Texas Coastal Resiliency Study
Final Report

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Prepared for:

Texas General Land Office

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Executive Summary

The main objective of the Texas Coastal Resiliency Study (TCRS) was to identify the critical infrastructure assets within the coastal county project study area that are most vulnerable to future storm impacts similar to those experienced during Hurricanes Dolly and Ike. During this project, CB&I identified existing projects and recommended new projects to mitigate potential damage to vulnerable infrastructure. These potential projects were then categorized according to risk based on an assessment of coastal storm impacts on vulnerable critical infrastructure. The categorized projects were then compiled into this document that can be used to aide communities in fast-tracking the application process in the event of a future storm.

The Resiliency Study was conducted over three separate phases: Phase I - Data Collection, Phase II - Resiliency and Infrastructure Assessments and Phase III - Final Project List and Report. Phase I was the discovery phase that is the foundation of all of the future analysis work that was conducted for the project. Work conducted during Phase I consisted primarily of collecting data and reports, conducting initial analysis, developing a database, tools and a spatial analysis platform and devising the methodology to carry out the resiliency and infrastructure assessments. Phase II of the study applied the information and spatial data compiled in Phase I to conduct assessments of critical infrastructure within the study area with the goal of developing a list of recommended projects. These potential projects were then categorized according to risk, based on an assessment of consequence and vulnerability of critical infrastructure. Phase III of the study consisted of the development of this document where the CB&I team created the final project portfolios and report containing the risk classified list of projects. These lists summarize the projects with the greatest impact on recovery and resiliency improvement in each of the communities evaluated in the study area.

CB&I conducted a comprehensive search to locate information related to the resiliency of the Texas coast, public awareness and preparedness and the vulnerability of local man-made infrastructure and natural resources within the Texas coastal counties. CB&I also identified and compiled similar studies conducted by other agencies and governmental entities pertaining to issues related to coastal resiliency. A searchable database was designed to house this information. Over 900 reports and documents were reviewed and an annotated bibliography describing the information contained in each entry was created.

Concurrent with this effort, spatial data for use in vulnerability and risk analysis was collected and incorporated into a Geographic Information System (GIS). This information included general basemap data, critical infrastructure data and hazard coverages. CB&I worked with the GLO to develop a list of infrastructure types that are critical to the resiliency of communities. The critical infrastructure data types were then grouped into seven general categories: Critical Facilities, Transportation, Energy/Industrial Facilities, Communications, Flooding, Environmental and Water Treatment/Waste. Spatial data representing each of these categories were located, formatted and incorporated into a GIS database for analysis. Five coastal hazards that could potentially impact critical infrastructure were also identified. These included flooding, storm surge, wave impacts, morphology and wind impacts. GIS coverages for each of the hazard types were developed. These hazard coverages were then used to create a composite hazard coverage that provides a spatial distribution of the combined risk.

During Phase II, the information and spatial data compiled in Phase I was used to conduct an assessment of critical infrastructure within the study area with the goal of developing a list of recommended projects prioritized for their impact in reducing risk. Projects were identified either as existing (previously proposed) projects or new projects through a series of technical working group meetings. The purpose of the meetings was to determine whether the existing, previously proposed projects had already been completed as well as to identify new projects that may benefit critical infrastructure protection within the respective communities. Working group meetings were organized through their respective Council of Governments (COGs) and were conducted COG by COG through the study area.

After the identification process was complete, confirmed existing and newly identified projects were entered into the GIS database according to the project type as well as the benefitted infrastructure type. A relative risk level was calculated for each project based on a vulnerability assessment due to coastal storm impacts. This methodology integrated the extensive infrastructure, hazard and project data identified and compiled in Phase I of the study with the local knowledge and expertise of the stakeholder communities. The hazard coverage maps developed in Phase I were used to determine vulnerability which was incorporated with a consequence scale to determine the relative risk level for each project. This relative risk determined the draft project ranking for each technical working group. The participants from each technical working group then reviewed the draft rankings prior to finalization of the project lists. Phase III of the study consisted of the development of this summary report.

Table of Contents

List of Figures

List of Tables

List of Appendices

List of Acronyms

API	Application Program Interface
ASCE	American Society of Civil Engineers
BEG	Bureau of Economic Geology
BOEM	Bureau of Ocean Energy Management
CBCOG	Coastal Bend Council of Governments
CB&I	Chicago Bridge & Iron
CEIS	Coastal Erosion Information System
CEPRA	Coastal Erosion Planning and Response Act
CIAP	Coastal Impact Assistance Program
COG	Council of Governments
CP	Communications Plan
DMP	Data Management Plan
DOT	Department of Transportation
EPA	Environmental Protection Agency
ESRI	Environmental Research Institute
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
GCRPC	Golden Crescent Regional Planning Commission
GIS	Geographic Information System
GLO	General Land Office
HGAC	Houston-Galveston Area Council
HRI	Harte Research Institute
LiMWA	Limit of Moderate Wave Action
LRGVDC	Lower Rio Grande River Valley Development Council
LSU	Louisiana State University
MEOW	Maximum Envelopes of Water/Wind
MoM	Maximum of Maximums
NFHL	National Flood Hazard Layer
NOAA	National Oceanic and Atmospheric Administration
PMP	Project Management Plan
SDE	Spatial Database Engine
SETRPC	Southeast Texas Regional Planning Commission
SLOSH	Sea, Lake and Overland Surge from Hurricanes
SSPEED	Severe Storm Prediction, Education and Evacuation from Disasters
SQL	Structured Query Search
TCOON	Texas Coastal Ocean Observation Network
TCRS	Texas Coastal Resiliency Study
THC	Texas Hurricane Center
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
UT	University of Texas

1.0 INTRODUCTION

Hurricanes Ike and Dolly made landfall in 2008. Hurricane Ike became the third costliest hurricane ever to make landfall in the United States and the costliest hurricane in Texas history. Hurricane Ike's storm surge rose over 20 feet and caused extensive damage. Hurricane Dolly, although much smaller, caused extensive flooding and damage in the Rio Grande Valley region of Texas. Combined, these storms caused more than $30 billion in damage to infrastructure, housing and ecological structures, plus an additional $142 billion in economic damage. In an effort to improve storm damage response efforts, CB&I was contracted by the Texas General Land Office (GLO) to identify projects that would help protect critical infrastructure from future coastal storms.

Project Goals and Objectives

The main objective of the Texas Coastal Resiliency Study (TCRS) was to identify the critical infrastructure assets within the twenty-two coastal county project study area (shown in Figure 1) that are most vulnerable to future storm impacts similar to those experienced during Hurricanes Dolly and Ike. During this project CB&I identified existing projects and worked with local stakeholders to develop new projects to mitigate potential damage to vulnerable infrastructure. These projects were then categorized according to risk based on an assessment of coastal storm impacts on vulnerable critical infrastructure. The categorized projects were then compiled into this document with the goal of the study to aide communities in fast-tracking the application process in the event of future storms.

The Resiliency Study was conducted over three separate phases: Phase I - Data Collection, Phase II - Resiliency and Infrastructure Assessments and Phase III - Final Project List and Report. Phase I was the discovery phase that was the foundation of all of the future analysis work conducted for the project. Work conducted during Phase I consisted primarily of collecting data and reports, conducting initial analyses, developing a database, tools and a spatial analysis platform and devising the methodology to carry out the resiliency and infrastructure. Phase II of the study applied the information and spatial data compiled in Phase I to conduct an assessment of critical infrastructure within the study area with the goal of developing a list of recommended projects. These potential projects were then categorized according to risk, based on an assessment of consequence and vulnerability of critical infrastructure. Phase III of the study consisted of the development of this document where the CB&I team created the final project portfolios and report containing the prioritized lists of projects. These lists summarize the projects with the greatest impact on recovery and resiliency improvement in each of the communities evaluated in the study area.

