Assessment of Sea Level Rise in Coastal Mississippi

Submitted to:

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Office of Coastal Management & Planning

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Consultants, Engineers, and Scientists

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1.0 EXECUTIVE SUMMARY

The *Assessment of Sea Level Rise in Coastal Mississippi* (the Assessment) borrows from FEMA's Hazard Mitigation Planning process to the extent that the research methodology assumes sea level rise as a natural hazard warranting mitigation. The assessment document includes an expanded outline containing the four primary mitigation planning steps associated with risk assessment plus a detailed vulnerability assessment addressing natural systems, public and private man-made systems including residential land uses, and other "concurrent" vulnerabilities such as impacts to flood zones and elevations, erosion potential, ground water level increases, and salinity. The Assessment is developed in accordance with the following outline:

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An analysis of global, regional, and local data indicates future sea level increases ranging from .1 inch on a local level per year to .84 inches per year on a global level with potential impacts to natural and man-made environments along the Mississippi coast. In addition, cumulative impacts associated with increased flood levels, higher storm surges, and generally higher tide levels can cause a multiplier effect to impacts associated with sea level rise. An assessment of the coast's vulnerability to these impacts considering variables including geomorphology, coastal slope, sea level rise, shoreline erosion or accretion, mean tide range, and mean wave height indicates the coastal region is at moderate risk to the impacts of sea level rise. The projected increases in sea level rise in coastal Mississippi should be a factor of consideration in planning efforts.

A number of mitigation strategies designed to minimize these risks and vulnerabilities and to increase the coast's resilience to sea level rise are included and are generally categorized in three primary response pathways including armoring, retreating, and adapting. Through a treatment train approach in implementing these strategies, local and regional entities have the potential to address future impacts of sea level rise and also address secondary management goals related to natural resource protection, protection of man-made systems, water quality maintenance, and maintenance and restoration of wetlands ecosystems.

Based on information collected in the development of this document and identified data gaps, it is recommended that the State of Mississippi consider development of a comprehensive strategy addressing potential impacts from sea level rise in coastal Mississippi. Such a strategy should be developed with input from a diverse group to include but not necessarily limited to resource managers, biologists, local planners, engineers, housing authorities, utility districts, business leaders, port directors, casino operators, and civic leaders.

2.0 DESCRIPTION OF THE PLANNING PROCESS

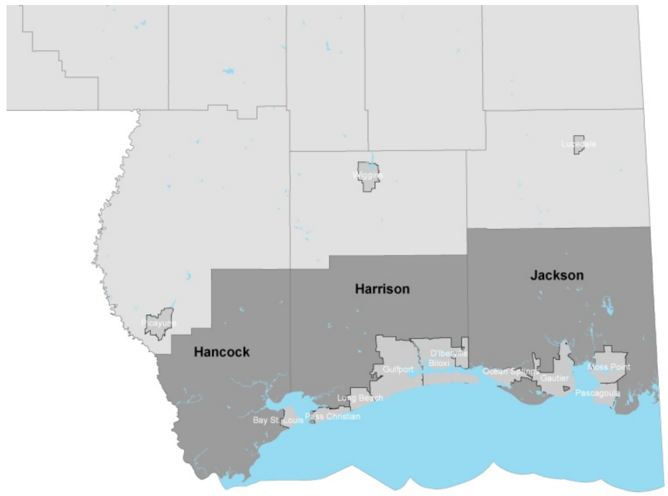
The Federal Emergency Management Agency (FEMA) utilizes and recommends a standardized planning methodology for States and local governments in planning for mitigation actions related to a variety of natural hazards. These state and local mitigation plans typically address multiple hazards by FEMA for consideration. The multi-hazard mitigation planning process includes four primary steps: 1) Organization of resources, 2) Assessment of risks, 3) Development of mitigation strategies, and 4) Implementation and monitoring of progress. FEMA illustrates the planning process as cyclical with an appropriate frequency of reviews and updates **(Figure 2.1)**.

Figure 2.1 FEMA Planning Cycle

A similar process to that of multi-hazard mitigation planning has been adopted for the development of this Assessment addressing sea level rise for the Mississippi Gulf Coast with two primary differences. The first difference is that unlike multi-hazard mitigation plans, this action plan addresses one particular hazard type, sea level rise. The second primary difference is that typical multi-hazard mitigation plans address only those potential impacts to man-made and human systems. This Assessment is intended to address these concerns but also addresses potential impacts and concerns related to natural systems such as estuaries, marshes, wetlands, and other coastal ecosystems.

3.0 INTRODUCTION TO THE PLANNING AREA

Figure 3.1 Planning Area



The assessment area includes cities and counties in coastal Mississippi with the highest probability of being impacted by sea level rise. The listing of cities and counties included in the planning study area are depicted in **Table 3.1.** The jurisdictions listied in **Table 3.1** includes the three counties adjacent to the coastline of the Gulf of Mexico and the incorporated cities located in those counties. These cities represent the most densely populated regions of the Mississippi Gulf Coast as represented in the population density map found in **Appendix A: Maps and Figures.** Mississippi's three coastal counties and the municipalities located within these counties represent the primary jurisdictions within the State of Mississippi most susceptible to the potential impacts of sea level rise. This Assessment focuses primarily on these jurisdictions as the primary planning study area. The following plan sections provide details specific to the demographic, geographic, and natural settings of the planning area in order to establish the context for this planning effort.

Table 3.1 Planning Study Area Cities and Counties

Hancock County	Harrison County	Jackson County
Bay St. Louis	Biloxi	Gautier
Waveland	D'Iberville	Moss Point
	Gulfport	Ocean Springs
	Long Beach	Pascagoula
	Pass Christian	

3.1 DEMOGRAPHIC SETTING

The Mississippi Gulf Coast, including Hancock, Harrison, and Jackson Counties, represents one of the more densely populated regions of the State of Mississippi with a total population of 370,702 (2010 Census) and an average population density of 202 persons per square mile compared to 63.25 persons per square mile for the State of Mississippi. A population density map is included in **Appendix A** and demonstrates population densities within the three coastal counties. The three coastal counties have an average population that is 77.76% white and 22.24% non-white compared to the State as a whole with a population that is approximately 60% white and 40% non-white. Population trends since 1960 show a consistent increase in population with the exception of a period from 2005 through 2006 as a result of Hurricane Katrina. Census population estimates from 2007 and 2008 along with data from the 2010

Census, indicate populations are increasing and are currently estimated to be within 10% of pre-Katrina populations[1]. **Table 3.2** provides a historic record of housing unit totals for the three counties from 2000 through 2008.

Table 3.2 Coast County Housing Units[2]

Mississippi Gulf Coast Housing Units			
Year	**Jackson**	**Harrison**	**Hancock**
2009	58,061	83,360	20,357
2008	57,159	80,920	19,009
2007	55,784	76,634	17,859
2006	54,320	74,105	16,466
2005	56,732	88,138	23,531
2004	55,548	86,555	22,997
2003	54,750	84,940	22,868
2002	54,019	83,680	22,480
2001	53,023	82,573	21,939
2000	51,946	80,224	21,245

Tables 3.3 and 3.4 provide population projections for the three coastal counties and eleven coastal municipalities through 2030 using a linear regression model for population forecasting. Population projections indicate consistent population growth through time.

Table 3.3 Mississippi Coastal County Population Projections

Year	Jackson County	Harrison County	Hancock County	Totals
1960	55,522	119,489	14,039	189,050
1970	87,975	134,582	17,387	239,944
1980	118,015	157,665	24,537	300,217
1990	115,243	165,365	31,760	312,368
2000	131,420	189,601	42,967	363,988
2008	130,694	178,460	40,140	349,294
2010	139,668	187,105	43,929	370,702
2015	149,887	197,378	47,467	394,733
2020	157,125	206,599	50,609	414,333
2024	162,915	210,195	53,123	426,233
2030	171,599	216,965	57,256	445,820

Table 3.4 Mississippi Coastal Municipalities Population Projections

Year	Moss Point	Pascagoula	Gautier	Ocean Springs	Bay St. Louis	Waveland	Gulfport	Biloxi	D'Iberville	Long Beach	Pass Christian	Total
1960	6631	17,155	N/A	5,025	5,073	1,106	30,204	44,053	3,005	4,770	3,881	120,903
1970	19321	27,264	2,087	9,580	6,752	3,108	40,791	48,486	7,288	6,170	2,979	173,826
1980	18,998	29,318	8,917	14,504	7,891	4,186	39,676	49,311	13,369	7,967	5,014	199,151
1990	17,837	25,899	10,088	14,658	8,063	5,369	40,775	46,319	6,566	15,804	5,557	196,935
2000	15,851	26,200	11,681	17,225	8,209	6,674	71,127	50,644	7,608	17,320	6,579	239,118
2007	13,951	23,609	16,306	17,149	8,052	5,249	70,055	45,670	7,928	12,234	3,993	224,196
2010	13,704	22,392	18,572	17,442	9,260	6,435	67,793	44,054	9,486	14,792	4,613	228,543
2015	16,324	25,506	19,187	19,892	9,314	6,620	73,928	46,805	8,424	11,557	5,283	242,839
2020	16,536	27,827	20,971	21,053	9,631	6,915	78,105	46,781	8,523	12,195	5,395	253,931
2024	16,706	26,518	22,399	21,982	9,884	7,150	81,447	46,762	8,602	11,835	5,484	258,768
2030	16,960	24,862	24,540	22,701	10,019	7,285	87,178	45,427	8,718	13,237	5,618	266,545

Current estimates indicate a total of 5,734 individual businesses and industries located throughout the coast. A report from the Mississippi Development Authority indicates that from August 2005 through January 2010 the coastal counties experienced a significant level of growth in expansion of existing facilities and creation of new facilities. **Table 3.5** provides a summary of the data generated from the report[3].

Table 3.5 Coast Business and Industry Expansion August 2005 – January 2010[4]

	Number of Facilities	Estimated Number of New Jobs	Estimated Capital Investment
Manufacturing Facilities			
Expanded	103	2,012	$510,396,599
New	8	729	$275,250,000
Total	**111**	**2,741**	**$785,646,599**
Non-Manufacturing Facilities			
Expanded	73	2,971	$3,140,965,933
New	53	3,944	$3,127,123,150
Total	**126**	**6,915**	**$6,268,089,083**
Overall Total	**237**	**9,656**	**$7,053,735,682**

3.2 GEOGRAPHIC SETTING

As previously stated, the study area for this Assessment consists of Mississippi's three coastal counties and the eleven municipalities located within these counties. Each of the counties has a southern boundary on the Gulf of Mexico, and all eleven municipalities have boundaries either directly on the coastline or on bays that connect directly to the gulf. The three counties combined encompass approximately 1,785 square miles of land area, or 3.8% of the land area in Mississippi. In addition, the three counties combined have a total of approximately 787 square miles of water area or approximately 52% of the State's total water area[5]. The total shoreline length spanning across the three counties is approximately 75 miles, exclusive of shorelines bordering the various bays and inlets across the coast. Of these 75 miles of shoreline, 20 are in Hancock County, 27 in Harrison County, and 28 in Jackson County[6]. The total shoreline including all bays and inlets is approximately 360 miles. In addition, 26 of the 75 miles of shoreline exist as public beaches with multiple public access points. **Table 3.2** provides details on the geographic setting of the planning area and **Figure 2** included in **Appendix A: Maps and Figures** provide a graphic depiction of the planning area, as well as its geographical context in the State of Mississippi.

Table 3.6 Planning Study Area Geographic Setting

County	Total Area (in Square Miles)	Total Land Area (in Square Miles)	Total Water Area (in Square Miles)	Population Density (in Persons per Square Mile)
Hancock	553	477	76	92.09
Harrison	976	581	395	322.04
Jackson	1043	727	316	192.12
Study Area Totals	2572	1785	787	202 (Average)
Mississippi	**48,434**	**46,914**	**1520**	**63.25**

3.3 NATURAL SETTING

The Mississippi Gulf Coast is an ecologically-diverse region of the State with a wide range of habitat types, species, and natural ecosystems. To understand the potential impacts of sea level rise on the coastal region, it is necessary to understand the ecological context of the region. In characterizing the ecological setting of the Mississippi coast, the various coastal ecosystems, regions, characteristics, and other natural areas protected by state or federal administrative mechanisms have been divided into thirteen categories and are characterized as either inland/near-shore or offshore resources. While it is understood that some of these categories are defined by man-made boundaries, they do contain critical habitats and natural systems that should be addressed within the context of sea level rise.

3.3.1 Inland and Near-Shore Ecological Resources

The identified inland and near-shore ecological resources include land-based natural features such as the following:

- Watersheds
- Forest Habitats
- Gulf Ecological Management Sites
- Sea Grasses
- Wetlands
- Surface Geology
- Major Land Resource Areas
- Barrier Islands
- Wildlife Management Areas
- National Wildlife Refuges
- Oyster Reefs
- Essential Fish Habitat
- Freshwater Wetlands

Maps depicting each of these features and their geographical context within the coastal region are included in **Appendix A: Maps and Figures**.

3.3.2 Watersheds

The Mississippi Gulf Coast Region lies within three major drainage basins (8-Digit HUC) including the Pearl River Basin, the Coastal Streams Basin, and the Pascagoula River Basin. Each basin is further divided into smaller watersheds (12-Digit HUC) identified with a lower order stream or river. All basins and watersheds in the coastal region drain either directly to the Gulf of Mexico or indirectly to the gulf via connected bays and inlets. Each basin and each

watershed represents a unique ecological sub-region of the coast and may be associated with specific habitat areas, geographic features, or other natural elements.

Basins and watersheds are natural features and are not deferential to political and administrative boundaries. From a water quality and water quantity standpoint, this attribute of watersheds creates a natural connection between the coastal region and other inland regions of the state. **Table 3.7** provides an overview of the basins and watersheds, as well as their HUC number and associated water feature.

Table 3.7 Coastal Basins and Watersheds[7]

Basin / Watershed Name	**HUC Code**	**HUC Name**
Coastal Streams Basin	03170009	Jourdan River
Bayou Casotte	03170009-070	Coastal Streams
Bayou LaCroix	03170009-130	Coastal Streams
Biloxi River	03170009-140	Coastal Streams
Lower Wolf River – Cane Creek	03170009-090	Coastal Streams
Rotten Bayou	03170009-110	Coastal Streams
Turkey Creek – Old Fort Bayou	03170009-160	Coastal Streams
Tuxachanie Creek	03170009-150	Coastal Streams
Upper Jourdan River	03170009-100	Coastal Streams
Upper Wolf River	03170009-080	Coastal Streams
Pearl River Basin	03180004	Lower Pearl River
Hobolochitto Creek	03180004-120	Lower Pearl River
Nicholson-Pearlington	03180004-140	Lower Pearl River
Pascagoula River Basin	03170006	Pascagoula River
Bluff Creek	03170006-030	Pascagoula River
Indian Creek	03170006-010	Pascagoula River
Pascagoula River Basin	03170007	Black and Red Creeks
Cypress Creek	03170007-030	Black and Red Creeks
Lower Red Creek	03170007-050	Black and Red Creeks
Pascagoula River Basin	03170008	Escatawpa River
Lower Escatawpa River	03170008-080	Escatawpa River

3.3.3 Wetlands

Wetlands are defined by 33CFR328 as "areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." Ecologically, wetlands provide a number of valuable functions including habitat and foraging opportunities for many species of animals. From a water quality perspective, wetlands provide attenuation of floodwaters, processing of nutrients, and infiltration of stormwater, all of which improve water quality.

The Coastal Region contains a variety of wetland community types including bottomland hardwood and riverfront forests, wet pine savannas/flatwoods, swamp forests/freshwater marshes, and estuarine marshes. Bottomland hardwood and riverfront forests are primarily found in and around rivers and streams throughout the Coastal Region. Swamp forests and freshwater marshes are also associated with smaller streams within the Coastal Region. Wet Pine Savannahs are found in areas where frequent rainfall occurs during the growing season and dense subsoils restrict infiltration of stormwater. Wet Pine Savannahs are generally found in the southern portion of the Coastal Region where low coastal relief impacts natural drainage function. Estuarine marshes include intertidal salt, brackish and tidal freshwater marshes and are found along the coastline and on the barrier islands. They are most often found surrounding bays, bayous and at the mouths of streams. The tidal marshes of the Gulf Coast are highly functional ecosystems that provide nursery habitat for a variety ocean species, protect the coastline from erosion during storm surges, and improve water quality by removing pollutants.[8]

3.3.4 Major Land Resource Areas and Forest Habitat Characteristics[9]

Major Land Resource Areas (MLRA) are boundary delineations based on soil and landscape characteristics, vegetation and climate. MLRA designations may contain a wide range of soil, plant, and landscape conditions. The Coastal Region is defined by two primary MRLAs including the Southern Coastal Plain in the northern-most sections of the region, and the Eastern Gulf Coast Flatwoods in the central to southern-most areas of the region. The following is a general description of conditions associated with each MLRA. **Figure 5** found in **Appendix A** includes a map depicting the specific MLRA's found in the coastal region.[10]

Southern Coastal Plain[11]

The Southern Coastal Plain MLRA in Mississippi extends from the northern portions of the coastal counties into the northern portion of the state with the primary exception of the Delta Region in northwest Mississippi and the Mississippi River Valley along the western edge of the state.

> **Land Use** in the Southern Coastal Plain typically consists of approximately 69% woodland, 17% cropland, and 11% pastureland with the remaining 3% in urban development or other uses. Throughout this MLRA, timber production is important and other cash crops include soybeans, corn, peanuts, and cotton.
>
> **Elevation and Topography:** Elevation ranges from 82' to 656' above mean sea level and increases gradually from the lower coastal plain northward. Stream valleys in this MLRA are narrow in their upper reaches but become broad with widely meandering

stream channels as they approach the coast. Local relief in the southern regions is generally limited to a few meters.

Climate: Average annual precipitation is around 60" with average annual temperatures of around 68 degrees. Maximum precipitation is typically in early winter and mid-summer and the average freeze-free period is from 250-280 days.

Water: Precipitation, perennial streams, and ground water provide an abundance of water. Municipal water supply is generally derived from deep water aquifers and domestic water supply is typically obtained from shallow wells. Ecological and natural resource concerns have historically prevented the damming of perennial streams for use as potable water supplies.

Natural Vegetation: This MLRA supports mixed oak-pine forest vegetation, loblolly, longleaf, slash, and shortleaf pines; sweetgum, yellow poplar, and red and white oaks are among the predominant overstory species. Dogwood, American holly, southern bayberry, and native lespedezas are common understory species.

Eastern Gulf Coast Flatwoods[12]

The Eastern Gulf Coast Flatwoods MLRA extends east to west from the State's common boundaries with Alabama and Louisiana and south to north from the coast line to the northern-most extension along the Pascagoula River and its major tributaries in to Perry County.

Land Use: Very little of this area is in production farms. Historically, much of it is in large land holding owned by pulp and paper companies. However, recent changes in land uses have diminished the amount of land set aside for these historical land uses. With a considerable amount of land placed in conservation areas or converted for residential development. Areas of this MLRA nearest the coastline are defined by urbanization associated with coastal communities and cities with the City of Gulfport existing as the second largest city in the state.

Elevation and Topography: Elevations range from sea level to around 80' above mean sea level. Locally relief is almost flat with variations of 8-10' feet at the most.

Climate: Average annual precipitation is around 64 inches with maximum precipitation in mid-summer and early winter. Average annual temperatures range from 68-70 degrees with average freeze-free periods of approximately 290 days.

Water: Abundant rainfall and numerous perennial streams provide important sources of water for wildlife and marine life. Municipal water supply is typically obtained from deeper aquifers. Shallow groundwater is plentiful by is affected by salinity in many areas adjacent to the coastline.

Natural Vegetation: This area supports pine forest vegetation with palmetto and wax myrtle as common woody shrubs. Longleaf and slash pine are the more common tree species.

3.3.5 Surface Geology

The planning area consists of three geological formations ranging in age from Late Pleistocene to Pliocene, which include the Late Pleistocene Pamlico Formation, the Pliocene Citronelle Formation, and the Pliocene Graham Ferry Member of the Pensacola Formation (Smith, 1975). The sediments were deposited in transitional marine environments.[13]

The Pamlico Formation is approximately 25 feet thick and consists of low terrace, windblown sand deposits that are tan, gray, and yellow in color. The southern edge of the Pamlico is covered by recent beach deposits and sand dunes. The Pamlico is exposed in broken belts several miles wide extending east to west across the counties (Smith, 1975).

The Citronelle is approximately 130 feet thick and sediments consist of reddish-brown fine to very coarse quartz sand, light-gray, orange, and brown sandy clay, and clayey gravel. Lenses of sandy clay and clayey sand, which range in thickness from 5 to 15 feet, are interbedded with gravelly sand. Sediments near the base of the formation have a high clay content. The Citronelle is exposed in the higher uplands of the counties (Carlston, 1950).[14]

The Graham Ferry Member of the Pensacola Formation is approximately 113 to 975 feet thick and consists of undifferentiated clays, clayey sands, and silty sands. Exposure is in the very northern part of the counties with road cuts and stream banks exposing a few feet of the Graham Ferry Member throughout the counties (Smith, 1975).

3.3.6 Wildlife Management Areas

Four individual Wildlife Management Areas (WMA) exist in Harrison and Jackson Counties. These include the Little Biloxi WMA in Harrison County, the Red Creek WMA in Harrison and Jackson Counties, the Pascagoula River WMA in Jackson County, and the Ward Bayou WMA in Jackson County. All designated WMAs in the coastal counties are in the northern reaches of the counties.[15]

3.3.7 National Wildlife Refuges

Jackson County, Mississippi is home to two designated National Wildlife Refuges (NWR), including the Mississippi Sandhill Crane NWR and the Grand Bay NWR. Both refuges exist in areas that have potential to be impacted by projected sea level rise increases. The Mississippi Sandhill Crane NWR encompasses approximately 19,336 acres and was established in 1975 under the authority of the Endangered Species Act to protect the critically endangered Mississippi sandhill cranes and their unique habitat. The habitat consists primarily of Pine Savannah, Wet Pine Savannah, and Pine Flatwoods and it particularly suited to the habitat needs of the sandhill crane.[16]

The Grand Bay NWR encompasses approximately 2,572 acres in Jackson County and was established in 1992 to help protect one of the largest remaining expanses of Gulf Coast wet pine savanna habitat. Other refuge habitats contained in the Grand Bay NWR include maritime forest, tidal and non-tidal wetlands, salt marshes, salt panes, bays, and bayous.[17]

As previously mentioned, both NWRs are potentially susceptible to impacts related to rising sea levels. Both contain wildlife and plant habitats that may be affected by increased water levels, salt intrusion, higher tide levels, and other effects of sea level rise.

3.3.8 Gulf Ecological Management Sites (GEMS)/Coastal Preserves

The Gulf Ecological Management Sites (GEMS) program is a partnership between the DMR, EPA and the Gulf of Mexico Program to study ecologically important areas of the Gulf region. The information gathered through this study is utilized to educate the public and promote restoration and preservation of ecologically significant areas. The State of Mississippi has 22 GEM sites, which have been included in the Mississippi Coastal Preserves. For each of the sites listed below the following information is provided on the Mississippi GEMS website[18] 1) Site Information and Points of Contact; 2) Geographic Information including: Narrative Description of the Site, Location, and Area of Influence; 3) Ecological/Cultural Characteristics including: Habitat Type and Uniqueness of Natural Community; 4) Current and Potential Use of Site, 5) Management Status; 6) Site Viability; and 7) Links for Additional Information. Generally, the GEMS sites have become synonymous with coastal preserve sites. The Coastal Preserves Program is dedicated to effectively preserve, conserve, restore, and manage Mississippi's coastal ecosystems to perpetuate their natural characteristics, features, ecological integrity, social, economic, and aesthetic values for future benefit. The long-term vision of the Coastal Preserves Program is the management of Mississippi's Coastal Preserves sites to provide long-term benefits to the natural resources and economic value of the region. The 22 GEMS sites are located within tidal zones and are as follows:

Gulf Ecological Management Sites/Coastal Preserves in Mississippi:

- Bayou La Croix
- Bayou Portage
- Bellefontaine Marsh
- Biloxi River Marshes
- Cat Island
- Davis Bayou
- Deer Island
- Deer Island Restoration Project
- Escatawpa River
- Grand Bay
- Grand Bayou
- Graveline Bay
- Hancock County
- Horn Island
- Jourdan River
- Old Fort Bayou
- Pascagoula River
- Petit Bois
- Round Island
- Sandhill Crane Refuge
- Ship Island
- Wolf River

3.3.9 Grand Bay National Estuarine Research Reserve (NERR)

The Grand Bay NERR, managed by the Mississippi Department of Marine Resources is part of a national network of protected estuaries, one of twenty-seven sites nationally that make up the National Estuarine Research Reserve System (NERRS). The reserves were established for long-term research, monitoring, education, and stewardship. In addition, the reserves provide excellent opportunities for study of coastal ecosystems and management. The NERRS recently initiated a Climate Change Program which will seek to provide a greater understanding of issues related to climate change such as sea level rise.

