Chapter 7: Urban Areas

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The largest Texas cities will more fully experience the effects of global climate change simply due to the intense concentrations of population and economic sectors at risk. Cities are also where the potential to adapt is the strongest – due to human, community and capital resources – and where system changes – such as infrastructure redevelopment – require more vision. This chapter describes vulnerabilities[1] of major Texas cities to climate change impacts, and variations that exist from city to city due their location within the state and subregional climate conditions.

According to the most recent IPCC reports, cities are now expected to experience localized impacts from higher average and peak temperatures, higher nighttime temperatures, changes in stormwater runoff, increased precipitation (5 to 25 percent), and more frequent and intense storms linked to urban expansion (Wilbanks et al, 2007). However, the global and regional effects due to urbanization, such as land use and land cover alterations, are not simulated in current global climate models (Christensen et al, 2007). Therefore, climate change effects of primary importance to cities cannot be projected with the same tools as climate phenomena. Responses to climate change vulnerabilities rely on technological and institutional changes that occur over several decades. These changes are the products of human and societal invention that result from discovery that takes place in the context of uncertain future conditions. Climate assessments, as they affect cities, must view the future in terms of vulnerabilities, rather than projections (Wilbanks et al, 2007. p. 364).

Communities and community leaders are faced with the worst kind of dilemma; that of taking action on the basis of uncertainties that have potentially severe consequences. As such, it has been common in Texas to deny that there is a problem or to choose inconsequential actions. In one reported exchange, regional leaders suggested that the phrases “climate change” or “global warming” should not be used, but instead the phrase “environmental effects” to “avoid the whole controversy.” (Houston Chronicle, 2007) As of this writing, only a few Texas cities and community leaders have acknowledged that climate change poses a threat, and have become willing to discuss issues and possible responses.

Cities have strong interdependencies between the physical infrastructure – transportation, energy, buildings and communications – and societal infrastructure – services, economic, political, governmental, institutional and health systems. Texas was transformed during the 20th century from a largely rural setting to an area in which three-quarters of its citizens and most of its economy are urban. Today’s Texans live and work in cities, and the future portends an even larger urban setting. Over time, cities adapted to Texas climate conditions in ways that have responded to the historical challenges of rainfall, drought, floods, heat waves, high temperatures, ice storms, tornados and hurricanes. Cities rely on physical and societal infrastructures that are vulnerable to global climate change impacts (see Ruth and Kirshen 2002). The wide-ranging climate conditions across Texas also mean that these vulnerabilities occur differently from place to place.

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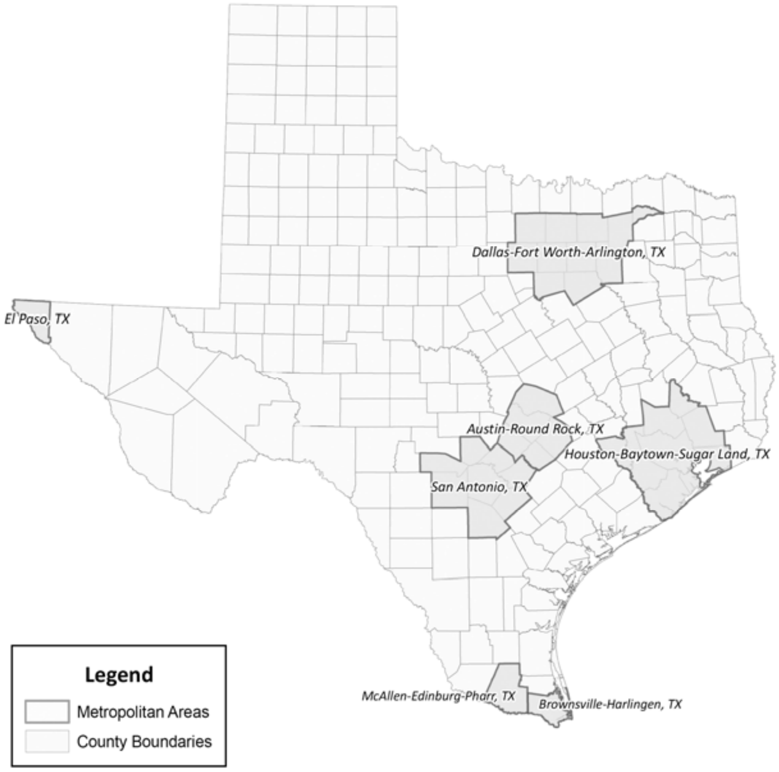
[1] “Vulnerable” is used here to indicate characteristics of locations that could result in climate change impacts; for example, Gulf Coast cities are *vulnerable* to sea level rise.

The largest Texas urban areas are home to over 18 million people. Some of the largest urban concentrations include Dallas-Ft. Worth, Houston, San Antonio, Austin, El Paso, the urbanized areas of the Lower Rio Grande and communities along the Texas Gulf Coast (Figure 7.1). Cities, such as El Paso, with a hot, arid climate, already face water resource challenges, and are vulnerable to a future hotter, dryer climate that will exacerbate these conditions. Gulf Coast areas, including Houston, face the prospect of more frequent and severe storms, as well as the threat of sea level rise. Central and North Texas cities, such as Austin, San Antonio and the Dallas-Ft. Worth area, are not directly vulnerable to sea level rise, but will experience the consequences of more frequent and severe Gulf Coast generated storms. Texas cities are projected to continue their pattern of growth and expansion, making them increasingly vulnerable to water supply shortages and the impacts of increased energy demand.

Figure 7.1. Texas Metropolitan Statistical Areas



Major cities have greater capacity to adapt to the consequences of climate change because of their relative wealth, infrastructure, financing capacity, health systems and governance capabilities. Governance in Texas urban regions involves hundreds of local governments of various sizes and capabilities. There are also hundreds of special districts that manage and control various functions, such as wastewater treatment. Statewide decision authority on many urban climate issues largely resides at the state government level, but this system must respond to a large and highly diverse set of political interests within a system that seeks a limited government role. While providing broader geographic coverage than urban areas, county governments in Texas have very limited authority. Texas urban regional authorities are limited primarily to planning activities and cooperation involving several jurisdictions. They lack regulatory authority to respond to issues such as those posed by climate change. To reach major decisions, large Texas cities have historically relied on business and community leaders rather than elected officials and local government. This has changed somewhat in recent years.

