The US Economic Impacts of Climate Change and the Costs of Inaction

A Review and Assessment by
the Center for Integrative Environmental Research (CIER)
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Table of Contents

1 Executive Summary

1.1 Introduction

As science continues to bring clarity to present and future global climate change, policymakers are beginning to respond in earnest and proposing policies that aim to curb greenhouse gas emissions and help society adapt to the impending impacts triggered by past emissions. Although these policies are gaining momentum, their importance is not understood by many, including Congress, the public and the media. All too frequently, inaction is motivated by the perceived high cost of reducing greenhouse gas emissions. The costs of not taking on the challenges posed by climate change are frequently neglected and typically not calculated.

The range of climatic changes anticipated in the United States – from rising sea levels to stronger and more frequent storms and extreme temperature events – will have real impacts on the natural environment as well as human-made infrastructure and their ability to contribute to economic activity and quality of life. These impacts will vary across regions and sectors of the economy, leaving future governments, the private sector and citizens to face the full spectrum of direct and indirect costs accrued from increasing environmental damage and disruption.

This report presents a review of economic studies for the United States and relates them to predicted impacts of climate change. The summary findings are organized by region and identify the key sectors likely affected by climate change, the main impacts to be expected, as well as estimates of costs. The report builds on the 2000 Global Change Research Program National Assessment, using additional regional and local studies, as well as new calculations derived from federal, state and industry data sources. From this review and quantification, five key lessons emerge:

1. Economic impacts of climate change will occur throughout the country.
2. Economic impacts will be unevenly distributed across regions and within the economy and society.
3. Negative climate impacts will outweigh benefits for most sectors that provide essential goods and services to society.
4. Climate change impacts will place immense strains on public sector budgets.
5. Secondary effects of climate impacts can include higher prices, reduced income and job losses.

These lessons are supported in much greater detail in the full report. In their totality, the data and information in this report strongly support a call for action to avoid the most severe impacts of climate change, as well as to prepare for and adapt to those impacts that are unavoidable.

LESSON 1: Economic impacts of climate change will occur throughout the country.

The effects of climate change will be felt by the entire nation:

- all sectors of the economy – most notably agriculture, energy, and transportation – will be affected;
- essential infrastructures that afford us reliable services and high standards of living (such as water supply and water treatment) will be impacted; and
- ecosystems, on which quality of life relies (such as forests, rivers, and lakes), will suffer.

In the West and Northwest, climate change is expected to alter precipitation patterns and snow pack, thereby increasing the risk of forest fires. Forest fires cost billions of dollars to suppress, and can result in significant loss of property. The Oakland, California fire of 1991 and the fires in San Diego and San Bernardino Counties in 2003 each cost over $2 billion. Every year for the past four years, over 7 million acres of forests in the National Forest System have burned with annual suppression costs of $1.3 billion or more.

The Great Plains and the Midwest will suffer particularly from increased frequency and severity of flooding and drought events, causing billions of dollars in damages to crops and property. For example, the North Dakota Red River floods in

1997 caused $1 billion in agricultural production losses, and the Midwest floods of 1993 inflicted $6-8 billion in damages to farmers alone.

The Northeast and Mid-Atlantic region will see increased vulnerability to sea level rise and storms. Depending on the category of the event, evacuation costs for the Northeast region may range, for a single event, between $2 and $6.5 billion. Since 1980, there have been 70 natural weather-caused disasters, with damages to coastal infrastructure exceeding $1 billion per event. Taken together, their combined impact surpassed $560 billion in damages.

Decreased precipitation levels in the South and Southwest will strain water resources for agriculture, industry and households. For the agriculturally productive Central Valley in California alone, the estimated economy-wide loss during the driest years is predicted to be around $6 billion per year. Net agricultural income for the San Antonio Texas Edwards Aquifer region is predicted to decline by 16-29% by 2030 and by 30-45% by 2090 because of competing uses for an increasingly scarce resource – water.