4.0 Risk Assessment

In considering the issue of sea level rise as a natural hazard to be mitigated, several key issues must be considered with respect to the overall assessment of the level of risk associated with rising sea levels and the levels of vulnerability on the Mississippi Gulf Coast. In general terms, the risk assessment relates to the probability and potential severity of the hazard or event. The vulnerability assessment analyzes those natural or man-made systems potentially vulnerable to the adverse impacts of the hazard or event. Conducting the risk assessment includes an analysis of the historic progression of sea level rise combined with existing models and predictions for future sea levels as affected by conditions such as climate change, subsidence, and erosion. The most critical component of conducting the risk assessment lies in determining which data set or sets are most credible and which have the most relevance for the particular geographical study area, in this case, the Mississippi Coastal Region.

4.1 Overview of Sea Level Rise Models and Data

Numerous organizations have been engaged in the art and science of predicting sea level rise in recent years. The broad application of science to issues related to sea level rise has resulted in often contradictory conclusions with respect to the potential severity of sea level rise on a global scale. Attempts to predict localized impacts of sea level rise are emerging and represent more recent efforts to understand the problem. However, these models are often referred to as "bathtub" models because they generally assume a static increase in sea level rise without consideration of subsidence, erosion, and other site-specific factors. The following sections will briefly outline the more notable sea level rise research and modeling efforts from both a global and regional perspective.

A general overview of the research and publications seems to indicate the prediction of sea level rise is not a perfectly exact science. As technologies and knowledge of the subject increase and improve, the predictive methodologies improve. While not entirely accurate, one method of predicting future events is to consider the past. Evidence indicates global sea levels have risen at a consistent rate of approximately 0.04 to 0.5 inches per year since 1900.[19] Since 1992, new methods of satellite altimetry using the TOPEX/Poseidon satellite indicate a rate of rise of 3 millimeters per year (NOAA Science on a Sphere). There are generally two separate mechanics involved in global sea level rise. The first is directly attributed to global temperature increases, which warm the oceans waters and cause them to expand. The second is attributed to the melting of ice over land which simply adds water to the oceans. Global sea level rise is likely caused by a combination of these two mechanics and can be exasperated on the local level by factors such as erosion and subsidence. To fully explore the risks associated with sea level rise, an overview of the predominant global and local or regional models and predictions will be presented.

4.1.1 International Panel on Climate Change (IPCC) 2007

One of the more commonly cited sources for global climate change and sea level rise prediction is the International Panel on Climate Change (IPCC). The IPCC convenes every six years and the most recent (IPCC 2007) provided the Fourth Assessment Report. This fourth report describes progress made in understanding the causal factors in both climate change and sea level rise and builds upon the Third Assessment Report by taking advantage of new findings, new and more comprehensive data, and improved analytical and predictive technologies.[20] IPCC 2007 utilized six different scenarios to establish its findings which ranged from 7.09 inches to 23.23 inches globally by the year 2099. However, the IPCC 2007 does not include variables related to climate-carbon cycle feedback and the potential effects of ice sheet flow, citing the overall lack of basis in published literature. The summary report does, however, indicate that larger values of sea level rise cannot be excluded. The overall understanding of the effects of the aforementioned variables is too limited at the time of publishing to provide accurate predictions.

To fully understand the context of the IPCC 2007 Report and other sources cited in this report, it is important to have an understanding of the scenarios of the future as described in IPCC 2007. While none of the following scenarios are intended to be predictive of a certain future, they do allow for estimations in sea level rise variables based on a number of probable future worlds.

Scenario A1: The A1 Scenario describes a future world of rapid economic growth with global populations peaking and beginning to decline in mid-century. A1 also describes a world that includes the rapid development and introduction of new technologies, greater social interaction, and significant reductions in regional differences in per capita incomes. The A1 Scenario is further divided into three groups as an attempt to describe possibilities for technology change with respect to energy production and use. A1FI is primarily fossil intensive; A1T describes a future that is primarily dependent on non-fossil energy sources; and A1B explores a world that is balanced and does not rely too heavily on one particular energy source.[21]

Scenario A2: The A2 Scenario describes a heterogeneous world with major themes relating to self-reliance and preservation of local identities. The A2 Scenario describes constantly increasing global populations with economic development, economic growth, and technology development being more regionally oriented resulting in slower and more fragmented growth and technological change as compared to other scenarios.[22]

Scenario B1: The B1 Scenario relates to a world with peaking and declining populations in mid-century as with A1 but with an economy primarily focused on service and information that would include the introduction of clean and efficient technologies. The B1 Scenario relies heavily on global solutions to economic, social, and environmental sustainability.[23]

Scenario B2: The B2 Scenario emphasizes local solutions to economic, social, and environmental sustainability with increasing global populations, moderate levels of economic development and more diverse technological change.[24]

Predictions with respect to climate change and global sea level rise based on the six scenarios presented in IPCC 2007 are summarized in **Table 4.0**

Table 4.0 IPCC 2007 Projected Global Average Surface Warming and Sea Level Rise[25]

Scenario	Temperature Change (^oC at 2090-2099 relative to 1980-1999)		Sea Level Rise (feet at 2090-2099 relative to 1980-1999)
	Best Estimate	Likely Range	Model Based Range
Constant Year 2000 Concentrations	0.6	0.3 - 0.9	Not Available
B1 Scenario	1.8	1.1 - 2.9	0.59 – 1.25
A1T Scenario	2.4	1.4 - 3.8	0.66 – 1.48
B2 Scenario	2.4	1.4 - 3.8	0.66 – 1.41
A1B Scenario	2.8	1.7 - 4.4	0.69 – 1.57
A2 Scenario	3.4	2.0 - 5.4	0.75 – 1.67
A1FI Scenario	4	2.4 - 6.4	0.85 – 1.94

4.1.2 Stefan Rahmstorf

Rahmstorf has been one of the more vocal critics of the IPCC reports, citing the general lack of quantifiable data concerning ice sheet flow. Using semi-empirical modeling, Rahmstorf argues that there is a direct and distinct connection between global sea level rise and mean surface temperatures. While acknowledging that the processes related to melting ice sheets are poorly understood, they do have the potential for a much greater impact on sea level rise than rising temperatures alone. Rahmstorf indicates an approximate proportionality constant of 3.4 millimeters per year per degree centigrade. Rahmstorf's semi-empirical model as applied to the IPCC future warming scenarios results in a projected global sea level rise of 19.68 to 55.12 inches above the 1990 level by the year 2100.[26]

4.1.3 Vermeer and Rahmstorf

In a later article, Martin Vermeer and Stefan Rahmstorf furthered their exploration into the potential impacts of ice sheet flow on global sea level rise as applied to the IPCC 2007 Scenarios. The revised model proposes a rapid-response term based on assumptions that some components of sea level have the potential to adjust quickly to a temperature change. Part of the impetus of the revised model was based on data indicating observed sea rise exceeded modeled predictions by nearly 50% for time periods including 1961-2003 and 1990-2006. Data generated from the revised model provides projections of sea level rise ranging from 29.53 to 74.8 inches from 1990-2100.[27]

4.1.4 Radley Horton et al.

In a 2008 paper, Horton, et al. combined the IPCC 2007 Scenarios and the Rahmstorf semi-empirical models and applied them to eleven individual Coupled Global Climate Models with each using differing formulations of atmospheric physical processes, and sea, ice, and land

components. Horton et al. also based their modeling efforts on current data as opposed to 1990 levels. The application of this modeling effort produced projections ranging from 29.13 – 39.37 inches by 2100.[28]

4.1.5 Grinsted et al.

In another modeling effort, Grinsted et al. used similar semi-empirical models coupled with the IPCC A1B Scenario with the addition of historical data dating to 200 A.D. The authors argue that accurate modeling must include historic data from a longer time period to be more accurate. The paper indicates that minimum sea level rise occurred during a time period around 1730 A.D. (-7.48 to -10.24 inches) and maximum sea level rise occurred around 1150 A.D. (4.72 to 8.27 inches). The determination is that IPCC projections of sea level rise are under-estimated by a factor of 3. The results indicate a 2090-2099 sea level rise projected at 116 to 167 feet for the IPCC 2007 A1B Scenario.[29]

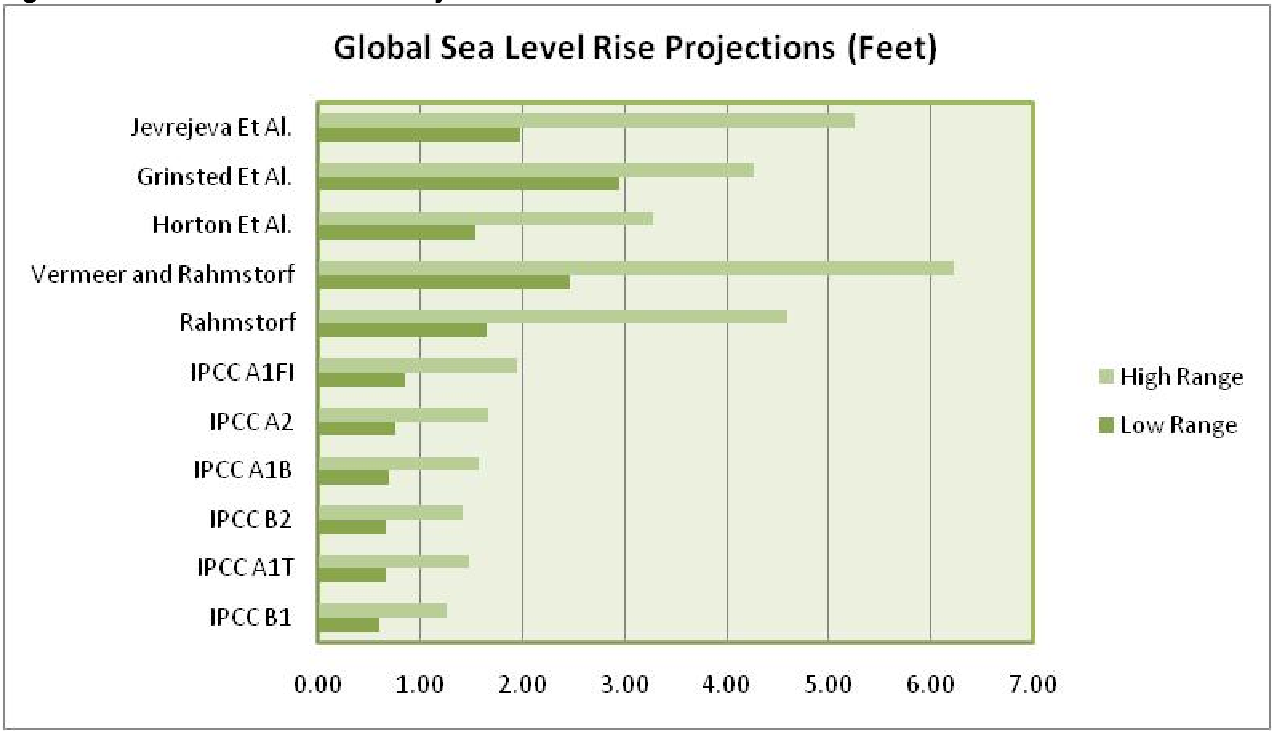
4.1.6 Jevrejeva et al.

In a more recent report, Jevrejeva, et al. considered both natural and anthropogenic forcings and the potential impacts on sea level rise by 2100. Their methodology involved the use of an inverse statistical model to examine potential sea level rise responses to changes in natural and anthropogenic forcings. The model again used the IPCC 2007 scenarios to estimate sea level rise of 23.62 to 62.99 inches by 2100. In this study, the authors estimated global sea level rise considering sea level rise as an integrated response of the entire global climate system with mean global sea level as an independent measurement of global response as opposed to simply a response to mean global temperature.[30]

4.1.7 Global Sea Level Rise Projection Summary

Figure 4.1 provides a summary of conclusions of the reviewed literature to provide a comprehensive context of the current conventional wisdom relative to sea level rise projections. All projections reflected in **Figure 4.1** are through the year 2100.

Figure 4.1 Sea Level Rise Projection Summaries



4.1.8 Summary of Global Sea Level Rise Data

In summary, the global sea level rise projections prepared through the cited sources indicates a mean global sea level increase from 1.34 to 2.99 feet by 2100. This mean translates into a linear mean increase of .18 to .40 inches per year. The data presented within the context of global sea level rise also represents a potential worst case scenario equal to approximately 6.25 feet of sea level rise by the year 2100 or approximately .83 inches per year. Based on this worst-case scenario, the Mississippi Gulf Coast could experience sea level increases of 4.15 inches in five years, 8.3 inches in ten years, 16.6 inches in twenty years, 41.5 inches in fifty years, and 74.7 inches by the year 2100.

4.2 REGIONAL PROJECTIONS, STUDIES, AND DATA

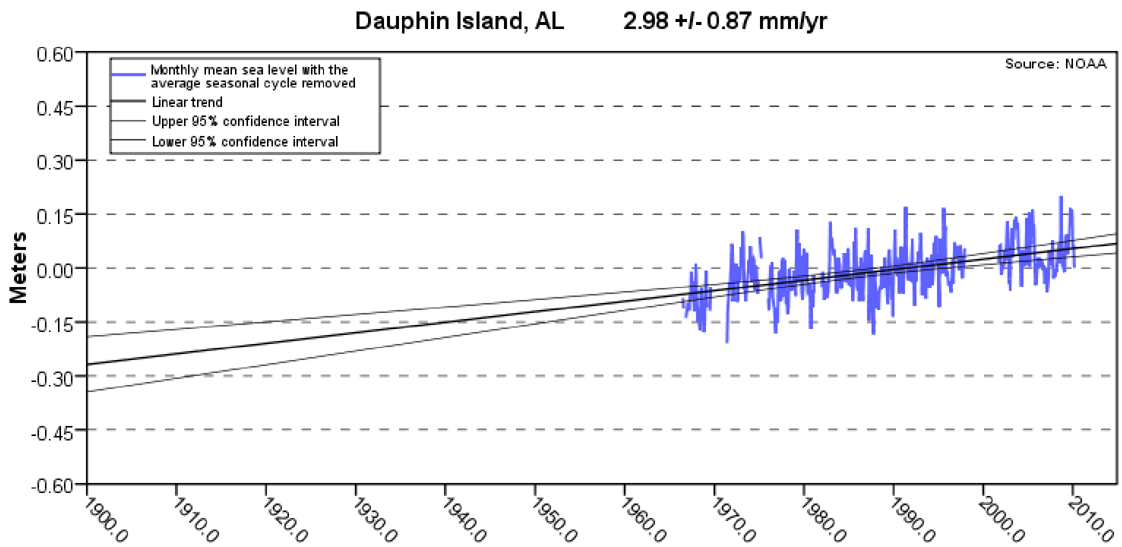
4.2.1 Introduction

Data relative to local or regional sea level rise projections is scarce. Regional projections must account for a greater number of variables. Historic data indicates that variations occur over time and also seasonally and interannually. In addition, recent data indicates regional variations throughout the northern Gulf of Mexico. Other local and/or regional variables to consider include local topography, erosion rates, subsidence, atmospheric pressure, water column density, thermocline depth, ocean circulations, and storm surges.

One indicator of future sea level lies in an analysis of recent history and trends in sea levels in the northern Gulf of Mexico. The NOAA Center for Operational Oceanographic Products and Services has maintained sea level data for approximately 150 years through measurements obtained from 128 long-term water level stations operating on all U.S. coasts. Through the National Water Level Observation Network, NOAA has computed changes in mean sea level (MSL) using a minimum span of 30 years of observations at each station. Data collected at these stations is averaged to remove the effect of high frequency phenomena such as tropical storms and hurricanes.[31]

Through this program, NOAA operates tide gauging stations throughout the northern Gulf of Mexico. The gauging stations in Mississippi waters do not have the depth of historical data that others have such as Pensacola, Florida and Dauphin Island, Alabama. To project trending over time and on a regional scale, data from five tide gauging stations was reviewed and analyzed. These stations include Pensacola, Florida; Dauphin Island, Alabama; Pascagoula NOAA Lab; Gulfport Harbor; and Bay Waveland Yacht Club. Trends represented at the Dauphin Island and Pensacola stations are illustrated in **Figures 4.2 -4.7**:

Figure 4.2 Dauphin Island, Alabama Sea Level Trend



The mean sea level trend is 2.98 millimeters/year (.12 inches) with a 95% confidence interval of +/- .87 mm/year based on monthly mean sea level data from 1966 to 2006 which is equivalent to a change of .98 feet (11.76 inches) in 100 years.[32]

Figure 4.3 Dauphin Island, Alabama Average Seasonal Cycle

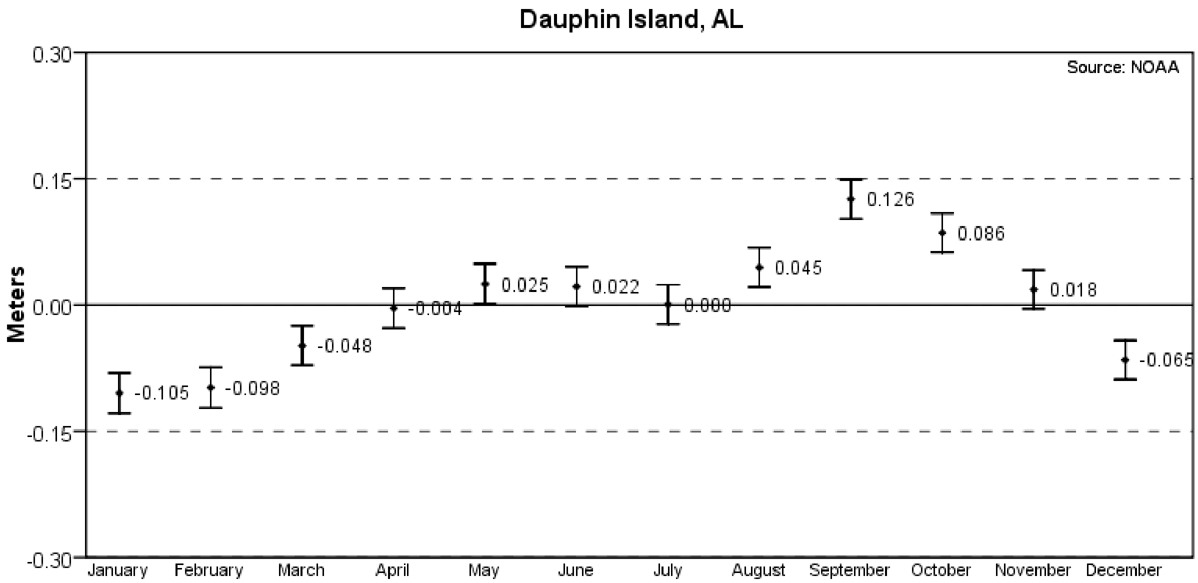


Figure 4.3 represents the average seasonal sea level cycle for Dauphin, Alabama as caused by regular fluctuations in coastal temperature, salinities, winds, atmospheric pressure, and ocean currents and indicates seasonal variations of from -4.15 inches below mean sea level to 4.96 inches above mean sea level.

Figure 4.4 Dauphin Island, Alabama Interannual Variation Since 1980

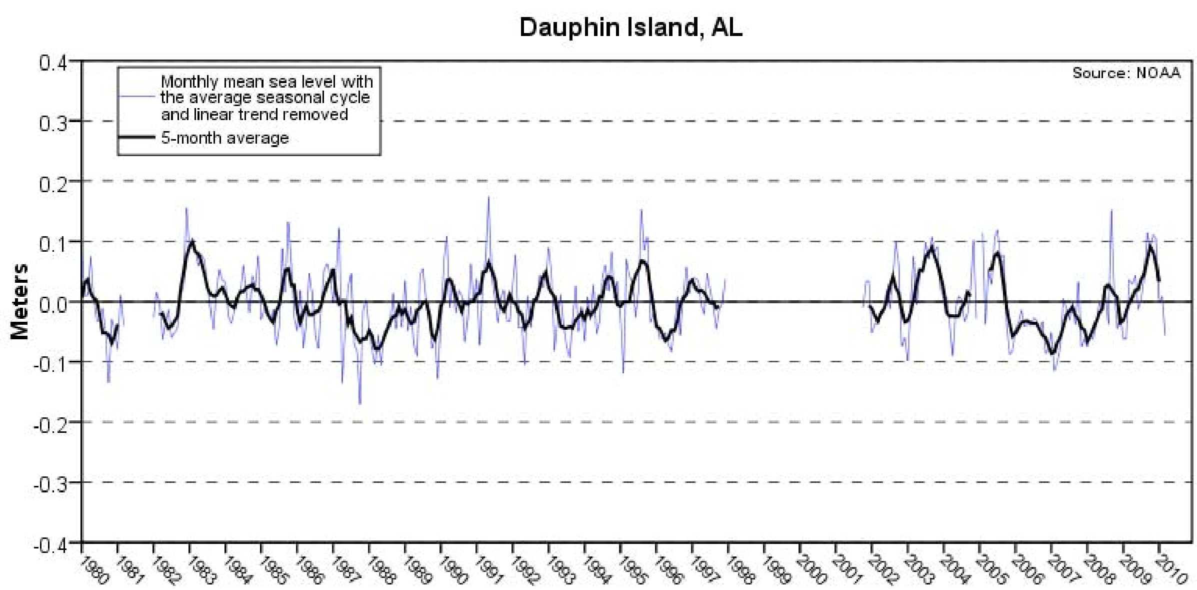
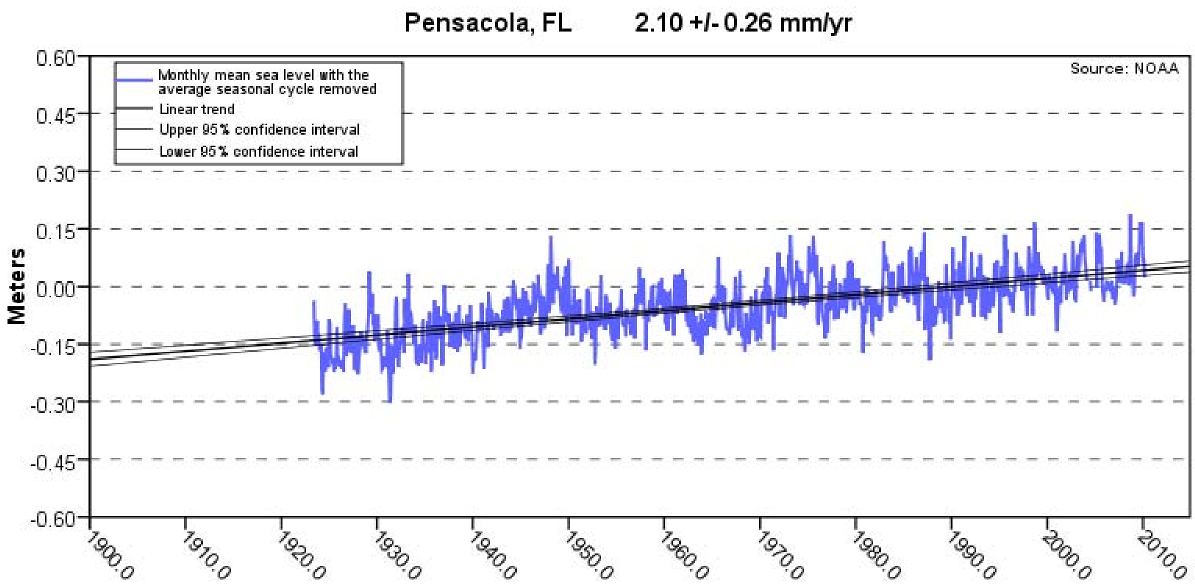


Figure 4.4 represents interannual variations in sea level trends for Dauphin Island, Alabama. Interannual variations are caused by irregular fluctuations in coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents.

