Houston-Galveston Area Council
Foresight Panel on Environmental Effects


To access the full report, accompanied by appendices and references, please visit www.h-gac.com/go/EnvironmentalEffects.

Executive Summary

Since its formation in 1966, the Houston Galveston Area Council ("H-GAC") has provided a venue for local governments to respond cooperatively to regional challenges. On November 20, 2007, H-GAC's Board of Directors ("Board") established an expert panel to develop recommendations for local governments to adapt to potential changes in the region's climate and associated environmental effects. This Foresight Panel on Environmental Effects ("the Panel") was comprised of experts in climate change and local infrastructure planning. The purpose of the Panel was not to address the validity of climate change models or the potential contributions of human activity to climate change. Rather, its charge was to recommend sound strategies for local governments to adapt to the potential effects of climate change should it occur.

Most Likely Environmental Effects Produced by Climate Change

The forecasts produced by existing climate models range widely in terms of the extent of possible environmental effects and the time frames in which they may occur. The Panel elected to use the climate change scenario used in the U.S. Department of Transportation's Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I ("the Gulf Coast Study"), which relied upon the Intergovernmental Panel on Climate Change. Adaptation strategies included in this report are based on these assumptions. This study identified the following as a range of possible climate effects by the year 2100:

- *Average annual temperature rise of two to seven degrees Fahrenheit*
- *Sea level rise of two to five feet*
- *Increased intensity and frequency of extreme weather events (such as hurricanes and tropical storms)*
- *Similar annual precipitation levels; however, occurring in more frequent and intense storms, interspersed with longer dry periods*

Potential Impacts of Climate Change on Human and Natural Environments

If the climate change components in the scenario in the Gulf Coast Study come to pass, they will impact the region's population, as well as its built and natural environments. Among the systems that could be affected are:

- *Human health and safety*
- *Public infrastructure*
- *Natural systems*

This report primarily focuses on adaptation strategies local governments can employ to offset the potential impacts on these systems produced by the environmental effects of climate change. Other systems that may also be affected include:

- *Energy generation and delivery*
- *Local and regional economies*
- *Ports and heavy industry*
- *Food production*

Actions to address possible impacts to these systems were viewed as generally outside the responsibility of local governments and, hence, were not covered in this report.

Regional Adaptation Recommendations

The region's local governments have many different goals and responsibilities. In developing its recommendations, the Panel focused primarily on adaptation strategies that would address the goals of protecting human health, property (including infrastructure) and the natural environment. Secondary goals considered included increasing efficiency of operations, reducing the need for vehicular transportation, and reducing urban heat island effect.

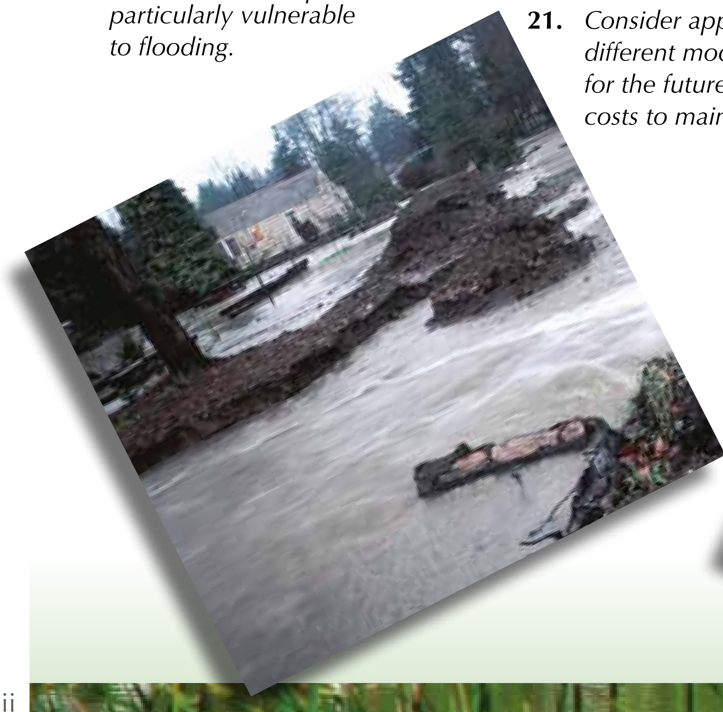
Each of the following strategies was thought to have broad application throughout the H-GAC region. Many of them will yield the added benefits of reduced maintenance and operating costs.

1. *Use historical climate record and credible climate change projections in planning.*
2. *Enhance coordination of evacuation plans and communication systems.*
3. *Review and strengthen mutual aid agreements to improve intergovernmental coordination and cooperation.*
4. *Adopt and implement water conservation plans to prepare for prolonged periods without rain and higher temperatures.*
5. *Utilize tree plantings and green roofs for shading, energy conservation and stormwater detention.*

6. *Develop heat wave management plans to prepare for increased temperatures.*
7. *Use alternative paving products that require less maintenance when exposed to higher temperatures and that reduce heat island effect.*
8. *Enhance shoreline erosion management, including reinforcement of existing levees and sea walls.*
9. *Prepare for increase in wildfires due to prolonged periods without rain and higher temperatures.*
10. *Prepare for increased illnesses from water-, food- and vector-borne sources.*
11. *Implement stricter emission controls to reduce number of days in which air quality standards are exceeded and protect those susceptible to respiratory illnesses exacerbated by poor air quality.*
12. *Advocate hurricane resistant building standards as the minimum building code standard for new construction in high risk areas.*
13. *Avoid new development in areas particularly vulnerable to flooding.*
14. *Avoid construction in areas subject to sea level rise.*
15. *Preserve wetland and riparian zones, which provide natural flood protection and improved water quality processes.*
16. *Implement regional wastewater treatment to distribute the costs of building, maintaining and repairing a larger, more centralized facility among a larger tax base.*
17. *Implement gray water reuse to conserve water, to reduce demand on municipal water systems during prolonged periods without rain and higher temperatures and to improve maintenance and operating costs.*
18. *Employ green building standards to reduce operating and maintenance costs and to reduce demand on natural resources.*
19. *Build compact communities to become more resilient after extreme weather events.*
20. *Build "livable centers" to alleviate traffic congestion and to become more resilient after extreme events.*
21. *Consider appropriateness of different modes of transportation for the future, given increased costs to maintain and operate.*
22. *Consider a longer term view of infrastructure needs than as planned today to take into account increased maintenance, construction and rehabilitation costs in the next 50-100 years.*
23. *Create financial mechanisms to aid Councils of Government ("COGs") with administering funds and setting regional climate change priorities.*
24. *Collaborate with COGs to develop and influence legislation needed to enable local governments to better adapt to climate change.*
25. *Collaborate with H-GAC and other local governments for climate change adaptation planning.*

Of course, the correct priority and phasing of these strategies will vary by jurisdiction, depending on local assets, vulnerabilities and resources. The Panel generally recommends an approach that focuses first on strategies that focus on existing operations and standards for new buildings and infrastructure. The more substantial investment required for retrofits, developing redundant systems, or relocations can be spread over time, or may be a part of recovery efforts.

To access the full report, accompanied by appendices and references, please visit *www.h-gac.com/go/EnvironmentalEffects*.



H-GAC Foresight Panel on Environmental Effects

Since its formation in 1966, the Houston-Galveston Area Council ("H-GAC") has provided a venue for local governments to respond cooperatively to regional challenges. On November 20, 2007, H-GAC's Board of Directors ("the Board") established an expert panel to develop recommendations for local governments to adapt to potential changes in the region's climate and associated environmental effects. This Foresight Panel on Environmental Effects ("the Panel") was comprised of experts in climate change and local infrastructure planning. A Panel Roster is included below.

The Board's charge to the Panel was not to address the validity of climate change models or the potential contributions of human activity to climate change. Rather, the charge was to recommend sound strategies for local governments to adapt to the potential effects of climate change should it occur. The Panel met regularly during 2008 and developed this final report, which was presented to the Board in December 2008.

The projections produced by existing climate models range widely in terms of the extent of possible environmental effects and the time frames in which they may occur. Most of these models are global or hemispheric in scale. In order to focus on the environmental effects most likely to occur in the Houston-Galveston region, the Panel elected to use the climate change scenario used in the U.S. Department of Transportation's Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I ("the Gulf Coast Study"), which relied upon the Intergovernmental Panel on Climate Change ("IPCC"). The Gulf Coast Study identified the following as a range of possible climate effects by the year 2100:

- *Average annual temperature rise of two to seven degrees Fahrenheit*
- *Sea level rise of two to five feet*
- *Increased intensity and frequency of extreme weather events (such as hurricanes and tropical storms)*
- *Similar annual precipitation levels; however, occurring in more frequent and intense storms, interspersed with longer dry periods*

Adaptation strategies included in this report are based on these assumptions. Additional research was conducted for an expanded list of variables. The results of this research as well as a discussion of model uncertainties are included in Appendix A.

Panel Roster

Panel Member Name	Affiliation
Phil Bedient, PhD	Rice University
Peter Bishop, PhD	University of Houston
Alan Clark	Houston-Galveston Area Council
Robert Harriss, PhD	Houston Advanced Research Center
Neal Lane, PhD	Rice University
Barry Lefer, PhD	University of Houston
Eugene Leong, PhD	Consultant
Mike Talbott, PE	Harris County Flood Control District
Arnold Vedlitz, PhD	Texas A&M University


The elderly and very young, the poor, and the infirm may be at increased risk of heat-related illnesses.

Potential Impacts of Climate Change on Human and Natural Environments

If the climate change components in the scenario in the Gulf Coast Study come to pass, they will impact the region's population, as well as the built and natural environments. The Panel discussed a wide range of these impacts. An extended impacts table is located in Appendix B. Using geographic information systems ("GIS"), H-GAC conducted a preliminary regional analysis of several types of local government infrastructure in various counties to determine how they would be affected by climate change. Three different climate change scenarios were conducted, including flooding of the 100-year floodplain, five feet of sea level rise and twenty-five feet of sea level rise. In these scenarios, H-GAC also estimated the population and property values affected by the climate scenarios. Results of the impacts scenarios are located in Appendix C. Among the systems that could be affected are:

Human Health and Safety

Heat-related illness – People whose professions involve outdoor labor, the elderly and very young, the poor, and the infirm may be at increased risk of heat-related illnesses.

Air quality - Sensitive health groups may also experience respiratory illness associated with poor air quality. The primary air quality concern in the region is the concentration of ozone. The region has long been vulnerable to high ozone concentrations due to significant vehicle traffic and a strong industrial base. Emissions from these sources, nitrogen oxides ("NOx") and volatile organic compounds ("VOCs"), create ground-level ozone through a chemical reaction in the presence of heat and sunlight. This occurs most frequently during summer months with strong sunlight and hot weather. Additionally, the region's proximity to the Gulf of Mexico and the meteorological conditions that arise from the region's location often enhance and increase ozone concentrations leading to those days with the most severe ozone concentrations. Increased temperatures resulting from climate change could lead to a greater number of days in which ozone levels exceed air quality standards and also are likely to exacerbate the region's already existing ozone difficulties.

Disease – Vector-borne diseases (transmitted by mosquitoes, ticks) such as malaria, encephalitis, West Nile virus, Dengue fever and Lyme disease have the potential to increase. Gastrointestinal and respiratory diseases and skin, ear and eye infections may result from eating contaminated fish and shellfish and diseases contracted during recreation in coastal waters. Bacteria levels in water bodies, resulting from runoff from failing septic tanks, pet waste and pasture animals, will increase after rain events and cause gastrointestinal diseases. These incidents are expected to increase with changes to temperature, rainfall and water salinity resulting from higher temperature and/or sea level rise. Higher temperatures will increase the incidence of seasonal allergies and lengthen the season because of more favorable growing conditions for plant allergens. More people will seek medical treatment.

Public safety – Flooding and extreme weather events will put populations with limited mobility in peril. Some hospitals will be subject to inundation due to sea level rise, flooding and storm surge. Threats to public safety from wildfires could also increase during periods of extreme heat and drought.