The true economic impact of climate change is fraught with "hidden" costs. Besides the replacement value of infrastructure, for example, there are real costs of re-routing traffic, workdays and productivity lost, provision of temporary shelter and supplies, potential relocation and re-training costs, and others. Likewise, the increased levels of uncertainty and risk, brought about by climate change, impose new costs on the insurance, banking, and investment industries, as well as complicate the planning processes for the agricultural and manufacturing sectors and for public works projects.

Since the early 1990s, and especially during the 21st century, significant progress has been made in understanding the impacts of climate change at national, regional, and local scales. These studies, many of which are discussed in the pages that follow, highlight physical processes that influence transportation, energy and water supply systems, agriculture and forestry, fisheries, tourism, and other important economic sectors. There is, however, a lack of research that quantifies and compares these impacts, and a deficiency in using what is known about climate impacts to guide adaptation actions from the national level down to the local level. Thus, the full economic costs will likely be much higher than what is reported currently.

LESSON 2. Economic impacts will be unevenly distributed across regions and within the economy and society.

Not all regions or sectors of the country will be equally affected by climate impacts because of differences in climatic, economic and social conditions whose interplay influences coping capacities. For example, in the Northeast, the maple sugar industry – a $31 million industry - is expected to suffer losses of between 15 and 40% ($5-12 million) in annual revenue due to decreased sap flow. The region can expect a decrease of 10-20% in skiing days, resulting in a loss of $405-810 million per year. The dairy industry is also highly sensitive to temperature changes, since the dairy cows' productivity starts decreasing above 77°F (25°C). In California, an annual loss of $287-902 million is expected for this $4.1 billion industry. Losses are expected to the $3.2 billion California wine industry as well, since grape quality diminishes with higher temperatures. In each case, these may be considered small niche sectors in their respective economies – accounting for less than one-tenth of gross state product – yet they are an essential element of local employment, history, culture and landscape.

Changes in climate conditions may foster the spread of pests and diseases. For example, spruce bark beetle outbreaks in Alaska could cause a 50% loss of harvestable timber, resulting in a $332 million annual loss (less than one-tenth of gross state product). The recent spread of Southern Pine beetle attributable in part to climate change, has affected sawtimber and pulpwood production in Alabama, Louisiana, Mississippi, Tennessee, Kentucky and the Carolinas. On average, annual losses have reached over 1% of gross state product.

It's hard to imagine another natural catastrophe on the scale of Hurricane Katrina. The economic cost estimates from Katrina range upward of $200 billion, or over 1% of US gross domestic product. Yet climate change may already be affecting the strength and length of tropical storms and hurricanes, and is expected to contribute to an increase in hurricane intensity and duration. With 53 percent of the total population in the US close to major bodies of water, people and infrastructure increasingly lie in harm's way.

Not only are sectors and regions impacted differently, climate change will also take its toll, in varied ways, on the nation's population. For example, temperatures are expected to increase across the country, resulting in an increase of extreme heat events. Events like the Chicago heat wave of 1995, which lasted for five days, could become more frequent. This event resulted in an 85% increase in heat-related mortality and an 11% increase in heat-related hospitalizations. Many of the affected were elderly or poor. Similarly, it is projected that by 2100, temperatures in Boston, MA, will be similar to those of today's Richmond, VA or Atlanta, GA. The number of days above 90ºF may rise from the current 13 day average to over 30 days per year within the next 25 years. These are clearly trends that significantly affect local populations and will result in individual- and community-level hardship.

LESSON 3. Negative climate impacts will outweigh benefits for most sectors that provide essential goods and services to society.