Figure 4.5 Pensacola, Florida Sea Level Trend



The mean sea level trend is 2.10 millimeters/year (.08 inches per year) with a 95% confidence interval of +/- 0.26 mm/yr based on sea level data from 1923 to 2006 which is equivalent to a change of .69 feet (8.28 inches) in 100 years.[33]

Figure 4.6 Pensacola, Florida Average Seasonal Cycle

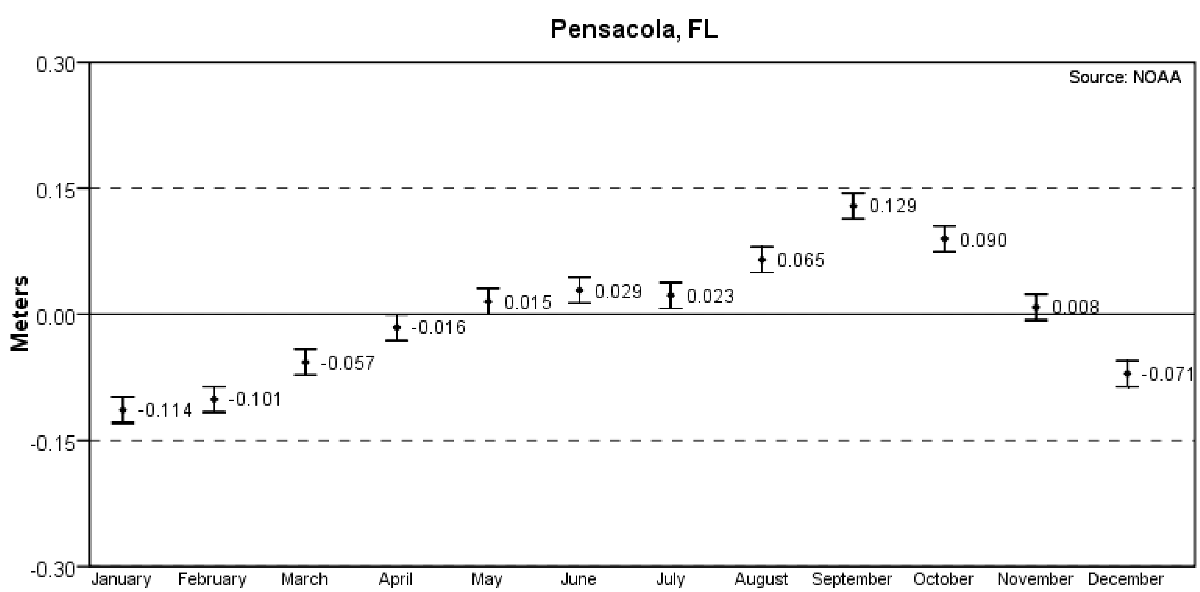


Figure 4.6 represents the average seasonal sea level cycle for Pensacola, Florida as caused by regular fluctuations in coastal temperature, salinities, winds, atmospheric pressure, and ocean currents and indicates seasonal variations of from -4.15 inches below mean sea level to 4.96 inches above mean sea level.

Figure 4.7 Pensacola, Florida Interannual Variation Since 1980

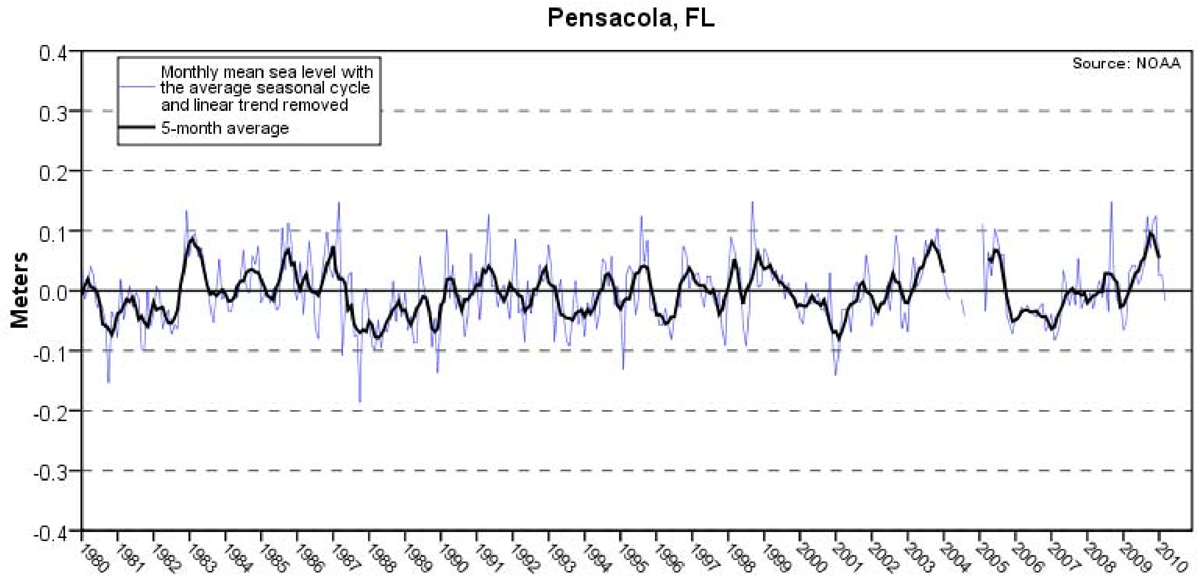
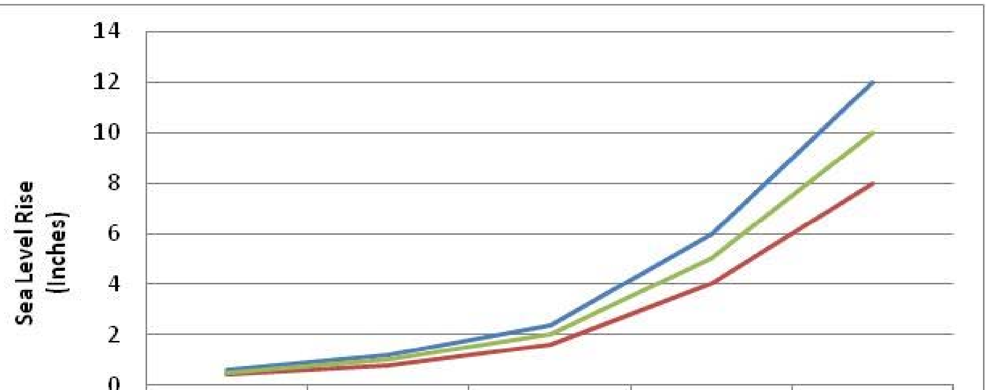


Figure 4.7 represents interannual variations in sea level trends for Pensacola, Florida. Interannual variations are caused by irregular fluctuations in coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. The mean sea level rise of the two stations combined is approximately .1 inches/year or approximately 10 inches in a 100 year period. This mean is approximately equal to the median of the ranges represented by the literature review discussed in **Section 4.1**. **Figure 4.8** provides a summary of the regional data discussed in this section.

Figure 4.8 Summary of Regional Sea Level Rise Projection Data



	5 Year Projection (Inches)	10 Year Projection (Inches)	20 Year Projection (Inches)	50 Year Projection (Inches)	100 Year Projection (Inches)
Dauphin Island, AL	0.6	1.2	2.4	6	12
Pensacola, FL	0.4	0.8	1.6	4	8
Regional Average	0.5	1	2	5	10

4.2.2 Summary of Regional Sea Level Rise Data

The absence of long-term sea level trend data for the Mississippi Sound necessitated an overview and analysis of trend data for nearby coastal regions with similar geomorphologies and other natural features. The closest tide gauging stations with long-term data in areas geomorphologically similar to the Mississippi Gulf Coast includes Dauphin Island, Alabama and Pensacola, Florida. An analysis of long-term data including approximately sixty years of sea level trends for Alabama and the Florida Panhandle indicates a linear trend of approximately .10 inches of sea level rise per year. Extrapolated over time, this trend indicates increases of ½, 1, 2, 5, and 10 inches in the 5, 10, 20, 50, and 100-year timeframes respectively.

4.3 MISSISSIPPI-SPECIFIC RESEARCH AND DATA

Biloxi Lighthouse, Circa 1892

As previously stated, much of the current research on sea level rise in the Gulf of Mexico has focused on areas such as the Mississippi River Delta, the Florida Keys, and the major bay along the Texas Gulf Coast. To accommodate for the lack of empirical data providing credible sea level rise projections for Mississippi, this plan will focus on data representing historical shoreline changes in Mississippi dating from the 1850s through the early 21st century. To fully understand both the natural and man-made processes affecting shoreline changes during this time period, it is important to briefly understand the history of development of the Mississippi Gulf Coast and specifically development of the man-made sand beaches that help define the shoreline today. Prior to the 1940s, the shoreline of the Mississippi Sound was still in its natural state and was primarily defined by natural outcroppings of trees and marshy areas. In the 1940s as “Beach Boulevard” or Highway 90 began to be developed as a four-lane highway, many areas of the shoreline were hardened and defined by a step seawall. It wasn’t until the early 1950s when the sand beach was created by pumping dredged sand materials onto the shoreline.[34] From 1850 through 1950, the Mississippi Gulf Coast experienced a net loss of approximately 1,224 acres mostly through natural processes. In contrast, from 1950 through 1986, the Mississippi Gulf Coast experienced a net gain of 9 acres, primarily due to the development of the sand beach, reclamation of wetlands and other man-made processes.[35]

A broader view of these changes can be seen in calculations of marsh losses from the 1950s through the 1990s. During this time period, the Mississippi Gulf Coast lost approximately 8,500 acres of marshland with approximately 2,300 acres of this loss attributed to water gain or sea

level rise and approximately 3,500 acres lost due to human activities. The loss of marsh lands since the 1950s averages to approximately 172 acres of loss per year.[36]

Additional studies of long-term shoreline change trends indicate a mean shoreline change of 7.54 feet per year (+- 6.23 feet) with 80% of the change attributed to erosion and 20% of the change attributed to accretion. These historical shoreline changes combined with current rates of sea level rise indicate a continued habitat loss. Expected increases in sea level rise rates will serve to heighten potential coastal loss.

Long-term rates of loss for the Mississippi mainland are moderated by extensive armoring and periodic beach nourishment along the Mississippi Sound. These man-made protective measures have served to slow rates of loss for the mainland. However, long and short-term rates of erosion and land loss of the barrier islands indicate land loss rates ranging from 10.17 feet per year to approximately 19 feet per year.[37]

4.3.1 Mississippi-Specific Sea Level Trends

Through the process of determining sea level change trends specific to the Mississippi Coast, data from three NOAA tide gauging stations located in the Mississippi Sound was collected and analyzed. This data was also compared and correlated to known data from tide stations at Dauphin Island, Alabama and Pensacola, Florida. The comparisons to these two gauging stations with long-term data were conducted to normalize the short-term nature of the data from Mississippi with longer-term data from Alabama and Florida. An analysis of short-term data from Mississippi compared to data from Alabama and Florida for the same time periods indicates a strong correlation and consistency in the data. Data for each of the three Mississippi gauging stations was graphed as a scatter plot with a trend line representing the trend in sea level change over time. Short-term data for the Mississippi tide gauging stations is illustrated in the following figures.[38]

Figure 4.9 Station 8741533 – Pascagoula NOAA Lab 5-Year Sea Level Trend (feet)[39]

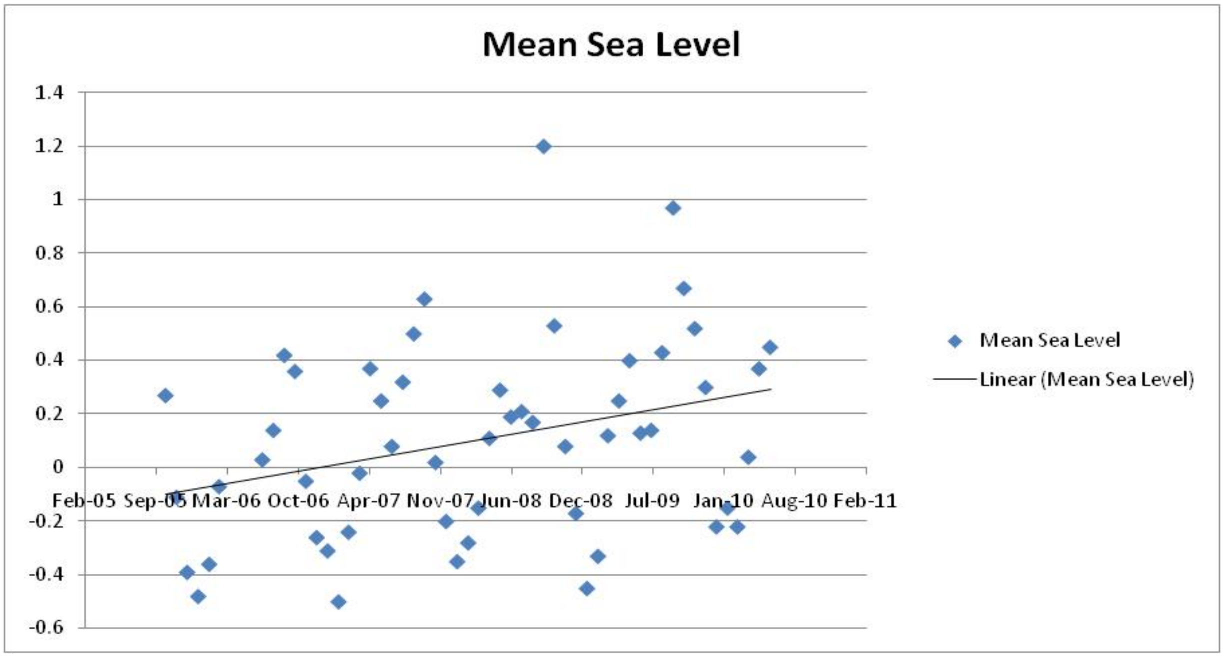


Figure 4.10 Station 8745557 – Gulfport Harbor 5-Year Sea Level Trend (feet)[40]

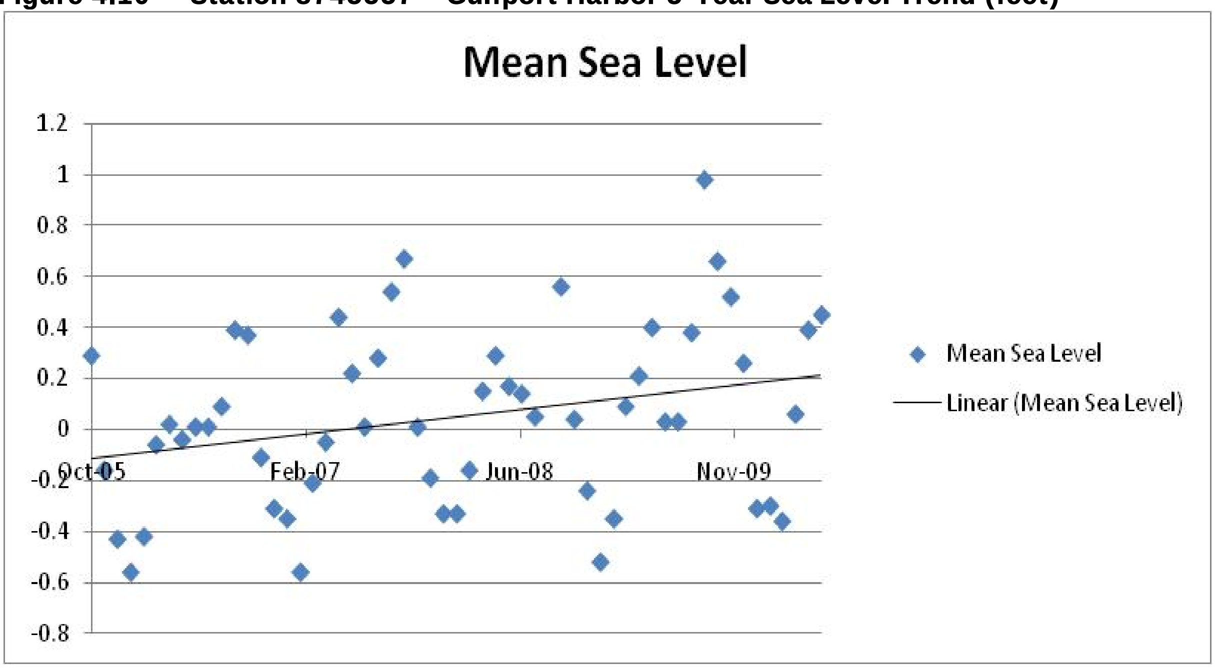
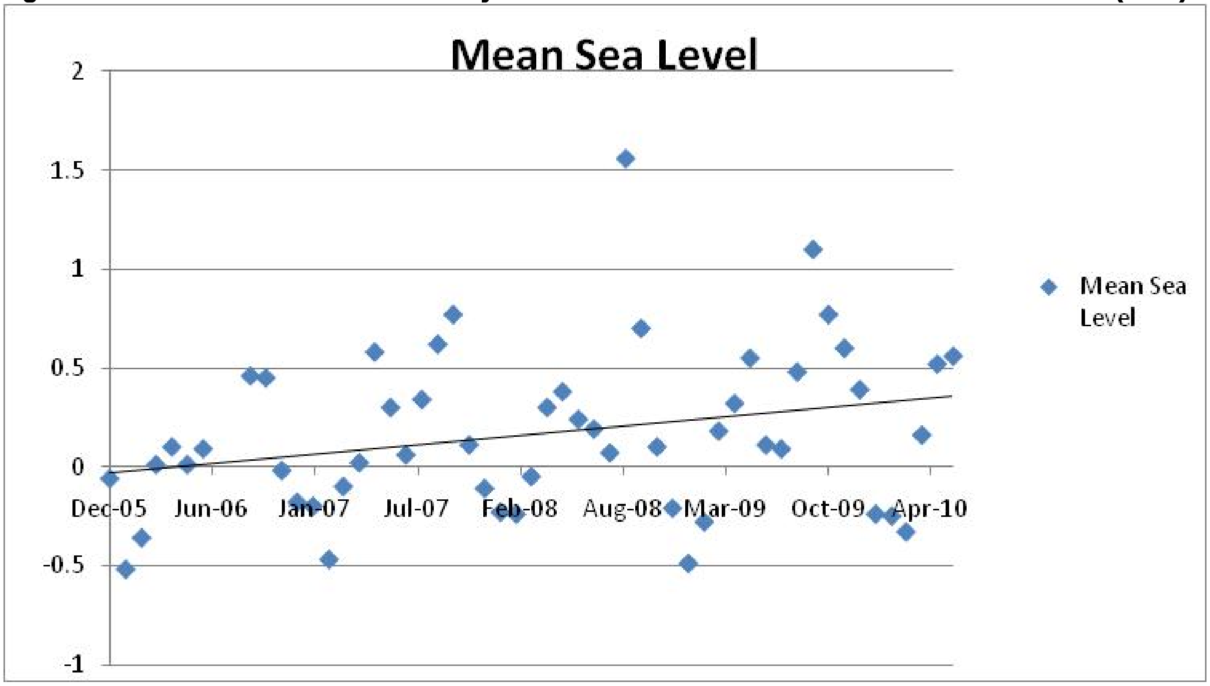
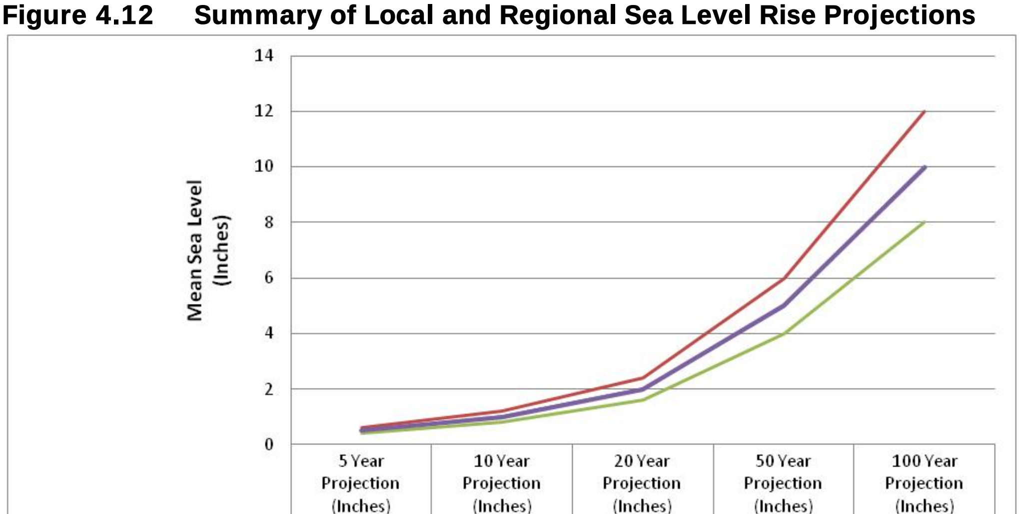


Figure 4.11 Station 8747437 – Bay Waveland Yacht Club 5-Year Sea Level Trend (feet)[41]



Comparing the short-term trends of the Mississippi tide gauging stations to those in Alabama and Florida provide confidence that historic trends will continue throughout the region in a similar linear fashion. This understanding provides the ability to conceptually project sea level into the future to help provide a context for planning considerations for the Mississippi Gulf Coast and the local governments located along the coast. **Figure 4.12** provides projection data for the Mississippi Gulf Coast.

Figure 4.12 Summary of Local and Regional Sea Level Rise Projections



	5 Year Projection (Inches)	10 Year Projection (Inches)	20 Year Projection (Inches)	50 Year Projection (Inches)	100 Year Projection (Inches)
Mississippi Tide Stations	0.5	1	2	5	10
Dauphin Island, AL	0.6	1.2	2.4	6	12
Pensacola, FL	0.4	0.8	1.6	4	8
Average of All Five Stations	0.5	1	2	5	10

4.3.2 Summary of Local Sea Level Rise Data

As illustrated in **Figure 4.12**, the linear trend for the Mississippi Tide Stations is statistically consistent with the trend illustrated for the Dauphin Island, Alabama and Pensacola, Florida Tide Stations. Given the data presented, Mississippi can expect a minimum sea level rise of approximately ten inches by the year 2100. However, data gaps including the lack of long-term historical sea level trends does impact the accuracy of data presented here. Actual sea level rise levels potentially experienced in the future are dependent on a number of factors that are potentially difficult to predict. These factors include erosion, accretion, and subsidence as local contributing factors. Other factors such as glacial melt and climate change are more global in nature but still have potential to impact future sea levels on the Mississippi coast.