Public Infrastructure

Transportation – Public transportation infrastructure (roads, bridges, rail transit) will be increasingly stressed by higher sustained temperatures; increased maintenance may be required. Maintenance vehicles, construction equipment, buses, and other transit vehicles may also require more maintenance themselves due to increased wear on engines and air conditioning systems during extreme heat. Increased wear on the engines, especially heavy-duty vehicles on sunny, hot days, could result in less reliable pollution control equipment, and more days where the region's ozone level exceed air quality standards. Construction and maintenance schedules may experience delays due to flooding associated with intense rain events and extreme heat and weather events. Transportation facilities may sustain damage and become temporarily inundated by floods and storm surge or permanently inundated due to sea level rise.

Water management – An increased number of intense rain events may stress dams, wastewater treatment plants, storm drains, levees and flood prevention infrastructure. Higher temperatures may reduce surface water levels, allowing for salt water intrusion and threatening drinking water supplies. Many existing wastewater treatment plants in the region may become inundated by sea level rise and storm surge, resulting in a higher risk of water-borne illness.

Solid waste – Interruptions in solid waste collection may occur, resulting in a higher risk of vector-borne illness.

Built environment – Buildings may be damaged or destroyed by sea level rise, extreme weather events and storm surge. Fewer but more intense rain events could also result in an increased chance of building flooding. Inhabitants of these buildings may also be injured or killed should building damage occur. Community facilities may experience an increase in the number of patrons during periods of extreme heat. Local governments may also experience higher energy costs to cool buildings. Power outages may occur due to the increase in electricity demand to cool buildings.

Natural Systems

Ecosystems – Aquatic ecosystems and wetlands may be affected by salinity intrusion and sea level rise. Increased water temperatures during periods of drought may result in reduced freshwater inflows in streams and bays, a threat to aquatic species and, consequently, the local fishing industry. The region may experience a change in the reach of invasive species and shifts in the distribution of existing plants and animal species. Forested areas and urban forestry may be at risk due to wildfires, drought periods, and invasive insect species.

Water quality – Water quality may be reduced due to several factors: increased erosion, nutrient loading, bacterial contamination, algal blooms and reduction of wetlands due to erosion and increased salinity. Shorelines are more vulnerable to erosion during hurricane season due to increased wave heights and storm surge.

Sectors Outside Local Government Purview

Regional Adaptation Goals

H-GAC has prepared specific recommendations to enable local governments to adapt to climate change and achieve achieving the following broad goals:

1. *Protect human health*
2. *Protect property*
3. *Protect natural environment*
4. *Increase efficiency of operations*
5. *Reduce need for vehicular transportation*
6. *Reduce urban heat island effect*

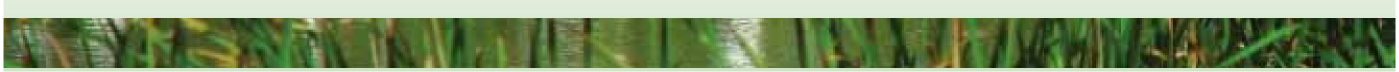
This report primarily focuses on adaptation strategies local governments can employ to offset the potential impact listed above. However, climate change also has the potential to affect the local economy, migration and socioeconomic factors in areas outside the purview of local governments including:

Energy generation and delivery – In most of the region, these services are provided by the private sector. Interruptions in energy service and delivery, whether from extreme weather or heightened demand, could impede the ability for local governments to conduct their normal business.

Local and regional economies – Local governments' tax revenues could be reduced if there are long interruptions of private sector retail activities or serious damage to the property tax base. Lowered revenues translate to a reduction in the level of service a local government provides.

Ports and heavy industry – Ports and their movement of goods are outside of local governments' jurisdictions, but impacts may be felt if supplies and equipment cannot be received. Heavy industry, particularly oil refining, could have interruptions in services during extreme weather events and cause supply problems for local governments.

Food production – Food prices may continue to increase and the availability of some crops may be lessened. Higher food prices could affect the remaining disposable incomes of citizens and reduce the sales tax base.



The region has long been vulnerable to high ozone concentrations due to significant vehicle traffic and a strong industrial base.

Specific Recommendations

To achieve these goals, H-GAC recommends local governments consider the recommendations below, as appropriate to their local circumstances.

How We Manage

1. ***Use historical climate record and credible climate change projections in planning*** *– Local governments should use historical climate record and credible climate change projections to determine design standards for retrofits and new public infrastructure. For historical values, emphasis should be placed on extremes for precipitation and temperature.*
2. ***Enhance coordination of evacuation plans and communication systems*** *– Evacuation planning should be coordinated among local governments not only in areas potentially impacted by storm surge, but also with areas that could be receivers of evacuees. Planning for worst case scenario should also be considered in evacuation planning.*
3. ***Review and strengthen mutual aid agreements to improve intergovernmental coordination and cooperation*** *– To prepare for the potential impacts of climate change, federal, state and local governments must work cooperatively and collaboratively. Local governments should review coordination within their own entities and different levels of government (local, regional, state and federal) to ensure the interoperability of systems, especially transportation and safety communications.*
4. ***Adopt and implement water conservation plans*** *– Because the region may experience extended periods between rain events and higher temperatures, local governments should adopt and implement water conservation plans with an array of best management practices, from low-flow fixtures to less water intensive landscaping practices to water restrictions, to suit that community's needs. Some building code changes may be required.*
5. ***Utilize tree plantings and green roofs for shading, energy conservation and stormwater detention*** *– The climate scenario used in this report indicates the region may experience higher temperatures and more flooding during intense rainfall events. Planting trees can provide significant shade on buildings and reduce energy consumption and urban heat island effect. Green roofs can provide more open space for communities, stormwater detention, and reduced building heating and cooling costs. Community leaders need a decision process aided by informed methodologies to prioritize use of these different options for a particular location.*
6. ***Develop heat wave management plans*** *– Because the region may experience higher temperatures, local governments should develop heat wave management plans. The plans should identify vulnerable social groups. Action plans may include altering schedules to cooler part of the day/night to reduce stress to construction and outdoor workers and equipment and extending the accessibility of hours of cool public buildings and public pools.*

Avoiding development in areas particularly vulnerable to flooding can minimize the need for evacuation and rehabilitation.

7. ***Use alternative paving products*** – *A result of higher temperatures is more road maintenance. Local governments should use alternative paving products that require less maintenance and can withstand higher temperatures. Using lighter colored products may lessen heat island affect by reflecting rather than absorbing heat.*

8. ***Enhance shoreline erosion management*** – *Local governments should enhance current erosion management to prevent or curtail erosion resulting from wave action, sea level rise and intense rainfall events. This enhancement may include strengthening existing levees and sea walls.*

9. ***Prepare for increase in wildfires*** – *First responders should expect increased chances of wildfires during extended periods of high temperatures without rain. Local governments may need to increase staffing, implement a public education campaign and determine if fire suppression water amounts are adequate.*

10. ***Prepare for increased illnesses*** – *Hospitals should prepare for increased incidents of heat, respiratory, water-, food- and vector-borne illnesses due to changes in temperatures, water quality and habitat for vectors. Public health campaigns should be implemented to educate the public about the sources, symptoms and dangers of these illnesses. There is a possible need to also increase the number of first responders for medical emergencies.*

11. ***Implement stricter emission controls*** – *Projected increased temperatures will have an effect on air quality. Local governments should consider stricter emission controls of their own operations and provide alternative transportation options to citizens to reduce NOx and VOCs, which combine in the presence of sunlight and hot weather to form ground-level ozone. Increased temperatures resulting from climate change could lead to a greater number of days in which ozone levels exceed air quality standards and also are likely to exacerbate the region's already existing ozone difficulties.*

How We Grow

12. ***Advocate hurricane resistant building standards as the minimum building code standard for new construction in high risk areas*** – *The climate change scenario indicates that the region may experience more frequent extreme weather events. Local governments should adopt hurricane resistant building standards for new construction to reduce risks of death, injury, property damage and economic losses.*

13. ***Avoid new development in areas particularly vulnerable to flooding*** – *The combination of more frequent and intense storms and impervious surfaces provides the opportunity for more flooding of streets and buildings to occur during intense rain events. Avoiding development in areas particularly vulnerable to flooding can minimize the need for evacuation and rehabilitation.*

14. ***Avoid construction in areas subject to sea level rise*** – *Local governments should avoid building new infrastructure in areas subject to sea level rise. Local governments can also restrict private development in these areas.*

15. ***Preserve wetland and riparian zones*** – *Preserve and protect areas that provide natural flood protection and improved water quality processes.*

16. ***Implement regional wastewater treatment*** – *The GIS-based scenario H-GAC conducted identified 70 facilities that would be inundated with five feet of sea level rise, 286 facilities impacted by 20 feet of storm surge and five feet of sea level rise, and 712 facilities that would be impacted if flooding occurred throughout the 100-year flood plain. These impacts would pose health risks to potentially millions of people and require costly repair. The costs of building, maintaining and repairing larger, more centralized and regional facilities could be spread among a larger tax base and become more cost effective.*

17. ***Implement gray water reuse*** – *Local governments spend millions of dollars to process and convey wastewater. Wastewater from restroom sinks, showers and laundry facilities comprises a large portion of wastewater, which could be reused for landscape irrigation, flushing toilets and janitorial uses. This gray water reuse could significantly cut energy costs and demand used for wastewater treatment and conveyance. For structures that use septic tanks, reuse of gray water puts less strain on failing septic tanks.*

18. ***Advocate green building standard region wide*** – *In the future, temperatures may increase and the periods between rain events may become longer. These climate changes could result in increased energy costs for local governments and more demand on the power grid. As mentioned earlier, some adaptation strategies can also save local governments maintenance and operations costs. Building Leadership in*

Energy and Environmental Design® ("LEED") certified buildings and employing water and energy conservation best management practices ("BMPs") can help local governments' building operations and maintenance budgets on these long term investments. Local governments can incentivize green building of private sector construction through tax abatement. For example, Harris County has begun a tax incentive program for buildings that are LEED® certified.

19. ***Build compact communities*** *– A compact community means less area for a local government to maintain, manage and protect and are less dependent on large transportation facilities, especially before and after extreme weather events. Compact communities also use less land than traditional developments, reducing the amount of impervious surface in the region's watersheds and lessening flooding impacts.*

20. ***Build livable centers*** *– Livable centers are mixed-use places with a concentration of jobs, shopping, entertainment, and/or housing. Clustering these activities creates opportunities for walking, bicycling and transit trips, thus reducing the need for car travel. Like compact communities, livable centers may also be more resilient during extreme weather events because they rely less on major transportation facilities and rely more on bicycle and pedestrian activities. For example, low density communities often rely heavily on major transportation facilities with low redundancy and are less able to function during hurricane evacuations.*

21. ***Consider appropriateness of different modes of transportation*** *- As local governments consider climate change impacts, they will need to consider the appropriateness of different modes of transportation. What is feasible given today's climate may not be a feasible option in the future. For example, elevated light rail may be a more cost effective option in the future than at ground service or even the expansion of roadways. Alternatives to the transportation of goods via trucks as the primary means of reaching markets will need to be reconsidered.*

