Participant Handbook

"Climate change, once considered an issue for a distant future, has moved firmly into the present."

– Third U.S. National Climate Assessment

Climate Change Preparedness and Resilience Exercise Series

Houston Climate Change

Preparedness and Resilience Workshop

October 6, 2014

FEMA

National Exercise Program
The White House

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National Aeronautics and Space Administration (NASA) Johnson Space Center

Gilruth Facility, Alamo Ballroom

2101 NASA Parkway

Houston, Texas (TX) 77058

October 6, 2014

8:30 a.m.–5:00 p.m. Central Daylight Time (CDT)

WORKSHOP SCHEDULE

Registration

Welcome and Opening Remarks

Overview and Administration

Video: Coastal Chapter, Third U.S. National Climate Assessment

Panel Session #1: Science: National & Regional Perspective

Break

Panel Session #2: Action: Challenges & Opportunities

Lunch

Panel Session #3: Impacts: State & Local Perspectives

Brief Introduction to the Tabletop Exercise

Tabletop Exercise

Participant Feedback / Hotwash

Closing Remarks

Adjournment

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INTRODUCTION

The Houston Climate Change Preparedness and Resilience Workshop is an element of the Climate Change Preparedness and Resilience Exercise Series sponsored by the White House National Security Council Staff, Council on Environmental Quality, and Office of Science and Technology Policy in collaboration with the Federal Emergency Management Agency (FEMA) National Exercise Division (NED). The Houston Workshop is one of three jurisdictional workshops being conducted in October 2014—additional workshops are being held in Fort Collins, Colorado and Anchorage, Alaska—with a goal of advancing the climate adaptation dialogue and identifying collaborative and sustainable approaches to community-based climate preparedness and resilience capabilities.

Hosted by Mayor Annise Parker, the City of Houston, and NASA's Johnson Space Center, the Workshop is comprised of three moderated and interactive panel sessions and one facilitated tabletop exercise. The morning panel sessions reflect a diverse group of panelists and disciplines with focuses on climate science (from national, regional, and local perspectives), effects of climate change (from state and local perspectives), and associated challenges and opportunities (from a whole community perspective). These sessions set a foundation for the afternoon tabletop exercise discussions that will focus on planning, infrastructure systems (energy and chemical sectors along the Houston Ship Channel), natural resources and ecosystems, health and social services, and the economy within the Houston-Galveston area. Ultimately, workshop participants will address the question of "what can be done now, as a whole community, to collaboratively and sustainably prepare, plan for, or help mitigate future projected climate impacts on the Houston-Galveston area."

In support of the desired outcome to improve collaboration with and between whole community partners, workshop participants include local, State, and Federal representatives as well as private sector, non-governmental, and academic partners who have roles, responsibilities, and expertise as they relate to climate adaptation, hazard mitigation, and resiliency planning efforts.

This Participant Handbook provides goals and objectives for the workshop, a detailed scenario with focus areas, and facilitator questions for discussion during the exercise.

Workshop Goal

The goal of the workshop is to provide a forum for numerous stakeholders in the Houston-Galveston area to identify and refine climate change preparedness and resilience requirements and initiatives in collaboration with critical whole community stakeholders.

Workshop Objectives

The workshop will have the following objectives:

1. Examine methods to better integrate existing and emerging scientific information and other requirements into current and future planning to manage and adapt to climate risks and vulnerabilities.

2. Identify collaborative and sustainable whole community approaches to advance and sustain local climate preparedness and resilience programs, policies, and strategies.

3. Examine investment opportunities and the development of coalitions between local, State, Federal, and private sector partners to support climate preparedness and resilience.

4. Examine relevant effects of climate change and hazard mitigation strategies for populations of disproportionate impact (vulnerable communities and populations).

Workshop Outcomes

The workshop will focus on the following outcomes:

1. Improved collaboration with and between whole community partners on climate preparedness and resilience strategies.

2. Identification of new research, information, and capabilities that will support local preparedness, adaptation, and hazard mitigation planning.

Workshop Output

Workshop outputs will include the following:

1. Workshop Summary Report that addresses key discussion points and identified climate preparedness and resilience information, innovations, and initiatives.

2. Potential climate change risks and vulnerabilities to be addressed in the local, State, and regional Threat and Hazard Identification Risk Assessment (THIRA) processes.

Workshop Format

The workshop is a one-day facilitated event tailored for the specific needs of the City of Houston. The morning panel sessions are based on current scientific projections and climate preparedness and resilience efforts, while the afternoon is a facilitated scenario-driven tabletop exercise.

Scientific information describing observed climate trends and projected future climate conditions is derived primarily from the Third U.S. National Climate Assessment.[1]

The exercise scenario is tailored to examine specific jurisdictional effects based on the existing Third National Climate Assessment regional scenarios and includes a specific scenario event – increased risks from storm surge and heat waves in the mid-21st century—to allow participants to focus their discussions.

[1] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2.

Workshop Participants

Workshop participants include local, State, and Federal climate adaptation and hazard mitigation planners, emergency managers, and subject matter experts (SMEs) as well as identified stakeholders and partners from the private sector, non-governmental organizations, and academic institutions. Federal participants include both region-based Department and Agency representatives as well as select representatives from the National Capital Region (NCR).

City of Houston

- Houston Advanced Research Center
- Houston-Galveston Area Council
- Port of Houston

Additional Local Communities

- Galveston County
- Harris County
    - Flood Control District
    - Metropolitan Transit Authority

Federal Departments/Agencies

- Federal Energy Regulatory Commission
- National Aeronautics and Space Administration
- U.S. Army Corps of Engineers
- U.S. Department of Agriculture
    - U.S. Forest Service
- U.S Department of Commerce
    - National Oceanic and Atmospheric Administration
    - U.S. Economic Development Administration
- U.S. Department of Defense
- U.S. Department of Energy
- U.S. Department of Health and Human Services

- U.S. Department of Homeland Security
    - Federal Emergency Management Agency Region VIII
    - Office of Infrastructure Protection
    - U.S. Coast Guard
- U.S Department of the Interior
    - U.S. Geological Survey
    - Fish and Wildlife Service
- U.S. Department of Transportation
    - Federal Highways Administration
    - Federal Transit Administration
- U.S. Environmental Protection Agency
- U.S. Global Change Research Program
- U.S. Small Business Administration
- White House
    - Council on Environmental Quality
    - Office of Science and Technology Policy
    - National Security Council Staff

Private Sector

- Centerpoint
- Lyondell Bassell
- NRG
- Shell
- Thermal Energy Corporation

Non-Governmental Organizations

- C40 Cities Climate Leadership Group
- The Nature Conservancy

- Galveston Bay Foundation
- Texas Medical Center

Academic Partners

- Louisiana State University
- Rice University
- Texas A&M University
- Texas Sea Grant Program
- Texas Tech University
- University of Houston
- University of South Alabama
- University of Texas

Workshop Scope and Assumptions

Exercises play a vital role in national preparedness by enabling whole community stakeholders to test and validate capabilities as well as identify potential capability shortfalls and planning requirements for improving preparedness. A well-designed exercise provides a low-risk environment to share understanding of requirements, familiarize personnel with roles and responsibilities, and foster meaningful interaction and communication across organizations. Exercises bring together and strengthen the whole community in its efforts to prevent, protect against, mitigate, respond to, and recover from all hazards. Overall, exercises are cost-effective and useful tools that help the nation practice and refine our collective capacity to build, sustain, and deliver the core capabilities needed to achieve climate preparedness and resilience.

Participants are encouraged to share their expertise, and the facilitator will ensure that participants have an opportunity to contribute. The scenario will integrate existing issues as identified through the planning process. Discussion questions aim to assist participants in achieving objectives of the workshop.

Participants should consider the following exercise ground rules to ensure that objectives are met in a reasonable amount of time and that the workshop runs smoothly:

1. Keep exercise objectives in mind throughout the workshop.
2. Participate openly and focus discussions on appropriate topics. Asking questions, sharing thoughts, and offering forward-looking, problem-solving suggestions will enhance the exercise experience.
3. Focus comments and consider time constraints.

In any exercise, assumptions are often necessary to complete play in the time allotted. During this exercise, the following assumptions apply:

1. The scenarios are plausible, and events occur as they are presented.
2. There are no "hidden agendas" or trick questions.
3. All players receive information at the same time.

Workshop Evaluation

The workshop evaluation process aligns with requirements of the National Exercise Program (NEP) and is consistent with Homeland Security Exercise and Evaluation Program (HSEEP) doctrine. Evaluation efforts validate strengths and identify opportunities for improving climate resiliency among participating organizations by capturing key discussion points, identifying strengths and areas for improvement, and consolidating these discussion points within a Summary Report. This approach affords participating organizations an opportunity to revise, update, or modify current climate change adaptation and hazard mitigation plans and strategies, as needed.

The Summary Report will capture key discussion points to include the following:

1. Recommendations on integration of climate preparedness and resilience requirements and initiatives into current and future planning to manage and adapt to climate risks and vulnerabilities.
2. Suggestions on maintaining collaborative partnerships and building new coalitions across the whole community.
3. Areas where additional information and research are needed.
4. Effects of climate change on Houston-Galveston area missions, policies and strategies, and resources required given the workshop scenario.

The NED assigns evaluators to capture participant discussions. The evaluation team will then produce the Summary Report and deliver it to the NED within two (2) weeks of the workshop's conclusion. The exercise planning team and key participants will be invited to participate in a virtual After-Action Meeting in November 2014 to review the draft Summary Report and validate and revise the findings and observations in order to produce a final Summary Report.

Core Capabilities

The National Preparedness Goal, released in September 2011, defines what it means for the whole community to be prepared for all types of disasters and emergencies. It identified five (5) mission areas—Prevention, Protection, Mitigation, Response, and Recovery—which encompass 31 distinct critical elements ("core capabilities") needed to achieve a secure and resilient Nation.

The workshop will focus on the Mitigation mission area, which is comprised of "the capabilities necessary to reduce the loss of life and property by lessening the impacts of disasters."

Five (5) of the Mitigation core capabilities will be explored through the workshop:

1. Community Resilience
2. Long-Term Vulnerability Reduction
3. Operational Coordination
4. Planning
5. Risk and Disaster Resilience Assessment

Descriptions[2] for the core capabilities that will be examined during the workshop are as follows:

Core Capability	Description
Community Resilience	Lead the integrated effort to recognize, understand, communicate, plan, and address risks so that the community can develop a set of actions to accomplish mitigation and improve resilience.
Long-Term Vulnerability Reduction	Build and sustain resilient systems, communities, and critical infrastructure and key resources lifelines so as to reduce their vulnerability to natural, technological, and human-caused incidents by lessening the likelihood, severity, and duration of the adverse consequences related to these incidents.
Operational Coordination	Establish and maintain a unified and coordinated operational structure and process that appropriately integrates all critical stakeholders and supports the execution of core capabilities.
Planning	Conduct a systematic process engaging the whole community as appropriate in the development of executable strategic, operational, and/or community-based approaches to meet defined objectives.
Risk and Disaster Resilience Assessment	Assess risk and disaster resilience so that decision-makers, responders, and community members can take informed action to reduce their entity's risk and increase their resilience.