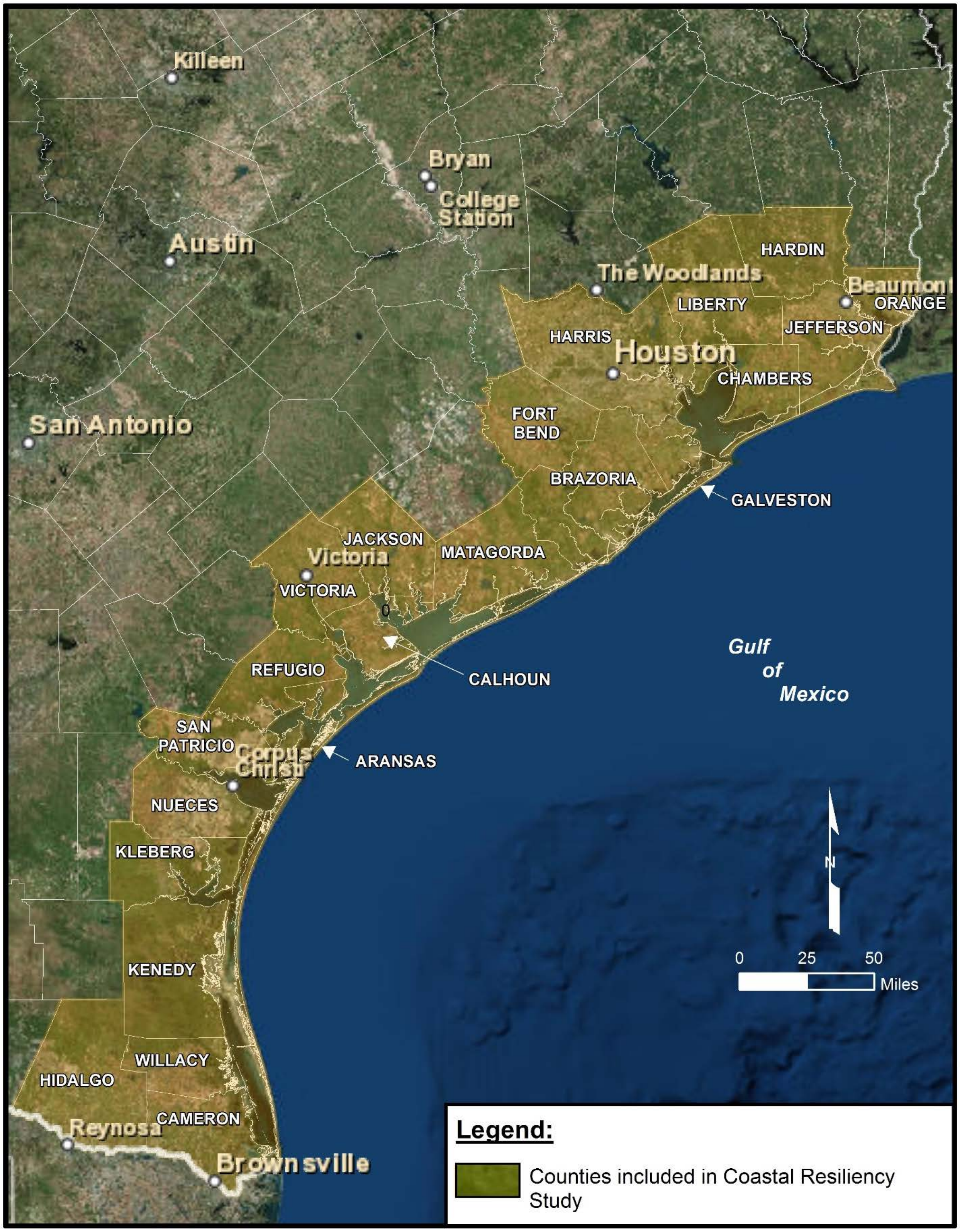


Figure 1. Twenty-two coastal Texas counties included in this study.

2.0 PHASE I PROJECT PLANNING, DATA COLLECTION AND DATABASE DESIGN

Phase I was primarily a data collection effort and included the identification and compilation of existing reports and spatial data; development of a database to house the information; report review; hazard analysis; and the development of a proposed methodology for the Phase II risk assessment. During Phase I, CB&I accomplished the following tasks:

1) Developed the following plans:
    a. Project Management Plan (PMP)
    b. GIS and Data Management Plan (DMP)
    c. Communications Plan (CP)
2) Compiled existing information related to the resiliency of the Texas coast, public awareness and preparedness and the vulnerability of infrastructure.
3) Compiled similar studies conducted by other agencies and governmental entities pertaining to issues related to coastal resiliency.
4) Created an annotated bibliography for the reports housed in the database.
5) Compiled spatial data related to critical infrastructure and hazards.
6) Developed a database and web-based GIS interface to allow the GLO and other parties to readily access the data compiled and collected over the course of the project.
7) Developed a proposed methodology for conducting the project identification and risk analysis to be conducted during Phase II.

Plan Development

Two documents were developed at the beginning of Phase I to provide an overview of key personnel, project tasks, GIS and data management. These guidance documents were intended to be "living" documents and were modified as necessary throughout the life of the project.

The Project Management Plan summarized the tasks conducted over the course of the project and documented any updates made to the work plan. It also provided an overview of the schedule, key personnel and their roles in the project.

The GIS and Data Management Plan served as a companion document to the Project Management Plan. It outlined how the CB&I team managed documents and data collected in support of the Texas Coastal Resiliency Study and how data was compiled, tracked, reviewed and stored. It provided the guidelines for data compilation, data formatting and quality assurance and quality control procedures (QA/QC) used in the project. This document defined the roles of the key personnel on the data management team and described the development and maintenance of the database and web-based GIS interface. The information from both of these plans is provided in the Phase 1 report.

Data Collection, Formatting & Storage

Phase I of this study included an extensive data collection effort. In this work, CB&I conducted a comprehensive search to locate information related to the resiliency of the Texas coast, public awareness and preparedness and the vulnerability of local man-made infrastructure and natural resources within the Texas coastal counties. CB&I also identified and compiled similar studies conducted by other agencies and governmental entities (in Texas and in other States) pertaining to issues related to coastal resiliency. During this phase, CB&I worked with the GLO to determine design and hosting requirements of a web-based GIS internet service that allowed the GLO and interested parties to readily access the data compiled and collected over the course of this project via the web. CB&I also worked with the GLO to establish risk-based criteria that was used to help identify and assess projects during the Phase II of the study.

Report and Data Types

During Phase 1, CB&I collected information from documents that generally were classified into eleven different report types as defined in Table 1. In addition to reports and other documents, existing digital data that assisted in the resiliency assessments was compiled for the communities within the project area. Data included existing hazard coverages, critical infrastructure locations as well as FEMA repetitive loss data.

Table 1. Results of Phase I report compilation.

Report Type	Number of Reports Uploaded
Assessment Methodology	105
Budget	12
Emergency Response Plans	131
Energy Infrastructure	22
Engineering/Infrastructure	68
Environmental	142
Floods	50
Local Plans	88
Regulation, Policy and Grants	74
Resiliency Planning (General and How-To)	152
Specific Disaster Information	70
Total:	**914**

Data Sources

A data source is a general location where resiliency information or data is anticipated to be found and is generally based on the agency or other institution that is housing the data (i.e. FEMA, Army Corps of Engineers, Texas A&M University). Based on knowledge of agencies and consultants located in Texas as well as major spatial data providers, CB&I developed a preliminary list of fifty-two potential sources that were anticipated to contain documents and spatial data relevant to this study. This list included educational institutions, consultants and local, state and federal agencies. This list is provided in Table 2 and was used by the data management team to track which resources had been reviewed for data. The list was modified as additional data sources were identified. When the review was complete the reports were obtained from eighty-two different sources, and spatial data were obtained from eighty-four different sources.

Table 2. Preliminary list of potential data sources.

Source Name	Source Name
American Society of Civil Engineers	National Science Foundation
AECOM	Nature Conservancy
Bureau of Economic Geology (BEG)	New York State Department of State
Bureau of Ocean Energy Management (BOEM)	NOAA
Coastal Bend, Bays and Estuaries Program	Rice University
Mission Aransas National Estuarine Reserve	SeaGrant
CB&I (Coastal Planning & Engineering)	Siemens
Coast & Harbor Engineering, Inc.	Texas A&M University
Dannenbaum Engineering Corporation	Texas Beach Watch Program
Department of Transportation	Texas Coastal Hazard Analysis Resources & Tech.
Emergency Operations Centers	Texas Coastal Management Program
Emergency Management	Texas Coastal Planning & Response Act
Entergy	Texas Commission on Environmental Quality
Environmental Defense Fund	Texas Department of Public Safety
Environmental Protection Agency	Texas Division of Emergency Management
FEMA	Texas General Land Office
Geological Survey of Texas	Texas Natural Resources Information System
Gulf of Mexico Alliance	Texas Parks and Wildlife Department
Harte Research Institute	The Infrastructure Security Partnership
HDR Engineering, Inc.	The Perryman Group
HUD	University of Texas
Independent Insurance Agents of Texas	Urban Land Institute
Institute for Business and Home Safety	USACE
International Union for Conservation of Nature	U.S. Coast Guard
LSU Coastal Sustainability Studio	U.S. Department of the Interior
National Infrastructure Advisory Council	U.S. Fish and Wildlife Service
National Research Council	

Report Review

Reports were uploaded in pdf format and the database was also populated with basic information about each report for the annotated bibliography. The reports were reviewed and a short summary of each report and a list of keywords that best reflected the content of each report were developed and uploaded to the database. During the review, any useful data was also identified and extracted. This typically consisted of existing projects from planning documents or spatial data related to critical infrastructure, existing projects or hazards. When projects were identified, key information about those projects were entered into the database. All document and data entry and uploads were done through the project interface, via the Microsoft SQL Server database. This database was spatially enabled with ESRI's SDE database technology.

Upon completion of Phase I, nine hundred and fourteen reports had been uploaded to the database and reviewed (Table 1). The majority of these reports were related to assessment methodology, emergency response, environmental issues and resiliency planning. These documents were summarized in the Phase I report.

Spatial Data Collection

To meet the objectives of this project, extensive spatial data were collected and formatted to develop a GIS database. GIS was selected as the analysis platform. The GIS database was populated during Phase I to include basemap features as well as hazard coverages, which are described below.

Basemap Data

Basemap data included place names, land use, demographics, repetitive loss data, existing projects and critical infrastructure. Critical infrastructure was defined as the assets or systems that if damaged or destroyed would have a debilitating effect on the community. During Phase I, a list of critical infrastructure to be evaluated during this project was developed. An initial list was generated by CB&I based on a literature review of coastal resilience indices and self-assessments. CB&I then worked with the GLO to refine the critical infrastructure types. The list of infrastructure types that was developed is provided in Table 3.