How We Reinvest

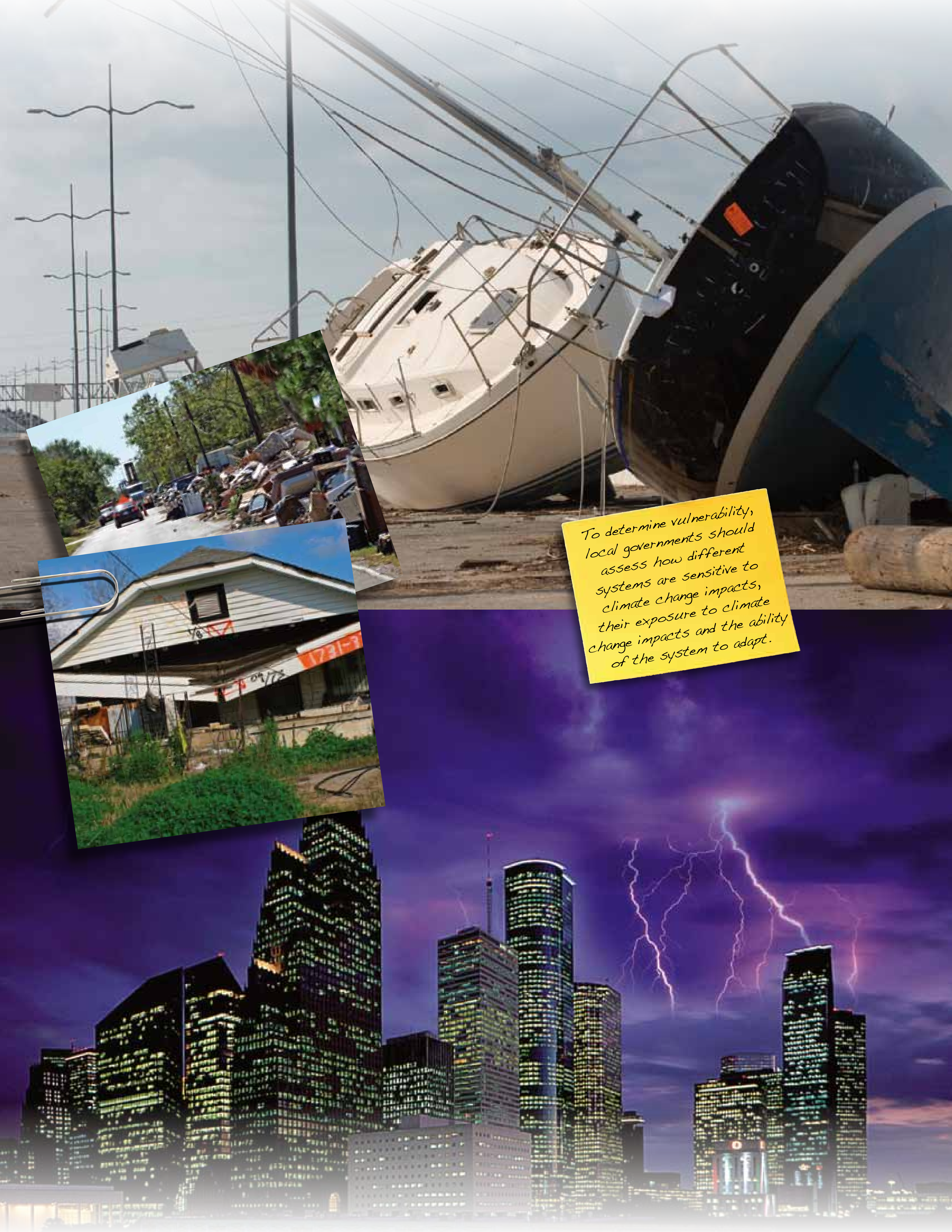
22. ***Consider a longer term view of infrastructure needs than as planned today*** *- Most local governments plan for five years in the future via the capital improvements program process. This short time horizon will not help them plan for shifts in costs associated with maintenance and preservation or shifts to different modes or climate changes over the next 50-100 years. Federal, state and local governments should work cooperatively and collaboratively to develop design standards for different facility types, choose appropriate materials for construction and consider appropriate funding mechanisms to address potentially increased maintenance, preservation and rehabilitation costs as well as increased costs due to changes in design standards.*

How We Recover and Reconstruct

23. ***Creation of financial mechanisms*** *– Develop disaster recovery plans and processes. Councils of Government ("COGs") could be a potential vehicle for administering funds and setting regional climate change priorities based on the various infrastructure interdependencies.*

24. ***COGs should assist legislators*** *– COGs should help legislators shape policies and laws needed to enable local governments to better adapt to climate change. An example of necessary policies for climate change adaptation includes providing counties with a broader regulatory authority for issues such as ordinances for development in storm surge zones and sea level prone areas. Another example is directing funding from the state and federal level to local governments for climate change planning and adaptation.*

25. ***H-GAC should assist local governments with climate change planning*** *– H-GAC should assist local governments with climate change adaptation planning strategies. H-GAC should partner with other public agencies and the academic sector on modeling and providing technical assistance in implementing planning tools, measurement tracking and monitoring.*



To determine vulnerability, local governments should assess how different systems are sensitive to climate change impacts, their exposure to climate change impacts and the ability of the system to adapt.

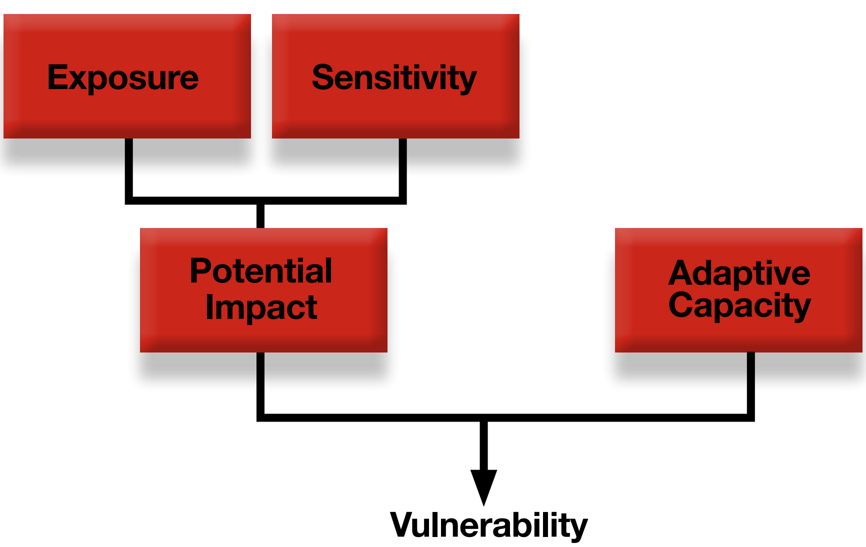
Local Government Preparation

The preceding recommendations were generalized for regional application. Local adaptation strategies should be based on a more detailed assessment of local vulnerabilities and risks. H-GAC recommends the following three steps in conducting such an exercise.

Assess What is Vulnerable

To determine vulnerability, local governments should assess how different systems are sensitive to climate change impacts, their exposure to climate change impacts and the ability of the system to adapt. Vulnerability can apply to the built environment, such as public infrastructure, but also socioeconomic groups. H-GAC can assist local governments with geospatial mapping for types of vulnerability.

Vulnerability and Its Components



Source: Climate Change Risk and Vulnerability (2005) Australian Government, Department of the Environment and Heritage, Australian Greenhouse Office.

- Exposure refers to the influence climate variables have on a system. Exposure can include the actual changes in climate variables as well as the changes in related system interdependencies.
- Sensitivity refers to the responsiveness of the natural system to climate change.
- Adaptive capacity refers to the ability of the human system to cope with change.

Two examples of a vulnerability assessment:

1 This vulnerability assessment could be applied to populations affected by heat illness. Heat illness could potentially affect certain parts of the populations, namely those that do not have access to air conditioning or have health problems such as the poor, the elderly, the very young, the infirm, or those with mobility issues. The exposure to the population would be to high temperatures. The sensitivity of these groups would be high because they are unable to cope with increased temperatures. Their adaptive capacity would be low because they are unable to access air conditioning or have medical issues that are exacerbated by heat. The result is a high vulnerability for this population.

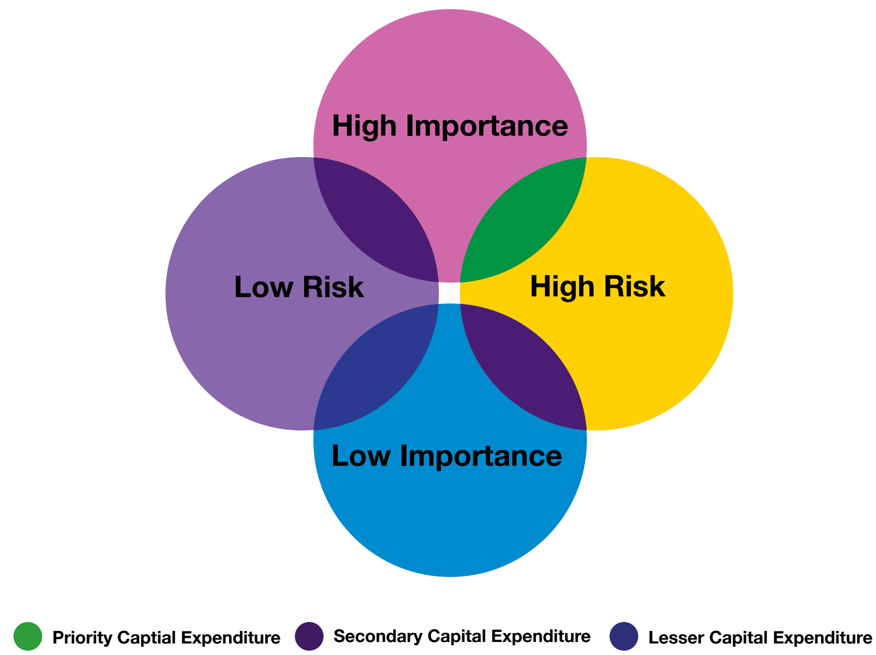
2 Another example of a vulnerability assessment is its application to the transportation sector, which would be exposed to high temperatures, rain events, sea level rise and extreme weather events. The sensitivity would be high because transportation facilities cannot easily adapt to these changes. Transportation facilities may buckle with increased temperatures and become inundated temporarily during rain events or permanently due to sea level rise. Destruction or damage may occur during extreme weather events. Adaptive capacity would be low because significant changes in maintenance and design would be necessary. The result is a high vulnerability for the transportation sector.

Identify Priorities

This step involves consideration of system vulnerabilities, costs and benefits. Local governments should weigh the importance of a system or asset with risk if no actions are taken with the cost effectiveness of an adaptation response.

Local governments should also consider the different systems and prioritize them accordingly. Most likely human health and safety would be the highest ranking system, followed by infrastructure, the built environment and natural systems. Local governments must consider the adverse consequences resulting from the failure of a system and the cost effectiveness of the response. For example, if a community is vulnerable to catastrophic flooding, is it more effective to reinforce the flood detention system or to buy out the residential properties?

Prioritizing Strategies



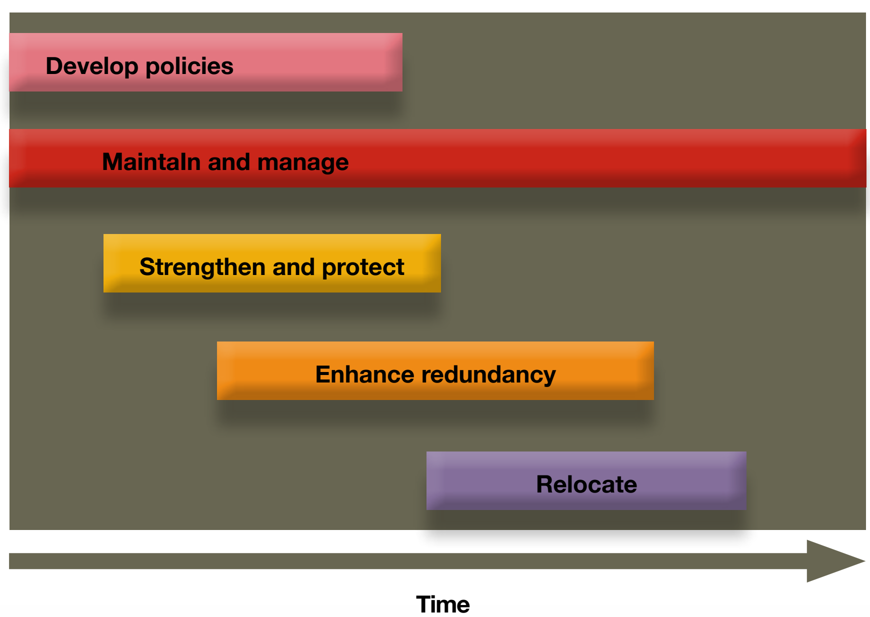
Implement Phasing Strategies

Owing to the high capital costs of implementing many adaptation strategies, local governments will need to spread the costs of these investments over time. The chart to the right shows a potential method of phasing adaptation strategies.

