Chapter 13

Urban Areas

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Executive Summary

The unique characteristics of Southwest cities will shape both the ways they will be impacted by climate change and the ways the urban areas will adapt to the change. The Southwest represents a good portion of the arid and semi-arid region of North America and many of its cities rely on large-scale, federally built water storage and conveyance

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Chapter citation: Pincetl, S., G. Franco, N. B. Grimm, T. S. Hogue, S. Hughes, E. Pardyjak, A. M. Kinoshita, and P. Jantz. 2013. "Urban Areas." In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 267–296. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

structures. Water regimes in this part of the country are expected to be significantly impacted by climate change because of higher temperatures, reduced snowpack, and other factors, including possibly reduced or more unpredictable patterns of precipitation, which will affect cities and their water supplies. Further, the cities are likely to experience greater numbers of high-temperature days, creating vulnerabilities among populations who lack air conditioning or access to cooling shelters. Myriad and overlapping governmental organizations are responsible for public goods and services in the region, as in other parts of the country. Their jurisdictions generally do not correspond to ecosystem or watershed boundaries, creating mismatches for climate adaptation programs and policies and significant barriers to cooperation and collaboration. Finally, many local governments are facing budget constraints, making it difficult to plan and implement new programs to anticipate the potential impacts of climate change.

In summary:

- The water supplies of Southwest cities, which are located in arid and semi-arid regions and rely on large-scale, federally built water storage and conveyance structures, will be less reliable due to higher temperatures, reduced snowpack, and other factors, including possibly reduced precipitation. (high confidence)
- Some Southwest cities are likely to experience greater numbers of extreme high-temperature degree days; residents who lack air conditioning or access to cooling shelters will be especially vulnerable to these changes. (high confidence)
- The large metropolitan areas that concentrate most of the population in the Southwest are governed by counties, cities, and hundreds or thousands of special districts, which makes coordination complex and therefore decreases the capacity for cities to adapt to climate change. (high confidence)
- Within metropolitan regions, substantial differences in fiscal capacity and in political and decision making capacities to plan and implement new programs to anticipate the potential impacts of climate change reduce the capacity for cities to adapt to climate change. (high confidence)
- Options for decreasing urban vulnerability to climate change include making data available to improve targeted programs for energy conservation (high confidence). For example, utility data (such as electric and gas bills) have heretofore been considered confidential, so understanding energy or gas use in a city, by land use, building type, or sociodemographic profile must be derived from surveys or national models. This makes it impossible to target specific energy use for reduction or as a model for conservation. (high confidence)
- Data availability will also improve the ability to develop new approaches to understanding urban energy flows (including wastes such as GHGs). Urban metabolism, for example, quantifies inputs and outputs to cities (Pincetl, Bunje and Holmes 2012) and can include the life-cycle analysis of supply chains that supply cities (Chester, Pincetl and Allenby 2012). Supply chains (which span all movement and storage of raw materials, manufacturing, and finished goods from point of origin to point of consumption) are poorly understood, and therefore their greenhouse gas (GHG) emissions are difficult to identify and reduce.[i] (high confidence)

- Monitoring for climate-related indices is weak throughout the region, and the data that are collected are usually not synthesized in ways that are useful to understand the urban causes and potential impacts of climate change. Most climate studies have been done at macro-scales or pertain to specific issues such as water supply. More local data, such as on water use in urban areas, would be useful in managing for climate change adaptation and planning for future impacts. (high confidence)

13.1 Cities in the Southwest

The importance of urban lands in climate change has been articulated in a previous assessment, which discussed the potential of urban planning, urban land management systems, and urban land regulation in addressing climate change challenges (Blanco et al. 2011). This chapter focuses on U.S. urban development impacts on climate and the potential effects of climate change on cities in the Southwest. Southwest cities grew throughout the twentieth century—a period of resource and land abundance—circumstances that shaped their land use, their residents' dependency on automobiles for transportation, the choice of building types, and patterns of resource use. Southwest cities have continued to grow at a tremendous pace, particularly the arid cities of Phoenix and Las Vegas (Figure 13.1).

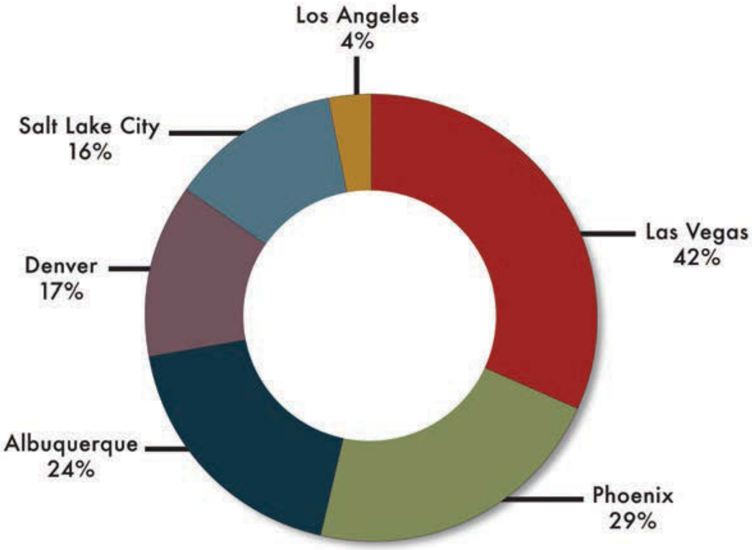

Figure 13.1 Population change in Southwest cities, 2000–2010. Source: U.S. Census Bureau, 2010 data (http://2010.census.gov/2010census/).

Continued growth of suburban and urban areas in the Southwest will affect their vulnerability to climate change, depending on factors such as the geographical distribution of this growth (see Chapter 3). Figure 13.2 shows one potential growth pattern that is compatible with the IPCC high-emissions (A2) scenario (Nakićenović and Swart 2000; Bierwagen et al. 2010), a scenario in which there is continued population growth. Two immediate conclusions can be reached about potential impacts in urban areas taking into account the projected potential changes in climate discussed in Chapters 6 and 7. First, cities would grow in areas that are projected to experience more rapid warming for the rest of this century. Second, urbanization would occur in areas that are projected to experience less predictable precipitation.

Areas of new urbanization in (shown in Figure 13.2), such as the Central Valley of California, also tend to coincide with the areas that are susceptible to large floods, as shown in Figure 13.3. Somewhat paradoxically, the probability of large flooding events rises with climate change in the Central Valley (Das et al. 2011), even if total precipitation levels go down.

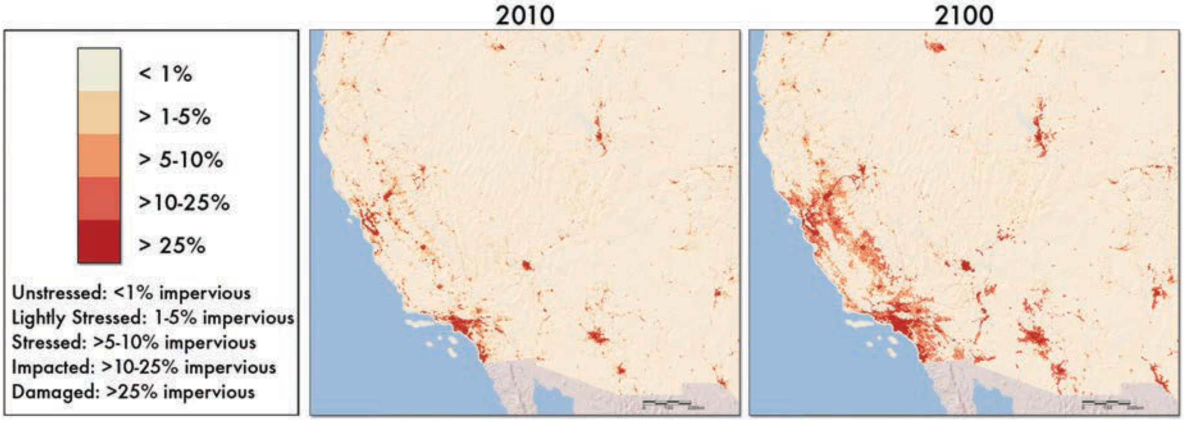

Figure 13.2 Human settlements (impervious surfaces) in the Southwest, 2000 and 2100. The 2100 scenario is compatible with the IPCC A2 high-emissions scenario. Reproduced from the ICLUS web viewer (http://134.67.99.51/ICLUSonline/, accessed on 2/12/2012).

Observed changes in climatic trends in major cities in the Southwest

Major cities in the Southwest and other parts of the United States are already experiencing changes in temperature. It is unclear, however, if these changes are mostly due to changes in land cover (as from the urban heat island effect)[ii] or if they are a manifestation of regional changes in climate. A recent study by Mishra and Lettenmaier (2011) tackled this issue by developing time series (data) of temperature and precipitation for 100 major cities and their surrounding rural areas in the United States and comparing their trends. Where the trend for an urban area is somewhat different than its surrounding rural area, changes in land cover (i.e., urbanization) may play a role. Therefore these changes may be reversible by making changes in urban morphology aimed at reducing the urban heat island. Mishra and Lettenmaier concluded that for the Southwest, changes in nighttime minimum temperatures and heating and cooling degree days are due to regional changes in climate, and urbanization is not the main reason for the already observed warming in cities (see Figure 13.4). The implications of this finding are that: (1) cities should prepare for increases in energy demand for space cooling and a reduction in energy demand for space heating, and (2) reducing the heat island effect should help but may not completely eliminate overall warming in the long term.