For some sectors of the economy and some regions, climate change may temporarily be beneficial. For example, Mid-Atlantic States' agricultural yields are likely to benefit from slightly higher temperatures temporarily. However, additional warming and the movement of agricultural areas mean not only economic losses for farms that lose production. They also add costs to farms that benefit from improved growing conditions because cultivation of new crops and changing farming practices may make prior investments in technology obsolete. More importantly, although the factors that provide temporary gains to some are the same that cause losses to others, overall, everyone suffers from the introduction of new pests and the spread of existing ones, disruption of the hydrological cycle, and the impacts of severe weather events. For example, New York State's agricultural yield may be reduced by as much as 40%, resulting in $1.2 billion in annual damages. Expected water shortages in California's Central Valley are likely to affect the agricultural sector in the area. The economy-wide annual losses generated are expected to be around $6 billion during particularly dry years. Agriculture around the San Antonio Texas Edwards Aquifer region is likely to suffer a similar fate. The regional impact may reach losses of $3.6-6.5 billion by 2030 and $6.75-10.13 billion by 2090. Even those farms and regions that temporarily benefit from altered environmental conditions (e.g., carbon fertilization and extended growing season) risk economic losses if temperatures exceed those preferred by the crops they currently produce.

Climate change will trigger increases in energy demand for cooling and will outpace declines in heating requirements. For example, electricity demand in Massachusetts may increase by 40% in 2030 because of climate change alone, most of which will occur in summer months and require significant investment in peak load capacity and energy efficiency measures. Nationwide, the required investment may exceed $300 billion by the middle of this century. Given the long lead times of capacity expansion in the energy sector, little time remains to act on anticipated warming trends.

LESSON 4. Climate change impacts will place immense strains on public sector budgets.

The effects of climate change will likely place immense strains on public budgets, particularly as the cost of infrastructure maintenance and replacement increases. At the same time, economic losses may translate into lost tax revenues. As a result, public officials may need to raise taxes or cut services. For example, climate change is expected to add $5-10 billion to Alaska's infrastructure maintenance budget through 2080, depending on the climate change scenario under consideration, because of major replacement costs and service disruptions generated by climate change effects. Recent estimates indicate that a sea-level rise of nearly 20 inches (50 cm) by 2100 would cause $23-170 billion in damages to coastal property throughout the US. In Hawaii, sea level rise will require upgrades to the drinking and wastewater infrastructures -- at a cost that exceeds $1.9 billion over the next 20 years.

In addition, managed ecosystems and the communities they border will require increased resources for their protection. In 2006, $1.5 billion in federal funds was used to protect over 9.3 million acres of forest land and adjacent communities. Climate change-induced warming will mean that Washington State, for instance, will face fire-suppression cost increases of over 50% by 2020 and over 100% by 2040, raising the expenses to $93 and $124 million respectively.

Federal insurance programs' funds are strained because of the increasing trends of adverse weather events. From 1980 to 2005, federal insurance agencies paid out more than $76 billion in claims. The overall risk exposure of the National Flood Insurance Program increased four-fold from 1980 to $1 trillion in 2005, and the Federal Crop Insurance Corporation's exposure reached $44 billion.

Planning and public policies that promote adaptation and occur in anticipation of climate change impacts are essential to reduce strain on budgets. For example, building codes and land use planning typically reflect historical experiences. With future climate conditions quite different from the past, many of those codes and standards are becoming obsolete. Yet, because we continue to build on the basis of these standards, infrastructures that are expected to last many decades may be outdated, requiring retrofits and upgrades shortly after they have been built. Thus, investments assumed to be completed will require additional resources far sooner than planned.

LESSON 5. Secondary effects of climate impacts can include higher prices, reduced income and job loss.

The indirect effects of climate change have rarely been quantified, yet they are likely substantial. Such effects may be present in the form of higher prices for products, because the prices of raw materials and energy, transport, insurance and taxes increase. As the costs for doing business increase, competitiveness of individual firms, entire sectors or regions may decline. With this decline may come a loss of employment and overall economic security. As climate change affects jobs and household income in the United States, and as resources are increasingly diverted to help maintain safety and adequate supply of goods and services, national security may be weakened.

For example, a 1988 Midwest drought cost the region over $49 billion – in part because river-borne commercial shipping routes had to be replaced by more expensive railroad transport due to Mississippi River's reduced water levels. The costs of future droughts are likely to extend beyond requirements to meet public and agricultural water needs, with the region's manufacturing sector incurring costs as well. Around 60,000 jobs and $3 billion annually depend on the movement of goods within the Great Lakes-St. Lawrence route. Drought could lower water levels in the Great Lakes, requiring additional dredging of sediments at an annual cost of between $85 and $142 million, simply to maintain shipping lanes; and overall decreases in connectivity flow are estimated to cost the manufacturing sector $850 million per year.