Enacting new development and building policies is a good first step, since it pushes capital costs forward and allocates them among the private sector and the public at large. Incorporating adaptation strategies into routine maintenance and operating procedures also spreads costs over time. Enhancing maintenance regimes may also produce net cost savings over the long term.

a. Develop policies – The existing regulatory authority afforded to local governments under the Texas Constitution could be employed to ensure that new development is more resilient to the effect of

Phasing Strategies



climate change. An advantage of policy-based strategies is that they spread the capital costs of adaptation strategies among the private sector and the public at large. Examples of the types of policies that can be employed include:

- *Development regulations*
- *Green building codes*
  - *Energy efficiency*
  - *Water efficiency*
- *Compact design*
- *Land use regulation*
- *Water use restrictions*
- *Floodplain ordinances*
- *Resiliency requirements in storm surge and high wind prone areas*

In addition to avoiding damage from sea level rise and flooding, these types of policies can also reduce energy costs and improve the efficiency of public infrastructure. One limitation in a policy-based approach is that counties in Texas have limited regulatory authority and a significant portion of the region's population lives outside of incorporated municipalities.

b. *Maintain and manage* – Normal operational maintenance may need to be increased to adapt to climate change. For example, rising temperatures may necessitate increased road maintenance. More vehicle maintenance may be required due to increased wear on engines in higher temperatures. Incremental costs are associated with maintenance and operations.

c. *Strengthen and protect* – Buildings and infrastructure design should include consideration for projected climate change impacts. Buildings may need to be hardened against severe weather events. Critical roadways and/or facilities may need to be raised to avoid inundation. The large capital expenditures associated with strengthening and protecting can be spread over time if they are undertaken as a part of planned rehabilitation.

Strengthening, protecting, building redundant systems and relocation all entail large capital costs which are more difficult to spread over time. These investments should be phased in accordance with their vulnerability and relative importance. Ideally, they can coincide with planned capital improvements. In the worst case, they can be employed when a facility needs to be completely replaced due to damage or deterioration.

d. *Enhance redundancy* – This step involves constructing infrastructure that is able to handle high usage and double as a backup should the initial infrastructure feature be destroyed or damaged. An example would be to construct a second bridge connecting one community to another in case the first bridge is damaged. Large capital expenditures are associated with enhancing redundancy.

e. *Relocate* – Existing infrastructure and investments that are not resilient to climate change may need to be relocated. In many cases, high capital expenses such as bridges may not be relocated or rebuilt until there is substantial damage. Large capital expenditures are associated with relocation.


BURN
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Appendix A - Climate Scenario

Model Uncertainties

Climate scenarios are plausible representations of potential future climate conditions, given a specific set of assumptions. They can be used to inform decision-makers regarding mitigation and adaptation strategies. However, projections produced by existing climate models range widely in terms of the extent of possible environmental effects and the time frames in which they may occur. Most of these models project impacts that are global or hemispheric in scale, but which can manifest quite differently at the regional level.

The Intergovernmental Panel on Climate Change ("IPCC") is the most widely recognized resource for climate change scenarios. The IPCC is a scientific intergovernmental body sponsored by the United Nations ("UN") Environment Programme and the World Meteorological Organization (an UN agency) and includes more than 2,000 experts from more than 150 countries. Since they require consensus among a large panel of international experts, the IPCC's assessments are considered to be on the conservative end of the spectrum. Assumptions contained within the IPCC assessments include future trends in energy demand, greenhouse gas emissions, and land use change. The uncertainty associated with these assumptions determines the range of possible scenarios and distinguishes them from forecasts or predictions.

In order to focus on the environmental effects most likely to occur in the Houston-Galveston region, the Panel elected to use the climate change scenario used in the U.S. Department of Transportation's Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I (the "Gulf Coast Study"). The Gulf Coast Study climate scenario was based on the IPCC's global assessment, but applied certain climate variables, such as rainfall and extreme weather events, that are specific to the Gulf Coast region. The scenarios of future climate referenced in the Gulf Coast Study, as well as the IPCC assessment, were generated using an ensemble of 21 different atmosphere-ocean coupled general circulation models for the Gulf Coast region.

The Gulf Coast Study climate scenario was based on the IPCC's global assessment, but applied certain climate variables, such as rainfall and extreme weather events, that are specific to the Gulf Coast region.

The table on the next page shows predicted outcomes from the Gulf Coast Study and other sources for variables which that study did not address. Certain climate variables were not specifically predicted in any of the models reviewed by the panel. In these cases, the historical event of record for the last century demonstrates the actual range of climate extremes. The Panel also discussed a wide range of climate variables that may change in the future; however, the environmental effects of the climate variables in the table rely upon four basic drivers: temperature (land surface), sea level rise, extreme weather events and precipitation.

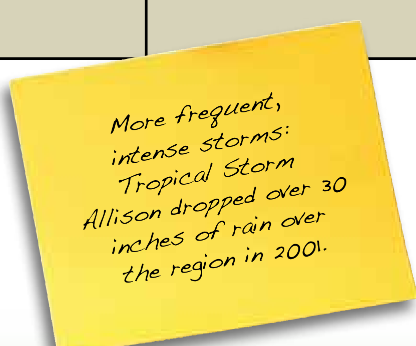
Climate Variable	Future Prediction	Historical	Source
Drought	Same amount of precipitation, but more frequent, intense storms. One can infer that the period between these intense storms may be prolonged.	Droughts in 1910, 1950s, 1988, 1996. 2005-6. 1917 - The driest year on record for southeast Texas with College Station reporting an annual rainfall total of 16.66 inches and Houston reporting an annual rainfall total of 17.66 inches.	*www.weather.com, www.weather.gov* *http://www.srh.noaa.gov/hgx/climate/holidays/hundred.htm* Dr. John Nielsen-Gammon, Texas A&M University, Texas State Climatologist, July 2008
Flooding Events	While average annual rainfall will remain relatively constant, the intensity of individual rainfall events is likely to increase.	Since 1937, nearly 30 damaging floods have occurred in the area, resulting in hundreds of millions of dollars in damages. After the 1940's, the Harris County area did not suffer a widespread, regional flood until June 2001 (TS Allison). October 1994 – excessive rain (10-15 inches) occurred for 9 days, killing 19, damaging 22,000 homes, causing $900 million in damages and displacing over 10,000 people.	Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I, U.S. Climate Change Science Program Synthesis and Assessment Product 4.7, US DOT *www.climatescience.gov/Library/sap/sap4-7/final-report/sap4-7-final-all.pdf* *http://www.dshs.state.tx.us/comprep/rna/setexfl.pdf* Dr. John Nielsen-Gammon, Texas A&M University, Texas State Climatologist, July 2008 *http://www.hcfcd.org/hcfloodhistory.html* *http://www.hcfcd.org/flash/FloodHistory.html*

Climate Variable	Future Prediction	Historical	Source
Gulf of Mexico Water Temperature	Water temperatures are expected to increase.	Annual mean temperature at water's surface is approximately 23°C.	Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I, U.S. Climate Change Science Program Synthesis and Assessment Product 4.7, US DOT *www.climatescience.gov/Library/sap/sap4-7/final-report/sap4-7-final-all.pdf* *www.nodc.noaa.gov*
Heat Waves	For 2032, there is 90% probability that Houston will experience 1-2 days during the summer at or above 37.8°C (100°F). For 2057, there is 100% probability that Houston will experience 1-4 days during the summer at or above 37.8°C (100°F). For 2099, there is 100% probability that Houston will experience 1-20 days during the summer at or above 37.8°C (100°F).	In 1980, Houston reported 32 days with high temperatures exceeding 100°F. Beginning on July 6, 1980, Houston endured 14 consecutive 100°F days. August 23, 1980: Houston's all-time high record of 107°F.	Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I, U.S. Climate Change Science Program Synthesis and Assessment Product 4.7, US DOT *http://www.srh.noaa.gov/hgx/climate/holidays/hundred.htm*

Climate Variable	Future Prediction	Historical	Source
Humidity	HadCM2 and CGCM1 project a more humid climate for the Texas coast. A 2-3% increase in specific humidity per decade is expected. Specific humidity is the ratio of water vapor to air (including water vapor and dry air) in a particular volume. For time periods between intense rain events, the region will experience drier conditions due to increased temperatures and decreased soil moisture and runoff. For time periods immediately following intense rain events, the region will experience more humidity due to saturated soils from intense rain events.	Increased by approximately 1-7% since the 1940s. In the southeastern United States, specific humidity increased 2-3% per decade between 1973 and 1993 and this trend is expected to continue. Specific humidity is the ratio of water vapor to air (including water vapor and dry air) in a particular volume.	Hadley Centre Model (HadCM2), Canadian Climate Centre Model (CGCM1) and Confronting Climate Change in the Gulf Coast Region, Union of Concerned Scientists and The Ecological Society of America Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I, U.S. Climate Change Science Program Synthesis and Assessment Product 4.7, US DOT *www.climatescience.gov/Library/sap/sap4-7/final-report/sap4-7-final-all.pdf* Dr. Robert Harriss, Houston Advanced Research Center, April 2008
Hurricanes	Risk will likely be exacerbated as the temperature of atmosphere and sea surface increase.	Post-Katrina (2005) high watermark surveys in New Orleans proper and east along the Mississippi Coast revealed storm surge heights approaching 8.5 meters (28 feet). From 1900-1999, 45 hurricanes and 41 tropical storms hit Texas coast (or within 50 miles of Texas coast) and produced storm surges as high as 22 feet.	Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I, U.S. Climate Change Science Program Synthesis and Assessment Product 4.7, US DOT *www.climatescience.gov/Library/sap/sap4-7/final-report/sap4-7-final-all.pdf* *www.srh.noaa.gov/lch/research/txhuclimo.php*

Climate Variable	Future Prediction	Historical	Source
Hydrologic Water Flow	In the 2004 National Wildlife Federation forecast for freshwater flows to Texas estuaries, Galveston Bay was projected to have 16 years with low spring or summer freshwater pulses, putting high freshwater inflows below target levels. Matagorda Bay was projected to have 31 years. Both have an overall ranking of "Danger", meaning, during dry times, these estuaries would face sustained periods of very low flows happening more frequently. During these low flow periods, many species are barely able to survive. If they are in this situation too often or for too long, they may be unable to recover quickly, or at all, when inflows increase with wetter times.	During 1956, the worst year of the decade-long drought, combined river discharges measured at the last streamflow gaging station on each major Texas river amounted to only about 14% of the average annual freshwater inflows to the state's bays and estuaries. Bay oyster production in Texas practically ceased, white shrimp harvests were drastically reduced, and estuarine-dependent fishes such as the black drum were blinded and exhibited body lesions from extreme high salinity stress.	Bays in Peril, A Forecast for Freshwater Flows to Texas Estuaries. National Wildlife Federation, 2004 Methods for Determining Minimum Freshwater Inflow Needs of Texas Bays and Estuaries. Powell, G.; Matsumoto, J.; Brock, D. Texas Water Development Board, 2002

Climate Variable	Future Prediction	Historical	Source
Precipitation	Same amount, but more frequent, intense storms.	Approximately 37-55 inch/year for the region. Tropical Storm Allison dropped over 30 inches of rain over the region in 2001.	Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I, U.S. Climate Change Science Program Synthesis and Assessment Product 4.7, US DOT *www.climatescience.gov/Library/sap/sap4-7/final-report/sap4-7-final-all.pdf* PRISM model, Spatial Climate Analysis, Service at Oregon State University, Natural Resources, Conservation Service (NRCS) Water and Climate Center, NRCS National Cartography and Geospatial Center (NCGC), and (or) the National Atlas of the United States
Sea Level Change	2050: Increase of approximately 1-3 feet. 2100: Increase of approximately 2-5 feet.	Approximately 1-2 mm/year since 1900.	Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I, U.S. Climate Change Science Program Synthesis and Assessment Product 4.7, US DOT *www.climatescience.gov/Library/sap/sap4-7/final-report/sap4-7-final-all.pdf* *http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_Ch05.pdf*