[2] Department of Homeland Security. *National Preparedness Goal*. September 2011.

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SCENARIO BACKGROUND: *Climate Information*

Regional Changes in the Climate for the Southeast and along the Coast

The Texas Gulf Coast averages approximately three (3) tropical storms or hurricanes every four (4) years, generating coastal storm surge and sometimes bringing heavy rainfall and damaging winds hundreds of miles inland. The expected rise in sea level, as predicted in the Third U.S. National Climate Assessment, will result in the potential for greater damage from storm surge along the Gulf Coast of Texas.[3]

The State of Texas is part of the U.S. Great Plains Region, as identified in the Third U.S. National Climate Assessment. The Houston-Galveston area has much in common with the information outlined in the Third U.S. National Climate Assessment's U.S. Southeast and Caribbean Region and Coastal Zone Development and Ecosystems chapters. Therefore, we have included the relevant key findings below as background information for the scenario.

The U.S. Southeast and Caribbean[4] regional findings include:

- **Key Message 1: Sea Level Rise Threats.** Sea level rise poses widespread and continuing threats to both natural and manmade environments and to the regional economy.
- **Key Message 2: Increasing Temperatures.** Increasing temperatures and the associated increase in frequency, intensity, and duration of extreme heat events will affect public health, natural and manmade environments, energy, agriculture, and forestry.
- **Key Message 3: Decreased Water Availability.** Decreased water availability, exacerbated by population growth and land-use change, will continue to increase competition for water and affect the region's economy and ecosystems.

The U.S. Coastal Zone Development and Ecosystems[5] regional findings include:

[3] Shafer, M., D. Ojima, J. M. Antle, D. Kluck, R. A. McPherson, S. Petersen, B. Scanlon, and K. Sherman, *2014: Ch. 19: Great Plains. Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 441-461. doi:10.7930/J0D798BC.

[4] Carter, L. M., J. W. Jones, L. Berry, V. Burkett, J. F. Murley, J. Obeysekera, P. J. Schramm, and D. Wear, *2014: Ch. 17:*
Southeast and the Caribbean. Climate Change Impacts in the United States: The Third U.S. National Climate Assessment, J. M.
Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 396-417. doi:10.7930/J0NP22CB.

[5] Moser, S. C., M. A. Davidson, P. Kirshen, P. Mulvaney, J. F. Murley, J. E. Neumann, L. Petes, and D. Reed, *2014: Ch. 25: Coastal Zone Development and Ecosystems. Climate Change Impacts in the United States: The Third U.S. National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, , 579-618. doi:10.7930/J0MS3QNW..

- **Key Message 1: Coastal Lifelines at Risk.** Coastal lifelines, such as water supply and energy infrastructure and evacuation routes, are increasingly vulnerable to higher sea levels and storm surges, inland flooding, erosion, and other climate-related changes.

- **Key Message 2: Economic Disruption.** Nationally important assets in vulnerable coastal locations, such as ports, tourism, and fishing sites, are increasingly exposed to sea level rise and related hazards. This threatens to disrupt economic activity within coastal areas and the regions they serve and results in significant costs from protecting or moving these assets.

- **Key Message 3: Uneven Social Vulnerability.** Socioeconomic disparities create uneven exposures and sensitivities to growing coastal risks and limit adaptation options for some coastal communities, resulting in the displacement of the most vulnerable people from coastal areas.

- **Key Message 4: Vulnerable Ecosystems.** Coastal ecosystems are particularly vulnerable to climate change because many have already been dramatically altered by human stresses. Climate change will result in further reduction or loss of the services that these ecosystems provide, including potentially irreversible impacts.

- **Key Message 5: The State of Coastal Adaptation.** Leaders and residents of coastal regions are increasingly aware of the high vulnerability of coasts to climate change and are developing plans to prepare for potential impacts on citizens, businesses, and environmental assets. Significant institutional, political, social, and economic obstacles to implementing adaptation actions remain.

Local Background Information for the Houston-Galveston Area

The Houston-Galveston area is home to more than six (6) million residents,[6] making it the fifth-largest metropolitan area in the United States by population.[7] Key industries include energy, transportation, and manufacturing. It is a focal point of Texas' and the nation's economic activity as a major cargo hub, a crucial center of domestic energy production and security, and the location of numerous critical infrastructure sites. The U.S. Department of Energy (DOE), NASA, and the U.S Coast Guard (USCG) are some of the Federal Agencies that maintain major installations in the area.

Like many urban centers, the Houston-Galveston area depends on infrastructure—including water and sewage systems, roads, bridges, and power plants—that is aging and in need of repair or replacement. Rising sea levels, storm surges, heat waves, and extreme weather events will compound these issues, stressing and overwhelming these essential services.

Houston-Galveston area residents are particularly vulnerable to disruptions in essential infrastructure services from climate change, in part because many of these infrastructure systems

[6] Based on 2013 census data of the 13 counties on the Houston-Galveston Area Council. http://www.h-gac.com/community/socioeconomic/census/documents/Estimates_Detail_Counties_Census.pdf
[7] "Houston now No. 5 in population, overtakes Philadelphia" April 5, 2012, http://www.bizjournals.com/houston/news/2012/04/03/houston-ranks-no-5-by-metro.html

are reliant on each other. For example, electricity is essential to multiple systems, and a failure in the electrical grid can affect water treatment, transportation services, and public health. These infrastructure systems are lifelines to millions of people and will continue to be affected by various climate-related events and processes.

Observed Climate Change Trends for the Houston-Galveston Area

Average annual temperature has increased. Data from Liberty, TX indicate that the average annual temperature has risen approximately 1 degree Fahrenheit over the past century. Maintaining a humid subtropical climate, the Houston-Galveston area typically experiences more than 100 days per year of temperatures exceeding 90 degrees Fahrenheit. In 2011, Houston set a record for the most number of days recording temperatures of 100 degrees Fahrenheit or higher in its recorded history.

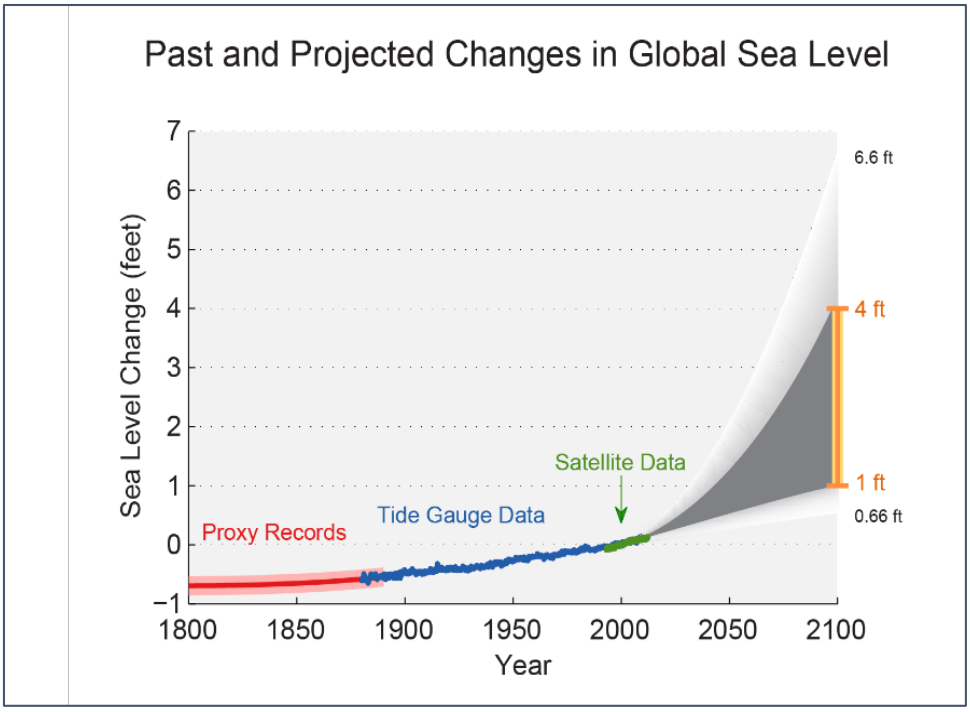

Figure 1. Estimated, observed, and projected future global sea level rise from 1800 to 2100, relative to the year 2000 (source: Third U.S. National Climate Assessment, 2014).

Precipitation patterns are changing. Extreme rainfall events (non-tropical/hurricane) are common throughout the year, especially those that occur in a one-day period, and can cause flash flooding. Flood events affect transportation infrastructure, making roads impassable and damaging transit systems, while also posing risks to public safety and community health.[8]

Sea level is rising and the land is sinking. Climate data collected over the past 100 years in the Houston-Galveston area demonstrate a long-term pattern of sea level and temperature rise. Long-term tide gauge data from Galveston show that the sea level has risen more than 26 inches during

[8] "Climate Impacts in the Great Plains." U.S. Environmental Protection Agency.

this same time period (0.26 inches per year), significantly greater than the global average.[9] This area is prone to high rates of land surface subsidence attributed to soil decomposition and compaction, deep fluid extraction, and the lack of sediment deposition. Because much of the region is exceptionally low-lying, with some areas only several feet above sea level, sea level rise and storm surge are pressing issues.