Cities are also constrained by the inertia of their investments in urban residential patterns, water and sewer infrastructure and transportation, as well as electric power systems. Such systems are difficult and expensive to retrofit or adapt. Additionally, as demonstrated in disasters such as Hurricane Katrina, and under disparate economic or environmental conditions, people will migrate to cities seeking better conditions. Major Texas cities must be prepared for such migrations.

FACTORS CONTRIBUTING TO URBAN VULNERABILITY TO CLIMATE CHANGE

Growing Urban Populations

More than two-thirds of the Texas population live and work in the six major urban centers: Austin-Round Rock, Dallas-Ft. Worth-Arlington, El Paso, Houston-Sugarland-Baytown, the Lower Rio Grande area (including both Brownsville and McAllen) and San Antonio. By 2040, these areas are projected to become a larger fraction (71 percent) of the state's total population. More revealing, these six areas will account for all but 16 percent of the State's population growth (Table 7.1).

Table 7.1. Population of Texas and Major SMSAs 2005 and 2040

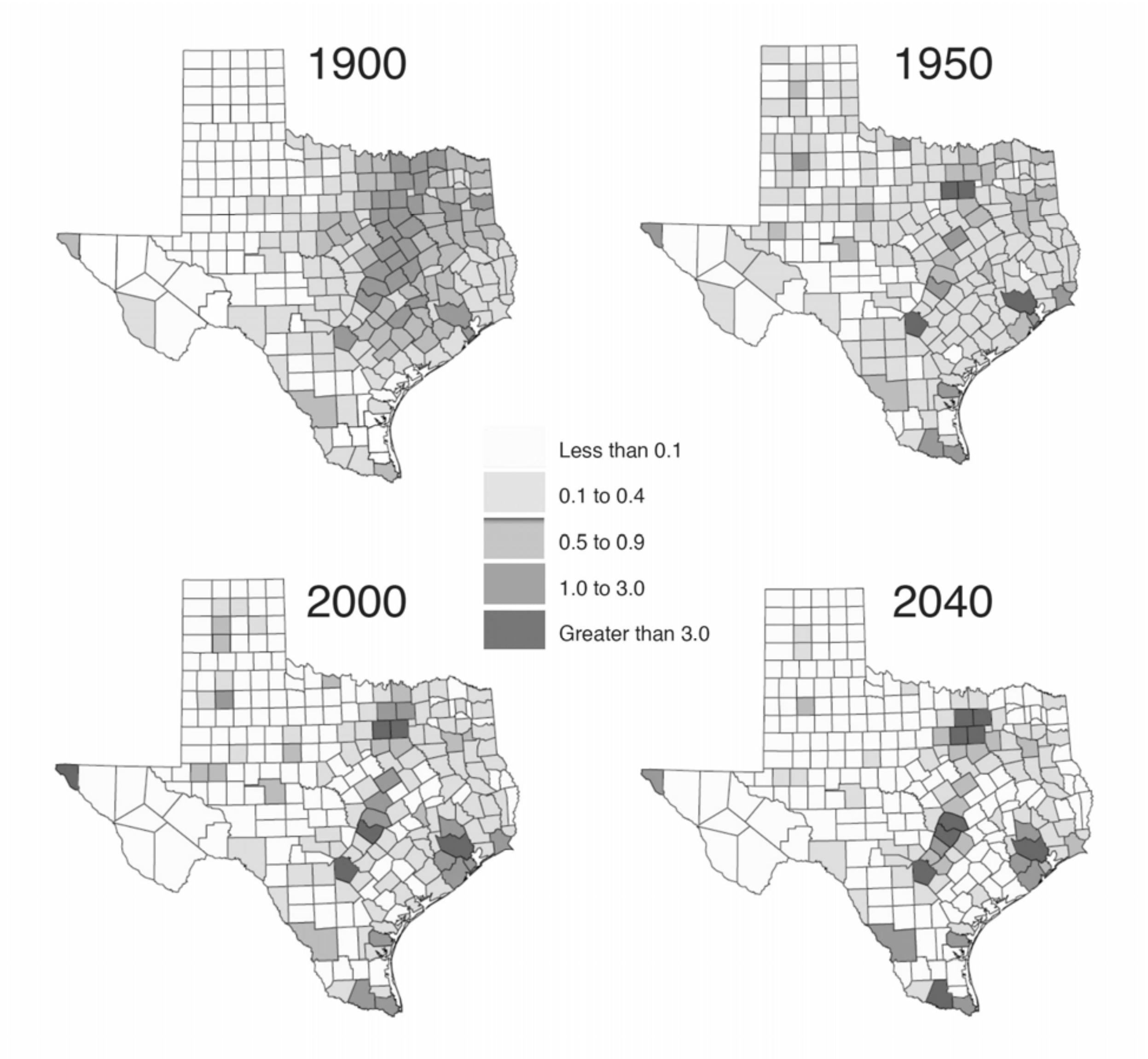
Area	2005	2040
Texas	22,556,054	35,761,201*
Major SMSAs		
Austin-Round Rock	1,405,638	2,658,510
Dallas-Ft. Worth-Arlington	5,667,966	10,106,814
El Paso	740,648	1,153,058
Houston-Sugarland-Baytown	5,121,006	8,400,148
Lower Rio Grande	1,032,392	2,115,220
San Antonio	1,833,252	2,512,021
Total Metro Areas (SMSAs)	15,800,902	26,945,771
Rest of State Total	6,755,152	8,815,430

*Note: Water Development Board population projections for 2040 are 36,893,267, 3 percent more than Texas State Data Center projections for 2040.

By 2040, the Dallas-Ft. Worth and Houston areas would add 7.7 million people (4.4 and 3.3 million respectively). Other urban centers located along the Gulf Coast, including the Beaumont-Port Arthur area and Corpus Christi, are expected to grow as well. The Lower Rio Grande area is projected to have the largest percentage increase at 105 percent, followed by

Austin at 89 percent. As illustrated in Figure 7.2, the widespread rural Texas population of the 1900s has moved from rural counties to the current major urban centers.