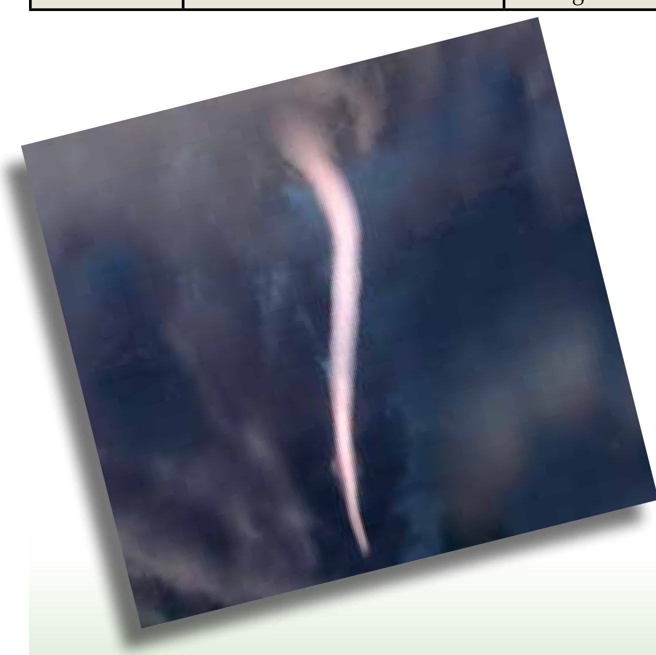
Climate Variable	Future Prediction	Historical	Source
Soil Moisture	Average soil moisture and runoff could decline due to increasing temperature, evapotranspiration rates and spacing between rainfall events. For time periods between intense rain events, the region will experience drier conditions due to increased temperatures and decreased soil moisture and runoff. For time periods immediately following intense rain events, the region will experience more humidity due to saturated soils from intense rain events.	No data.	Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I, U.S. Climate Change Science Program Synthesis and Assessment Product 4.7, US DOT *www.climatescience.gov/Library/sap/sap4-7/final-report/sap4-7-final-all.pdf* Dr. Robert Harriss, Houston Advanced Research Center, April 2008

For time periods between intense rain events, the region will experience drier conditions due to increased temperatures and decreased soil moisture and runoff.

Climate Variable	Future Prediction	Historical	Source
Subsidence	1995-2030: up to 2 additional feet of subsidence in NW Harris County and 2.5 feet in southwest Harris County and NE Fort Bend county. Note: According to the Harris Galveston Coastal Subsidence District, this number is the most recent projection but out of date and probably too high as the groundwater to surface water conversion has been accelerated in Harris and Fort Bend Counties and in the City of Houston.	From 1906-2000, subsidence has ranged from 1-10 feet in Harris, Galveston and Fort Bend Counties.	Tom Michel, Harris Galveston Coastal Subsidence District, May 2008
Temperature (Land surface air temperature)	2050: Approximately 2- 7° F increase. 2100: Approximately 3-11°F increase.	From 1905-2003, the 1920s and 1950s were the warmest decades for the Gulf Coast. The coolest period occurred in the 1960s, while a warming trend is evident beginning in the 1970s and extending through 2003.	Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I, U.S. Climate Change Science Program Synthesis and Assessment Product 4.7, US DOT *www.climatescience.gov/Library/sap/sap4-7/final-report/sap4-7-final-all.pdf* Dr. John Nielsen-Gammon, Texas A&M University, Texas State Climatologist, July 2008

From 1905-2003, the 1920s and 1950s were the warmest decades for the Gulf Coast. The coolest period occurred in the 1960s, while a warming trend is evident beginning in the 1970s and extending through 2003.

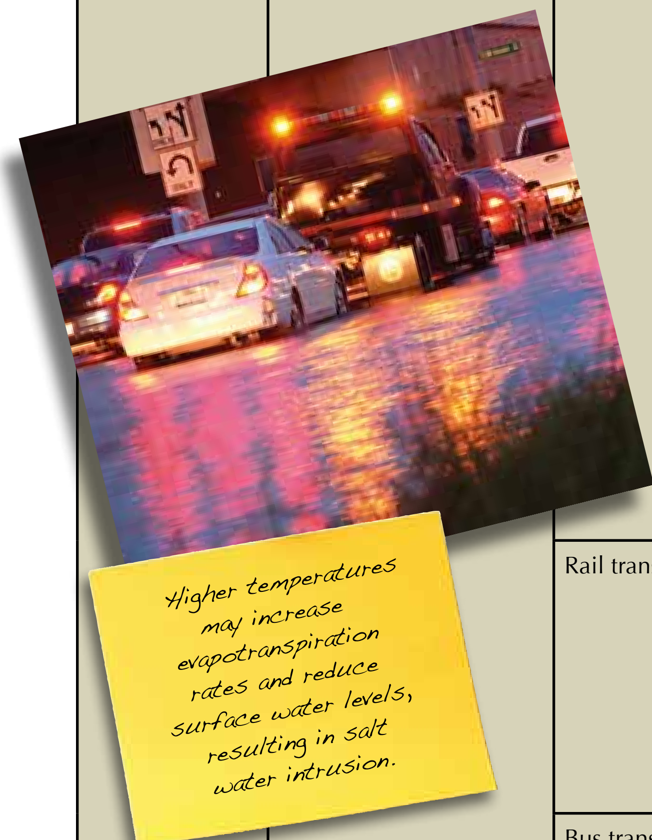
Climate Variable	Future Prediction	Historical	Source
Tornadoes	Numbers expected to increase especially if the number of hurricanes is expected to increase.	November 1992: A line of severe thunderstorms produced 18 tornadoes across SE Texas, 34 people injured. F4 tornado ripped through Channelview destroying over 200 homes and damaging 1000. F2 tornado sliced through Houston from near Hermann Park to IAH damaging over 600 structures.	One Hundred Years of Southeast Texas Weather (1900-2000), NOAA/NWS *www.srh.noaa.gov/hgx/climate/holidays/hundred.htm*
Winter weather	Winter minimum increase <3°F - ~5°F.	Jan 29-Feb 2, 1951 Ice storm: Temperature in Houston was below freezing, average temperature during period was 28°F. Galveston remained below freezing for 3 consecutive days. One and forty-two hundredths inches of liquid precipitation fell, producing one of worst ice storms in city history and agriculture losses.	Hadley Centre Model (HadCM2), Canadian Climate Centre Model (CGCM1) and Confronting Climate Change in the Gulf Coast Region, Union of Concerned Scientists and The Ecological Society of America *www.srh.noaa.gov/hgx/climate/holidays/hundred.htm*



Appendix B - Impacts on Major Sectors, Sub-Sectors and Planning Areas

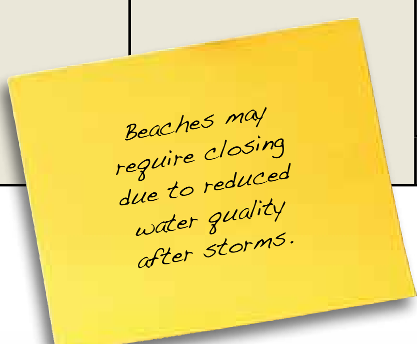
The Panel discussed the effects of climate change on the region's major public sectors, sub-sectors and planning areas. Below are the results of those discussions and, in some cases, GIS analysis which is summarized in Appendix C.

Sector	Sub-Sector	Planning Area	Impact
Infrastructure	Transportation	Road operations and maintenance	More maintenance: faster deterioration due to increased temperatures, sea level rise, and rainfall. Pavement buckling, bridge scour, culvert washouts, stormwater management capacity exceedance, right of way could be subject to brush fires during droughts, interruption of road traffic, interruption of construction and maintenance schedules during extreme heat events when it is difficult for crews to work outside. Design: peak streamflows could affect the sizing requirement for bridges, culverts, and stormwater management facilities. Stresses on animal and plant populations brought on by higher temperatures and changes in rainfall patterns could make it more difficult and expensive to mitigate the impacts of highway development on the natural environment. Safety: higher incidence of crashes and delays, debris obstructions from storms. Approximately 9,690 miles of roads temporarily affected by flooding if the entire 1% floodplain is flooded. Approximately 1,812 existing miles of roads permanently affected by sea level rise. Approximately 6,400 inundated by sea level rise and storm surge; damage or destruction could result.[1]
		Rail transit	Rises in temperature could lead to greater maintenance and air conditioning costs and an increased likelihood of rail buckling and derailment from "sun kinks", stresses on engines and air conditioning systems, affect vehicle availability rates and disrupt service. Higher intensity precipitation could lead to higher accidence rates. Coastal rail systems are at high risk to storm surge.
		Bus transit	Higher temperatures may increase use of air conditioning on buses and exacerbate the issue of vehicle availability rates and raised costs due to increased fuel consumption. Higher intensity precipitation could lead to higher accident rates.
	Hydrology and Water Resources	Flood/stormwater control	An increased number of intense storms may stress adequacy of dams, levees, storm drains and flood-damage reduction infrastructure.
		Water supply management	Higher temperatures may increase evapotranspiration rates and reduce surface water levels, resulting in salt water intrusion.



[1] *Result of H-GAC GIS analysis, summarized in Appendix C.*

Sector	Sub-Sector	Planning Area	Impact
Infrastructure		Wastewater management	Seven hundred twelve existing wastewater treatment plants (WWTP) may experience interruptions in service or be damaged if the 1% floodplain is flooded. Seventy existing WWTP may be permanently inundated by sea level rise. Two hundred eight-six WWTP may be inundated by combination of sea level rise and 20-foot storm surge; damage and/or interruption of service may result.[1] Inundation and/or failure of on-site sewage facilities, resulting in higher risk of water-borne illness.
	Public Facilities	Parks, libraries, schools and community centers	One hundred sixty-six existing public schools may be damaged if the 1% floodplain is flooded. Six existing public schools may be permanently inundated by sea level rise. One hundred twenty-four existing public schools and the majority of NASA Johnson Space Center (JSC) (approximately 1,589 acres) may be inundated and damaged by combination of sea level rise and 20-foot storm surge.[1] Coastal areas will experience gradual erosion and permanent flooding with damage to buildings, infrastructure and natural ecosystems or through increasing damages during extreme events as the storm surge increases and the beach or wetland buffer is gradually lost. Increased cooling/heating costs. Air conditioned facilities may experience an increase in patrons on extreme heat days. Beaches may require closing due to reduced water quality after storms. Beaches may erode at a faster rate due to sea level rise and larger storm surge impacts.
	Municipal Solid Waste	Collection, disposal and processing	Interruption of collection during floods and extreme events increase in odor issues. Flooding of eight existing landfills if 1% floodplain is flooded, permanent inundation of two existing landfills by sea level rise, inundation of nine landfills by combination of sea level rise and 20-foot storm surge.[1]
		Storm debris	Delays in processing materials during floods, extreme weather events, road closures.
Ecosystems and Natural Resources	Ecosystems	Aquatic ecosystems and wetlands	Salinity intrusion, reduction of fringing wetlands that absorb flooding and hurricane impacts. Increased water temperature and periods of drought may result in reduced flows in streams and lower dissolved oxygen concentrations and increased bacterial re-growth in summer months. Habitat may be reduced by increases in hydrological variability, reduction of migratory bird and wildlife populations.
		Invasive species	Increases in invasive species.