The methodology used to determine linear projections of sea level rise for the Mississippi coast included an analysis of both short and long-term data for the Dauphin Island and Pensacola Tide Stations and a comparison of data from those stations to the short-term data available for Mississippi Tide Stations including stations located at the Pascagoula NOAA Lab, the Gulfport Harbor, and the Bay-Waveland Yacht Club. The lack of long-term data from Mississippi stations necessitated comparison of short-term data from all stations to determine the presence of statistical consistencies. It was determined that statistical consistencies existed. As a result, the mean projected linear sea level rise trend for Mississippi was determined to be an average of .10 inches per year, yielding projections of .5 inches in five years; 1 inch in ten years, 2 inches in twenty years; 5 inches in fifty years, and 10 inches in 100 years. This trend represents a best-case scenario for the Mississippi Gulf Coast. This best-case scenario combined with the worst-case scenario illustrated in **Section 4.1.8** provides a range of predictions for future sea levels on the Mississippi coast ranging from .10 inch per year to approximately .83 inches per year. Maps provided in **Appendix A** as **Figures 14 – 15** and are designed to assist in visualizing potential impacts from sea level rise within the best and worst-case scenarios as presented.[42]

4.3.3 On-going Mississippi Sea Level Rise Research and Monitoring

In recent years, several sea level rise research, monitoring, and modeling efforts have been initiated to address sea level rise along the northern Gulf of Mexico, including in Mississippi. Additional efforts are also underway such as the NOAA Climate Community of Practice aimed at providing and sharing knowledge about climate change impacts with local community leaders in Mississippi. The following table provides an overview of examples of on-going research and monitoring activities:

Table 4.1 Current and On-going Sea Level Rise Research Projects

Project Name	Principal Investigators
Modeling Impacts of Global Climate Change on Gulf of Mexico Marsh Birds: What We Know, What We Need to Know, and How We Learn	Bob Cooper, University of Georgia, Julia Cherry, University of Alabama, Mark Woodrey, Grand Bay NERR
SLAMM Analysis of Grand Bay NERR and Environs	Jorge Brenner, the Nature Conservancy
Integrated Modeling for the Assessment of Ecological Impacts of Sea Level Rise	Scott Hagen, University of Central Florida

Project Name	Principal Investigators
Enhancing Gulf Coast Spatial Infrastructure for Resilience and Restoration (Tide Station, CORS, SETS	Galen Scott, NOAA – National Geodetic Survey Office, Grand Bay NERR Staff, Weeks Bay NERR Staff
Long-Term Study of the Effects of Natural Disturbances (Fires, Hurricanes, Etc.) on Coastal Transition Habitats Along the Northern Gulf of Mexico	Grand Bay NERR Staff; Loretta Battaglia, University of Southern Illinois, Weeks Bay NERR
The Role of Seedbanks in Coastal Vegetation Response to Incursions of the Sea	Hannah Kalk, University of Southern Illinois
Climate Change and Chinese Tallow (Tridica sebifera) Invastion in Grand Bay NERR Mississippi, USA	Shishir Paudel, University of Southern Illinois
The Utility of FEMA/MEMA Buyout Properties for Adaptation to Sea Level Rise	Diane Harsberger, University of Southern Illinois
Fire Effects Study on Marsh Accretion	Julia Cherry, University of Alabama; Grand Bay NERR Staff
Will Climate Change Cause Wetland Loss on the Mississippi Gulf Coast More than Upland Land Use/Land Cover Change within the Next Century	Wei Wu
The Impact of Accelerated Sea Level Rise on Tidal Marshes and Storm Surge	Wei Wu; Maria Kalcic; Kevin Yeager
Modeling of the Hydrochemical Responses of High Elevation Watersheds to Climate Change and Atmospheric Deposition	Charles T. Driscoll; John L. Campbell; Katarine Hayhoe; Wei Wu

5.0 VULNERABILITY ASSESSMENT

The previous sections illustrate some of the issues related to identifying a viable, quantitative method of predicting future sea levels with great accuracy. However, the relative vulnerability of different coastal environments to sea level rise can be quantified on a regional and national level using a few basic variables. The vulnerability assessment approach combines a coastal system's susceptibility to change and its natural ability to adapt to constantly changing environmental conditions. This approach also yields a relative measure of a systems' natural vulnerability to the effects of sea level rise, regardless of the predicted rate.

The USGS, in order to develop a means of assessing coastal vulnerabilities related to sea level rise, developed a Ranking of Coastal Vulnerability Index (CVI) based on six physical variables including:

- Geomorphology,
- Coastal slope (percent),
- Rate of relative sea-level rise (inches/year),
- Shoreline erosion and accretion rates (inches/year),
- Mean tidal range (feet), and
- Mean wave height (feet). [43]

The method developed and employed by USGS was created with the goal of predicting future coastal changes with a degree of certainty useful for planning considerations and coastal management. The approach also follows similar methods developed to determine vulnerabilities associated with seismic and volcanic hazards. The comprehensive vulnerability assessment of the Mississippi Gulf Coast will include a compilation of the CVI, social vulnerabilities, vulnerabilities of natural systems, and vulnerabilities of manmade systems. The combination of these different vulnerabilities will be considered as a whole to gauge the overall vulnerability of the coast. Each of these vulnerabilities will be detailed in subsequent sections.[44]

Each of these physical variables is assigned a relative risk value based on the potential magnitude of its contribution to potential physical changes as sea levels rise. **Table 5.0** provides the risk values associated with each of the six physical variables used in the CVI. The purpose of using the CVI is to quantify vulnerabilities that may exist due to current geomorphological and hydrological conditions regardless of the projected rate of sea level increase. The CVI provides a static quantification of the region's vulnerability to the effects of sea level rise but does not provide an indicator of future sea level increases or decreases.

Table 5.0 Ranking of Coastal Vulnerability Index[45]

Ranking of Coastal Vulnerability Index					
Variable	**Very Low 1**	**Low 2**	**Moderate 3**	**High 4**	**Very High 5**
Geomorphology	Rocky, cliffed coasts, fiords	Medium cliffs, indented coasts	Low cliffs, Glacial drift, Alluvial Plains	Cobble beaches, Estuary, Lagoon	Barrier beaches, sand beaches, Salt marshes, Mud flats, Deltas, Mangrove, Coral reefs
Coastal Slope (%)	>11.5	11.5 to 5.5	5.5 to 3.5	3.5 to 2.2	<2.2
Sea Level Rise (in/yr)	<.07	.07 to .098	.098 to .12	.12 to .134	>.134
Shoreline Erosion/Accretion (ft/yr)	>6.56	3.28 to 6.56	-3.28 to +3.28	-3.61 to -6.56	>-6.56
Mean Tide Range (ft)	19.69	13.45 to 19.69	6.56 to 13.12	3.28 to 6.23	<3.28
Mean Wave Height (ft)	1.81	1.81 to 2.79	2.79 to 3.44	3.44 to 4.10	>4.10

The Coastal Vulnerability index uses the variables as indicated in **Table 5.0** which are then applied to the formula as follows: $CVI=\sqrt{((a*b*c*d*e*f)/6)}$, where:

- a = geomorphology
- b = coastal slope
- c = relative sea-level rise rate
- d = shoreline erosion/accretion rate
- e = mean tide range
- f = mean wave height[46]

In calculating the CVI, certain variables add more weight to the index than others. In those cases, the variables with the highest ranking is said to dominate the index. In other words, certain variables may have a higher impact on an area's vulnerability than others. The following sections provide data specific to the vulnerability of the Mississippi Gulf Coast. **Table 5.1** provides generalized rankings for each of the three coastal counties and a coast-wide average using the NOAA CVI. CVI values below 8.7 are considered low risk for sea level rise vulnerability. Values from 8.7 to 15.6 are considered moderate risk. Values from 15.6 to 20.0 are considered high risk, and values greater than 20.0 are considered very high risk.[47] The three coastal counties and the Mississippi Coast as a whole ranked in the moderate risk range.

Table 5.1 Coastal Vulnerability Index – Coastal Mississippi

Variable	Harrison Value	Harrison Rank	Hancock Value	Hancock Rank	Jackson Value	Jackson Rank	Coast Wide Value	Coast Wide Rank
Geomorphology		5		5		5		5
Coastal Slope (%)[48]	3.56%	3	4.45%	3	6.53%	2	4.85%	3
Relative Sea Level Rise Rate (inches/year)[49]	0.1	3	0.1	3	0.1	3	0.1	3
Shoreline Erosion/Accretion Rate (feet/year)[50]	-7.54	5	-7.54	5	-7.54	5	-7.54	5
Mean Tide Range (feet)[51]	1.652	5	1.602	5	1.429	5	1.561	5
Mean Wave Height (feet)[52]	1.41	1	1.41	1	1.41	1	1.41	1
CVI	**13.69**		**13.69**		**11.18**		**13.69**	

5.1 VULNERABILITY OF NATURAL SYSTEMS

Specific natural areas vulnerable to the effects of sea level rise include the Mississippi GEMS sites, the Mississippi Sandhill Crane and Grand Bay NWRs, the coastal barrier islands, and the approximately 300 miles of natural shoreline that exists in the three coastal counties. Along this natural shoreline are estuaries, marshes, and wetlands. Off shore natural assets to be considered include various ocean and reef habitats including the oyster reefs located throughout the Mississippi sound and other natural and man-made reefs that provide habitat to a variety of marine species. The GEMS/Coastal Preserves Sites, NWRs, and the barrier islands were selected for analysis of vulnerabilities of natural systems due to the presence of ecosystems in these areas representing a broad cross-section of the various ecosystems that exist on the Mississippi coast and in the Mississippi Sound.

5.1.1 Mississippi GEMS/Coastal Preserve Sites and National Wildlife Refuges

As previously mentioned the Mississippi GEMS sites include twenty-two areas specifically designated by the State as coastal preserves. Each site is designated as a result of unique and ecologically valuable habitats. The goals of the program are:

- to promote information exchange about the ecology and management of GEMS sites,
- to increase awareness of the national and international significance of GEMS,
- to improve understanding of the Gulf of Mexico ecosystem, and
- to further conservation through interagency coordination, public/private partnerships, and targeting of research, monitoring, and action projects.[53]

The Mississippi GEMS/Coastal Preserves sites include representations of many of the near-shore ecological resources previously discussed and therefore provide a good comprehensive snapshot of the potential impacts of sea level rise to near-shore environments and ecosystems. Most, if not all Mississippi GEMS/Coastal Preserves sites contain a combination of fresh and saltwater marshes and wetlands and many of these are tidal in nature due to the proximity to the Mississippi Sound, the Gulf of Mexico, or various bays and inlets that exist along the Mississippi shoreline. These wetlands provide a variety of critical functions to the overall coastal ecosystem and include:

Water and Water Quality
- Recharging groundwater
- Water quality control
- Salt extraction
- Nutrient retention & recycling

Buffer Zones
- Flux control
- Storm protection
- Sediment retention
- Erosion control & coast stabilization

Critical Habitats
- Nursery areas
- Primary habitat for migratory species
- High biodiversity habitat
- Fish and shellfish habitat

Two GEMS/Coastal Preserve sites are also designated by the U.S. Fish and Wildlife Service as National Wildlife Refuges. These include the Grant Bay NWR and the Mississippi Sandhill Crane NWR. Potential impacts and vulnerabilities for these NWR's are similar in nature to those presented for all the GEMS/Coastal Preserves sites and will be addressed concurrently.

Sea level rise has the potential to convert areas such as wetlands with emergent and submerged vegetation into areas of open water, resulting in a subsequent loss of wetland functions associated with the loss of vegetated wetlands. If coastal wetlands are not able to accrete vertically (through sediment deposition or other means), at rates equal to relative sea level rise, they become stressed and ultimately disappear.[54]

The rate of wetland conversion due to sea level rise largely depends on the topography of the coastal zone. Shallow sloped shorelines fare better for wetland migration than do steep shorelines. However, multiple factors including the complexity of the topography and overall drainage density can have equivalent impacts on wetland conversion and wetland migration.[55]

It is anticipated that the loss of wetlands along the Mississippi coast as a result of sea level rise will not be uniform, just as the topography and coastal conditions are not completely uniform. The high rate of dependency of gulf coast fisheries and other critical habitats on estuarine

wetlands increases the potential natural resource impacts of sea level rise. Over 90% of all commercial and recreational species spend some part of their life cycle in coastal wetlands. The potential loss of coastal wetlands and wetland habitats due to sea level rise could have significant adverse impacts on coastal fisheries and in-turn, significant impacts on local economies that rely heavily on commercial and recreational fishing.[56]

5.1.2 Oyster Reefs

In the same manner that coral reefs are critical to tropical marine habitats, oyster reefs provide critical functions to estuarine environments. Through their natural processes, oyster reefs:

- Provide important filtration and water quality functions. A single oyster can filter as much as 50 gallons per day.
- Oyster reefs provide food and habitat to a variety of estuarine and marine species including fish, crabs, and birds.
- Oyster reefs also provide natural coastal buffers from boat wakes, sea level rise, and tropical storms.[57]

While oyster reefs play a role in protecting estuarine areas from the affects of sea level rise, they can also be susceptible to impacts of sea level rise including changes in water level, changes in pH, and changes in salinity.[58]

5.1.3 Mississippi's Barrier Islands

The Mississippi Sound is defined by a series of six barrier islands including Cat Island, Ship Island, Horn Island, Petis Bois Island, and the more near shore Dear Island and Round Island. These barrier islands play a critical role in protection of the shore line and critical habitats found in and around the Mississippi Sound.

The Mississippi Barrier Islands provide habitat to important marine species, help define the natural ecosystem of the Mississippi Sound, and provide protection to the mainland from hurricanes and other tropical weather activity. While we know that the habitat, ecosystem, and even the geographic shape of the islands are ever changing, impacts from sea level rise have the potential to adversely affect both the condition and function of the barrier islands.

Uncertainties relative to land loss associated with the barrier islands are attributed to multiple factors including sediment availability, sediment transport, and rising sea levels. In contrast to barrier islands in neighboring states, the Mississippi barrier islands are not migrating landward as they decrease in size. Rather, they are gradually moving westward in the direction of the predominant littoral drift through processes of up-drift erosion and down-drift deposition. Research indicates the sand spits and shoals of the islands are being transferred westward while the vegetated interior cores of the islands remain fixed. While sea level increases are the primary factor in coastal land loss over geological time scales, land loss potential can be minimized if sufficient sediment supply is available. When sediment supply is significantly reduced, land loss is exacerbated due to an inability of natural systems to replenish and redistribute these sediments.[59]

5.1.4 Essential Fish Habitat

Sea level rise could potentially impact essential fish habitat by altering water depths, changing pH of ocean waters, warming waters, and by drowning certain habitats. The Gulf States Marine Fisheries Commission has addressed sea level rise in Regional Fisheries Management Plans for flounder, sheepshead, and striped bass and to a lesser degree for blue crab, menhaden, and spotted sea trout. Future plans should consider changes in sea level rise affecting various life history stages of marine and estuarine aquatic resources.

5.1.5 Summary of Vulnerabilities of Natural Systems

Natural ecosystems within the Mississippi Sound are vulnerable to direct and indirect impacts of sea level rise. Direct impacts include impacts to wetlands and other estuarine environments that have the potential to affect these systems' ability to migrate as sea levels increase or decrease. Indirect impacts include changes in salinity, impacts to emergent vegetation, and the ability of sediments to migrate and settle in areas of potential land loss. Area including GEMS sites, NWRs, and the Mississippi Barrier Islands provide a good cross-representation of the various marine and estuarine ecosystems that exist across the Mississippi Coast. Impacts to these systems have already been realized and are evidenced by changes and shifts in the shape and location of the barrier islands, and loss of wetlands over time. Continued increases in sea levels will continue to place these systems at risk and will serve to increase the vulnerability of Mississippi's coastal ecosystem.

5.2 VULNERABILITY OF MAN-MADE SYSTEMS

Coastal Mississippi, as one of the more populated regions of the state, includes a variety of types of man-made systems that are potentially vulnerable to the effects of sea level rise. These systems include 1) the built environment such as residential, commercial, institutional, and industrial structures; 2) the socio-economic environment such as at-risk populations; 3) public infrastructure including utilities, transportation systems and critical facilities such as hospitals and public safety facilities; and 4) recreational facilities such as parks, playgrounds, and public access points.

5.2.1 The Built Environment

The vast majority of population in the three coastal counties exists south of Interstate 10 and in areas likely to be impacted by potential increases in sea level and by associated impacts of storm surge and increasing flood levels. Counties located within the planning area have an average of 40 or more Severe Repetitive Loss Properties (SRL) as defined by FEMA. A SRL property is one that has had at least four National Flood Insurance Program (NFIP) claim payments over $5,000 each, with at least two claims occurring within a ten-year period; and with a cumulative claim amount exceeding $20,000. Supplemental to that definition are properties that have

experienced at least two separate claims exceeding the total value of the property within a ten-year period.[60] In addition, data indicates 11.07% of the land area in Hancock County, 3.51% of the land area in Harrison County, and 8.35% of the land area in Jackson County exists with potential sea level rise zones.[61] The existence of numerous severe repetitive loss properties is an indication of properties that have potential vulnerability related to sea level rise. As the population on the Mississippi coast continues to increase and new development and infrastructure is developed, additional properties become at risk to sea level rise impacts. Potential impacts include increased flooding frequency, potential damage to critical infrastructure, and increasing public costs associated with flood insurance claims, infrastructure repair and maintenance, and increased costs associated with emergency management efforts.

Concurrent to concerns related to vulnerability of the built environment are social vulnerabilities associated with potentially at-risk populations located in coastal Mississippi. Approximately 44% (145,697) of the coast's population resides within FEMA designated flood zones. In addition, 35% (20,373) of the coasts population living at or below the poverty level and 47% (17,704) of the coast's population over the age of 65 live in designated flood zones.[62] These at-risk populations represent segments of the population particularly vulnerable to impacts related to sea level rise.

5.2.2 Critical Facilities

Critical facilities such as fire stations, police stations, hospitals, clinics, and shelter facilities located in areas potentially susceptible to sea level rise present concerns related to a community's ability to effectively respond to emergency situations and to provide an appropriate level of response and recovery from flood events and other natural disasters potentially exacerbated by sea level rise. Recent data indicates 45 schools, 4 police stations, 8 fire stations, 1 emergency center, and 2 communications facilities currently existing within FEMA designated flood zones.[63] Mapping of existing infrastructure and critical facilities combined with appropriate levels of public capital facilities and land use planning are critical to minimizing and potentially eliminating vulnerabilities associated with critical public facilities.

5.2.3 Summary of Sea Level Rise Impacts on Man-Made Systems

With high population densities and relatively high development densities in the near-shore areas of the Mississippi Gulf Coast, several categories of man-made systems on the coast are potentially vulnerable to direct and indirect impacts of sea level rise. These include residential and commercial land use areas, critical facilities and infrastructure, and potentially vulnerable populations. Compounding potential impacts to these man-made systems is the presence of existing FEMA designated flood zones that have a significant history of flooding during "normal" rain events. Increases in sea levels combined with man-made systems located in areas considered to be at-risk will potentially increase the impacts to these systems. The saying, "Today's flood is tomorrow's high tide" is particularly applicable to areas that are frequently inundated due to seasonal rain events. Careful considerations relative to land use planning and site selection for critical facilities and infrastructure are important considerations in reducing the potential vulnerabilities and impacts of sea level rise on man-made systems.

5.3 SEA LEVEL RISE AND EFFECTS ON COASTAL STORMS

A significant consideration within the context of climate change and sea level rise for the Mississippi Gulf Coast is the potential for variations in water temperature and sea levels to affect the frequency, duration, and intensity of tropical weather activity. Atlantic hurricanes are high pressure systems with clockwise rotation that typically originate in the eastern Atlantic Ocean, Caribbean Sea, or the Gulf of Mexico. The Atlantic hurricane season extends from June 1 to November 30th and coincides with warm weather periods in the south Atlantic, Caribbean, and Gulf of Mexico region. One of the primary factors contributing to the origin and growth of tropical storm and hurricanes systems is water temperature. Ideal conditions are 80° ocean temperatures to a depth of approximately 150 feet.[64]

Significant theoretical and research data supports the position that temperature increases in the world's oceans and rising sea levels may potentially increase the frequency, duration, and intensity of hurricanes originating in the Atlantic Basin. Much of this same data supports the idea that increases in sea level will also equate to increased storm surges driven by hurricanes affecting the gulf coast region. Evidence of these factors is seen in an analysis of Accumulated Cyclone Energy (ACE) data from 1950 – 2009. While the data shows no clear trend in hurricane intensity, it does indicate a noticeable increase in intensity over the previous 20 years with six of the ten most active hurricane seasons occurring since the mid-1990s.[65]

6.0 SEA LEVEL RISE PLANNING AND POLICY STRATEGIES

Local and regional responses to sea level rise generally fall into one of three primary categories including armoring, retreating, or adapting. Armoring strategies are those that are intended to physically armor the shoreline against rising sea levels. Retreating strategies are associated with policies related to "no-build" zones, deed restrictions, rolling easements, and other mechanisms designed to minimize impacts to the human and built environment. Adaptation strategies include measures such as elevation of structures and including consideration of sea level rise into local and regional planning documents such as comprehensive plans and local hazard mitigation plans. In determining specific pathways of response to sea level rise, it is rarely an "either-or" scenario but rather a decision process to determine which combination of pathways or strategies are most effective and most sustainable for a given situation.

Retreating and accommodating strategies may also have the potential to raise significant legal issues related to 5th Amendment rights and certain legal considerations related to common law and the Public Trust Doctrine. The 5th Amendment to the U.S. Constitution states in part that, "no person shall be deprived of life, liberty, or property without due process of law, nor shall private property be taken for public use without just compensation". This "takings clause" of the 5th Amendment brings to light sensitive issues as they relate to shoreline retreat, extension of shoreline buffers, and other legal mechanisms such as rolling easements.[66] The Public Trust Doctrine is a legal principal taken from English Common Law. The essence of which is that waters of the state are a public resource owned by and available to all citizens equally for purposes of navigation, commerce, fishing, recreation, and similar uses. Essentially, the Public Trust Doctrine limits public and private use of tidelands and other shorelands to protect the public's right to use the waters of the state.[67] Legal issues related to takings and public use rights are complex and it is not the intention of this plan to discuss in detail or clarify those issues as they relate to planning and mitigation strategies. Rather, this plan seeks to provide a menu of potential mitigation, planning, and policy options to local and regional entities. Local governments seeking to enact policies or planning measures that may relate to taking of private land for public use or the Public Trust Doctrine should consult with appropriate and expert legal counsel before enacting such measures.

The various options that exist for local and regional responses to sea level rise must also be weighed within the contexts of sustainability, environmental sensitivity, local political feasibility, and fiscal feasibility. **Figures 6.1-6.4** depict the relative feasibility of different response options.[68] In addition, a "no action" option exists as local communities work through their response decision pathways. The no action option must also be considered within the context of environmental sensitivity, sustainability, political feasibility, and fiscal feasibility.

Figure 6.1 Response Pathways: Environmental Sensitivity[69]

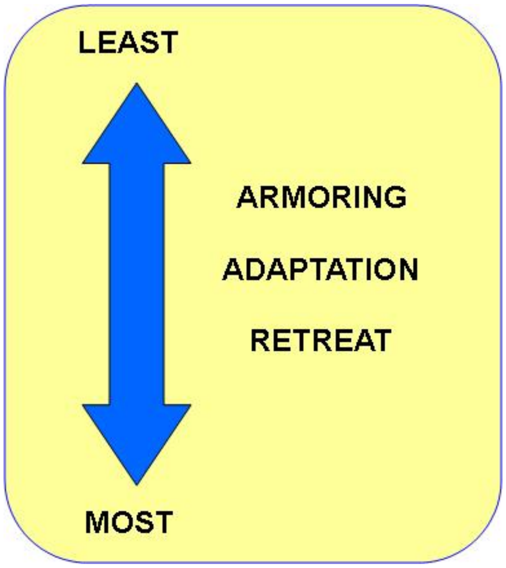


Figure 6.1 represents the relative environmental sensitivity of the three primary sea level rise response pathway approaches with armoring generally being the least environmentally sensitive and retreating options being the most environmentally sensitive. Exceptions to this may exist depending on the particular strategy or set of strategies to be employed. Overall environmental sensitivity will be dependent on the particular ecosystem potentially impacted by a given strategy, materials employed in execution of the strategy, and the potential long or short-term nature of the strategy.

Figure 6.2 Response Pathways: Sustainability[70]

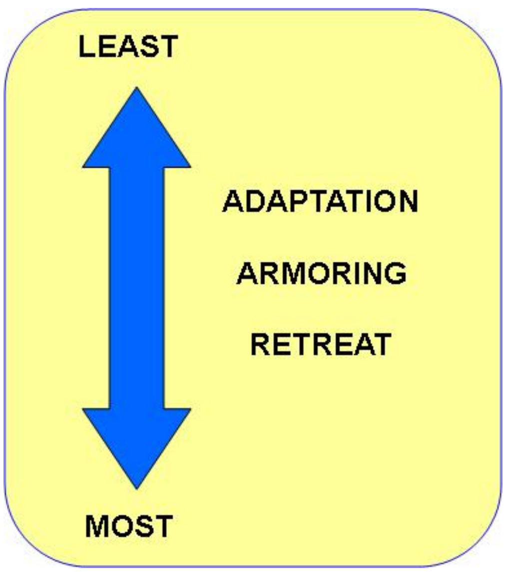


Figure 6.2 illustrates the relative sustainability of the three primary sea level rise response pathways with adaptation being generally the least sustainable and options associated with the retreat pathway seen as the most sustainable. Exceptions to this illustration of relative sustainability will exist depending on the particular strategy or set of strategies to be employed.