Figure 7.2. Urbanization of Texas 1900, 1950, 2000 and 2040 (projected)
Percent of State Population by County
Source: Texas State Data Center



As suggested here, population growth in Texas cities will be a major determinant of future climate change response needs. Cities can respond proactively to this growth in ways that could accommodate expected climate change effects, including provisions within infrastructure standards, building standards and development controls. As providers of public health and public safety, cities will also need ways of responding in these areas. Texas urban centers face a range of vulnerabilities, but will also discover some common elements that can be put in place regardless of the particular vulnerability. For example, energy efficiency measures, whether applied to buildings or vehicles, work across the board to reduce impacts and improve response capabilities. Longer public sector investment timelines for infrastructure (i.e., 50 year life rather than 20 year life) could improve infrastructure resiliency while reducing overall life-cycle costs. Such public investment decisions can also better incorporate environmental and other "externalities" relevant to climate change.

Climate Diversity

The major Texas urban centers are found across a wide range of climatic conditions from the hot, arid climate in far west Texas to humid, subtropical conditions in Houston. These variations suggest that adaptation strategies will differ from city to city. Average annual precipitation varies across these cities by almost 40 inches. Of the six areas, only Austin, San Antonio and Houston have the same energy code designations, while the other three areas are each in different ones (Table 7.2).

Table 7.2. Climate Features of Major Texas Urban Areas

Texas Major Urban Areas	Climate Region*	Avg. Rainfall Inches/ year	Aug Avg High/Low Temps ºF**	Jan Avg High/Low Temps ºF**	Energy Code Region***
Austin-Round Rock	South Central	33.6	96/73	60/40	4
Dallas-Ft. Worth-Arlington	North Central	34.7	95/74	54/34	5
El Paso	Far West	9.4	92/70	57/33	6
Houston-Sugarland-Baytown	Southeast	47.8	94/73	62/41	4
Lower Rio Grande	South	27.6	93/75	69/50	2
San Antonio	South Central	32.9	95/74	62/39	4
Ranges/ Variation	na	9.4-47.8	4ºF/5ºF	15ºF/17ºF	na

Sources: *see Chapter 2, **National Weather Service data, ***Texas Residential Building Guide to Energy Code Compliance, May 1, 2001. Energy Systems Laboratory, Texas A&M University.

Severe weather, such as hail, wind and tornadoes, occurs more frequently in the Dallas-Ft. Worth area than the five other urban areas, with lower frequencies in Brownsville and El Paso. The Houston and Lower Rio Grande areas are more vulnerable to hurricanes and tropical storms.

Although climate variables, such as maximum hourly rainfall, are accounted for in urban development and building codes, climate variations and new extremes, such as those projected with global climate change, are not. Cities are built based on historical climate conditions and, to a certain degree, historical climate extremes. If climate changes are not somehow anticipated in such codes and urban policies, adaptation measures are slowed by delaying initial responses. While planners and government agency staff may be concerned about climate change in Texas, without decisions by city leaders, they are not openly incorporating such factors in relevant activities. As such, climate relevant scenarios are omitted from planning for urban functions such as stormwater infrastructure, transportation facilities, air quality planning, building codes and water resources.

Clearly, one-size-fits-all responses will not work within the climate variations across Texas cities. Cities do need a common framework, including data and forward looking projections, to incorporate climate change in their planning.

Urban Heat Islands

Because of the urban heat island (UHI) effect, cities are hotter than rural surroundings by several degrees (up to 10º F). With climate change induced temperature increases, the UHI effect will be intensified. Urban heat island effects occur when vegetative cover is reduced or removed for urban development, and replaced with heat absorbing materials, such as dark paving and roof surfaces. UHI effects include not only higher temperatures, but other climate variables such as soil moisture, rainfall patterns, wind direction and intensity, and lightening strikes.

The three types of urban heat island effects include canopy layer, boundary layer and surface heat island. The urban canopy extends from the ground surface to the average building height. The boundary layer extends up to 1 km, expanding with heat during the day and contracting during the cooler nighttime. The urban heat effect is often pictured as a dome of air or island over the city. The surface heat island is associated with urban surface characteristics such as hot roofing surface temperatures, which can reach 180ºF during hot summer days.

Paving and roofing surfaces comprise over 60 percent of developed urban areas. Higher urban temperatures are associated with higher average and peak energy demand for cooling and with higher levels of ozone. In Houston, paving and roofing account for 50 percent of urban surfaces (29 percent and 21 percent respectively)(Rose, et al, 2003). As cities develop, the extent of the urban heat island increases (Oke 1973 and Streutker 2002). Vegetative cover can reduce urban temperatures through transpiration (evaporative cooling from released moisture) and shade. Trees and buildings also affect wind flow and wind patterns in cities. Human induced heating in cities also comes from motor vehicle engines, air conditioning condensers, building cooling towers, generators, power plants and industrial processes.

Studies of urban temperature change show that average daytime temperatures have increased in the past by 0.2 to 0.8ºF per decade (Akbari, 2003, p 3). At Dallas Love Field, average wintertime temperatures increased by 0.8ºF per decade from 1970 to 2006 while summertime temperatures increased by 0.4ºF per decade. These increases occurred as the surrounding area developed over this time. Houston Hobby Airport experienced increases as well, but at a much lower rate (less than 0.1ºF per decade from 1970 to 2006).

Cities in the southern tier of the U.S. experienced intensification of the urban heat island effect over the past 50 years as measured by differences in urban and rural temperatures over time (Stone 2007). Average daily temperature increases over 0.9ºF per decade were observed (Oklahoma City). Dallas, Austin and San Antonio experienced increasing heat island intensity. Heat island intensity was lessened in the Houston area, perhaps due to the moderating effects of the Gulf Coast climate. Dallas and Austin experienced increases of 0.4 to 0.5ºF per decade. Urban heat island effects also occur differently from city to city. For example, the Dallas-Ft. Worth area’s nighttime heat island is more prominent than the Houston area (Darby and Senff 2007).

UHI effects and mitigation are relatively well understood, although not extensively applied. The basic ways of reducing UHI effects are increased vegetative cover (more trees), reduced heat absorbing, impervious surfaces (less paving, use of pervious paved surfaces), and increased solar reflectance of urban surfaces (lighter paving and roofing). California was the first state to aggressively pursue cool roof technologies by including these in the statewide building code. Despite the availability of methods and technologies to reduce urban temperatures, most heat island initiatives have been incremental, rather than systemic. Cities to date have been unwilling to take on the comprehensive measures required to change urban surfaces sufficiently to minimize urban heat island effects (Hitchcock, 2004; EPA HIRI 2008).