[1] *Result of H-GAC GIS analysis, summarized in Appendix C.*

Sector	Sub-Sector	Planning Area	Impact
Ecosystems and Natural Resources		Species diversity	Shifts in distribution of plants and animal species. Habitat may be reduced with increases in hydrological variability. Reduction of cordgrass stands in estuaries, decreases in fish, shrimp and crab habitat. Plant life could be at risk of brush fires.
		Urban forestry	Potential risk of brush fires, invasive species, insect pests, altered growth rates and species migration.
	Natural Resources	Water quality	During floods: decrease in conductivity; increase in nutrient, TSS and bacterial loading. During drought: increase in conductivity, decrease in nutrient and TSS loading; increase in harmful algal blooms. During drought and periods of increased water temperature: reduced flows in streams, lower dissolved oxygen concentrations and increased bacterial re-growth in summer months. Reduction of fringing wetlands, increased shoreline erosion, increased salinity into coastal and freshwater bodies, increased coastal erosion.
		Erosion management	Increased erosion, degraded shorelines. Shorelines are more vulnerable to erosion during hurricane season due to increased wave heights.

The more days ozone levels exceed air quality standards could lead to an increased number of respiratory-related hospital admissions.

Sector	Sub-Sector	Planning Area	Impact
Public Health and Safety	Emergency Response	Communications	During drought and periods of increased water temperature: reduced flows in streams, lower dissolved oxygen concentrations and increased bacterial re-growth in summer months.
		Emergency medical	Reduction of fringing wetlands, increased shoreline erosion, increased salinity into coastal and freshwater bodies, increased coastal erosion.
		Evacuation planning	Storm surge zone will be expanded due to sea level rise.
		Fire	Higher risk of brush fires during drought conditions.
	Public Health	Air quality	Greater number of days in which ozone levels exceed air quality standards could lead to an increased number of respiratory-related hospital admissions. The production of plant allergens could intensify the severity of seasonal allergies, lengthen allergy season and cause more people to seek medical treatment.
		Ability to provide health care	More stress applied to health care system. Increases in heat- and respiratory-related hospital admissions. Higher potential for injuries during flooding. Twenty-six hospitals may be affected if the 1% floodplain is flooded, 15 hospitals may be affected by combination of sea level rise and 20-foot storm surge.[1]
		Heat-related illness	Incidents likely to increase. Elderly, very young, infirm and the poor are most vulnerable to heat illnesses.
		Vector-borne and water-borne illness	Vector-borne diseases (transmitted by mosquitoes, ticks) such as malaria, dengue fever and Lyme disease have the potential to increase. Gastrointestinal and respiratory diseases and skin, ear and eye infections can result from eating contaminated fish and shellfish and diseases contracted during recreation in coastal waters. These incidents are expected to increase with changes to temperature, rainfall and water salinity.

Gastrointestinal and respiratory diseases and skin, ear and eye infections can result from eating contaminated fish and shellfish and diseases contracted during recreation in coastal waters.

Appendix C: GIS Impacts Scenario

Using its geographic information system ("GIS"), H-GAC analyzed potential impacts of flooding and sea level rise on several types of public infrastructure. Three different scenarios were produced to loosely model potential environmental effects of climate change. These included flooding of the 1% (100-year) floodplain, sea level rise of five feet and twenty-five feet. In addition to infrastructure impacts, H-GAC also estimated the population and value of property that would be affected in each scenario.

Resources available for this project did not allow for the development of a robust model to simulate increases in flooding, sea level rise and extreme weather events; therefore, staff used a simplified version based on elevation. The resulting summaries and maps depict what infrastructure would be inundated should flooding of the 1% floodplain occur and what infrastructure would be permanently inundated from sea level rise. The twenty-five feet of sea level rise scenario is a surrogate for storm surge, but is not a representation of a true storm surge model, which would incorporate factors such as pressure, storm size, forward speed, track and winds. Results of the scenarios and an extended impacts table are located below.

Floodplain Impact Analysis Summary

Existing Infrastructure (13-County area) Impacted by Flooding 1% Floodplain

Existing Infrastructure Type	Total in 1% Floodplain	Total in Region	% of Total
Schools in Floodplain	165	1,494	11%
Wastewater Treatment Plants (WWTP) in Floodplain	710	1,336	53%
Hospitals in Floodplain	26	110	24%
Landfills in Floodplain	8	45	18%
Miles of Roads in Floodplain	9,623	51,352	19%
NASA Johnson Space Center ("JSC"): Acres Inside Floodplain	76[1]	1,589	5%

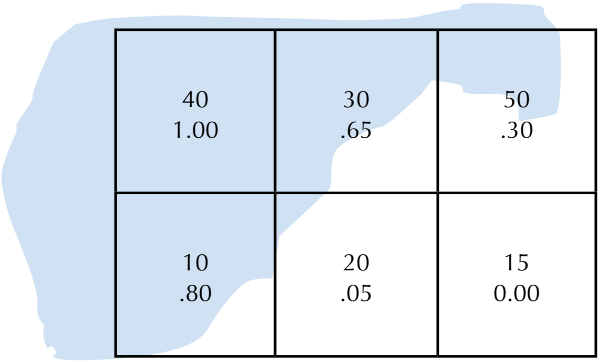
To view resulting infrastructure map see page C-5.

In the analysis results below, a "High Estimate" indicates that if all, or a portion, of a grid cell (1,000 ft x 1,000 ft) intersected with a floodplain, the full value of the population was assumed. For "Medium Estimate", H-GAC estimated the allocation of population that may be in the portion of the grid cell that is in the floodplain if the entire grid cell was not within the floodplain. The medium estimate approach assumes uniform distribution of population.

To view resulting population maps see pages C-6 and C-7.

[1] *Seventy-six acres of NASA JSC inside the 1% floodplain represents approximately 5% of the NASA's total area. No structures are affected by this scenario.*

Example of a High Estimate and Medium Estimate Calculation



- *Whole Number represents grid cell value (population).*
- *Fractional number represents percentage of grid cell covered by floodplain.*

Floodplain

High Estimate Method:

Take full grid cell value if floodplain intersects with grid cell.

40 + 30 + 50 + 10 + 20 = 150

Medium Estimate Method:

Multiply percentage of inundation by grid cell value; assumed uniform distribution across grid area.

(40 * 1.00) + (30 * 0.65) + (50 * 0.3) + (10 * 0.80) + (20 * 0.05) + (15 * 0.00) = 84

Population (High Estimate) Impacted by Flooding of 1% Floodplain

County	2005		2035	
	Population in thousands	% of Population in Floodplain	Population in thousands	% of Population in Floodplain
Brazoria County	96	36%	176	38%
Chambers County	10	34%	18	35%
Fort Bend County	118	27%	291	31%
Galveston County	116	43%	170	42%
Harris County	1,134	30%	1,909	33%
Liberty County	18	24%	30	25%
Montgomery County	104	28%	265	31%
Waller County	13	36%	26	35%
8-County Region	**1,609**	**31%**	**2,886**	**33%**

Population (Medium Estimate) Impacted by Flooding of 1% Floodplain

County	2005		2035	
	Population in thousands	% of Population in Floodplain	Population in thousands	% of Population in Floodplain
Brazoria County	61	23%	122	26%
Chambers County	6	21%	11	22%

County	2005		2035	
	Population in thousands	% of Population in Floodplain	Population in thousands	% of Population in Floodplain
Fort Bend County	45	10%	148	16%
Galveston County	84	31%	123	31%
Harris County	539	14%	981	17%
Liberty County	11	14%	18	15%
Montgomery County	38	10%	110	13%
Waller County	7	19%	14	19%
8-County Region	**789**	**15%**	**1,527**	**18%**

The numbers below include all parcels whether they were entirely inside the floodplain, or only partially. This approach was used because the exact locations of buildings on parcels are unknown.

Property (2007 Valuations) Impacted by Flooding of 1% Floodplain

County	Property Values		
	Land (in millions of dollars)	Improvement (in millions of dollars)	Total (in millions of dollars)
Brazoria County	1,401	2,569	3,970
Fort Bend County	2,528	5,784	8,312
Galveston County	2,685	6,122	8,807
Harris County	19,552	27,553	47,105
Montgomery County	952	2,072	3,025
Waller County	92	176	268

Sea Level Rise (5 feet) Impact Analysis Summary

Existing Infrastructure (13-county area) Impacted by 5 feet of Sea Level Rise

Existing Infrastructure Type	Total Impacted by Sea Level Rise	Total in Region	% of Total
Schools	6	1,494	< 1%
WWTP	70	1,336	5%
Hospitals	0	110	0%
Landfills	2	45	4%
Miles of Roads	886	51,352	2%
NASA JSC	0	1,589	0%

Population (8-county area) Impacted by 5 feet of Sea Level Rise

Year	Population (in thousands) Impacted by Sea Level Rise	Households (in thousands) Impacted by Sea Level Rise
2005	70	29
2035	110	47

Property Impacted by 5 feet of Sea Level Rise (2007 valuations)

Land (in millions of dollars)	Improvement (in millions of dollars)	Total (in millions of dollars)	Number of Parcels
1,132	1,829	2,961	41,666

Sea Level Rise (25 feet) Impact Analysis Summary

Existing Infrastructure (13-county area) Impacted by 25 feet of Sea Level Rise

Existing Infrastructure Type	Total Number Impacted by Storm Surge and Sea Level Rise	Total in Region	% of Total
Schools	124	1,494	8%
WWTP	286	1,336	21%
Hospitals	15	110	14%
Landfills	9	45	20%
Miles of Roads	6,400	51,352	12%
NASA JSC	1,589	1,589	100%

To view resulting infrastructure map see page C-8.

Population (8-county area) Impacted by 25 feet of Sea Level Rise

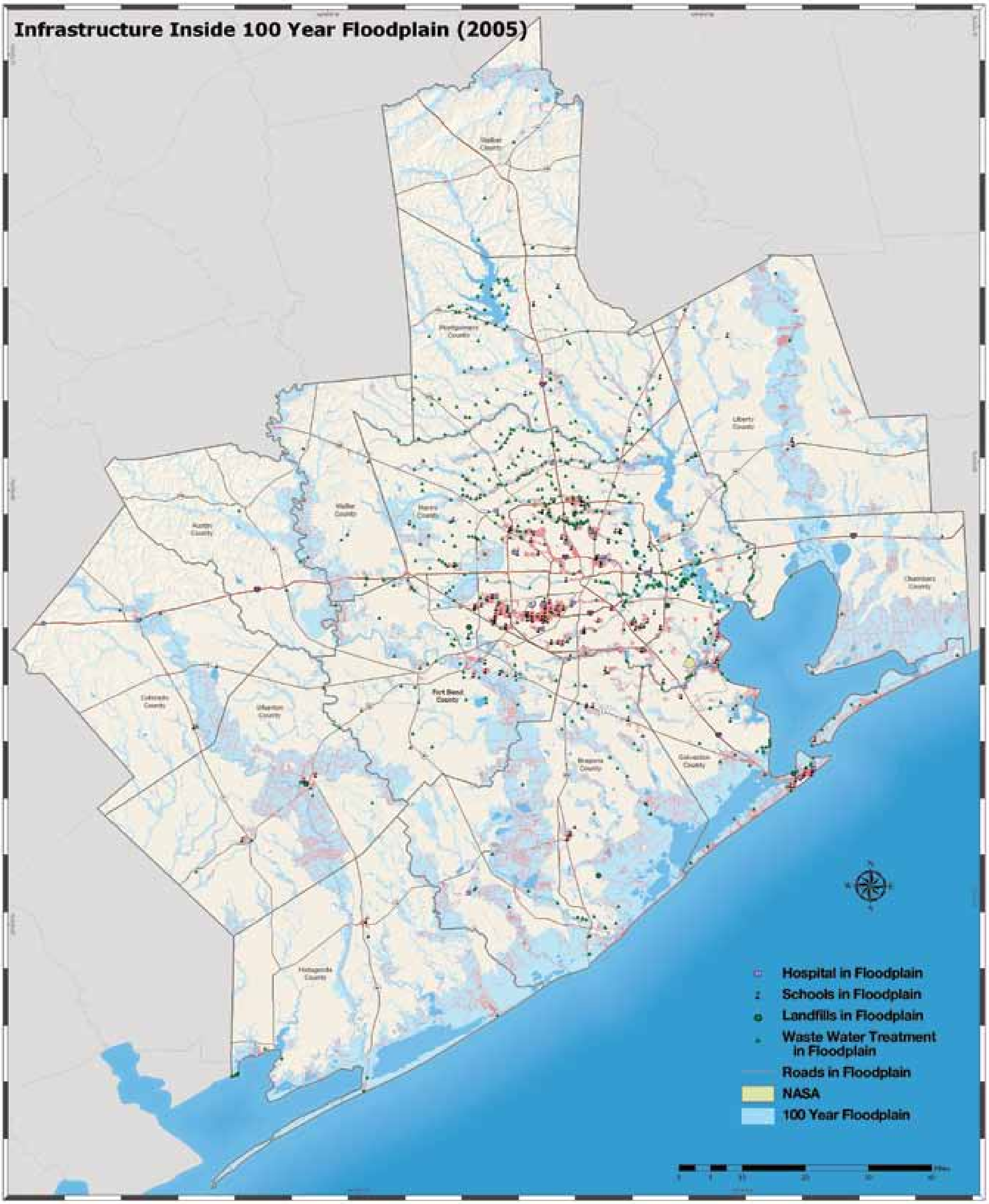
Year	Population (in thousands) Impacted by Storm Surge and Sea Level Rise	Population (in thousands) Impacted by Storm Surge and Sea Level Rise
2005	470	181
2035	772	312

To view resulting population maps see pages C-9 and C-10.