Damages from severe hurricanes can span many economic sectors. Hurricane Katrina, for example, damaged not only hundreds of thousands of housing units and other urban infrastructure, but it also affected as many as 2,100 oil platforms and damaged over 15,000 miles of pipelines. Lost revenues due to these damages amounted to nearly $11 billion.

1.2 Conclusions and Recommendations

Scientific evidence is mounting that climate change will directly or indirectly affect all economic sectors and regions of the country, though not all equally. Although there may be temporary benefits from a changing climate, the costs of climate change rapidly exceed benefits and place major strains on public sector budgets, personal income and job security. Because of the economic costs of climate change, we conclude that delayed action (or inaction) on global climate change will likely be the most expensive policy option. **A national policy for immediate action to mitigate emissions coupled with efforts to adapt to unavoidable impacts will significantly reduce the overall costs of continued climate change.**

Climate change will pose major challenges for the country as a whole. At the same time, the very nature of climate impacts and adaptation options requires focus on issues at regional and sectoral scales. The number, breadth and sophistication of case studies estimating economic costs of impacts are increasing. Yet, coverage continues to be limited to some of the main sectors of the economy and discrete regions or even single states, with little attention to their interdependencies. Furthermore, most estimates of the economic cost of climate impacts are for direct impacts, and few consider indirect and induced impacts. By virtue of neglecting the adverse economic ripple effects throughout the regional and national economy, many of the direct impacts listed here may be low estimates of total impacts.

The dominant methodology to judge adaptation options is to calculate the benefits associated with incremental expansion of adaptation actions and suggest that an optimum level of adaptation is reached once these benefits are equal to the marginal cost of adaptation. Many of the adaptation studies on which this report is based employ such a marginalist approach. A more adequate methodology would treat adaptation actions as bulky investments in natural, human-made and social capital, with the goal of maintaining or enhancing the services they provide. A methodological approach consistent with that viewpoint will need to rest in portfolio choice theory (i.e. how rational investors will use diversification to optimize their portfolios, and how a risky asset should be priced or valued) and needs to include methods and tools from the theory of investment and finance under risk and uncertainty. Here lies a methodological frontier to be explored in future research.

Because improved understanding of climate impacts, and the costs and benefits of these impacts, is in the national interest, **the federal government should organize and finance a set of region- and sector-specific studies that help guide climate policy and investment, using appropriate methodologies.** A wide range of resources should be brought to bear on the problem – it should be a multi-agency effort that mobilizes universities, research centers and national laboratories. Although Congressional oversight of such studies would be necessary, the intellectual power of the nation's universities and labs should be set free to do cutting-edge, original research and help to inform policy and investment decision making while we can still avoid the high cost of inaction.

2 Introduction

As science continues to bring clarity to present and future global climate change, policymakers are beginning to debate and consider various options for a national response that achieves a range of beneficial outcomes. All too frequently, inaction is motivated by the perceived high cost of mitigation and adaptation and becomes the default policy option. The direct costs of not taking on the challenges posed by climate change are often neglected – and typically not calculated. The indirect effects of climate change are considered even less frequently, yet they are likely substantial.

The true economic impact of climate change is fraught with "hidden" costs. Besides the replacement value of infrastructure, for example, there are real costs of re-routing traffic, workdays and productivity lost, provision of temporary shelter and supplies, potential relocation and re-training costs, and others. Likewise, the increased levels of uncertainty and risk, brought about by climate change, impose new costs on the insurance, banking, and investment industries, as well as complicate the planning processes for the agricultural and manufacturing sectors and for public works projects.