Extreme weather events are occurring more frequently; in particular, tropical storms, coastal flooding, and drought. As a humid, subtropical climate, the Houston-Galveston area typically experiences more than 100 days per year of temperatures exceeding 90 degrees Fahrenheit, which has increased the vulnerability of outdoor workers to heat-related health impacts and stressed infrastructure systems.[10] In August 2011, Houston had the most number of days reaching temperatures of 100 degrees Fahrenheit or higher in its recorded history (see **Figure 2**). Tropical storms in the region bring extreme rainfall, strong winds, and coastal flooding. The Houston-Galveston area is one of the nation's most hurricane-prone regions[11] (see **Figure 4**). In June 2001, Tropical Storm Allison caused more damage than any tropical storm in U.S. history, with estimates in excess of $5 billion. Most of the damage, and 22 fatalities, occurred in Houston. Storm rainfall totals peaked at 36.99 inches in the Port of Houston.[12] In September 2005, Hurricane Rita prompted the evacuation of approximately two (2) million Houston-Galveston residents, resulting in massive traffic jams and at least 49 indirect fatalities, mostly due to excessive heat and a fire on an evacuation bus. Rita, a Category 3 storm by the time it made landfall near the Sabine Pass, did little physical damage to the Houston-Galveston area, but it stressed the region's infrastructure and evacuation systems.[13][14] In September 2008, Hurricane Ike resulted in storm surges between 10 and 20 feet and caused an estimated $29.5 billion in damages to the Houston-Galveston area.[15] In the 12-months following the storm, the estimated economic losses stemming from Hurricane Ike totaled $142 billion.[16]

Projected Future Climate Conditions for the Houston-Galveston Area

Average annual temperatures and extreme high temperatures are projected to increase. Climate models project continued warmer temperatures in the region. The average temperature in the Gulf Coast region appears likely to increase by at least 2.7 degrees Fahrenheit ± 1.8 degrees Fahrenheit during the next 50 years. Extreme high temperatures are also projected to increase, with the number of days above 90 degrees Fahrenheit very likely to increase significantly across the study area. Within 50 years, the probability of experiencing 21 days per year with temperatures of 100 degrees Fahrenheit or above is greater than 50 percent. Projected

[9] Ibid, page 3-20.
[10] Houston Advanced Research Center, *"HARC Helps Houston Plan for Climate Change Impacts on Municipal Operations*", November 21, 2013.
[11] *Top 5 Most Vulnerable U.S. Cities to Hurricanes*. Climate Central, June 6, 2012.
[12] NOAA Service Assessment Report, "Tropical Storm Allison, Heavy Rains and Floods, Texas and Louisiana, June 2001," September 2001
[13] 8 years ago, seemingly all of Houston evacuated ahead of Hurricane Rita." Houston Chronicle, September 24, 2013
[14] "Post-Tropical Cyclone Report: Hurricane Rita." National Weather Service, Houston/Galveston TX, November 30, 2005
[15] *Hurricane Ike Five Years Later: Photos Show Damage, and Recovery, in Houston and Galveston*. The Weather Channel, September 26, 2013.
[16] *Hurricane Ike Impact Report*. Texas Engineering Extension Service, August 15, 2011.

hotter summer temperatures will stress many aspects of the manmade environment, requiring more maintenance to sustain safe living and working conditions.[17]

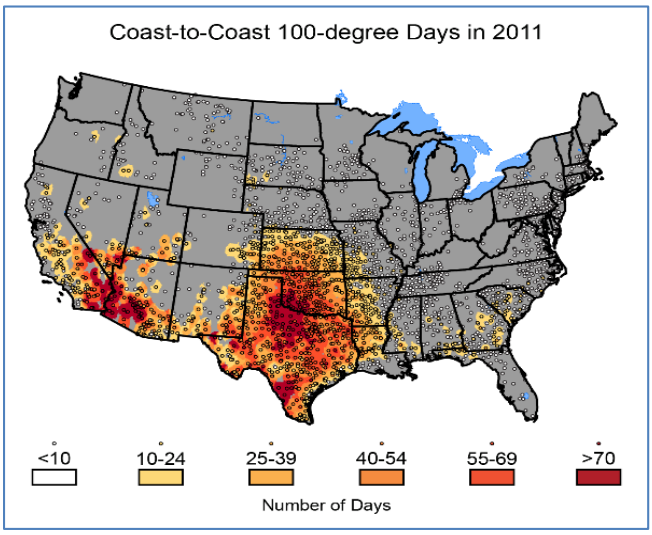

Figure 2. Map displays the numbers of days with temperatures above 100ºF during 2011 (source: Third U.S. National Climate Assessment, 2014).

Precipitation changes are uncertain. Data regarding future precipitation patterns in the Gulf Coast region are inconclusive. Some analyses, including the Global Climate Model results from this study, indicate that average precipitation will increase in this region, while others indicate a decline of average precipitation during the next 50 to 100 years. Although average annual rainfall may increase or decrease slightly, the intensity of individual rainfall events is likely to increase during the 21st Century.

Sea level is projected to rise. Climate models project continued sea level rise in the region. Relative sea level[18] along the Gulf Coast from Houston-Galveston to Mobile, Alabama is likely to increase at least one (1) foot across the region and possibly as much as six (6) to seven (7) feet in some parts of the Gulf Coast area during this century. The analysis of a "middle range" of potential sea level rise of two (2) to four (4) feet indicates that a vast portion of the Gulf Coast from Houston to Mobile may be inundated over the next 50 to 100 years. Sea level rise, coupled with storm surge, will continue to increase the risk of impacts to major coastal infrastructure, such as airports, ports and harbors, roads, rail lines, tunnels, and bridges. Increased coastal erosion, saltwater intrusion into aquifers and estuaries, changes in sediment transport and tidal flows, and more frequent flooding from higher storm surges are also likely.

[17] A Report to the Houston-Galveston Area Council. *Adaptation to Climate Change in the Houston-Galveston Area: Perceptions and Prospects*. The Bush School. Texas A&M University. 2009.
[18] Relative sea level rise (RSLR) is the combined effect of the projected increase in the volume of the world's oceans (eustatic sea level change), which results from increases in temperature and melting of ice, and the projected changes in land surface elevation at a given location due to subsidence of the land surface.

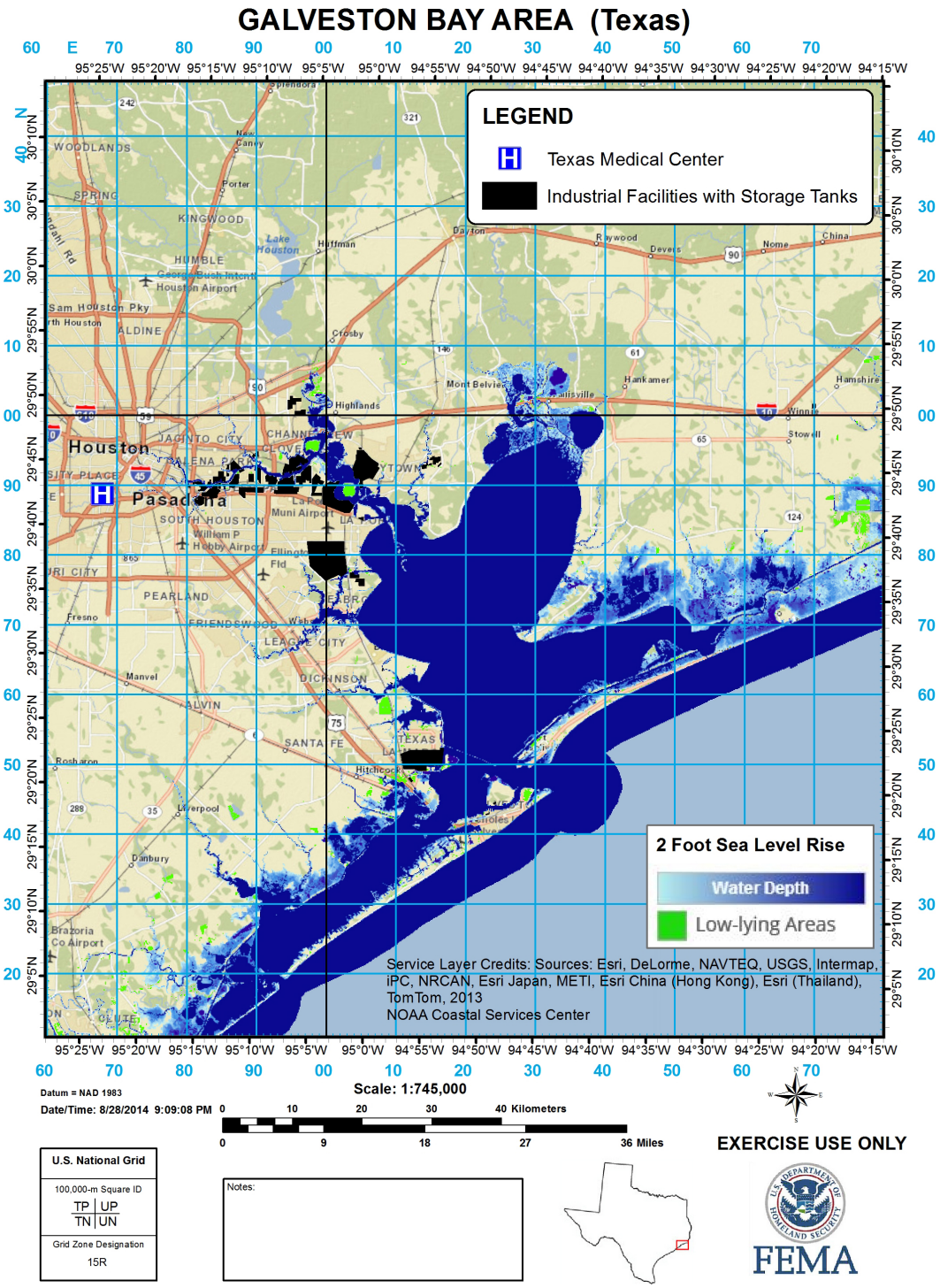

Figure 3. Projected impacts of two (2) feet of sea level rise in the Houston-Galveston area.

Extreme weather events are projected to become more powerful. Storm surge and sea level rise may be the greatest climate threats to the Houston-Galveston area. The region has always been subject to hurricanes and associated high winds, storm surge, and flooding. Rising sea level and land subsidence will increase the risk of catastrophic storm surge impacts on regional infrastructure assets, human capital, and natural resources. The Atlantic Ocean and Gulf of Mexico are getting warmer, making hurricanes more frequent and more powerful. Rising relative

sea level will exacerbate exposure to storm surge and flooding. Depending on the trajectory and scale of individual storms, facilities at or below 30 feet could be subject to direct storm surge impacts. Extreme floods and storms associated with climate change will also lead to increased movement of sediment and buildup of sandy formations in port channels. Projected changes in the frequency of extreme events (such as hot and cold days) may also lead to large impacts.

Local Impacts in the Face of a Changing Climate for the Houston-Galveston Area

Human health and well-being. As urban areas develop, changes occur in their landscape. Buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist become impermeable and dry. These changes cause urban regions to become warmer than their rural surroundings, forming an "island" of higher temperatures in the landscape.[19] Urban heat islands, combined with an aging population and increased urbanization, are projected to increase the vulnerability of urban populations to heat-related health effects in the future. Additionally, sea level rise and increased storm surge can contribute to saltwater contamination of freshwater supplies, urban flooding, sewer overflows, and other public health risks in the Houston-Galveston area.

[19] U.S. Environmental Protection Agency. Basic Information—What is an Urban Heat Island? 2013. Online resource.