CHALLENGES FACING POLICY MAKERS

Water Demand

Texas urban centers are a dominant factor in future water demand. The shift from rural to urban water uses will continue this trend far into the future (TWDB 2007). Urban uses such as electric power generation (steam electric) and manufacturing growth are also projected to drive future water demand. Decreased precipitation, reduced stream flows and increased evaporation from reservoirs due to climate change will hamper the state's ability to meet future urban water needs, particularly in those areas where population expansion and economic growth will occur – major Texas cities.

Past Texas water management policies focused primarily on reservoir development and greater reliance on surface waters. The State's regional planning process has changed to include methods such conservation, reuse and desalination (although many of these measures are pushed far into the future). This is particularly evident in water regions containing major urban centers. Since population growth is the largest single determinant, future demand will come largely from urban regions (Table 7.3).

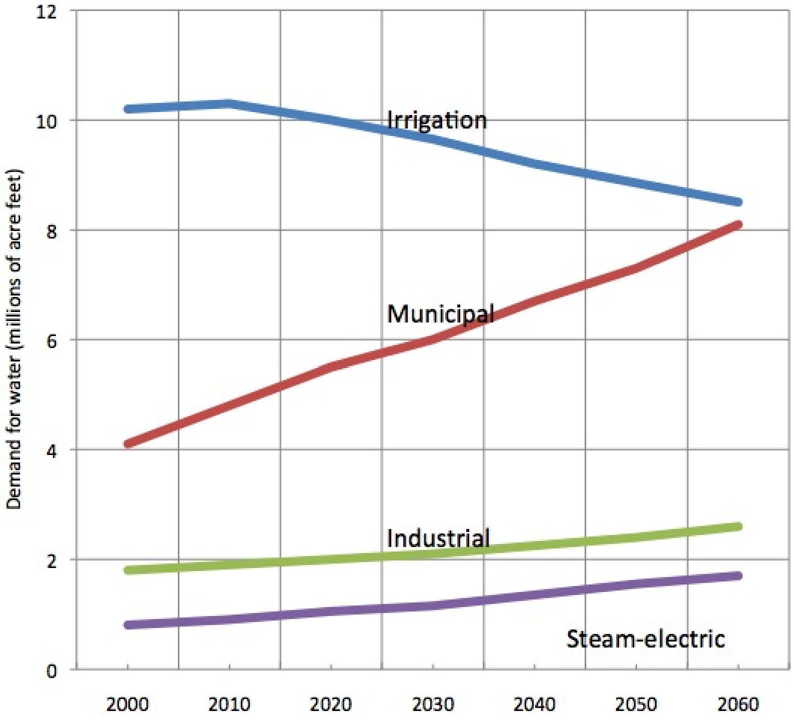
Table 7.3. Population and Water Demand (million acre-feet) in Urban and Non-Urban Regions

	2010	2040	% Change
Water demand			
Urban regions	7.37	10.15	37.8
Non-urban regions	5.08	5.99	17.9
Population			
Urban regions	18.66	28.87	54.7
Non-urban regions	5.77	7.48	29.7

*Region O is not included in non-urban regions because of the size of water demand in relation to state totals. Region O represents 27 percent of all water demand in Texas in 2000, primarily for irrigation and most of that from ground water. Source: Texas Water Development Board, 2007. Water for Texas: 2007

Municipal water projections, which include residential and commercial uses, are based on the combined factors of population change and per capita water use. Statewide, the total municipal demand is projected to grow more rapidly than other uses, increasing by two-thirds from 2000 to 2040, and more than doubling from 2000 to 2060 (Figure 7.3). By 2040, water usage is also projected to increase by 50 percent for manufacturing and more than double for steam electric power (Table 7.4). (TWDB 2007. p. 123)

Figure 7.3. Projected Texas Water Demand by Major Uses (2000 to 2060)



Source: Texas Water Development Board, 2007. Water for Texas: 2007

Table 7.4. Projected Water Demand by Use (2000 and 2040)(million acre-feet)

Water Use	2000	2010	2020	2030	2040	% change 2000-2040
Municipal	4.05	4.77	5.48	6.12	6.740	66.5
Manufacturing	1.56	1.83	2.00	2.16	2.32	48.7
Mining	0.28	0.27	0.28	0.29	0.28	-0.9
Steam-electric	0.56	0.76	0.89	1.03	1.17	109.2
Livestock	0.30	0.34	0.37	0.38	0.39	29.2
Irrigation	10.22	10.35	9.98	9.59	9.21	-10.0
Total	16.98	18.31	19.01	19.57	20.10	18.4

Source: Texas Water Development Board, 2007. Water for Texas: 2007

All regions where Texas urban centers are located are projected to have increased water demand from urban uses: residential, commercial, manufacturing and steam electric power generation (Table 7.5). Projected demand and water needs (demand minus supply) vary widely among these regions, with projected demand increasing by 77 percent (2010 to 2060). By comparison, the demand increase for the remaining regions is 50 percent. The increases range from a low of 60 percent in the El Paso region (where considerable water conservation measures are being applied), with irrigation demand being shifted to urban uses. The highest increase is projected for the Lower Rio Grande region with a 124 percent increase. Increases in municipal

Table 7.5 Projected Water Demand (million acre-feet) in Regions with Major Urban Centers (2000 and 2040)

Urban Centers	Water Planning Region	2000 Water Demand	2040 Water Demand	% Increase
Austin	Region K	1.00	1.24	23.2
Dallas-Ft. Worth	Region C	1.38	2.62	90.0
El Paso	Region E	0.67	0.70	4.9
Houston	Region H	2.09	2.94	40.9
Lower Rio Grande	Region M	1.33	1.50	12.3
San Antonio	Region L	0.90	1.15	28.8
Total Urban Regions		7.37	10.15	37.8
Texas		16.98	20.10	18.4

Source: Texas Water Development Board, 2007. Water for Texas: 2007

Table 7.6. Summary of Projected Urban Water Demand and Needs.