The range of climatic changes anticipated in the United States – from rising sea levels to stronger and more frequent storms and extreme temperature events – will have real impacts on the natural environment as well as human-made infrastructures and their abilities to contribute to economic activity and quality of life. These impacts will vary across regions and across sectors of the economy, and in many cases are intricately linked with each other. For example, just at the time when a heat wave reduces stream flow and increases water temperatures, energy demand for cooling will increase, yet power generation must be curtailed because of limitations on the use of cooling water.

Not all environmentally induced impacts on infrastructures, economy, society and ecosystems reported here can be directly or unequivocally related to climate change. However, historical as well as modeled future environmental conditions are consistent with a world experiencing changing climate. Models illustrate what may happen if we do not act now to effectively address climate change and if adaptation efforts are inadequate.

Estimates of the costs of adapting environmental and infrastructure goods and services to climate change can provide insight into the very real costs of inaction, or conversely, the benefits of maintaining and protecting societal goods and services through effective policies that avoid the most severe climate impacts. Since it is typically at the sectoral and local levels where those costs are borne and benefits are received, cost estimates can provide powerful means for galvanizing the discussion about climate change policy and investment decision-making.

Two kinds of quantifications of climate change costs and benefits typically can be found in the literature. One stems from standard microeconomic theory and assumes that adaptation actions would be taken as long as those actions increase consumer welfare. Since taking those actions also has associated costs, it is in society's best interest to halt expansion of adaptive measures at the point at which the benefits from another unit of action are equal to the cost of the next unit of adaptation. For example, increasing the height of dikes to protect against sea level rise would stop at the point at which the cost of the next inch of dike elevation would equal the benefits from that next inch.

Key underlying assumptions necessary for the standard economics approach to work include the notion that adaptation measures can be perceived as "marginal" and separable projects where benefits increase at a decreasing rate. This is the approach most frequently chosen in economic assessments of the optimal levels of mitigation and adaptation. An alternative viewpoint posits that adaptation costs are investments in the preservation of natural, human-made and social capital, and that they are "bulky", i.e. they can often not be carried out meaningfully in small increments. Adaptation, so the argument goes, would then be best understood as part of a larger portfolio, with decisions guided towards the maintenance or improvement of the quality of life. The size of dikes, for example, would be determined by the effectiveness with which wetlands, emergency preparedness, land use and development codes, and other measures and strategies interact to reduce vulnerability to sea level rise impacts down to a socially accepted level. In this context, issues of distributional impacts of climate change begin to play a role not seen in standard economic analysis.

In this report, we present estimates of climate impacts on the US, using information from case studies and modeling exercises that fall into one of these two quantification schemes. Where prior research enables us to numerically illustrate adaptation costs, we will use them as proxies for costs of impacts of climate change. Since adaptation costs are borne by specific localities and individual entities in the public, private and non-profit sectors, they are more tangible than gross economic measures of impacts. Adaptation costs might include repair of infrastructure affected by storms or sea level rise, investment in new power generation capacity to meet cooling energy needs, and investment in water storage and irrigation systems for municipalities and agriculture affected by drought.

In the following section we will use the 2000 Global Change Research Program National Assessment as a starting point for discussing regional and local climate change, impacts and adaptation options. More details are presented for specific geographic regions, including: the Northeast and Mid-Atlantic, Midwest, West, Great Plains, Southeast, Pacific Northwest, Alaska, and Hawaii and US Affiliated Islands. Where the National Assessment explored economic impacts, we report and expand upon them with results from additional regional and local studies, as well as new calculations using federal, state and industry data sources. Additionally, to standardize the results, all of the figures used in this report have been converted to 2005 dollars (Inflation Calculator 2007).

The definitive total cost of inaction is lacking due to the diversity of methodological approaches in estimating impact and adaptation cost, and the diversity of climate-induced challenges faced by society. Despite such gaps, it is clear from available information that climate change impacts are real and significant. National action to avoid the most severe impacts must be taken. The report, therefore, closes with recommendations for regional, multi-agency and multi-jurisdictional investigations that are based on a consistent and theoretically sound methodology, utilize state-of-the-art data acquisition and analysis, and present a comprehensive portrait of adaptation.