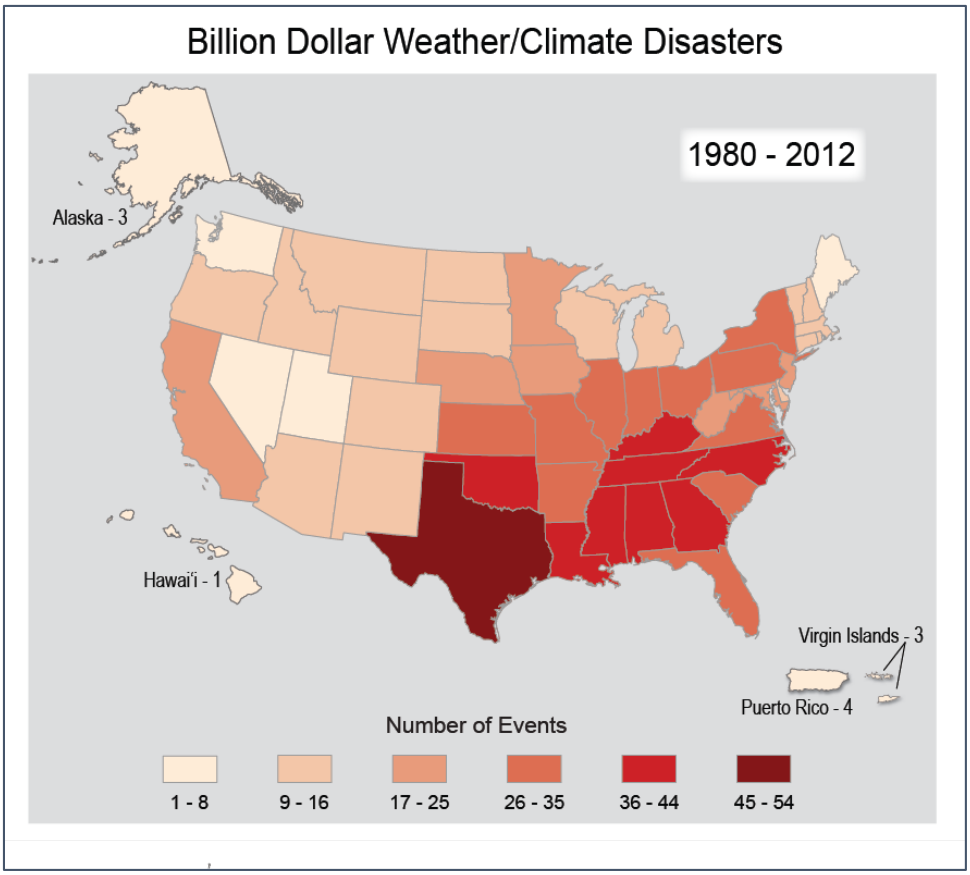

Figure 4. This map summarizes the number of times each state has been affected by weather and climate events over the past 30 years that have resulted in more than one (1) billion dollars in damages (source: Third U.S. National Climate Assessment, 2014).

Essential infrastructure and economic activity. The Port of Houston is one of the busiest ports in the nation and one of the most important in terms of energy supply and security. Current estimates place financial losses of Houston Ship Channel disruption at approximately $300 million per day. Given the fact that the refining facilities around the Houston Ship Channel are responsible for nearly 12 percent of U.S. oil refining capacity, a disruption lasting longer than just several days can significantly affect U.S. energy supplies.[20]

Coastal lifelines. The projected rise in sea level will result in the potential for greater damage from storm surge along the Gulf Coast of Texas. Approximately one-third of the Gross Domestic Product (GDP) for the State of Texas is generated in coastal counties.[21] According to a recent study co-sponsored by a regional utility, coastal areas in Alabama, Mississippi, Louisiana, and Texas already face losses that annually average $14 billion due to hurricane winds, land subsidence, and sea level rise.[22] According to a recent study, projected sea level rise increases

[20] "Spill brings concerns of potential economic impact." Houston Chronicle, March 23, 2014.
[21] Houser, T., R. Kopp, S. Hsiang, R. Muir-Wood, K. Larsen, M. Delgado, A. Jina, P. Wilson, S. Mohan, D. J. Rasmussen, M. Mastrandrea, and J. Rising (2014). *American Climate Prospectus: Economic Risks in the United States*. New York, NY: Rhodium Group.
[22] America's Wetlands Foundation, Entergy Corporation, *Building a Resilient Energy Gulf Coast: Executive Report.* America's Energy Coast, October 2010.

average annual losses from hurricanes and other coastal storms. In Galveston, a typical single-family coastal home worth $191,000 faces $4,752 in average annual hurricane losses today that will likely grow by $1,035 to $1,392 by 2030 and $2,488 to $3,303 by 2050.[23]

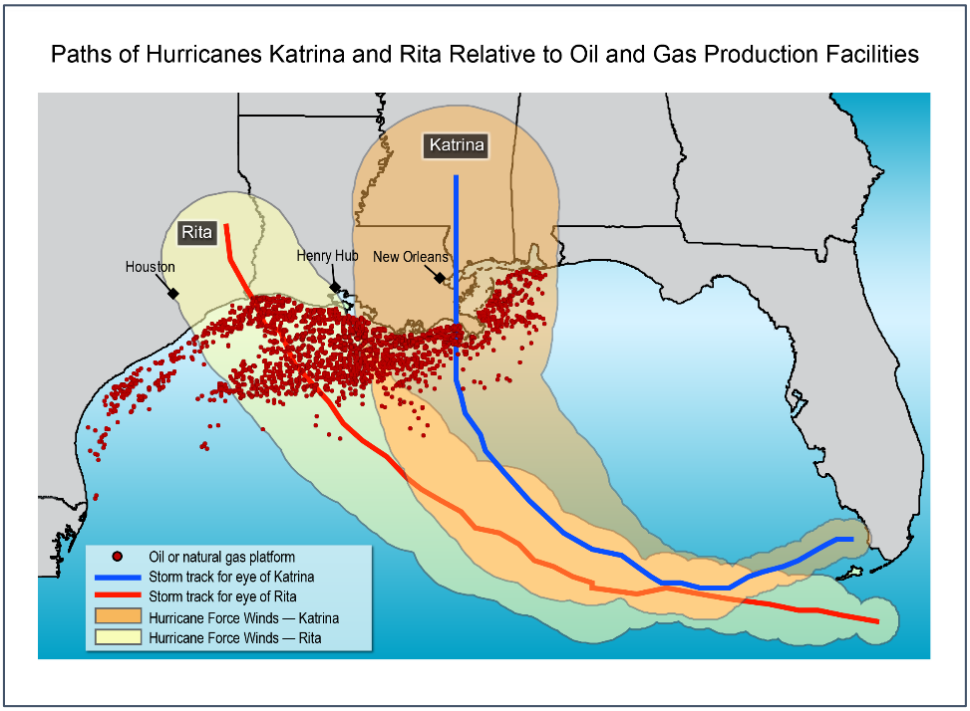

Figure 5. A substantial portion of U.S. energy facilities is located along the Gulf Coast and offshore in the Gulf of Mexico, where they are particularly vulnerable to storms, hurricanes, and sea level rise (source: Third U.S. National Climate Assessment, 2014).

Fresh water availability. Rapid population growth places increasing demand on diminishing water supplies in Texas. Along the Texas Gulf Coast, climate change-related saltwater intrusion into aquifers and estuaries poses a serious risk to local populations. In 2011, many locations in Texas experienced more than 100 days over 100 degrees Fahrenheit, with the state setting new high temperature records. Rates of water loss were double the long-term average, which depleted water resources and contributed to more than $10 billion in direct losses to agriculture alone.

Ecosystem services. The ecological effects of climate change to the Texas Gulf Coast are another critical issue confronting the Houston-Galveston area. Texas coastal marshes and wetlands are fertile breeding grounds for a wide variety of marine life, impede erosion, and help to block some types of inland flooding. Sea level rise threatens to reduce marsh and wetland areas, depriving the Texas Gulf Coast of these benefits. Higher water temperatures and shifting balances between fresh and salt water can negatively alter marine life habitats, creating problems for this region's large aquaculture economy. The Texas coastal agricultural economy, including livestock, rice, cotton, and citrus cultivation, is threatened by the combination of salt or brackish water from sea level rise and reduced freshwater levels from changes in temperature and

[23] Houser, T., R. Kopp, S. Hsiang, R. Muir-Wood, K. Larsen, M. Delgado, A. Jina, P. Wilson, S. Mohan, D. J. Rasmussen, M. Mastrandrea, and J. Rising (2014). *American Climate Prospectus: Economic Risks in the United States*. New York, NY: Rhodium Group.

precipitation.[24] Coastal ecosystems are particularly vulnerable to climate change because many have already been dramatically altered by human activity, which creates additional stresses. Climate change will result in further reduction or loss of the services that these ecosystems provide. Oil and chemical spills that require extensive clean-up efforts highlight these ecological and economic dangers. Moreover, these types of incidents may increase in frequency due to storm-surge induced accidents.[25]

[24] University of Texas Bureau of Economic Geology, *Sea Level Changes and the Texas Coastal Environment*, accessed at www.beg.utexas.edu on September 22, 2014.
[25] Blackburn, J.B., P.B. Bedient, L.G. Dunbar. Severe Storm Prediction, Education, and Evacuation from Disasters (SSPEED) Center 2014 Report. Houston, TX: Rice University, 2014

SCENARIO EVENT:
Increased Risks from Storm Surge and Heat Waves in the Mid-Century

Summer 2044—Houston-Galveston Area

It is the year 2044. The model projections described earlier have occurred. Since 2008, average annual temperatures have increased by 2.5 degrees Fahrenheit. Houston is currently experiencing a 14-day stretch during which the heat index has exceeded 110 degrees Fahrenheit. Increased use of air conditioning and water cooling mechanisms is stressing aging energy supply and transmission systems as well as local water supply systems. Area healthcare systems are stressed by an increase in the number of elderly patients, those with access/functional needs, and other populations of disproportionate impact due to the extreme heat wave. Additionally, outdoor workers are experiencing heat injuries at much higher rates than normal (2.4 deaths per million workers compared to an average of 1.6 over the previous 50 years).

Extreme weather events, such as more-powerful hurricanes, longer and hotter heat waves, and more extensive flooding, have impacted area residents, infrastructure, and ecosystems as well as the Houston-Galveston economy over the past several years. A series of sub-tropical and tropical storms hit the area in previous years, and dredging operations to clear local shipping channels of excess silt are ongoing. The average sea level at the Port of the Houston has risen approximately 16 inches, due to the combination of eustatic sea level rise and land subsidence.

Tropical Storm Brandy, now 200 miles west of Miami, is expected to strengthen to a large Category 3 hurricane before making landfall in the Houston-Galveston area in three (3) days, bringing with it a potential 20-foot storm surge. Ocean temperatures in the Atlantic Ocean and Gulf of Mexico have increased, making hurricanes more powerful.