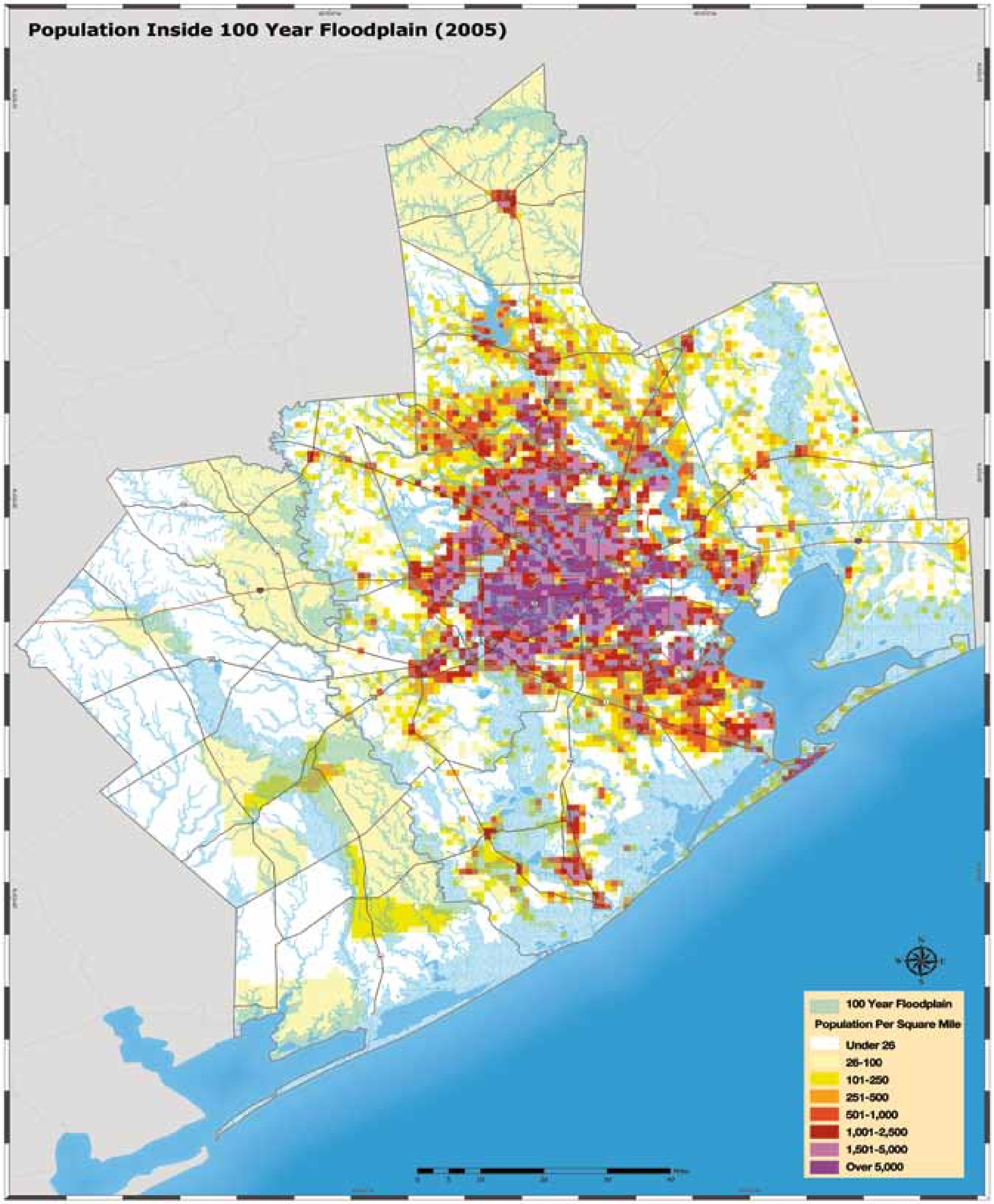
Property (2007 valuations) Impacted by 25 feet of Sea Level Rise (for Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller Counties only)

Land (in millions of dollars)	Improvement (in millions of dollars)	Total (in millions of dollars)	Number of Parcels
7,190	19,394	26,585	258,047

Three different scenarios were produced to loosely model potential environmental effects of climate change.



Electronic versions of maps are available at www.h-gac.com/go/environmentaleffects.



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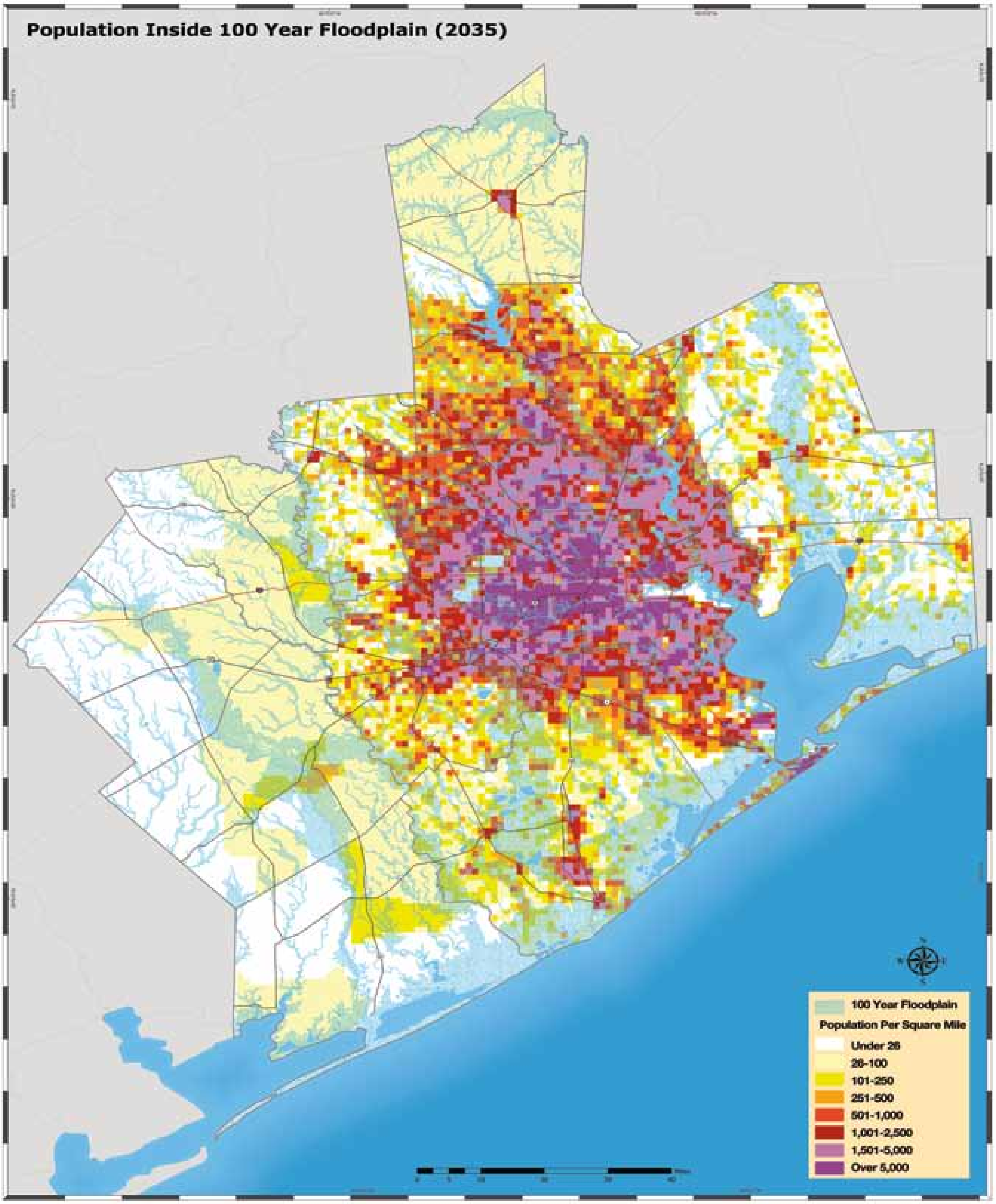

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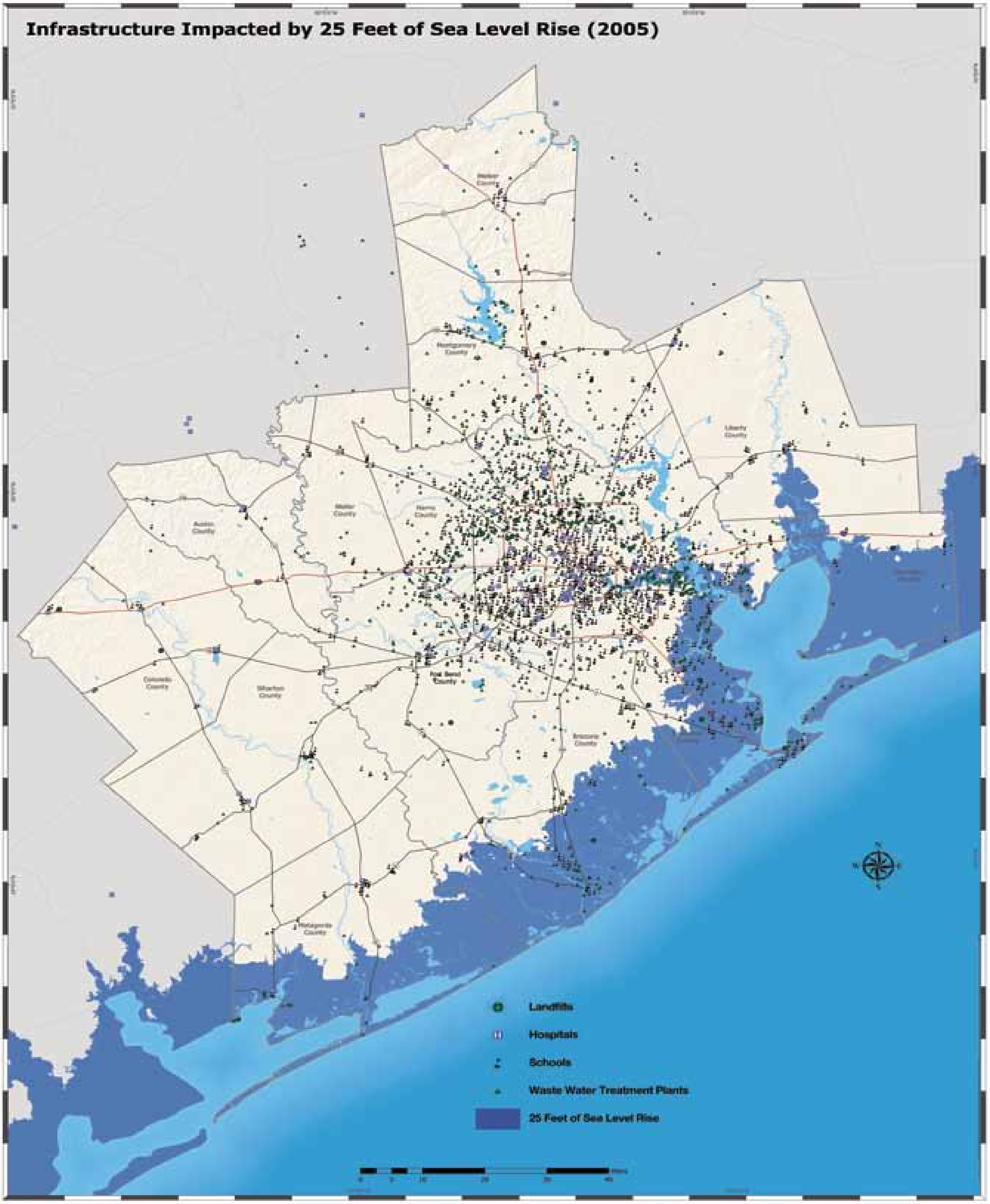

