of transportation infrastructure lost over 100 years due to inundation. The inundation of transportation infrastructure shapefile was then used to create an indexed map book detailing the potential impact of subsidence and sea-level rise on the transportation infrastructure titled *PROJECTED INUNDATION OF MAJOR TRANSPORTATION INFRASTRUCTURE ALONG COASTAL TEXAS MAP SERIES*. The map book consists of 52 pages, a cover page, and 51 adjoining map sheets. The inundation of transportation infrastructure shapefile was symbolized based on their 10-year intervals using a graduated red scale. The cover page and an example of one of the map series sheets can be viewed in Figures 14 and 15 below.





**Figure 13.** Coastal Texas Callout of 100-Year Projected Inundation.

**Table 4.** Projected Loss of Transportation Infrastructure.

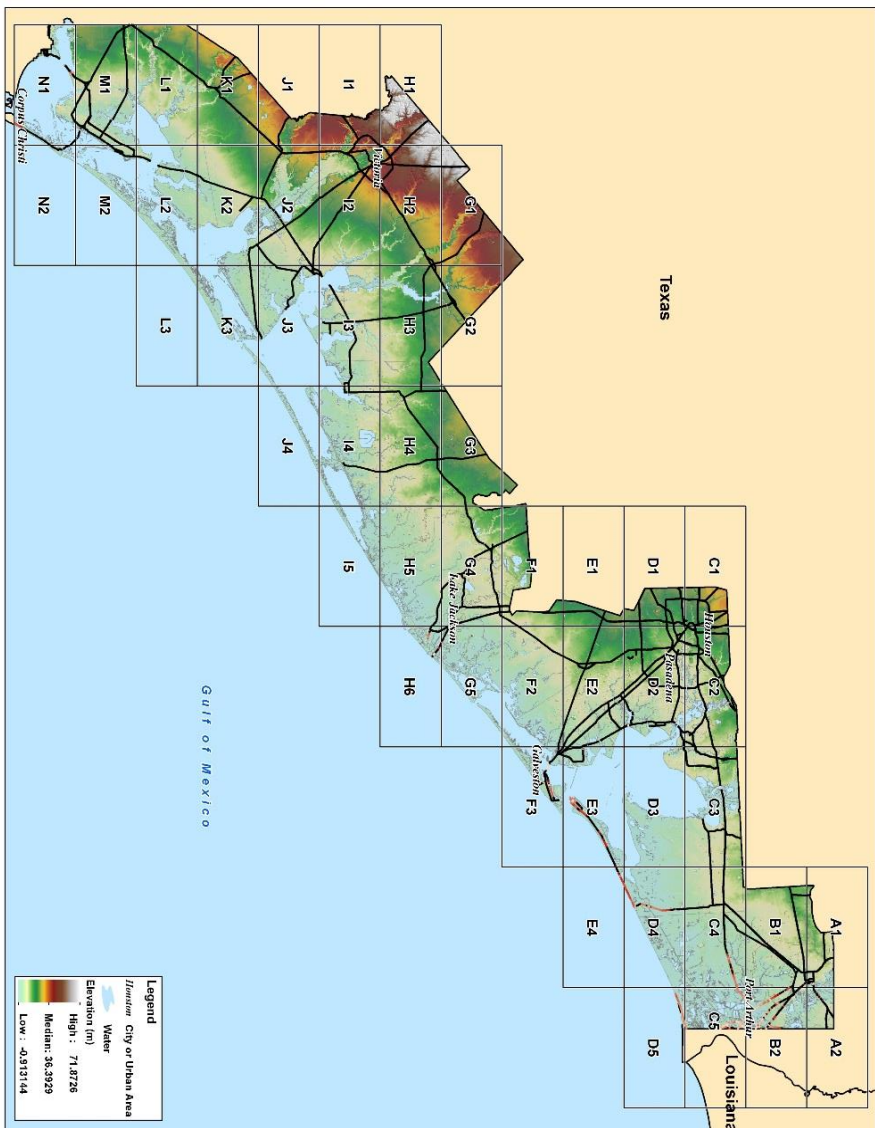
<b>Projected Inundation Years</b>	<b>Total Infrastructure Loss (Miles)</b>	<b>Percentage of Loss</b>
Not impacted	3812.71	94.1%
10	6.68	0.2%
20	17.53	0.4%
30	29.52	0.7%
40	28.24	0.7%
50	32.99	0.8%
60	26.89	0.7%
70	21.12	0.5%
80	23.38	0.6%
90	24.28	0.6%
100	29.03	0.7%
<b>Total 10 - 100</b>	<b>239.65</b>	<b>5.9%</b>
<b>TIGER Primary &amp; Secondary Roads Total Length (Miles)</b>		
<b>4052.36</b>		



**PROJECTED INUNDATION OF MAJOR TRANSPORTATION INFRASTRUCTURE ALONG COASTAL TEXAS MAP SERIES**

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**Summary of Map Series Sheets**



The projected inundation of Major Transportation Infrastructure along Coastal Texas Series indexes the sheets of coastal Texas at 1:75,000 scale for improved detection of variance in the inundation. Transportation Infrastructure dataset. The map series is index based on sheet names which begin with a letter ranging from A to N which is followed by a number ranging from 1 to 6. The sheet names and their spatial locations for the series are displayed to the left. The series covers most all, or portions of Texas Department of Transportation districts Beaumont, Corpus Christi, Houston, and Tarrant. The data was derived from the National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management Coastal Inundation Digital Elevation Model: Aggregate (IDARK) dataset. The data accounts only for potential inundation due to sea level rise. The data does not account for potential topography. All sheets in their sheet order found in the top left of the map and highlighted in red in the Reference Diagram.

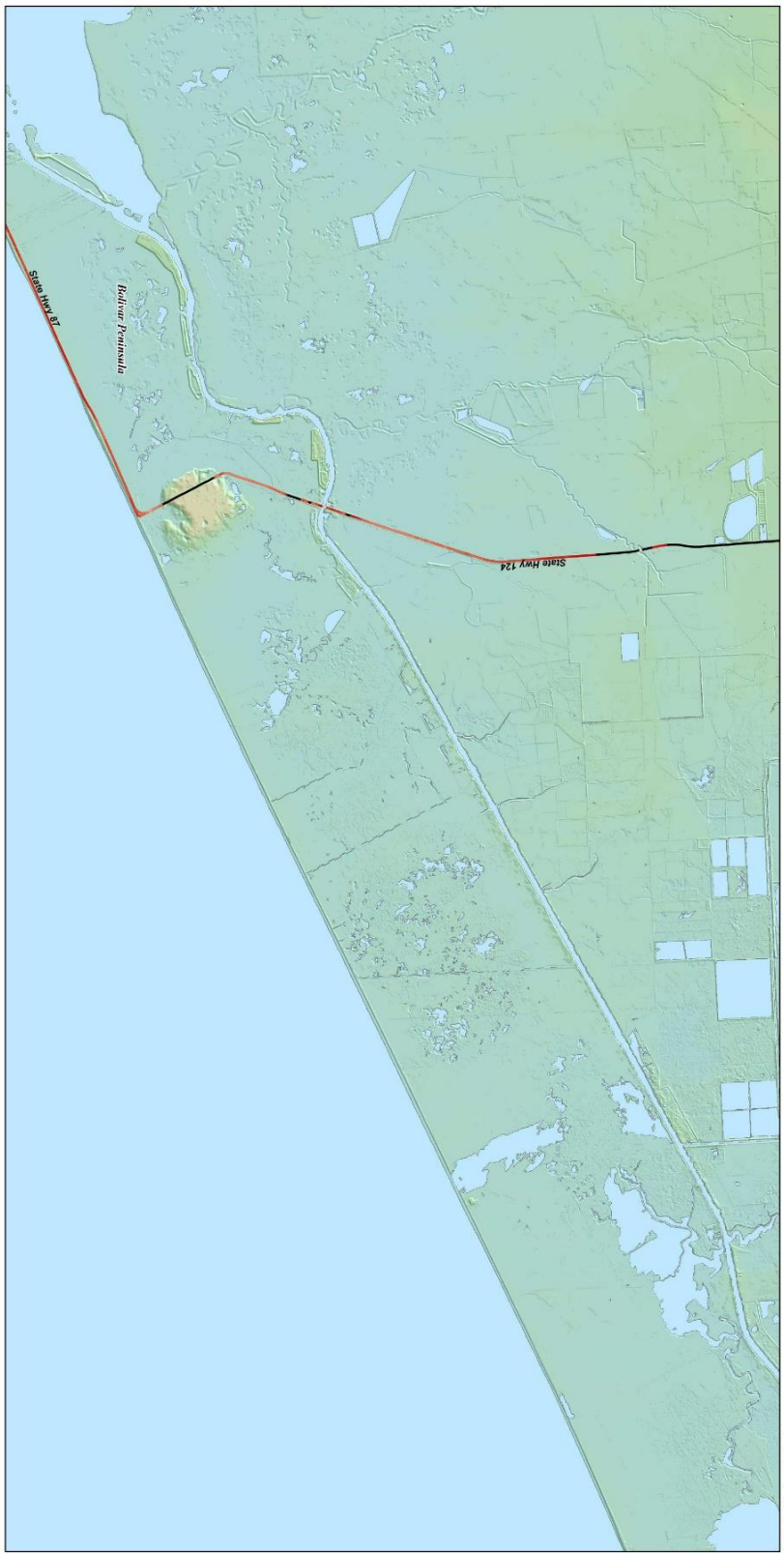
**Summary of Inundated Transportation Infrastructure Data**

The projected inundated transportation infrastructure data is symbolized based on ten-year intervals ranging from 10 to 100 years out of the latest date of the LIDAR dataset from which it was created. The latest date of the NOAA Office for Coastal Management Coastal Inundation Digital Elevation Model: Aggregate Record (IDARK) dataset is 2016. The data was derived from the National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management Coastal Inundation Digital Elevation Model: Aggregate Record (IDARK) dataset. The data was created from the intersection of TIGERLine: Primary and Secondary Roads and ten-year interval inundation data which reflect current inundation and sea level rise rates. The data does not account for projected uncertainties such as increases in subsidence rates or sea level rise.

2026 2036 2046 2056 2066 2076 2086 2096 2106 2116 Unaffected



Figure 14. Map Book Cover Page.

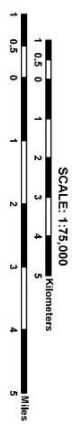
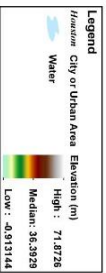


**Summary of Inundated Transportation Infrastructure Data**

Projected Inundation (Years)

2026	2046	2066	2086	2106	Unaffected
------	------	------	------	------	------------

The projected inundated transportation infrastructure data is symbolized based on ten-year intervals ranging from 10 to 100 years out of the latest date of the LDAR dataset from which it was created. Model Aggregate Record LDAR dataset is 2016. The data is accurate within a range of 20 feet or 9.144 meters and two-years of projection dates. The data considers only for potential inundation due to an elevation at or below zero and surrounding topology. The data was created from the intersection of current infrastructure and sea level rise rates. The data does not account for projected uncertainties such as increases in subsidence rates or sea level rise.



Vector Citation: US: Bureau of the Census, TIGER/Line, Places, Area Hydrography, Primary at Washington D.C.; Bureau of the Census, 2017. (Last accessed Apr. 25, 2018).

Coordinate System: MAD 1983 Lambert Conformal Conic  
 Projection: Lambert Conformal Conic  
 Datum: NAD 83  
 Spheroid: GRS 1980  
 Prime Meridian: Greenwich

Map frames correspond to their sheet label found in the top left of the map and highlighted in red in the Reference Diagram.

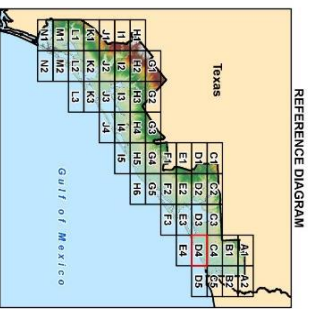


Figure 15. Map Series Sheet D4.

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