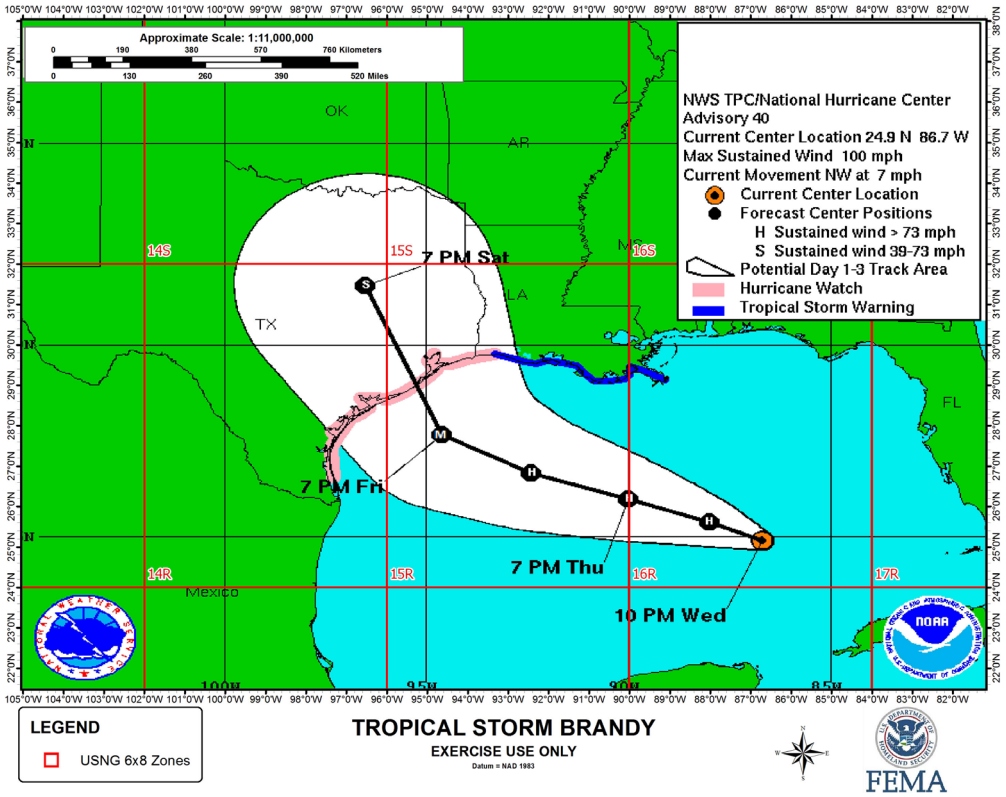

Figure 6. NOAA forecast map for Hurricane Brandy.

If Tropical Storm Brandy strengthens as expected and follows the forecast track, it will make landfall on the Texas coast at or near San Luis Pass. Previous modeling efforts for such a hurricane have forecast potentially devastating consequences for the Houston-Galveston area. Based on modeling conducted in the wake of Hurricane Ike (2008), and taking relative sea level rise into account, the storm surge could reach 34 feet in the Houston Ship Channel and along the west coast of Galveston Bay, in addition to expected heavy rains and 120-mph winds.

Storm surges of this magnitude will overwhelm existing barriers and bring devastating consequences, including the loss of homes, businesses, and livelihoods on Galveston Island, the Bolivar Peninsula, and the communities along the western edge of Galveston Bay.

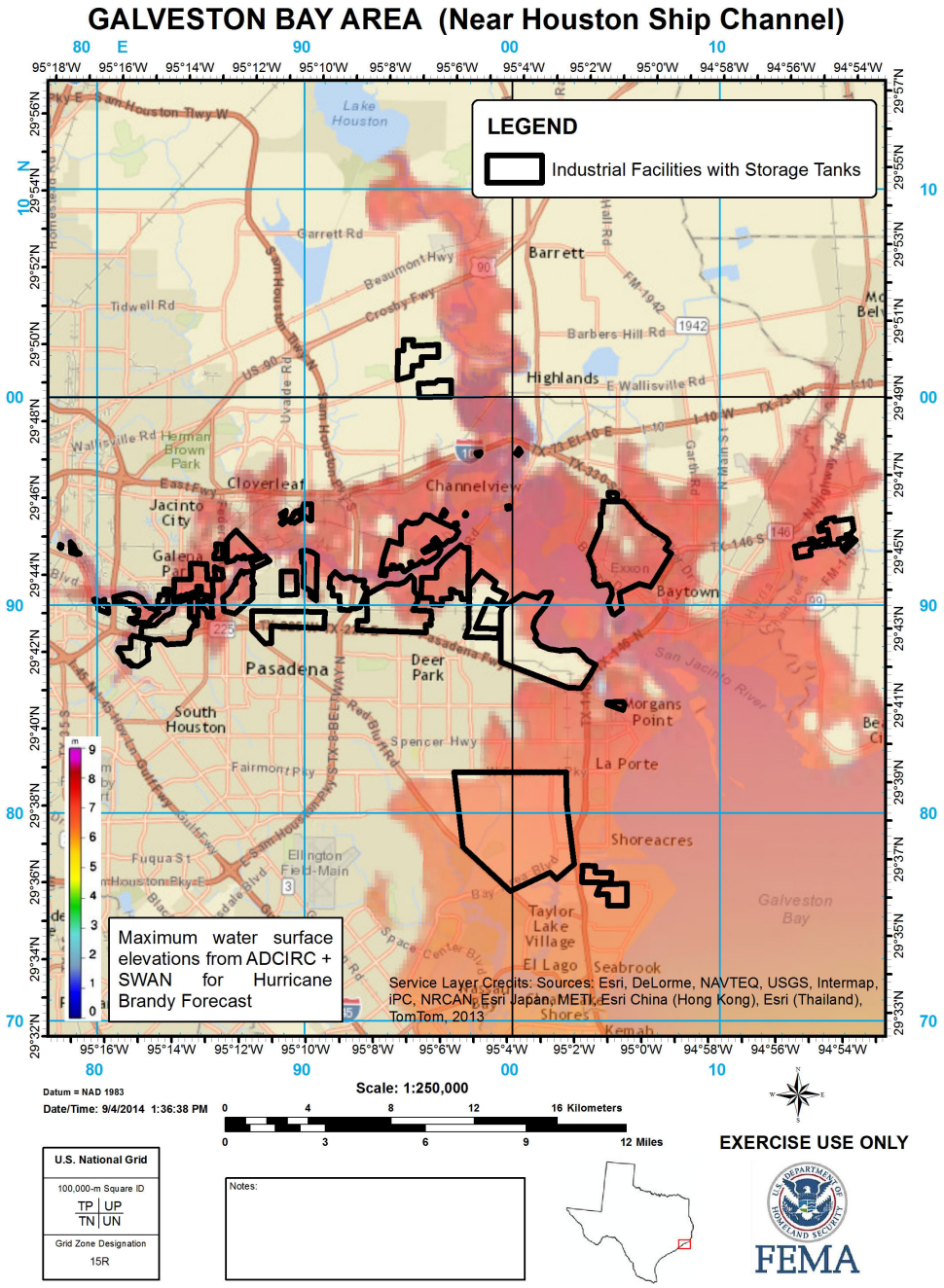

Figure 7. Potential Hurricane Brandy inundation in the Houston Ship Channel.

Particularly vulnerable is the Houston Ship Channel, and the multitude of ports, refineries, and petro-chemical facilities located along it. Previous studies have indicated the potential for $100 billion in damage to the manmade infrastructure along the channel, and estimates place financial losses due to ship channel disruption at approximately $300 million per day.

The Houston Ship Channel is the location of approximately 12 percent of U.S. oil refining capacity; any disruption lasting longer than several days will negatively affect U.S. energy supplies. There are also 3,600 energy-related companies, including 600 exploration firms and 170 pipeline companies, in the Houston-Galveston area that would be impacted by such a storm. Relative sea level rise has already negatively affected many of these facilities, and caused many

others to be more susceptible to storm surge. A 2014 DOE pilot study on risks to energy facilities due to relative sea level rise indicates that 16 energy facilities in Houston will be inundated by 2050 (based on the Third U.S. National Climate Assessment intermediate-high and high emission scenarios).

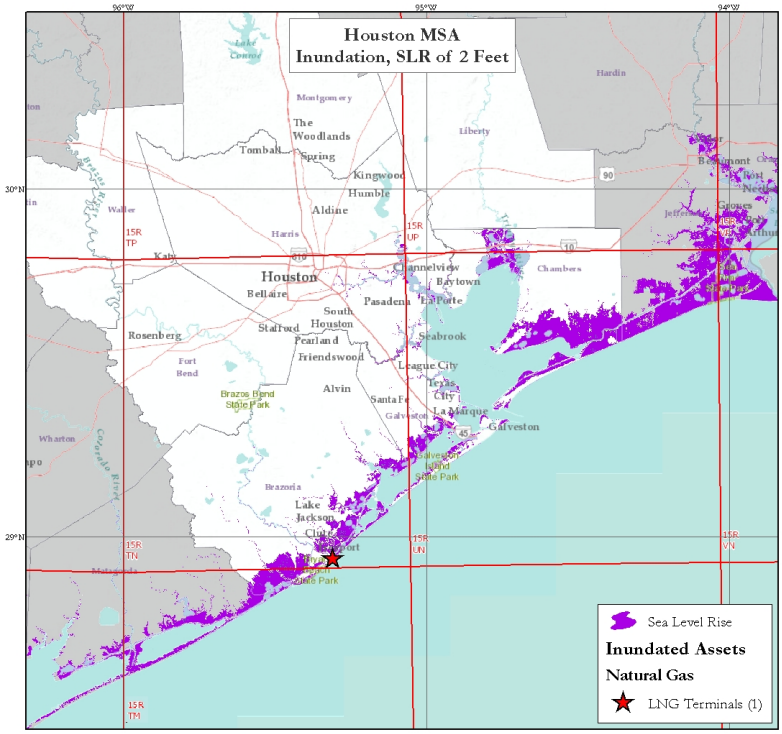

Figure 8. Inundation of energy infrastructure by relative sea level rise of 2 feet (top).