Figure 6.3 Response Pathways: Political Feasibility[71]

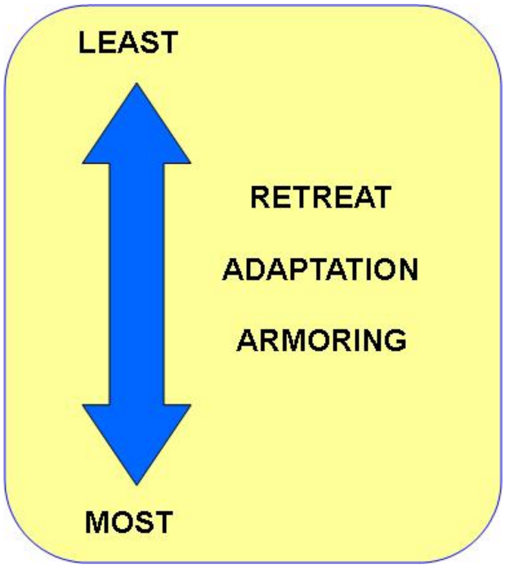


Figure 6.3 illustrates the relative political feasibility of the three primary sea level rise response pathways. In general terms, options related to retreating from sea level rise are seen as the least politically feasible and options related to armoring are seen as the most politically feasible. This illustration of political feasibility has a high potential for relativity due to potential various in local and state political climates, local stakeholder views on sea level rise and apparent risks, and local and state regulations governing implementation of various sea level rise response options.

Figure 6.4 Response Pathways: Fiscal Feasibility[72]

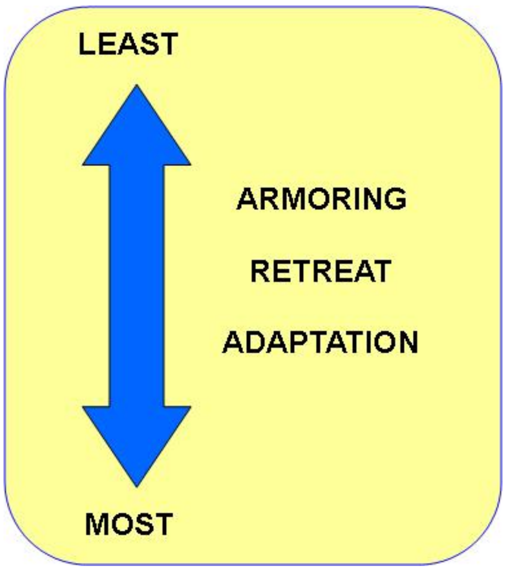


Figure 6.4 illustrates the relative fiscal or financial feasibility of the three primary sea level rise response pathways with armoring generally seen as the least fiscally feasible (or most expensive) long-term option and adaptation seen as the most fiscally feasible (or least expensive) long-term option. As with the other variables illustrated in **Figures 6.1-6.3** some variation will exist with respect to fiscal feasibility of a given response option or set of options.

6.1 ARMOR

Sea level rise mitigation measures and strategies related to armoring are generally engineer designed structures or systems designed to hold back the sea and to protect primarily man-made assets from sea level increases. Examples include levees, groins, sea walls, and other hard structures. **Table 6.1** provides specific details of armoring practices that could potentially be deployed along the Mississippi coast.

Table 6.1 Armoring Strategies[73]

Armoring Strategy	Benefiting System	Secondary Management Goals Addressed	Benefits	Constraints
Trap sand through construction of groins – a barrier-type structure that traps sand by interrupting longshore transport.	Maintenance of sediment transport.	Preserve coastal land/development; maintain shorelines.	Creates more natural shore face than bulkheads or revetments; quick fix.	Can potentially trigger or accelerate erosion on the down drift side and loss of beach habitat.
Manage realignment and deliberately realign engineering structures affecting rivers, estuaries, and coastlines.	Preservation of coastal land and development including infrastructure.	Preserve habitat for vulnerable species; maintain / restore wetlands; maintain sediment transport.	Reduces engineering costs; protects ecosystems and estuaries; allows for natural migration of rivers.	Can be costly.
Install rock sills and other artificial breakwaters in front of tidal marshes along energetic estuarine shores.	Shoreline maintenance (“soft” measures”).	Preserve coastal land / development; maintain water quality.	Naturally protect shorelines and marshes and inhibit erosion inshore of the reef; will induce sediment deposition.	May not be sustainable in the long-term because breakwaters are not likely to provide reliable protection against erosion in major storms.
Composite systems – Incorporation of elements of two or more methods (e.g. breakwater, sand fill, and planting vegetation.	Shoreline maintenance (“soft” measures”).	Preserve coastal land / development.	Incorporates benefits of multiple systems; can address longer stretches of coastline.	“Softer” approaches require more maintenance over time and can become costly.
Fortification of existing dikes.	Shoreline maintenance (“hard” measures).	Maintain water quality, preserve coastal land / development.	Protect land subject to flooding and storm surges.	Can be costly, does not necessarily address migrating salinity gradients.
Harden shorelines with bulkheads – anchored, vertical barriers constructed at the shoreline to block erosion.	Shoreline Maintenance (“hard” measures).	Preserve coastal land / development.	Most common; simple materials used for construction; quick fix.	Loss of intertidal habitats; adjacent properties must be bulkheaded to maintain consistent shorefront – where does it end?
Harden shorelines with seawalls.	Shoreline maintenance (“hard” measures).	Preserve coastal land / development.	Withstand greater wave energy than bulkheads; simple materials	Loss of intertidal habitats. As with bulkheads, adjacent properties must be seawalled to

Armoring Strategy	Benefiting System	Secondary Management Goals Addressed	Benefits	Constraints
			used for construction; quick fix.	maintain consistent shorefront – where does it end?
Harden shorelines with revetments that armor the slope face of the shoreline.	Shoreline maintenance ("hard" measures).	Preserve coastal land / development.	Simple materials used for construction; quick fix.	Loss of intertidal habitats; often constructed poorly and lead to destabilization of banks, increasing erosion.
Harden shorelines with breakwaters – structures placed offshore to reduce wave action.	Shoreline maintenance ("hard" measures).	Maintain water quality; preserve coastal land / development.	Employs materials that are locally available; quick fix; creates good habitat for marshes and other calm water systems.	Down drift coast may be deprived of sediment, increasing erosion; loss of habitat.
Headland control – reinforce or accentuate an existing geomorphic feature or create an artificial headland (e.g. geotextile tube).	Shoreline maintenance ("hard" measures).	Preserve coastal land / development.	Can be cost effective.	May reduce sediment supply to adjacent shores, increasing erosion; loss of habitat.

6.2 RETREAT

Sea level rise mitigation strategies related to retreating are typically policy-related measures that seek to prevent or minimize development in near shore areas of the coastline. Examples of retreat options include enhanced buffer zones, no-build zones, conservation easements, and rolling easements. Since these policies are typically associated with land use and land ownership rights, care should be taken in choosing options presented here. As previously mentioned, legal issues associated with 5th Amendment rights and rights provided through the Public Trust Doctrine have the potential to be associated with these particular measures. **Table 6.2** provides a variety of options related to measures and strategies associated with the retreat option.

Table 6.2 Retreating Strategies[74]

Retreating Strategy	Benefiting System	Secondary Management Goals Addressed	Benefits	Constraints
Allow coastal wetlands to migrate inland (e.g. through setbacks, density restrictions, land purchases).	Maintaining / restoring wetlands.	Preservation of habitat for vulnerable species; preservation of coastal land / development.	Maintains species habitats; maintains protection for inland ecosystems.	In highly developed areas, there is often little or no land available for wetland migration, or could potentially be costly to landowners.
Establish rolling easements.	Maintaining / restoring wetlands.	Maintain water quality; maintain sediment transport.	Lower long-term costs; sediment transport remains undisturbed; property owner bears risks of sea level rise.	Does not prevent migration of salinity gradient.
Land exchange programs – owners exchange property in the floodplain for publicly-owned land outside of the floodplain (i.e. transfer of development rights).	Preservation of coastal land / development.	Preserves habitat for vulnerable species; maintain / restore wetlands.	Preserves open spaces; more land available to protect estuaries.	Program is voluntary; land must be available for development elsewhere; not currently allowed legislatively in Mississippi.
Create permitting rules that constrain locations for landfills, hazardous waste dumps, mine tailings, and hazardous materials facilities.	Preservation of coastal land / development.	Preserve habitat for vulnerable species; maintain / restore wetlands; maintain sediment transport.	Zones accordingly to protect estuaries and coastal zones.	Enactment of these types of zoning regulations may be difficult.
Land acquisition program – purchase coastal land that is damaged or prone to damage and reuse for conservation purposes.	Preservation of coastal land / development.	Preserve habitat for vulnerable species; maintain / restore wetlands.	Can provide a buffer to inland areas; prevents development on the land.	Can be cost prohibitive; land may not be available; voluntary.
Create marsh by planting the appropriate species – typically grasses, sedges, or rushes – in the existing substrate.	Shoreline maintenance ("soft" measures).	Maintain water quality; maintain / restore wetlands; preserve habitat for vulnerable species; invasive	Provides protective barrier; maintains and often increases habitat.	Conditions must be right for marsh to survive (e.g. sunlight for grasses, calm water) can be

Retreating Strategy	Benefiting System	Secondary Management Goals Addressed	Benefits	Constraints
		species management.		affected by seasonal changes.
Restrict or prohibit development in erosion zones.	Shoreline maintenance ("soft" measures).	Preserve coastal land / development; maintain / restore wetlands.	Allows for more land available to protect estuaries.	Will not help areas already developed; difficult to get all parties to agree; potential takings issues.
Increase shoreline setbacks.	Shoreline Maintenance ("soft" measures).	Preserve coastal land / development.	Protects coastal property in the long term and prevents development directly on the shoreline.	Will not help areas already developed; potential takings issues.
Retreat from, and abandonment of, coastal barriers.	Preservation of habitat for vulnerable species.	Maintain / restore wetlands.	May help protect estuaries, allowing them to return to their natural habitat.	Generally not politically favored due to the high value of coastal property and infrastructure; potential takings issues.
Purchase upland development rights or property rights.	Preservation of habitat for vulnerable species.	Maintain / restore wetlands; maintain water quality.	Protects habitats downstream.	Costly; uncertainty about sea level rise leads to uncertainty in the amount of property purchased; similar to transfer of development rights, not currently allowed legislatively in Mississippi.
Prevent or limit groundwater extraction from shallow aquifers.	Maintain water quality.	Preserve coastal land / development; maintain / restore wetlands; maintain water availability.	Will limit relative sea level rise by preventing subsidence and reducing saltwater intrusion into freshwater.	May create a costly need to identify alternative municipal water sources.

6.3 ADAPT

Policies and strategies related to adaptation are those that provide some level of flexibility in policy, design, and implementation of strategies. Adaptation strategies include measures such as elevation of structures and including consideration of sea level rise into local and regional planning documents such as comprehensive plans and local hazard mitigation plans. As previously mentioned, these strategies are not meant to be a "one size fits all" approach but rather a "treatment train" approach should be considered and adopted that uses one or more strategies working concurrently and in concert to address specific management goals. **Table 6.3** provides details on a variety of adaptation strategies.

Table 6.3 Adaptation Strategies[75]

Adaptation Strategy	Benefiting System	Secondary Management Goals Addressed	Benefits	Constraints
Promote wetland accretion by introducing sediment.	Maintain / restore wetlands.	Maintain sediment transport.	Maintains sediment transport to wetlands, which protects coastal lands from storms.	Requires continual maintenance; can be very costly.
Prohibit hard shore protection.	Maintain / restore wetlands.	Preserve habitat for vulnerable species; maintain sediment transport.	Allows for species migration.	Alternatives of bulkhead construction are more expensive and may be more difficult to obtain permits for.
Remove existing hard protection or other barriers to tidal and riverine flow (e.g. riverine and tidal dike removal.	Maintain / restore wetlands.	Maintain sediment transport; maintain shorelines.	May allow for wetland migration.	Costly and destructive to shoreline property.
Incorporate wetland protection into infrastructure planning (e.g. transportation planning, sewer utilities).	Maintain / restore wetlands.	Maintain water quality; preserve habitat for vulnerable species.	Protects valuable and important infrastructure.	
Preserve and restore the structural complexity and biodiversity of vegetation in tidal marshes, and seagrass meadows.	Maintain / restore wetlands.	Maintain water quality; maintain shorelines; invasive species management.	Vegetation protects against erosion, protects mainland shorelines from tidal energy, storm surge, and wave forces,	

Adaptation Strategy	Benefiting System	Secondary Management Goals Addressed	Benefits	Constraints
			filters pollutants, and absorbs atmospheric CO_2.	
Identify and protect ecologically significant areas such as nursery grounds, spawning grounds, and areas of high species diversity (e.g. GEMS, coastal preserves).	Maintain / restore wetlands.	Invasive species management; preserve habitat for vulnerable species.	Protecting critical areas will promote biodiversity and ecosystem services (e.g. producing and adding nutrients to coastal systems serving as refuges and nurseries for species).	Some areas / circumstances may require federal or state protection.
Trap or add sand through beach nourishment – the addition of sand to a shoreline to enhance or create a beach area.	Maintain sediment transport.	Preserve habitat for vulnerable species; preserve coastal land / development; maintain shorelines.	Creates protective beach for inland areas; replenishes sand lost to erosion; potentially creates new public access and tourism / recreation areas.	Periodic maintenance cycle required; potentially high costs to import beach material.
Create a regional sediment management plan.	Maintain sediment transport.	Maintain water quality.	Preserves natural sediment flow and protects water quality of downstream reaches.	Improvements and plan recommendations may be costly.
Develop adaptive stormwater management practices (e.g. promoting natural buffers, adequate culvert sizing).	Maintain sediment transport.	Maintain water quality.	Preserves natural sediment flow and protects water quality of downstream reaches.	Improvements and retrofits may be costly.
Integrate coastal management into land use planning.	Preservation of coastal land / development.	Preserves habitat for vulnerable species; maintain / restore wetlands.	Potentially requires more state agency oversight; allows for	May be difficult to have local and state agencies agree on specific plan elements; private

Adaptation Strategy	Benefiting System	Secondary Management Goals Addressed	Benefits	Constraints
			conservation and management goals to be incorporated locally; allows for locally comprehensive coastal management in cooperation with state efforts.	property rights; current legislation is prescriptive but not required.
Consider Integrated Coastal Zone Management – using an integrated approach to achieve sustainability and resiliency.	Preservation of coastal land / development.	Preserve habitat for vulnerable species; maintain / restore wetlands; maintain water availability; maintain water quality; maintain sediment transport; maintain shorelines.	Considers all stakeholders in planning, balancing objectives; addresses all aspects of climate change.	Stakeholders must be willing to compromise; requires much more effort in planning.
Incorporate consideration of climate change and sea level rise impacts into planning for new infrastructure. (homes, buildings, water, sewer, streets, critical facilities, etc.	Preservation of coastal land / development.	Preserve habitat for vulnerable species; maintain / restore wetlands.	Engineering could be modified to account for changes in precipitation or seasonal timing of flows; siting decisions could take into account sea level rise.	Land owners may resist relocating away from prime coastal locations.
Replace shoreline armoring with living shorelines – through beach nourishment, vegetation, etc.	Shoreline maintenance (“soft” measures).	Maintain / restore wetlands; preserve habitat for vulnerable species; preserve coastal land / development.	Reduces the negative effects of armoring (down drift erosion); maintains beach habitat.	Can be costly; requires more planning and materials than armoring.
Introduce submerged aquatic vegetation to stabilize sediment and	Shoreline maintenance (“soft”	Maintain / restore wetlands; preserve habitat	Stabilizes sediment; does not require	Seasonality – grasses diminish in winter months when

Adaptation Strategy	Benefiting System	Secondary Management Goals Addressed	Benefits	Constraints
reduce erosion.	measures).	for vulnerable species; preserve coastal land / development.	costly construction procedures.	wave activity is often more severe because of storms; natural light availability is critical.
Create dunes along the backshore of beaches; includes planting dune grasses and sand fencing to induce settling of wind-blown sand.	Shoreline maintenance (“soft” measures).	Preserve coastal land / development.	Protects both the beach and inland areas from sea level rise; potentially reduce volumes of wind-blown sand into other infrastructure such as Highway 90 / Beach Boulevard.	Costs of importing sand; potentially takes land away from public use; may impair viewsheds in certain circumstances.
Use natural breakwaters such as oyster reefs or other man-made / natural materials to dissipate wave action and protect shorelines.	Shoreline maintenance (“soft” measures).	Preserve coastal land / development; maintain water quality; invasive species management.	Naturally protect shorelines and marshes and inhibit erosion inshore of the reef; will induces sediment deposition.	May not be sustainable in the long-term because breakwaters are not likely to provide reliable protection against erosion in major storms.
Redefine riverine flood hazard zones to match projected expansion of flooding frequency and extent.	Shoreline maintenance (“soft” measures).	Preserve coastal land / development; maintain / restore wetlands.	Protects riverine systems and zones accordingly.	Potential impacts on flood insurance (e.g. may place new properties/structures into the floodplain; may require changes to zoning ordinances or local flood hazard protection ordinances.
Strengthen rules that prevent the introduction of invasive species (e.g. enforce no discharge zones for ballast water).	Invasive species management.	Maintain / restore wetlands; preserve habitat for vulnerable species.	Prevents difficult and costly eradication of invasives by preventing their introduction.	May require state action; may be difficult to regulate.

Adaptation Strategy	Benefiting System	Secondary Management Goals Addressed	Benefits	Constraints
Remove invasive species and restore native species.	Invasive species management.	Maintain / restore wetlands; preserve habitat for vulnerable species.	Local removal of invasives is locally viable to improve marsh and wetlands characteristics that promote native fish and wildlife.	Difficult (if not impossible) on larger scales.
Expand the planning horizon of land use and comprehensive planning to incorporate longer climate predictions.	Preservation of habitats for vulnerable species.	Preserve coastal land / development.	Could inhibit risky development and prove protection for estuarine habitats.	Land use plans rarely incorporate hard prohibitions against development close to sensitive habitats and have limited durability over time; current legislation is prescriptive, not required.
Adapt protections of important and critical habitats as the locations of these areas change with climate and sea level changes.	Preservation of habitats for vulnerable species.	Maintain / restore wetlands.	Allows for migration of critical areas.	Will require continuous monitoring efforts.
Connect landscapes with habitat corridors to enable migrations.	Preservation of habitats for vulnerable species.	Maintain / restore wetlands.	Allows for species migration with climate change; sustains wildlife biodiversity across the landscape.	May require significant efforts and resources.
Design estuaries with dynamic boundaries and buffers.	Preservation of habitats for vulnerable species.	Maintain / restore wetlands.	Protects breeding and foraging habitats of highly migratory species.	In highly developed areas, boundaries may be unmovable.
Replicate habitat types in multiple areas to spread risks associated with climate change	Preservation of habitats for vulnerable species.	Maintain / restore wetlands; invasive species management.	Protects biodiversity and critical areas.	Land may not be available for habitat replication.

Adaptation Strategy	Benefiting System	Secondary Management Goals Addressed	Benefits	Constraints
and sea level rise.				
Design and implement new coastal drainage systems.	Maintain water quality.		Many systems may need to be restructured anyway.	Planning, engineering, and construction can be very costly and time consuming.
Integrate climate change scenarios into water supply system.	Maintain water quantity.	Preserve coastal land / development.	Takes changes in temperature, precipitation, and sea level rise into account in planning.	Could show that major restructuring is needed; changes could be costly.
Manage water demand (through water reuse, recycling, rainwater harvesting, desalination, etc.).	Maintain water quantity.		Increases availability of water for all uses.	Requires coordination among water agencies, utilities, and districts.
Consider modifications to local Flood Hazard Prevention Ordinances to increase freeboard requirements.	Preserve coastal land / development.	Maintain water quality; protect life and property; increased resiliency.	Provide for additional protection of residential structures from higher tides, storm surges, flooding.	Will require local adoption; will increase costs of development in coastal zones and flood prone areas.
Consider incorporation of sea level rise and climate change impacts into local, regional, and state hazard mitigation plans.	Preserve coastal land / development.	Protect life and property; increased resiliency.	Enhances a proven and required planning mechanism; includes input from stakeholders.	Will require local adoption.
Incorporate risk-based land use planning into local comprehensive plans.[76]	Preserve coastal land / development.	Protect life and property; increased resiliency.	Integrates natural hazards into local land use planning; potentially provides incentives for selection of alternative development sites.	Availability of alternate land for development; requires local adoption; current legislation is prescriptive, not required.
Integrate climate change and sea level rise impacts into due	Preserve coastal land / development.	Protection of life and property; increased	Allows investors and asset managers	Will require cooperation among financial and real

Adaptation Strategy	Benefiting System	Secondary Management Goals Addressed	Benefits	Constraints
diligence for investment and lending.[77]		resiliency.	to manage risks associated with real estate located in potentially impacted areas.	estate sectors.
For communities currently participating in FEMA's Community Rating System (CRS) consider program or policy changes that would specifically address Activity 430 – Credit for Higher Regulatory Standard, Activity 430 – Credit for Coastal A Zone Regulations, and Activity 610 – Credit for Flood Warning Systems.	Preserve coastal land / development;	Protection of life and property; enhanced resiliency.	Potentially increased premium discounts for National Flood Insurance policy holders; enhanced protection in flood prone areas.	Requires existing participation in the CRS system, Rating upgrades can potentially be expensive and time consuming.
For communities not currently participating in FEMA's CRS, consider enrollment in the program.	Preserve coastal land / development.	Protection of life and property; enhanced resiliency.	Potentially increased premium discounts for National Flood Insurance policy holders; enhanced protection in flood prone areas.	Application and enrollment in the program can be expensive and time consuming.

7.0 Conclusion and Recommendations

Current research and historical data indicate sea level rise is occurring on a global scale and on a regional scale specific to the Mississippi Gulf Coast. Specific geographical areas in Mississippi potentially impacted by rising sea levels include Hancock, Harrison, and Jackson Counties and the eleven municipalities that exist within these three counties. The three Mississippi coastal counties and eleven municipalities include a population of approximately 370,702 people, representing approximately 12% of the State's total population. In addition, the coast's population is expected to increase by approximately 27% in the next twenty years. Within the context of sea level rise, an existing high population density combined with anticipated population increases along the Mississippi Gulf Coast equates to potential impacts in the future.

An analysis of the risks associated with sea level rise on the Mississippi coast indicates future sea level increases ranging from .1 inch per year on a local scale to .84 inches per year on a global scale. These predictions are best and worst-case scenarios. Data providing sea level rise projections were taken from global and regional research and provide a range of possible impacts. An assessment of the coast's overall vulnerability to sea level rise indicates the coast is at moderate risk to impacts related to sea level rise.

Anticipated sea level increases have the potential to impact both natural and man-made systems including wetlands, essential fish habitat, a National Estuarine Research Reserve, the Gulf Islands National Seashore, designated coastal preserves, National Wildlife Refuges, commercial and residential land uses, and critical infrastructure. The long-term vulnerability of these systems is partially dependent on choices made in the short-term, both on the local and regional levels.

Strategies divided into three primary response "pathways" including Armoring, Retreating, and Adapting have been discussed in this assessment. Within each of these primary pathways are numerous strategies designed to prepare the coastal region for rising sea levels. In addition, each of the proposed strategies identifies secondary management goals that can be realized through implementation.

7.1 Recommendations

Strategic planning by local planners and decision makers within the overall context of a comprehensive approach to sea level rise management, natural resource and ecosystem management, land use planning, and capital facilities planning should be conducted. The preferred approach in determining which strategies to utilize is a "treatment train" approach that seeks to incorporate a series of strategies designed to comprehensively address issues related to sea level rise, as well as other cumulative impacts and planning considerations.