The critical infrastructure data types were then grouped into seven general categories: Critical Facilities, Transportation, Energy/Industrial Facilities, Communications, Flooding, Environmental and Water Treatment/Waste. Individual data types within the categories were reviewed in aggregate to ensure that the most important data sets were included on the list. Once the list was finalized, spatial critical infrastructure data were located, formatted and incorporated into a GIS database for analysis. This data included, but was not limited to: dikes, levees, vessel/shipping routes, major ports, pipeline and cable routes, nuclear power plants, refineries, chemical plants, locations of alternative energy sources (i.e. windfarms), evacuation routes, emergency shelters, emergency operation centers and areas of service and transportation routes (air and rail).

Table 3. Critical infrastructure types with samples of data within each category.

Critical Facilities	Transportation
Government Buildings	Streets
Communications Office/Substations	Aviation Transportation
Correctional Facilities	Evacuation Routes
Emergency Shelters (Including Animal)	Bridges
Emergency Operations Center	Rail Transportation
Law Enforcement Facilities	Ferries
Schools	Public Transportation
Fire Stations	Low Water Crossings
Critical Records Storage	Ports
Hospitals	
Financial Institutions	
Energy/Industrial Facilities	**Communications**
Power Plants	Phone Lines
Power Grids	Cell Phone Towers
Alternate Energy Sources	Fiber Optic Cables
Chemical Plants/Refineries	Early Warning Systems
Chemical Storage	Radio Systems
Oil & Gas Infrastructure	Information Technology
Flooding	**Environmental**
Flood Control Structures	Artificial Reefs
Water Flow and Stage Gauges	Environmentally Sensitive Area
Drainage Structures	Wildlife Refuge
Coastal Protection Structures	Fisheries
Water Treatment/Waste	
Waste Disposal Facilities	
Water Treatment Plants	
Wastewater Treatment Plants	

Basemap Formatting

Spatial data was formatted for incorporation into the database. The extent and type of formatting was dependent on the original data format. For example, tabular data was converted to shapefiles, while images were georectified and data digitized from them, if possible. Fields in existing shapefiles were added or modified for future analysis. If no metadata existed, new metadata was created using FGDC compatible metadata standards.

Basemap QA/QC Procedures

Following data formatting, an independent review of the files for data integrity and completeness was conducted by a data analyst. This review included verification of the projection and datum, testing of the functionality of hyperlinks, and a comparison between the original data and the final formatted data to ensure completeness and accuracy. In addition, each dataset was plotted to visually verify that the data was geographically correct. The corrected files were then submitted to the data manager for a final review and completeness assessment. The data manager also reviewed the data for redundancy, metadata completeness and accuracy and performed a geographic assessment of each dataset. Any issues identified by the data manager were corrected and the revised data was reviewed again before being finalized.

Basemap Database Upload

The formatted data was passed to the Lead GIS Analyst. This data was grouped into feature classes based on the critical infrastructure types identified in Table 3. Attribute tables for these feature classes were developed based on the commonality of the attributes from the original different data sources and needs of this study. Once all of the data was uploaded into the database, a final QA/QC effort was undertaken. During this process, the data was reviewed for gaps and, where necessary, additional data was identified.

Hazard Analyses

A hazard is a source of potential danger or risk. Therefore, a hazard coverage represents the area that would be impacted by a specific hazard. Five coastal hazards associated with coastal storms that could potentially impact critical infrastructure were identified in coordination with the GLO. Since the main objective of this study was to evaluate vulnerability due to coastal storms similar to Hurricanes Ike and Dolly, the selected hazards were directly related to the risks associated with hurricanes. The selected hazards types evaluated were: flooding, storm surge, wave impacts, morphology and wind impacts. GIS hazard coverages for each of the hazard types were identified and used in the Phase II spatial vulnerability assessments.

To identify hazard coverages for incorporation into the database, existing hazard coverages and modeling data were reviewed (CB&I, 2014). Since coastal processes related to hurricanes along the Texas coast have been extensively modeled by academic groups, government agencies and private consultants, it was determined that no new modeling analysis would be required. Of the existing data, multiple data sets relating to each of the primary hazards were identified and compared to one another to assess the quality, completeness and relevance of each data set. For each hazard type (flooding, storm surge, wave impacts, morphology and wind impacts), the datasets that were found to be most suitable for incorporation in a vulnerability analysis were then reviewed for gaps in data coverage.

Relevant hazard data were reviewed from thirty-four sources which included academic institutions, consultants and local, state and federal agencies. A list of sources used is provided in Table 4. The results of the data review and recommendations for each of the relevant hazard types are provided in Table 5.

Table 4. List of data sources assessed during the data review and compilation.

Source Name	Source Name
American Society of Civil Engineers (ASCE)	Taylor Engineering, Inc.
Arcadis	Texas A&M University
Bureau of Economic Geology (BEG)	Texas Coastal Hazard Analysis Resources & Tech.
Department of Transportation (DOT)	Texas Coastal Management Program
Entergy	Texas Coastal Ocean Observation Network (TCOON)
Environmental Protection Agency (EPA)	Texas General Land Office (GLO)
Environmental Systems Research Institute (ESRI)	Texas Hurricane Center for Innovative Technology
Federal Emergency Management Agency (FEMA)	Texas Natural Resources Information System
Harris County, TX	Texas Tech University
Harte Research Institute (HRI)	Texas Water Development Board
Industrial Development Corp. of City of Galveston	University of Texas (UT)
Louisiana State University (LSU)	U.S. Army Corps of Engineers (USACE)
National Research Energy Laboratory	U.S. Department of Homeland Security, National Infrastructure Simulation and Analysis Center
National Oceanic and Atmospheric Administration (NOAA)	United States Geological Society (USGS)
Rice University, Severe Storm Prediction, Education and Evacuation from Disasters (SSPEED) Center	University of Notre Dame
Sandia National Laboratories	University of Pennsylvania
SeaGrant	Woods Hole Research Center

Hazard coverage needs for the study area were met by utilizing the existing hazard data and analysis of the existing data sets. The selected datasets for each of the 5 hazard coverages is provided in Table 5 and discussed in detail below.

Table 5. Selected Hazard Coverage Sources.

Hazard	Hazard Data Source
Flooding	FEMA Flood Insurance Rate Maps (FIRM)
Storm Surge	NOAA Sea, Lake and Overland Surge from Hurricanes (SLOSH) Maximum of Maximums (MoMs) model
Wave Impacts	FEMA Limit of Moderate Wave Action (LiMWA) contour data
Morphology	USGS Coastal Vulnerability Index shoreline change data
Winds	Texas A&M Wind Risk Zones based on Maximum Envelopes of Water/Wind (MEOW) model supplemented with observed wind data from the Texas Hurricane Center for Innovative Technology (THC)

Flood Coverage

The flood hazard coverage represents inundation of normally dry land. FEMA defines flooding as a general and temporary condition of partial or complete inundation of two or more acres of normally dry land area or two or more properties from overflow of inland or tidal waters, mudflow or unusual and rapid accumulation or runoff of surface waters from any source (FEMA, 2013).

The flood coverage selected for the project was derived from the Flood Insurance Rate Maps (FIRM) published by FEMA (FEMA, 2012). These maps provide full coverage of the study area. FIRM data were used throughout the study area, an example of this coverage is provided in Figure 2.

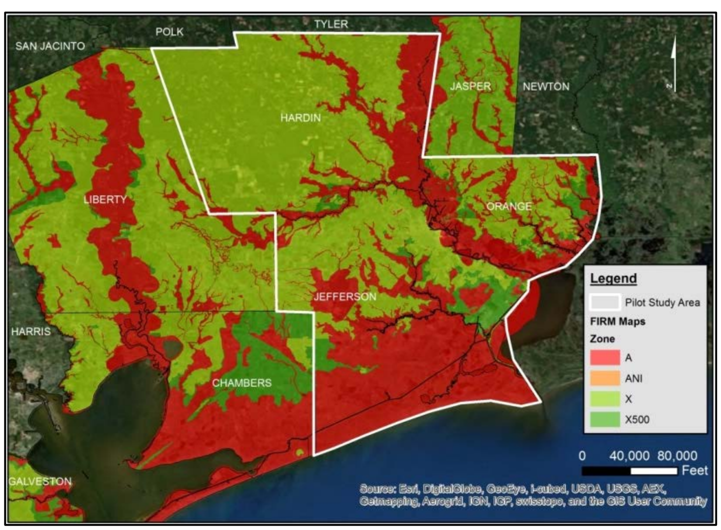


Figure 2. Example FEMA Flood Insurance Rate Maps (FIRM) data.

Storm Surge Coverage

The storm surge hazard coverage represents a rising of water levels as a result of atmospheric pressure changes and wind associated with a storm. It is described by NOAA as an abnormal rise of water generated by a storm over and above the predicted astronomical tide. The maximum potential storm surge for a particular location depends on a number of factors including storm characteristics (intensity, forward speed, size, angle of approach to the coast, central pressure), the shape and characteristics of coastal features (i.e. bays and estuaries) and the width and slope of the continental shelf. NOAA's Sea, Lake and Overland Surge from Hurricanes (SLOSH) Maximum of Maximums (MOMs) model data was applied to the Phase II risk assessment (NOAA, 2013). An example of these data are shown in Figure 3.

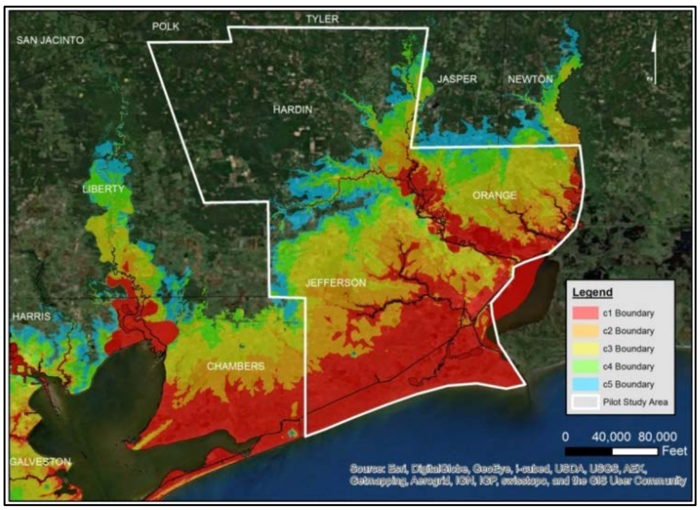


Figure 3. Example Storm surge data obtained from NOAA.

Morphology Coverage

The morphology hazard coverage represents changes to coastal characteristics as a result of wind or wave action that may result in changes in erosion rates, storm response, etc. The morphology hazard coverage (Figure 4) is from the U.S. Geological Survey (USGS) National Assessment of Coastal Vulnerability, which quantifies shoreline change on barrier islands and in bays (USGS, 2000). These data were derived from the Coastal Erosion Information System (CEIS), reports, shoreline change maps, field surveys and aerial photographic analysis.

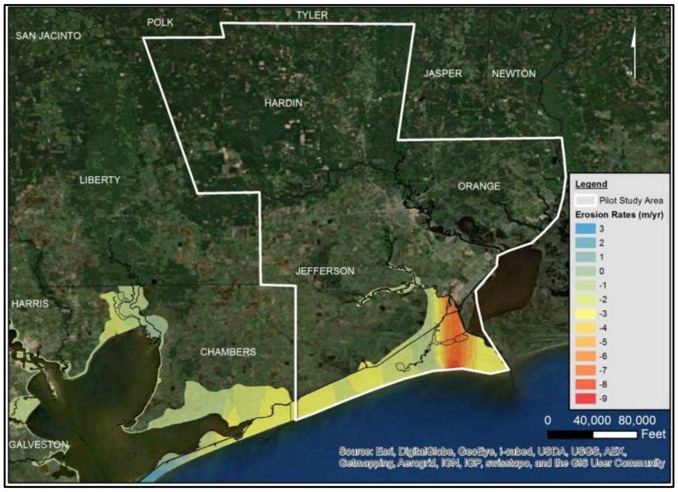


Figure 4. Example Morphology hazard coverage from the USGS National Assessment of Coastal Vulnerability and Shoreline Change on Barrier Islands and in Bays.

Wave Coverage

The wave hazard coverage represents destructive forces generated by wave action during hurricanes or storms. These destructive forces migrate inland due to storm surge inundation. FEMA's Limit of Moderate Wave Action (LiMWA) contour was selected to be used in the Phase II risk assessment. The LiMWA identifies areas that will be affected by waves with a 1.5 foot wave height or greater within the coastal A Zone. It is likely that properties and structures within the LiMWA will receive substantial damage from wave action during a one-percent-annual-chance (100 year) flood event. This contour was used to define the areas along the Texas coast that are at the highest risk for structural damage due to wave impacts. Figure 5 shows an example of the LiMWA data incorporated into the Phase II risk assessment. This contour represents the approximate landward limit of the 1.5 ft breaking wave on flood maps and is included in the FEMA FIRM maps and was used to determine the landward limit of wave propagation during storms.

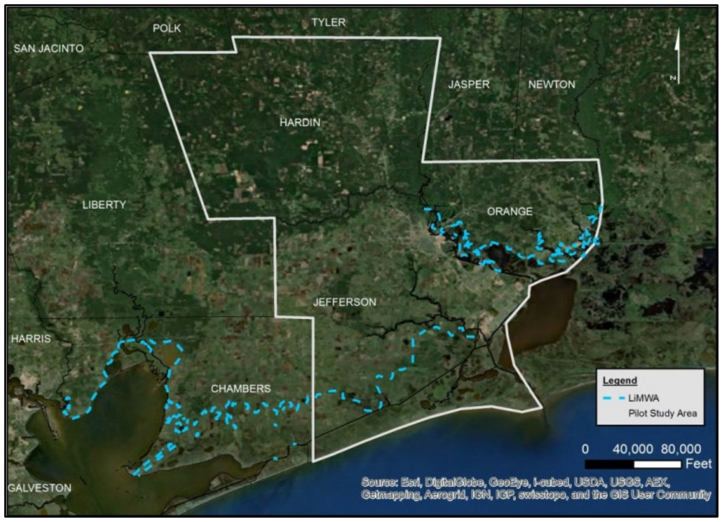


Figure 5. Example LiMWA contour data obtained from FEMA.

Wind Coverage

The wind hazard coverage represents the risk or threat to communities and infrastructure caused by extreme wind events such as hurricanes or tornados. In Phase II, the Maximum Envelopes of Water (MEOW) developed by Texas A&M University and described by Peacock *et al.* (2009) were used to assess wind impact risk. This data is available throughout the eighteen coastal counties in Texas. However, data coverage was not available in Hardin, Fort Bend and Hidalgo Counties. In the areas without MEOW coverage, the data was interpolated using the general trends of data in the surrounding areas. An example of this data is shown in Figure 6.

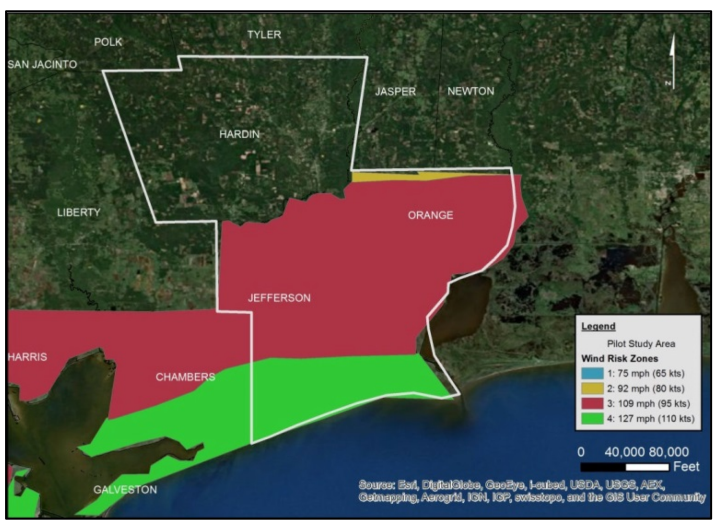


Figure 6. Wind Risk Zones based on the MEOW developed by Texas A&M and described by Peacock *et al.*, 2009.

Composite Coverages

Each of the five hazards identified for the Phase II analysis are associated with hurricane impacts. During a single hurricane event, storm surge, flooding, high winds and waves, and erosion all are potential simultaneous risks. Developing composite maps integrated the potential impacts from identified hazards. Figure 7 depicts a representation of composite map development.

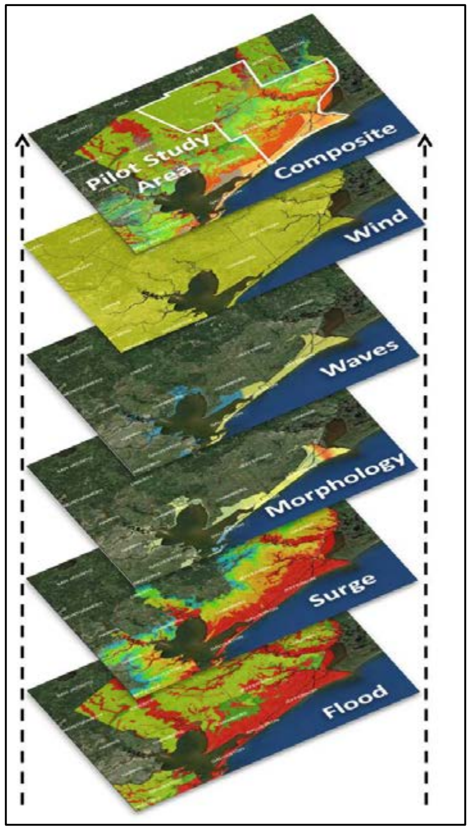


Figure 7. Example Composite Map Layering.

Composite maps are generated by overlaying the hazards to determine where the regions of highest vulnerability exist. The hazard coverages used to develop a composite map are based on studies with different accuracies, assumptions, and bias. The scales and units of the results are often not the same. Hazard coverages may be presented in terms of magnitude, frequency or area of effect. In order to develop a meaningful composite, the various data types and scales must be properly weighted to best normalize the vulnerability represented.

The coverages used to develop the composite were weighted based on the specific hazard categories for each individual dataset. For example, for the flood hazard category, different FEMA flood zones were weighted against each other in terms of likelihood of occurrence; while storm surge is based on the maximum inundation that is expected to be caused based on the Saffir-Simpson Hurricane Scale categories. Each coverage is a raster image with 100 ft cell size. Raster images maintain values of each cell. In this case, the values are related to the vulnerability scale.

Database Development

In Phase I, CB&I developed a database with a web interface to house and track all report, project and GIS information and to facilitate record collection and maintenance. One of the main goals of this database was to improve data quality by enforcing standard nomenclatures during the literature and data collection phase of this project.

Database Design & Structure

CB&I designed a project-specific web-based database that allows spatial viewing and analysis of the digital data. All project documents, project information and spatial data were stored within a Microsoft SQL Server database. The database is spatially enabled with ESRI's SDE database technology. The SQL database integrated the project geographic information system (GIS) to provide mapping and GIS querying and functionality. CB&I stored all of the data compiled during Phase I, as well as the project information gathered during Phase II in this database. The database structure was standardized and enforced through a user interface that was designed for this project. Tools were developed to facilitate data analysis and to automatically export standardized reports and summary worksheets that were used in the final report. Upon conclusion of the project, the Microsoft SQL Server database was provided to the GLO for future administration.

Website

The database structure was standardized and enforced through a web-based user interface that was designed specifically for this project. All data entry and uploads were completed through this interface.

Mapping

An interactive web map was built utilizing ESRI's Javascript API. The goal was to aid in the visualization of the data compiled during this study and to help identify gaps in the data. The web map interface is shown below in Figure 8 and can also be accessed through the website discussed above. The website basemap utilizes ESRI's ArcGIS online basemap services, including imagery, streets and topography.

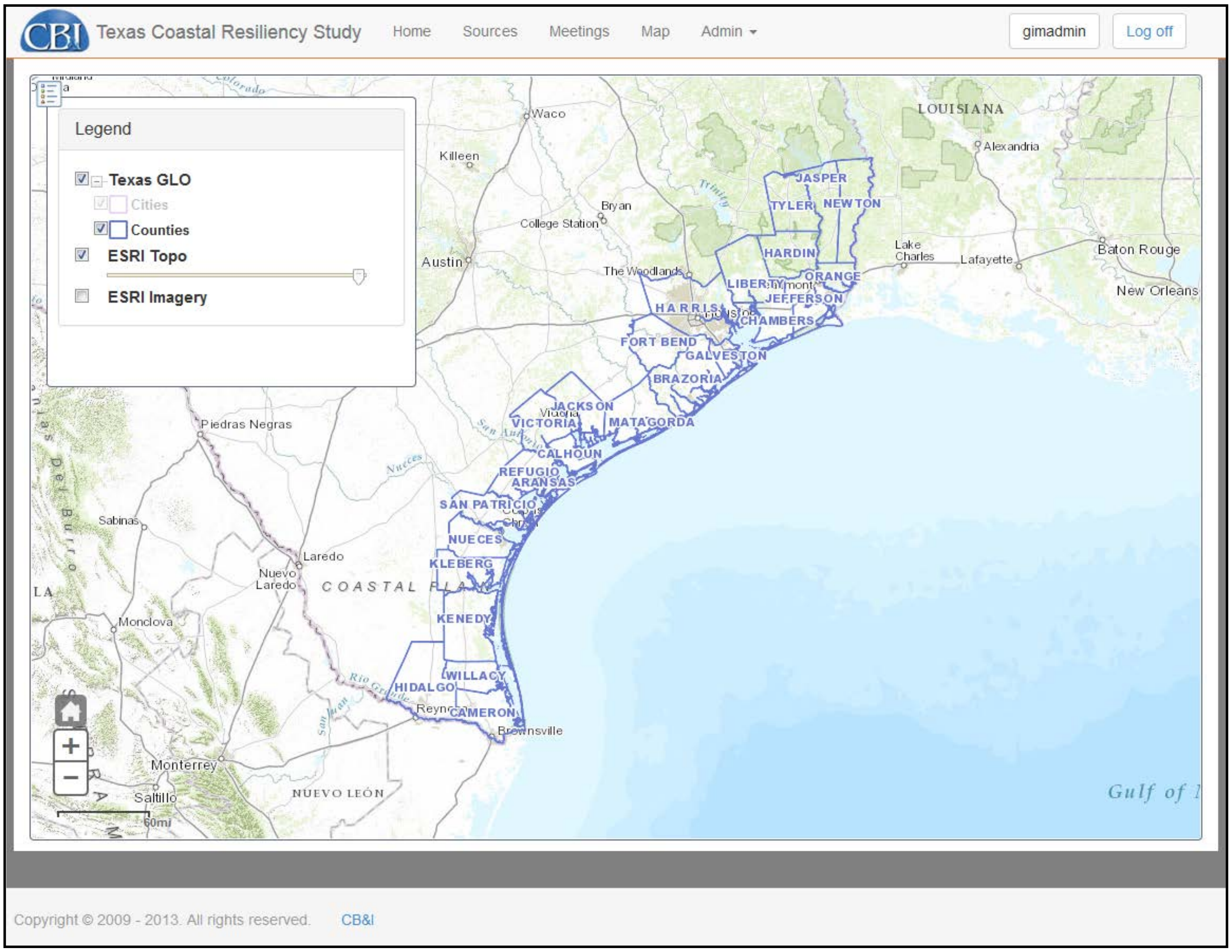


Figure 8. Map interface.

Security

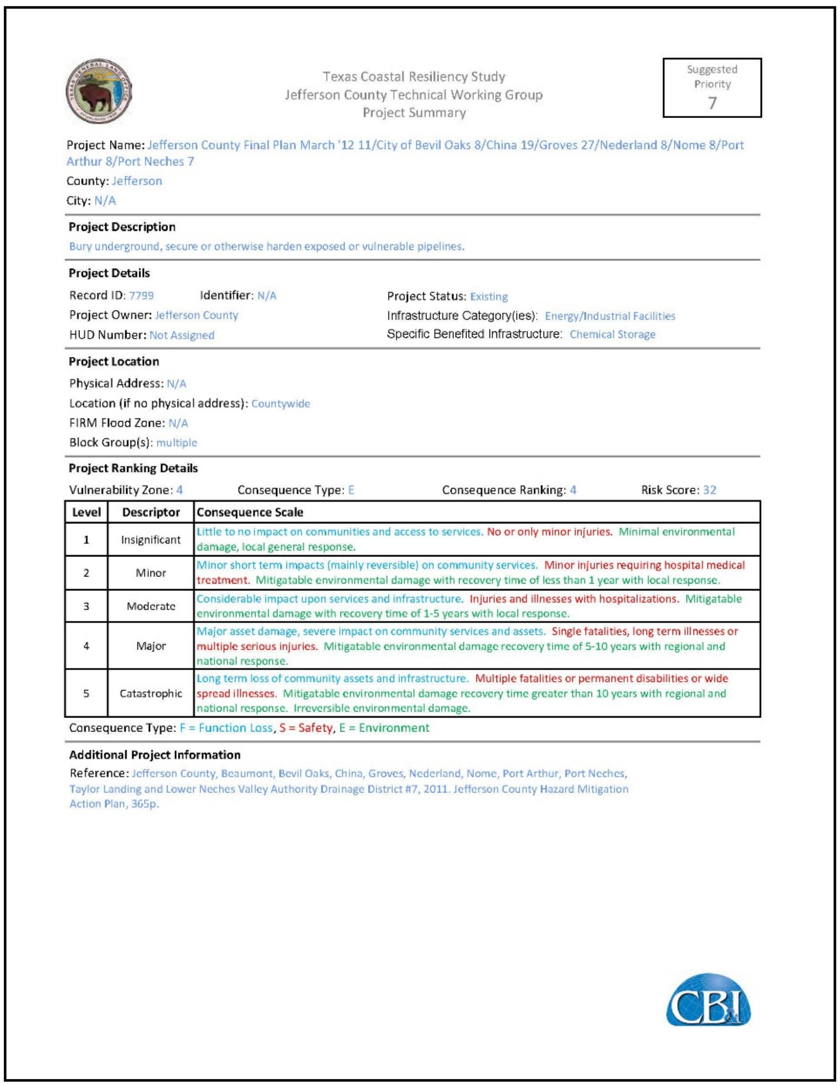
The Texas GLO project was developed as a Microsoft MVC ASP.NET 4.5 website. It utilized standard ASP.NET Simple Membership with Role-based security for website authentication. This allowed the site administrator to assign unique user names and passwords to access the database, and allowed permission and access restrictions to be managed. Website user logins are stored in a project specific database and passwords are encrypted and hashed.

Tools/ Functionality

CB&I improved the functionality of the database and user interface through the development of several tools. Querying tools enable users to search through reports for a particular report type, using keywords, or through a text query function. Export functions include formatted and standardized worksheets and tabular data exports for analysis outside of the database structure.

Two main document search tools were developed. The first was based on a predefined list of keywords that was developed as reports were uploaded to the database. As each report was reviewed, a list of keywords that best described the subject of the text was developed. A comprehensive list of these keywords was maintained in the database. A keyword filter was then added to enable users to search the report summaries for particular keywords. The second search tool developed was a document text filter. This tool functions similar to that found on internet search engines.

Project data can be exported to a tabular format and to standardized reports. The tabular export is useful for analysis, however the format does not allow for ease of review of individual projects. The Individual Project Summary Sheet export tool was developed to provide the information in a way that facilitates project review outside of the database (Figure 9).



Texas Coastal Resiliency Study
Jefferson County Technical Working Group
Project Summary

Suggested Priority 7

Project Name: Jefferson County Final Plan March '12 11/City of Bevil Oaks 8/China 19/Groves 27/Nederland 8/Nome 8/Port Arthur 8/Port Neches 7
County: Jefferson
City: N/A

Project Description

Bury underground, secure or otherwise harden exposed or vulnerable pipelines.

Project Details

Record ID: 7799 Identifier: N/A
Project Owner: Jefferson County
HUD Number: Not Assigned
Project Status: Existing
Infrastructure Category(ies): Energy/Industrial Facilities
Specific Benefited Infrastructure: Chemical Storage

Project Location

Physical Address: N/A
Location (if no physical address): Countywide
FIRM Flood Zone: N/A
Block Group(s): multiple

Project Ranking Details

Vulnerability Zone: 4 Consequence Type: E Consequence Ranking: 4 Risk Score: 32

Level	Descriptor	Consequence Scale
1	Insignificant	Little to no impact on communities and access to services. No or only minor injuries. Minimal environmental damage, local general response.
2	Minor	Minor short term impacts (mainly reversible) on community services. Minor injuries requiring hospital medical treatment. Mitigatable environmental damage with recovery time of less than 1 year with local response.
3	Moderate	Considerable impact upon services and infrastructure. Injuries and illnesses with hospitalizations. Mitigatable environmental damage with recovery time of 1-5 years with local response.
4	Major	Major asset damage, severe impact on community services and assets. Single fatalities, long term illnesses or multiple serious injuries. Mitigatable environmental damage recovery time of 5-10 years with regional and national response.
5	Catastrophic	Long term loss of community assets and infrastructure. Multiple fatalities or permanent disabilities or wide spread illnesses. Mitigatable environmental damage recovery time greater than 10 years with regional and national response. Irreversible environmental damage.

Consequence Type: F = Function Loss, S = Safety, E = Environment

Additional Project Information

Reference: Jefferson County, Beaumont, Bevil Oaks, China, Groves, Nederland, Nome, Port Arthur, Port Neches, Taylor Landing and Lower Neches Valley Authority Drainage District #7, 2011. Jefferson County Hazard Mitigation Action Plan, 365p.

Figure 9. Project summary sheet export.

3.0 PHASE II ASSESSMENTS AND RISK ANALYSIS

During Phase II, assessments of critical infrastructure within the study area were conducted with the goal of developing a list of recommended projects prioritized for their impact in reducing risk and providing guidance to local communities for project implementation. In order to achieve this goal, a methodology for selecting mitigation projects and conducting risk assessments was developed. The approach for this phase was established after extensive review of previous methodologies, studies and risk assessment standards. These sources include such documents as the Federal Emergency Management Agency (FEMA) State and Local Mitigation Planning How-to-Guide (FEMA, 2003) and the International Standards Organization (ISO) guidance for risk management (ISO 2009). Once these reviews were complete, an analysis methodology was developed that is consistent with industry standard risk assessment approaches while adapted to the specific needs of this study.

Technical Working Group Coordination

Local experience, input and guidance was critical to the development of the coastal resiliency project list. The success of this project depended on accurately identifying the true vulnerabilities of the local communities, which ultimately drove project selection. The target participants for these Technical Working Group meetings were advisors who had direct knowledge and understanding of the critical infrastructure assets in their communities, as well as their vulnerabilities. Their role was to assist in proposing potential projects to mitigate risk due to coastal storm impacts. The technical advisors for the working group meetings varied from community to community but were often senior level staff such as city managers, emergency management coordinators, city engineers and planners. In addition, elected officials such as mayors, council members and county judges often participated in the meetings. Over 70 local level working group meetings were conducted within the entire project study area.

Coordination was initiated at the regional level In order to identify the appropriate technical advisors and ensure support at the local, county and regional levels. Five Councils of Governments (COG's) fall within the study area. Each COG represents multiple counties. One of the many functions of COG's is to coordinate regional hazard mitigation and emergency planning, therefore, they have significant institutional knowledge that was instrumental to structuring the Technical Working Groups. Initial outreach was conducted to the administration of each respective COG to ensure the organizations were knowledgeable of the intent of study and the work that will be conducted. The recommendations and advice from each of the COG's were followed to determine the local level points of contact. Meetings were planned sequentially based on the five COG's (Table 6).

Table 6. Council of Governments.

Order	Council of Government	Counties	Meeting Timeline
1	Southeast Texas Regional Planning Commission (SETRPC)	Jefferson, Orange, Hardin	5/2014 – 7/2014
2	Lower Rio Grande Valley Development Council (LRGVDC)	Cameron, Willacy, Hidalgo	8/2014 – 10/2014
3	Houston-Galveston Area Council (H-GAC)	Harris, Fort Bend, Galveston, Chambers, Liberty, Brazoria, Matagorda	1/2015 – 3/2015
4	Coastal Bend Council of Governments (CBCOG)	Refugio, Aransas, San Patricio, Nueces, Kleberg, Kenedy	7/2015 – 8/2015
5	Golden Crescent Regional Planning Commission (GCRPC)	Calhoun, Liberty	7/2015 – 8/2015

After initial contact with the COG's, additional coordination outreach was conducted at local and regional levels including often including both elected officials such as county Judges as well as key high level staff such as County emergency management coordinators. These coordination meetings provided the guidance on how to structure the individual working group meetings. This advice consisted of recommendations for points of contact and appropriate groupings of communities that share similar issues or have a history of working well together.

Once the structure of the working group meetings was identified through the local and regional coordination, the meetings were conducted with the goal of verifying the status of previously proposed (existing) projects and identifying the new potential projects. Meeting participants typically consisted of emergency management coordinators, city managers, city engineers and planners as well as mayors and county judges. A summary of the technical working group participants and regions for each COG are included in Appendices 1 through 5.

Project Identification

Prior to meeting with the local technical advisors, materials to facilitate project identification were developed. Vulnerability maps were created for each Technical Working Group, which provided visualization of the hazard data, critical infrastructure, previously proposed projects and repetitive loss data. Lists of previously identified projects were compiled for each group to determine where mitigative action has been planned. These proposed projects include those provided by various sources such as the GLO Post Storm Damage Assessments (Texas General Land Office, 2009), Coastal Erosion and Response Act (CEPRA) projects, Coastal Impact Assistance Program (CIAP) projects, as well as from local and regional level hazard mitigation action plans. As the existing projects came from static reports, their status was unknown. Updates to these lists included identifying which projects had already been completed or funded and which are still proposed and awaiting funding and implementation.

To facilitate the project review, lists of previously identified (existing) projects were distributed to the local technical advisors. The project team worked with the technical advisors to update the lists to reflect current project status. Changes to project status were then updated within the project and GIS components of the database and changes reflected on the maps. These maps, along with an updated list of existing projects, were the primary materials used in local coordination efforts.

Local knowledge of the performance of the regions critical infrastructure during previous storm events was essential in evaluating potential vulnerabilities during future storms. In order to develop a comprehensive project list, working group meetings with the technical advisors were held during this phase of the analysis. Individual regional meetings were scheduled to review the preliminary vulnerability maps and updated project listings. The purpose of these meetings was to ground truth the vulnerable infrastructure identified in the GIS analysis and to identify new mitigation projects for the present study.

During the meetings, the Project Team worked with the local technical advisors to identify new projects that protect critical infrastructure from coastal storms. Additionally, project lists were updated for recently proposed projects that were not captured in previous hazard mitigation project recommendations.

Based on the vulnerability map analysis and the review and coordination with the local stakeholders, a comprehensive list of projects to mitigate impacts to critical infrastructure during a major coastal storm was developed. This project list consisted of both proposed projects from previous studies and new projects identified during the local level meetings.

Risk Assessments

Once projects were identified and locally vetted, they were classified according to their mitigated risk. According to industry standard risk management techniques, risk is traditionally defined as the combination of likelihood and consequence of an event. This format is applicable to decision making processes where both the likelihood and consequence of an event are variable. This was not the case in this study as the likelihood of an event is fixed since the focus of the study is to assess potential risk due to coastal storms. Instead, a modified version of the risk was utilized with consequence evaluated against a vulnerability scale. Although related to likelihood, vulnerability provided a scale for assessing the susceptibility for damage due to hazards from a single future coastal storm event spatially across the study areas. The hazard data represented the magnitude or likelihood of a particular danger, and was used to define a vulnerability scale. The composite hazard map was used to determine the spatial distribution of vulnerability as it combines data representing five hazard types associated with coastal storms. An example of the vulnerability overlay is shown in Figure 10.