GALVESTON BAY AREA (Texas)

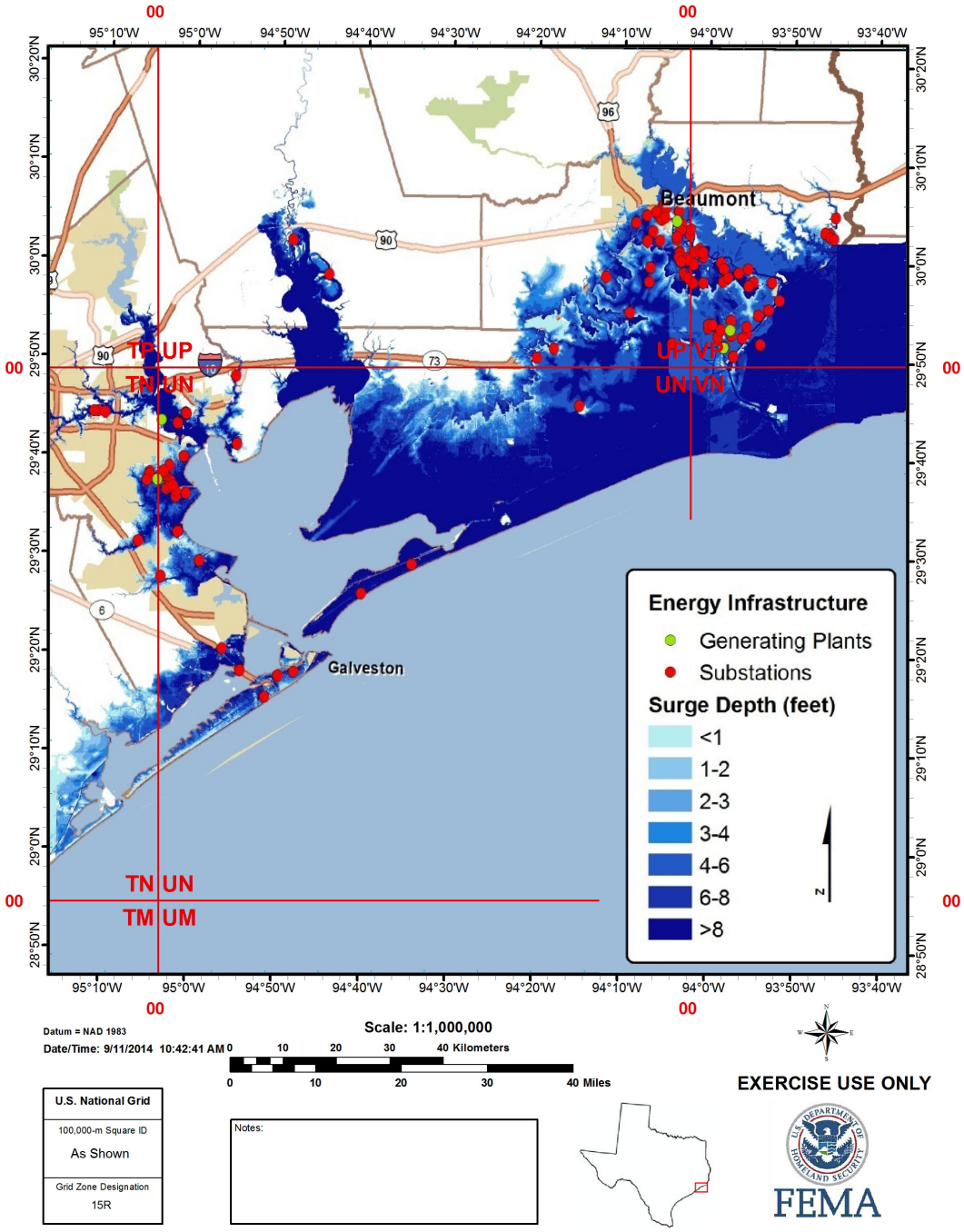

Figure 9. Inundation of energy facilities by Hurricane Brandy storm surge.

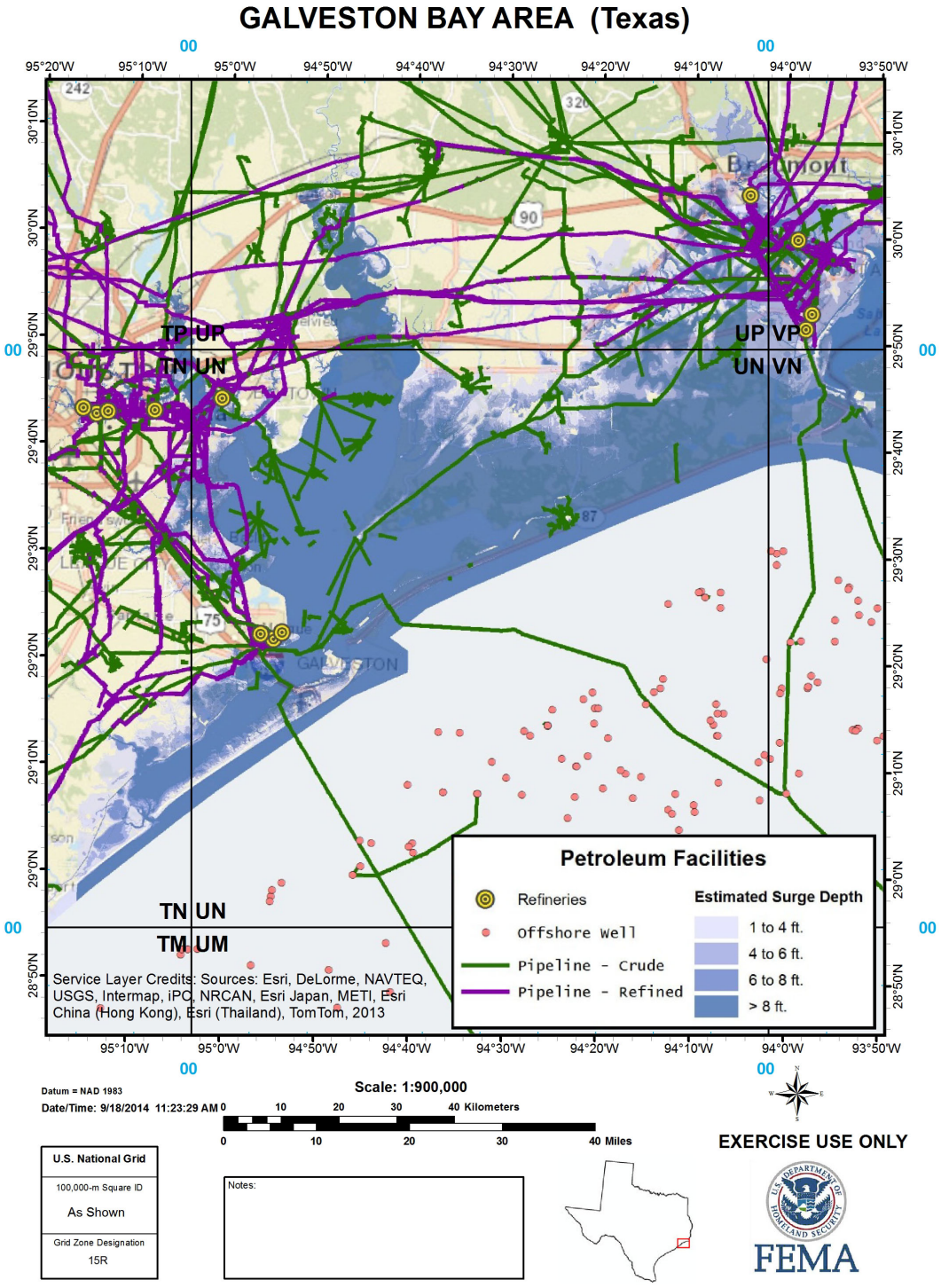

Figure 10. Inundation of pipelines by Hurricane Brandy storm surge.

The Houston Ship Channel is also the location of a large percentage of U.S. agrochemical (e.g., fertilizer and pesticides) production capacity; any disruption lasting longer than several weeks will negatively affect the food security of the United States and our trading partners.

Additionally, there are 405 chemical plants employing 36,000 people in the Houston-Galveston area. These facilities are responsible for approximately 40 percent of the nation's capacity to

produce basic chemicals used by downstream chemical operations, and the area is a key production center for derivative chemicals and specialty chemicals as well. Relative sea level rise has already negatively affected many of these facilities, and caused many others to be more susceptible to storm surge.

Major damage to the petroleum and chemical processing facilities along the Houston Ship Channel could result in major releases of toxic materials into the waterways, creating both an acute environmental disaster and a long-term negative impact on the tourism and fishing industries in the area. Pollution of Galveston Bay and its marshlands could have long-term effects on the health of shrimp, blue crab, salmon, tuna, and other commercially valuable species on which the area's commercial fishing industry depends.[26] In addition to these potential toxic chemical releases, the natural environment of the Galveston Bay is at risk from the storm. Relative sea level rise and past storms have already claimed more than 200 square miles of low lying land area along Galveston Bay and inundated many fresh water marshes with salt water, This has altered the ecology of the area, increased the vulnerability of the coast to storm surge, and negatively affected the sport fishing and tourism industries.

The Houston-Galveston area healthcare infrastructure is also at risk. The Texas Medical Center (2450 Holcombe Blvd #1, Houston, TX 7702 [29° 42.402'N, 95° 23.946'W; USNG 15R TN 67901 88694]) is the largest medical center in the world. It has one of the highest densities of clinical facilities for patient care, basic science, and translational research and receives an average of 3,300 patients per day. The center hosts 54 medicine-related institutions, which include the following: 21 hospitals; eight (8) specialty institutions; eight (8) academic and research institutions; three (3) medical schools; six (6) nursing schools; and schools of dentistry, public health, pharmacy, and other health-related practices. Located in Greater Houston adjacent to Brays Bayou, the Center has historically been subject to flooding during extreme rain events, regardless of the exact landfall point along the Texas coast.

Figure 11. Texas Medical Center (© 2014 Texas Medical Center Corporation).

[26] "Oil Spill Threatens Galveston Bay's Fishing Industry." Texas Tribune, March 26, 2014.