Planning for sea level rise on the Mississippi coast is complicated by an apparent shortage of historical data specific to the Mississippi Sound as well as limited available technologies capable of modeling sea level increases beyond simple "bathtub" models. It is recommended that additional research be conducted specific to the Mississippi coastal region as new data becomes available and modeling technologies improve.

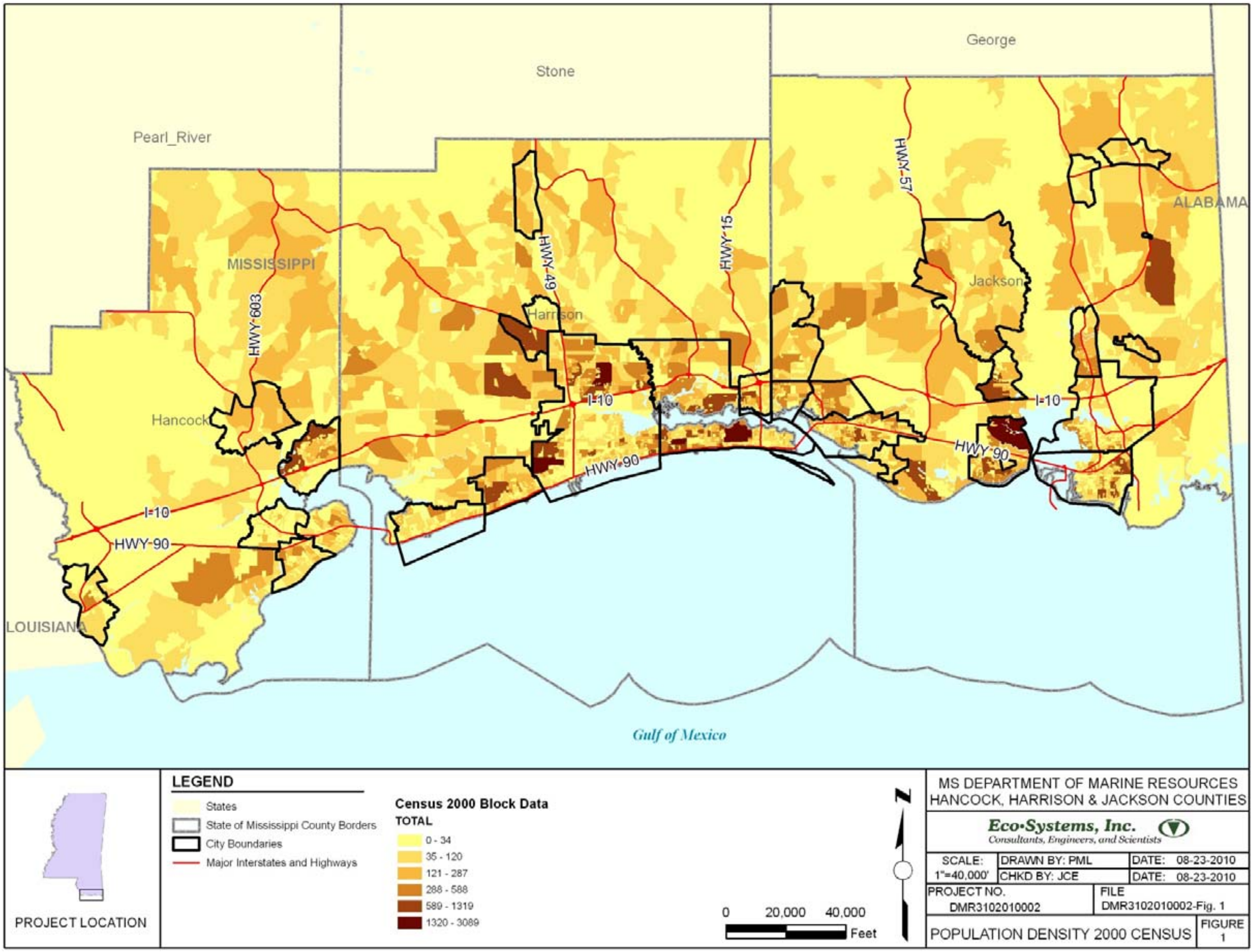
Sea level rise is a phenomenon that is expected to continue and potentially increase over time. The most important recommendation is to begin planning for impacts now. Considerations for sea level rise should be incorporated into local and regional plans addressing land use, hazard mitigation, natural resource management, and capital facilities planning. By effectively planning now for future impacts, the coastal region can become more resilient to sea level rise impacts and will be better positioned to respond to and address related issues as they arise.

The next action steps in addressing sea level rise issues in coastal Mississippi are dependent in part on the will of state and local leaders. The fact remains, sea level is rising along our coast and impacts will need to be addressed in a proactive manner. The following recommendations should be considered as research or specific actions moving forward and are included as supplementary actions designed to mitigate data gaps and other research deficiencies specific to Mississippi:

1. Establish a climate change commission/task force to consider and plan for the potential effects of sea level rise and other climate change effects.
2. Development of a statewide research and monitoring effort to measure the affected environment including:
    a. Shoreline erosion;
    b. Storm frequency, intensity, rainfall, coastal flooding;
    c. Changes in coastal waters (i.e. pH, temperature, salinity, depth);
    d. Hydrological changes;
    e. Saltwater intrusion;
    f. Habitat loss/change; and
    g. Changes in population dynamics of coastal and marine species.
3. Utilization of standardized monitoring techniques.
4. Designation and maintenance of a central repository for statewide climate/sea level rise data, including mapping, models, and monitoring products.
5. Assessments of sea level rise vulnerability requiring the following information:
    a. Accurate LIDAR topographic data;
    b. Continuous water level data;
    c. Wave height and frequency;
    d. Inundation maps/storm surge data;
    e. Historical and current marsh surface elevation change data;
    f. Inventory of public and private infrastructure at risk;
    g. Public perceptions of climate change/sea level rise; and
    h. Assessments of public support for strategic response options.
6. Conduct detailed vulnerability assessments of public infrastructure to include:
    a. Drinking water;
    b. Transportation systems;
    c. Wastewater treatment facilities and infrastructure;
    d. Public utilities; and
    e. Industrial facilities.
7. Development of specific adaptation strategies for affected sectors including:
    a. Forestry resources;

   b. Marine resources;
   c. Water resources;
   d. Terrestrial ecosystems; and
   e. Human health.
8. Development of location-specific vulnerability assessments and adaptation plans for coastal communities.
9. Development of a state climate/sea level rise planning guidance to assist local adaptation and response efforts.
10. Reauthorization of the Coastal Zone Management Act to include climate/sea level rise planning and implementation of adaptation strategies.
11. Research on the potential impacts of sea level rise on property ownership.
12. Research on the potential impacts to insurance coverage and costs related to sea level rise.
13. Identification of high priority areas for habitat protection and restoration related to habitat migrations.
14. Promotion of development of sustainable shorelines.
15. Development and implementation of a communications strategy to engage local stakeholders, local support, and funding.
16. Coordination of management across agencies for human health and safety.
17. Development and implementation of long-range plans to minimize economic impacts of sea level rise to the natural resource based industries (i.e. commercial fishing, oystering, shrimping, etc.).