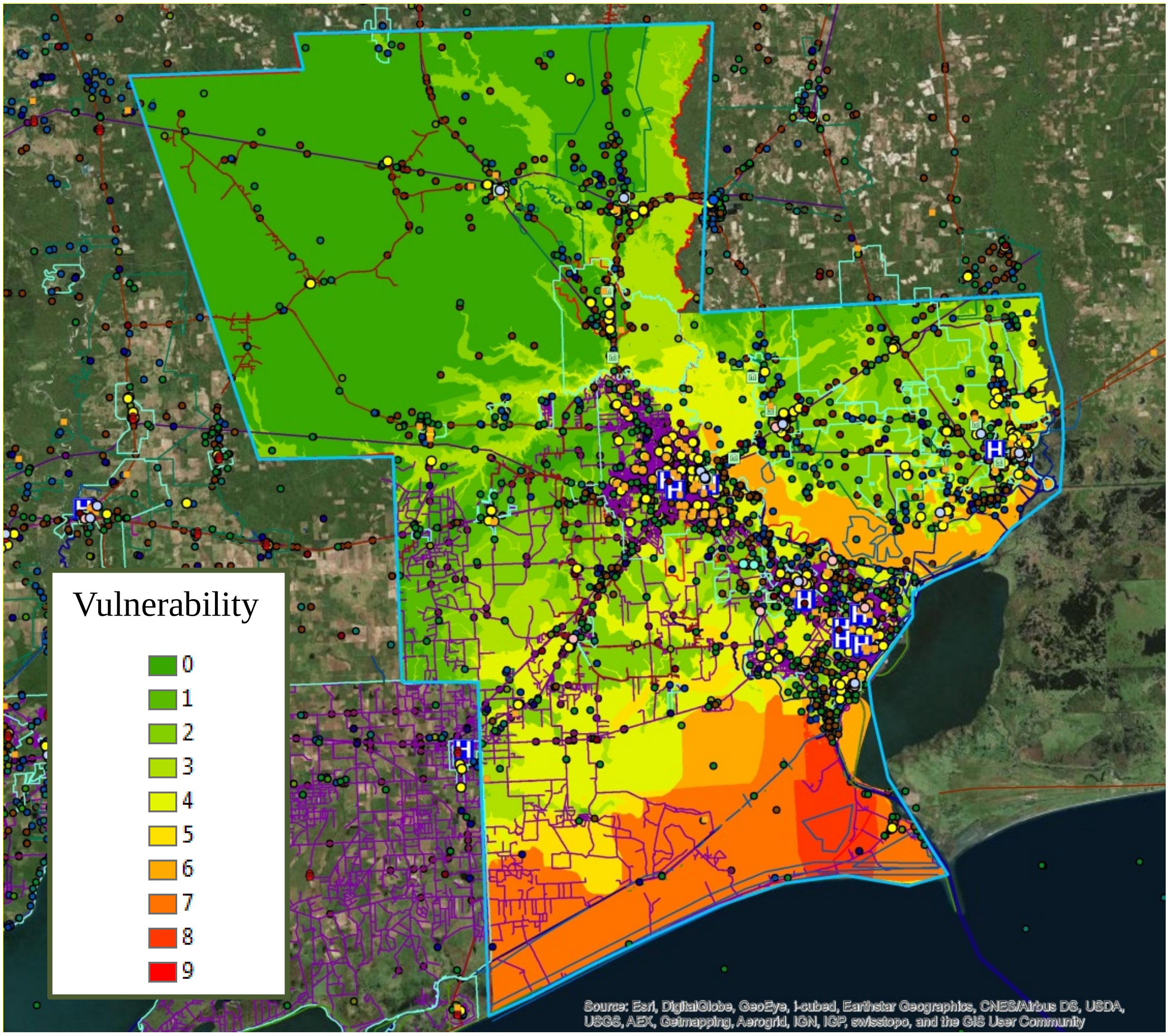


Figure 10. Vulnerability map example.

The second component of risk is consequence ranking. Consequence is the result of an impact, such as a coastal storm. Three categories of impacts were used to evaluate consequence: safety, function loss and environmental. These elements were integrated into a project specific consequence scale (Table 7). Safety considerations include permanent disabilities or fatalities as a result of the incident, injuries (degree of injury and amount of medical treatment needed), occupational illnesses, disruption to medical treatment (amount of medical staff available to minimize impacts). Environmental issues include damage to potential habitats, hazardous material releases, time and personnel availability for clean-up efforts, and loss of agricultural lands. Function loss results from the physical damage to infrastructure which includes issues such as loss of use of housing, down time resulting from business critical systems becoming unavailable, reduction or loss of community services, work days lost, and loss of client and consumer trust.

Table 7. Consequence Scale.

Level	Descriptor	Consequence Scale
1	Insignificant	Little to no impact on communities and access to services. No or only minor injuries. Minimal environmental damage, local general response.
2	Minor	Minor short term impacts (mainly reversible) on community services. Minor injuries requiring hospital medical treatment. Mitigatable environmental damage with recovery time of less than 1 year with local response.
3	Moderate	Considerable impact upon services and infrastructure. Injuries and illnesses with hospitalizations. Mitigatable environmental damage with recovery time of 1-5 years with local response.
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5	Catastrophic	Long term loss of community assets and infrastructure. Multiple fatalities or permanent disabilities or wide spread illnesses. Mitigatable environmental damage recovery time greater than 10 years with regional and national response. Irreversible environmental damage.

Consequence Type - F = Function Loss, S = Safety, E = Environment

The consequence scale has five levels that range from insignificant to catastrophic impacts. Each impact level is described in terms of the function loss, safety and environmental components. Ecological impacts are measured by anticipated recovery time, and the level of response required. Safety is measured in terms of the potential for illness, injury or loss of life. Function loss is a measure of the impact to services and infrastructure. The consequence ranking is, therefore, based on the types of projects identified. This insures that the appropriate measures are applied. The scale was applied after working with the communities and discussing perceived consequence of the no action alternative for the selected projects.

Analysis and Results

Project Data Analysis

After completion of the working group meetings for each respective COG area, the collected project descriptions were entered into the database and the identified project locations were typically digitized based on the meeting maps for integration into the GIS database. GIS feature classes were developed based on the respective project type (critical facilities, transportation, energy/industrial, communications, flooding, environmental, water/waste water treatment). Within each feature class, sub-feature classes were also identified to further describe the affected infrastructure. The feature and sub-feature classes were merged with the project database in order to link all of the project information to the attribute tables.

The projects were represented by different GIS geometries. Projects with discrete locations were identified with individual points while regional projects were identified by representative shapes that cover each projects representative area. For example, a new lift station generator was represented with a single point location within GIS at the site of the lift station. While improvements to an evacuation route were represented by a line over the length of the required road improvements. Projects that represented needs in larger areas, such as drainage studies, were typically digitized as polygons. In some cases projects were either citywide or countywide. In those cases the project locations were represented by the appropriate city or county boundary.

The vulnerability "value" of each identified project was determined from the spatial data. Vulnerability was assessed for each project and was based on the project location in relation to the vulnerability zones from the composite hurricane hazard map. The vulnerability zones ranged from 1 to 10 with 10 having the greatest vulnerability. The quantification of the vulnerability was used in the risk scoring and eventual project rankings. The hazard coverage is a raster image which means that the image is composed of cells which each have a vulnerability zone value. For projects identified by point locations, the vulnerability was determined by the numerical vulnerability value as represented by the composite hazard coverage at that point. For linear or spatial project area coverages, the vulnerability was derived based on the average value of the cells of the project area.

The consequence ranking for each identified project was assigned based on the scale descriptions shown Table 7. The risk assessment score was developed as a measure of the potential risk that each project mitigates. This score is computed as a combination of the project vulnerability and consequence ranking level. The risk score is used to provide guidance to the community(ies) represented by each workgroup to make informed decisions on the relative need for the identified projects. The risk score is based on the following relationship:

Risk Score = (Vulnerability Zone) X (2 X Consequence Ranking)

Based on this approach, projects identified within each working group were initially ranked by risk according to their spatial vulnerability and identified consequence. These rankings were then compiled and distributed to the representatives from their respective technical working group meetings for review and comment. The purpose of the review was to verify that the calculated rankings matched the real world expectation of project importance. After project rankings were reviewed by these representatives, the lists were finalized for the report development.

Final Products Developed

Database

CB&I designed a project-specific web-based GIS that allowed spatial viewing and analysis of the digital data. This web-based GIS was maintained over the life of the project, and allowed GLO to readily access the data compiled and collected over the course of this project via the web. Appropriate data available within the compiled documents has been converted into a digital format and is included in the GIS database.

Appendices

Data collected during the working group meetings were entered into the Texas Coastal Resiliency Study database and then used to develop the items provided in the appendices. The appendices contain lists of invited communities and Technical Working Group meeting participants. Sub-appendices were developed for each Technical Working Group meeting and may include:

Technical Working Group Meeting Minutes. The meeting minutes describe the work conducted during the meeting including the status of existing projects, a list of newly developed projects and remaining action items.

Table of Projects Prioritized by Risk. This table contains basic information about each of the projects identified by the technical working groups. The projects are prioritized according to risk. A legend describing the risk components and how they are applied is included with the project tables.

Individual Project Summary Sheets. A summary sheet containing additional information from the database was developed for each project identified by the technical working groups.

Table of Existing Projects of Unknown Status. In some cases, invited communities did not send representatives to the Technical Working Group meetings. When this occurred, the status of existing projects could not be determined, and a table of these projects was developed.

Results by COG

Over the course of this project, a total of 2,256 eligible and 1,083 unknown projects were identified (Table 8).

Table 8. Summary of Projects Identified.

COG	Technical Working Group	Eligible	Unknown
SETRPC	Beaumont Technical Working Group	35	0
	Bridge City Technical Working Group	5	0
	City of Groves Technical Working Group	8	0
	City of Nederland Technical Working Group	12	0
	City of Port Neches Technical Working Group	6	0
	City of Vidor Technical Working Group	17	0
	Jefferson County Technical Working Group	60	0
	Orange County Technical Working Group	74	0
	Port Arthur Technical Working Group	14	0
	Hardin County Technical Working Group	151	0
	West Orange Technical Working Group	28	0
	Total:	**410**	**0**
LRGVDC	Cameron County and City of Harlingen Technical Working Group	108	0
	East Cameron County Technical Working Group	18	0
	West Cameron County Technical Working Group	21	0
	Central Cameron County Technical Working Group	8	0
	City of Brownsville and Brownsville PUB Technical Working Group	48	0
	Willacy County Technical Working Group	19	1
	Port Mansfield Technical Working Group	4	0
	Raymondville Technical Working Group	6	0
	Central Hidalgo Technical Working Group	38	57
	East Hidalgo Technical Working Group	0	55
	West Hidalgo Technical Working Group	0	27
	Total:	**270**	**140**
HGAC	Brazoria County Technical Working Group	8	0
	North Brazoria (Bonney, Iowa Colony, Manvel, Hillcrest Village, Alvin, Pearland, Brookside Village)	54	33
	South Brazoria (Surfside Beach, Quintana, Freeport, Oyster Creek, Clute, Richwood, Lake Jackson)	33	25
	East Brazoria (Liverpool, Danbury, Angleton, Holiday Lakes, Bailey's Prairie)	0	72
	West Brazoria (Sandy Point, West Columbia, Sweeny, Brazoria, Jones Creek)	13	7
	Chambers County (Countywide)	37	46
	Fort Bend County (countywide)	24	0
	North Fort Bend (Kendleton, Beasley, Orchard, Simonton, Weston Lakes, Fulshear, Katy)	26	68
	South Fort Bend (Arcola, Thompsons, Needville, Fairchilds, Pleak, Rosenberg, Richmond)	38	47
	East Fort Bend (Missouri City, Sugar Land, Stafford, Meadows Place)	37	38
	Galveston County (countywide, unincorporated)	131	39
	East Galveston (Clear Lake Shores, Kemah, Texas City, La Marque)	13	91
	West Galveston (Santa Fe, League City, Dickinson, Friendswood)	119	64

	Galveston Bay (Bayou Vista, Tiki Island, Hitchcock)	79	49
	Galveston Island (Jamaica Beach, Galveston)	29	0
	Harris Working Group 1 (Tomball, Waller)	13	3
	Harris Working Group 2 (Humble)	0	5
	Harris Working Group 3 (Baytown)	39	0
	Harris Working Group 4 (Jacinto City, Galena Park)	33	22
	Harris Working Group 5 (Pasadena, Deer Park, La Porte, Morgan's Point, South Houston)	86	0
	Harris Working Group 6 (Shoreacres, Taylor Lake, Seabrook, El Lago)	99	0
	Harris Working Group 7 (Nassau Bay, Webster)	30	0
	Harris Working Group 8 (West University Place, Southside Place, Bellaire)	27	11
	Harris Working Group 9 (Hilshire, Spring Valley, Hedwig, Hunters Creek, Bunker Hill, Piney Point)	16	40
	Harris Working Group 10 (Jersey Village)	27	0
	Harris Working Group 11 (Countywide)	67	83
	Northeast Liberty (Hardin, Daisetta)	58	23
	Northwest Liberty (Cleveland, North Cleveland, Plum Grove)	20	8
	Southeast Liberty (Liberty, Ames, Devers)	13	27
	Southwest Liberty (Kenefick, Dayton Lakes, Dayton)	34	27
	Matagorda County (countywide)	42	47
	Total:	**1,245**	**875**
CBCOG	Aransas County Technical Working Group	55	0
	Refugio County Technical Working Group	37	5
	San Patricio County Technical Working Group	49	0
	Nueces County Technical Working Group	37	0
	Kenedy and Kleberg County Technical Working Group	18	0
	Corpus Christi Technical Working Group	28	0
	Total:	**224**	**5**
GCRPC	Calhoun County Technical Working Group	39	4
	Victoria County Technical Working Group	68	5
	Jackson County Technical Working Group	0	54
	Total:	**107**	**63**

4.0 SUMMARY

The Resiliency Study was conducted over three separate phases: Phase I - Data Collection, Phase II - Resiliency and Infrastructure Assessments and Phase III - Final Project List and Report. Phase I was the discovery phase that is the foundation of all of the future analysis work that was conducted for the project. Work conducted during Phase I consisted primarily of collecting data and reports, conducting initial analysis, developing a database, tools and a spatial analysis platform and devising the methodology to carry out the resiliency and infrastructure assessments. Phase II of the study applied the information and spatial data compiled in Phase I to conduct assessments of critical infrastructure within the study area with the goal of developing a list of recommended projects. These potential projects were then categorized according to risk, based on an assessment of consequence and vulnerability of critical infrastructure. Phase III of the study consisted of the development of this document where the CB&I team created the final project portfolios and report containing the risk classified list of projects. These lists summarize the projects with the greatest impact on recovery and resiliency improvement in each of the communities evaluated in the study area.

CB&I conducted a comprehensive search to locate information related to the resiliency of the Texas coast, public awareness and preparedness and the vulnerability of local man-made infrastructure and natural resources within the Texas coastal counties. CB&I also identified and compiled similar studies conducted by other agencies and governmental entities pertaining to issues related to coastal resiliency. A searchable database was designed to house this information. Over 900 reports and documents were reviewed and an annotated bibliography describing the information contained in each entry was created.

Concurrent with this effort, spatial data for use in vulnerability and risk analysis was collected and incorporated into a Geographic Information System (GIS). This information included general basemap data, critical infrastructure data and hazard coverages. CB&I worked with the GLO to develop a list of infrastructure types that are critical to the resiliency of communities. The critical infrastructure data types were then grouped into seven general categories: Critical Facilities, Transportation, Energy/Industrial Facilities, Communications, Flooding, Environmental and Water Treatment/Waste. Spatial data representing each of these categories were located, formatted and incorporated into a GIS database for analysis. Five coastal hazards that could potentially impact critical infrastructure were also identified. These included flooding, storm surge, wave impacts, morphology and wind impacts. GIS coverages for each of the hazard types were developed. These hazard coverages were then used to create a composite hazard coverage that provides a spatial distribution of the combined risk.

During Phase II, the information and spatial data compiled in Phase I was used to conduct an assessment of critical infrastructure within the study area with the goal of developing a list of recommended projects prioritized for their impact in reducing risk. Projects were identified either as existing (previously proposed) projects or new projects through a series of technical working group meetings. The purpose of the meetings was to determine whether the existing, previously proposed projects had already been completed as well as to identify new projects that may benefit critical infrastructure protection within the respective communities. Working group meetings were organized through their respective Council of Governments (COGs) and were conducted COG by COG through the study area.

After the identification process was complete, confirmed existing and newly identified projects were entered into the GIS database according to the project type as well as the benefitted infrastructure type. A relative risk level was calculated for each project based on a vulnerability assessment due to coastal storm impacts. This methodology integrated the extensive infrastructure, hazard and project data identified and compiled in Phase I of the study with the local knowledge and expertise of the stakeholder communities. The hazard coverage maps developed in Phase I were used to determine vulnerability which was incorporated with a consequence scale to determine the relative risk level for each project. This relative risk determined the draft project ranking for each technical working group. The participants from each technical working group then reviewed the draft rankings prior to finalization of the project lists. Phase III of the study consisted of the development of this summary report.

5.0 LITERATURE CITED

CB&I, 2014. *Texas Coastal Resiliency Study, Phase I Data Collection: Interim Modeling Report.* Boca Raton, FL: CB&I, 27p. (Prepared for Texas General Land Office).

FEMA, 2003. State and Local Mitigation Planning How-to Guide: Developing the Mitigation Plan, (FEMA 386-3). Washington, D.C.: FEMA, 126p.

FEMA, 2012. Q3 Flood Insurance Rate Maps. Coastal Flood Loss Atlas v 4.0. http://184.72.33.183/GISData/CFLA/

FEMA, 2013. *FEMA Product Catalog.* https://msc.fema.gov/webapp/wcs/stores/servlet/StoreCatalogDisplay?storeId=10001&catalogId=10001&

ISO, 2009. ISO 31000:2009, *Risk management – Principles and guidelines.*

NOAA, 2013. http://www.nhc.noaa.gov/surge/slosh.php

Peacock, W.G., Kang, J.E., Lin, Y., Grover, H., Husein, R. and Burns, G.R., 2009. *Status and Trends of Coastal Hazard Exposure and Mitigation Policies for the Texas Coast: The Mitigation Policy Mosaic of Coastal Texas*. College Station, TX: Hazard Reduction and Recovery Center, College of Architecture, Texas A&M University, 45p.

Texas General Land Office, 2009. Post Storm Damage Assessments.

USGS, 2000. National assessment of coastal vulnerability to sea-level rise. USGS Open-File Report 99-593.