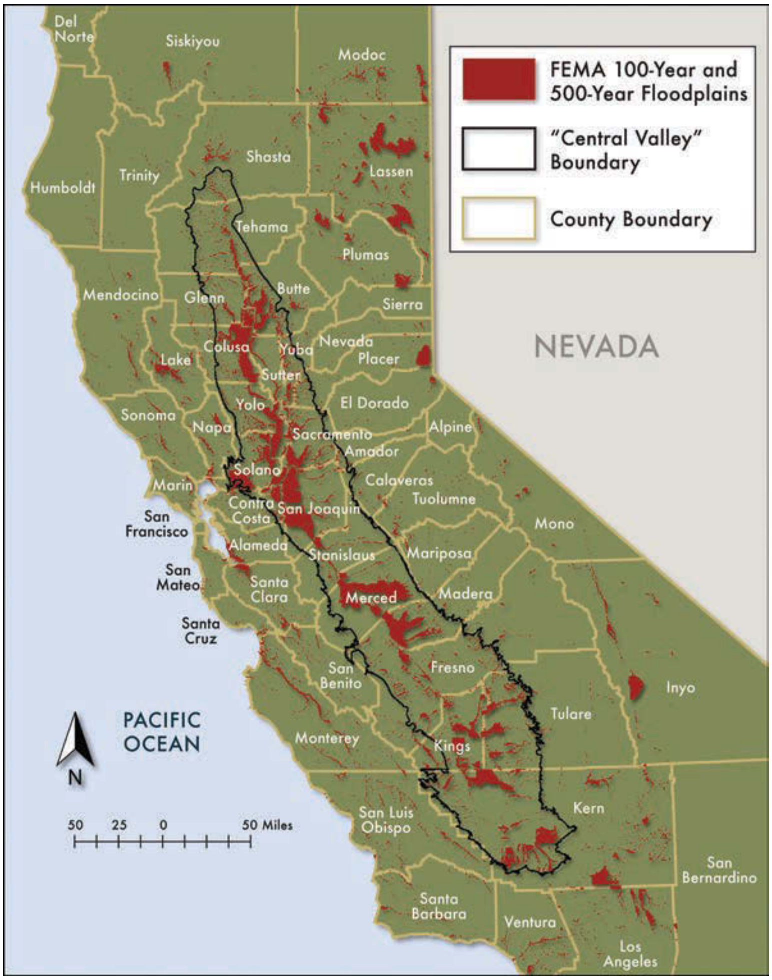

Figure 13.3 FEMA 100-year and 500-year floodplains in California. Adapted from Galloway et al. (2007).

The potential for extreme precipitation events is important for urban managers to consider because the amount of rain and duration of these events determine the needed design capacity of the stormwater infrastructure. Substantial increases in extreme precipitation events may result in the failure of stormwater systems if new extreme precipitation levels are outside their design envelope. So far, the historical trends for extreme precipitation for cities in the Southwest are less clear, with no uniform regional trends as shown in Figure 13.5, suggesting that there is not a clear imminent risk to stormwater systems from flooding of this type. As reported in Chapter 7, climate projections for the Southwest and throughout the country suggest an increase in extreme precipitation events but these projections are highly uncertain. It is possible that the climate-change signal is still emerging from the "noise" created by climate variability. In any event, flood control managers in California are preparing for potentially unusually high incidences of precipitation and consequent flooding (see, for example the projects listed on the California Dept. of Water Resources FloodSAFE website).[iii]

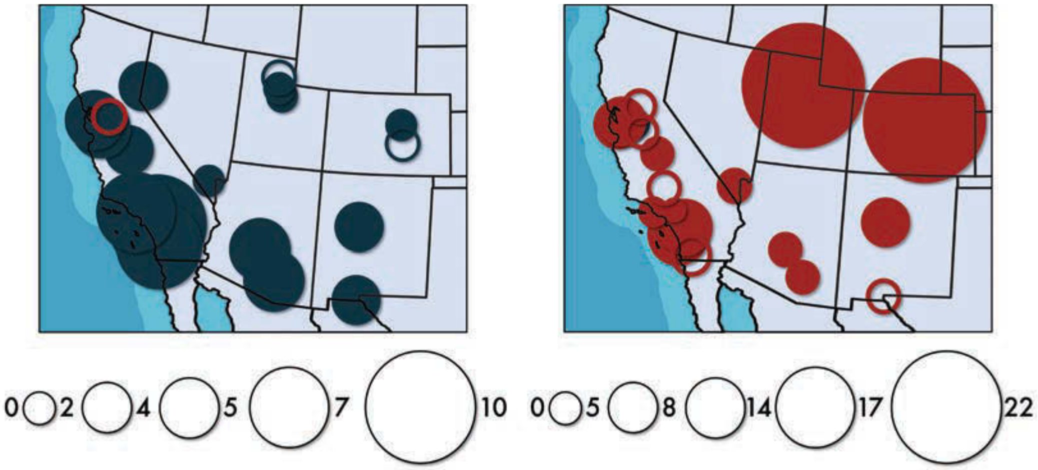

Figure 13.4 Trends in heating and cooling degree days in major urban areas of the Southwest. Trends in heating degree-days (left) and cooling degree-days (right) are based on 65°F (18.3°C) and 75°F (23.9°C) bases, respectively, for the period 1950 to 2009 in seventeen urban areas. Blue circles represent decreasing trends and red increasing trends. The trends are proportional to the diameter of the circles. Filled circles represent statistically significant trends. See glossary for definitions of heating and cooling degree-days. Adapted from Mishra and Lettenmaier (2011) with permission from the American Geophysical Union.

Figure 13.5 Trends in the annual 1-day maximum daily precipitation amounts in major urban areas of the Southwest. Blue circles represent decreasing trends and red increasing trends. The trends are proportional to the diameter of the circles. Filled circles represent statistically significant trends. Adapted from Mishra and Lettenmaier (2011) with permission from the American Geophysical Union.

Urban processes that contribute to climate change

The contribution of urban areas in the Southwest to climate change is a function of a variety of features: urban form (dense or sprawling); the allocation of land to commercial, industrial, and residential uses, and their spatial disposition; infrastructure (including building technologies); impermeable surfaces; surface albedo; water supply and disposal systems; and transportation systems. Yet the body of research and amount of available data about the impact of such features on emissions and climate are relatively small. For example, the size of buildings, their construction materials, and building standards for energy efficiency all have greenhouse gas (GHG) emissions implications, but the exact relationships are not well understood. Levels of affluence and consumption in cities; whether cities depend on long or short supply chains for their goods and services; the energy used in the manufacturing and distribution of goods: all these play significant but poorly accounted-for roles in contributing to climate change. These energy-related flows are components of a city's *urban metabolism* (Kennedy, Cuddihy, and Engel-Yan 2007; Chester, Martin, and Sathaye 2008; Kennedy, Pincetl, and Bunje 2010). Comprehensive accounting that includes life-cycle analyses and cradle-to-grave GHG accounting of cities' metabolisms simply does not exist. Nor are the redirection of flows (such as water reuse and recycling or advanced nutrient recycling) well documented and quantified. Thus, both a city's contributions to climate change and the effects of its efforts to reduce those impacts remain unquantified due to lack of observational data.

Specifically, the dynamics of an increase in urban heat, or *heat flux,* that results from the transfer of heat energy to the atmosphere from pavement and other hard surfaces, heat generation from vehicles, and the consumption of electricity and heating fuel, are poorly understood. Sailor and Lu (2004) estimated these fluxes for a number of U.S. cities including Los Angeles and Salt Lake City, and Grossman-Clarke and colleagues (2005) estimated them for different land covers in Phoenix during the summer (see Figure 13.6). They found most cities have peak values during the day of approximately 30 to 60 watts per square meter (W/m^2, the power per unit area radiated by a surface). Salt Lake City and Los Angeles had relatively low fluxes compared to other cities, with peak values less than 15 W/m^2 and 35 W/m^2, respectively. Salt Lake City's flux level was particularly low due to low population density. For all of the cities (across the United States) analyzed in the Sailor and Lu study, heating generated from vehicles was the dominant cause of heat flux in the summer, accounting for 47% to 62% of it. Wintertime heating was also a very important cause, but less so in Southwest cities where winters are not as cold as in other parts of the United States. Recently, Allen and colleagues (2010) developed a global model for human-caused fluxes and found that globally the average daily urban heat flux due to human causes has a range of 0.7 W/m^2 to 3.6 W/m^2. Globally, they found heat release from buildings to be the most important contributor.

Several studies have included the effects of anthropogenic heat fluxes in global climate models (GCMs) (Flanner 2009; McCarthy, Best, and Betts 2010; McCarthy et al. 2012). While these models are at the global scale and cannot effectively quantify specific urban areas, they provide some insight into the importance of these fluxes. For example, McCarthy et al. (2011) ran simulations with both CO_2 doubling and anthropogenic urban heat fluxes. They found that by 2050 in the Los Angeles area, the number of hot days experienced in urban areas would be similar to the number of hot days experienced in

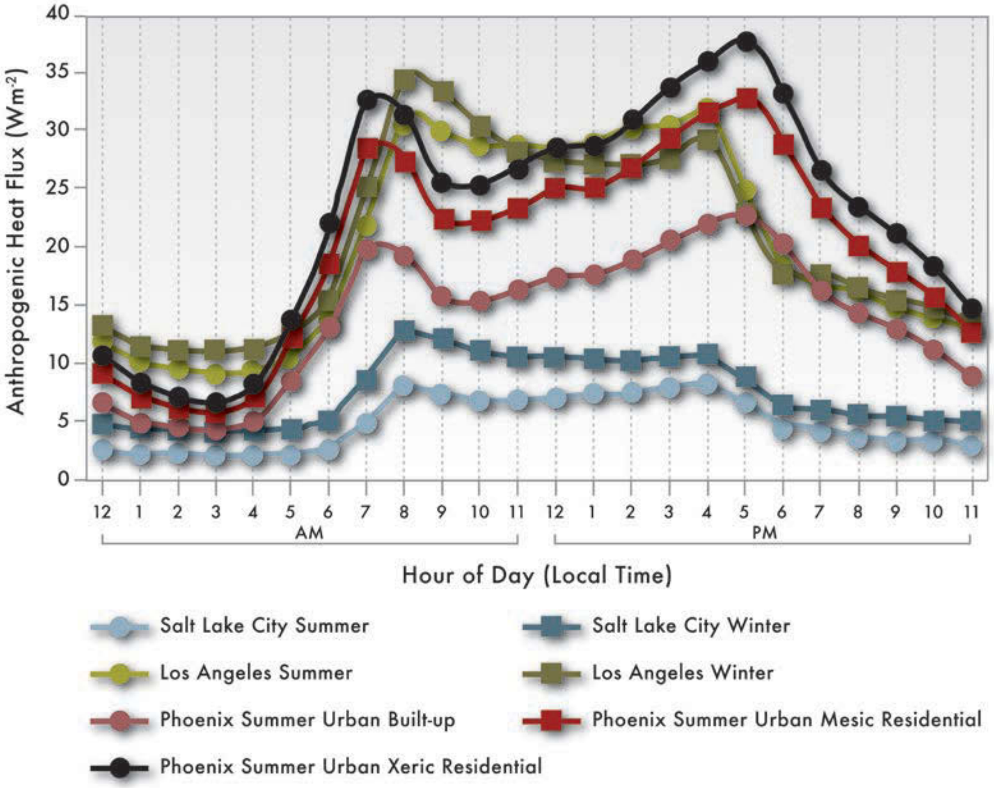

Figure 13.6 Anthropogenic heat flux estimates for three Southwest cities, shown in watts per square meter. Urban built-up (no vegetation), urban mesic residential (well-watered flood or overhead irrigated), and urban xeric residential (drought-adapted vegetation with drip irrigation) are distinguished by their type of vegetation and irrigation, listed in parentheses. Adapted from Sailor and Lu (2004) and Grossman-Clarke et al. (2005).

rural areas. However, the annual frequency of hot *nights* would increase more in the city than in the rural areas for the CO_2 doubling scenario. In the city of Los Angeles the number of hot nights would increase by two days with 20 W/m^2 of anthropogenic heating and by ten days with 60 W/m^2.