3 A Summary of US Impacts and Cross-Cutting Issues

The impacts of climate change will vary greatly across the US due to the country's size, diverse topography, ecosystems, climates and economies, and its dispersed populations and lifestyles. How this large and diverse nation, which generates a GDP of more than $13.6 trillion (current dollars, BEA 2007) and is home to more than 302 million people (US Census Bureau 2007), responds to climate change will depend on many factors. The severity of impacts is among those factors, as are the ability to understand the full implications of impacts, and the extent to which that knowledge is reflected in investment and policy decisions.

Since the early 1990s, and especially during the 21st century, significant progress has been made in understanding the impacts of climate change at national, regional, and local scales. These studies, many of which are discussed in the pages that follow, highlight physical processes that influence transportation, energy, water supply systems, agriculture and forestry, fisheries, tourism, and other important economic sectors. There persists, however, a lack of research that quantifies and compares these impacts and a deficiency in using what is known about climate impacts to guide adaptation actions, from the national down to the local level.

3.1 Water Supply and Agriculture

One of the most significant impacts of climate change in the US may be related to water supply. Surface and subsurface water flow and storage already are stressed by natural and anthropogenic causes. As a result, availability for human consumption, irrigation, energy production and industry may be reduced (Groisman et al. 2004). Climate change will exacerbate existing and future stresses placed on supplies by continued economic and population growth.

The uneven nature of climate change impacts throughout the country make the net impacts of global warming on the agricultural sector uncertain. Some northern regions are likely to experience fleeting economic benefits with more profitable crops migrating there (as the climate becomes hospitable to those crops). As climate conditions continue to change, however, those temporary benefits may be lost. Other regions, such as the Southeast, West, and southern Great Plains, may face challenges from increased temperatures, water stress, saltwater intrusion, and the potential increase in invasive species and pests – the impacts of which may cause costs to outweigh benefits.

Certain areas will experience greater precipitation levels, while others are likely to undergo prolonged droughts. In cases where more precipitation may occur in the future, damage to agricultural production may be considerable. For example, the US Midwest floods of 1993 inflicted $6-8 billion in damages to farmers. The North Dakota Red River floods in 1997 caused $1 billion in agricultural production losses. One study estimates that extreme weather-related damages to US agricultural crops are on the order of $1.5 billion per year. Expected increases in excess soil moisture conditions likely will result in an increase of their annual loss to $3 billion by the 2030s (Rosenzweig et al. 2002).

Economic impacts on the agricultural sector will vary by region. In the areas where precipitation levels are likely to stay constant or diminish, warmer temperatures may lead to increased risk of severe drought by increasing the rate of evaporation. The effects of future drought and decreased soil moisture on agriculture and natural vegetation (such as forests) are uncertain and may, at least in part, be temporarily offset by fertilization effects of higher atmospheric concentrations of CO_2 (Triggs et al. 2004). Nonetheless, the net impacts of global warming on the agricultural sector are, at least for the short- to medium-term, uncertain. Some northern regions are likely to temporarily see benefits, as more agriculturally valuable crops migrate there. However, that migration may also mean loss to some southern regions in which growing conditions may no longer be favorable for currently profitable crops. As climate continues to change, benefits from expanded production opportunities in the north may be lost as well.

Other regions, such as the Southeast, West, and southern Great Plains, may already in the short-term face challenges from increased temperatures, water stress, saltwater intrusions, and the potential increase in invasive species and pests (NAST 2001). The success of adaptation to the negative effects will likely be dependent on water availability, which already is overextended in many areas.