Appendix A – Maps and Figures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Stone
Pearl_River
MISSISSIPPI
HWY-603
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HWY-90
LOUISIANA
Gulf of Mexico
PROJECT LOCATION
LEGEND
States
State of Mississippi County Borders
City Boundaries
Major Interstates and Highways
Census 2000 Block Data
TOTAL
0 - 34
35 - 120
121 - 287
288 - 588
589 - 1319
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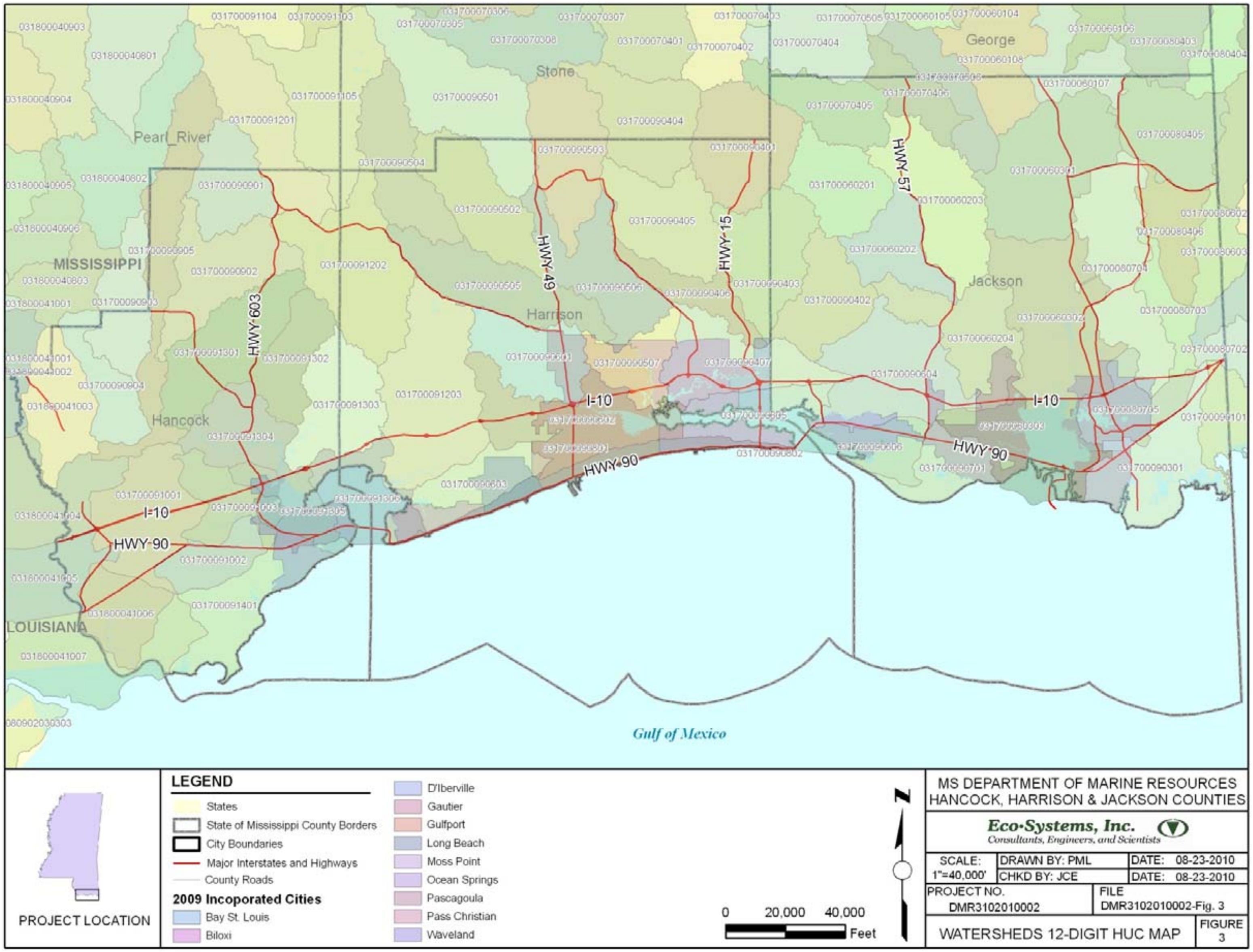
MS DEPARTMENT OF MARINE RESOURCES
HANCOCK, HARRISON & JACKSON COUNTIES
Eco•Systems, Inc.
Consultants, Engineers, and Scientists
SCALE: 1"=40,000'
DRAWN BY: PML
CHKD BY: JCE
DATE: 08-23-2010
DATE: 08-23-2010
PROJECT NO. DMR3102010002
FILE DMR3102010002-Fig. 1
POPULATION DENSITY 2000 CENSUS
FIGURE 1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Gulf of Mexico
LEGEND
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Major Interstates and Highways
County Roads
2009 Incoporated Cities
Bay St. Louis
Biloxi
D'Iberville
Gautier
Gulfport
Long Beach
Moss Point
Ocean Springs
Pascagoula
Pass Christian
Waveland
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Eco-Systems, Inc.
Consultants, Engineers, and Scientists
SCALE: 1"=40,000'
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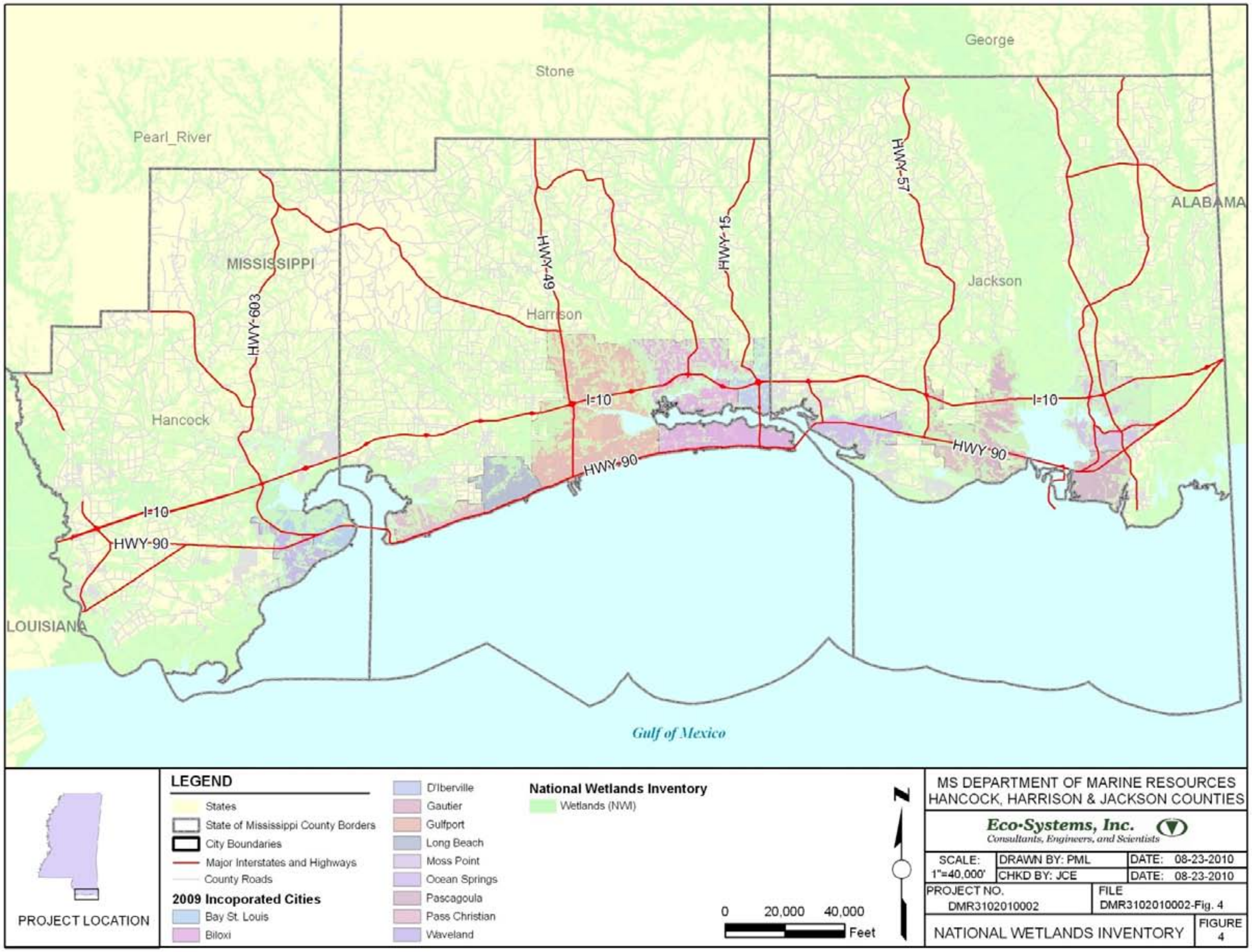
FILE DMR3102010002-Fig. 3
WATERSHEDS 12-DIGIT HUC MAP
FIGURE 3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Long Beach
Moss Point
Ocean Springs
Pascagoula
Pass Christian
Waveland
National Wetlands Inventory
Wetlands (NWI)
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PROJECT LOCATION
MS DEPARTMENT OF MARINE RESOURCES
HANCOCK, HARRISON & JACKSON COUNTIES
Eco-Systems, Inc.
Consultants, Engineers, and Scientists
SCALE: 1"=40,000'
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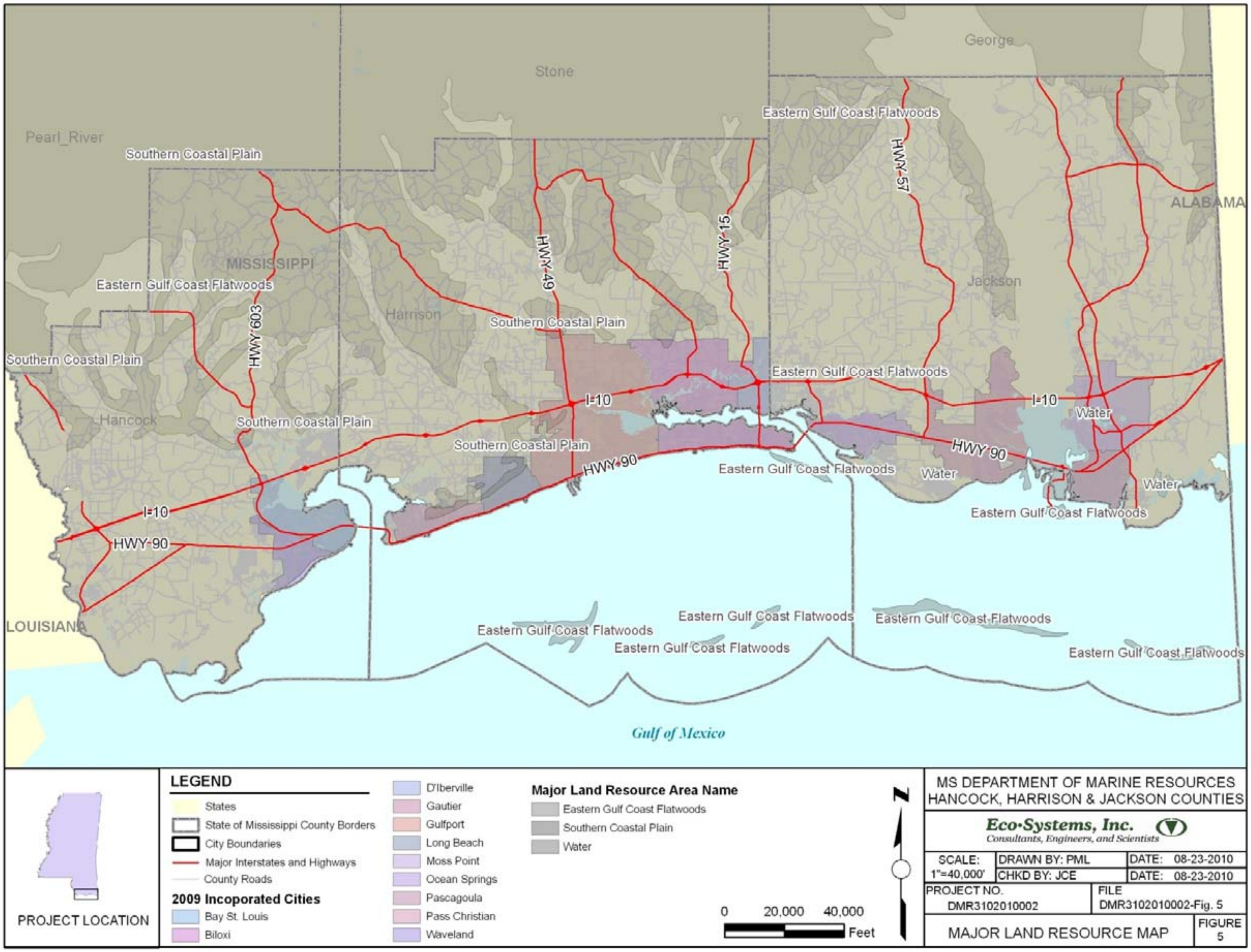
CHKD BY: JCE
DATE: 08-23-2010
PROJECT NO. DMR3102010002
FILE DMR3102010002-Fig. 4
NATIONAL WETLANDS INVENTORY
FIGURE 4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Gulf of Mexico
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Pascagoula
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Major Land Resource Area Name
Eastern Gulf Coast Flatwoods
Southern Coastal Plain
Water
PROJECT LOCATION
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HANCOCK, HARRISON & JACKSON COUNTIES
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Consultants, Engineers, and Scientists
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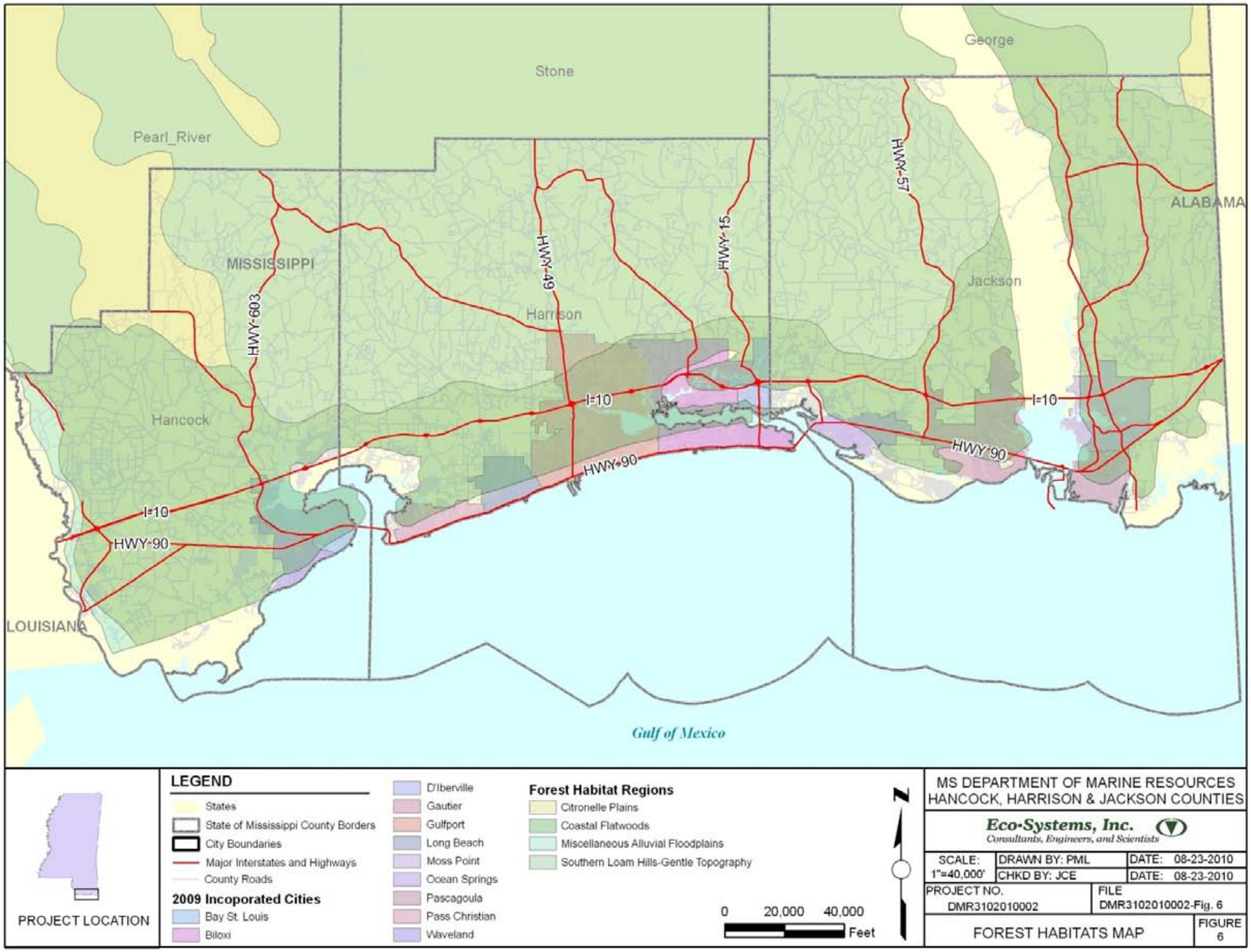
FILE DMR3102010002-Fig. 5
MAJOR LAND RESOURCE MAP
FIGURE 5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Long Beach
Moss Point
Ocean Springs
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Pass Christian
Waveland
Forest Habitat Regions
Citronelle Plains
Coastal Flatwoods
Miscellaneous Alluvial Floodplains
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Consultants, Engineers, and Scientists
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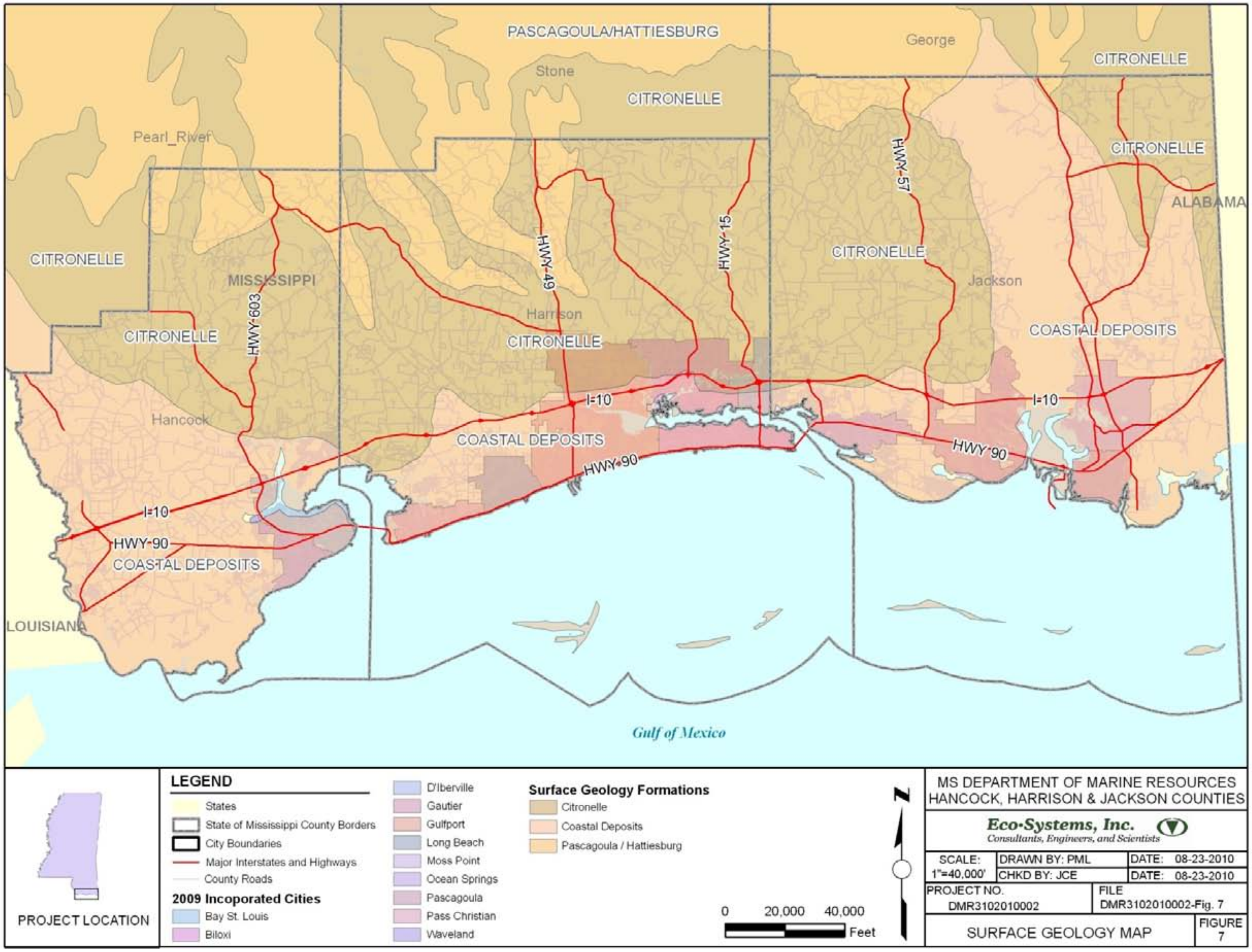
FILE DMR3102010002-Fig. 6
FOREST HABITATS MAP
FIGURE 6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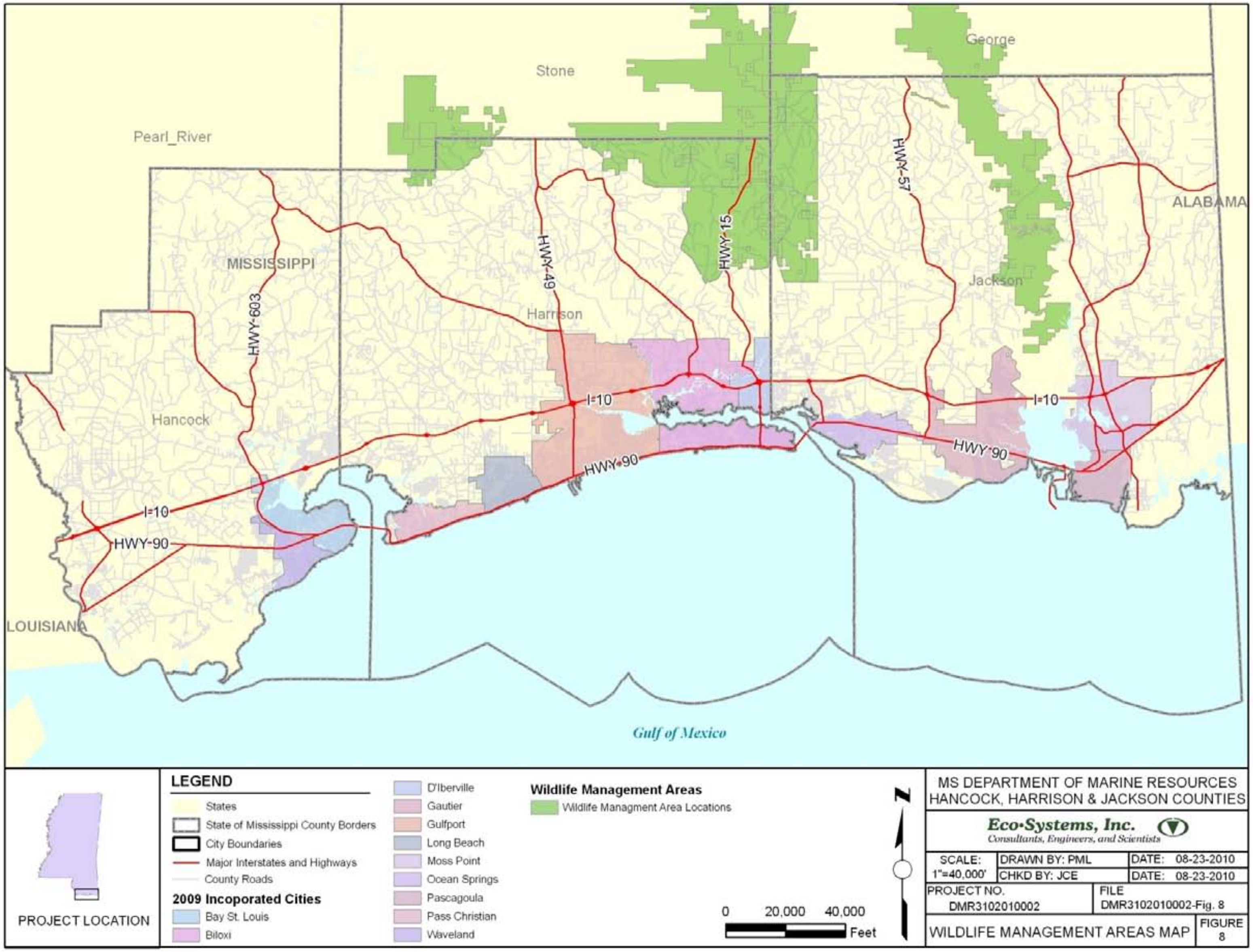
SURFACE GEOLOGY MAP
FIGURE 7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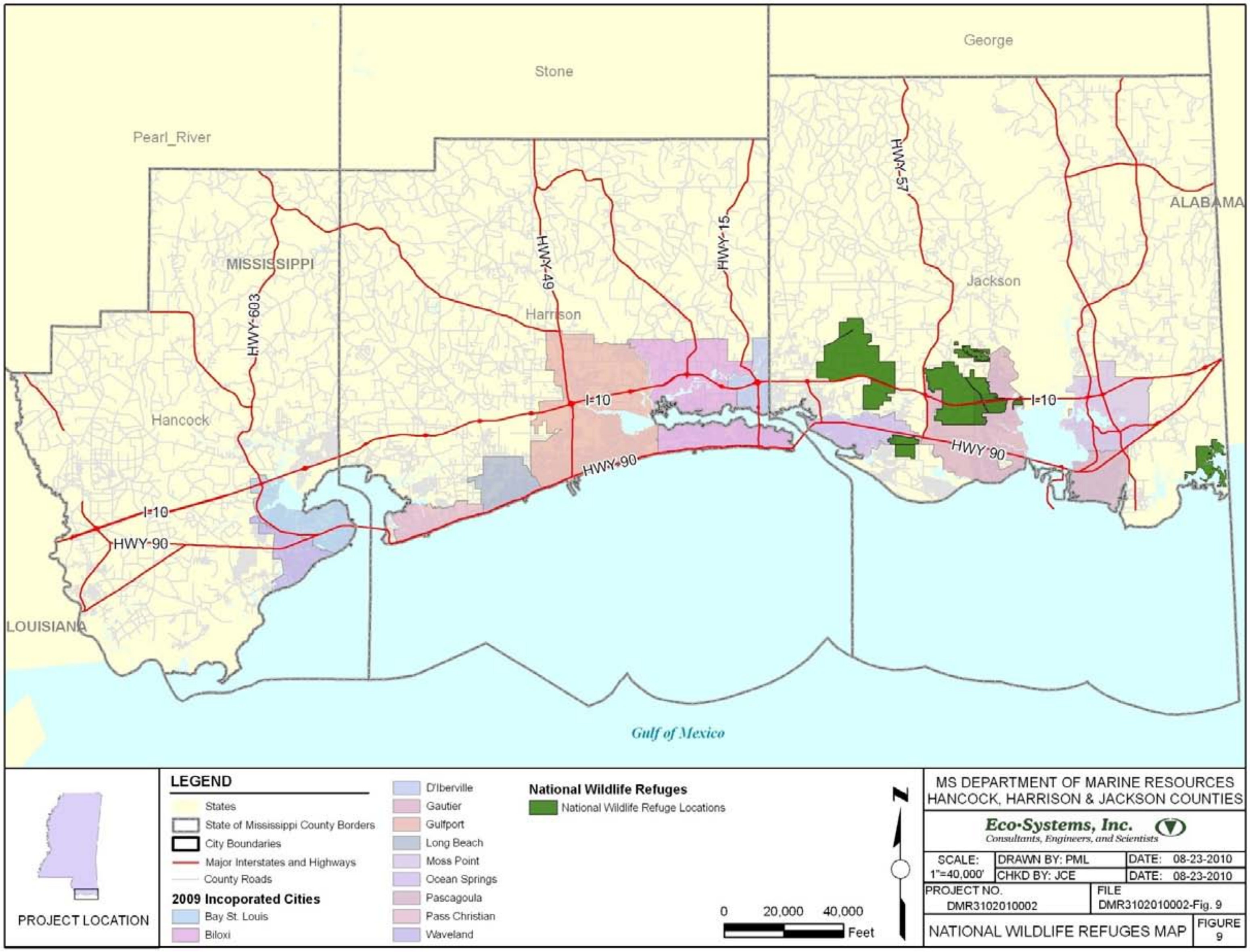
PROJECT NO. DMR3102010002
FILE DMR3102010002-Fig. 8
WILDLIFE MANAGEMENT AREAS MAP
FIGURE 8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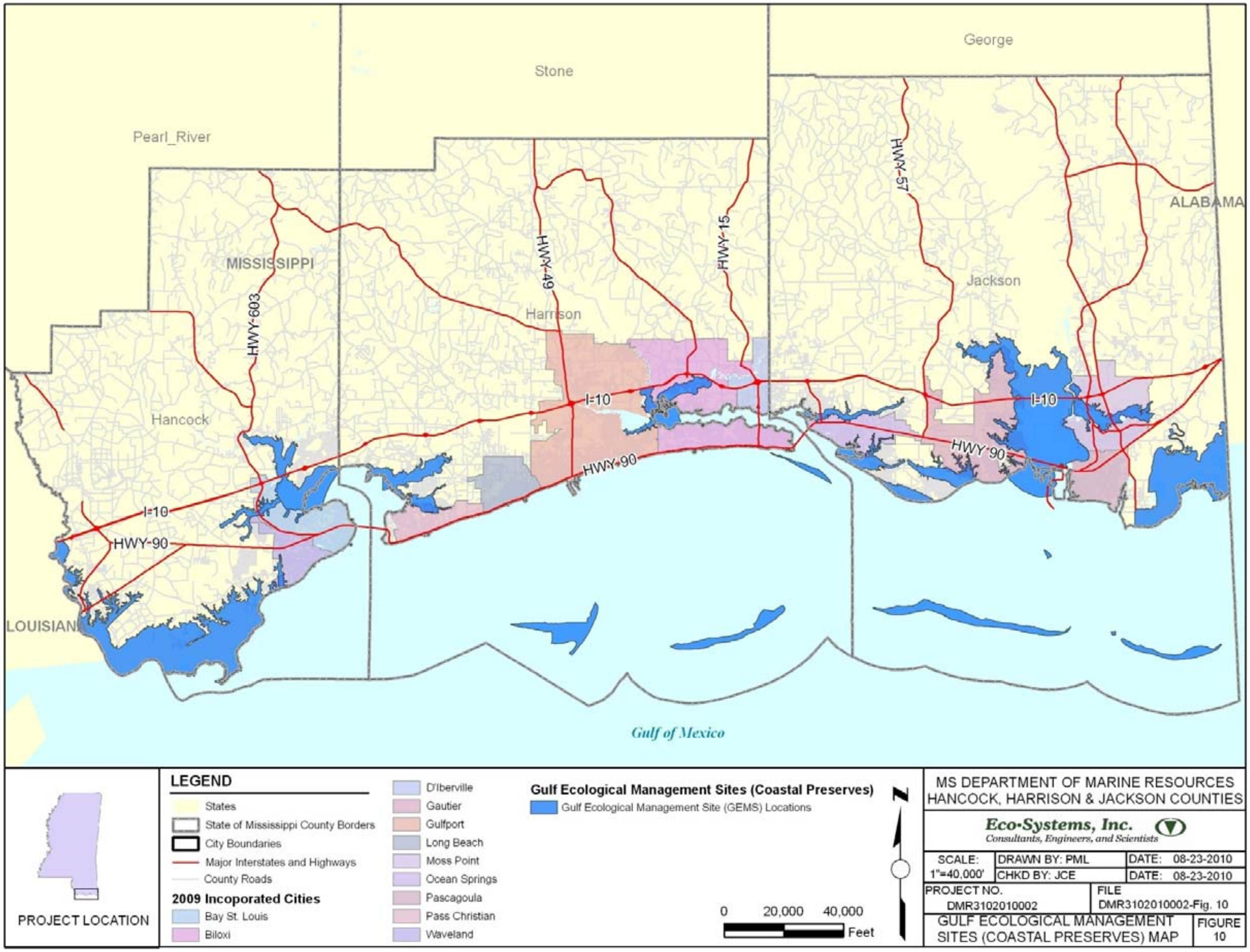
NATIONAL WILDLIFE REFUGES MAP
FIGURE 9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Pascagoula
Pass Christian
Waveland
Gulf Ecological Management Sites (Coastal Preserves)
Gulf Ecological Management Site (GEMS) Locations
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DATE: 08-23-2010
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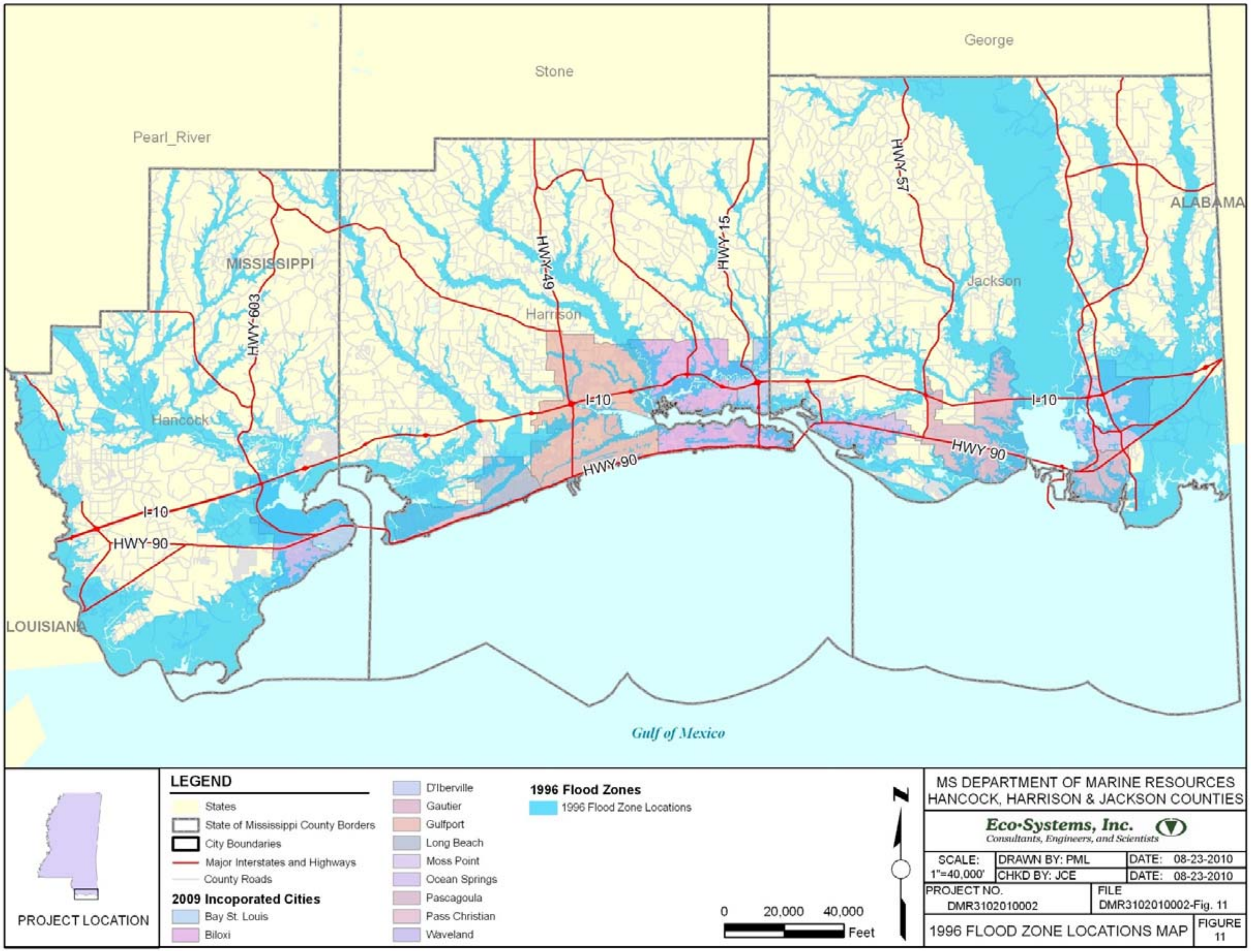
FILE DMR3102010002-Fig. 10
GULF ECOLOGICAL MANAGEMENT SITES (COASTAL PRESERVES) MAP
FIGURE 10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Gulfport
Long Beach
Moss Point
Ocean Springs
Pascagoula
Pass Christian
Waveland
1996 Flood Zones
1996 Flood Zone Locations
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PROJECT LOCATION
MS DEPARTMENT OF MARINE RESOURCES
HANCOCK, HARRISON & JACKSON COUNTIES
Eco-Systems, Inc.
Consultants, Engineers, and Scientists
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DATE: 08-23-2010
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PROJECT NO.
DMR3102010002
FILE
DMR3102010002-Fig. 11
1996 FLOOD ZONE LOCATIONS MAP
FIGURE
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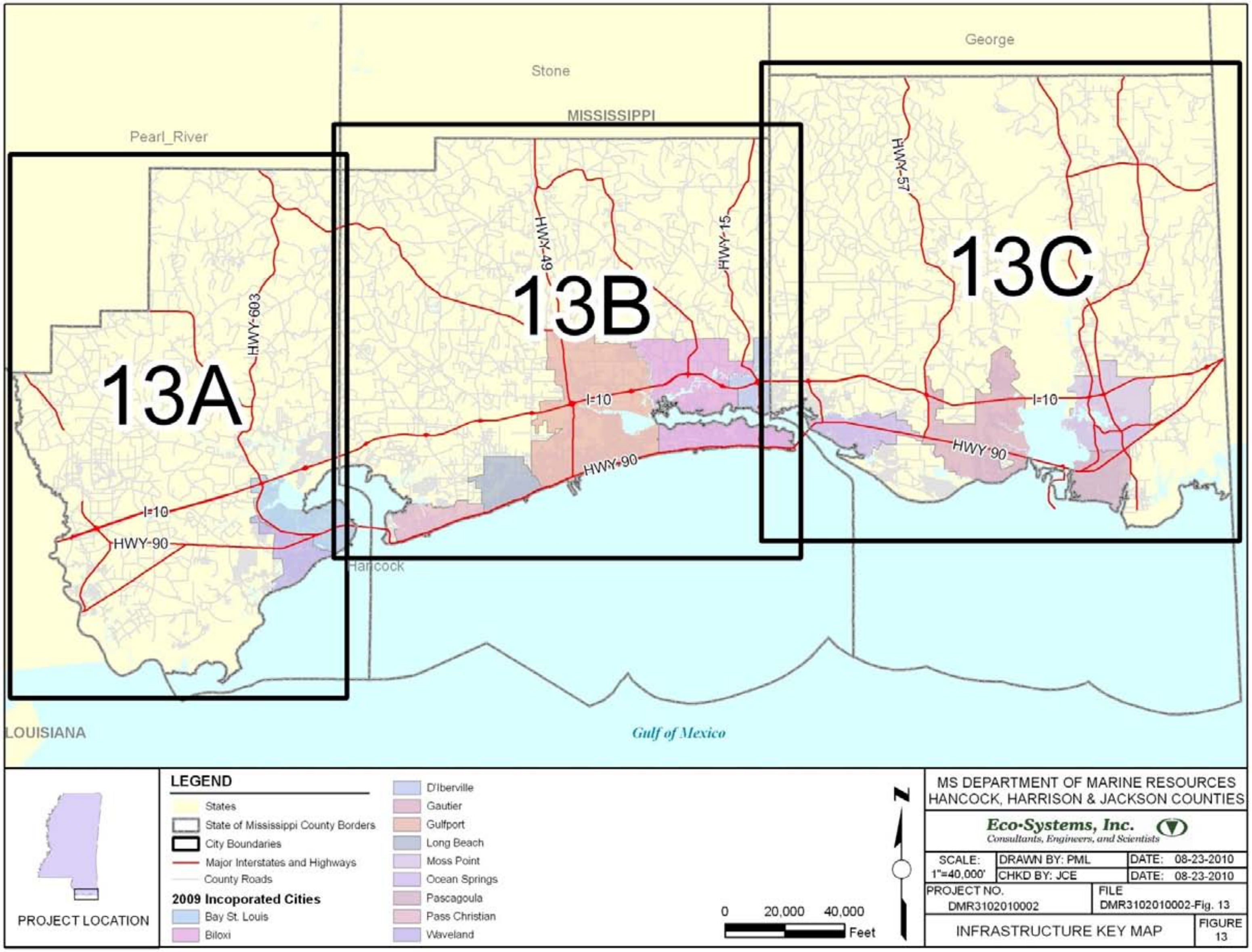
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MS DEPARTMENT OF MARINE RESOURCES
HANCOCK, HARRISON & JACKSON COUNTIES
Eco-Systems, Inc.
Consultants, Engineers, and Scientists
SCALE: 1"=40,000'
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CHKD BY: JCE
DATE: 08-23-2010
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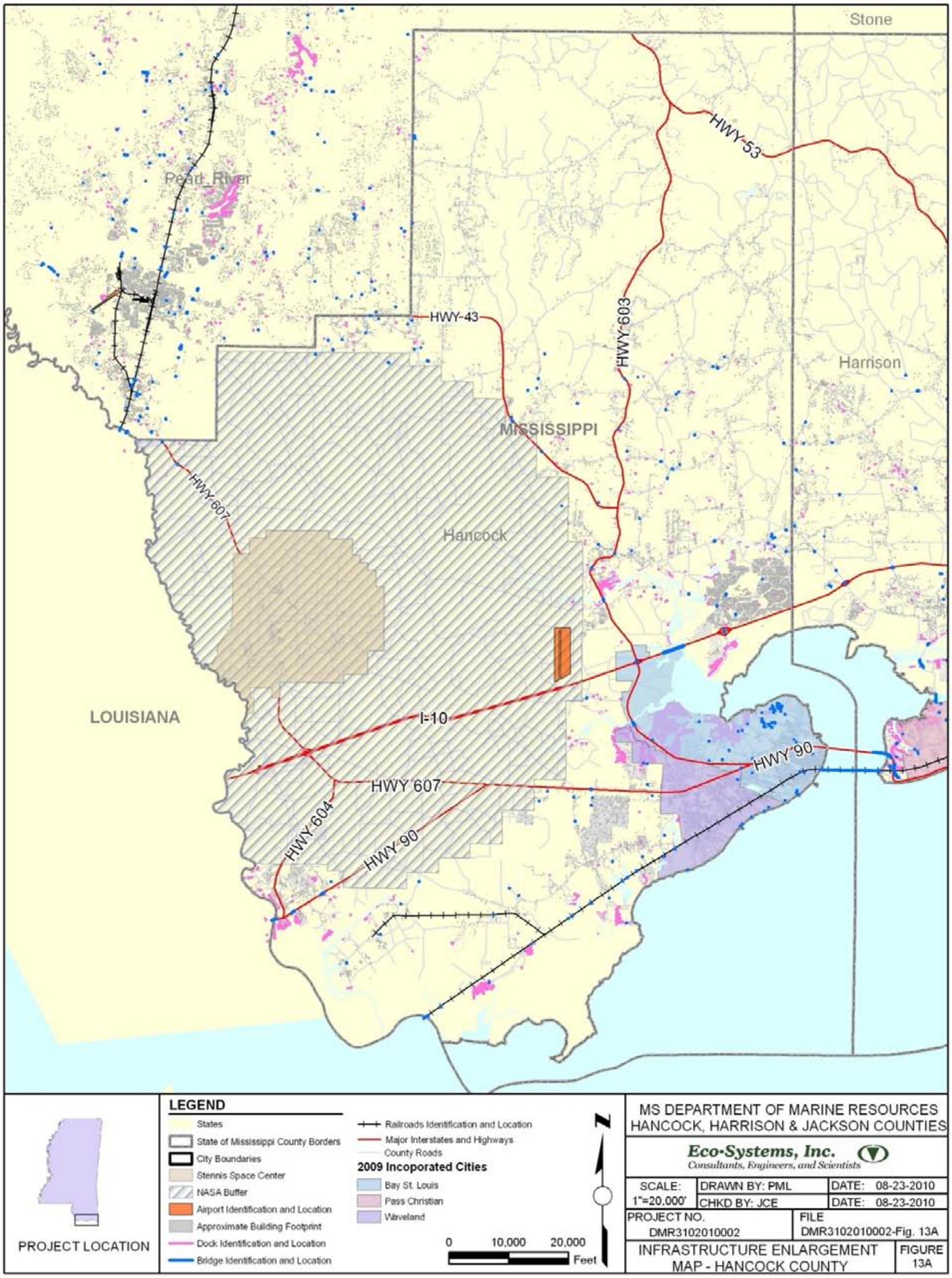
PROJECT NO. DMR3102010002
FILE DMR3102010002-Fig. 13
INFRASTRUCTURE KEY MAP
FIGURE 13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NASA Buffer
Airport Identification and Location
Approximate Building Footprint
Dock Identification and Location
Bridge Identification and Location
Railroads Identification and Location
Major Interstates and Highways
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HANCOCK, HARRISON & JACKSON COUNTIES
Eco-Systems, Inc.
Consultants, Engineers, and Scientists
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DATE: 08-23-2010
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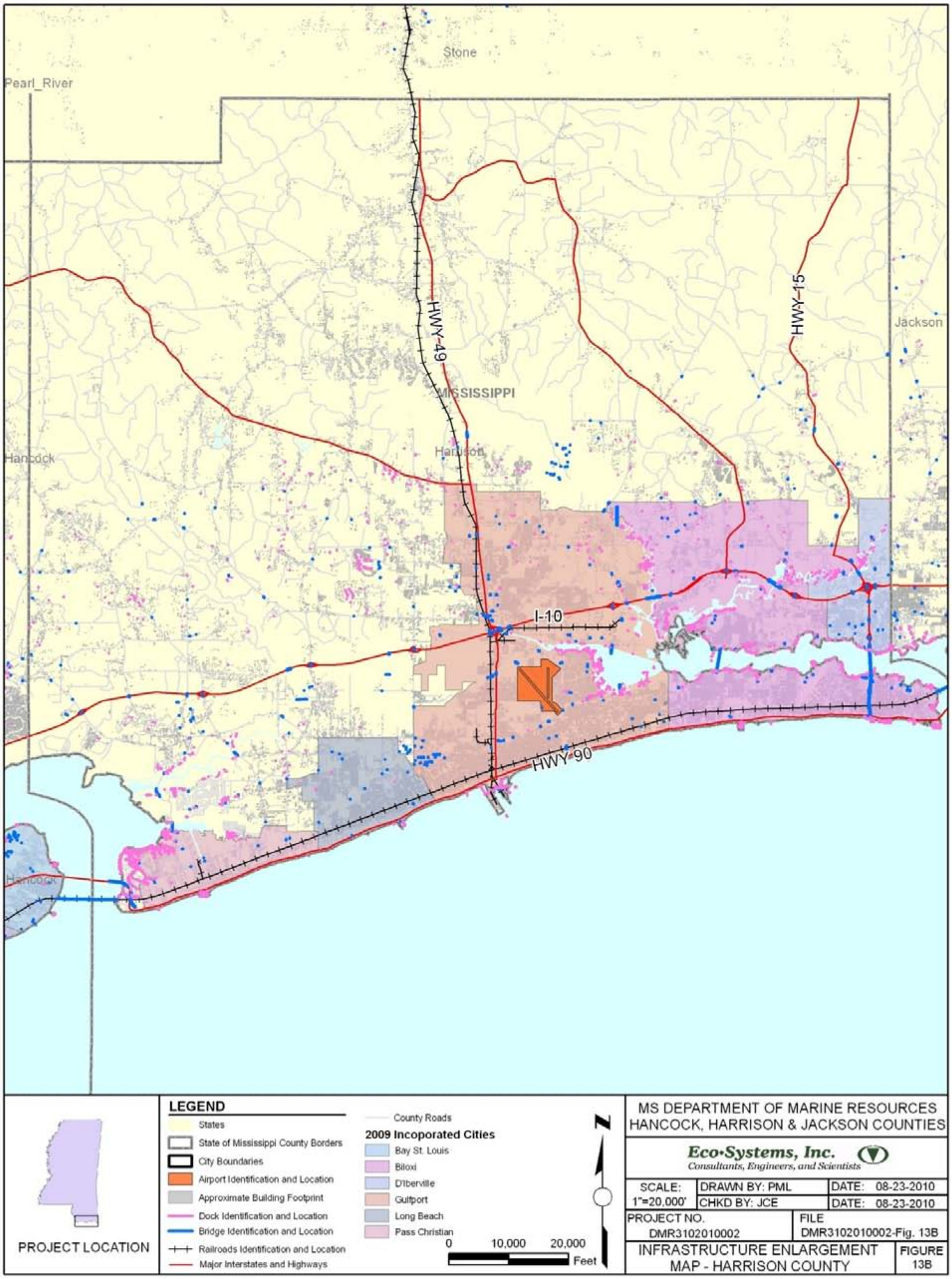
DATE: 08-23-2010
PROJECT NO. DMR3102010002
FILE DMR3102010002-Fig. 13A
INFRASTRUCTURE ENLARGEMENT MAP - HANCOCK COUNTY
FIGURE 13A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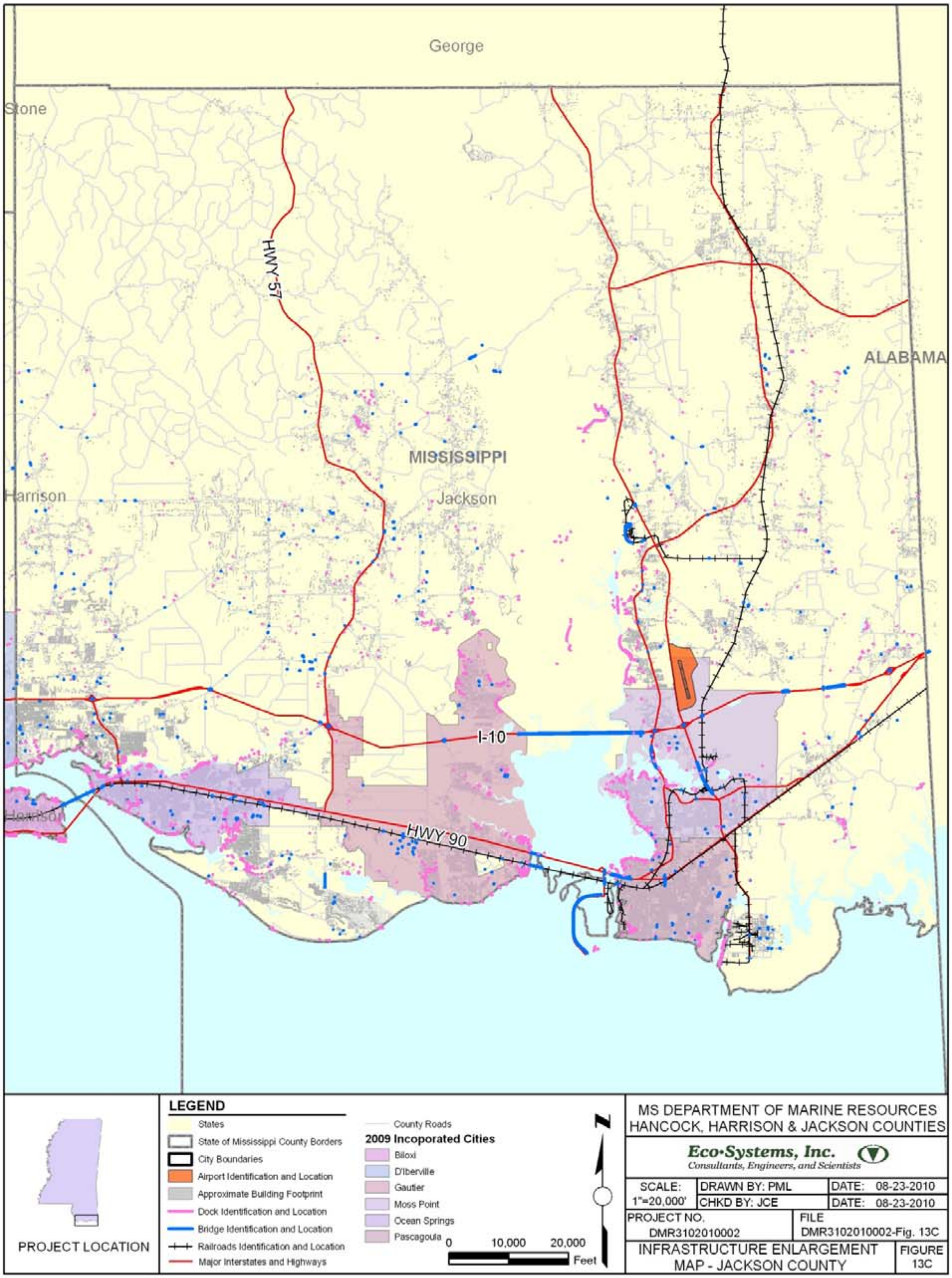
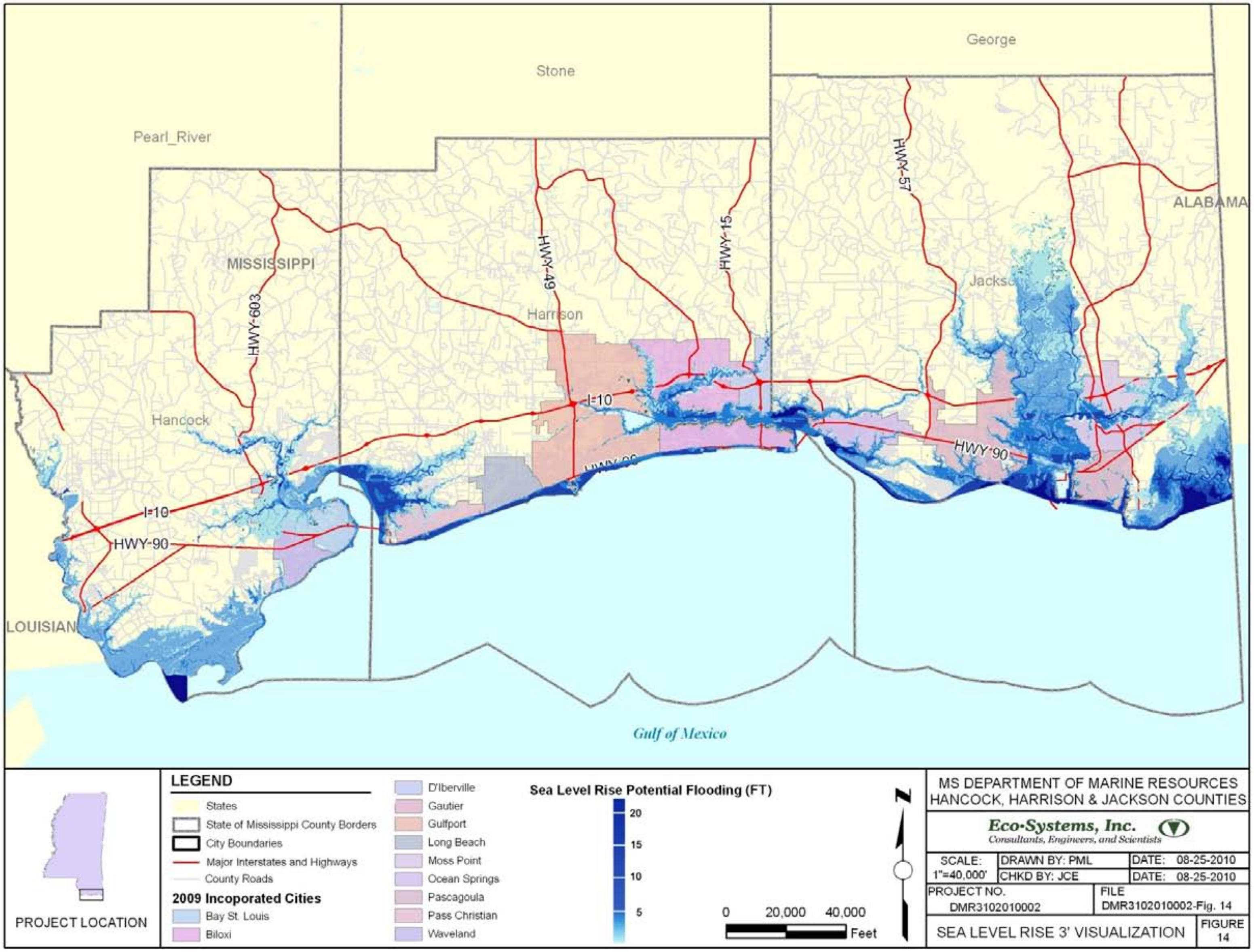
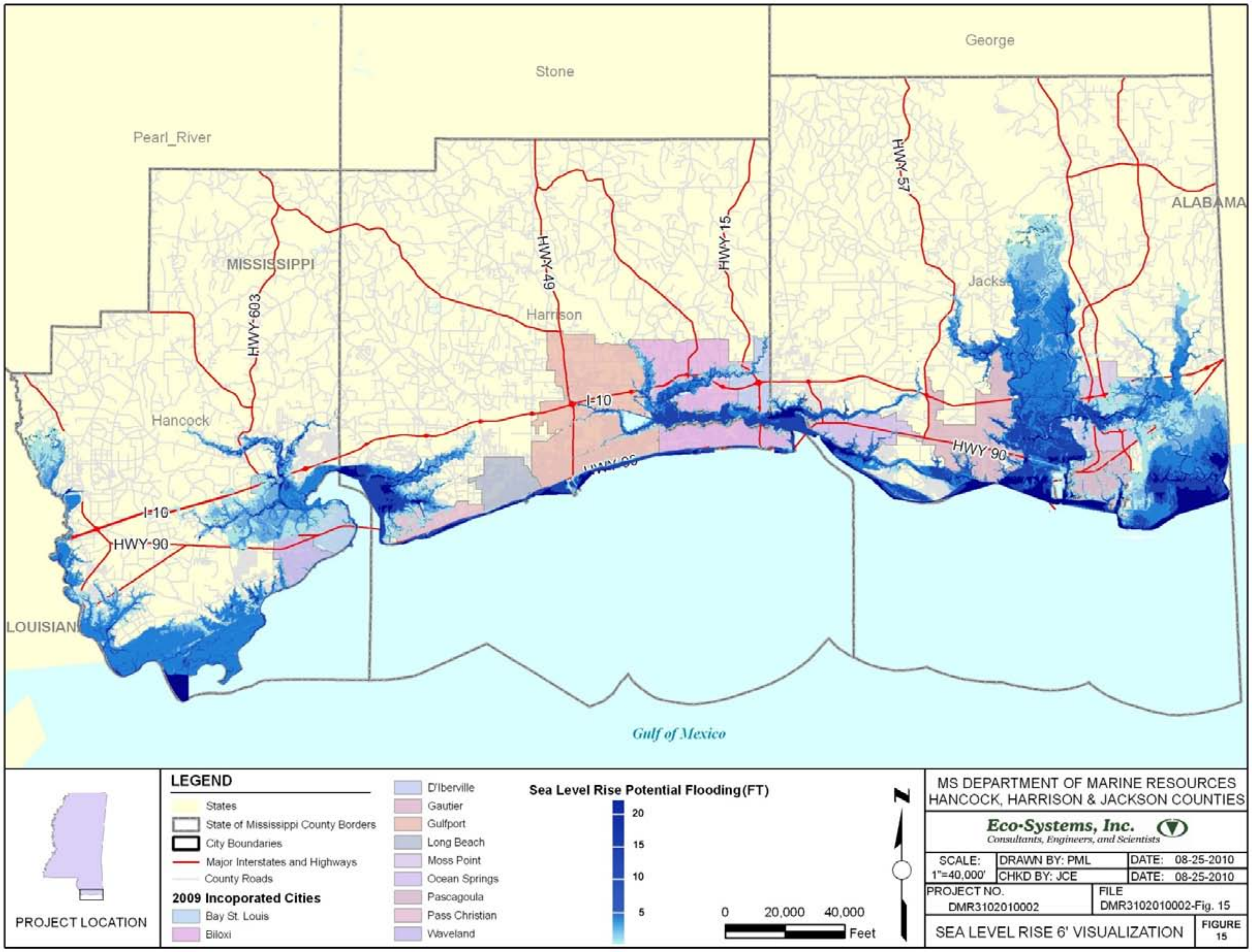
Approximate Building Footprint
Dock Identification and Location
Bridge Identification and Location
Railroads Identification and Location
Major Interstates and Highways
County Roads
2009 Incoporated Cities
Bay St. Louis
Biloxi
D'Iberville
Gulfport
Long Beach
Pass Christian
0 10,000 20,000
Feet
MS DEPARTMENT OF MARINE RESOURCES
HANCOCK, HARRISON & JACKSON COUNTIES
Eco-Systems, Inc.
Consultants, Engineers, and Scientists
SCALE: 1"=20,000'
DRAWN BY: PML
DATE: 08-23-2010
CHKD BY: JCE
DATE: 08-23-2010
PROJECT NO. DMR3102010002
FILE DMR3102010002-Fig. 13B
INFRASTRUCTURE ENLARGEMENT MAP - HARRISON COUNTY
FIGURE 13B