Urban Area	Projected Water Demand
Austin (Region K)	Municipal and manufacturing demand projected to double from 2010 to 2060, and steam-electric by almost 50%. By 2040, water needs* for municipal use are projected to increase by seven-fold
Dallas/Ft. Worth (Region C)	From 2010 to 2060, municipal water use is projected to increase by 92 percent, while steam-electric water use increases by 1.5 times. Manufacturing is projected to increase by 50%. By 2040, municipal water needs* are projected to increase by 3.7 times.
El Paso (Region E)	Most of this region’s water is used for irrigation with municipal uses projected to increase by 50% by 2060. Steam electric water demand is projected to triple by 2060. By 2040, municipal water needs* are projected to increase slightly; population growth needs being met from existing supplies.
Houston (Region H)	Municipal water demand is projected to increase by 75% (2010 to 2060), steam-electric water demand by 138%, while manufacturing would increase by almost one-third. By 2040, municipal needs* are projected to increase by five-fold.
Lower Rio Grande (Region M)	Municipal demand is projected to more than double from 2010 to 2060, with steam-electric increasing by 142 percent. By 2040, municipal needs* are projected to increase almost 9-fold.
San Antonio (Region L)	Municipal demand is projected to increase by 50% from 2010 to 2060, with similar increases in manufacturing. Steam electric water demand would more than double. By 2040, municipal needs* are projected to increase by 2.5 times.

*Water need is defined as demand minus supply.

Source: TWDB 2007

water needs from 2010 to 2040 are projected to range from almost zero in El Paso (Region E) to a nine-fold increase in the Lower Rio Grande region (Region M)(Table 7.6).

While future water resources and demand vary widely from region to region, similar adaptation strategies can be transferred somewhat from area to area. For example, El Paso and other resource-limited regions have already established strict demand reduction measures while pursuing new technologies for resource recovery and use. In some respects, these areas are already better equipped to address future water supply challenges. Similar approaches will be needed in other Texas cities in response to climate change effects and to accommodate population growth. Many Texas cities currently use a large portion of potable water for lawn irrigation and household uses, practices likely to change due to climate change. Cities can rapidly adopt more stringent, cost effective water use measures as part of resource planning and decision-making. Water demand for future steam electric power can be addressed through already available energy efficiency measures that reduce electric power use, peak power demand management, distributed generation technologies, and strategies for renewable energy.

Urban Energy Use

Most electricity and transportation energy use occurs in major cities and urbanized areas of Texas. Higher temperatures from climate change will increase total urban electric power demand as well as peak period use. Higher wintertime temperatures will reduce heating energy demand in Texas cities, largely from natural gas use. The net effect on energy demand will vary from city to city due to regional climate differences.

Cities are also the places where higher levels of efficiency can be achieved to reduce greenhouse gas emissions (i.e., lower fuel use per passenger or ton mile of travel, less distribution losses for electric power due to development densities, etc.). This is due to urban population and economic densities. For example, with sufficient motivation and policy leadership, transportation fuel consumption could be reduced through increased transit use and other available demand reduction measures in all major Texas cities. Likewise, urban development standards can be changed to mitigate the inefficient patterns and styles of development currently dominant in Texas.

Texas electric power systems (generation, transmission and distribution) are designed with the capacity to meet peak demands that occur in Texas during the hottest summer days. Urban area air conditioning typically drives electric power demand loads. Peak demand is the critical factor in determining generating capacity and requirements for more robust transmission and distribution systems (U.S. CCSP 2007). To adapt to higher urban temperatures (both from climate change and urban heat island effects), the existing building inventory in Texas cities will need to be retrofitted for much higher levels of efficiency (as well as use of distributed generation technologies). This applies particularly to existing buildings that were designed for cheap electricity and lax buildings standards.

<u>Cooling degree days</u> (CDDs) is an indicator of electric power demand due to air conditioning. The number of CDDs varies widely among major Texas urban areas; El Paso having 2,094 and the Lower Rio Grande area almost twice that number (4,076). The four other major urban regions range from 2,763 to 3,016 CDDs, but all are more than double the U.S. average of 1,242 CDDs (Table 7.7).

Table 7.7. Cooling-degree (CDD) and heating-degree (HDD) days in major Texas cities

	Annual Average CDD	Annual Average HDD
Austin-Round Rock	3,016	1,688
Dallas-Ft. Worth-Arlington	2,763	2,259
El Paso	2,094	2,708
Houston-Sugarland-Baytown	3,012	1,371
Lower Rio Grande	4,076	693
San Antonio	2,996	1,644

Source: www.Fedstats.gov

Heating requirements among these areas vary even more widely from city to city. The number of heating degree days (HDDs) ranges from 693 in the Lower Rio Grande to 2,708 in El Paso. Higher wintertime temperatures due to climate change would reduce heat energy requirements and natural gas use, the most common source of heating in Texas cities. As such, El Paso and the Dallas-Ft. Worth areas would experience the most reduction in heating energy use. The adoption of more stringent energy codes in these cities, coupled with extensive retrofitting of the existing building inventory, would further reduce heating energy demand and associated greenhouse gas emissions.

Texas cities are only indirectly involved in electricity generation, distribution and use, with the exception of those with municipal utilities, such as Austin and San Antonio. Texas cities also play a role in the state's electric utility regulation through intervening in issues directly affecting them. In 2006, several Texas cities, including Dallas and Houston, joined legal efforts to oppose permitting of proposed coal power plants in north Texas. Part of their opposition was based on increased carbon dioxide emissions that would be generated by the addition of these plants. The Dallas-Ft. Worth region has also faced the challenge of meeting the federal ozone standard, and these new plants were shown to have negative effects on the region's air quality.

City building and development codes also affect electric power consumption. Texas adopted its first statewide building energy code in 2001. The cities of Austin (a national leader in green building standards), Houston and Dallas have adopted even more stringent building energy codes in recent years. These newly-adopted codes expressly exceed EPA's ENERGYSTAR™ program. In the 2008 Dallas City Council resolution adopting its green building program, greenhouse gases were specifically referenced as part of the basis for this new program. The resolution stated: "WHEREAS, commercial and residential buildings consume 40 percent of our nation's energy and are responsible for 40 percent of the greenhouse gas emissions in the United States" (Dallas City Council, 2008). Even with these new standards, existing, less energy efficient buildings are not affected, although Austin is developing an ordinance that will require an energy audit as part of the disclosure process for prospective buyers of houses more than ten years old.

Development codes, such as zoning and subdivision regulations, can allow and/or require higher density, more efficient developments than might be accomplished otherwise. Such development reduces transportation fuel use and associated carbon emissions. Texas cities have not overtly used development codes for the stated purpose of greenhouse gas reductions or mitigation of climate change effects.