About 60 million people live in the Southwest, the majority of whom reside in major metropolitan urban centers and consume the majority of goods and services. As indicated before, good information is lacking about the direct and indirect GHG emissions from urban populations. However, new studies have shown that the net emissions associated with imports and exports of goods and services in the United States are substantial (Peters and Hertwich 2008; Davis and Caldeira 2010), as shown in Figure 13.7.

Estimates of consumption-based emissions (which take into account net imports and exports of goods and services) for the United States are about 12% higher than production-based inventories (i.e., conventional inventories) (Davis and Caldeira 2010). Preparing consumption-based inventories for cities should be a priority to identify potential unrecognized sources of indirect emissions. By implementing life-cycle analysis for goods and services, such information could be developed.

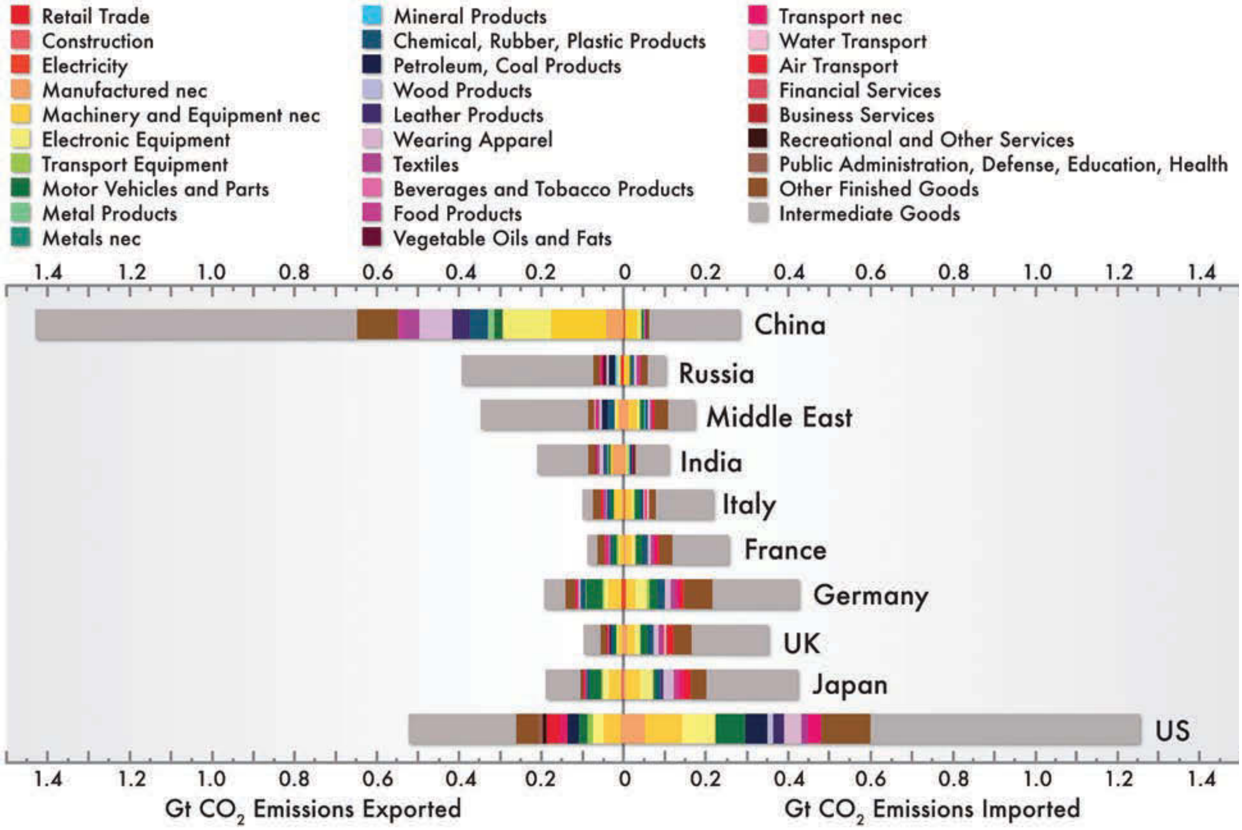

Figure 13.7 Embodied CO_2 emissions associated with goods and services exported (left) and imported (right), for selected countries. Colors represent trade of finished goods by industry sector. Reproduced from Davis and Caldeira (2010).

While direct-emission measurements of GHGs in cities are rare, a number of urban studies do exist (e.g., Velasco and Roth 2010; Crawford et al. 2011 and references therein; Ramamurthy and Pardyjak 2011). These researchers have begun to quantify CO_2 emissions from different types of urban surfaces using the eddy covariance (EC) method[iv] that has been employed by researchers of non-urbanized ecosystem sites around the world for many years (Aubinet et al. 2000; Baldochhi 2003). The dearth of urban data is partly a result of a number of difficulties in making these measurements (Velasco and Roth 2010).[v] The measurements are, however, very important as they provide spatial and temporal information about the sources and sinks[vi] of emissions that cannot be obtained from conventional inventory methods. A framework for a global Urban Flux Network[vii] now exists to help identify those cites that currently measure fluxes or have recently made such measurements around the world. Only two sites are currently listed in the Southwestern United States: Salt Lake City (Ramamurthy and Pardyjak 2011) and a USGS-operated site in Denver.

While only a limited number of urban EC studies exist, a general understanding of important mechanisms related to the emissions process is starting to form. For example, as shown in Figure 13.8, for a wide range of urban areas around the world there is a surprisingly strong correlation between the proportion of vegetated area and net CO_2 fluxes during the summer. Because of their very low urban density and the presence of substantial vegetation (e.g., urban forests), suburban areas such as in Salt Lake City are relatively small net producers of CO_2. These human-planted urban forests in semi-arid climates provide benefits such as CO_2 sequestration and microclimate mediation during the summer (e.g., temperatures are reduced from shading and evapotranspiration-related cooling), but require irrigation. Increased water demands from urban vegetation, while potentially mitigating some aspects of climate change, could increase water use in urban areas already challenged by scarce water resources. This trade-off is still not well-quantified.

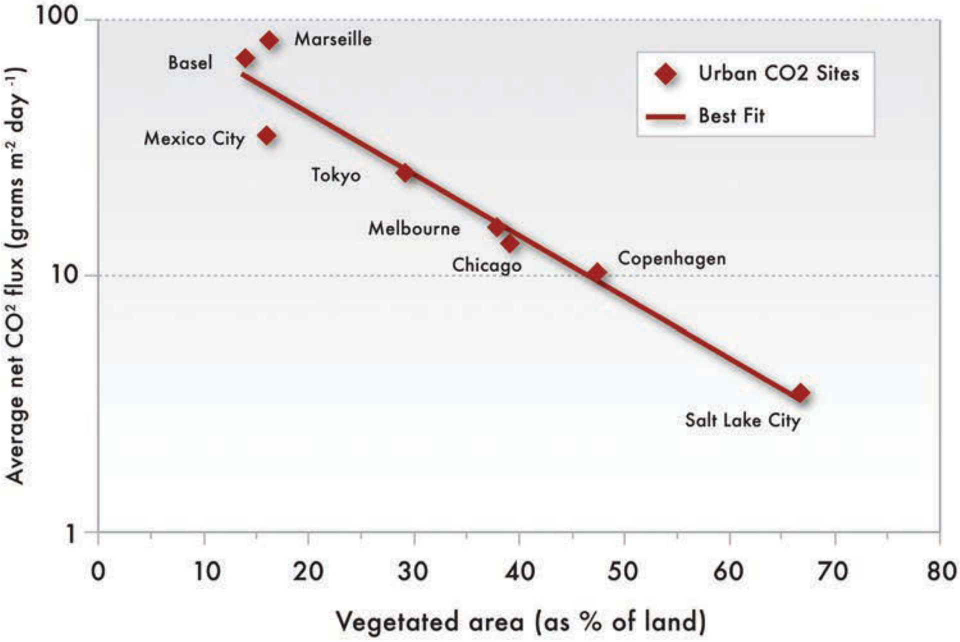

Figure 13.8 Average daily net CO_2 emissions for different cities around the world during summer months. Adapted from Ramamurthy and Pardyjak (2011).

Yet, even the most densely vegetated suburban and urban areas have been found to be net sources of CO_2 (Velasco and Roth 2010). Some well-vegetated suburban areas such as Baltimore take in more CO_2 than they release in the summer through uptake by abundant foliage, yet they are still annual net sources of CO_2 (Crawford et al. 2011). Salt Lake City has a very large urban forest (Pataki et al. 2009); the suburban area monitored there showed significant periods of CO_2 uptake during the daytime in summer, but daytime fluxes still were a net source of CO_2. More research is needed to correlate urban ecosystem parameters with gas exchanges to better understand the mechanisms of transfer. In addition, it is important to recognize that the quantity of CO_2 sequestered by vegetation is dwarfed by urban emissions.

Atmospheric CO_2 concentrations in urban areas are usually much higher than annual global averages because of the local sources of emissions. For example, measurements in Phoenix showed peak CO_2 ambient concentrations that were up to 75% higher than in its rural areas (Idso, Idso, and Balling 2001). In Salt Lake City, Pataki, Bowling and Ehleringer (2003) found peak CO_2 ambient concentrations during wintertime atmospheric inversions that were around 60% higher than in its rural areas, while summertime afternoon values were very close to background levels. Jacobson's 2010(a) Los Angeles study of the potential implications of these "urban domes" of CO_2, found that higher ambient CO_2 concentrations result in small but important increases in air pollution (ozone and particulate matter; see Figure 13.9).[viii] This is in addition to potential increases in air pollution from a global increase of GHGs in the atmosphere reported by others (e.g., EPA 2009; Jacobson and Street 2009; Zhao et al. 2011). Local control of CO_2 emissions would provide a means of improving urban air quality conditions in cities if the urban "dome effect" is confirmed.

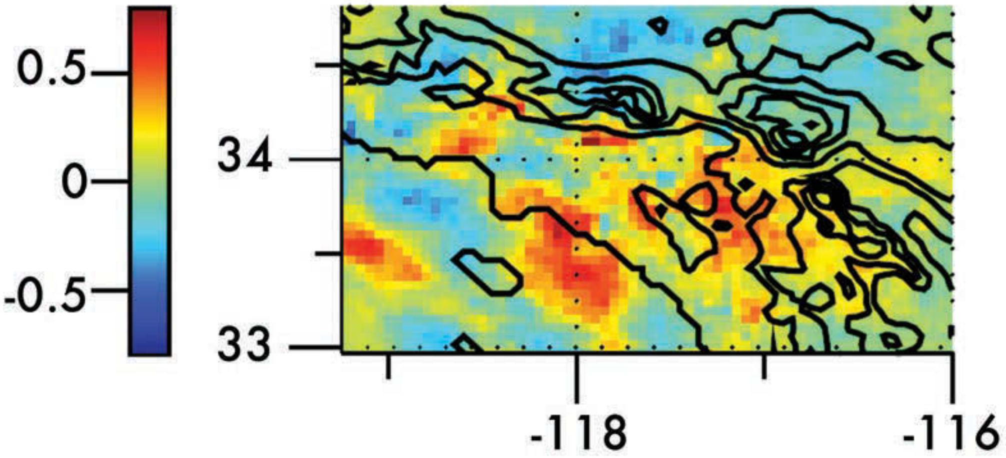

Figure 13.9 Changes of ozone (O_3) concentrations due to the "CO_2 dome" effect in Los Angeles. Modeled differences in ozone concentration in parts per billion from two simulations (with and without CO_2 emissions in Los Angeles); August-October. Contour lines indicate topography. The darker areas inland, to the south and west of the San Gabriel and Santa Ana Mountains (e.g., at approximately 33.7°N, 117.2°W), show increases in surface ozone, due to increased CO_2 aloft. Increased ozone is implicated in air pollution-related deaths. Adapted with permission from the American Chemical Society (Jacobson 2010a, 2501).

Climate change will affect Southwest cities differently, due to their unique geographical locations, settlement histories, population growth rates, shapes and infrastructure, economies, and socio-demographic characteristics. Impacts to residents will in turn depend on where they live and their own capacities and incomes. Southwestern cities—especially the largest metropolitan areas in each of the Southwestern states—have shared characteristics that may cause climate to impact them differently than cities in other regions of the country. Historic development paths of cities continue to influence development patterns and constrain the potential for mitigation and adaptation to climate change. Cities are the products of a particular historical period; most in the Southwest were shaped by the concerns and aspirations of the early twentieth century. These cities were built in a time when there seemed to be no resource constraints, and so their location and form may be less appropriate and functional than in generations past, as climate changes over the next century and beyond. What were hot summers in Phoenix, for example, may become extremely hot summers by the second half of the century, affecting generations that are not yet born.

Government characteristics of large metropolitan regions in the Southwest

The largest metropolitan regions in each state are Albuquerque (New Mexico), Denver (Colorado), Las Vegas (Nevada), Los Angeles (California), Phoenix (Arizona), and Salt Lake City (Utah). One characteristic of Southwest cities is that they are often part of much larger urbanized regions. For example, the city of Los Angeles is one of eighty-eight cities in Los Angeles County, a fully urbanized political jurisdiction. To distinguish Los Angeles from the other cities within the county in terms of its climate contributions or impacts is difficult, as all are intertwined through shared infrastructure and airsheds (shared paths of airflow and pollutants). Thus, one of the important obstacles for cities relative to potential impacts of climate change and adaptation is coordinating governance in complex, fragmented metropolitan regions.

Jurisdictional boundaries in these metropolitan areas are particularly important for the management of environmental resources. Political jurisdictions—such as cities, counties, and special district governments—are superimposed upon ecosystems, watersheds, groundwater resources, and climate zones in ways that do not conform to their physical processes and properties, making it challenging to manage them in a coherent or integrated fashion. There are few requirements for coordinated management or integrated approaches across jurisdictions with regard to infrastructure, natural resources, or any of the daily tasks of local government. This jurisdictional fragmentation of the built environment and infrastructure is complex and place-specific, making it complicated to manage emissions from these large urban areas or to plan and implement mitigation and adaptation measures to address climate impacts. For example, coordinated watershed management for greater water recapture and reuse is difficult because of the number of jurisdictions that have to be integrated (Green 2007). Jurisdictional complexity, differences in scale, and differences in the way data are gathered and made available are significant problems to overcome in order to understand regional contributions to climate change and how those regions may respond.

Southwest cities as distinctive federal creations

To understand the distinctiveness of Southwest cities, it is useful to put their development in historical context. As the nation developed, lands west of the 100th meridian were a source of interest to the federal government (because of their potential) and of special concern (due to their aridity). For the region to become populous and develop a viable economy, providing water was essential (see also Chapter 10). Localities, territories, and states lacked sufficient resources to develop the size and scale of water projects necessary to move water long distances and store it for when it was needed, or the infrastructure to harness major rivers such as the Colorado River (Hundley 2001). Federal water infrastructure was the major factor (driver) for growth of Southwest cities. Federal investments in water development were accompanied by expansion of the electric grid and provision of electricity (Lowitt 1984), which also contributed to urban growth (Table 13.1). At the turn of the twentieth century, the federal government invested the financial resources of the nation to build Southwest water projects, enabling both large-scale agriculture and urban development to occur. Federal water development projects harnessed the Colorado River and other rivers to provide essential water for the growth of the Los Angeles region, and subsequently Phoenix and Las Vegas. Denver benefited from the Colorado-Big Thompson Project. Salt Lake City too complemented its water resources with the Central Utah Project that included water storage (Lowitt 1984). Though Albuquerque relies on groundwater and some surface water, federal funds were provided to relieve flooding and drainage issues in the area, and to bring Rio Grande water in for irrigators and urban use. There are also many small water providers in these cities and region that may rely on local water sources as well. Understanding the full water supply system in these metropolitan regions is very difficult as there are many retail water suppliers, created over time as city regions grew, that buy water from large water wholesale agencies like the Southern California Metropolitan Water District, and/or have small local water resources they sell directly or blend with water from large-scale suppliers. Federally subsidized water projects made water abundant and inexpensive in the Southwest. Water agencies' mission became one of meeting demand from what seemed to be limitless water availability (Hundley 2001).

With increasing uncertainty about snowpack and rainfall due to potential climate change impacts, the historic allocation of Colorado River water distributed by federal infrastructure is once again becoming an increasingly contentious issue among Southwestern states and between competing urban and agricultural demands (see also

Table 13.1 Major water supply projects for Southwestern cities

City	Major Water Supply Projects
Albuquerque	Rio Grande Project (1906–1952), Elephant Butte Dam (1916), Middle Rio Grande Conservancy District (1928– present), Rio Grande Compact (1938–present), San Juan-Chama Project (1962–present)
Denver	Colorado-Big Thompson Project (1938–1957)
Las Vegas	Colorado River dams (1932–1961), Southern Nevada Water Authority (~1947)
Los Angeles	Colorado River dams (1932–1961), Central Valley Project (1937–1979)
Phoenix	Central Arizona Project (1946–1968), Horseshoe Dam (1944–1946)
Salt Lake City	Central Utah Project (1956)

Chapter 10, Box 10.1). Natural areas and ecosystems have been the last to receive rights to water, due to the relatively recent acknowledgement of the importance of ecosystem services (which recognize the value of services provided by an ecosystem, such as recreation, flood control, and reduction of nitrates and other contaminants) and the protection of endangered species. Water rights are hierarchical in time, the oldest users having the first rights under prior appropriation water law. The new ecological concerns have added yet one more water client. Water rights among the different water constituents in the West raise delicate policy questions about the best use of water: for irrigation, for municipal and industrial use, or for ecosystems. Colorado in 1973 recognized the importance of protecting streamflows for the preservation of the natural environment and has a program of water rights acquisitions through the Colorado Water Conservation Board. In New Mexico, in-stream water transfers are left largely to the state engineer, but it is unclear who is eligible to transfer the rights or to hold them. California's in-stream protections derive from the federal Central Valley Project Improvement Act, passed in 1992, which mandated changes in the management of the Central Valley Project to protect and restore habitat for fish and wildlife and has influenced water management throughout the state. Nevertheless, during drought years there is contention about water allocation, and in a future of restricted or unpredictable water supply, determining priorities for water will become more pressing. There are currently no institutions or frameworks to resolve these trade-offs, either within the states themselves or among them. Historically, abundant and inexpensive water (supplied by the federal water systems and more recently by state systems) fueled expectations of an infinite water supply and enabled profligate water use in the Southwest, including extensive outdoor water use in residential areas. Fortunately this is beginning to change (Cohen 2011), but expectations of an infinite water supply were directly linked to federal investments in the West. Urban water use is now consistently declining in every Southwest city, which may reflect increasing awareness of scarcity and the implementation of water conservation policies (Figure 13.10).

Concerns about demands for water and other resources for the Southwest and its emerging cities also led to the setting aside of lands in forests and mountains that still remained in the public domain at the end of the nineteenth century. At that time, no large-scale water transfer systems had been put in place to bring water to growing cities from far-flung places, and the growing understanding that poor forest practices led to floods provided a strong justification for watershed protection. President Benjamin Harrison, for example, designated the lands surrounding the Los Angeles Basin as national forests in 1892 (Pincetl 1999). This federal policy shift resulted in most of the contemporary metropolitan regions in the Southwest being surrounded by public lands that provide important ecological services, including flood control and recreation. This shift also created an extensive wildland-urban interface. Despite their size, the largest Southwestern cities are relatively isolated from other metropolitan areas, are often surrounded by public lands, and rely heavily on imported water (see the satellite images of Los Angeles and Phoenix in Figure 13.11).

Federal spending in the Southwest region during and after the Second World War also fueled growth and created multiplier effects throughout the economy. Airfields and military bases were built, Los Alamos National Laboratory was created in New Mexico, and other investments in the aerospace and ancillary industries provided the

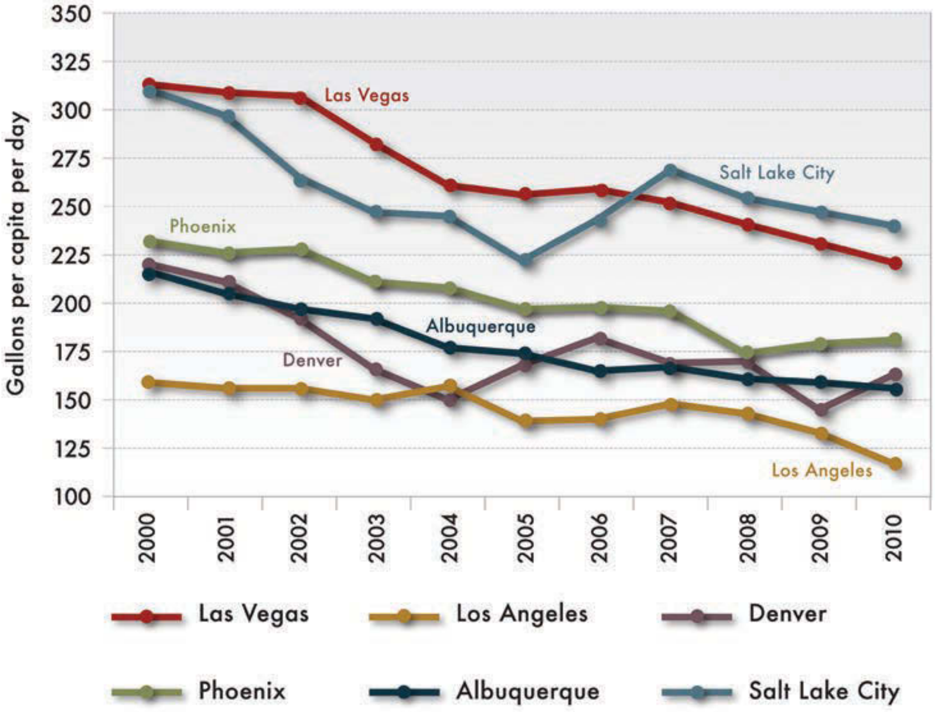

Figure 13.10 Per capita water use in Southwest cities (2000–2010). Source: Great Western Institute (2010), Salt Lake City Department of Public Utilities (SLCDPU 2009), Los Angeles Department of Water and Power (LADWP 2011), City of Albuquerque (http://www.cabq.gov/), City and County of Denver (http://www.denvergov.org/), Southern Nevada Water Authority (http://snwa.com/), Salt Lake City Public Utilities (http://www.slcclassic.com/utilities/), City of Phoenix (http://phoenix.gov/), Los Angeles Department of Water and Power (http://www.ladwp.com/).

employment base for urban development. The Southwest became the home of new techniques for mass home building (also made possible by the expanding water supplies) and populations in the metropolitan areas grew rapidly (Nash 1985; Kupel 2003). The Kaiser Company, for example, built worker housing in Los Angeles near its manufacturing facilities, pioneering the development of planned, dense, automobile-dependent, single-family tracts with nodal shopping malls and other services. Home building was modeled on assembly-line aircraft construction, making it possible to considerably accelerate the pace of construction (Hise 1997). These factors have made cities of the Southwest both expansive and relatively denser than other cities in the country: ten of the fifteen densest metropolitan areas in the United States are located in California, Nevada, and Arizona (Eidlin 2010). Growth of the Southwest cities coincided with both automobile-dominant transportation and federal investment in it, including the Federal Highway Act of 1956, a Cold War-related national system built for defense purposes. As a result, the morphology of Southwest cities is densely suburban. Nationally, the automobile-dependent urban form is a product of post-war suburban growth, with highways and home mortgages subsidized by the federal government.

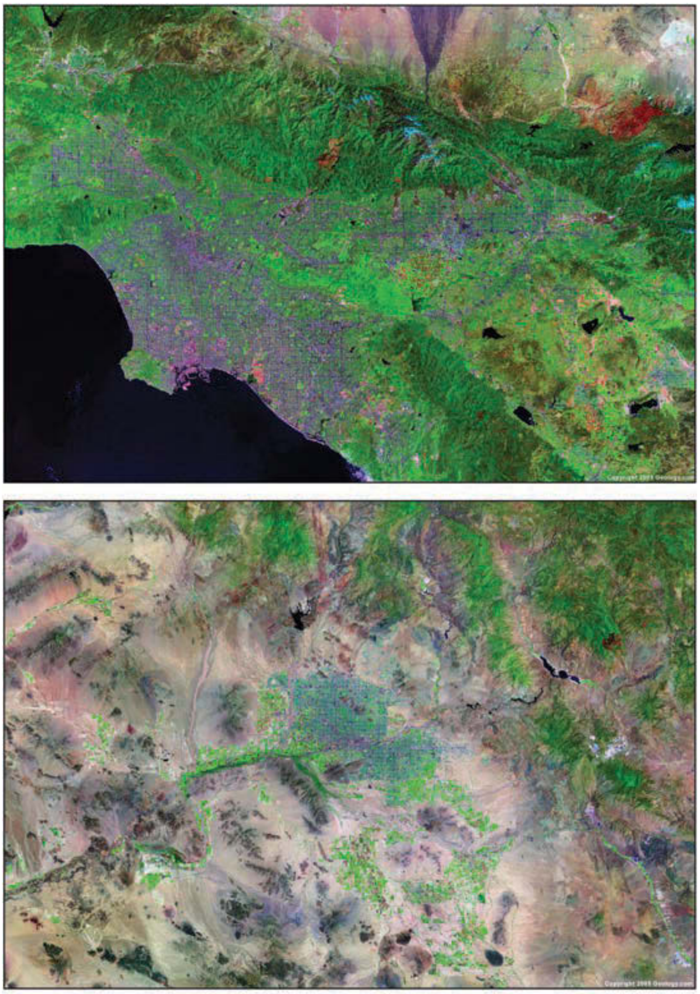

Figure 13.11 Satellite image of urban Los Angeles (top) and Phoenix (bottom). The two cities are surrounded by undeveloped mountainous areas and public lands. Image by Geology.com using Landsat data from NASA.

13.2. Pathways Through which Climate Change Will Affect Cities in the Southwest

Fire hazards

The extensive public lands surrounding these major metropolitan regions and the corresponding urban-wildland interface make them susceptible to increased wildfires driven by a drier climate, extensive and scattered urbanization in the public lands, a history of fire suppression, and changing vegetation in the natural lands themselves.

The Southwest cities are not equally prone to wildfires (Figure 13.12) nor are they equally likely to suffer increased fire impacts due to differences in the types of ecosystems in the surrounding natural lands. But for the cities at risk, the cost of fire protection is significant. Increased fire incidence will cause property damage and impose related costs, some of which are only beginning to be understood. Issues such as who should pay for fire protection can be contentious, as can be the development of new building regulations for greater fire resistance and land-use regulations to prevent construction in high-fire-zone areas (Pincetl et al. 2008). Less evident impacts are also likely. For example, in the Los Angeles National Forest Station Fire, vegetation burned that had not burned since before the introduction of air pollution controls. Stormwater samples taken after the Station Fire showed high levels of heavy metals that had been deposited before Clean Air Act requirements were imposed (Burke et al. 2011). Water from the front range of the Los Angeles National Forest is a key source of groundwater recharge, and infiltration basins have been inundated with these post-fire pollutants. Except for the study of the L.A. Station Fire, little or no monitoring of such impacts has been done. Increased incidents of urban-fringe fires will require improved post-fire monitoring and management and treatment of stormwater runoff to reduce impacts to city water supplies and downstream ecosystems (see also Chapter 3, Section 3.2.1, and Chapter 8, Section 8.4.2).

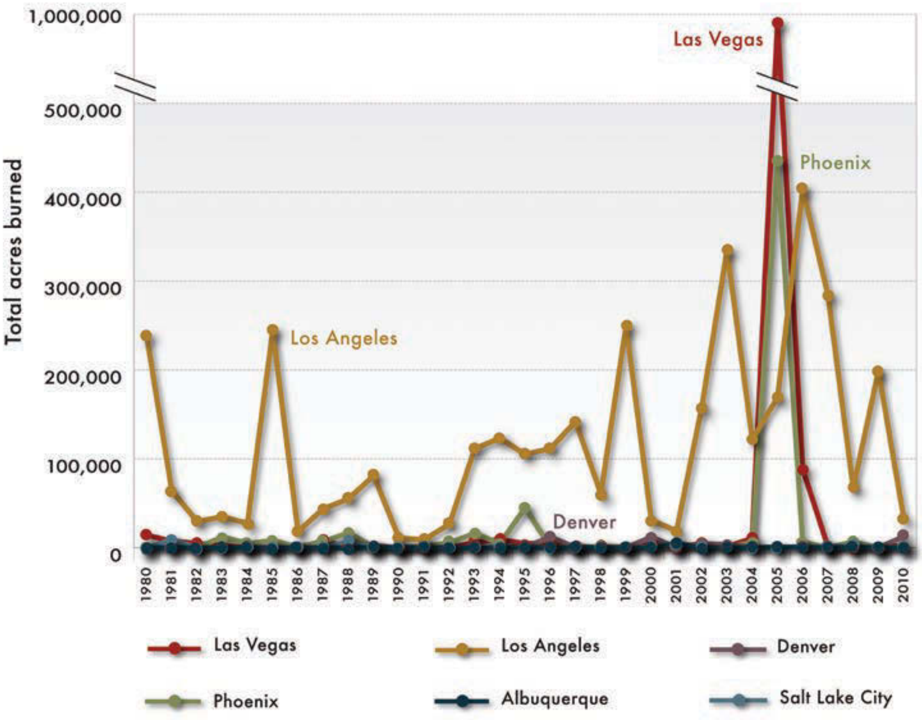

Figure 13.12 Total acres burned in wilderness/urban interface zones of six Southwestern cities. Source: U.S. Department of the Interior's Geospatial Multi-Agency Coordination Group (GeoMAC) Wildland Fire Support (http://www.geomac.gov), State of California Fire and Resource Assessment Program (http://frap.cdf.ca.gov).

The built environment

The built environment itself can be a conduit for climate impacts. High percentages of impermeable surfaces like asphalt—which is commonly used in cities—increase surface temperatures, amplify heat waves, and reduce stormwater infiltration, contributing to potential flooding. Lack of energy-conservation standards increases the vulnerability of residents to heat waves. For example, Arizona, Colorado, and Utah have no statewide energy codes for building construction, deferring to the localities to develop their own. In contrast, California that has energy conservation regulations at the state level, continues to lead the nation in building-energy efficiency. State-level regulations create an even playing field, relieving localities from having to develop their own codes, and provide the technical expertise that can be required. Instead, currently there is a patchwork of different energy-conservation standards, and some states have none at all. New Mexico, Nevada, and California have statewide mandatory requirements to which specific cities have imposed additional requirements.[ix] Building-energy standards are a method to reduce the impact of extreme heat incidences.

In each of the cities, energy providers have instituted financial incentives for conservation and in some cases the use of alternative energies; city and county governments have also developed various types of regulatory frameworks to encourage efficiency and “green” building (Table 13.2) (see also Chapter 12, Section 12.3.5).

Cities in the Southwest also have very different patterns of infrastructure use and regulation. The percentage of each city’s population using public transit, for example, ranges from 1.6% in Albuquerque to 6.2% in Los Angeles (Figure 13.13). According to the American Association of State Highway and Transportation Officials, light-duty trucks and automobiles contribute 16.5% of U.S. GHG emissions. Cities have done inventories on their own vehicle use and GHG emissions, but city-wide and county-wide GHG emissions are not available across the Southwest though under Senate Bill 375 in

Table 13.2 Energy-efficiency incentives and regulations in Southwestern cities

City	Financial Incentives	Rules, Regulations and Policies
Albuquerque	Green Building Incentive program	Energy conservation code
Denver	Energy-efficiency rebates from service provider	“Green building” requirement for city-owned buildings
Las Vegas	Energy-efficiency rebates from service provider	County-wide energy conservation code
Los Angeles	Renewable energy and energy-efficiency support and rebate programs from service provider	County-wide green building programs and LEED certification for public buildings
Phoenix	Renewable energy and energy-efficiency support and rebate programs from service provider	Design standards for city buildings; renewable energy portfolio goals
Salt Lake City	Renewable energy and energy-efficiency support and rebate programs from service provider	Green power purchasing by city; high-performance buildings requirement

Sources: City of Albuquerque (http://www.cabq.gov/); City and County of Denver (http:// www.denvergov.org/); City of Las Vegas (http://www.lasvegasnevada.gov/); City of Los Angeles (http://www.lacity.org/); City of Phoenix (http://phoenix.gov/); Salt Lake City (http://www.slgov.com/).

California, such inventories are being conducted. Still, fossil-fuel combustion generates GHGs and in regions where there is a greater reliance on fossil fuels and on single-occupancy vehicles, there will be more production of GHGs. While public transportation also emits GHGs, reducing overall vehicle miles traveled (as by single occupancy vehicles rather than multiple passenger public transportation) will reduce regional GHG emissions. (More information on passenger travel and emissions can be found in Chapter 14, Section 14.2.)

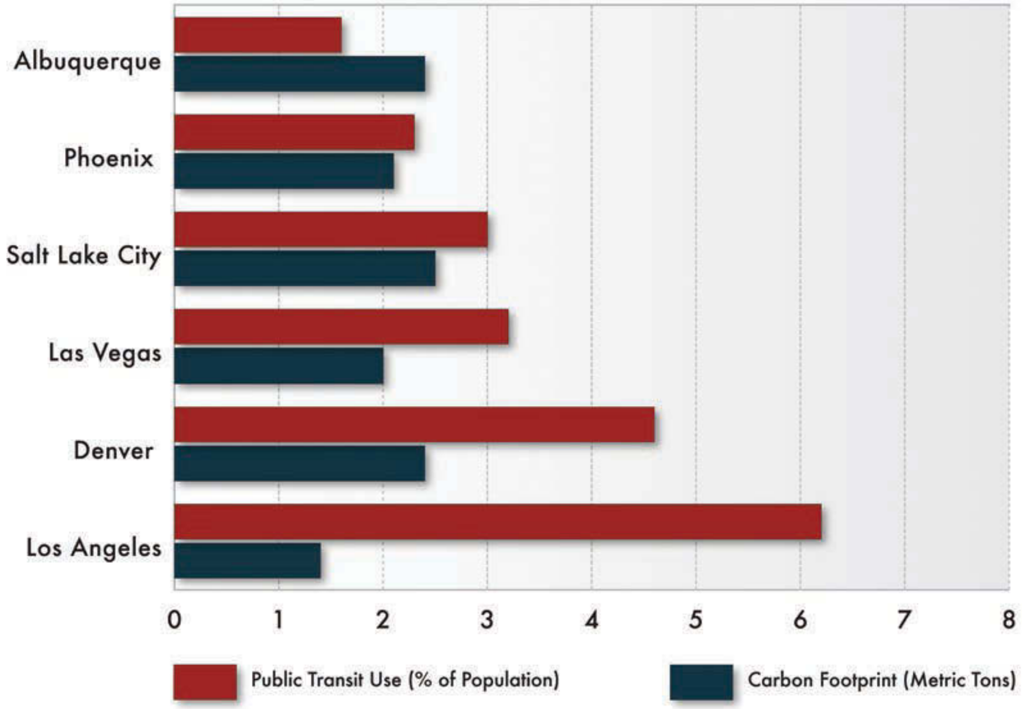

Figure 13.13 Public transit use and carbon footprints of Southwest cities. Source: U.S. Census Bureau American Community Survey 2009 (http://www.census.gov/acs/www/data_documentation/2009_release/), and Brown, Sarzinski and Southworth (2008).

Smart growth and new urbanism initiatives have been influential in the Southwest. The concept of smart growth is to place new development near existing urban infrastructure, especially transportation, and to make urban areas more compact. New urbanism promotes the creation and restoration of diverse, walkable, compact, and mixed-use communities based on specific design principles (Haas 2012). These ideas for new ways to build cities were inspired by concerns about health, walkability, and livability, as well as cost. Living near transit lines and in walkable neighborhoods has multiple benefits; it so happens that these benefits are lined up with the mitigation of climate change as well. One major initiative has been the California and Utah Regional Blueprint Planning Program, with the federal Environmental Protection Agency acting as a partner. In the Salt Lake City region, this effort, along with the infrastructure development for the 2002

Olympics, created the infrastructure and incentives for more compact development and development adjacent to already developed areas. For the major cities in California, the process has engaged thousands of residents in articulating a vision for the long-term future of their region and understanding the implications of different types of growth relative to impacts on land use, transportation, energy, and (increasingly) climate. This has also led to yearly *California Regional Progress* reports, available online at the California Department of Transportation website. The Phoenix, Mesa, and Valley Metro Rail systems are also receiving assistance from EPA to develop a regional strategy that will encourage compact, mixed-use, and transit-oriented development (see its Region 9 SmartGrowth web page[x]).

Climate change and urban water

In the Southwestern United States, potential impacts of climate change on water resources have been summarized by numerous researchers (e.g., Knowles and Cayan 2002; Miller, Bashford, and Strem 2003; Hayhoe et al. 2004; Mote et al. 2005; Cayan et al. 2010; MacDonald 2010; and Chapters 6 and 10 of this report). Most climate models indicate that the Southwest will become drier in the twenty-first century, and that there will be increased frequencies of extreme weather events, including drought, flooding, and heat waves (IPCC 2007). Increasing temperatures are expected to alter precipitation patterns (i.e. volume, frequency, and intensity) and correspondingly alter regional streamflow patterns. Increasing temperatures will impact urban populations in the Southwest; their impacts may be already felt in communities such as Phoenix, whose annual number of misery days (days where people feel strongly impacted by temperature and there can be adverse health impacts) has been increasing[xi] (Figure 13.14) (Ruddell et al. forthcoming). Annual minimum temperatures in all six of the Southwest cities considered here are also increasing (Figure 13.15). For further discussion on the effects of climate change on human health in urban areas, see Chapter 15.

Precipitation patterns in the Southwest are typically highly variable (Figure 13.16). Climate change is anticipated to make variable and extreme precipitation even more common and to result in changes in flood frequency and extreme runoff events (Lopez, Hogue, and Stein 2011). Highly structured and in-filled cities (cities that have high proportions of impermeable surfaces due to roads and buildings, little open space, and existing infrastructure such as for stormwater) have little capacity to adapt to increasing flows—for example by devoting existing open spaces to stormwater infiltration—and so may be especially vulnerable to extreme flooding. Enhanced, intensified water flows will increase the wash-off of suspended sediments and other pollutants, degrading water quality, as was the case in the Station Fire in Los Angeles mentioned above (Benitez-Gilabert, Alvarez-Cobelas, and Angeler 2010; Lopez, Hogue, and Stein in review). Altered flow regimes and degraded water quality also have significant implications for downstream ecosystems that receive polluted urban stormwater. There have been some initial efforts to restore such ecosystems. For example, since 1997, the Wetlands Recovery Project (WRP) in Southern California has invested over $500 million in the acquisition and restoration of coastal wetlands. Unfortunately, they are now at accelerated risk of degradation due to increased potential for increased high-precipitation events and fires. Wetlands in other parts of the Southwest are at similar risk of fire impacts on water quality.

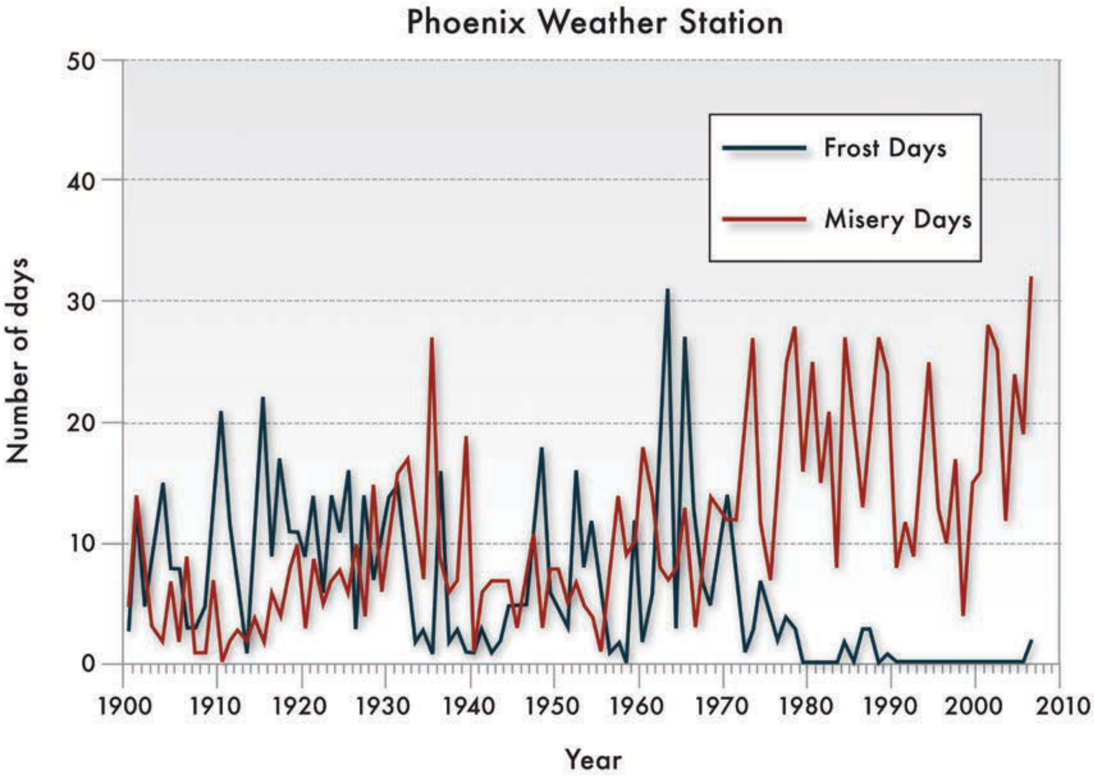

Figure 13.14 Number of misery and frost days in Phoenix, 1900–2010. Note the increase in misery days, and decrease in frost days during the last 40 years. Source: Ruddell et al. (2012).

Temperature increases will also impact vegetation across the Southwest, increasing evapotranspiration rates. If this holds true, water demand in urban ecosystems will increase. This is especially true in cities with extensive vegetation that is not climate-appropriate and has heavy water demand. For instance, the city of Los Angeles likely uses 40% to 60% of its residential water for outdoor and landscaping application (LADWP 2011), much of this going to non-native and non-climate-appropriate species such as turf grass. The trend toward urban tree planting to reduce the urban heat island effect and provide other benefits, as exemplified in the Los Angeles Million Tree Planting program, may also lead to unintended increased water demand (Pataki et al. 2011).[xii] However, landscaping and greenspace (protected and reserved areas of undeveloped land) are unequally distributed in many of the Southwest urban centers. Many residents will be limited in their capacity to plant and maintain greenspace relative to local resources and incomes, compromising their ability to mitigate increased temperatures and their associated energy needs. There are complex environmental justice implications in the distribution of greenspace as many low income neighborhoods suffer from lack of tree canopy and other vegetation and so are hotter (Grossman-Clarke et al. 2010; Chow, Chuang, and Gober 2012; Pincetl et al. 2012).

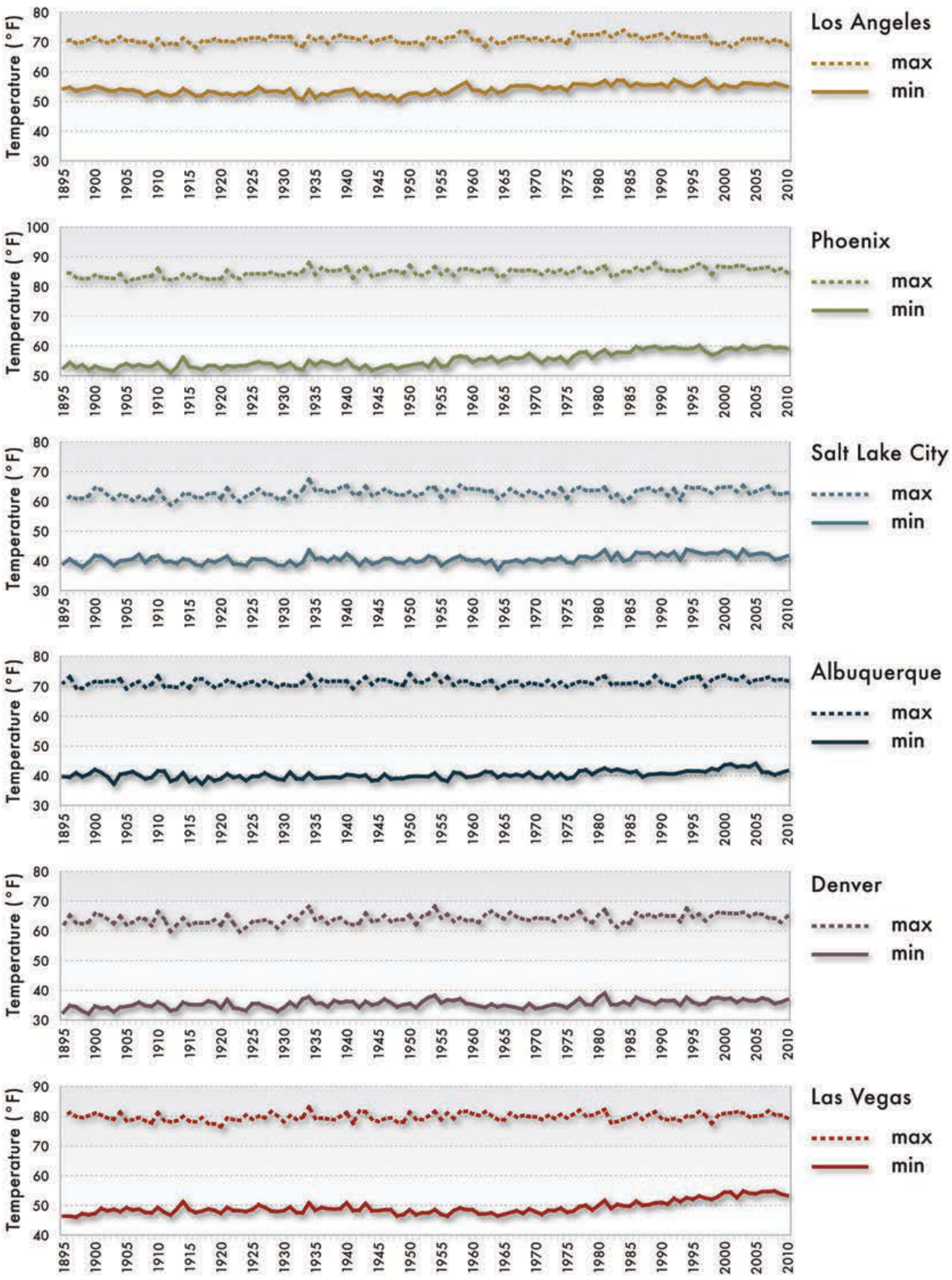

Figure 13.15 Average annual minimum temperatures for six Southwestern cities (in °F). Source: Prism Climate Group (2011), Oregon State University, http://prism.oregonstate.edu.

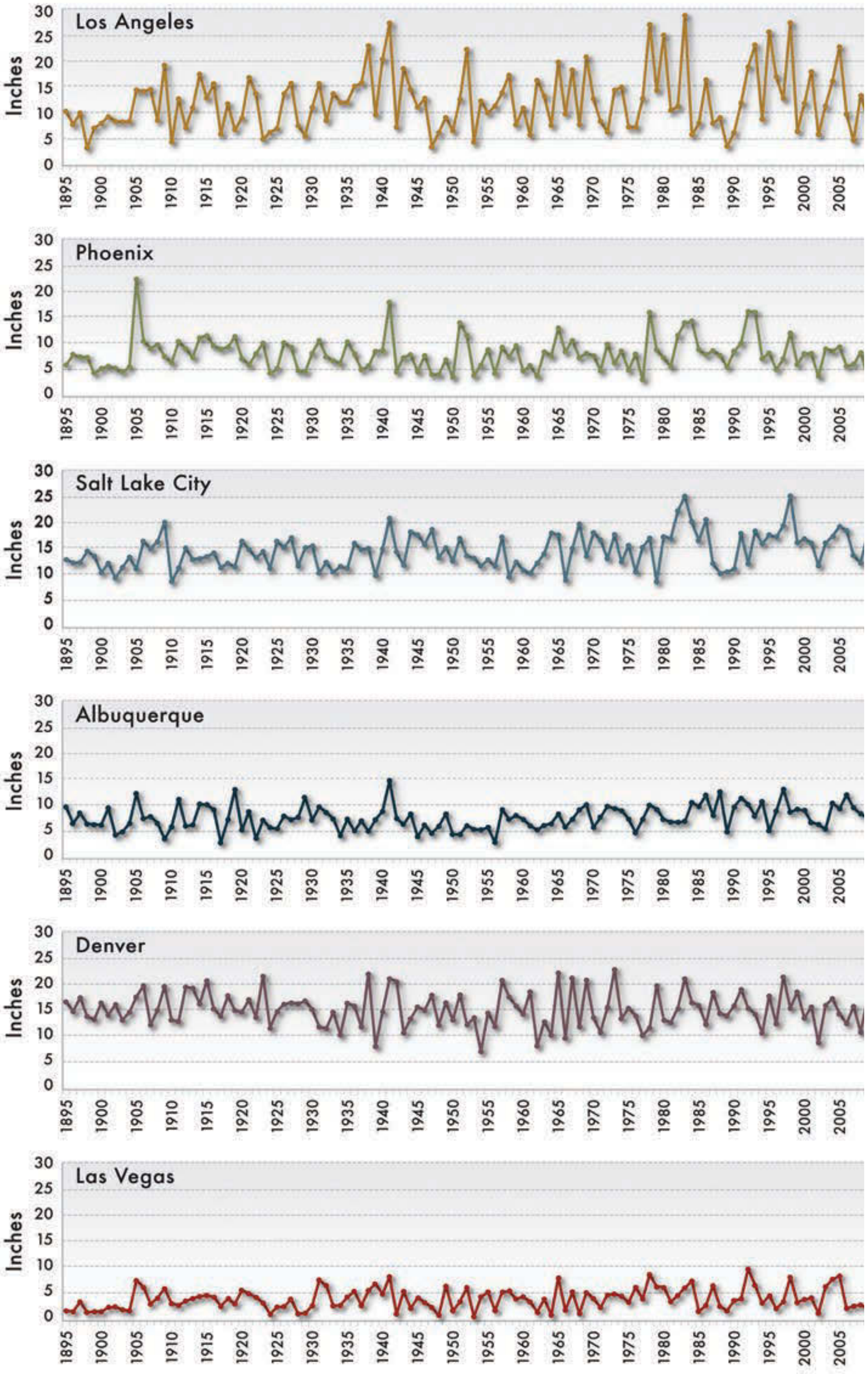

Figure 13.16 Average annual rainfall (in inches) in six Southwestern cities, 1895–2010.
Source: Prism Climate Group (2011), Oregon State University, http://prism.oregonstate.edu.

Sea-level rise in Southwest cities is a third consequence of rising temperatures. Its potential impacts are described further in Chapter 9. Observations over the last century show sea-level rise of about 8 inches (about 203 mm) along California's coast (see Chapter 9, section 9.2.2). Sea-level rise has a range of associated consequences, but a key concern for Southwest coastal cities, such as Los Angeles, is the salinization of groundwater and estuaries, which reduces freshwater availability (Bloetscher et al. 2010; Quevauviller 2011). Sea-level rise is expected to shift the fresh water/saline interface inland due to salt water intrusion, potentially contaminating groundwater supplies used in urban coastal cities. Ultimately, this may result in increased costs associated with infrastructure to segregate sea water from fresh water (these include barrier well injections[13] and/or the implementation of additional barrier systems) (Webb and Howard 2011).

Wastewater and stormwater infrastructure, as well as reclamation and recharge projects are also vulnerable to sea-level rise, especially in low-lying coastal regions (Bloetscher et al. 2010). Model simulations by Webb and Howard (2011) indicate that aquifers can take several centuries to gain equilibrium following a cessation in sea-level rise, largely dependent on the aquifer's properties.

Sea-level rise will likely affect private property and also infrastructure such as sewage treatment plants located along the coast, as well as roads and rail lines. A number of coastal cities and regions are beginning to prepare for the potential of this impact, integrating costs and plans in their capital improvement programs. The Port of Los Angeles is planning for adaptation to sea-level rise by seeking expert advice, contracting with Rand Corporation to identify key vulnerabilities and develop a set of general approaches based on alternative models. (See additional discussion in Chapter 9, Box 9.4). Such planning raises questions of jurisdictional responsibility, as infrastructures such as sewage treatment plants often serve regional cities. Land-use impacts may affect only some jurisdictions and not others, and funding can be complicated as well.

13.3 Critical Missing Data and Monitoring in Cities

For complex urban regions, where the majority of the Southwest population lives, greater inter-jurisdictional collaboration of data collection and planning will be required to allow cities to adapt to climate change and become more resilient. One such approach is the Los Angeles Regional Collaborative for Climate Action and Sustainability,[xiv] which operates at the level of Los Angeles County (the county encompasses eighty-eight cities, 10 million inhabitants and over 1,000 special districts). The goal of the collaborative is to develop a plan for climate action and sustainability that draws on the strengths of each member to build an integrated and coherent response to potential impacts of climate change. Best management practices across the region will be shared, as well as funding for programs and projects. Although few examples of this type of initiative currently exist, it represents a feasible strategy for Southwest cities to move adaptation forward. (See additional examples in Chapter 18.)

Quantification of energy flows into urban regions and pollution sinks is also required so that carbon-mitigation strategies can be based on rigorous data analyses that incorporate a life-cycle-based understanding of the generation of GHGs. Tracking of pollution sinks—such as methane from landfills or the deposition of air pollutants on soils that may then become captured in runoff—will help determine the impacts of urban systems. Such urban energy flow studies—known as urban metabolism—can improve our understanding of a host of climate-change vulnerabilities. A key need in conducting such analyses are geographically specific data, such as household, commercial, and industrial energy-use data, that are currently not available due to privacy concerns. Coupling household-level energy use with land-use data will reveal important aspects of urban activities and help identify mechanisms by which they may be improved.

Observations on land-atmosphere interactions in Southwest urban centers are also lacking. For example, while local temperature data are generally available from government agencies, the scattered distribution of temperature gauges often do not accurately reflect the spectrum of microclimates in an urban area. There is also a need for more measurements of atmospheric CO_2 and urban energy fluxes, as discussed, and for distributed runoff data. Other key data that would be useful in evaluating urban water consumption patterns and trade-offs are vegetation type and species used in urban areas and separate metering for indoor and outdoor water use. Air-quality monitoring is equally sparse and often limited to criteria pollutants. GHG monitoring is nonexistent, as are comprehensive data on the health impacts of heat waves and air-quality deterioration.

Cities in the Southwest of the United States have unique but regionally shared characteristics. They are artifacts of federal policy, including protection of the public lands that surround many of them. Federal land, transportation, and water policies have shaped the urban form, creating a dense urban sprawl characterized by thirsty, climate-inappropriate vegetation in urban areas that are dependent on inexpensive and abundant fuels and water. The impacts of climate change on these arid cities are largely centered on probable water scarcities over the course of the twenty-first century, punctuated by extreme weather events that will bring flooding, fires, and extreme heat events. Fortunately, water consumption per capita is beginning to decrease in most western states (Cohen 2011). In some states there is increased investment in and ridership of public transportation, offering the hope that transportation-related GHG emissions will decrease. Measures such as capturing landfill GHGs are advancing as well, and numerous cities and towns are planning, directly or indirectly, for climate change impacts, including requiring buildings to become more energy-efficient.

The fragmented governance of these cities makes coordinated and integrated programs and responses difficult, and budgetary constraints are significant. Governance experiments such as the Los Angeles Regional Collaborative for Climate Action and Sustainability provide a vision of a process that could effectively coordinate climate responses in fragmented Southwest cities. Governance and fiscal capacity will play an important role in the ability of regions to adapt.

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Endnotes

i An urban metabolism refers to the total urban systems flows of materials, energy and inputs, and outputs in the form of waste. Supply chains are components of the urban metabolism.

ii Urban heat island effect was defined as "the relative warmth of a city compared with surrounding rural areas, associated with changes in runoff, the concrete jungle effects on heat retention, changes in surface albedo, changes in pollution and aerosols, and so on" by the IPCC (2007).

iii See http://www.water.ca.gov/floodsafe/.

iv The EC method is a widely used micrometeorological technique designed to measure turbulent exchanges of mass, momentum, and heat between an underlying surface and the atmosphere (see Aubinet, Vesala and Papale 2012 and references within). For CO_2 exchange, rapid measurements of vertical velocity fluctuations and CO_2 mixing ratio are made on a tower well above the buildings and trees of an urban surface in the so-called constant flux layer. From these quantities, a covariance is computed (Baldocchi 2003). If appropriate assumptions are satisfied, the covariance is a measure of the net differences between the uptake of CO_2 by photosynthesis and the emission of CO_2 by anthropogenic and biological processes.

v Difficulties are both practical and technical. Practical difficulties include funding for such equipment as flux towers, their siting in urban areas, and funds to conduct the monitoring and data analysis. Additional technical difficulties exist related to quantifying important contributions to fluxes, such as those related to complex distributions of sources and sinks and their relationship to advection and non-homogeneous surfaces that are common in urban areas (Feigenwinter, Vogt, and Christen 2012).

vi A *source* is a process or activity through which a greenhouse gas is released into the atmosphere. A *sink* is something that acts as a reservoir to absorb it on a short- or long-term basis.

vii See http://www.urban-climate.org.

viii CO_2 concentrations can cause higher levels of PM 2.5 by increasing vapor pressures in some locations (Jacobson 2010b).

ix See http://www.energycodes.gov/states/state (U.S. Department of Energy's Building Energy Codes Program).

x See http://www.epa.gov/region9/climatechange/smart-growth.html.

xi Misery days are days when the temperature maximum is greater than or equal to 110°F or when the temperature minimum is less than 32°F.

xii Stomata, the microscopic pores on the leaves and stems of plants, are the means by which plants transpire, or lose water vapor to the atmosphere. Although there is some debate on plant stomatal response to increasing temperatures, a significant body of research indicates that evapotranspiration rates (the combination of evaporation and transpiration) may increase (Gutzler and Robbins 2011; Matonse et al. 2011; Lopez, Hogue, and Stein in review).

xiii A barrier well intrusion barrier is a well used to inject water into a fresh water aquifer to prevent the intrusion of salt water.

xiv See http://www.environment.ucla.edu/larc/.