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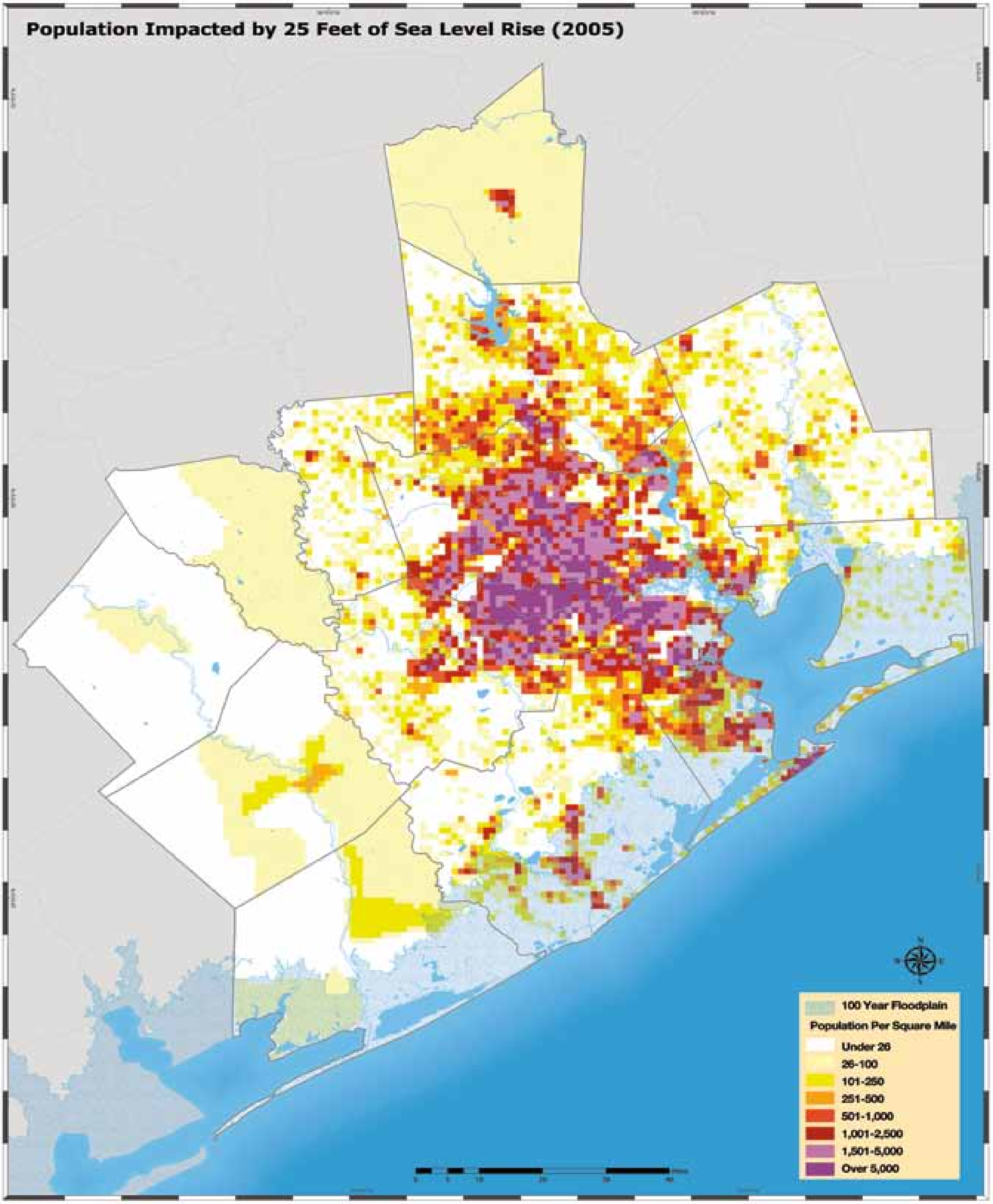
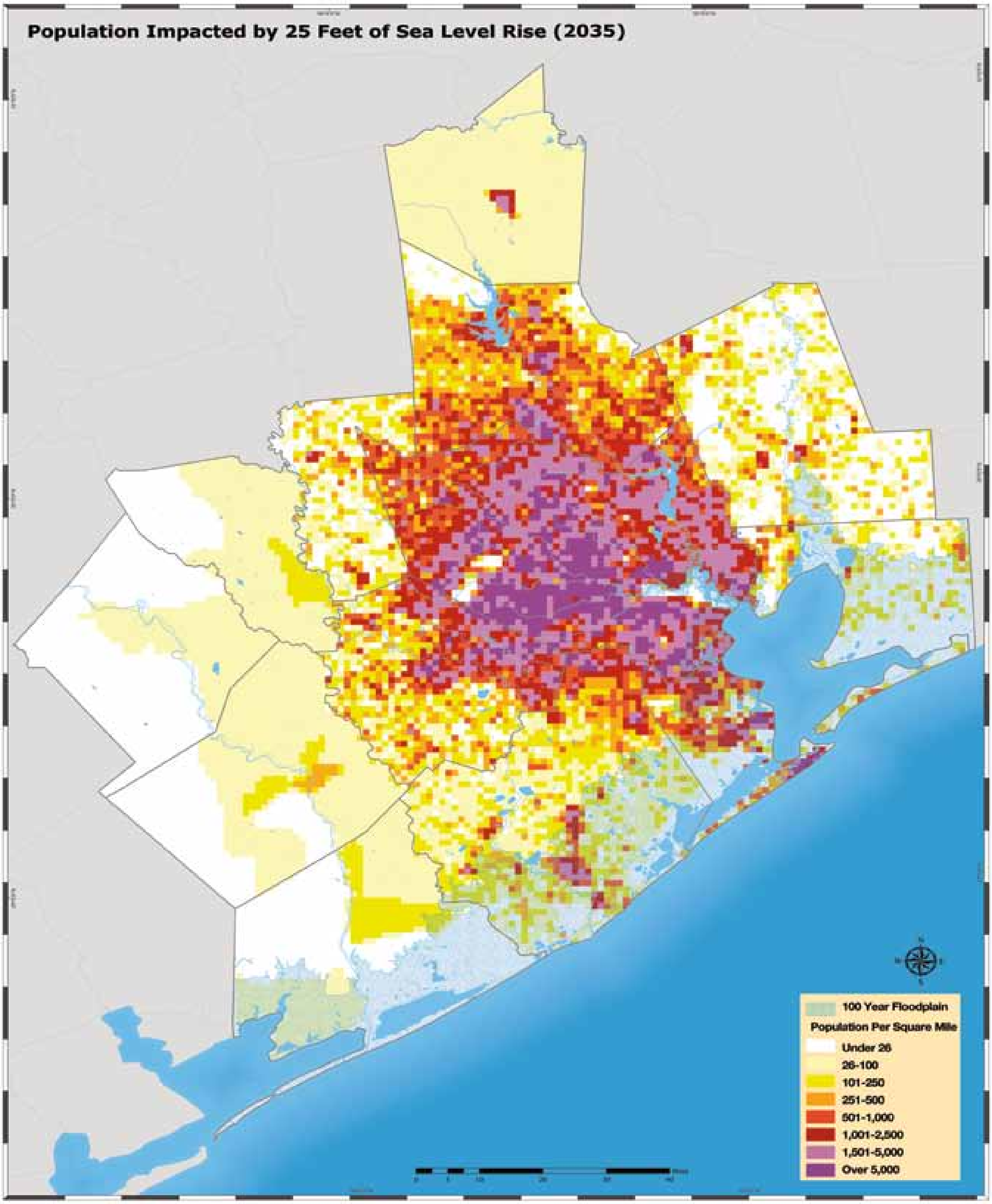


Electronic versions of maps are available at www.h-gac.com/go/environmentaleffects.



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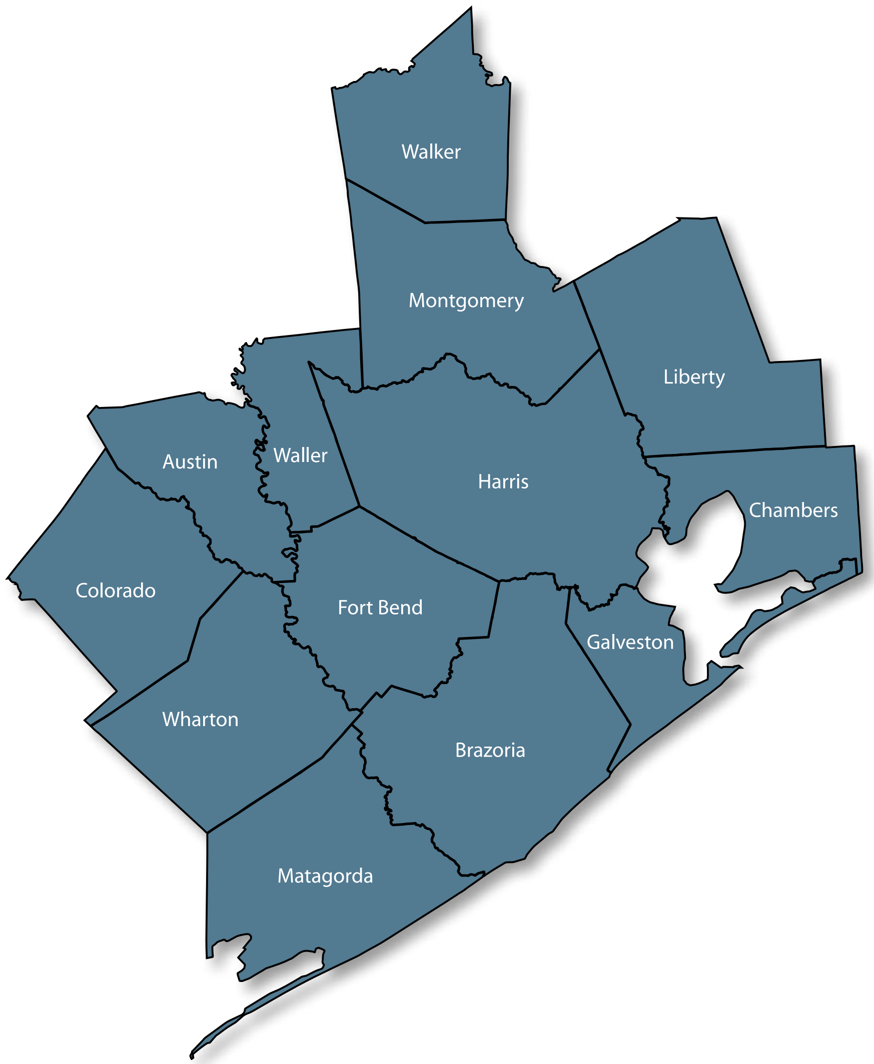
The Houston-Galveston Area Council is the region-wide voluntary association of local governments in the 13-county Gulf Coast Planning region of Texas. Its service area is 12,500 square miles and contains more than 5.7 million people.

H-GAC's mission is to serve as the instrument of local government cooperation, promoting the region's orderly development and the safety and welfare of its citizens.



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