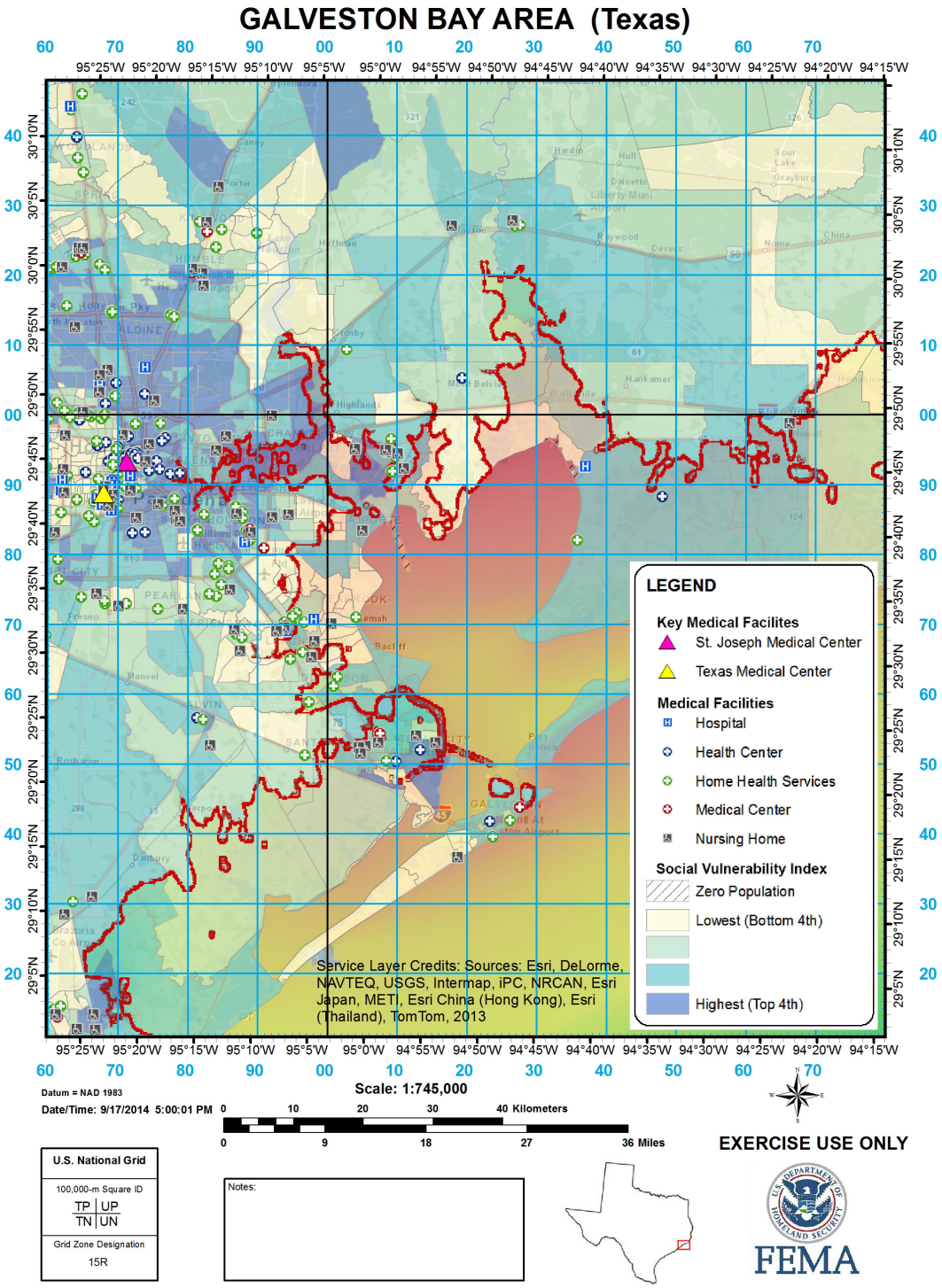

Figure 12. Inundation of Galveston Bay by Hurricane Brandy. Graphic shows area healthcare facilities and the social vulnerability index of affected areas. Maximum extent of inundation is shown by the red line (i.e., areas south and east of the red line are inundated, except for circled areas).

The St. Joseph Medical Center (1401 St. Joseph Parkway, Houston, Texas 77002 [29° 44.881'N, 95° 21.958'W; USNG 15R TN 71201 93209]) is also at risk of flooding from Hurricane Brandy. This acute-care 792-bed facility, with a level III trauma center, serves populations of disproportionate impact in Houston.

HOUSTON FACILITATOR DISCUSSION QUESTIONS

Given the observed climate trends and projected future conditions in the Houston-Galveston area, as well as the specific scenario event-increased risks from storm surge and heat waves in the mid-21st century, the following discussion questions will allow workshop participants to focus on the overarching question "what can be done now, as a whole community, to collaboratively and sustainably prepare, plan for, or help mitigate future projected climate impacts on the Houston-Galveston area." Specific attention should be paid to planning, infrastructure systems (energy and chemical sectors along the Houston Ship Channel), natural resources and ecosystems, health and social services, and the economy within the Houston-Galveston area.

Planning

1. What long-term planning efforts are underway in the Houston-Galveston area that would be affected by inclusion of either the heat wave or Hurricane Brandy?

    a. Do these planning efforts take climate change—particularly sea level rise, temperature increases, variable but more intense precipitation, and stronger storms/higher storm surge—into account?

    b. What local and State agencies are involved in these planning efforts?

    c. How can the Federal government and, particularly, regional Federal partners best support these efforts?

2. How can Federal Departments and Agencies and, particularly, regional Federal partners collaborate to enhance their assistance to local and State planning efforts?

    a. How can we increase communication and awareness between Federal Agencies, all with the same over-arching mission, and avoid duplicating efforts?

3. What additional actions must be taken now or in the near-term to avert mission failure or mitigate these risks?

    a. What changes need to be made to your Department/Agency's plans and policies?

    b. How can emerging information be continuously integrated into planning efforts?

    c. How is the Houston-Galveston area integrating climate considerations into the Threat and Hazard Identification and Risk Assessment (THIRA) process (examining how climate change potentially exacerbates existing threats and hazards)?

4. Are there currently coalitions being organized between local, State, Federal, and private sector partners to support adaptation planning for future storm surge and heat wave conditions as described in the scenario?

    a. What would make it easier to build these coalitions?

   b. What governance structures are in place within the Houston-Galveston area and the State of Texas to support collaborative climate adaptation planning efforts and coalitions across the whole community?

5. What obstacles have your Departments and Agencies encountered that affect adaptation planning?

   a. Are there specific barriers that discourage investment?

   b. Are there changes that need to be made to local, State, Tribal, and Federal legal, regulatory, and policy frameworks to support adaptation and hazard mitigation strategies?

   c. What are other innovative approaches to overcoming these obstacles?

   d. What actions are you taking as a jurisdiction to make climate adaptation a priority consideration for resource planning support?

6. What incentives should we pursue to enhance local, State, Tribal, and Federal preparedness and resilience in the face of climate change risks?

7. How can Federal Agencies better serve the multitude of private companies at risk (in terms of both infrastructure and lives) in understanding the risks?

8. What public messaging/communications strategy are you developing or implementing to connect with the public on issues related to climate adaptation and hazard mitigation?

   a. How can Federal Departments and Agencies best support local, State, and Tribal climate adaptation communications and outreach efforts?

   b. What progress has been made in developing training and educational tools?

Infrastructure Systems

1. Is there an existing inventory available of transportation infrastructure in the area? Utility infrastructure? Water/Sewer Systems?

   a. Does that inventory include an assessment of the vulnerability of major infrastructure? Has functionally obsolete infrastructure been identified?

   b. Are plans in place to address any weaknesses in basic infrastructure and/or update the infrastructure to the latest disaster resilient standards?

2. What long-term energy and chemical infrastructure development, modification, or re-engineering efforts are underway in the Houston-Galveston area, and in the Houston Ship Channel in particular, that would be affected by inclusion of either the heat wave or Hurricane Brandy?

   a. Do these infrastructure development/modification/re-engineering efforts take climate change—particularly sea level rise, temperature increases, variable but

more intense precipitation, and stronger storms/higher storm surge—into account?

b. What local agencies are involved in these efforts?

c. How can the Federal government and, particularly, regional Federal partners best support these efforts?

d. How can whole community and, particularly, private sector partners best support these efforts?

3. How can Federal Departments and Agencies and, particularly, regional Federal partners collaborate to enhance their assistance to local, State, Tribal, and private sector infrastructure development/modification/re-engineering efforts?

4. What are some of the most significant cascading affects from a major disruption to Houston-Galveston chemical and energy production capabilities at the local, State, and Federal levels?

5. In the event that an intense tropical storm or hurricane results in severe disruption to Houston-Galveston chemical and energy supply chains (such as Tropical Storm Brandy, as described in the exercise scenario), what can local, State, and Federal planners—from both the public and private sectors—do today to mitigate the negative effects to national chemical and energy supplies?

6. What interagency coordination is most needed today to ensure the survivability of chemical and energy supply chains in 2044? What are some the most significant barriers to that interagency coordination?

7. Currently (2014), the Port of Houston has a $499B annual economic effect ($1.38B/day, $57M/hour, $1M/hour). How would these numbers compare in 2044 if the Port were devastated by a major hurricane and faced a lengthy closure?

8. What can be done today, in terms of planning and infrastructure development, to ensure the sustainability of Houston Ship Channel operations in the wake of a major hurricane in the 2044 timeframe?

a. What interagency and public-private coordination is required?

b. What are the barriers to this coordination?

9. What science information, data, or modeling capabilities exist to support decision-making requirements or investment decisions related to infrastructure systems?

Natural Resources/Ecosystems

1. What long-term natural resources/infrastructure development or re-development efforts are underway in the Houston-Galveston area that would be affected by inclusion of either the heat wave or Hurricane Brandy?

a. Do these infrastructure development/re-development efforts take climate

change—particularly sea level rise, temperature increases, variable but more intense precipitation, and stronger storms/higher storm surge—into account?

b. What local and State agencies are involved in these efforts?

c. How can the Federal government and, particularly, regional Federal partners best support these efforts?

d. How can whole community partners best support these efforts?

2. How can Federal Departments and Agencies and, particularly, regional Federal partners collaborate to enhance their assistance to local, State, Tribal, and private sector infrastructure development/re-development efforts?

3. Given the severe ecological effects likely from a hurricane (such as the one presented in the scenario), what can be done today to mitigate the ecological damage in the 2044 timeframe?

a. From a planning perspective?

b. From an engineering and infrastructure perspective?

c. From an economic and commercial perspective?

Health and Social Services

1. How would health and social services in the Houston-Galveston area be affected by either the heat wave or Hurricane Brandy, given the expected rise in population and projected socio-economic conditions of the mid-21st Century?

a. In particular, what steps could be taken to better protect the Texas Medical Center and St. Joseph's Medical Center from storm-related flooding, electrical service interruptions, and supply chain disruptions?

b. What steps can be taken to better protect populations of disproportionate impact and those with access and functional needs from disruptions to area health and social services?

c. What local and State agencies are involved in these efforts?

d. How can the Federal government and, particularly, regional Federal partners best support these efforts?

2. How can Federal Departments and Agencies and, particularly, regional Federal partners collaborate to enhance their assistance to local, State, Tribal, and private sector health and social services planning efforts?

3. What can local, State, and Federal planners—from both the public and private sectors—do today to mitigate the effects of a forced evacuation of the Texas Medical Center due to structural damage, power outages, etc. in the 2044 timeframe?

4. What data or modeling capabilities exist to support decision-making requirements or investment decisions related to the provision of health and social services?

Economy

1. What short-term and long-term investments must be made to build and sustain capabilities to support adaptation planning?

    a. How can local, State, Tribal, and Federal investments be leveraged to support multi-agency requirements and vice versa?

    b. How can public-private partnerships be leveraged to support multi-agency requirements?