Urban Transportation

All modes of transportation are vulnerable to climate change impacts, and in Texas these impacts will vary widely from region to region (TRB 2008, p. 84). Transportation modes include land (highways, rail and pipeline), marine (ports and harbors) and air. Texas cities have infrastructure and operations that will be differentially affected by impacts that include: (1) higher temperatures and temperature extremes, (2) heavy precipitation and sea level rise, and (3) more intense tropical storms.

Higher temperatures are primarily a concern for northern U.S. climates (e.g., permafrost melting), but extended periods of high temperature will damage road surfaces, airport runways, bridge joints and rail lines, and disrupt transportation operations. Hotter urban areas are more vulnerable to these types of impacts. Lower water levels in waterways would reduce the port capacities of Houston and other Gulf Coast ports. Higher temperatures also affect the lift that is needed for aircraft takeoffs, potentially reducing air travel and cargo capacity (TRB 2008 p. 66-67).

Intense precipitation events are already affecting Texas urban transportation and these would increase under climate change conditions. In 2006 during a one week period, heavy rainfall totaling almost an entire year’s average flooded El Paso, closing streets and damaging roads and drainage infrastructure. Annual heavy rainfall events in Houston cause roadway flooding, highway closures and infrastructure damage. Such events also occur in other Texas cities, producing travel delays and roadway damage. The extensive pipeline networks in Texas, particularly near Houston and the Gulf Coast, can be affected by heavy precipitation events that reduce soil cover and cause subsidence (TRB 2008, p. 68). Intense precipitation events can flood port facilities and operations resulting in shipping delays and interruption of service.

Houston and other Texas Gulf Coast cities are vulnerable to sea level rise (and land subsidence). The IPCC Fourth Assessment Report on North America identifies this and associated storm surges as “one of the most serious problems” for the Gulf Coast (TRB 2008, p. 68). Storm surges, in combination with sea level rise, can eliminate portions of the intercoastal waterway along the Gulf Coast, affecting freight and port movement and ending barge traffic in these areas (TRB 2008, p. 69). The IPCC report on human settlements identifies extreme storm events as the principle vulnerability for transportation systems, as well as other impacts, such as sea level rise and extreme temperature effects on transportation infrastructure (Wilbanks 2007. p. 371).

Hurricanes Katrina and Rita that hit the Gulf Coast during late summer of 2005 are examples of recent storms that had an impact on transportation in Texas cities (as reported in studies by the Transportation Research Board (TRB 2008) and the U.S. Climate Change Science Program (Savonis 2008)). These events affected all transportation modes to some degree and provided lessons for changing transportation systems to adapt for future storms. The lessons learned from these events include the need for redundancy in transportation systems, the importance of electricity and manpower following such events, and the need for redesign and relocation in anticipation of future storms. Transportation operations during Hurricane Ike in 2008 were considerably improved, possibly from what was learned from Katrina and Rita, such as staged evacuations and contraflow lanes. The changes instituted are primarily disaster response measures. However, the responses continue to raise issues about the resiliency of urban transportation systems. The implications for future transportation infrastructure include a need for changes in materials, maintenance and operations, as well as changes to design standards that better reflect climate change vulnerabilities.

To date, most climate change transportation studies in the U.S. focus on greenhouse gas reductions, rather than adaptation measures or measures to improve transportation system resiliency. State and federal legislative initiatives (such as the California low carbon fuel standard) have followed a similar carbon emission reduction focus. Recent regional transportation studies about climate change identify transportation systems vulnerabilities in the study regions, but not measures to adapt to risks or become more resilient (Savonis 2008). Studies of Texas regional or city specific adaptations have not been reported to date.

A 2008 Federal Highway Administration report on climate change and transportation planning (ICF 2008) includes a chapter on adaptation. The report points out that Metropolitan Planning Organizations (MPOs), the regional entities with primary transportation planning responsibilities, and state departments of transportation (DOTs) face large uncertainties with respect to climate change responses. The report noted that MPOs and DOTs "have little if any information on precisely what impacts they can expect, where, and in what time frames. As a result, agencies are largely not acting to adapt the transportation system to climate change, or are waiting for further guidance on the topic." (ICF 2008. p. 31) Texas MPOs and the state's DOT are likely to await guidance from federal agencies before incorporating climate change in the planning process. Additionally, they may choose to learn from the near term experience of other states that are more actively engaged in climate change policies and studies (e.g., Washington, New York, Florida, and California).

Long range transportation plans in Texas do not address climate change impacts or vulnerabilities. Only Houston's long-range plan mentions climate change as part of the context for long range planning. None of the plans discuss carbon issues or associated issues that arise from escalating fuel and energy prices that directly affect infrastructure financing (Capital Area 2005; El Paso 2007; North Central Texas 2007; San Antonio 2004). Indirect references to carbon emissions included more efficient transportation systems (i.e., transit, bicycle, ridesharing options, better fuel mileage, etc.) and goals for increasing use of "clean, alternative fuels", which in Texas has included various fossil fuels including natural gas propane, and low-sulfur diesel. None of the plans include explicit goals or actions to reduce transportation carbon emissions as part of climate change concerns or to adapt transportation to climate change impacts.

The Houston area plan released in 2007 includes a brief discussion of climate change and transportation. H-GAC, the region's metropolitan planning organization, participated in recent climate change studies of the Gulf Coast region, and has initiated a process to examine climate change impacts (organized under the title "Foresight Panel for Environmental Effects"). The regional transportation plan states that inclusion of climate change is a first step in further consideration of the effects on regional transportation. While the plan points out that the region's air quality actions may reduce carbon emissions, no specific policies or adaptation measures are discussed. The inclusion of climate change is remarkable in and of itself, and may have occurred due to the extraordinary climate events and conditions in this region, which has been marked by recent tropical storms and frequent severe flooding.

According the FHWA, many states and metropolitan planning organizations are beginning to include climate change issues in transportation planning. However, FHWA also reports that many of these organizations believe that effective measures to reduce greenhouse gas emissions and to adapt to vulnerabilities are largely outside of their responsibilities or capacity (ICF 2008, p. 36). With transportation responsibilities divided across many entities (federal, state and local), the ability to respond by any particular entity is restricted.

Reducing transportation greenhouse gas emissions is a relatively straightforward process if emissions are treated in a manner similar to current air quality planning. While there are difficult technical and regulatory issues with this approach, an <u>emission reduction</u> context parallels much of what occurs in air quality planning in Texas. U.S. transportation researchers and other state air quality organizations have been identifying and quantifying carbon emission reduction strategies for several years, and many of the analytical and modeling tools are already available to Texas.

Adaptation to climate change effects are not likely to be part of any single known process at this point in time. Adaptive responses for transportation systems in major Texas cities would vary widely with respect to vulnerabilities and local needs. Houston and Gulf Coast cities will need to focus on more severe and frequent storms, disaster response, and flooding. This means redesign and relocation of parts of the transportation infrastructure in ways that provide system redundancy and resilience. Public transportation, railroads, freight, pipelines, ports and air travel are essential components of regional transportation that must be part of adaptation measures in Texas cities. New ways of planning, managing and financing such responses will be needed.

Adaptation measures in other major Texas cities must incorporate higher temperatures, extended heat waves and changes in precipitation levels in shaping future transportation systems. These impacts can affect the facility design, the materials used in transportation infrastructure as well as maintenance of this infrastructure. All of these adaptations require strategic planning, operational planning and adequate financing.

Human Health

Air Quality

Higher temperatures will result in worsened air quality in Texas urban areas, including longer ozone seasons and higher summer ozone concentrations. The potential for increased concentrations of health damaging fine particulates can also occur due to higher temperatures. In the Dallas-Ft. Worth area, a longer ozone season would accompany higher temperatures, extending into the spring and fall months. In the Houston area, higher winter temperatures would ensure a year round ozone season. Higher temperatures also produce higher levels of biogenic volatile organic compounds (VOCs) emissions, such as isoprene, which would contribute to higher ozone concentrations, but also to higher levels of background ozone that can move into urban airsheds. For major Texas cities, except possibly El Paso, oxides of nitrogen (NOx) will need to be reduced even more drastically, perhaps approaching zero for some sources. As a primary precursor to ozone formation, this poses a particularly difficult challenge. NOx emissions are a product of all hydrocarbon combustion, whether from gasoline or diesel engines, coal or natural gas in power plants, or fossil fuels in industrial boilers.

Ozone is a reactive form of oxygen (O_3) that can damage human respiratory tissue as well as vegetation, and is regulated as a “criteria pollutant” under federal law. It forms in the presence of sunlight through chemical reactions involving two primary precursors – oxides of nitrogen (NOx, primarily from fuel combustion from industry, motor vehicles, and power plants) and VOCs from evaporation, industrial processes, and biogenic sources. Heat and sunlight are an essential part of these chemical reactions (see Walcek and Yuan 1995).

In May 2008 the federal 8-hour standard for ozone was exceeded in Houston (HGB 8-county area), Dallas-Ft. Worth (DFW 9-county area) and Beaumont-Port Arthur (BPA 3-county area). In addition, San Antonio (3 counties) is designated an Early Action Compact Area and is seeking an attainment designation. Houston and BPA have requested a more stringent designation (Severe and Moderate respectively) due to failures to demonstrate attainment of the current standard. A recently approved tightening of the 8-hour standard (from 0.08 ppm to 0.075 ppm) is expected to result in additional Texas urban areas being designated nonattainment, including Austin, San Antonio, El Paso, Corpus Christi and Longview.

Increased temperatures in cities, whether from climate induced changes or urban heat island effects, intensify ozone formation. For Los Angeles, every 1.8ºF increase in temperatures above 71.6ºF could increase ambient ozone concentration by 5 percent (Akbari 2003. p. 2). Similar increases can be expected in Texas cities. Higher temperatures also require more energy for air conditioning, thereby providing additional ozone precursors (NOx) from power plant emissions. Higher temperatures increase the rate of evaporation of VOCs from vehicle fuels (i.e., hydrocarbons in gasoline and additives) and from biogenic sources released by some plant species in response to higher temperatures (i.e., isoprene from various species of oak trees).

Heat Mortality

Higher temperatures, particularly if they occur as extended heat waves, negatively affect human health. Heat mortality is the largest weather-related cause of death in the U.S. (Davis et al 2003), and death and mortality are underreported since victims usually have other contributing health conditions (Wilhelmi et al 2004). Extended heat events occur when temperatures remain above a threshold level for several days. The thresholds, which include temperature and humidity, are higher in cities with hotter climates due to human adaptation to local conditions; for example, 110ºF in Houston compared with 103ºF in Chicago and 88ºF in Portland (Kalkstein and Greene 2007). Heat related illnesses and deaths have declined over time due to the greater availability of air conditioning. However, extreme heat waves in northern U.S. cities and Europe raise longer-term concerns that heat events will overload electric power systems and disrupt air conditioning availability. While the Texas population is more adapted to higher temperatures, vulnerable urban populations, including anyone lacking access to air conditioned space, will need protection from extended heat waves.

Infectious Diseases

Increased temperatures and changes in rainfall from climate change contribute to the occurrence of disease and its transmission across the human population. Cities are particularly vulnerable because of high population concentrations and rapid migration into cities during times of stress. Projections by researchers generally support the view that health effects from climate change will be negative (IOM 2008 p. 2). The diseases discussed as possibly resulting from climate change effects include malaria, dengue fever, tick-borne diseases and diseases associated with diarrhea, such as cholera (IOM 2008 p. 1). While malaria is virtually non-existent in the U.S., dengue fever infected almost 4,000 people in the last 25 years. In 2002, West Nile Virus, also carried by mosquitoes, was identified in bird populations in Houston. The virus was first detected in New York in 1999 and in 2008 human infections were reported in eleven Texas counties (Texas Department of State Health Services 2008). Following Hurricane Katrina, there was concern in the Houston area that infectious diseases would be brought from Louisiana. While there were a few cases of vibrio vulnificus, a non-contagious virus in the cholera family, it was contracted from direct exposure to contaminated water, not exposure to people. Speculations about post-storm disease migration to Houston have not been realized.

IPCC reports and studies indicate that the severity of disease effects is expected to be greatest worldwide in low lying coastal areas that lack the capacity to respond effectively to health needs. This suggests that capacity to respond is a key factor in considering health effects, rather than disease specific factors. Currently large U.S. cities, including those in Texas, have the best capacity to address medical and public health responses. Unfortunately, it cannot be known with any degree of certainty whether or not these capacities will be sufficient in the decades ahead under alternative climate scenarios.