George
Stone
HWY-57
ALABAMA
MISSISSIPPI
Harrison
Jackson
I-10
HWY 90
Harrison
PROJECT LOCATION
LEGEND
States
State of Mississippi County Borders
City Boundaries
Airport Identification and Location
Approximate Building Footprint
Dock Identification and Location
Bridge Identification and Location
Railroads Identification and Location
Major Interstates and Highways
County Roads
2009 Incoporated Cities
Biloxi
D'Iberville
Gautier
Moss Point
Ocean Springs
Pascagoula
0
10,000
20,000
Feet
MS DEPARTMENT OF MARINE RESOURCES
HANCOCK, HARRISON & JACKSON COUNTIES
Eco•Systems, Inc.
Consultants, Engineers, and Scientists
SCALE: 1"=20,000'
DRAWN BY: PML
DATE: 08-23-2010
CHKD BY: JCE
DATE: 08-23-2010
PROJECT NO. DMR3102010002
FILE DMR3102010002-Fig. 13C
INFRASTRUCTURE ENLARGEMENT MAP - JACKSON COUNTY
FIGURE 13C


George
Stone
Pearl_River
MISSISSIPPI
HWY-603
HWY-49
HWY-15
HWY-57
Harrison
Hancock
Jackson
ALABAMA
I-10
HWY-90
LOUISIANA
Gulf of Mexico
LEGEND
States
State of Mississippi County Borders
City Boundaries
Major Interstates and Highways
County Roads
2009 Incoporated Cities
Bay St. Louis
Biloxi
D'Iberville
Gautier
Gulfport
Long Beach
Moss Point
Ocean Springs
Pascagoula
Pass Christian
Waveland
Sea Level Rise Potential Flooding (FT)
20
15
10
5
0 20,000 40,000
Feet
PROJECT LOCATION
MS DEPARTMENT OF MARINE RESOURCES
HANCOCK, HARRISON & JACKSON COUNTIES
Eco-Systems, Inc.
Consultants, Engineers, and Scientists
SCALE: 1"=40,000'
DRAWN BY: PML
DATE: 08-25-2010
CHKD BY: JCE
DATE: 08-25-2010
PROJECT NO. DMR3102010002
FILE DMR3102010002-Fig. 14
SEA LEVEL RISE 3' VISUALIZATION
FIGURE 14


George
Stone
Pearl_River
ALABAMA
MISSISSIPPI
Harrison
Hancock
Jackson
LOUISIANA
HWY-603
HWY-49
HWY-15
HWY-57
I-10
HWY-90
Gulf of Mexico
LEGEND
States
State of Mississippi County Borders
City Boundaries
Major Interstates and Highways
County Roads
2009 Incoporated Cities
Bay St. Louis
Biloxi
D'Iberville
Gautier
Gulfport
Long Beach
Moss Point
Ocean Springs
Pascagoula
Pass Christian
Waveland
Sea Level Rise Potential Flooding(FT)
20
15
10
5
0 20,000 40,000
Feet
PROJECT LOCATION
MS DEPARTMENT OF MARINE RESOURCES
HANCOCK, HARRISON & JACKSON COUNTIES
Eco-Systems, Inc.
Consultants, Engineers, and Scientists
SCALE: 1"=40,000'
DRAWN BY: PML
DATE: 08-25-2010
CHKD BY: JCE
DATE: 08-25-2010
PROJECT NO. DMR3102010002
FILE DMR3102010002-Fig. 15
SEA LEVEL RISE 6' VISUALIZATION
FIGURE 15

Appendix B – Endnotes

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