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APPENDIX A: RESOURCES

Useful Links:

WHITE HOUSE RESOURCES

- **Council on Environmental Quality:** http://www.whitehouse.gov/administration/eop/ceq/initiatives/resilience
- **Office of Science and Technology Policy:** http://www.whitehouse.gov/administration/eop/ostp
- **White House Climate Data Initiative:** http://www.data.gov/climate/

FEDERAL RESOURCES

- **The U.S. Global Change Research Program:** www.globalchange.gov.
- **Third U.S. National Climate Assessment:** http://nca2014.globalchange.gov/
- **Third U.S. National Climate Assessment Download Materials:** http://www.globalchange.gov/nca3-downloads-materials
- **The U.S. Global Change Research Program Adaptation Page:** http://www.globalchange.gov/explore/adaptation
- **The U.S. Global Change Research Program Federal Adaptation Resources Library:** http://www.globalchange.gov/browse/federal-adaptation-resources
- **Department of Transportation—Gulf Coast Study:** http://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/index.cfm
- **Environmental Protection Agency—Region 6:** http://www2.epa.gov/aboutepa/epa-region-6-south-central
- **National Aeronautics and Space Administration—Johnson Space Center:** http://www.nasa.gov/centers/johnson/home/
- **Federal Emergency Management Agency—Region 6:** http://www.fema.gov/region-vi-arkansas-louisiana-new-mexico-oklahoma-texas
- **U.S. Coast Guard—Houston, TX:** http://www.uscg.mil/nmc/recs/hou.asp

REGIONAL RESOURCES

- **The State Climatologist:** http://climatexas.tamu.edu/
- **The Texas Sea Grant Program:** http://texas-sea-grant.tamu.edu/

- **Southern Regional Climate Center:** http://www.srcc.lsu.edu/
- **Southern Regional Climate Services Director:** http://www.ncdc.noaa.gov/rcsd/southern
- **National Weather Service—Southern Region:** http://www.nws.noaa.gov/om/csd/index.php?section=programs#southern
- **West Gulf River Forecast Center:** http://www.srh.noaa.gov/wgrfc/
- **National Estuarine Research—Mission-Aransas Reserve:** http://www.nerrs.noaa.gov/Reserve.aspx?ResID=MAR
- **U.S. Department of Agriculture's Southern Plains Climate Hub:** http://www.usda.gov/oce/climate_change/regional_hubs.htm
- **South Central Climate Science Center:** http://www.interior.gov/csc/southcentral/index.cfm
- **Gulf Coast Prairie Landscape Conservation Cooperative:** http://gulfcoastprairielcc.org/
- **Harte Research Institute:** http://www.harteresearchinstitute.org/
- **Rice University's Baker Institute for Public Policy:** http://bakerinstitute.org/
- **Texas Tech University:** http://www.depts.ttu.edu/politicalscience/

LOCAL RESOURCES

- **City of Houston—Mayor's Office of Sustainability:** www.greenhoustontx.gov
- **The Houston Advanced Research Center:** www.harc.edu
- **Galveston Bay Foundation:** http://www.galvbay.org/
- **University of Houston:** http://www.icas.uh.edu/
- **Texas A&M University—Galveston Campus:** http://www.tamug.edu/

Attached Fact Sheets:

1. Federal Highway Administration, Summary of FHWA Climate Adaptation Initiatives
2. U.S. Department of Transportation, *Draft* Hydraulic Engineering Circular No. 25 (Volume 2).

Summary of FHWA Climate Adaptation Initiatives

(Available at: http://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/summary/index.cfm)

The Federal Highway Administration (FHWA) began to address the impacts of climate change near the beginning of the George W. Bush administration. Climate change impacts, such as more frequent and intense heat waves and flooding, threaten the considerable federal investment in transportation infrastructure. FHWA is partnering with state and local transportation agencies to increase the resilience of the transportation system to these impacts.

Initial Efforts Focused on Impacts of Climate Change on Transportation Systems

FHWA's initial efforts focused on understanding the scope and scale of climate change impacts on transportation. DOT (with FHWA support) commissioned a series of short papers by researchers across government and convened a conference in 2002. FHWA then led the Impacts of Climate Variability and Change on Transportation Systems and Infrastructure: Gulf Coast Study. Issued in March 2008, the report concluded that many critical transportation assets were extremely vulnerable. For example 19% of major roads and 5% of rail lines in the central Gulf Coast region could be affected if sea levels rise by just 2 feet, a conservative estimate of projected sea level rise in the region over the next 50 to 100 years. Hurricane Katrina further underscored this conclusion. FHWA's Potential Impacts of Global Sea Level Rise on Transportation Infrastructure - Atlantic Coast Study followed in October 2008. The impacts of climate change also began to arise as issues on a few highway projects, such as the Bonner Bridge replacement project along the Outer Banks of North Carolina.

From the initial projects, FHWA learned that climate change impacts threaten key goals of safety, system reliability, asset management, and financial stewardship. More frequent heat waves stress materials while heavier rainfall, rising sea levels, and stronger hurricanes cause flooding that damages roadways and disrupts traffic. FHWA also learned that, due to the global nature of climate models, the resulting climate projections were not well suited for making design decisions at the project-level. Transportation agencies needed climate projections at a fine enough scale to develop effective strategies to adapt to climate change at the project and systems level.

Next Steps: Developed Tools and Information for States to Assess Vulnerabilities

FHWA then embarked on a series of efforts designed to gain experience applying climate information and to develop capacity in state departments of transportation (DOTs) and metropolitan planning organizations (MPOs) (FHWA's main stakeholders).

- FHWA produced the report Regional Climate Change Effects: Useful Information for Transportation Agencies in May 2010. This report provided projections of temperature, sea level rise and precipitation over three different time periods out to 2100.
- To raise awareness of climate adaptation and resiliency, FHWA held several practitioner peer exchanges and conducted numerous webinars.
- To help DOTs and MPOs better understand their vulnerabilities to climate change, FHWA produced a conceptual framework in 2009. Piloted in five locations in 2010 and 2011, FHWA updated it with feedback and examples from the pilots and released it in 2012 as the FHWA Climate Change & Extreme Weather Vulnerability Assessment Framework.
- The updated Framework is being used by a second round of demonstration projects at 19 different agencies across the nation, including inland areas facing more severe droughts and flooding from heavier downpours. Many of these are analyzing adaptation options in addition to vulnerabilities. FHWA will update the framework again upon completion of the 19 pilots in 2015.

- To date, 24 state DOTs and 30 MPOs have assessed their vulnerability to climate change, as tracked for the FHWA Strategic Implementation Plan.

Recent Efforts Analyze Strategies to Improve Resilience

FHWA's most recent efforts include research to help areas analyze adaptation strategies to increase resiliency. FHWA is conducting engineering analyses of adaptation options such as enlarging culverts, raising bridges, or using more heat resistant materials as part of three projects discussed below.

- To be completed in Fall 2014, the Gulf Coast Phase 2 project is assessing vulnerability and risk to multi-modal assets in Mobile, AL. The project is also producing transferable tools for using climate projections at the local level, assessing vulnerabilities, and analyzing adaptation options.
- As short-term recovery to Superstorm Sandy wrapped up, FHWA began working with the region to build long-term resilience to future storms. FHWA is now working with MPOs, DOTs and other owner/operators in the NY-NJ-CT region on the Hurricane Sandy Follow-up, Vulnerability Assessment and Adaptation Analysis.
- The Engineering Strategic Initiative Adaptation Study will develop recommended engineering solutions to adapt to climate vulnerabilities for specific highway facilities around the country. Three additional Strategic Initiatives projects newly funded for 2014 will develop methods to incorporate changes in precipitation patterns in the highway design process, research climate impacts on geohazards, and conduct a watershed sensitivity study to help owners identify drainage assets at high risk.

Integrating Climate Resilience into FHWA Programs

FHWA is integrating climate resilience considerations into the agency's programs, guidance, and policies, consistent with existing transportation law, [1] the Secretary's 2011 policy statement on climate adaptation, and the President's Executive Order 13653 on climate preparedness.

- FHWA issued a memo in 2012 clarifying that climate adaptation activities are eligible for FHWA funding, including vulnerability assessments and design and construction of projects or features to protect assets from damage associated with climate change.
- FHWA updated the Emergency Relief Manual to reflect concerns tied to resilience.
- FHWA is developing a rule to implement the legislative requirement that state DOTs develop risk-based asset management plans. Climate change is one of multiple risks that impact asset management. The legislation also includes requirements to consider alternatives for facilities repeatedly needing repair or replacement using federal funding.[2]
- FHWA is updating multiple engineering circulars with climate resiliency considerations: Hydraulic Engineering Circular (HEC) 25 Highways in the Coastal Environment, HEC-17 Highways in the River Environment, and Hydraulic Design Series (HDS) 2 Highway Hydrology.

The actions outlined above assist FHWA and stakeholders in responsibly managing the risks posed by a changing climate. Managing these risks is critical to FHWA's core mission to improve highway system performance—particularly its safety, reliability, effectiveness, and sustainability.

[1] Transportation law charges FHWA with extending the useful life of highways, promoting highway safety, and serving as a wise steward of Federal funds (see 23 U.S.C. 109, 116, and 134 among others).
[2] Moving Ahead for Progress in the 21st Century (MAP-21) Section 1315b

Hydraulic Engineering Circular No. 25 (Volume 2)
Highways in the Coastal Environment: Assessing Extreme Events

Authors:
Scott L. Douglass, Bret M. Webb, and Roger Kilgore

Targeted Publication Date: November 2014

Synopsis:

This manual provides technical guidance and methods for assessing the vulnerability of coastal transportation facilities to extreme events and climate change. This is a standalone supplement, a "Volume 2," to the existing, primary FHWA Hydraulic Engineering Circular (HEC) manual: "Highways in the Coastal Environment," HEC-25 (2nd ed., FHWA 2008). The focus of this supplement is quantifying exposure to sea level rise, storm surge, and waves considering climate change. It is anticipated that there will be multiple uses for this guidance including risk and vulnerability assessments, planning activities, and design procedure development.

The critical coastal processes controlling the vulnerability of transportation assets to extreme events are identified by region along with some available methods for modeling them and the likely impacts of climate change. Global sea level rise, including projections of future sea levels, is emphasized because of its importance. A site-specific example of how to estimate future sea level rise based on USACE guidance ER 1100-2-8162, Incorporating Sea Level Change in Civil Works Programs, is given.

Tools for developing vulnerability assessments for coastal transportation infrastructure are described within the framework of engineering risk. Storm damage mechanisms, often exacerbated by sea level rise and climate change, are described. Adaptation approaches for coastal transportation infrastructure are also described.

Many of the adaptations required for climate change and sea level rise are the same adaptations required for improving infrastructure resilience to extreme events with today's sea levels. Specific approaches for assessing exposure of coastal infrastructure to extreme events and climate change are presented in three different "levels of effort" ranging from use of available data to original numerical modeling. The inclusion of trained coastal scientists and engineers in the analysis team is suggested at all levels of effort. Three case studies from the existing literature on coastal vulnerability assessments to extreme events and climate change are described. Our coastal transportation infrastructure is highly exposed to extreme events today and that exposure is going to increase with sea level rise and climate change.

Hydraulic Engineering Circular No. 25 (Volume 2)
Highways in the Coastal Environment: Assessing Extreme Events

Draft Outline: