Chapter 26. North America

Coordinating Lead Authors
Patricia Romero-Lankao (Mexico), Joel B. Smith (USA)

Lead Authors
Debra Davidson (Canada), Noah Diffenbaugh (USA), Patrick Kinney (USA), Paul Kirshen (USA), Paul Kovacs (Canada), Lourdes Villers Ruiz (Mexico)

Contributing Authors
Hannah Brenkert-Smith (USA), Jessie Carr (USA), Anthony Cheng (USA), Thea Dickinson (Canada), Ellen Douglas (USA), Rob de Loë (Canada), Hallie Eakin (USA), Melissa Haeffner (USA), Maria Eugenia Ibarraran Viniegra (Mexico), Elena Jiménez Cisneros (Mexico), Amrutasri Nori-Sarma ( ), Landy Sánchez Peña (Mexico), Catherine Ngo (USA), Greg Oulahen (Canada), Diana Pape (USA), Ana Peña del Valle (Mexico), Roger Pulwarty (USA), Ashlinn Quinn (USA), Bradley H. Udall (USA), Jason Vogel (USA), Fiona Warren (Canada), Kate Weinberger (USA),Tom Wilbanks (USA)

Review Editors
Ana Rosa Moreno (Mexico), Linda Mortsch (Canada)

Volunteer Chapter Scientist
William Anderegg (USA)

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Executive Summary

The climate of North America has already been warming and changes in extremes and means are being observed. Some of these stresses are from changes in average conditions such as sea level rise, higher temperatures and earlier snowmelt. Other stresses are the result of changes in extreme events or disturbance. (e.g., wildfire and pests have disrupted many forests, ecosystems and human settlements across North America). Extreme climate events such as droughts and hurricanes have led to large economic losses. The region is very likely to face increasing warming and extreme high temperatures, higher sea levels, more intense precipitation and droughts, more intense storms, and reduced snowpack and higher sea levels. [26.1.1, 26.2.2, 26.4.1, 26.5]

Attribution of observed changes in North America to anthropogenic climate change has been established for some physical systems (e.g., snowpack), some ecosystems (e.g., forests dieback, vector diseases and pests distribution) and cases, but not in managed systems (e.g., agriculture). [26.2.2.1.1, 26.4.1, 26.6.1]

Ecosystems across North America are already being affected by climate change and are at high risk from further climate change. Biodiversity and ecosystem services are very likely to be reduced. [26.4]

For different reasons (e.g., lack of access particularly in Mexico, insufficient maintenance and ineffective management) the quality of *infrastructures* across North America increases vulnerability to climate change. [26.9]

Climate change is projected to pose major challenges to *water supplies*, flooding, and water quality, with water supplies of most concern in western and southern areas (already stressed) and flooding from poor drainage systems or from rivers of concern in most areas. Water quality threats are throughout the region. [26.3]

Human health risks include impacts from more extreme storm and heat events, air pollution, pollen, and infectious diseases. The effects can be modified by intervening factors including economic status, access to health care, and adaptations. Health impacts are likely to be greatest for economically disadvantaged both within and across countries in North America. [26.8]

North America is a major source of global food supplies. Increases in extreme events and exceeding thresholds can offset gains to North American agriculture productivity. Adaptation can ameliorate many, but not all, adverse impacts provided adequate institutional support. Small farmers in Mexico are among the most vulnerable groups to climate change. [26.6]

Interacting dynamic processes determine differences in *vulnerability* and *adaptive capacity*.
- *Rural communities* are relatively vulnerable because of high natural resource dependency, increased market specialization, high rural impoverishment (Mexico), and contraction of insurance and credit (Mexico). [26.7]
- *Urban centers'* capacities to respond relate not only to location, population demographics, social capital, wealth, values, behavior or political power, but also to built-environment features, levels of regional environmental degradation and the institutional settings regulating urban life. [26.10]

Most sectors of the North American economy have recent experience reacting and adapting to extreme weather, including hurricanes, flooding and intense rainfall, but lessons learned are often not well documented in the literature. [26.11]

Some economic sectors and settlements have begun adapting to climate. For example the *insurance* has changed practices in response to recent extreme events and in some northern areas, the design and construction of buildings has changed. [26.11.3]

A number of governments across North America have begun the process of addressing adaptation. This is particularly evident in municipalities. Some state and provincial governments have begun planning for adaptation.

The three national governments have also initiated adaptation activities, including providing technical support for adaptation. Many cities in the three countries have instituted at some adaptation planning (e.g., Boston, NY, Miami, San Francisco, Toronto, and Mexico City). These efforts are in a nascent stage and scholarship is starting to evaluate how effective they will be in reducing the impacts of climate change and in particular how effective they will be should climate change in line with relatively high projections of future greenhouse gas emissions. [26.10.4, Box 26-5]

Literature is emerging on such issues as the potential social effects of climate change including impacts on vulnerable populations and the potential for increased migration from Mexico to the north. [26.6.2, 26.10]

26.1. Introduction

North America ranges from the tropics to frozen tundra and contains a diversity of topography, ecosystems, economies and cultures. While across the continent, adaptive capacity is relatively high, there is diversity in levels of economic and human development, demographic dynamics and governance structures. The vulnerability of North American societies and ecosystems to climate change varies considerably depending on geography, scale, social or ecological systems, demographic sectors and institutional settings. This chapter attempts to account for some of this diversity by analyzing a number of economic sectors, regions, demographic groups and “natural systems” that will be affected by climate change in different ways. Impacts on the North American Arctic region are discussion in Chapter 28: Polar Regions.

Key Findings from the Fourth Assessment Report (AR4)

This section summarizes key findings on North America, as identified in chapters 13 and 14 of the Fourth IPCC assessment focused on Latin America/Mexico (Magrin et al., 2007) and Canada and the USA, respectively (Field et al., 2007). Over the past decades, economic damage (particularly to infrastructures in US and Canada) from severe weather, including hurricanes, other severe storms, floods, droughts, heat waves and wildfires has increased dramatically (high to very high confidence). Changes in precipitation, and increases in temperature and in the rate of SLR were also documented for Mexico.

Although Canada and the US have considerable adaptive capacity, their vulnerability depends on the effectiveness and timing of adaptation and the distribution of coping capacity, which vary spatially and among sectors (very high confidence). For Mexico the development of early warning systems and risk analysis in the areas of agriculture, human health, water resources, fisheries and coastal resources, has increased their capacity for planning and management (high confidence). In Canada and the US, traditions and institutions have encouraged a decentralized response framework where adaptation tends to be reactive, unevenly distributed, and focused on coping with rather than preventing problems. ‘Mainstreaming’ climate change issues into decision making was seen as a key prerequisite for sustainability.

Coastal communities and habitats in the three countries will be stressed by sea level rise, storm-surge flooding and other climate change impacts interacting with developmental and environmental stresses (e.g., salt intrusion, pollution population growth and the rising value of infrastructure in coastal areas) (very high confidence in chapter 14). Current adaptation is uneven and readiness for increased exposure is low.

For Mexico, land use changes have intensified the use of natural resources and exacerbated many of the processes of land degradation (high confidence). Significant species extinctions in many tropical areas of Mexico is projected (high confidence). Agricultural lands will be subjected to desertification and salinization processes in many areas (high confidence), and this will have important consequences for the well-being, particularly of rural populations. While increases in grain yields in U.S. and Canada were projected, the picture is mixed for wheat, maize), whose behavior is more erratic depending on the scenario imposed.

Millions in Mexico are projected to be at risk from the lack of adequate water supplies (medium confidence), while in the US and Canada rising temperatures will diminish snowpack and increase evaporation, affecting seasonal availability of water. This will imposed further constrains to over-allocated water resources, increasing competition among agricultural, municipal, industrial and ecological uses (very high confidence).

Changes in geographical distribution and transmission of diseases have been observed in Mexico and changes in the geographical distribution of dengue are also projected. Climate change impacts on infrastructure and human health and safety in urban centres of Canada and the US will be compounded by ageing infrastructure, maladapted urban form and building stock, urban heat islands, air pollution, population growth and an ageing population (very high confidence). Warming and climate extremes are likely to increase respiratory illness, including exposure to pollen and ozone. Climate change is likely to increase risk and geographic spread of vector-borne infectious diseases, including Lyme disease and West Nile virus.

Disturbances such as wildfire and insect outbreaks are increasing in Canada and the US and are likely to intensify in a warmer future with drier soils and longer growing seasons (very high confidence). Over the 21st century, pressure for species to shift north and to higher elevations will fundamentally rearrange North American ecosystems. Differential capacities for range shifts and constraints from development, habitat fragmentation, invasive species, and broken ecological connections will alter ecosystem structure, function and services.

Without increased investments in such countermeasures as early warning and surveillance systems, air conditioning, access to health care, hot temperatures and extreme weather in Canada and the US are likely to cause increased adverse health impacts from heat-related mortality, pollution, storm-related fatalities and injuries, and infectious diseases (very high confidence). Therefore chapter 13 suggested streamlining adaptation strategies with national / regional sustainable development plans.

26.2. Current and Future Trends

26.2.1. Demographic, Socioeconomics, and Institutional Trends

Canada, Mexico and USA differ in in three dimensions shaping vulnerability and adaptation: population dynamics, economic development, and institutional capacity. Notwithstanding the current economic crisis, Canada and United States have continued to enjoy generally higher levels of human and economic well-being than Mexico. While United States and Canada rank fourth and sixth on the 2011 Human Development Index, Mexico ranks fifty seventh. After registering rates of growth of about 2% yearly during 1987-2005, the per capita GDP (in 2005 dollars) of three countries decreased during 2008-2009 (particularly in Mexico). Yet, in 2011 the USA GDP per capita ($42,448 in 2005 dollars) was 1.2 times the Canadian one and 4 times the Mexican one, despite trade integration in the region.

The three countries have become more economically integrated following the 1994 North American Free Trade Agreement. For instance the US-Mexico border was before the 2007-2008 fall in trade, a region of dynamic growth in industry, employment and global trade of agricultural and manufactured goods (Robertson *et al*., 2009). However, institutional asymmetry and fragmentation can be source both of opportunities (examples) and potential vulnerabilities in managing trans-border environmental resources and issues. (Wilder *et al*., 2010);(1260 Scott, C.A. 2008)

Overall, population growth slowed in North America, although Mexico´s fertility rates were above replacement levels by 2010 (2.4 TFR). Population in North America is projected to keep growing over the next decades and reach 590 million in 2050 (1257 Anonymous). Also, 81% of the region's population lives in urban areas in 2010. With small differences between countries, urban population could grow to 85% of the 2030 population, and Mexico is likely to experiment the largest increase (1262 United Nations Department of Economic and Social Affairs, Population Division 2010). Large population concentrations challenge capacity to cope with environmental impacts and to maintain functional urban infrastructure, such as water, electricity and transport networks(1213 Hallegatte, S. 2011). These challenges are severe in Mexico, where 14% of the urban population lives in slums, lacking basic infrastructure and services (1257 Anonymous).

A declining rural population currently faces lower income levels, reduced access to public services and labor markets that might enhance rural sensitivity to climate events. Rural population isolation could be aggravated high dispersion levels in areas of Canada and Mexico given. Rural poverty could be aggravated because agricultural changes, particularly in Mexico where 65% of the rural population is poor, agriculture production is seasonal, and most households lack insurance (1256 Scott, J. 2007)Increases in food prices, partially a result of climate events, contribute to poverty levels in urban and rural areas(1259 Anonymous);(Lobell *et al*., 2011). Lower fertility rates and gains in life expectancy contribute to an aging population in North America. In 2010, 20% of the population was 60 years and older in Canada, 18% in USA, and 9% in Mexico; however ageing in Mexico is projected to progress rapidly, so that 27% of the 2050 population would be elderly(1262 United Nations Department of Economic and Social Affairs, Population Division 2010). Studies show that the elderly population is more vulnerable to extreme weather events, heat waves in particular, and risk increases for those living alone(1214 Martiello, M.A. 2010); Newsome 2011(Diffenbaugh and Scherer, 2011; White-Newsome *et al*., 2011); (1144 Romero-Lankao, P. 2012). Expected increases of single-person households and female-headed households could also exacerbate population groups' vulnerability. Institutional capacity may be limited by challenges posed by population ageing and their stress on health and economic performance.

Education, another key determinant of adaptive capacity, is expected to expand to low-income households, minorities, and women; this could increase households' capacity to cope with environmental risks and could have a positive impact on economic growth (1261 Goujon, A. 2004). However, income disparities and poverty could hinder such improvements. Inequality in Mexico is larger, having a Gini index of 0.56, in contrast to 0.317 for Canada and 0.389 for USA(1264 OECD Volume 2010/2) . Limited economic growth expected in the short run for the region would not help to reduce the income gap across and within countries(1253 OECD 2010).

26.2.2. Physical Climate Trends

Summary of IPCC AR5 Assessment and CMIP5

Some processes important for climate change in North America are assessed in other Chapters of the AR5, including Chapter 2, Chapter 14 and Annex I of WGI, and Chapter 21 of WGII. Additional information is also available from the CMIP5 ensemble that is not included in Annex I of WGI.

Climate trends

Chapter 2 of WGI assesses observations of the climate system. It is noted that observations show increases in the occurrence of severe hot events over the U.S. over the late 20th century (922 Kunkel, K.E. 2008) WGI 2.7.1), a result in agreement with observed late-20th-century increases in extremely hot seasons over a region encompassing northern Mexico, the U.S. and parts of eastern Canada (Diffenbaugh and Scherer, 2011). These increases in hot extremes have been accompanied by observed decreases in frost days over much of North America (Alexander et al., 2006); (1149 Brown, P. J., R. S. Bradley, and F. T. Keimig 2010); WGI 2.7.1), decreases in cold spells over the U.S. (922 Kunkel, K.E. 2008) WGI 2.7.1), and increasing ratio of record high to low daily temperatures over the U.S. (Meehl, G. A., C. Tebaldi, G. Walton, D. Easterling, and L. McDaniel, 2009). However, mean cooling has occurred over central North America and the eastern USA (e.g., (Alexander et al., 2006); (922 Kunkel, K.E. 2008);; Peterson et al. 2008; WGI 2.7.1), associated primarily with changes in maximum temperatures (WGI 2.7.1). WGI notes that observations show increases in heavy precipitation over Mexico, the U.S. and Canada between the mid-20th century and the early 21st century(1151 Peterson, T.C. et al. 2009); (DeGaetano, 2009); WGI 2.7.2(Pryor, S. C., R. J. Barthelmie, D. T. Young, E. S. Takle, R. W. Arritt, D. Flory, W. J. Gutowski Jr., A. Nunes, and J. Roads, 2009)). Observational analyses of changes in drought are more difficult and equivocal over North America, with mixed sign of trend in dryness over Mexico, the U.S. and Canada (WGI 2.72 and Fig 2.42)(Dai, 2011). WGI notes evidence for earlier occurrence of peak flow in snow-dominated rivers globally ((1155 Rosenzweig, 2007); WGI 2.7.2). Observed snowpack and snow-dominated runoff have been extensively studied in the western U.S. and western Canada, with observations showing primarily negative trends in spring snowpack from 1960-2002 (with the most prominent exception being the central and southern Sierra Nevada) (Mote, 2006) and primarily earlier trends in the timing of peak runoff over the 1948-2000 period (Stewart *et al*., 2006). WGI also assess observed changes in extreme storms in North America, noting that observational limitations prohibit conclusions about trends in severe thunderstorms (WGI 2.7.2) and tropical cyclones (WGI 2.7.3). The most robust trends in extratropical cyclones over North America are determined to be towards more frequent and intense storms over the northern Canadian Arctic and towards less frequent and weaker storms over the southeastern and southwestern coasts of Canada over the 1953-2002 period (WGI 2.7.4);(Wang, X. L. L., V. R. Swail, and F. W. Zwiers, 2006).

Climate change projections

Chapter 14 of WGI assesses processes important for regional climate change, with section 14.3.3 focused on North America. Many of the WGI conclusions are drawn from the WGI Annex I Atlas.

The CMIP5 ensemble projects robust seasonal warming over North America, with the greatest warming in winter over the high latitudes (WGI Annex I and Figure 26-1)(Diffenbaugh and Giorgi, in review). The CMIP3 ensemble suggests that the response of warm-season temperatures to elevated radiative forcing is far more robust than the response of cold-season temperatures, and that the response of low-latitude areas of North America is more robust than the response of high-latitude areas (Diffenbaugh and Scherer, 2011). In addition, the CMIP3 ensemble and an ensemble of high-resolution climate model simulations also suggest that the signal-to-noise ratio of 21^{st} century warming is far greater over the western U.S., northern Mexico and the northeastern U.S. than over the central U.S. (Diffenbaugh, N.S, M. Ashfaq, and M. Scherer, 2011).

[INSERT FIGURE 26-1 HERE
Figure 26-1: Projected changes in the extremes of seasonal temperature, precipitation, snow accumulation and runoff. The panels show the percentage of years exceeding respective thresholds in the 2040-2069 period of the CMIP5 RCP8.5 realizations. The upper left panel shows the percentage of years in which the March accumulated snow amount falls below the 1976-2005 median value. The upper right panel shows the percentage of years in which the March-April-May (MAM) total surface runoff falls below the 1976-2005 minimum value. The lower left panel shows the percentage of years in which the June-July-August (JJA) surface air temperature falls above the 1976-2005 maximum value. The lower right panel shows the percentage of years in which the December-January-February (DJF) precipitation falls below the 1976-2005 minimum value. The top panels are from Diffenbaugh et al. (submitted to Nature Climate Change). The bottom panels are from Diffenbaugh and Giorgi (in review, Climatic Change Letters), with the field of view zoomed over the North American region.]

CMIP5-projects increases in seasonal precipitation over Canada and Alaska consistent with projections of poleward shift in the dominant cold-season stormtracks [add WGI section](Yin, 2005), extratropical cyclones (Trapp *et al*., 2009) and areas of moisture convergence (WG1 14.3.3), as well as with projections of shift towards positive North Atlantic Oscillation (NAO) trends (Hori, M. E., D. Nohara, and H. L. Tanaka, 2007);(Karpechko, 2010); (Zhu, Y. L., and H. J. Wang, 2010); WGI 14.3.3). CMIP5- also projects decreases in seasonal precipitation over the southwestern U.S. associated with the poleward shift in the dominant stormtracks and the expansion of subtropical arid regions (Seager, R., and G. Vecchi, 2010); WGI 14.3.3). However, there are uncertainties in hydroclimatic change in western North America associated with the response of the tropical Pacific sea surface temperatures (SSTs) to elevated radiative forcing (Cayan, D. R., K. T. Redmond, and L. G. Riddle, 1999);(Findell, K. L., and T. L. Delworth, 2010);(Seager, R., and G. Vecchi, 2010); WGI 14.3.3).

Mexico and the western U.S. emerge as prominent aggregate climate change hotspots, particularly in the late 21^{st} century period of RCP8.5, primarily as result of extreme seasonal heat, extreme seasonal dry conditions, and increases in interannual variability of seasonal precipitation (Diffenbaugh and Giorgi, in review). The CMIP5 models project substantial increases in the occurrence of extremely hot seasons in early, middle and late 21^{st} century periods of RCP8.5, including greater than 80% of summers exceeding the late 20^{th} century maximum during the 2070-2099 period (Diffenbaugh and Giorgi, in review). The CMIP5 ensemble also projects substantial decreases in surface snow amount over the U.S. and Canada, including greater than 80% (30%) of years with March snow amount below the late 20^{th} century median (minimum) over much of the western U.S. and western Canada beginning the middle 21st century period of RCP8.5 (Diffenbaugh *et al*., submitted). These decreases in spring snow amount are associated with substantial changes in the timing of total surface runoff, including greater than 30% of years above (below) the baseline winter (spring) runoff over the high elevation areas of the western U.S. and western Canada during the 2070-2099 period, greater than 50% of years below the summer maximum runoff over the high elevations of northwestern Canada, and greater than 30% of years above the baseline winter maximum runoff over most of central Canada during the 2070-2099 period (Diffenbaugh *et al*., submitted) .

26.3. Water Resources and Management

26.3.1. Current Conditions

Chapter 3 of the WG2 report summarizes the observed impacts of climate change on the hydrology of North America including detection and attribution and also presents projections of the future. This chapter assesses impacts upon water conditions and uses for human society. Considering long-term average conditions and water demands, water conditions are already stressed (meaning that withdrawals or consumption are too large a fraction of renewable supplies) in parts of North America. Water withdrawals for most of the Continental USA west of the Mississippi River are already exceeding stressful levels especially in the southwest (Lane *et al*., 1999). Essentially all of the Mexico north of and including Mexico City is highly water stressed with the Mexico City region itself very highly stressed (National Water Commission of Mexico, Statistics on Water in Mexico, 2010 Edition, June 2010. 2010). Depending upon the parameter monitored, 10 % to 30 % of the water quality monitoring sites in Mexico have polluted or heavily polluted water (National Water Commission of Mexico, Statistics on Water in Mexico, 2010 Edition, June 2010. 2010). In the USA, (1238 EPA, U.S. 2004) reported that about 44% of assessed stream miles, and 64% of assessed lake acres were not clean enough to support uses such as fishing and swimming.

26.3.1.1. Water Quality Impacts

Reduced flow conditions in rivers can result in a host of impacts on water quality due to temperature increases, increases in the concentrations of dissolved substances and changes in levels of dissolved oxygen ((1171 Daley, M.L. 2009)(Delpla *et al*., 2009.),(Benotti *et al*., 2010),(Novotny and Stefan, 2007)). Increased wildfires linked to a warming climate are expected to affect water quality downstream of forested headwater regions (Emelko *et al*., 2011)). Simulation of lakes under higher air temperatures (Tahoe, Great Lakes, shallow polymictic lakes, Lake Onondaga) resulted in increased phytoplankton, and fish and cyanobacteria biomass, lengthened stratification periods leading to increased risks of significant hypolimnetic oxygen deficits in late summer triggering solubilization of accumulated phosphorous and heavy metals and accelerated reaction rates, and decreases in lake clarity due to less settling of fine sediments (Dupuis and Hann, 2009.), (Trumpickas *et al*., 2009), (Sahoo *et al*., 2010), (Taner *et al*., 2011). Many found through simulation seasonal changes in nonpoint source loads due to climate change (Marshall and Randhir, 2008; Tu, 2009), but in some cases the total load staying the same (Praskievicz and Chang, 2011) in Oregon). (1176 Tu, J. 2009) (1178 Praskievicz, S. 2011),(Daley *et al*., 2009), (Tong *et al*., 2012), and (Wilson and Weng, 2011) all find that the joint impacts of climate change and development result in poorer water quality and, where investigated, climate change impacts are greater than land use changes.

Operators of drinking water treatment and distribution systems will be affected negatively by changes in physical-chemical-biological parameters and micropollutants (Delpla *et al*., 2009), (Emelko *et al*., 2011), (Trumpickas *et al*., 2009).

Increased rainfall will result in more wet weather inflow to wastewater treatment plants. Plants will be more vulnerable to flooding due to increased river and coastal flooding and higher sea levels will lead to reduced hydraulic capacities. There will be reduced treatment efficiency due to increases in inflow and infiltration (New York City Department of Environmental Protection. 2008. *the NYCDEP Climate Change Program,* DEP with Contributions by Columbia University Center for Climate Systems Research and HydroQual Environmental Engineers and Scientists, P.C., New York, NY, Http://www.Nyc.gov/dep, 2008), (King County Department of Natural Resources and Parks, 2008. Vulnerability of Major Wastewater Facilities to Flooding from Sea-Level Rise.

Seattle, Washington: King County (WA) Department of Natural Resources and Parks, Wastewater Treatment Division, 13p, 2008), (Flood and Cahoon, 2011)). Higher sea levels will also threaten the sewage collection systems themselves(105 Rosenzweig, C. 2007), (King County Department of Natural Resources and Parks, 2008. Vulnerability of Major Wastewater Facilities to Flooding from Sea-Level Rise. Seattle, Washington: King County (WA) Department of Natural Resources and Parks, Wastewater Treatment Division, 13p, 2008).

26.3.1.2. Water Supply

In the arid and semi-arid areas of western USA and Canada and most of Mexico except the southern tropical area, water supplies most likely will be further stressed by climate change. Impacts in Mexico would include reduced water availability, increased water demand, salt water intrusion, and increased groundwater and surface water pollution (Leal *et al*., 2008). This will most likely lead to overexploitation of groundwater even though the region already has many reservoirs(1193 Anonymous 2011). In the south central highland area of Mexico, dominated by metropolitan Mexico City and irrigation in the non-urban area, for scenarios A2 and A1B, it is projected that by mid-century there will be higher water stresses in all sectors due to decreased water availability, increased demand, and groundwater pollution (Leal *et al*., 2008), (1193 Anonymous 2011),(1181 Mendoza, V.M. 1997). The Colorado River Basin portion in Colorado is not only facing decreased flows but crop irrigation requirements for pasture grass in the area, which are currently 80% of irrigated water use, are projected to increase by 20% in 2040 and by 31 % in 2070 (AECOM, 2010). In the Rio Grande basin in New Mexico under the most severe climate change scenario of three runoff is projected to be reduced by nearly 30% by 2080. In general, ecosystems and irrigation are the most stressed as water is transferred to urban and industrial users with greater economic productivity. Economic losses under the most severe climate scenario are at least $100 million per year in 2080. Water transfers will likely entail significant transaction costs associated with adjudication and potential litigation. In addition, transferring water reduces ecological, environmental, social, and cultural attributes (Hurd and Coonrod, 2012). In Canada, approximately two-thirds of irrigated land is found in southern Alberta . This region is projected to experience declines in mean annual streamflow, with summer declines being especially significant (Shepherd *et al*., 2010.).

In other parts of the North American region, stresses due to climate change will most likely vary. Over the entire tropical southern region of Mexico, using the GFDLR-30, CCC and MTC models, no vulnerability of water reserves for these uses is projected for 2050(1181 Mendoza, V.M. 1997). By 2050, however, under greater precipitation projections the three GCMs show hydropower and water storage from 10 dams will likely become more vulnerable because the large amounts of excess water may cause floods that destroy the dams(1181 Mendoza, V.M. 1997). For Seattle, Everett, and Tacoma Washington, without adaptation to climate change, average seasonal drawdown of reservoir storage is projected to increase in all three systems throughout the 21st century. Reliability of all systems in the absence of demand increases, however, is robust through the 2020s and remains above 98% for Seattle, Everett and Tacoma in the 2040s and 2080s. With demand increases, reliability of the systems in their current configurations and with current operating policies progressively declines through the century(1108 Vano, J. 2010). Municipal utilities may face significant increases in water demand in what are now the spring and fall ‘shoulder months’ of demand

In the eastern USA, water supply systems will be impacted if streamflows and groundwater recharge lessen and snowpack storage is lost. In addition, systems will be further impacted by rising sea levels, increased storm intensities, salt water intrusion, increased low flows, land use and population changes and other non-climate related stresses (Obeysekera *et al*., 2011), (Sun, G., McNulty, S. G., Moore Myers, J. A., & Cohen, E. C., 2008).

26.3.1.3. Flooding

Increased flooding will likely damage sectors ranging from agriculture and livestock in southern tropical Mexico(1194 Anonymous 2010; 1193 Anonymous 2011), urban infrastructure in areas such as Dayton OH)(Wu, 2010) and metro Boston (Kirshen *et al*., 2006), and California water infrastructure, especially in the Bay-Delta region (1195 Anonymous 1995) . Without the development of additional flood management infrastructures, increased flooding due to climate change will be compounded, as it is now by, by urbanization (Hejazi and Markus, 2009), (Ntelekos *et al*., 2010a) estimate that annual riverine flood losses in the USA could increase from approximately $2 billion now to $7 billion to $19 billion annually by 2100 under business as usual conditions of growth and floodplain management in the USA and climate change.

Drainage infrastructure designed using mid-20th century rainfall records will be subject to a future rainfall regime that is greater than current design standards (Mailhot and Duchesne, 2010), (Kirshen *et al*., 2011).

26.3.1.4. Instream Uses

In the arid and semi-arid areas of Mexico, three GCMs models (GFDLR-30, CCCM and MTC) show hydropower will not be vulnerable to streamflow changes in 2050, due to water storage capacity inland. The desert areas show medium vulnerability for hydropower in 2050 because of low storage capacity (1181 Mendoza, V.M. 1997). By 2040 hydropower production in the US Pacific Northwest is projected to increase by approximately 5 % in winter and decrease by about 13% in summer, with annual reductions of about 2.5%. Larger decreases of 17.1% to 20.8% in summer hydropower production are projected for the 2080s(1125 Hamlet, A. 2010). Estimated impacts of climate change on the Peribonka River system in Quebec are that annual mean hydropower production would decrease by 1.8% for the period 2010-2039; in contrast, during the periods 2040-2069 and 2070-2099, there would be increases of 9.3% and 18.3%, respectively (Minville *et al*., 2009). The extent to which benefits such as these can be realized will depend strongly on other demands for water that may exist. For instance, hydropower production is only one among many water management objectives in British Columbia; others include flood control, recreation, and ecological goods and services (Hamlet, 2011). Navigation in the Great Lakes basin would be negatively affected by reduced lake levels, due to restrictions on vessel drafts, reductions in the cargoes that can be carried. This would result in an increase in the number of trips needed to transport the same amount of cargo.

26.3.2. Energy-Water Nexus

The energy demands for water supply and wastewater treatment are (California, 2005), (U.S. DEPARTMENT OF ENERGY, ENERGY DEMANDS ON WATER RESOURCES, REPORT TO CONGRESS ON THE INTERDEPENDENCY OF ENERGY AND WATER, DECEMBER 2006, 2006), (Carlson and Walburger, 2007), (U.S. EPA. 2008. Ensuring a Sustainable Future: An Energy Management Guidebook for Water and Wastewater Utilities. 113pp. 2008), NYSERDA, 2008,GAO, 2011, McMahon and Price, 2011) are projected to increase under climate change ((National Association of Clean Water Agencies and National Association of Metropolitan Water Agencies, 2009: Confronting Climate Change: An Early Analysis of Water and Wastewater Adaptation Costs, Prepared by CH2M Hill, Inc. 103 Pp.), 2009)). Conversely, cooling of USA thermoelectric power plants accounts for approximately 50% of the nation's water withdrawals (Kenny *et al*., 2009)). Some mitigation strategies for energy production such as carbon capture, nuclear power, and some biofuels will exacerbate stresses on water supplies and water quality (1223 Cooper, D.C. 2012), (1226 Delucchi, M.A. 2010), (Engelhaupt, 2007), (Powers *et al*., 2011), (Stone *et al*., 2010)). On the other hand, various carbon pricing policies may decrease thermoelectric power plant freshwater withdrawals and consumption in the continental USA compared to business as usual policies (Chandel *et al*., 2010)).

26.3.3. Adaptation Strategies

Urban water adaptation options include improved drought management plans, reduced water consumption, system interconnections, improved water quality, improved coordination with other organizations in the water supply watersheds, holistic management of storm water, flood waters, water supply, and wastewater management, incorporating climate change impacts into municipal bond ratings, security through diversity of supplies including development of local resources, expansion of regional storage including aquifer storage, including projected future changes in climate into masterplans and source protection, land use management, and better alignment of revenues with fixed and variable costs (Lempert and Groves, 2010), (Smith, 2009), (105 Rosenzweig, C. 2007), , (Novotny and Brown, 2007), (Zoltay *et al*., 2010), (Gleick, 2010), (Daigger, 2009), (de Loë, 2011), IMTA, 2010(IMTA, 2010, Efectos Del Cambio Climático En Los Recursos Hídricos De México, Volumen III. Atlas De Vulnerabilidad Hídrica En México Ante El Cambio Climático. Instituto Mexicano De Tecnología Del Agua, México. Available at Http://www.Atl.Org.mx/atlas-Vulnerabilidad-Hidrica-Cc/ , 2010),(1192 Leal Asencio, M.T. 2008). Based upon a survey of water managers in the mid-Atlantic USA, Dow et al (2007), however, found they are concerned about financial, regulatory, and management issues at least as much as water scarcity. (Flory and Panella, 1994) warn of the perils of demand hardening, where long-term water use conservation is so effective that extra water cannot be conserved during short-term droughts .

Irrigation can be adapted to reduced water availability by decreasing irrigation demands. A cooperative approach to accomplishing this during a drought took place in Alberta, Canada where water is apportioned under a “first-in-time, first-in-right” prior allocation system. In 2001, the parts of the Oldman River Basin faced a projected water supply of only 50% of the median annual flow. Rather than relying on the priority system to determine which users would receive water, a cooperative approach was brokered among license holders. As a result of this approach, considerable social and economic disruption was avoided. Importantly, farm production was not significantly reduced, largely because water use efficiency was increased. (1242 Anonymous 2008)recommends soil enhancement practices, greenhouses, efficient irrigation and a forestry focus on reforestation and conservation. Agriculture may also benefit from meteorological forecasting(1243 Anonymous 2008). Possible adaptations reported for some potential impacts due to biofuel production include improved farming practices and switching to less water consuming biofuel feedstocks (Engelhaupt, 2007), (Stone *et al.*, 2010).

One adaptation is to adjust water infrastructure over time as the climate changes. For example, the 540-foot high, 1300-foot long concrete Ross Dam in the state of Washington was built on a special foundation so it could be later raised in height. A distributed technology such as Low Impact Development storm management techniques can be added to a region as possible and necessary (Roseen *et al.*, 2011)

Some adaptations to the USA National Floodplain Insurance Program (NFIP) to lessen flood losses include: updating elevation and land use datasets every 10 years, improved hydrologic and hydraulic modeling, predicting extent of future floodplains as the climate changes and uncertainties decrease, eventually charging pre NFIP buildings full rates to decrease repetitive losses, and increasing enforcement of the NFIP. Others mentioned are European polices of “Making Room for Rivers”, low-impact development, and removal of buildings in flood-prone areas (Ntelekos *et al.*, 2010b).

Adaptation policies for decreasing thermoelectric power cooling water use include replacement of once-through cooling systems with recirculating systems, less water intensive carbon capture and storage systems, dry and hybrid cooling systems, and increased use of saline and waste water with increased costs for the necessary water treatment (reference to be added).

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Box 26-1. The Columbia River Basin: Transboundary Challenges in a Changing Climate

The Columbia is the fourth largest river of North America, in terms of flow. Most of the annual precipitation in the Basin falls as snow in the winter and is released in the spring as snow melt. Under climate change April 1st snow-water equivalent (SWE) is projected to increase going to 2050 but, to decline in the post-2050 period. For all the locations there are projected increases in the winter (DJFM) runoff in all future decades, which will affect management tradeoffs based upon runoff timing(1244 Elsner, M., 2010);(1125 Hamlet, A. 2010);(1245 Mote, P.W., 2010).

Water management in the basin operates in a complex institutional setting, involving two sovereign nations (the 1964 Columbia River Treaty, hereafter referred to as “the Treaty”), indigenous peoples with defined treaty rights, and numerous federal, state, provincial and local government agencies(1247 Bates, B.C. 2008). The Treaty obligated Canada to construct water storage dams in the Columbia River Basin in British Columbia, and called for the ongoing, coordinated operation of storage and hydroelectric projects in British Columbia and the US Pacific Northwest for the purposes of flood control and power generation. The original Treaty did not recognize protecting or improving habitat conditions for salmon and other fish and wildlife in the Columbia, or any other environmental benefits, as an equal purpose for system operations.

At present, planning and analysis are being undertaken by both the US and Canadian sides to meet a 2014 decision point on future coordinated management of the basin. Potential management paradoxes exist in that changing system management to be more responsive to flexible power system needs may be opposite to fish sustainability goals. On the other hand, so-called 'fish-first' rules would reduce firm power reliability by 10% under the present climate and by 17% in years during the warm phase of the Pacific Decadal Oscillation (PDO)(1249 Payne, J.T. 2004).

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26.4. Ecosystems and Biodiversity

Climatic changes are expected to affect North American ecosystems in manifold and interacting ways. Because many elements of species physiology are sensitive to climate variables (e.g., (Root, 1988); (Adams *et al.*, 2009)), changes in temperature, precipitation amount and timing/form, carbon dioxide concentrations, sea-level rise, and fire patterns can have differential effects across species and ecological communities (Parmesan, 2006)). Recent research has documented gradual changes in phenology (Root *et al.*, 2005)) and distributions in North American ecosystems (e.g., (Kelly and Goulden, 2008)). For example, shifts in plant, mammal, bird, lizard, and insect species' distributions in concert with 20th century temperature increases have been documented extensively in the western United States and eastern Mexico (Kelly and Goulden, 2008);(1229 Moritz, C. 2009); (Tingley *et al.*, 2009); (Parmesan, 2006);(Sinervo *et al.*, 2010). These gradual climate-induced shifts in species will probably interact with other environmental changes such as land-use change, hindering the ability of species to respond.

Different techniques have been used to assess the vulnerability of various North American ecosystems to changes in climate (e.g.,(Sala *et al.*, 2000);(Scholze *et al.*, 2006);(Loarie *et al.*, 2009). A risk analysis for ecosystems using coupled climate-vegetation models found >40% risk of substantial decreases in boreal forest ecosystems in Canada is estimated with >3 C global average warming (Scholze *et al.*, 2006)). The study assigned a high probability of increases in wildfires in the western U.S. (Scholze *et al.*, 2006). Due to topographic and projected climate differences, northwestern Mexico, central U.S., and central and northern Canada are estimated to experience some of the highest climate velocities – the rate at which climate isotherms move across the land per year (Loarie *et al.*, 2009). In particular for North American ecosystems, desert and xeric shrublands (0.71 km/yr), temperate grasslands (0.59 km/yr), and boreal forests (0.54 km/yr) are projected to experience the highest mean climate velocities between 2000 and 2100 (Loarie *et al.*, 2009).

In addition to gradual responses to climate variables, growing attention has been paid to the roles of extreme events and disturbance with a changing climate in North American ecosystems. Since the AR4, drought, wildfire, and insect infestation have emerged as major climate stressors to forests in the western United States and Canada (Westerling *et al.*, 2006); (838 Kurz, W.A. 2008);(Bentz *et al.*, 2010). Recent "climate change-type" droughts (Breshears, D. D., N.S. Cobb, P.M. Rich, K.P. Price, C.D. Allen, R.G. Balice, W.H. Romme, J.H. Kastens, M.L. Floyd, J. Belnap, J.J. Anderson, O.B. Myers, and C.W. Meyer, 2005)) and projected increases in drought severity in southwestern United States and northwestern Mexico (Seager *et al.*, 2007) suggest that these ecosystems may be increasingly vulnerable to rapid changes such as vegetation mortality (Adams *et al.*, 2009); (Williams *et al.*, 2010); (Overpeck and Udall, 2010)) and an increase of biological agents such as beetles, borers, pathogenic fungi, budworms and other pests (Worral, J. J., L. Egeland, T. Eager, E.R. Mask, E.W. Johnson, P.A. Kemp, and W.D. Shepperd, 2008); (Breshears, D. D., N.S. Cobb, P.M. Rich, K.P. Price, C.D. Allen, R.G. Balice, W.H. Romme, J.H. Kastens, M.L. Floyd, J. Belnap, J.J. Anderson, O.B. Myers, and C.W. Meyer, 2005);(Allen, C. D., A. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, P. Gonzales, T. Hogg, A. Rigling, and D.D. Breshears, 2010)).

Other extreme events such as floods and storm damage can also affect ecosystems in the eastern United States and Mexico (Chambers *et al.*, 2007). Nonetheless, North American forests were a net carbon sink between 1990-2007

(Pan *et al*., 2011) but new measurements suggest a reduction in the global net primary production of 0.55 petagrams of carbon due a large-scale droughts in the past decade (2000 to 2009)(1210 Zhao,Maosheng 2010).

We discuss below observed and projected impacts due to droughts, infestations, and wildfires as salient emerging ecosystem stressors. The prominence of these stressors has emerged since the AR4, and thus we review them in greater depth.

26.4.1. Tree Mortality and Forests Infestations

Across large areas of western North America, tree mortality has already increased, likely in response to the impacts of climatic warming and drought (van Mantgem *et al*., 2009)). Droughts of unusual severity, extent, and duration have affected large areas of southwestern North America, and resulted in regional-scale dieback of forests in the US (Breshears, D. D., N.S. Cobb, P.M. Rich, K.P. Price, C.D. Allen, R.G. Balice, W.H. Romme, J.H. Kastens, M.L. Floyd, J. Belnap, J.J. Anderson, O.B. Myers, and C.W. Meyer, 2005)). An estimated 10.3-18% of forests/woodlands in this region have experienced high levels of mortality between 1984-2006 due to wildfire, drought stress, or beetle attack (Williams *et al*., 2010)). Across the western US and Canada, trembling aspen (*Populus tremuloides)*, pinyon pine (*Pinus edulis)* and lodgepole pine *(Pinus contorta)* have experienced substantial die-off (Worral, J. J., L. Egeland, T. Eager, E.R. Mask, E.W. Johnson, P.A. Kemp, and W.D. Shepperd, 2008); (Anderegg *et al*., 2012); (Raffa *et al*., 2008)). Both the aspen and pinyon pine die-off have been related to extreme "climate change-type drought" events, in which severe drought is exacerbated by higher summertime temperatures (Breshears, D. D., N.S. Cobb, P.M. Rich, K.P. Price, C.D. Allen, R.G. Balice, W.H. Romme, J.H. Kastens, M.L. Floyd, J. Belnap, J.J. Anderson, O.B. Myers, and C.W. Meyer, 2005); (Anderegg *et al*., 2012). This indicates that even if drought intensity or severity does not increase, these systems will be vulnerable due to the temperature rise alone (Adams *et al*., 2009). Widespread forest-mortality events triggered by extreme climate events can alter ecosystem structure, function, and severely impact biodiversity (Allen, C. D., A. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, P. Gonzales, T. Hogg, A. Rigling, and D.D. Breshears, 2010); (Phillips, O. L., L. Aragao, S.L. Lewis, J.B. Fisher, J. Lloyd, G. Lopez-Gonzalez, Y. Malhi, A. Monteagudo, J. Peacock, and C.A. Quesada, 2009)).

Increases in the average mortality rate of 4.7% yr −1 between 1963 and 2008 were reported for Canada's boreal forests, with higher increases in the mortality rate in western regions than in eastern regions (about 4.9 versus 1.9% yr −1 , respectively) (Peng *et al*., 2011). Dieback of aspen was first observed in the early nineties (Hogg, E. H., J.P. Brandt, and B. Kochtubajda, 2002)). Aerial surveys and tree ring analysis suggest that the 2001–2003 droughts likely contributed to widespread mortality of aspen trees in western Saskatchewan and eastern Alberta (Williamson, T.B., S.J. Colombo, P.N. Duinker, P.A. Gray, R.J. Hennessey, D. Houle, M.H. Johnston, A.E. Ogden, and D.L. Spittlehouse, 2009);(Hogg, E. H. and P. Y. Bernier, 2005); (Hogg *et al*., 2008);(Michaelian, M., E.H. Hogg, R.J. Hall, and E. Arsenault, 2010)).

Since tropical forests are often organized along environmental gradients of precipitation, frequent droughts may change forest structure and distribution at the regional scale. For example, this would favor greater prevalence of deciduous species in the forests of Mexico (Figure 26-2) (Trejo, I., E. Martínez-Meyer, E. Calixto-Pérez, S. Sánchez-Colón, R. Vázquez de La Torre and L. Villers-Ruiz, 2011);(Drake, B.G., L. Hughes, E.A. Johnson, B.A. Seibel, M.A. Cochrane, V.J. Fabry, D. Rasse, and L. Hannah, 2005)). The decline of oak forests in the state of Guanajuato Mexico was associated with occurrences of extreme temperatures and severe droughts, making the trees vulnerable to infestation susceptible fungal pathogens (Vázquez Silva, L., J.C. Tamarit Urias, J. Quintanar Olguín, and L. Varela Fregoso, 2004).

[INSERT FIGURE 26-2 HERE
Figure 26-2: Climate-induced species migration in Mexico. Source: Trejo et al., 2011.]

Drought and warmer temperatures have allowed budworm and other insects to become epidemic in regions in which they are usually endemic (Drake, B.G., L. Hughes, E.A. Johnson, B.A. Seibel, M.A. Cochrane, V.J. Fabry, D. Rasse, and L. Hannah, 2005)). There is little rigorous evidence that insect-attacked forests are more susceptible to fire. However, increased extent and frequency of insect epidemics like spruce budworm, jack pine budworm and forest tent caterpillar may hasten the conversion of ecosystems in changing climates (Drake, B.G., L. Hughes, E.A. Johnson, B.A. Seibel, M.A. Cochrane, V.J. Fabry, D. Rasse, and L. Hannah, 2005)).

Recent outbreaks of Mountain Pine Bark Beetles (MPBB) in the Western Rockies of the USA have devastated the lodgepole pine forests from Alaska down to Colorado (838 Kurz, W.A. 2008). In addition, outbreaks have emerged in the high elevation areas of the Rockies in the white bark pine systems and have resulted in massive die-offs of these highly vulnerable species. The climate controls on over-wintering populations of the mountain pine bark beetle have been overcome by recent warmer winters allowing a greater number of larvae to survive(855 Bentz, B.J. 2010) (see Box 26-2).

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Box 26-2. Mountain Pine Beetles

The influences of climate change on ecosystem disturbance, such as insect outbreaks have become increasingly salient and suggest that these disturbances could have a major influence on North American ecosystems and economy in a changing climate. Warm winters in Western Canada and U.S. have allowed the larvae of mountain pine beetle to overwinter, causing the "largest and most severe [outbreak] in history" from Alaska to Colorado (Bentz, 2008), with massive die-offs in some regions. An estimated 18,177 km2 of U.S. forests is affected (Williams *et al*., 2010). British Columbia, Canada had the largest impact (Figure 26-3;(854 Brown, M. 2010), with mortality in over 7 million hectares (Aukema *et al*., 2006)). The extent and severity of this outbreak is attributed to climate change (838 Kurz, W.A. 2008), and further expansion is projected into higher latitudes and elevations (Bentz *et al*., 2010)). Such outbreaks can convert forests into carbon sources (Kurz *et al*., 2008a; Kurz *et al*., 2008b).

[INSERT FIGURE 26-3 HERE
Figure 26-3: Geographic extent of mountain pine beetle outbreak in North America. Source: Kurz et al., 2008.]

Predicted climate warming is expected to have profound effects on bark beetle population dynamics in the southwestern United States and Northern part of Mexico (478 Waring, K. M., D.M. Reboletti, L.A. Mork, Ch. Huang, R.W. Hofstetter, A.M. Garcia, P.Z. Fulé, and T.S. Davis 2009). Temperature-mediated effects may include increases in developmental rates, generations per year, and changes in habitat suitability. As a result, the impacts of *Dendroctonus frontalis* and *Dendroctonus mexicanus* on forest resources are likely subject to amplification (Waring, K. M., D.M. Reboletti, L.A. Mork, Ch. Huang, R.W. Hofstetter, A.M. Garcia, P.Z. Fulé, and T.S. Davis, 2009).

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26.4.2. Coastal Zones

The rate of sea level rise in North America has increased significantly during the 20th century. The increase in the absolute rate of sea level rise of 3 mm per year as observed in North Carolina is comparable with findings from other studies performed along the Atlantic coast (Leonard, L., J. Dorton, S. Culver, and R. Christian, 2009);(Kemp, A., B.P. Horton, S.J. Culver, D.R. Corbett, O. Van De Plassche, and R. Edwards, 2008)). Studies in Mexico show different values of sea level rise, depending on the site monitored: the highest value for the Gulf of Mexico has been observed in Cd. Madero, Tamaulipas (9.2mm per year), while that for the Pacific was observed in Guaymas, Sonora (4.2mm per year). Furthermore, the trend continues clearly to be that of an increasing rate of sea level rise (Zavala-Hidalgo, J., R. de Buen, R. Romero-Centeno, and F. Hernández, 2010), see section 26.10).

Highly productive estuaries, wetlands and mangroves occur across the East and West coasts of North America. The high diversity of flora and fauna that characterize these fragile ecosystems are vulnerable to extreme events such as the increase in hurricanes, marine temperature increases, and sea level rise. Sea level rise will result in the loss of coastal wetlands in many areas of North America due to erosion, flooding and saltwater intrusion. The combined forces of both sea level rise and other risks such as storm surge are of particular concern.

It is estimated that 1m rise in sea level by 2100 would, with no defensive measures taken, inundate approximately 9% of coastal areas along the Gulf and southern Atlantic coasts located at or below 6 m (Weiss and Overpeck J.T. and Strauss, B., 2011). Using a variety of national level data bases, (522 Weiss, J.L., J.T. Overpeck, and B. Strauss. 2011) estimate the areas more exposed to SLR are located in the south Atlantic and Gulf Coast states. Relatively the west coast is generally less exposed.

The U.S. coastal regions expected to be most vulnerable to sea level rise are concentrated along the Atlantic coast and the Gulf coast, including the coastlines of Florida, Louisiana, North Carolina, and Texas. Louisiana is projected to experience the greatest loss of wetlands due to rising sea level (Leonard, L., J. Dorton, S. Culver, and R. Christian, 2009), (Kemp, A., B.P. Horton, S.J. Culver, D.R. Corbett, O. Van De Plassche, and R. Edwards, 2008)). Rising sea levels are projected to change the flood level of mangroves and wetlands and to reduce the level of tolerance and recovery capacity of many plants. A loss of 20 to 94% is projected for these areas in the Gulf and Pacific coast of Mexico depending on dominant topography (Flores Verdugo, F.J., P. Moreno-Casasola, G. De La Lanza-Espino, and C. Agraz Hernández, 2010). Sea level rise has been suggested to cause beach erosion by reducing the distribution of plants in Galveston Island, Texas (Feagin, R.A., D.J. Sherman, and W.E. Grant, 2005).

Ecological effects of tropical storms and hurricanes indicate that storm timing, frequency, and intensity can alter coastal wetland hydrology, geomorphology, biotic structure, energetic, and nutrient cycling. The increase in the frequency of high intensity hurricanes will directly affect the mangroves over a period of at least25 years and completely change their structure and age (Kovacs, J. M., J. Malczewski, and F. Flores-Verdugo, 2004).

Elevated temperatures have been cited as the cause for the increase in bleaching events and direct effects of acidity and temperature severely threaten coral reefs and other marine ecosystems (Doney, S.C., V.J. Fabry, R.A. Feely, and J.A. Kleypas, 2009); (Hernández, L., H. Reyes-Bonilla, and E.F. Balart, 2010); (Mumby, P.J., I.A. Elliott, C.M. Eakin, W. Skirving, C.B. Paris, H.J. Edwards, S. Enríquez, R. Iglesias-Prieto, L.M. Cherubin, and J.R. Stevens, 2011)). Important coral reefs in terms of beauty and biological diversity, both in the Pacific, the Gulf of California, and the Atlantic Mesoamerica can be affected by sea warming. However, tropical corals are subject to many other stressors in the North Atlantic, including increased nutrient input from coastal development and the indirect effects of overfishing. The growing incidence of coral diseases, as well as disease prevalence and rate of spread on coral colonies, is attributed to increases in pathogen prevalence and virulence associated with global warming and low water quality (ICES (The International Council for the Exploration of the Sea), 2011)).

Bleaching will be exacerbated by the effects of degraded water-quality and increased severe weather events. In addition, the progressive onset of ocean acidification will cause reduction of coral growth and retardation of the growth of high magnesium calcite-secreting coralline algae. If CO_2 levels are allowed to reach 450 ppm (due to occur by 2030–2040 at the current rates), reefs are projected to be in rapid and terminal decline world-wide from multiple synergies arising from mass bleaching, ocean acidification, and other environmental impacts. Damage to shallow reef communities will likely become extensive with consequent reduction of biodiversity followed by Extinctions (Veron, J.E.N., O. Hoegh-Guldberg, T.M. Lenton, J.M. Lough, D.O. Obura, P. Pearce-Kelly, C.R.C. Sheppard, M. Spalding, M.G. Stafford-Smith, and A.D. Rogers, 2009)).

26.4.3. Adaptation and Mitigation Strategies

Both the relatively rapid rate of climate changes and the degraded and fragmented state of many forest ecosystems reduce the capacity of the species and ecosystems to adapt or to be resilient (Magrin, G., Gay, C. with Cruz Choque, D. Jiménez, J.C. Moreno, A.R. Nagy, G., Nobre, C. Villamizar, A., 2007), (Noss, 2001)). The capacity of forests to resist change depends on biodiversity at multiple scales. Increasing forest biodiversity in planted and semi-natural forests will have a positive effect on resilience and often on productivity (including carbon storage); >80% of the studies reviewed supported this concept(1212 Thompson, I.D. 2010).

Forest biodiversity is the key to reduce forest infestations and some Canadian adaptation options are to increase plant community composition and biological diversity(1230 Johnston, M., T. Williamson, A. Munson, A.Ogden, M. Moroni, R. Parsons, D. Price, and J. Stadt 2010). Efforts have been made in breeding programs for resistance to diseases and insect pests that have had significant local impacts; however, the successes are largely for a few of the main commercial programs which have had substantial resources and structures in place to deliver the gain (Yanchuk, A. and G. Allard, 2009).

Improving climate resilience and adaptation will require changes in the approach to protected area planning, establishment and management. Adaptation research suggests that improving climate resilience and adaptation in protected areas will be much more difficult and, in some cases, not sufficient if global temperature rise exceeds 2ºC above preindustrial levels. *(Mansourian and A. Belokurov and P.J. Stephenson, 2009)*.

Forest tree species might need human help to cope with changes that exceed their natural capacity of adaptation. Human-assisted migration has been proposed as a potential management option to maintain optimal health and productivity of forests; in order to maximize adaptation to climate change (1211 Keel, B. G. 2007) (1237 Winder, R., Nelson E. A., and Beardmore, T. 2011).

Probably one of the more notable short-term changes in the policy arena is the discussion of GHG emissions reduction through CDM and REDD+ and management, conservation and restoration of forest carbon stocks. Mitigation through forestry, however, must also be cognizant of the manifold ways through which forests influence the climate both biogeochemically (e.g. carbon sequestration) and biophysically (e.g. albedo and roughness)(891 Anderson, R. G. 2011)

For the forest manager much of the challenge lies in adjusting management practices in favor of carbon accumulation, while at the same time maintaining biodiversity, recognizing the rights of indigenous people and contributing to local economic development(1231 FAO 2012)

26.5. Wildfires

26.5.1. Observed Trends

Wildfires have increased in the region recently. Since 2000, the annual acres burned in the U.S. have more than doubled, to 7.0 million (www.nifc.gov). The Western U.S. in particular has experienced a six-fold increase in forest area burned since 1986, and the average duration has increased from 7.5 to 37.1 days (Westerling *et al*., 2006). 11 of the 20 largest fires on record in California occurred in the past decade (CDFFP, 2010). Historic patterns of fire occurrence in Western Canada have likewise increased significantly ((Williamson, T.B., S.J. Colombo, P.N. Duinker, P.A. Gray, R.J. Hennessey, D. Houle, M.H. Johnston, A.E. Ogden, and D.L. Spittlehouse, 2009)): while the average area burned between 1920 and 1979 was 1.5 million hectares, this figure has exceeded 5 million hectares several times since (Peter *et al*., 2006)).The Northwestern US and southwestern Canada, previously largely free of fires, have experienced recent fire events (Westerling *et al*., 2006); (Kitzberger *et al*., 2007); (McKenzie *et al*., 2004). In Mexico between 1999 and 2009 216 thousand hectares per year were lost in wildfires, but the worst year in the recent history was 2011, were 954 727 hectares were lost exceeding the area burned in 1998 (CONAFOR (National Forestry Comission), 2011))

Non-Climate-Related Contributing Factors

Drought conditions are strongly associated with wildfire occurrence, as they increase dead fine fuels, and thus promote the incidence of firebrands and spot fires (Keeley, J. E. and P. H. Zedler, 2009). During the 2002 drought in Alberta, the area burned was 5 times larger than average (Kulshreshtha, 2011). Historical fire records dating back 100 years indicate that large burned areas in mixed-conifer forests in Yellowstone National Park and drier central Idaho ponderosa pine forests coincide with drought intervals (Pierce, J. and G. Meyer, 2008). In southern California and Baja California Mexico, large conflagrations are usually associated with wind events that follow the long spring and summer droughts (Keeley, 2004); (Holden *et al*., 2007). Phases (positive or negative) of ocean-atmosphere oscillations like the El Niño-Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO) and the Atlantic Multidecadal oscillation (AMO) contribute to drought conditions, sometimes for decades or more (Kitzberger *et al*., 2007); (Collins *et al*., 2006); (Heyerdahl, E. K., D. McKenzie, L. D. Daniels, A. E. Hessl, J. S. Littell, N. J. Mantua., 2008); (Brown *et al*., 2008). In Mexico, ENSO events have led to uncontrolled wildfires and increases in area burned, mainly in the northwest and central-northern part of the country (Villers-Ruíz, L., y Hernández-Lozano, J., 2007)). . Southern and western Canada, Alaska and Mexico have all experienced a trend toward drier conditions since the 1950s (922 Kunkel, K.E. 2008). Increased drought conditions are projected for a large proportion of the Western interior, Florida, and Mexico by 2100.

Human behavior also contributes to wildfire activity. Increased human presence in fire-prone regions undoubtedly increases the probability of ignitions (Keeley, 2004); (CONAFOR (National Forestry Comission), 2011), and in Mexico in particular, the agricultural practice of burning stubble in the dry season near forests is a primary cause of ignition (CONAFOR (National Forestry Comission), 2011). Land management, such as grazing or fire suppression, also interacts strongly with wildfire probability. Land management changes in species composition and the concentration and arrangement of flammable fuels may alter the fire regime (Bond, W. J. and J. E. Keeley, 2005). Recent stand-replacing fires in ponderosa pine forests in US are attributed to changes in forest management, in combination with increasing temperatures and drought severity during the 20th century (Pierce, J. and G. Meyer, 2008). Fire suppression practices in fire-prone ecosystems can significantly enhance the risk of large fires. In mixed conifer forests, for example, which are associated with a natural cycle of small and non-crown fire regimes, fire suppression could increase the likelihood of massive crown-fires. Since the late 1800s, fire suppression, combined with ecological and climatic changes has greatly reduced fire frequency, amounting to a forest “fire deficit” in the western United States (1266 Marlon, J.R. 2012). While recent large fire events have begun to address the fire deficit, it is continuing to grow (1266 Marlon, J.R. 2012).

Since the late 1800s, combined effects of historical fires suppression, ecological, and climate changes caused a large decline in burning. Consequently, there is now a forest “fire deficit” in the western United States(1266 Marlon, J.R. 2012). While large fires in the late 20th and early 21st century have begun to address the fire deficit, it is continuing to grow (1266 Marlon, J.R. 2012).

26.5.2. Association with Climate Change

Future temperature and precipitation scenarios forecast not only increases in the frequency and intensity of drought conditions, thereby enhancing wildfire risk, but also longer and drier summers, drier winters, and warmer springs with earlier and more rapid snow melt in many parts of western North America, which are similarly linked to wildfire occurrence (Westerling *et al*., 2006); (McKenzie *et al*., 2004); (Flannigan *et al*., 2005). The area burned in the North American boreal forest has been linked to the dynamics of large-scale climatic patterns (Macias Fauria, M. and E. A. Johnson, 2006; Macias Fauria, M. and E. A. Johnson, 2008), (Skinner, W.R., E. Shabbar, M.D. Flannigan, and K. Logan, 2006)). Climate effects on forests and wildfire risk are not uniform, however. Complex interactions among topography, altitude, forest composition, suppression history, forest health, and pest infestation all influence wildfire likelihood and severity (Romme *et al*., 2006); (Schoennagel *et al*., 2004); (Sherriff and Veblen, 2008).

26.5.2.1. Ecological Impacts

While fire plays a beneficial ecological role in many forest types, significant increases in their frequency and intensity, particularly in stands that have been subject to fire suppression, can alter the composition of those ecosystems. Increasing wildfire frequency can lead to changes in dominant vegetation types or changed community structure (Gedalof *et al*., 2005). The introduction of fire into non-fire-prone forest types such as tropical forests can have a devastating impact on those ecosystems (CONANP and TNC, 2009)). Mediterranean-type vegetation has been identified as the system most vulnerable to wildfires (Fischlin, A., G.F. Midgley, J.T. Price, R. Leemans, B. Gopal, C. Turley, M.D.A. Rounsevell, O.P. Dube, J. Tarazona, A.A. Velichko, 2007).

26.5.2.2. Socioeconomic Impacts

While healthy forest ecosystems provide carbon sequestration that benefits climate change mitigation, forests affected by pests and fires do not, and wildfires themselves are a source of emissions. Furthermore, fires pose a direct threat to the property, health, and lives of people. Response expenditures increase accordingly: fire management costs for the 2003 Canadian fire season approached $1 billion (ibid.). In an analysis of fires in Montana from 1985-2007, Gude *et al.* (forthcoming) determined that a 1ºC increase in average Spring and Summer temperature is associated with a 305% increase in area burned and 107% increase in property protection costs.

Concurrently, population growth in the southwestern U.S., including housing development in the wildland-urban interface (WUI)—where structures intermingle with wildland vegetation (Gude *et al.*, 2008); (Hammer *et al.*, 2009); (Peter *et al.*, 2006);(Radeloff *et al.*, 2005); (Theobald and Romme, 2007)—has increased human exposure. Large financial losses have occurred despite record expenditures on fire suppression, a majority of which is directed at protecting property (USDA, 2006). Financial loss is not the only cost, the impacts to families and communities can be significant. The record-breaking 2004 fire season in Alaska directly threatened 20 communities (Trainor *et al.*, 2009). In Slave Lake, Alberta in 2011, a 4,700-hectare fire precipitated evacuation of the entire population of 6,700; one-third of the homes and businesses were destroyed, and $400 million of the total $700 million in losses were uninsured (CBC, 2011).

Wildfires pose direct health threats as well. To date, only a few dozen studies have been conducted on the health effects of wildfires, prescribed burns, and peat bog fires (Weinhold, 2011). According to the EM-DAT disaster database, over the last 30 years 155 people were killed in wildfires across North America: 103 in the United States, 50 in Mexico and 2 in Canada (CRED, 2012) Direct effects include injury and respiratory effects from smoke inhalation, with firefighters at increased risk (1267 Reisen, F. 2009; 1268 Reisen, F. 2011); (Naeher *et al.*, 2007). Adverse mental health outcomes are also a concern for fire victims (1269 Marshall, G. 2007); (Laugharne *et al.*, 2011)). At the population level, however, the indirect effects of wildfire become increasingly important, and a particular concern is the impact of wildfire smoke on respiratory diseases. Wildfire smoke contains high concentrations of particles and gases, including a number of products known to adversely affect human health (Naeher *et al.*, 2007);(Stefanidou *et al.*, 2008); (Wittig *et al.*, 2008)); (Delfino *et al.*, 2009); (Wegesser *et al.*, 2009). Epidemiological studies in N. America have consistently found associations between wildfire PM and respiratory distress, particularly among asthmatics and sufferers of chronic diseases such as COPD (Delfino *et al.*, 2009); (1270 Künzli, N. 2006) ; (Vora *et al.*, 2011); (Henderson *et al.*, 2011)). Cardiovascular outcomes associated with wildfire smoke have been less well defined, but a recent study of hospital admissions following a 2008 peat bog fire in North Carolina reported a significantly elevated risk of emergency department visits for cardiopulmonary symptoms and heart failure during the event (Rappold *et al.*, 2011)). Based on this evidence, it is possible to conclude with high confidence that, conditional on changing wildfire regimes under future climate, health impacts at the individual and population level of the sort observed historically would be expected to change accordingly.

26.5.3. Adaptation Strategies

Further research on the relationships between climate and wildfire and attention to the variable impacts of population growth, land-use planning, elevation, and forest structure is important to adaptation planning. Prescribed fire may be an important tool for managing fire risk in Canada and US (Hurteau and North, 2010);(1012 Hurteau, M.D. 2011); (Wiedinmyer and Hurteau, 2010). Managers in the U.S. have encouraged reduction of flammable vegetation around structures with some success (Stewart *et al.*, 2006). Physical aspects that influence likelihood of fire-related losses (housing density, type, building materials, etc.) can be altered in development planning (Cohen, 2000).

Such efforts, however, depend largely on the socio-economic capacity of communities at risk, the extent of resource dependence, community composition, and the risk perceptions, attitudes and beliefs of decision-makers, private property owners, and the public (Brenkert-Smith, 2010); (Collins and Bolin, 2009); (Martin *et al.*, 2009); (McFarlane, 2006); (Repetto, 2008); (Trainor *et al.*, 2009). Forest management also requires stakeholder involvement and investment. The provision of adequate information on smoke, managed fire/fire-use, pest management, and forest thinning is crucial, as is building trust between stakeholders and land managers (Chang *et al*., 2009); (Dombeck *et al*., 2004); (Flint *et al*., 2008). Adaptation also requires institutional shifts in forest management from reliance on historical records toward incorporation of climate forecasting (Kolden and Brown, 2010); (McKenzie *et al*., 2004); (Millar *et al*., 2007).

26.6. Food Security

Climate change is projected to cause food price increases and declines in caloric availability globally (Nelson *et al*., 2009). Diversion of production into biofuels can also affect supply and price (Searchinger *et al*., 2008); (Liverman and Kapadia, 2010); (Valero-Gil and Valero, 2008). Canada and the U.S. are relatively food secure, although there are significant disparities. Households living in poverty and unengaged in food production are the most vulnerable. Mexico has high levels of food insecurity, where food constitutes a much higher proportion of household budget on average (Figure 26-4; (Juarez and Gonzalez, 2010). Indigenous peoples reliant on subsistence foods with high cultural relevance are also especially sensitive. Because North America is a major food exporter, shifts in productivity here have direct implications for global food security. The U.S. and Canada are the world's first and third largest exporters of wheat (*FAOstat exports: Countries by commodity, wheat* 2009), the second largest global human food crop. The U.S. also produces 41% and 38% of the global corn and soy crop, respectively (Schlenker and Roberts, 2009).

[INSERT FIGURE 26-4 HERE
Figure 26-4: Household Budget Share of Food Comparison. Compiled by Gerardo Otero, Simon Fraser University.]

26.6.1. Observed and Projected Impacts

Attempts to attribute observed changes in productivity to anthropogenic climate change remain inconclusive (Lobell *et al*., 2011), Figure 26-5), but several studies highlight the climate sensitivity of productivity, attributing increases in yield in Canada and the U.S. since 1960 in part to warmer temperatures and high precipitation (Sakurai *et al*., 2011); (Nadler and Bullock, 2011); (Pearson *et al*., 2008). In contrast, observed impacts include a reduction in land area suitable for corn in Mexico (Rivas *et al*., 2011); (Buechler, 2009). The impact of drought on agriculture is well-known. Drought-related losses borne by California's agriculture sector in 2008 alone reached $308 billion (CDFA 2009). Aridity also promotes soil salinity, currently costing Western U.S. agriculture $2.5 billion per year (Sabo et al 2010, cited in (MacDonald, 2010). Shifts in the timing of water availability also affect productivity. (Stewart *et al*., 2005) attribute shifts earlier by 1-4 weeks in the timing of snowmelt stream flow from 1948-2002 across Western North America to temperature increase. Climate also affects product quality for several commodities, including coffee (Lin, 2007), wine grapes (Jones *et al*., 2005); (Hayhoe *et al*., 2004), wheat (Porter and Semenov, 2005), fruits and nuts (Lobell *et al*., 2006); and cattle forage (Craine *et al*., 2010).

[INSERT FIGURE 26-5 HERE
Figure 26-5: Nonlinear relation between temperature and yields. Source: Schlenker and Roberts, 2009.]

Many future projections of U.S. and Canadian agriculture anticipate productivity gains (Costello *et al*., 2009); (Hatfield *et al*., 2008); (Pearson *et al*., 2008). Warming trends and a decrease in frost risk may enhance the yields of some crops in Western Canada (Wheaton *et al*., 2010), and longer and warmer growing seasons allow for expansion of warm season crops or introduction of new crops (Nadler and Bullock, 2011).

Other recent studies express higher levels of caution and more attention to variability and extremes. Using historic data, (Schlenker and Roberts, 2009) determine that yield increases for corn and soy occur up to 29ºC and 30ºC; after which yields decline steeply, resulting in projected declines, without adaptation, of between 30-46% (B1) and 63-82% (A1F1) before 2100 (HAD3). Declining snow pack, new pests and diseases, hotter days during flowering, more intense precipitation, and lack of soil moisture are all noted threats to Canadian yields (Kulshreshtha, 2011). (1271 Jackson, L. 2009) warn of new agricultural pests and diseases in California. The Midwestern U.S. is also projected to face increased risk of invasive weeds and insects, and fruit and dairy productivity will likely decline with higher temperatures (Wolfe *et al*., 2008). Rain-fed corn yields in Iowa are estimated to decline 23%–34% by 2055, on the basis of a downscaled scenario derived from 18 GCMs (Cai *et al*., 2009)). (Chhetri *et al*., 2010) forecast declines in corn productivity in southeastern U.S., even accounting for adaptation (RegCM2). (Monterroso Rivas *et al*., 2011) anticipate a decrease in the spatial extent of land suitable for rain-fed corn production from 6.2% currently to between 3% (UKHadley B2) and 4.3% (ECHAM5/MPI A2) by 2050, and an increase in land classified as of limited suitability from 31.6 % currently to between 33.4% (ECHAM5/MPI A2) and 43.8% (GFDL-CM2.0 A2). The temperature-humidity index for livestock in Veracruz is expected to reach the dangerous zone by 2020, in both A2 and B2 scenarios and across three GCMs (Hernandez *et al*., 2011).

While disagreement regarding the effects of increased CO_2 on productivity persists (e.g.,(835 Long, S.P. 2006), recent studies note that elevated CO_2 can result in reduced nitrogen and protein content in grains (Karl *et al*., 2009), reduced forage quality, and declining efficacy of herbicides (United States Global Change Research Program (USGCRP), 2009).

Moisture deficits are likely to negate forecasted warming-induced increases in productivity (Pearson *et al*., 2008); (867 Vano, J.A. 2010). Declines in water availability are projected for U.S. Western/Southwestern regions (United States Global Change Research Program (USGCRP), 2009). (Esqueda *et al*., 2010)projects significant declines in water availability for Mexican agriculture, using A2 and B2 scenarios and three different GCMs.

Extreme events will affect agricultural yields and production costs (Chen and McCarl, 2009); (Kulshreshtha, 2011). According to the SREX, global increases in frequency and magnitude of warm daily temperature extremes and decreases in cold extremes are virtually certain in 21st Century. Increases in length, frequency and/or intensity of heat waves are very likely for most regions, and a 1-in-20 year hottest day is likely to become a 1-in-2 year event (A1b and A2 scenarios), or 1-in-5 (B1 scenario).

26.6.2. Vulnerability

1.9% of Americans and 2.8% of Canadians are employed in agriculture, compared to 25% of Mexicans(892 Saldaña-Zorrilla, S.O. 2006) .While the agricultural sectors in Canada and the U.S. are largely commercial, the Mexican farming population is comprised of a small number of commercial and medium-sized producers, and a large number of subsistence farmers (2.1 million), and agricultural workers (3.3 million) (Claridades Agropecuarias 2006).

The climate vulnerability of farming households is complex. For example, productivity declines induce higher commodity prices that increase food insecurity, but benefit farmers producing those crops (Hertel *et al*., 2010)). Larger farms have more capital and credit but face the highest potential declines in asset value. High capital investments in certain technological improvements or commodities enhance productivity but limit opportunities for future innovation. Extreme weather is likely to be the climate impact to which farmers are most sensitive (Belliveau *et al*., 2006); (Reid *et al*., 2007)); successive extreme events can quickly surpass coping thresholds (Endfield and Tejedo, 2006). Key forms of social sensitivity include financial loss, inequitable distribution of impacts, multiple stressors, and social conflict.

Climate change impacts are very likely to impose increased input costs and/or income and asset losses, resulting from, for example, pest and disease outbreaks (925 Kiely, T. 2005) and lost efficacy of weed control practices (e.g. (860 Wolfe, D.W. 2008)(Hatfield *et al*., 2008)). Using a Ricardian analysis, (Mendelsohn *et al*., 2010) estimated that by 2100 agricultural land values in Mexico would decline 42-54% (range reflecting three models: PCM, MIMR, HADCM3). Farm values and water availability are also strongly correlated (Schlenker *et al*., 2007)). In Mexico, 80% of weather-related financial losses over the past 20 years were borne by the agricultural sector (890 Saldaña-Zorrilla, S.O. 2008).

Vulnerability is related to degree of dependence on farm income (Eakin and Appendini, 2008); (Eakin and Bojorquez-Tapia, 2008), and extant levels of poverty. The North American agricultural sector exemplifies the high degree of socio-economic disparity characterizing this continent, translating into highly differentiated vulnerability.

20% of Mexicans live in extreme poverty, and the livelihood of 72% of these is in farming ((890 Saldaña-Zorrilla, S.O. 2008), and these are concentrated in the South (Araujo *et al*. 2002). Most subsistence farmers in Mexico have land bases so small that production options are limited. (Eakin, 2005) found that farmers plant maize for food security despite the climate sensitivty of this crop. Small Mexican farmers face limited access to credit and insurance (Saldaña-Zorilla and Sandberg, 2009); (951 Eakin, H. 2006); (Wehbe *et al*., 2008).

(Feng *et al*., 2010) estimated the emigration of an additional 1.4 to 6.7 million Mexicans by 2080 due to climate-induced declines in agricultural productivity. Lack of capital has been the key inducement for migration in response to historic droughts (Gilbert and McLeman, 2010); (Fraser, 2007). However, Mexican outmigration from regions experiencing recurrent disasters outpaces outmigration from regions with lower socio-economic status (892 Saldaña-Zorrilla, S.O. 2006).

Farming households face multiple sources of non-climatic stress that interact with climate vulnerability (Coles and Scott, 2009); Eakin 2006; (Eakin and Wehbe, 2009). Involvement in export markets expose producers to increased economic volatility (1272 Eakin, H. 2003) ; (951 Eakin, H. 2006); (Saldaña-Zorilla and Sandberg, 2009). Mexican farmers have experienced a 60% net drop in maize prices since 1980 through at least the middle of the 2000's, due primarily to trade liberalization (892 Saldaña-Zorrilla, S.O. 2006).

Social conflict may emerge when and where water supply is reduced (United States Global Change Research Program (USGCRP), 2009); (836 Lal, P. 2011)), as access by junior rights holders will be likely be withheld first (1108 Vano, J. 2010; 867 Vano, J.A. 2010). The combined demands of rapid population growth and agricultural water demand in the Southwest U.S. are likely to conflict with projected water supply declines (MacDonald, 2010). The migration of Mexican farmers into cities in Mexico and the U.S. has the potential to induce conflict, particularly when opportunities for employment in cities are limited, and if farm employment in the U.S. declines due to climate impacts on productivity (889 Saldaña-Zorrilla, S.O. 2009).

26.6.3. Adaptation and Adaptive Capacity

Multiple adaptation options exist for North American agriculture (Belliveau *et al*., 2006). Planting varieties better suited to future climate conditions has potential in many areas (Bootsma *et al*., 2005); (Coles and Scott, 2009; Eakin and Appendini, 2008)). Economic and crop diversification have mediated the impacts of climate and market shocks in northeastern Mexico (Eakin and Appendini, 2008; Eakin and Bojorquez-Tapia, 2008).

High social capital enhances adaptive capacity (Wittrock and Kulshreshtha, 2011), particularly stronger ties among producers (Chiffoleau, 2009). Price increases due to climate-induced yield declines may motivate investment (Li *et al*., 2011). A high proportion of farming families in all three countries derive some off-farm household income as an important supplement to household income.

Adaptation barriers are multiple, however, particularly access to capital. In Mexico, agricultural credit has decreased 80% in the past decade (ECLAC 2006) . Irrigation is an oft-cited adaptation mechanism, but levels of irrigation are low in some areas, with just 18% of cultivated land in Mexico irrigated (Skoufias *et al*., 2011), and the costs of installation are high. Even when capital is available, technological improvements can increase yield under normal conditions but do not protect harvests from extreme events (United States Global Change Research Program (USGCRP), 2009). Irrigation was an insufficient buffer during the Canadian Prairie drought of 2001-2, as surface water sources had reduced flow (Wittrock and Kulshreshtha, 2011). In many regions high water demand by agriculture and other sectors limit options for expanding irrigation (Coles and Scott, 2009).

Farm-level decisions dictated by economic competitiveness also limit adaptive capacity. Heavy capital investments in crop-specific technologies constrain management decisions (Chhetri *et al*., 2010). Crops introduced to enhance economic competitiveness can be more climate-sensitive. In Canada, cold-hardy French hybrid grapes have been replaced with higher-quality varieties that are more sensitive to winter injury (e.g., (Alayon-Gamboa and Ku-Vera, 2011; Belliveau *et al*., 2006)). One study of small-holder farmers in Mexico ironically showed that subsistence-based farmers recovered from Hurricane Isidore (2002) sooner than commercial farmers due to higher labour investments and earlier sowing post-hurricane (Alayon-Gamboa and Ku-Vera, 2011).

Studies also indicate gaps in effective institutional support for adaptation (Bryant *et al*. 2008; (Jacques *et al*., 2010); (1273 Tarnoczi, T.J. 2010).

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Box 26-3. Impacts and Adaptation in the Mexican Coffee Sector

Coffee is an important export for Mexico, supporting approximately a half-million primarily indigenous households, nearly two-thirds of which have one hectare or less of land (González Martínez, 2006)). Coffee production is projected to decline in response to climate change by as much as 34% by 2020 (Gay *et al*., 2006); (Schroth *et al*., 2009)). Losses associated with Hurricanes Stan (2005) and Agatha (2010) were especially detrimental , occurring at a time of falling commodity prices ((952 Eakin, H. 2006) . In one study, 40% of farmers interviewed in Chiapas planned to emigrate ((890 Saldaña-Zorrilla, S.O. 2008).

[INSERT FIGURE 26-6 HERE
Figure 26-6: Photo indicating damage caused by Hurricane Stan, courtesy of Hallie Eakin.]

Many current agro-ecological practices associated with sustainability enhancement may help smallholders adapt (918 Lin, B. B. 2008) (Schroth *et al*., 2009). Research demonstrates that coffee farmers are aware of increases in the frequency and intensity of drought and torrential rainfall (Eakin *et* al., forthcoming) motivating some to plant different varietals, modify shade cover, and practice soil conservation. Some households are entering niche markets, joining coffee cooperatives, and adopting organic practices. Others, particularly those highly specialized in coffee, are exploring alternative crops, or diversifying into non-farm activities (Eakin *et al*. 2011).

International coffee retailers and non-governmental organizations are increasingly engaged in enhancing farmer adaptive capacity . Coffee cooperatives may also enhance adaptive capacity, although there are obstacles to participating (Eakin *et al*. 2006; (Frank *et al*., 2011)).

_____ END BOX 26-3 HERE _____

26.6.4. Fisheries

Many fisheries in North America are already under stress from multiple factors. A study of freshwater fish in California found 26% of populations in danger of extinction in the near future (Moyle *et al*., 2011)). Historical warm periods have coincided with low salmon abundance (486 Crozier, L. G., R.W. Zabel, and A. Hamlet 2008; 960 Crozier, L.G. 2008). The restriction of fisheries in Alaska has been attributed to climate change (United States Global Change Research Program (USGCRP), 2009)). Coral cover and complexity in the Caribbean Basin, important habitat for many species, has declined by an estimated 80% since the 1970s (1301 IPCC 2012).

Projected impacts include contraction of coldwater fish habitat and expansion of warm-water fish habitat (Janetos *et al*., 2008)), which can function as invasive species threatening resident populations. Up to 40 % of Northwest salmon populations may be lost by 2050 due to climate change (Battin J., M.W. Wiley, M.H. Ruckelshaus, R.N. Palmer, E. Korb, K.K. Bartz, and H. Imaki, 2007)). Climatic effects on temperature and salinity may reduce nutrient availability, and acidifcation will be especially detrimental to shell fish and coral reefs (Barange and Perry, 2009). Further declines in coral cover and complexity in the Caribbean Basin are estimated to reduce fish production by 30-40% by 2015, resulting in losses of $95-140 million for over 100,000 fishers (Trotman *et al*., 2009). Predicted impacts at long time scales are highly uncertain, but for rapid time scales (a few years) (Barange and Perry, 2009) express high confidence that increasing temperatures will "caus[e] significant limitations for aquaculture, changes in species distributions, and likely changes in abundance."

26.6.4.1. Social Sensitivity

Alaska is home to the largest number of commercial and subsistence fishers in the U.S. (836 Lal, P. 2011), and Alaska's rural residents harvest an average of 225 pounds of fish per person (USFWS 2010). Fishing is also important in Northwestern Mexico, where fishers catch on average 1.5 million tons per year (Arroyo *et al*., 2010). Families engaged in fishing livelihoods in North America represent an especially vulnerable group. Fish provide both income and food security (Badjek *et al*., 2010). Coastal fishing communities face the combined threats of direct exposure to rising sea level and increased frequency and intensity of storms, affecting both community and fishing infrastructure (Badjek *et al*., 2010); (Daw *et al*., 2009); livelihood sensitivity to fish population shifts; and erosion of tourist amenities (Daw *et al*., 2009). Increased intensity and severity of storms also translates into reduced harvest time or increased personal hazard risk.

Inter-related factors affecting vulnerability include overfishing, and land use activities such as logging that contribute to declines in stocks. In Alert Bay, British Columbia, historic catches of up to one million salmon dropped to 5,800 by 2000 (Brklacich *et al*., 2008). (Badjek *et al*., 2010) note that efforts to adapt in other sectors (e.g. irrigation or flood control infrastructure) may exacerbate declines in fisheries.

26.6.4.2 Adaptive Capacity

Fisher-people have historical experience with adaptation. Climate change poses a threat to some species, but the potential for other species to expand. Small-scale fishers are less able to adapt to shifting fish distribution patterns than large-scale operations due to limited mobility. Access to capital for adoption of new harvesting techniques is an important source of adaptive capacity ((954 Daw, T. 2009)).

26.7. Rural Communities

North America's rural population is proportionally small (U.S. 17%; Canada 20%, Mexico 23%) but has distinct vulnerability characteristics. Most rural communities depend in some way on local ecosystems, and are therefore especially sensitive to climate change (Molnar, 2010); (Johnston *et al*., 2008). Single-sector economic dependence in particular has been shown to contribute significantly to disaster vulnerability in a national-level study of the U.S. (1274 Cutter, S.L. 2003). Because of limited economic diversity, irreversible climate changes are a particular concern. Recent extreme events affecting rural communities include drought in the Canadian Prairies (2001-2); drought in Southwestern U.S. (2010-2011) (argued to be the most severe in history (MacDonald, 2010) and subsequent wildfires; flooding in the U.S. Midwest (2011), and hurricanes in Mexico (2004-5). Communities in coastal and water-scarce interior locations are of particular concern. Droughts have decreased in occurrence historically in the U.S.(1301 IPCC 2012), but several regions have experienced increases (United States Global Change Research Program (USGCRP), 2009). Forecasts of increased water scarcity, and intensification of drought (1301 IPCC 2012), medium confidence) are particular concerns due to dependence on drought-sensitive sectors (forestry, agriculture, water-based recreation) (836 Lal, P. 2011).

Other sensitivity characteristics include high poverty and unemployment (particularly in Mexico) ((836 Lal, P. 2011)); (Whitener and Parker, 2007); (Skoufias *et al*., 2011); (Exposed: Social Vulnerability and Climate Change in the US Southeast, 2009)); aging populations (U.S. and Canada) (831 McLeman, R.A. 2010) and lower education levels (836 Lal, P. 2011); limited extreme event response capacity (836 Lal, P. 2011)); physical infrastructure (Krishnamurthy *et al*., 2011); (McLeman and Gilbert, 2008)); and limited health care access (836 Lal, P. 2011). Mexico is one of five developing countries globally that is estimated to experience the highest increases in poverty due to climate change-induced extreme events (52% increase in rural households; 95.4% in urban wage-labor households) (A2 scenario) (Ahmed *et al*., 2009).

The consequences of extreme events for communities that are very small (less than 1,000) and/or isolated (several hours' commute from large population centre) are more severe due to limited local services; non-redundant transportation corridors that can be compromised; and difficulties accessing external government resources (Cervantes-Godoy, 2009);(Chouinard *et al*., 2008).

Rural communities have developed adaptive capacity throughout history, and studies indicate high levels of climate change awareness among residents ((1069 Matthews, R.);(McLeman and Gilbert, 2008). Rural communities face many adaptation constraints, however--particularly limited revenues combined with higher costs of supplying adaptation services--warranting state and national investments into rural adaptive capacity (Williamson *et al*., 2008). (Posey, 2009) found a direct relationship between the socio-economic status of a municipal population and engagement in adaptation. Building adaptive capacity can also address poverty and sustainability (Badjek *et al*., 2010).

Indigenous, tourism- and forest-based communities are discussed below. Agricultural and fishing communities were discussed previously. Northern Aboriginal communities are discussed in Chapter 28: Polar Regions.

26.7.1. Indigenous Communities

26.7.1.1. Social Sensitivity

Indigenous-dominant rural communities are located throughout North America and thus the types of climate change impacts to which they are exposed vary greatly. Other factors contributing to vulnerability are held in common, however, including social factors influencing sensitivity and adaptive capacity. Sources of climate sensitivity for Indigenous communities include reliance on natural-resource-based sectors; dependence on local hunting and harvesting of climate-sensitive resources for food security (Impacts of Climate Change on Tribes in the United States, 2009); (Hardess *et al*., 2011); (*Climate Change Impacts on Abundance and Distribution of Traditional Foods and Medicines—Effects on a First Nation and their Capacity to Adapt Final Report*, 2007)); high extreme poverty (Downing and Cuerrier, 2011);(Climate Risks and Adaptive Capacity in Aboriginal Communities Final Report, 2009); significant infrastructure deficits; high rates of substance abuse and other social problems (Hardess *et al*., 2011);(1069 Matthews, R.); (Brklacich *et al*., 2008); and the cultural significance of traditional foods in decline, like salmon (Jacob *et al*., 2010); (*Climate Change Impacts on Abundance and Distribution of Traditional Foods and Medicines—Effects on a First Nation and their Capacity to Adapt Final Report*, 2007). For many, local livelihoods are doubly threatened by the combined impacts of climate change and industrial development (*Climate Change Impacts on Abundance and Distribution of Traditional Foods and Medicines—Effects on a First Nation and their Capacity to Adapt Final Report*, 2007). Water supply and quality are of special concern for Canadian First Nations communities (*Climate Change and Water: Impacts and Adaptations for First Nations Communities*, 2008), and Native American communities in Southwestern U.S.(836 Lal, P. 2011). Drinking water available to 85 out of 615 First Nation reserves was recently identified as high-risk (*Climate Change and Water: Impacts and Adaptations for First Nations Communities*, 2008; Plan of Action for Drinking Water in First Nation Communities, 2008). Many Indigenous people have limited relocation options given their residential status on reserves, rendering them especially vulnerable to regional impacts (836 Lal, P. 2011).

26.7.1.2. Adaptive Capacity

Indigenous peoples have centuries-long relationships with the land, generating high acceptance of change and extensive local knowledge. Indigenous peoples also express high awareness of recent changes in weather, wildlife, water and ice conditions, and winter roads (Climate Change Impacts on Ice, Winter Roads, Access Trails, and Manitoba First Nations Final Report, 2006). Adaptive capacity is higher among communities able to integrate traditional culture with contemporary forms of knowledge, education and economic development (Hardess *et al*., 2011). The legacy of their colonial history, however, has stripped Indigenous communities of many of their sources of social and human capital, introduced insecurity in land tenure, and contentious inter-governmental relations, all of which constrain adaptive capacity.

26.7.2. Tourism-based Communities

26.7.2.1. Observed and Projected Impacts

Nature tourism is concentrated in alpine regions and along coastlines and inland water bodies, all of which are exposed to climate impacts with implications for tourist amenities. Impacts will be highly differentiated by region and type of tourist activity.

Observed shifts in spring temperatures have been linked to a shift in the timing of peak attendance in US National Parks (Buckley and Foushee, 2011). Increased mountain park visitation (up to 29% by 2050 in Canada, e.g.) are projected as a result of forecasted increasing in warm degree days (186 Scott, D. 2007), but fires, loss of desired fishing species and mega-fauna, and loss of glaciers may counter this trend (Scott *et al.*, 2007a). Winter sports face shorter seasons, with snowfall declines forecast for the Northeast U.S., leading to 8-100% reductions in length of snowmobile season, and 6-21% reduction in length of ski season by 2039 (B1 and A1Fi), range depicting regional variations (Scott *et al.*, 2008). Findings for Canada are similar: declines in season length by 11-44% in different regions (low-emission scenario), and 39-68% (high emission scenario) by 2020 (McBoyle *et al.*, 2007). The popularity of other tourist destinations, such as Mexican beach resorts, has been found to be less affected by environmental change (Buzinde *et al.*, 2010a; Buzinde *et al.*, 2010b).

Increased occurrence of extreme events introduces high economic volatility that many small tourism communities will likely have difficulty absorbing. 2008). In forested regions, extreme events of concern include wildfires and pest outbreaks, discussed below and in Box 26-2.

26.7.2.2. Social Sensitivity

Tourism communities are dominated by low-wage, service-based employment, and small businesses. Adjustments in tourism employment due to climate change will be inevitable as some opportunities shrink (skiing) and others emerge (summer recreation), but social insurance programs are not well suited to this sector translating into high vulnerability for employees (Tufts, 2010).

Extreme events are of particular concern due to infrastructure damage potential, and the predominance of small businesses that lack resources for effective emergency preparation and recovery. Recent fires in the Okanagan, British Columbia caused total losses of 10-20% in revenues; some businesses lost 90%. Smaller businesses were less likely to invest in emergency planning, even following the event (Hystad and Keller, 2006; Hystad and Keller, 2008).

26.7.2.3. Adaptive Capacity

Snow-making equipment may mediate climate impacts in ski regions, although the expense, and high water and energy requirements could be prohibitive, especially if revenues fall due to shorter seasons or if water is not available (Scott *et al.*, 2007b). Some communities are engaged in adaptation innovation. Several coastal tourism communities in eastern Canada, for example, are experimenting with saltwater marsh restoration as an adaptation to rising sea levels, which also has ecological benefits (Marlin *et al.*, 2007).

26.7.3. Forest-based Communities

The effect of climate change on forests is addressed in Section 26.3. This analysis examines the socioeconomic consequences of such changes.

26.7.3.1. Social Sensitivity

Contraction of the forestry sector has hit Canadian communities especially hard. The Canadian forest sector shed 100,000 jobs since 2005, due to structural change in the industry and the mountain pine beetle epidemic (Holmes, 2010). Projected climate-induced increases in global supplies may lower prices, further reducing the competitiveness of some North American regions (Brown, 2009). (Sohngen and Sedjo, 2005) estimate average annual producers' surplus losses from climate change in the Canadian/U.S. timber sector of $1.4 – $2.1 billion per year over the next century. Extreme events pose an additional layer of vulnerability, threatening directly local ecosystems, timber inventories, infrastructure and lives in forest-based communities. For instance, the Mountain Pine Beetle infestation encouraged increased harvests as companies removed merchantable timber ahead of the path of the outbreak, but regional economies face a long term net decline in forestry income levels of 25% or more (British Columbia's Mountain Pine Beetle Action Plan 2006-2011: Sustainable Forests, Sustainable Communities, 2006). Anticipated future supply reductions vary from -10 to -62% (Patriquin *et al*., 2007). (Parkins and MacKendrick, 2007);(MacKendrick and Parkins);(Parkins, 2008) identified more than 30 communities and 25,000 families directly affected, but vulnerability varied by degree of economic dependency and socio-economic conditions. Since the outbreak, several community-level adaptation initiatives have emerged.

26.7.3.2. Adaptive Capacity

One adaptation option is the assisted migration of tree species more tolerant to anticipated future conditions, currently receiving attention in British Columbia. Mitigation innovations, including carbon sequestration plantations and biofuels, may temper declines in production or competitiveness (Holmes, 2010). Economic diversification is an oft-promoted adaptation strategy for resource-based communities, however there are several constraints to doing so (Joseph and Krishnaswamy, 2010).

Financial stressors command more attention in forest-based communities than climate change (Ogden and Innes, 2007), limiting motivation and resources available for municipal adaptation planning. Studies indicate that attention to adaptation among companies and government is limited as well, which is concerning given the large proportion of public and industrial tenure of forestlands (Brown, 2009); (Spittlehouse, 2008); (Johnston *et al*., 2008).

26.8. Human Health: Observed and Projected Impacts

Climate-related impacts and vulnerability related to population health and the systems that promote health has been the focus of considerable research and assessment in North America since AR4. In particular, large national assessments of climate and health have been carried out in both the US and Canada (cite 2008 Canada report and US Synthesis and Assessment Report 4.6 from 2008). There is also a growing literature addressing climate-related health risks in Mexico. The national assessments have highlighted the potential for changes in impacts of extreme storm and heat events, air pollution, pollen, and infectious diseases, drawing from a growing NA research base analyzing observed and projected relationships among weather variables, vulnerability factors and health outcomes. The causal pathways leading from climate to health are complex, and are often modified by intervening factors including economic status, pre-existing illness, age, other health risk factors, access to health care, built and natural environments, adaptation actions and others. This complexity makes it extremely difficult to detect and attribute climate change-related health impacts. Health impacts of wildfire are discussed in Section 26.X

26.8.1. Extreme Storms, Floods, Drought

WGI chapter X and SREX discuss evidence for observed and predicted trends in extreme storms (SREX). Hurricanes can cause extensive direct losses of life as well as longer term, more indirect health impacts, particularly in Mexico and the Southern US. However, the magnitude of health impacts of extreme storms depends on the interaction between hazard exposure and characteristics of the affected communities ((1275 Keim, M.E. 2008). Coastal and other low-lying infrastructure and populations can create vulnerabilities related to communications, healthcare delivery, and evacuation. Health impacts include direct effects (eg: death and injury) and indirect, long-term effects on contamination of water and soil, vector-borne diseases, respiratory health and mental health (Gamble *et al*., 2008). Infectious disease impacts from flooding include creation of breeding sites for vectors (1276 Ivers, L.C. 2006) and bacterial transmission through contaminated water sources causing gastrointestinal disease. Impacts on diarrheal disease morbidity and mortality are particularly relevant in Mexico, where these diseases are more prevalent in general. Additionally, chemical toxins can be mobilized from industrial or contaminated sites (1277 Euripidou, E. 2004) . Elevated indoor mold levels associated with flooding of buildings and standing water have been identified as risk factors for cough, wheeze and childhood asthma (1279 Jaakkola, J.J.K. 2005; 1278 Bornehag, C.G. 2001). Mental health impacts may be among the most common and long-lasting impacts of extreme storms as well as draughts; however to date they have received relatively little study (Berry *et al*., 2010). Stress of evacuation, property damage, economic loss, and household disruption are some of the triggers that have identified through recent work with populations in the Gulf Coast and Midwest region (Weisler *et al*., 2006); (Gamble *et al*., 2008).

26.8.2. Extremes of Temperature

A large body of literature in North America has associated high temperatures with increased mortality and morbidity (e.g., (O'Neill and Ebi, 2009); (Anderson and Bell, 2009). During a recent severe heat wave in California, more than 140 deaths and 1000 hospitalizations were documented (CDHS, 2007); (42 Knowlton, K. 2007). Most available NA evidence derives from the US and Canada. However one recent study reported significant heat- and cold-related mortality impacts in Mexico City ((1280 McMichael, A.J. 2008). Urban areas are especially vulnerable because of the high concentrations of susceptible populations and enhanced heating. However, projecting future public health consequences of gradual climate warming is challenging, due in large part to uncertainties in the nature and pace of adaptations that populations and societal infrastructure will undergo in response to long-term climate change (Kinney *et al*., 2008). Additional uncertainties arise from changes over time in population demographics, economic well-being, and underlying disease risk, as well as in the model-based predictions of future climate and our understanding of the exposure-response relationship for heat-related mortality. In spite of these complications, one can state with high confidence that climate warming will lead to additional health stresses related to extreme high temperatures, particularly for the northern parts of NA. The magnitude of health impacts will depend on the pace and extent of adaptation/acclimatization to high temperatures (1302 Romero Lankao, P., Qin, H., and Dickinson, K., Forthcoming), which will tend to reduce health risks. The health implications of warming winters remain uncertain. While it is possible that acute cold-snap related health effects could diminish, adaptation to warmer winters may lead to higher susceptibility to more rare cold events. Well-documented winter season increases in respiratory and cardiovascular deaths do not show evidence of direct response to warming winter temperatures (1281 Kinney, P.L. 2012).

26.8.3. Air Pollution

Poor air quality results from a combination of unfavorable weather conditions and high emissions of criteria pollutants (Jacob and Winner, 2009). Urbanization tends to concentrate emission sources, leading to higher air pollution levels, often in close proximity to vulnerable populations. Ozone and particulate matter (e.g., PM2.5 and PM10) have been associated with adverse health effects in many locations in NA (1302 Romero Lankao, P., Qin, H., and Dickinson, K., Forthcoming). Weather and climate play important roles in determining concentrations of air pollution over multiple scales in time and space. Emissions, transport, dilution, chemical transformation, and eventual deposition of air pollutants all can be influenced by meteorological variables such as temperature, humidity, wind speed and direction, and mixing height (Kinney, 2008).

Since AR4 there has been a substantial expansion of the modeling literature examining climate influences on air quality in North America, particularly for ozone (Tao *et al*., 2007); (Kunkel *et al*., 2007); (Holloway *et al*., 2008); (Lin *et al*., 2008); (Nolte *et al*., 2008); (Wu *et al*., 2008); (Avise *et al*., 2009); (Chen *et al*., 2009); Dawson et al. 2009 (Liao *et al*., 2009); (Racherla and Adams, 2009); (Lin *et al*., 2010); Tai et al. 2010. This work suggests with medium confidence that ozone concentrations in NA would increase slightly (under 15%) under future climate change scenarios if pollution precursor emissions were held constant at historical levels. However, there is little consistency in regional changes projected from models, and emissions controls on precursors can overcome the "climate penalty" for air quality (Jacob and Winner, 2009). The literature for PM2.5 is smaller and less consistent (Liao *et al*., 2007); (Tagaris *et al*., 2008); (Avise *et al*., 2009); Dawson et al. 2009; (Pye *et al*., 2009); (Mahmud *et al*., 2010)). One study projected decreases in both ozone and PM2.5 concentrations in N. Mexico and S. Canada when the A1B scenario was modeled along with projected decreases in air pollution emissions in the US and Canada (Tagaris *et al*., 2008). Several recent studies have projected future health impacts due to air pollution in a changing climate (Bell *et al*., 2007); (Tagaris *et al*., 2009); (Tagaris *et al*., 2010); (Chang *et al*., 2010)). Results of these studies follow directly from the underlying climate/chemistry modeling outputs, and generally do not take into account future changes in population demographics, underlying disease risk, or sensitivity to air pollution.

26.8.4. Pollen

Exposure to pollen has been associated with a range of allergic outcomes, including exacerbations of allergic rhinitis (Cakmak *et al*., 2002), (Villeneuve *et al*., 2006)), exacerbations of allergic asthma (1282 Delfino, R.J. 2002) , and allergic sensitization (BjÃ¶rkstÃ©n and Suoniemi, 1981), Porsbjerg et al. 2002). Higher temperature and greater precipitation, in the months prior to the pollen season, lead to increased production of many types of tree and grass pollen(1283 Lo, E. 2007), (Reiss and Kostic, 1976), (1285 Minero, F.J.G. 1998), USEPA 2008). Furthermore, ragweed pollen production has been observed to increase in response to increased temperatures and concentrations of atmospheric carbon dioxide (Singer *et al*., 2005), (Wayne *et al*., 2002), (Ziska and Caulfield, 2000), (Ziska *et al*., 2003). Because pollen production and release can be affected by temperature, precipitation, and CO2 concentrations, it is possible that future patterns of pollen exposure and allergic disease morbidity could change in response to climate change. However, to date, the only evidence for observed climate-related impacts are for the timing of the pollen season. Many studies have indicated that pollen seasons are beginning earlier (Ariano *et al*., 2010), (1284 Clot, B. 2003), (1286 Emberlin, J. 2002) (1287 Frei, T. 2008), (Levetin and Van, 2008), (1288 Rasmussen, A. 2002), (1289 Teranishi, H. 2006). These changes have been described most thoroughly in Europe, although evidence of an earlier start to the pollen season has also been documented in the United States and Asia. Some pollen types, such as ragweed, also have shown an increase in season length (Ziska *et al*., 2011), (Ariano *et al*., 2010). However, research on trends in NA has been hampered by the lack of long-term, consistently collected pollen records (USEPA 2008).

26.8.5. Waterborne Diseases

Waterborne infections remain an important source of morbidity and mortality in NA. Infections may be contracted through consumption of drinking water, by inhalation of aerosols containing bacteria, and by direct contact with recreational or floodwaters. Commonly reported infectious agents in recent US and Canadian outbreaks include legionella bacterium, the cryptosporidium parasite, campylobacter, and giardia (CDC, 2011), Séguin 2008. Along with these, cholera remains an important agent in Mexico (Greer *et al*., 2008). Risk of waterborne illness is to be greater among infants, elderly, pregnant women, and immunocompromised individuals (Rose *et al*., 2001);(Gamble *et al*., 2008). In 1993, 85% (46) of the deaths from a cryptosporidiosis outbreak in Wisconsin occurred among patients suffering from AIDS (Craun *et al*., 2006).

Changes in the temperature and the hydrological cycle can influence the risk of waterborne diseases (Curriero *et al*., 2001), (Greer *et al*., 2008), (Harper *et al*., 2011)). Floods also enhance the potential for runoff to carry sediment and pollutants to water supplies (Karl *et al*., 2009)). Disparities in access to treated water were identified as a key determinant of under age-5 morbidity due to water borne illnesses in the central State of Mexico (JimÃ©nez-MoleÃ³n and GÃ³mez-Albores, 2011)).

[INSERT FIGURE 26-7 HERE
Figure 26-7: 2005 waterborne disease incidence for <age 5 in the State of Mexico. Source: Jiménez-Moléon and Goméz-Albores, 2011.]

26.8.6. Vectorborne Diseases

The extent to which climate change has altered, and will alter, the geographic distribution of vectors of infectious disease remains uncertain because of the inherent complexity of the ecological system. Spatial and temporal distribution of disease vectors depend not only on climate factors, but also on land use/change, socio-economic and socio-cultural factors, prioritization of vector control, access to health care and human behavioral responses to perception of disease risk, among other factors (Lafferty, 2009); (Wilson, 2009). Although temperature drives important biological processes in these organisms, variability in climate on a daily, seasonal or interannual scale may result in organism adaptation and a shift in geographic range, not necessarily an expansion in range (Lafferty, 2009); (Tabachnick, 2010); (McGregor, 2011)). This shift may alter the incidence of disease depending on host receptiveness and immunity, as well as the ability of the pathogen to evolve so that strains are more effectively and efficiently acquired (1290 Beebe, N.W. 2009); (Epstein, 2010; Reiter, 2008); (Reiter, 2008); (Rosenthal, 2009); (Russell, 2009).

North Americans are currently at risk from a number of vector-borne diseases, including Lyme disease (Diuk-Wasser *et al*., 2010; Ogden *et al*., 2008); (Diuk-Wasser *et al*., 2010)), dengue fever (Jury, 2008);(Ramos *et al*., 2008); (Johansson *et al*., 2009); (Kolivras, 2010); (1291 Degallier, N. 2010) ; (Lambrechts *et al*., 2011), and Rocky Mountain spotted fever, to name a few; this population is also increasingly at risk from invasive vector-borne pathogens, such as chikungunya and Rift Valley fever viruses 8(Greer *et al*., 2008). Mexico is the sole NA country listed as high risk for dengue fever by the WHO. Whether warmer winter temperatures in the United States and Canada will result in locally acquired transmission of diseases like dengue and malaria is uncertain, in part, because of access to amenities such as air-conditioning that provide barriers to human-vector contact. Better longitudinal datasets and empirical models are needed to address knowledge gaps in research on climate-sensitive infectious diseases, as well as to provide a better mechanism for weighting the roles of external drivers such as climate change on a macro/micro scale, human-environmental changes on a regional to local scale and extrinsic factors (such as immunity, phenotype plasticity and evolution) in the transmission of vector-borne infectious diseases (Wilson, 2009); (McGregor, 2011).

26.9. Infrastructure

Infrastructure provides critical services including water supply, sanitation, flood control, electricity, natural gas, transportation, and communications that can be disrupted in manifold ways by climate variability and change although detailed assessments of existing and projected damages are mostly limited to US and Canada (Handmer, J., Y. Honda, Z.W. Kundzewicz, N. Arnell, G. Benito, J. Hatfield, I.F. Mohamed, P. Peduzzi, S. Wu, B. Sherstyukov, K. Takahashi, and Z. Yan, 2012). For example, while infrastructures on the East Coast could be affected by SLR ((114 Kirshen, P. 2008)) in the Gulf of Mexico area they can and are already affected by hurricane and flood damages (Conrad, 2010). The Gulf Coast is among the highest disaster loss regions in the United States (19 Cutter, S.L. 2008). However, rather than to increased intensity or frequency of hazards (e.g., hurricanes) trends in loses are due both to the increasing value of infrastructure at risk (e.g., along the coast (1300 Field, C. B., L.D. Mortsch, M. Brklacich, D.L. Forbes, P. Kovacs, J.A. Patz, S.W. Running and M.J. Scott 2007), (19 Cutter, S.L. 2008)and to increasing social vulnerability (Pielke Jr *et al*., 2003; Pielke Jr *et al*., 2008).

Damage to or disruption of infrastructure affects not only the infrastructure itself, but also the services infrastructure provides. Disruption of service in one infrastructure can affect other infrastructures, particularly in urban areas (Wilbanks *et al*., 2008). The risks from climate change to infrastructure should be put in context of the state of infrastructure. Infrastructure in good condition (or that is climate proofed) will be more resistant to climate change impacts than aging or deficient infrastructure. The ability of a society to build and maintain its infrastructure is an indicator of its adaptive capacity.

Pubic infrastructure across North America appears to be aging, or - in the case of Mexico - lacking, and is vulnerable to climate extremes. The American Society for Civil Engineers notes that of the more than 81,000 dams in the U.S., more than 4,000 are deficient. The reliability of 85% of the 100,000 miles of levees is unknown. More than one-fourth of the nation's bridges are structurally deficient or functionally obsolete (513 American Society for Civil Engineers 2009).

There are hundreds of billions to trillions of dollars of needed investment in public infrastructure in the United States alone. The American Society for Civil Engineers estimates that more than $2 trillion are needed to bring infrastructure in the US up to "good condition" (513 American Society for Civil Engineers 2009; p. 6.) As of 2008, $298 billion was identified by the U.S. Environmental Protection Agency (USEPA) as being needed for wastewater pipes and treatment facilities; combined sewer overflow (CSO) correction; and stormwater management through 2028 to rehabilitate aging infrastructure, to meet higher water quality standards, and serve population growth. (511 U.S. Environmental Protection Agency 2008) . In addition, USEPA found that $334.8 billion is needed over the next 20 years to expand, replace or rehabilitate existing pipes, treatment facilities, storage tanks, or other assets to provide clean drinking water (510 U.S. Environmental Protection Agency Office of Water 2009). The U.S. Department of Transportation estimated that between $100 and $175 billion would be needed in the next 20 years to upgrade U.S. highways (514 Federal Transit Administration 2008). Based on infrastructure surveys from the 1980s and '90s Mirza and Haider (2003) report an investment deficit in Canadian infrastructure of $125 billion (517 Mirza, M. Saeed 2003).

Climate change can threaten infrastructure through sea level rise, changes in extreme temperatures, winds, and flooding. (749 Wilbanks, T. 2012) (520 Wilbanks, TJ 2008)note that disruption of infrastructure can have significant consequences for social well-being and the economy. The greatest climate risks to infrastructure arise from extreme events. Impacts on one infrastructure can affect other infrastructure.

26.9.1. Transportation

Transportation infrastructure is crucial for economic activity (e.g., 7 and 3 of the Gulf of Mexico region ports account for about 70% of waterborne commerce ton-miles in the United States and 75% of the tonnage of Mexican imports and exports respectively (Conrad, 2010).The Transportation Research Board found that increases in high temperature events, intense precipitation, drought, sea level, and storm surge can affect transportation across the US. They concluded the greatest risks would be to coastal transportation infrastructure. There also can be benefits, e.g., to marine and lake transportation in high latitudes from shorter period with ice cover (Transportation Research Board, 2008).

(Savonis *et al*., 2008) estimated that rise in sea level of 1.2 meters would risk inundating 27% of major roads, 9% of rail lines, and 72% of ports in the U.S. Gulf Coast. They estimated a storm surge at 7 meter could inundate 64% of interstate highways andv57% of arterials, almost half of the rail miles, 29 airports, and virtually almost all of the ports in the central Gulf. Higher temperatures and changes in precipitation could also necessitate changes in materials and construction of transportation infrastructure (Savonis *et al*., 2008)

Mills et al. 2009 projected that in southern Canada by the 2050s, low temperature cracking would decrease, structures would freeze later and thaw earlier, and higher extreme temperatures would increase the potential for rutting (Mills *et al*., 2009). Overall, they found the effects of climate change to be "modest."

(519 Chinowsky, P. Submitted) estimated that a scenario corresponding to a 1.5oC increase in global mean temperature would increase the costs of keeping paved and unpaved roads in the United States in service by $2.8 billion per year by 2050. Under a scenario corresponding to a 1.0oC increase in global mean temperature, the costs would be about $1.9 billion per year (Chinowsky *et al*., Submitted).

(518 Wright, L. 2012) projected that up to 100,000 bridges in the U.S. crossing rivers and streams could be made vulnerable by increasing peak flows in the mid- and late-21st Century. Currently deficient bridges, about one-fourth of the current bridges, would be most vulnerable. Strengthening the vulnerable bridges in response to climate change is estimated to cost $138 to 247 billion, but the costs could be reduced by 27 to 28% if currently deficient bridges are strengthened (Wright *et al*., 2012)

26.9.2. Energy

Energy systems are particularly sensitive to climate change, as energy requirements for cooling and heating are expected, refineries in dry areas can face water availability problems (971 Boyd, R. 2009) and energy demand for different energy sources will be differently affected by extremes (e.g., heat waves). Some energy sectors (hydroelectricity, solar and wind power) are particularly sensitive to climate variability (section 26.2). The potential impacts of climate change in Canada include significant increase in electricity requirements for cooling; adverse effects on hydroelectric potential in both western and eastern Canada; combining demand and supply impacts, increased number of blackout/brownout events (Minville *et al*., 2009) estimate that annual mean hydropower in the St. Lawrence and Great Lakes region of Canada would decrease by 1.8% in the period 2010–2039 and then increase by 9.3% and 18.3% during the periods 2040–2069 and 2070–2099, respectively.

According to specific studies assessed by (520 Wilbanks, TJ 2008)the net change in energy demand by 2080 is estimated to range from -15 to +4% (520 Wilbanks, TJ 2008). (Mansur *et al*., 2008) used cross-section data of current energy demand and develop a base case of population and economic activity in 2100 for the US. They estimate that oil and gas consumption will decrease with higher temperatures and net electricity consumption will increase. They estimate that 2.5oC increase in mean US temperature would reduce welfare by $26 billion per year (1990$), with $16.2 billion from residential and $9.9 billion from the commercial sector. A 5.0oC warming and a 15% increase in precipitation would increase the welfare loss to $56.7 billion per year, with $35.1 billion in welfare loss coming from the residential sector (526 Mansur, Erin T. 2008). (Wilbanks *et al*., 2012) conclude that peak demand for electricity may increase more than average demand for electricity, necessitating capacity expansion in many areas.

Other impacts are likely as well, including effects on energy production of rising temperatures (which reduce thermal power plant efficiencies) and limited water supplies in many regions (which can affect power plant cooling) and effects on renewable energy sources other than hydropower. For example changing cloud cover affects solar energy resources, changes in winds affect wind power potentials, and temperature change and water availability can affect biomass production (for instance, water requirements for biofuel production) (520 Wilbanks, TJ 2008).

Regional differences exist in the energy impacts of warming. Regionally in the US, major concerns include effects of increased cooling demands and water scarcity in the west; effects of extreme weather events, sea-level rise, and seasonal droughts in the southeast; effects of increased cooling demands in the northern regions; effects of warming on energy production and transportation in Alaska; and effects of climate policy on regions whose economies are closely tied to fossil energy production and conversion (520 Wilbanks, TJ 2008).

Other types of infrastructure such as water resources, coastal protection, and communications will also likely be affected directly or indirectly by climate change (520 Wilbanks, TJ 2008).

26.10. Urban

In North American urban areas, the concentration of populations, economic activities, cultural amenities and built environments creates higher risks from hazards (floods, heat waves) that climate change is expected to aggravate. At the same time, factors such as economies of scale and cities' role as development hubs and centers of innovation, endow cities with opportunities to play pivotal roles in adaptation efforts (UN-HABITAT United Nations Human Settlements Programme, 2011); (Romero-Lankao and Dodman, 2011)).

26.10.1. Multilevel Hazards and Stresses

Cities are currently being faced with a multilevel array of hazards, some related to climate change and others that are not (e.g., industrial, technological, (McGranahan *et al*., 2007), (De Sherbinin *et al*., 2007), Satterthwaite et al., 2009; (Romero-Lankao and Dodman, 2011)). However, as these hazards interact, they may present complexity and greater societal challenges. For instance, factors such as urban growth on cities' perimeters, forest fuel build-up, and cultural practices produce an elevated risk from wildfires (Brenkert-Smith, 2010); (Collins and Bolin, 2009). Increasing salinity levels (e.g., the Delaware River in Philadelphia US) is an example of how sea level rise can negatively impact power stations, water treatment plants, food and beverage manufacturers and oil refineries (183 Sharp, J.H. 2010).

In the absence of effective policies, the concentration of populations and economic activities can result in poor air quality, particularly when coupled with unfavorable weather conditions ((723 Romero-Lankao, P. 2012); section 26.7). Urbanization changes land-use and land-surface physical characteristics (e.g., surface albedo (718 Chen, F. 2011). Cities also affect atmospheric and hydrological conditions through dynamic effects (e.g., distorting synoptic systems) (Bornstein and Lin, 2000); aerosol effects (e.g., cloud condensation); and thermo-dynamical effects (e.g., the heat island effect, UHI). The UHI, which varies across and within cities (Miao *et al.*, 2011); (Harlan *et al.*, 2008) also increases health risks from heat (section 26.7)

The warming of the atmosphere and ocean can result not only in sea level rise and storms affecting North American coastal cities (Nicholls *et al.*, 2008); (102 Kirshen, P. 2008) (Weiss, J.L., J.T. Overpeck, and B. Strauss., 2011);, but also in an acceleration of the hydrologic cycle that would bring both increased precipitation intensity and higher flood risks and more prolonged dry periods (section 26.3). Urbanization, therefore, may enhance or reduce precipitation depending on the climate regime, geographical location and patterns of land, energy and water use in a city's region (720 Cuo, L. 2009).

26.10.2. Observed and Predicted Social and Economic Impacts

Climate variability and change already have a variety of implications for urban populations, buildings, economic sectors (e.g., industry, retail and commercial services) and on infrastructures such as energy, waste water and transportation (Gasper and Ruth 2011, Table 26-1)(Gasper *et al.*, 2011). Not only SLR has been observed affecting 17 Mexican cities (Zavala et al., 2010(Zavala-Hidalgo, J., R. de Buen, R. Romero-Centeno, and F. Hernández, 2010)), but also severe weather events including heavy precipitation, storm surges, flash-floods and wind creating risks to the built environment, including homes and places of business ((331 Jonkman, S.N. 2009)(Collins *et al.*, 2009), (Comfort, 2006), (41 Kirshen, P. 2008), (6 Romero-Lankao, P 2010). Impacts on water supply, sanitation and energy provision can increase the costs of insurance coverage (section 26.9; (Mills, 2005). Retail and commercial services, or tourism ((186 Scott, D. 2007); (1027 Manuel-Navarrete, David 2011), and industrial facilities may also be affected, especially if they are located in risk prone areas, depend on climate sensitive inputs (Mendelsohn and Neumann, 2004);(Bin *et al.*, 2007) or foster mass tourism increasing social inequalities, degrading ecosystems, and amplifying overall exposure to extreme events (e.g., Cancun; (1027 Manuel-Navarrete,David 2011)).

[INSERT TABLE 26-1 HERE
Table 26-1: Dimensions and determinants of urban adaptive capacity. Source: Romero-Lankao, 2012.]

Although case studies sometimes focus on economic, social or ecological impacts individually, research increasingly emphasizes their interrelated nature (Gasper *et al.*, 2011). For instance, under current financial constraints at the local level, economic losses from adverse climate events can reduce resources available to address social issues and, by doing so, pose a serious threat to local institutional capacity and urban livelihoods ((368 Kundzewicz, ZW 2008)).

Scholarship on the future impacts of climate change on cities has found that populations and significant portions of the built environment, economic activities and infrastructures are at risk from climate related changes and hazards on the Pacific coast (48 Miller, N.L. 2009)); US-Mexico Gulf coast (Sobel *et al.*, 2010); (Conrad, 2010); ("U.S. Government Accountability Office, http://www.gao.gov", 2007; Wittrock and Kulshreshtha, 2011)); Canadian prairie cities (Wittrock and Kulshreshtha, 2011)); US-Mexico border cities (Collins, 2008); (Collins *et al.*, 2009)) as well as in Boston, New York, Chicago, Washington, DC, Maryland, Virginia, North Carolina, Mexico City (Bin *et al.*, 2007);(102 Kirshen, P. 2008; 41 Kirshen, P. 2008); (Hayhoe *et al.*, 2010);(Gallivan *et al.*, 2011).

26.10.3. Urban Vulnerability and Resilience

Hurricanes, heat waves and other hazards do not exclusively create negative effects, however. The existence of insurance, emergency response systems and water conservation strategies illustrate that urban actors can have the ability to recover from and even take advantage of some stresses (Collins and Bolin, 2009); (Coffee *et al*., 2010); (6 Romero-Lankao, P 2010); (Aguilar and Santos, 2011). Multiple interacting factors explain differences in adaptive capacity: e.g., differences in the use of information and flexibility for learning and innovation (e.g., Chicago, New York, Mexico City, Canadian prairie cities). Urban capacity to respond is also shaped by long-term processes (e.g., water overexploitation limits Mexico City capacity to manage flood risks, (6 Romero-Lankao, P 2010); and short-term triggers (e.g., droughts in Canadian prairie cities led to conservation imposed on urban water users (Wittrock and Kulshreshtha, 2011).

For urban populations, class and socio-spatial segregation are key determinants of urban risks and vulnerabilities through two mechanisms: First, economic elites are able to monopolize the best land and enjoy the rewards of environmental amenities such as clean air, safe drinking water, open space, and tree shade (Morello-Frosch *et al*., 2002); (Harlan *et al*., 2006; Harlan *et al*., 2008); (Ruddell *et al*., 2009); second, although wealthy sectors are moving into risk prone coastal and forested areas (Collins, 2008), and although certain hazards such as air pollution can affect both rich and poor alike (723 Romero-Lankao, P. 2012), climate risks tend to be disproportionally borne by the poor or otherwise marginalized populations, such as ethnic minority groups (Cutter *et al*., 2008);(Collins *et al*., 2009); (6 Romero-Lankao, P 2010); (Wittrock and Kulshreshtha, 2011). Some peri-urban areas are being inhabited by marginalized populations, with inadequate services, a portfolio of precarious livelihood mechanisms, and inappropriate risk-management institutions [for US(Collins *et al*., 2009) and(Colten *et al*., 2008); for Canada Iqaluit: for Mexico (Aragón-Durand, 2007); (Eakin *et al*., 2010); (Monkkonen, 2011). Equally important determinants, however, are individual levels of social trust, participation in networks and family support in reducing vulnerabilities (Pelling and High, 2005);(1302 Romero Lankao, P., Qin, H., and Dickinson, K., Forthcoming).

Such other characteristics as housing stock, urban form, built environment and availability of urban and ecologic services also affect urban vulnerability. For example, the large, impermeable surfaces and concentration of buildings characteristic of cities can disrupt natural drainage channels and accelerate run-off (Walsh *et al*., 2005). The resulting damage from floods can be much more catastrophic if settlements lack drainage or waste collection systems, or if these are not sufficient to deal with recent and expected peak flows. While infrastructures in many Canadian and US cities are in need of major upgrades or repairs (Doyle *et al*., 2008); (Conrad, 2010)), Mexican urban areas are additionally faced with deficits in roads, water and sanitation provision (Niven *et al*., 2010); (Hardoy and Romero Lankao, 2011)), as well as with high levels of socio-spatial exclusion and informality (Smolka and Larangeira, 2008)). Hence, while adequately served cities mostly face the challenge of repairing or expanding their infrastructures and buildings, or enhancing their capacity to anticipate and manage extreme-weather events, many Mexican cities have the additional burden of overcoming development deficits.

The evolution of cities as economic hubs is also of relevance for understanding vulnerability and resilience (Leichenko, 2011). Because of lifestyles, economic or geopolitical considerations, urban centers expand onto mountain, agricultural, protected and otherwise risk-prone areas ((1292 Boruff, B.J. 2005) ;(McGranahan *et al*., 2007); (16 Collins, T.W. 2009) ; (Conrad, 2010). These socio-ecological systems invariably alter their and their hinterlands' environments. Depending, at least partially, on their socioeconomic and environmental histories, paths are open going from increasing reduced resilience (e.g., irreversible overexploitation and degradation of groundwater resources, inflexibility and ineffectiveness of management systems) to an increasing ability of urban populations and urban-relevant decision makers' to repair damage, sustain the environment and foster urban actors' capacity for learning and adaptation (Collins *et al*., 2009); (6 Romero-Lankao, P 2010) ; (Aguilar and Santos, 2011)).

26.10.4. Urban Climate Responses

Urban populations have long had to cope with a wide range of climatic and non-climatic risks to their economic activities, lives and livelihoods (1293 Romero-Lankao, P. 2011). Measures such as green roofs, forest thinning and urban agriculture (Chicago, New York, Kamloops, Mexico City, Toronto), flood protection (New Orleans, Chicago), private or governmental insurance (Browne and Hoyt, 2000); (Ntelekos *et al*., 2010a, section 26.10); (418 Toronto 2008;)), safe saving schemes (common in Mexico), reinforcing homes to withstand extreme weather (740 Simmons, K.M. 2007), air pollution controls (Mexico City), warning systems or diversifying livelihoods, for instance, through circular (or temporary) migration (Newland *et al*., 2008); (Rose and Shaw, 2008)) become the most frequent types of response to climate hazards.

Urban authorities are starting to assess their climate change vulnerabilities and designing their adaptation programs (table to be developed).(Ford *et al*., 2011)found that two-thirds of adaptations in developed countries are happening at the municipal level. Some of these responses have involved the development of "integrated" climate change strategies, e.g., New York and Chicago ((108 Rosenzweig, C. 2010);(Perkins *et al*., 2007), and myriad "projects" for reducing climate risk to specific sectors (e.g., water conservation in Phoenix, US and Regina Canada; wildfire protection in Kamloops, Canada and Boulder, US). For example, New York adopted "plaNYC" in 2007, which incorporates climate change into sustainable development of housing and neighborhoods, parks and public spaces, brownfields, waterways, water supplies, transportation, energy, air quality, and solid waste (421 New 2011). However many cities have not yet moved into the implementation stage, and most of the adaptation programs are in the process of problem diagnosis and adaptation planning (Perkins *et al*., 2007); Dodman et al., 2011; (Moser and Ekstrom, 2011); (Carmin *et al*., 2012);(724 Romero-Lankao, P. 2012).

Some smaller municipalities have initiated adaptation efforts. In Mexico, the "*Safe Municipality*" (SIAT-CT) has been adopted by cities such as Acapulco, Tijuana, Tuxtla Gutierrez y Monterrey, while other cities such as Hermosillo (Sonora) and Villahermosa (Tabasco) are trying various strategies to manage water-related stresses, including floods and droughts. The city of Keene, New Hampshire with a population around 20,000, has an adaptation plan which addresses reducing a number of risks including flooding and extreme heat (420 Keene 2007). Dawson City in the Yukon is exploring technologies that will promote permafrost conservation; assessing the need to increase the level of an existing dyke; and educating and advocating local food consumption and sustainable fishing methods to present and future generations (417 Jones 2010).

Engaging stakeholders in urban adaptation has proved effective in getting legitimacy for public decisions and helping capture local realities (e.g., Mexico City, (195 Aguilar, A.G. 2011)). However, potential issues might arise: delays in decision making; tensions and conflicts among stakeholder groups embedded in power relationships that can constrain the access of the general population to decision making processes (Few *et al*., 2007); (Colten *et al*., 2008).

Adapting urban areas to climate change is complicated by the fact that it is undertaken at different temporal, spatial and sectoral scales (724 Romero-Lankao, P. 2012), thus requiring a careful assessment of the different layers involved in land-use planning, emergency responses, housing, health and other sectoral policies and their effects on the determinants of urban vulnerability at the city, neighborhood and individual levels (Table 26-1). Traditionally, environmental or engineering agencies are frequently made responsible for managing climate issues (e.g., Mexico City, or Edmonton and London, Canada), but do not have the decision making power nor the resources available to address all the dimensions involved. Planning requires not only shorter term actions at the governmental level, but also longer term measures by businesses, grassroots organizations and individuals to adapt to climate change (e.g., Vancouver and Halifax, Canada; New York and Chicago (Romero-Lankao, 2007); (Croci *et al*., 2010); (Burch, 2010).

26.10.5. Adaptation, Mitigation, and Urban Development

Climate change impacts can hamper current progress towards sustainability (UN-HABITAT United Nations Human Settlements Programme, 2011)) and have the potential to exacerbate existing challenges such as deficits in infrastructure (e.g., insufficient coverage, need of major upgrades and climate proofing), or in institutional capacity to prevent climate effects (e.g., hot weather) on the health of their populations (O'Neill and Ebi, 2009). Hence, cities require adaptations that create synergies and overcome conflicts with mitigation and other development goals. For instance, painting roofs white (Akbari *et al*., 2009) can reduce the effects of heat waves and local energy demand for cooling, presenting a possible mitigation-adaptation co-benefit. Conversely, sea walls can protect coastal properties, yet they negatively affect the structure and functioning of coastal ecosystems. Therefore, both synergies and trade-offs exist between actions addressing the mitigation challenge and other policy dimensions (industrial development, energy security, health; (Hamin and Gurran, 2009); (Laukkonen *et al*., 2009)). As illustrated by Mexico City, Denver, New York and Los Angeles, climate change policies are an outcome of efforts driven by economic security and local concerns, but also by the drive to be at the forefront of initiatives among a cohort of city leaders ((160 Rosenzweig, C. 2010) ; (Anguelovski and Carmin, 2011);(724 Romero-Lankao, P. 2012). Policies addressing other environmental and social problems, such as air pollution (Harlan and Ruddell, 2011)), or the provision of adequate shelter to the poor (Colten *et al*., 2008) can often be adapted at low or no cost in order to fulfill sustainability goals and improve human wellbeing simultaneously.

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Box 26-4. Climate Change: Additional Challenges on the Water System of Mexico City Metropolitan Area (MCMA)

MCMA has 21.4 million people, over four million vehicles, intricate energy and water systems, transportation infrastructures and populations vulnerable to extreme weather (1294 Tortajada, C 2006) ;(724 Romero-Lankao, P. 2012). In 1900-2005, there has been a 66% increase in precipitation with a temperature rise of around 1.5ºC, both not thought to be associated with climate change but mainly with an increasing heat-island effect ((1217 Galindo, I. 2009). Of the 85.7 m3/s of water used, 67% comes from the aquifer, 31%, from the Lerma and Cutzamala Basins and 2% from local rivers and wells. 90% of wastewater from MCMA is not treated, but is used for agricultural irrigation.

While it has one of the highest coverage levels nationally, in terms of population receiving piped water and sanitation, MCMA water system is faced with many sustainability challenges. The local aquifer is overexploited by between 19.1 and 22.2 m3/s. Not even its sophisticated drainage system has been effective at controlling the floods that continue to affect different sectors and areas. Problems of water availability make water users (especially poor sectors, Figure 26-8) vulnerable to existing and future changes in availability. Groundwater levels have continuously fallen and caused subsidence, thus undermining the foundations of buildings and infrastructure and increasing the vulnerability of these areas' populations to earthquakes and heavy rains ((6 Romero-Lankao, P 2010). According to projections, giving no consideration to global warming, between 2005 and 2030 the population of MCMA will increase by 17.5%, while between 2007 and 2030 available water will diminish by 11.2%.

[INSERT FIGURE 26-8 HERE
Figure 26-8: Woman fetching water in a periurban area southwest of Mexico City. Mexico City has made important strides in the provision of water and sanitation; however, in some urban neighborhoods, fetching water from outside of the home is common. Source: Courtesy of Patricia Romero-Lankao (September 2011).]

The situation is likely to be exacerbated by climate change. While past increases in intense rain events are thought to be linked to the heat-island effect (Magaña, 2008), projections for 2046-2085 using the B1 scenario and the GFDLCM2 model indicate that rainfall events of greater than 60 mm over 24 h will increase between 150 and 200% (Soto et al., 2010). An increased number of summer droughts is also predicted (1218 Carabias, J. 2005; 1219 Legorreta, J. 2005) which will disproportionately affect those water users who already face recurrent shortages during the dry season or in drought periods. For example, 81.2 per cent of people affected by droughts during 1980 to 2006 live in Netzahualcoyotl, one of the poorer municipalities of the city.

State authorities of Mexico City's Federal District have undertaken efforts to address water and climate change and to build synergies with other state agencies. Policy networks such as ICLEI, political leaders (e.g., Mayor Marcelo Ebrard) and research groups, such as the Molina Center, have been critical in launching a climate agenda. However, policy making has been constrained by insufficient financial and human resources to address the underlying processes of environmental deterioration and the lack of coordination and institutional fragmentation of the different tiers of government (Romero-Lankao, 2007).

Any policy aimed at solving MCMAs water sustainability issues and adapting to climate change will need to grapple with these constraints. However, opportunities may also be created. Infrastructural upgrades that take climate change into consideration can be made with an eye toward correcting current shortfalls while introducing water conservation measures and storm and wastewater collection and treatment across the entire system. The service to areas and populations currently underserved or not served at all enhances their safety and quality of life, and costs for disaster response and management can be decreased. For this to work, the institutional fragmentation of the multiple layers and spatial jurisdictions of government and civil society will need to be lessened (1220 Romero Lankao, P. 2011).

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Adaptation by states, provinces, and the three national governments in North America is discussed in Box 26-5.

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Box 26-5. Adaptation at the State/Provincial and National Levels in North America

State and Provincial Level

Some states and provinces in all three countries have developed adaptation plans and taken other measures. Nunavut was the first territory, province or state in North America to develop a climate change strategy in 2003 (Nunavut Department of Sustainable Development, 2003). Among the states and provinces developing adaptation plans are California, Maryland. Alaska, Washington, British Columbia, Ontario, Veracruz, Mexico City, Nuevo Leon, Guanajuato, Puebla, Tabasco, and Chiapas. Table 26-2 identifies some of the adaptation activities at the state and provincial level.

[INSERT TABLE 26-2 HERE
Table 26-2: Examples of state and provincial adaptation activities in North America.]

Federal Level

All three national governments are addressing adaptation to some extent. Mexico is developing a national strategy, Canada a national policy, and the United States is having all federal agencies develop adaptation plans.

In 2005, the *Inter-Secretarial Commission to Climate Change* (CICC – Comisión Inter-Secretarial de Cambio Climático) was created by the Mexican government as a cross-sectoral government structure to coordinate adaptation activities across eleven ministries (Comisión Inter-Secretarial de Cambio Climático, 2005)(SEMARNAT, 2010). The *National Plan for Development 2007-2012* is attempting to 1) design and develop capacities for adaptation; 2) develop climate scenarios at regional scale; 3) assess impacts, vulnerabilities and adaptation to climate change in various socioeconomic sectors and ecological systems, and 4) promote the dissemination of information about those impacts, vulnerabilities, and adaptation measures (Presidencia de la República, 2007). The *National Strategy for Climate Change 2007-2012* identifies priorities in climate change adaptation research and capacity development at various levels of government and society(Intersecretarial Commission on Climate Change, 2007).

The *Special Programme on Climate Change 2009-2012* (CICC, 2009) seeks to build synergy with other federal government agencies and programmes. So far, strategies on adaptation consist of setting up early warning systems, developing shared-risk schemes for agriculture and livestock activities, and creating insurance schemes against disasters. They also include campaigns for raising public awareness on various topics, including climate impacts on health, and natural resource degradation. Moreover, other sorts of strategies have also tried to support adaptation by opening up new opportunities for green investments (i.e. PES, alternative energy, and ecotourism).

The *Policy Framework for Medium Term Adaptation* (CICC, 2009) aims at framing national initiatives, such as the ones above mentioned, into a single national public policy approach on adaptation with a time-horizon up to 2030. It provides principles and guidelines for the integration of climate change adaptation across government departments. The four general principles are: 1) integrated land planning approach; 2) guaranteed human rights and equity; 3) public participation; and 4) access to information.

The Canadian Federal Government is working towards creating an Adaptation Policy Framework that is intended to mainstream climate risks and impacts into programs and activities to help frame government priorities (Environment Canada, 2011). In 2011, the Canadian Government announced continued adaptation funding for of $148.8 million for five years, to be distributed among several government departments and programs. The funding includes renewed financial support for Environment Canada's Climate Change Prediction and Scenarios Program (Canada's state-of-the-art network that has contributed to the IPCC Assessment Reports) and Canada's Heat Alert and Response System, and provides new funding to create a Climate Adaptation and Resilience Program for Aboriginals and Northerners, and to finance the integration of adaptation into National Codes and Standards (Environment Canada, 2011).

Following the release of the 2007 assessment, the Government of Canada made a four-year commitment to climate change adaptation by providing domestic funding of $85.9 million, of which NRCan received $35 million to develop the Regional Adaptation Collaborative (RAC) in provinces across Canada. The collaboratives (six in total) range in size and scope, focusing on issues from flood protection and drought planning, to extreme weather risk management and assessing the vulnerability of Nunavut's mining sector to climate change(Natural Resources Canada, 2011).

In the U.S. government, the Interagency Climate Change Adaptation Task Force is led by the White House Council on Environmental Quality (CEQ), the White House Office of Science and Technology Policy (OSTP), and the National Oceanic and Atmospheric Administration (NOAA) (1239 The White House 2009). CEQ released "Instructions for Implementing Climate Change Adaptation Planning in Accordance with Executive Order 13514" (Executive Order 13514, 2011a) and a Support Document (Executive Order 13514, 2011b) to establish an agency climate change adaptation policy; to increase agency understanding of how the climate is changing; to apply understanding of climate change to agency missions and operations; to develop, prioritize, and implement actions; and to evaluate adaptations and learn from experience. The task force is requiring federal agencies to prepare adaptation plans by the middle of 2012.

Some federal agencies have already taken steps to address climate change adaptation prior to this broader interagency effort. In 2010, the U.S. Department of Interior created Climate Science Centers to integrate climate change information and management strategies in eight regions and 21 Landscape Conservation Cooperatives. These institutions are designed to inform science-based adaptation and mitigation strategies and adaptive management techniques at the state and local level (Secretary of the Interior, 2010). There are other, less comprehensive federal agency strategies that also predate the interagency efforts, such as the EPA's office of water's strategy (U.S. Environmental Protection Agency National Water Program, 2011).

The US Government provides technical and information support for adaptation by non-federal actors, but does not provide direct financial support for adaptation. Among the technical support mechanisms by the US Government are the National Oceanographic and Atmospheric Administration's Regional Integrated Science and Assessment (RISA) program centers (Parris *et al*., 2010) and the U.S. Geological Survey's Science Centers. Both provide information on climate trends and projections (413 Geological 2011;).

Discussion

Most adaptation activities have only involved planning for climate change (Preston *et al*., 2010) (Carmin *et al*., 2012) surveyed more than 300 urban areas in the US, Canada, and Mexico (and 498 internationally). About three-fifths stated they are engaging in planning for climate change, mostly involving generating an adaptation plan, not sector-specific or detailed implementation plans. Many cities have not yet moved into the implementation stage, and most of the adaptation programs are in the process of problem diagnosis and adaptation planning ((Perkins *et al*., 2007);(128 Romero-Lankao, P. 2011); (Moser and Satterthwaite, 2009). Most Canadian cities have created adaptation commissions and are inventorying adaptation activities. Most US cities engaged in adaptation are planning for climate change, but a lower share of US cities are conducting assessments or planning relative to other regions (Carmin *et al*., 2012). None of the three national governments requires that provinces, states, or municipalities develop adaptation plans.

The most important barriers to adaptation identified by the cities were funding and staff availability (Moser and Satterthwaite, 2009))(Carmin *et al*., 2012). Obtaining accurate scientific data was ranked less important (Carmin *et al*., 2012).(Eakin and Patt, 2011) concluded that adaptation activities in the U.S. tended to address hazards and propose adaptations that tend to protect current activities rather than facilitate long term change. In addition, the adaptation plans generally do not attempt to increase adaptive capacity (Eakin and Patt, 2011).

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26.11. Key Economic Sectors

26.11.1. Manufacturing and Mining

26.11.1.1. Manufacturing

There is little literature focused on climate change and manufacturing, although one study found that manufacturing could be among the most sensitive sectors to weather in the United States (Lazo *et al*., 2011) Figure 26-9). Climatic sensitivities of the sector, however, could be exacerbated by projected changes in climate. For example, a reliable supply of water is necessary for many manufacturers, with water availability affecting site selection and day-to-day operations. The drier conditions projected for many regions of North America (Seager, R., and G. Vecchi, 2010; Sun, G., McNulty, S. G., Moore Myers, J. A., & Cohen, E. C., 2008; Wehner *et al*., 2011)) would present challenges, especially for manufacturers located in regions already experiencing water stress. Increased conflicts over water between sectors and regions are likely. There is also the concern that certain regions would become less desirable to new manufacturing facilities if water stress becomes a recurrent issue.

[INSERT FIGURE 26-9 HERE
Figure 26-9: The most weather-sensitive sectors U.S. production and weather data, 1930-2008. This figure shows the interannual aggregate dollar variation in U.S. economic activity that is attributable to weather variability of the 2008 gross domestic product. Source: Lazo, 2011.]

Delays or disruptions in supply related to weather events can be costly for manufacturers. In 2011, automobile manufacturers in North America experienced production losses associated with shortages of components due to flooding in Thailand (Newswire, 2011). For food manufacturing, climate impacts on agricultural production could be significant. In addition to climate extremes, gradual changes are also important to the supply chain. Declining water levels in the Great Lakes, for instance, would increase shipping costs by restricting vessel drafts, reducing vessel cargo volume (Millerd, 2011). For manufacturers dependent on raw materials from mining, the impacts on transportation (*see* section 26.10.1.2) could be expensive.

Another potential concern for manufacturing relates to impacts of heat on worker safety and productivity. Several studies suggest that higher temperatures and humidity would lead to decreased productivity and increased health risks (e.g., (Hanna *et al*., 2011; Kjellstrom *et al*., 2009; Kjellstrom and Crowe, 2011). Manufacturers may also experience increased air conditioning demands, though in more northern regions, these may be partially offset by decreased heating costs in colder months.

There is evidence that some companies are beginning to recognize the risks climate change presents to their manufacturing operations, and consider strategies to build resilience to these risks (National Round Table on the Environment and the Economy, 2012)). Coca Cola, for example, has a water stewardship strategy, that focuses, among other things, on improving water use efficiency at its manufacturing plants, while Rio Tinto Alcan is assessing climate change risks for their operations and infrastructure, which include, among other issues, vulnerability of transport systems, increased maintenance costs, and disruptions due to extreme events (National Round Table on the Environment and the Economy, 2012).

26.11.1.2. Mining

Climatic sensitivities of mining activities (including exploration, extraction, processing, transportation and site remediation) have been noted in the limited literature on climate and mining (e.g.,;(1206 Locke, P. 2011);;(753 Ford, J.D. ,Pearce, T. , Prno, J. , Duerden, F. , Ford, L.B. , Beaumier, M. , Smith, T. 2010; 754 Ford, J.D., Pearce, T., Prno, J., Duerden, F., Ford, L.B. , Smith, T.R. , Beaumier, M. 2011); (Chiotti and Lavender, 2008; Furgal and Prowse, 2008; Gómez-álvarez, A., Valenzuela-García, J. L., Meza-Figueroa, D., de la O-Villanueva, M., Ramírez-Hernández, J., Almendariz-Tapia, J., 2011; Kirchner, J. W., Austin, C. M., Myers, A., & Whyte, D. C., 2011; Meza-Figueroa, D., Maier, R. M., de la O-Villanueva, M., Gómez-Alvarez, A., Moreno-Zazueta, A., Rivera, J., 2009; Pearce, T.D., Ford, J.D. , Prno, J. , Duerden, F. , Pittman, J. , Beaumier, M. , Berrang-Ford, L. , Smit, B., 2011)). Drought-like conditions have affected the mining sector by limiting water supply for operations ((Pearce, T.D., Ford, J.D. , Prno, J. , Duerden, F. , Pittman, J. , Beaumier, M. , Berrang-Ford, L. , Smit, B., 2011)), enhancing dust emissions from quarries ((Pearce, T.D., Ford, J.D. , Prno, J. , Duerden, F. , Pittman, J. , Beaumier, M. , Berrang-Ford, L. , Smit, B., 2011)) and increasing concentrations of heavy metals in sediments ((758 Gómez-álvarez, A., Valenzuela-García, J. L., Meza-Figueroa, D., de la O-Villanueva, M., Ramírez-Hernández, J., Almendariz-Tapia, J., 2011)). Heavy precipitation events have caused untreated mining wastewater to be flushed into river systems (Pearce et al., 2011(Pearce, T.D., Ford, J.D. , Prno, J. , Duerden, F. , Pittman, J. , Beaumier, M. , Berrang-Ford, L. , Smit, B., 2011)). High loads of contamination (metals, sulfate and acid) at three mine sites in the US were measured during rainstorm events following dry periods ((Nordstrom, 2009)). An increase in heavy precipitation events and more intense and/or frequent droughts are projected for much of North America (e.g., (Gutzler and Robbins, 2011); (Nordstrom, 2009; Warren and Egginton, 2008).

Interviews conducted with mine practitioners in Canada found that heavy rainfall, heavy snowfall and storm events currently affect operations, and climate change is perceived as an emerging risk, and in some cases, a potential opportunity(753 Ford, J.D. ,Pearce, T. , Prno, J. , Duerden, F. , Ford, L.B. , Beaumier, M. , Smith, T. 2010; 754 Ford, J.D., Pearce, T., Prno, J., Duerden, F., Ford, L.B. , Smith, T.R. , Beaumier, M. 2011); (National Round Table on the Environment and the Economy, 2012; Pearce, T.D., Ford, J.D. , Prno, J. , Duerden, F. , Pittman, J. , Beaumier, M. , Berrang-Ford, L. , Smit, B., 2011)). Impacts on transportation were found to represent a key issue for Canadian mines(754 Ford, J.D., Pearce, T., Prno, J., Duerden, F., Ford, L.B. , Smith, T.R. , Beaumier, M. 2011). Transportation by road (including ice roads), air, and water will be affected by extreme events (e.g., heavy rainfall, snow storms, flooding) and gradual changes (e.g., higher temperatures, sea level rise). Resultant disruptions to the supply chains could be costly.

Limited water availability is a key concern for mining companies (Acclimatise, 2009)), which would be exacerbated by the drier conditions projected for many regions of North America (Seager, R., and G. Vecchi, 2010; Sun, G., McNulty, S. G., Moore Myers, J. A., & Cohen, E. C., 2008). Adjustments to management practices to deal with short-term water shortages, including reducing water intake, increasing water recycling and establishing infrastructure to move water from tailings ponds, pits and quarries, have worked successfully in the past (Chiotti and Lavender, 2008). Despite awareness of the potential role of adaptation within the mining industry there is presently little evidence of proactive planning for climate change impacts within the mining sector(753 Ford, J.D. ,Pearce, T. , Prno, J. , Duerden, F. , Ford, L.B. , Beaumier, M. , Smith, T. 2010; 754 Ford, J.D., Pearce, T., Prno, J., Duerden, F., Ford, L.B. , Smith, T.R. , Beaumier, M. 2011); (Acclimatise, 2009).

26.11.2. Construction and Housing

The risk of damage from climate perils is a significant issue for the housing and construction industries, though little research has systematically explored the topic (Morton, T., Bretschneider, P., Coley, D. and Kershaw, T., 2011)). Engineering and construction knowledge exists to design and construct new buildings to accommodate the risk of damage from historic extremes and anticipated changes in severe weather (Institute for Business and Home Safety, 2012; Kelly, 2010; Ministry of Municipal Affairs and Housing, 2011). Older buildings may be retrofit to increase resilience, but these changes are often more expensive to introduce into an existing structure than if they were including during initial construction.

The housing and construction industries have made advances toward climate change mitigation by incorporating energy efficiency in building design (Heap, 2007). Less progress has been made in addressing the risk of damage from extreme weather events (Kenter, 2010). In some markets, like the US Gulf Coast, change is underway in the design and construction of new homes in reaction to recent hurricanes, but in most markets across North America there has been little change in building practices. The cost of adaptation measures combined with limited long-term liability for future buildings influenced some builders to take a wait and see attitude (Morton, T., Bretschneider, P., Coley, D. and Kershaw, T., 2011).

Adaptation strategies for the industry include avoiding building in hazardous areas (e.g. in a floodplain) and safer building design (e.g. wind-resistant roof fastenings). Both strategies are influenced by government through land use planning and building codes. A builder can choose to surpass the minimum requirements in response to consumer demand, insurer incentives or the builder's desire to offer a premium product. Exploratory work is underway to consider implementation of building codes that would focus on historic weather experience and also introduce expected future weather risks(1236 Ontario Ministry of Environment 2011); (Kelly, 2010).

26.11.3. Agriculture, Forestry, Energy, and Other Goods Industries

Impacts and adaptation in the other goods producing industries are addressed elsewhere in this chapter.

26.11.4. Insurance and Other Service Industries

26.11.4.1. Insurance

Insurance is one of the most studied sectors with respect to weather and climate impact and adaptation. There is extensive evidence of adaptation in insurance practices, particularly over the past decade, and an expectation of further adaptation ((779 Mills, E. 2009; 1208 Leurig, S. 2011); (Autorite des Marches Financiers, 2011; Mills and Lecomte, 2006; Mills, 2007)). Most adaptation in the insurance industry has been in response to an increase in severe weather damage and there is little evidence of proactive adaptation in anticipation of expected future change in the climate.

Property insurance and reinsurance companies across North America experienced a significant increase in severe weather damage claims paid over the past three or four decades(Cutter and Emrich, 2005);(1232 Munich Re 2011);;(1222 Bresch, D. 2011). Most of the increase in insurance costs has been attributed to increasing exposure of people and assets in areas of risk (Barthel and Neumayer, 2010; Pielke Jr *et al.*, 2008). A role for climate change has not been excluded, but the increase to date in damage claims is largely due to growth in wealth and population(790 Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley 2012).

Without adaptation, there is an expectation that severe weather insurance damage claims will increase significantly over the next several decades across North America (World Bank, 2010). The risk of damage is expected to rise due to continuing growth in wealth, the population living at risk, and climate change. There is also an expectation that some weather perils in North America will increase in severity, including Atlantic hurricanes and the area burned by wildfire (Karl *et al*., 2008), and frequency, including intense rainfall events(790 Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley 2012).

Severe weather and climate risks have emerged over the past decade as the leading cost for property insurers across North America, resulting in significant change in industry practices. The price of insurance increased in regions where the risk of loss and damage has increased, and discounts were introduced where risks have been reduced. Catastrophe models were developed to help insurers manage the risk of insolvency, their capital needs and the appropriate use of reinsurance. In addition to pricing decisions based on an actuarial analysis of historic loss experience, many insurance companies now use model information to help determine the prices they charge and discounts they offer. And most insurance companies have established specialized claims handling procedures for responding to catastrophic events (Kovacs, 2005);(779 Mills, E. 2009).

Insurance companies are also working to influence the behavior of their policyholders, seeking to champion actions that reduce the risk of damage from climate extremes (Allianz and WWF, 2006);(Kovacs, 2005);(779 Mills, E. 2009). For example, the industry supports the work of the Insurance Institute for Business and Home Safety in the United States, and the Institute for Catastrophic Loss Reduction in Canada working to champion change in the building code and communicate best practices for reducing the risk of damage from extreme events to property owners, governments and other stakeholders.

In 2010, the per capita spending on property and casualty insurance was $2,112.80 in the United States, $1,870.60 in Canada and $92.90 in Mexico (1233 Bevere, L. 2012). Few homeowners and businesses in Mexico purchase insurance so there is an increased risk that the impact of severe weather may be catastrophic for those who experience loss (1234 A.M. Best 2012; 1235 Insurance Information Institute 2010; 1222 Bresch, D. 2011). There is a growing literature identifying policy options for introducing and expanding the role of insurance in developing markets (Warner *et al*., 2009);(Bals *et al*., 2006).

26.11.4.2. Other Service Industries

Service industries are continuously adapting to changing circumstances, with weather-related risks among many factors affecting performance. Most service industries are less climate-sensitive than goods-producing industries, except insurance and tourism(753 Ford, J.D. ,Pearce, T. , Prno, J. , Duerden, F. , Ford, L.B. , Beaumier, M. , Smith, T. 2010; 754 Ford, J.D., Pearce, T., Prno, J., Duerden, F., Ford, L.B. , Smith, T.R. , Beaumier, M. 2011), (Lazo *et al*., 2011). Insurance and tourism are two sectors where there is extensive literature but there are few studies assessing most other service industries. Impacts and adaptation in the tourism industry is addressed elsewhere in this chapter. Three broad categories of impacts of climate extremes can affect tourism destinations, competitiveness, and sustainability. The first relates to direct impacts on hotels, access roads and other tourist infrastructures, on such operating costs as heating/cooling, snowmaking, irrigation, food and water supply, evacuation, and insurance, on emergency preparedness requirements, and on business disruption (e.g., sun-and-sea or winter sports holidays). The second category refers to indirect environmental change impacts of extreme events on biodiversity and landscape change (e.g., coastal erosion), which may negatively affect the quality and attractiveness of tourism destinations. Last but not least, particular touristic regions can suffer as a result of tourism-adverse perception after occurrence of the extreme event itself (1107 Scott, D., Amelung, B., Becken, S., Ceron, J-P., Dubois, G., Gössling, S., Peeters, P., Simpson, M. 2008).

_____ START BOX 26-6 HERE _____

Box 26-6. Adapting in a Transboundary Context: the Mexico-US Border Region

Extending over 3169 km (1969 miles), the border between the United States and Mexico is one of the longest between a high-income and middle income country (Figure 26-10), and offers both challenges and opportunities to respond to climate change in a transboundary context. Sharing common climate regimes, natural resources, regional economies and urban areas, in recent years the region has been subject to severe droughts, and floods, and these events are likely to become more frequent and intense as climate change progresses. Additionally, there is a prevalence of incipient or actual conflict, given by currently or historically contested land boundaries or natural resources (1298 Udall, S.N. 1993) and management of shared resources by distinct entities (1299 Megdal, S.B. 2011).Climate change, therefore, as it interplays with socio-economic changes in the area, will most likely bring significant consequences for water resources, ecosystems, human health, and rural and urban communities.

[INSERT FIGURE 26-10 HERE
Figure 26-10: The US-Mexico Border. Source: EPA, 2012.]

Changing Socio-Economic Conditions

The population of the Mexico-US Border Region is rapidly growing and urbanizing, with population increasing from just under 7 million in 1983 to over 15 million in 2012. Since 1994, rapid growth in the area has been fueled by a fast-paced economic change resulting from the passage of the North American Free Trade Agreement (NAFTA) (U.S. Environmental Protection Agency and Secretaría de Medio Ambiente y Recursos Naturales, 2011; U.S. Environmental Protection Agency, 2012). Since 1965, urbanization was driven by the promise of work in maquiladoras, or duty-free foreign owned manufacturing plants, but this urbanization increased substantially after NAFTA. Between 1990 and 2001 the number of maquiladoras in Mexico had more than doubled, from 1700 to nearly 3,800, *with* 2,700 in the border area. By 2004, it was estimated that more than one million Mexicans were employed in the more than 3,000 *maquiladoras* located along the border.

Notwithstanding this explosive growth in economic activity and population in the region, many infrastructural needs there remain unmet. For example, an estimated 98,600 households in the region lacked safe drinking water, and an estimated 690,700 homes lacked adequate wastewater collection and treatment services. Given this infrastructural deficit, any effort to increase regional adaptive capacity needs to take existing gaps into account.

Changing Climate and Water Resources

The region is characterized by high temperatures and aridity, with about half of its precipitation coming in the summer monsoon but has experienced particularly dry conditions in recent years. For example, the current drought, concentrated in Texas and extending into Mexico, is the most extreme in over a century of recorded precipitation patterns for the area (977 Cayan, D.R. 2010)(1167 Seager, R., and G. Vecchi 2010)(1059 Nielsen-Gammon, J.W. 2011), Figure 26-11). Streamflow in already oversubscribed rivers such as the Colorado and Rio Grande has also decreased, threatening water resources. In fact, climatological conditions for the area have been particularly unprecedented, with sustained high temperatures that may exceed any experienced for 1,200 years. While these changes cannot conclusively be attributed to anthropogenic climate change, they are consistent with climate change model projections (Woodhouse et al., 2010).

[INSERT FIGURE 26-11 HERE
Figure 26-11: Soil-Humidity anomaly during April 2011. Source: Magana, 2011.]

Ecosystems

Population growth, economic development and urbanization are already fragmenting and degrading the region's highly diverse habitats, species and ecosystems, such as the California saga and chaparral, the Sonoran desert, the Chihuahuan desert, and the Tamaulipan mezquital. Of the region's over 6,500 animal and plant species, 235 on the Mexican side are classified in a risk category and 85 are considered endangered under Mexico's law. While on the U.S. side, 148 species are listed as endangered under the U.S. Endangered Species Act. (975 U.S. Environmental Protection Agency 2011;).

Human Health

In the absence of adequate policies and governance structures, upward trends in population growth and economic activity have brought with them more air pollution sources, including motor vehicles, industries and power plants. Heavy diesel trucking is also concentrated along several highways and border crossings, creating local hotspots for fine particle pollution. Border monitoring stations show that there were some days with violations of ozone or PM10 air quality standards in the past five years, but with variations from year to year(1303 World Health Organization 2007).

As climate change enters the equation, it may impact human health in the region in diverse ways: For instance, long-term draught in the region increases respiratory impacts from wind-blown dust. Rising temperatures increase ozone levels (U.S. Environmental Protection Agency and Secretaría de Medio Ambiente y Recursos Naturales, 2011). As climate change interacts with socio-economic factors in the region, the human health stressors may be compounded.

In the fragile ecosystems of this region, opportunities and challenges, resources and environmental and health impacts are shared across international borders, creating the need for cooperation in the governance between, local, national and international actors. In the SOD we will briefly discuss findings on these challenges and opportunities as they pertain to both sides of the border in the context of climate variability and change.

_____ END BOX 26-6 HERE _____

26.12. Concluding Remarks

(to be drafted)

Frequently Asked Questions

FAQ 26.1: What makes North America especially unique compared with other continents when it comes to climate vulnerabilities?

North America is unique in the very broad diversity of geography, climate, economic development, social fabric and governance systems which can be found across its broad landmass, and result in different vulnerabilities and capacities to adapt across sectors and regions. Layered on top of this broad diversity is a similarly broad range of climate trends and projections. For example rapid observed and projected further warming of northern NA will lead to major changes in transportation, agriculture, and native livelihoods. Meanwhile, strong drying trends in the western US and Mexico are leading to major stresses on water supplies, agriculture, and ecological services.

FAQ 26.2: Will changing patterns of precipitation be experienced in NA and if so, in what ways?

Future projections over NA suggest increases in annual precipitation in Canada and Alaska. However decreases in the southwestern US and much of Mexico are projected. These average trends will be accompanied by increasing intensity of precipitation events along with longer, more intense periods of draught. Thus, variability in precipitation appears to be a hallmark of future climate in NA. Extreme storm events can have significant impacts on local infrastructure and human health when they exceed the intensity for which these systems have been developed over many decades. The large concentration of human and infrastructure resources in the Gulf of Mexico and other coastal regions can exacerbate this vulnerability.

FAQ 26.3: What sectors/regions are more vulnerable? What factors/drivers contribute to a vulnerable situation?

- *Water supplies and quality in many regions*: Runoff throughout most of Mexico, except the south, much of the western United States and southwestern Canada is likely to decrease. These areas are already facing stress from limited water supply and lower future runoff is likely to result in increased competition for water supplies, decreased agricultural production, and harm to aquatic ecosystem.

- *Agriculture in Mexico*, particularly among smallholders: Higher temperatures, a decrease in runoff, and lower soil moisture, which are all considered to be likely for many agricultural-producing areas of Mexico, will likely decrease agricultural production. Only a small proportion of cultivated land is irrigated, furthermore, and the availability of insurance to small-holders in particular is limited. This risks reducing food security, and increasing social instability and migration. Mention something about the wet tropical south
- *Many ecosystems*: In particular, wildfire and pest outbreaks have increased in North America and both of these trends have been linked to climate change. Forest ecosystems, forest-based industries, and human settlements have been impacted negatively by recent wildfire and pest events. Forecasts indicating increasing frequency and intensity of both processes suggest a high likelihood for further reductions in biodiversity, loss of habitat, decreases in ecosystem services, challenges for forest-based industries, and increased economic and health consequences for local communities

FAQ 26.4: What lessons can be drawn from existing adaptation actions on the factors shaping effective responses?

Different economic and demographic sectors and tiers of government are starting to assess their climate change vulnerabilities and designing adaptation programs. Many responses are in diagnosis and planning stage and have not yet moved into the implementation.

Engaging stakeholders in adaptation has proved effective in gaining legitimacy for public decisions and helping capture local realities. The use of scientific information in participatory exercises has also been crucial. However, potential issues might arise: delays in decision making; tensions and conflicts among stakeholder groups embedded in power relationships that can constrain the access of the general population to decision making processes. In addition, adaptation may be constrained by a general unwillingness to address long-term changes (e.g., many decision makers have relatively short term planning and management horizons).

Adapting to climate change is complicated by the fact that it is undertaken at different temporal, spatial and sectoral scales, thus requiring a careful assessment of the different sectoral and spatial layers involved (e.g., land-use planning, emergency responses, housing, and health). Often, environmental or engineering agencies are responsible for managing climate issues, but do not have the decision making power nor the resources available to address all the dimensions involved. Adaptation requires not only shorter term actions, but also longer term measures and perspectives by the different tiers of governmental, businesses, grassroots organizations and individuals.

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Table 26-1: Dimensions and determinants of urban adaptive capacity. Source: Romero-Lankao, 2012.

Hazards	**Systems**	**Impacts (changes in)**	**Determinants of adaptive capacity/resilience**	
			City wide	**Individual level**
Sea level rise	Health	Disease	Land use planning	Age
Temperature	Energy	Mortality	Urban design	Gender
Precipitation	Built environment	Water availability	Transportation	Ethnicity
Heat waves	Economic sector	Air & water quality	Water, sanitation, energy, waste	Migration status
Surges	Demographic group	Economic disruptions	Housing	Income
	Infrastructure	Migration	Social networks	Education
	Transport	Infrastructures damages	Community base organizations	Health condition
	Hinterland	Livelihoods	Policy (emergency) responses	Knowledge, experience
	Ecosystems services		Governance	Savings
				Insurance

Table 26-2: Examples of state and provincial adaptation activities in North America.

State or Province	Activities
British Columbia	Initiatives include community based adaptation to water allocation and forestry management. BC is modernizing its *Water Act* to alter water allocation during drought to reduce agricultural crop, livestock loss and community conflict, while protecting aquatic ecosystems.(British Columbia Ministry of the Environment, 2010)
California	Statewide adaptation plan calls for a 20% reduction in per capita water use by 2020 (California Natural Resources Agency, 2009)
Maryland	Developed a plan focusing on coastal adaptation and then developed a more comprehensive adaptation plan (Maryland Commission on Climate Change Adaptation and Response Working Group, 2008).In Phase II, Maryland developed adaptation plans for a number of sectors (Maryland Department of the Environment on behalf of the Maryland Commission on Climate Change, 2010)
Mexico City	Developed *Climate Action Programme for Mexico City 2008-2012* (SMA, 2006; 2008).
Nunavut	Developed Permafrost Monitoring Network in 2008 with eleven monitoring stations collecting data on permafrost temperature and change. (Nunavut Department of the Environment, 2011)
Ontario	2011-2014 Adaptation Strategy and Action Plan contains 37 adaptation actions including requirement that provincial legislation, policies and programs take climate change impacts into consideration. Provincial Ministry of Municipal Affairs and Housing required to update the building code to ensure that new buildings in Ontario take climate change into account to increase resilience and increase water and energy conservation. (Ontario Ministry of the Environment, 2011)
Washington	Advisory groups on built environment, infrastructure, and communities; human health and security; ecosystems, species, and habitat; and natural resources (Washington State Built Environment: Infrastructure & Communities Topic Advisory Group (TAG), 2011; Washington State TAG 4 Natural Resources Working Lands and Waters, 2011; Washington State Topic Advisory Group (TAG) Report- TAG 2 Human Health and Security, 2011; Washington State Topic Advisory Group 3 Species, Habitats and Ecosystems, 2011)

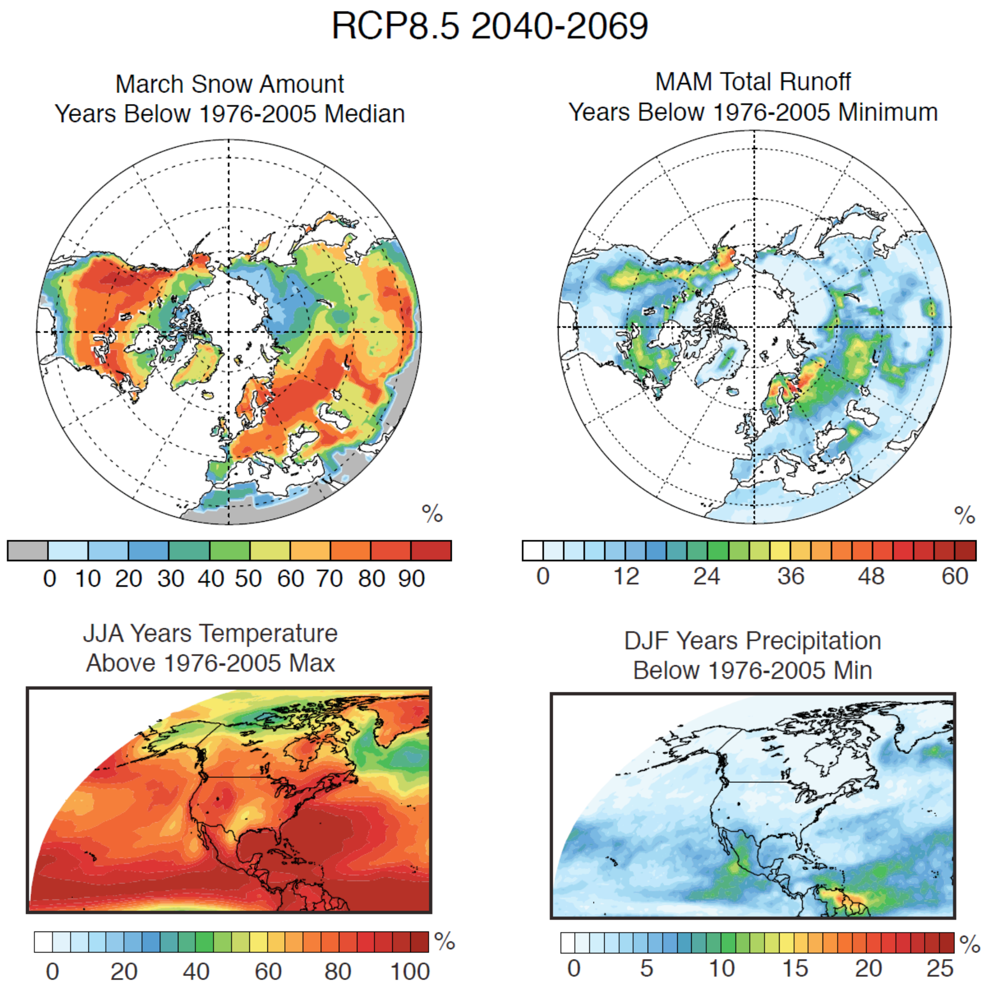
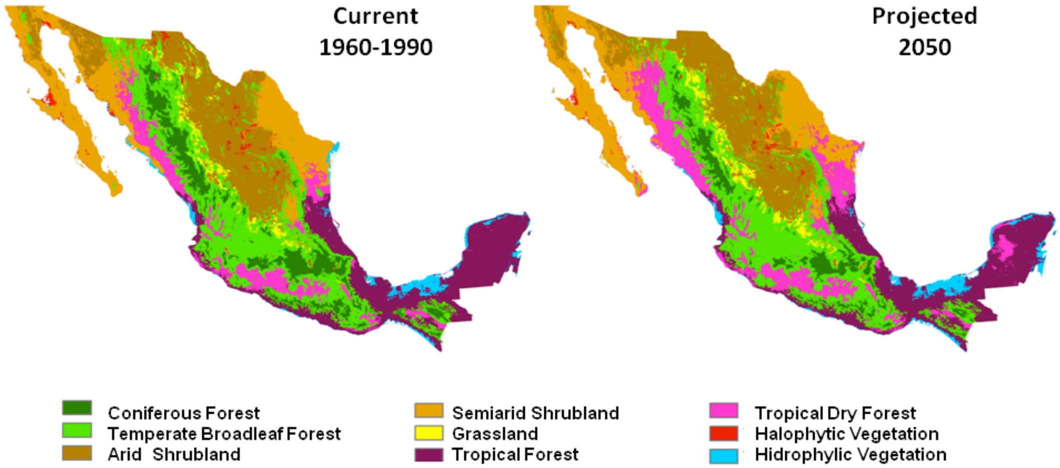


Figure 26-1: Projected changes in the extremes of seasonal temperature, precipitation, snow accumulation and runoff. The panels show the percentage of years exceeding respective thresholds in the 2040-2069 period of the CMIP5 RCP8.5 realizations. The upper left panel shows the percentage of years in which the March accumulated snow amount falls below the 1976-2005 median value. The upper right panel shows the percentage of years in which the March-April-May (MAM) total surface runoff falls below the 1976-2005 minimum value. The lower left panel shows the percentage of years in which the June-July-August (JJA) surface air temperature falls above the 1976-2005 maximum value. The lower right panel shows the percentage of years in which the December-January-February (DJF) precipitation falls below the 1976-2005 minimum value. The top panels are from Diffenbaugh et al. (submitted to Nature Climate Change). The bottom panels are from Diffenbaugh and Giorgi (in review, Climatic Change Letters), with the field of view zoomed over the North American region.



The maps show the actual and projected potential vegetation for Mexico according to the GCM UKHADGEM1 and A2 scenario. The most remarkable changes are the decrease of coniferous forests and the expansion of the tropical dry forest. This projection considers the soil conditions of the vegetation types considered as a constraint for changes.

Figure 26-2: Climate-induced species migration in Mexico. Source: Trejo et al., 2011.

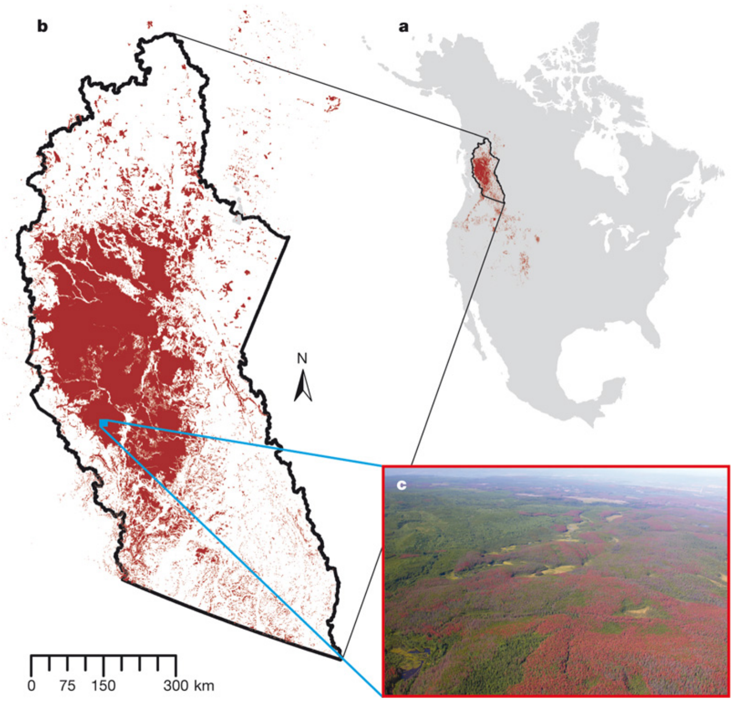


Figure 26-3: Geographic extent of mountain pine beetle outbreak in North America. Source: Kurz et al., 2008.

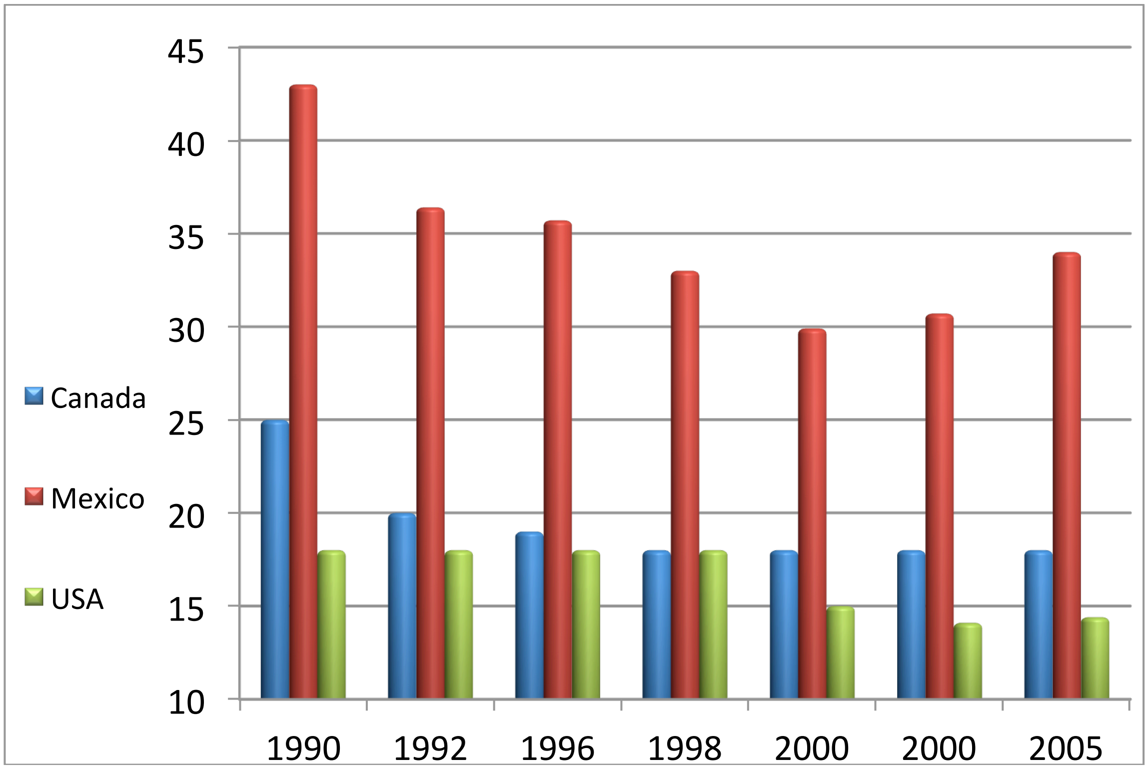


Figure 26-4: Household Budget Share of Food Comparison. Compiled by Gerardo Otero, Simon Fraser University.

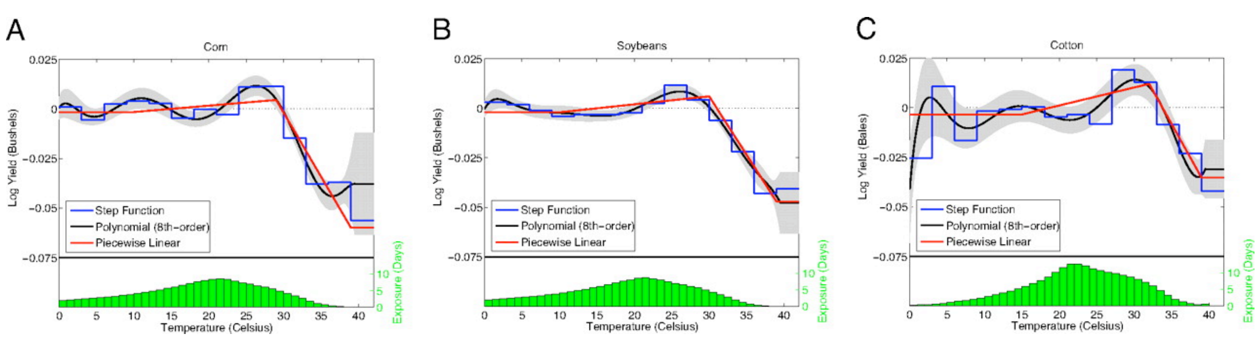


Figure 26-5: Nonlinear relation between temperature and yields. Source: Schlenker and Roberts, 2009.

Figure 26-6: Photo indicating damage caused by Hurricane Stan, courtesy of Hallie Eakin.

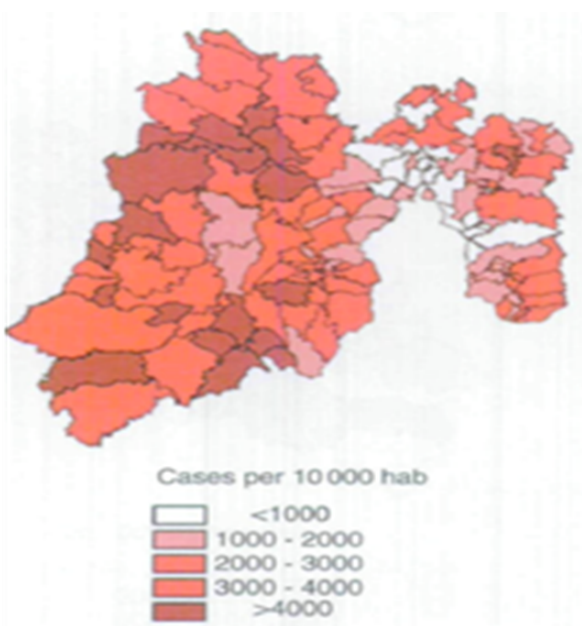


Figure 26-7: 2005 waterborne disease incidence for <age 5 in the State of Mexico. Source: Jiménez-Moléon and Goméz-Albores, 2011.

Figure 26-8: Woman fetching water in a periurban area southwest of Mexico City. Mexico City has made important strides in the provision of water and sanitation; however, in some urban neighborhoods, fetching water from outside of the home is common. Source: Courtesy of Patricia Romero-Lankao (September 2011).

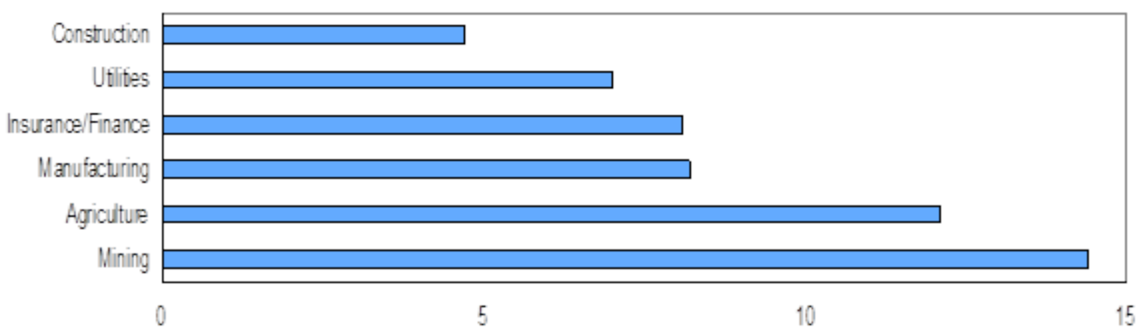


Figure 26-9: The most weather-sensitive sectors U.S. production and weather data, 1930-2008. This figure shows the interannual aggregate dollar variation in U.S. economic activity that is attributable to weather variability of the 2008 gross domestic product. Source: Lazo, 2011.

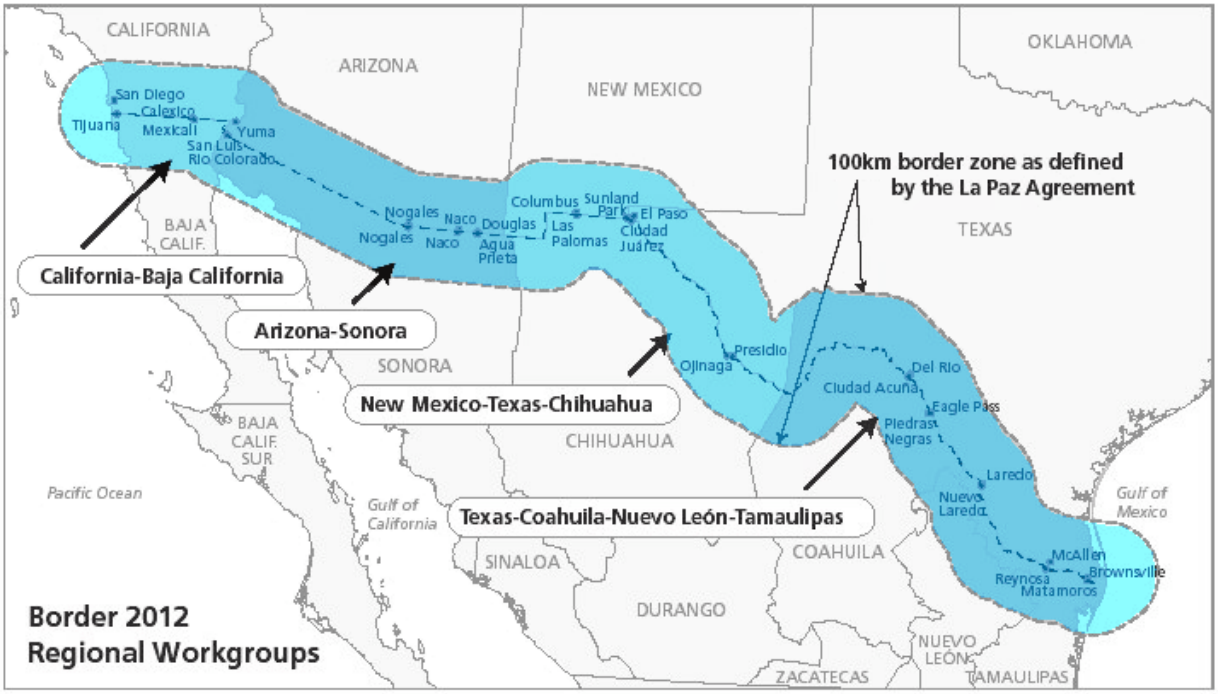


Figure 26-10: The US-Mexico Border. Source: EPA, 2012.

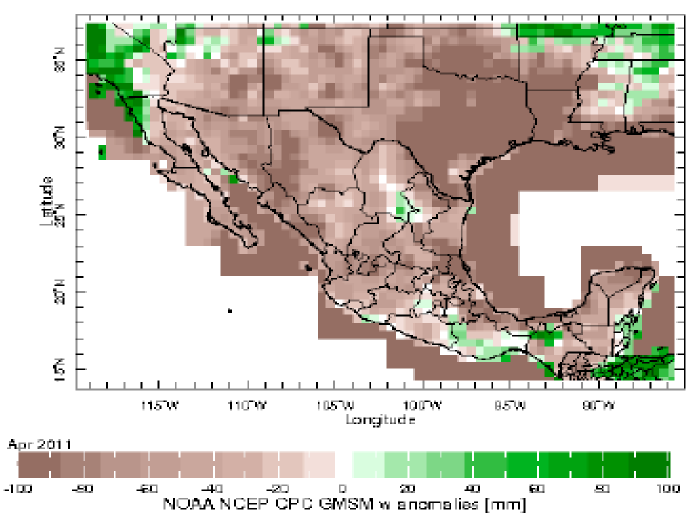


Figure 26-11: Soil-Humidity anomaly during April 2011. Source: Magana, 2011.