Media reports of possible disease outbreaks often identify alternative causes, with climate change being a likely mention whether or not there is evidence of a causal link. Looking into the future, the interplay of societal factors and disease exposure is another unknown. For example, availability of air conditioning across most income levels in major Texas cities has greatly reduced exposure to mosquito borne diseases. Under a favorable scenario, large improvements in energy efficiencies, use of renewable energy, and more resilient infrastructure could further the trend toward affordable, sustainable air conditioned space. Alternatively, under conditions of economic and energy failures, many more people could be exposed to mosquito borne diseases, (regardless of whether this exposure is driven by climate change effects). Likewise, the future availability of effective preventive and treatment measures or mosquito control measures are unknown or highly uncertain in the time frame of climate change effects.

Within this framework of uncertainty, health system responses to vulnerabilities are being considered (IOM 2008). First and foremost is the need for effective long-term monitoring of disease dynamics associated with climate change. Without such information, it will be difficult to distinguish between a single outbreak and more widespread problems. At the same time, the capacity to respond to such diseases must be present as part of the state's public health system, and, more importantly, within major cities where vulnerable populations are concentrated. Training of health professionals working in Texas will need to include detection and treatment of diseases that are more likely to occur under changed climate conditions. These too may vary regionally across the state.

URBAN LEADERSHIP

While there has been relatively little response in Texas to climate change concerns, the leadership that has emerged is found among local government officials. Several Texas mayors are participating in climate change initiatives, twenty-two mayors having signed the Conference of Mayors Climate Protection Agreement, including the mayors of Austin, Dallas, San Antonio, Ft. Worth, El Paso and Arlington. The City of Arlington, a suburban community of 370,000 located between Dallas and Ft. Worth, has published a baseline inventory of greenhouse gas emissions including municipal operations, which are controlled by local government, and the community at large (City of Arlington, Texas 2008). Arlington's mayor, Robert Cluck, M.D., has played a prominent role in state and national climate discussions. In 2008, the Mayor of

Houston, Bill White, issued a plan for substantially reducing city government carbon emissions (those generated by city functions) by 2010. The City of Austin's Climate Protection Plan, published in 2007 with leadership from Austin's current and previous mayors, sets forth the goal of making all city facilities, vehicles and operations carbon neutral by 2020. Other plan components address the City's utility (Austin Energy), homes and buildings, and the broader community carbon emissions. The current mayors of Houston, Arlington and Austin have been active in efforts to acknowledge climate issues and to reduce related carbon emissions. Austin, Houston and San Antonio are also Solar Cities under a current U.S. Department of Energy Initiative.

To date, urban leadership in response to climate change has been primarily about reducing carbon emissions through energy efficiency, transportation measures and alternative energy. Severe storms, flooding and sea level rise have been viewed largely in the context of disaster response and stormwater management, although citizens often link climate change with these events. The longer range view of adaptation and resilience are only now becoming part of the vocabulary of urban issues as the reality of climate change becomes more of an accepted part of the public dialogue.

CONCLUSIONS

As population and economic centers, Texas cities are particularly vulnerable to the impacts of global climate change. These vulnerabilities vary from city to city, depending on their location with respect to climate change risks and their subregional climate conditions. Coastal population centers, from Houston to the Lower Rio Grande Valley, are vulnerable to sea level rise, increased storm intensity and accompanying flooding. The impacts can affect millions of people while disrupting and damaging road, air and port transportation systems. All major Texas cities face the possibility of impacts on air quality, energy, health and other temperature related effects. All major cities face the prospect of declining water resources within the timeframe examined here.

Cities and urban regions that currently fail air quality health standards face the likelihood of continued difficulty reach these standards due to higher ambient temperatures and intensified urban heat island effects. Background ozone levels are already high enough to trigger events in major Texas cities. If current state and federal pathways are pursued in the absence of broader changes, urban air quality goals are unlikely to be accomplished. Additionally, the current momentum for future emission levels would do little to achieve the needed carbon emission reductions. In Texas, the emerging attention to carbon emissions could serve as a key element for pursuing both air quality and greenhouse gas reductions in concert. Known and foreseeable changes in transportation – including fuels, vehicles and travel modes – could reduce transportation emissions significantly, even approaching zero net carbon levels with some sectors. However, this would require redirection of state and national actions to restructure urban transportation and energy policies, as well as changes in travel and related consumer behaviors. Both air quality and greenhouse gas reduction will benefit from rapid movement toward a more electric transportation system and the use of low carbon Texas renewable energy sources.

Major cities are vulnerable to higher electric power demand and insufficient water resources, but there are also known ways of reducing vulnerabilities. Existing and near term technologies can improve the efficiencies of electric power and water management systems – wasteful lawn irrigation practices being a well known example of needed water resource redirection. Energy consumption in buildings could be cut in half or more through efficiency improvements and to net zero carbon through wide spread deployment of distributed generation technologies for buildings. While such changes are available and relatively well known, more responsive governmental, economic and consumer actions would be needed for cities to make these changes (see Harriss 2007).

Texas cities have greater ability and capacity across the board to adapt and otherwise respond to the consequences of climate change due to their relative wealth, infrastructure, financing capacity, health systems and governance capabilities. Some cities may incur gradual climate change effects – e.g., rising nighttime temperatures or declining water availability – while others will experience abrupt events, such as tropical storms or severe flooding. The inertia of existing urban investments – residential patterns, water and sewer services, transportation systems, and electric power systems – pose difficult and expensive barriers to retrofitting cities. Foresight, leadership and financing are needed for some adaptations that will require decades to achieve. Decisions on such changes are needed despite the uncertainties about future vulnerabilities.

Common guidelines and regional decision frameworks are needed by cities to consider how to best respond. Changes in governance authority will likely be needed as well. Hundreds of communities within urban areas need to respond in ways that are somewhat consistent with each other and the vulnerabilities facing them. Regional transportation planning will change at some point in response to federal guidelines and funding. Water resource planning will change in response to state guidelines learning from best practices in other areas of the country. Utilities will change in response to prices and federal regulatory responses to climate change. Public health services as well as disaster preparedness functions will change in response to conditions and events. All of these functions need information that is garnered from research, data assembly, program design and testing, and policy interactions among the affected entities, including frequent interaction with decision makers and stakeholders.

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