3.2 Coastal Impacts

With a majority of US cities and people located along the coasts (over 153 million people in 673 counties), significant and costly impacts to coastal infrastructure from storms and sea level rise are likely (Höppe and Pielke 2006). The number of people in coastal areas may grow another 7 million by 2008 (NOAA 2004). This growth, in turn, will likely increase the value of personal property and public infrastructure investment in coastal areas. As the number and intensity of adverse weather events will likely continue to increase in the future (NAST 2001), costs of climate change impacts will likely rise. Whether the surge of hurricane activity during the 2005 Atlantic Hurricane Season was due in any way to climate change is debatable (Webster et al. 2005; Hoyos et al. 2006; Kossin et al. 2007; Landsea et al. 2006), but it does provide a striking example of the costs associated with landfall of a major hurricane in a large, unprepared urban area. Real and perceived increases in the social vulnerability of coastal areas is affecting insurance coverage and rates along the Gulf and Atlantic Coasts (Mills 2005). The present rate of sea level rise is 0.08-0.12 inches per year for most of the US coast, and taking into account local subsidence, a 1-3 foot sea level rise is anticipated over the next century (Zervas 2001; IPCC 2001a). Loss of wetlands and developable land to sea level rise and erosion, as well as increased salinity of groundwater supplies and estuaries, affect agriculture and commercial fisheries, in addition to residential and economic development.

3.3 Energy

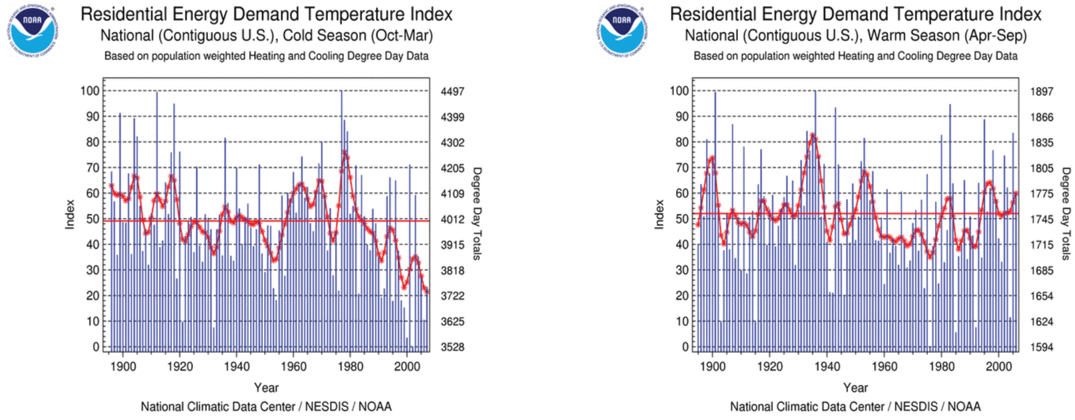
Future changes in energy supply and demand are also projected. Actual changes in production, use, and utility bills in urban areas will vary seasonally and by region (Hadley et al. 2006; Scott et al. 2005). Analysis of heating and cooling degree days, which are highly correlated with energy consumption, helps explain these changes in demand (NOAA 2007). A national trend in residential energy demand for cooling during the summer months is less apparent (no clear increase or decrease) than a national trend in heating degree days and energy use during the winter months over the last century (Figure 1). Region-specific studies, however, show very clear trends. For example an analysis of changes in heating and cooling demand in Boston, Massachusetts indicates that, depending on the climate scenario, household electricity consumption in peak summer months may be nearly three times that of the 1960-2000 average, with over 25% of the increase directly attributable to climate change (Amato et al. 2005). Similarly, Ruth and Lin (2006) show that for Maryland, approximately 24% of the increase in household electricity use and almost 10% of the increases in industrial electricity use by the year 2025, compared with the 1977-2000 average, are attributable to climate change. Such significant increases over only a few decades may render current planning for peak load capacity inadequate and may require more investment in the energy sector of those states and, likely, elsewhere in the nation.

Energy demand may also increase for irrigation (pumping water) as temperatures rise and local hydrology shifts (Peart et al. 1995; IPCC 2001b).

Conservation may become an important adaptation tactic to balance increased demand and decreased supply (Franco and Sanstad 2006; CEPA 2006). But this may also impose significant program implementation costs, such as expenditures on educational campaigns and monitoring systems.

Figure 1. NOAA Heating and Cooling Degree Days Data and Energy Demand

Residential Energy Demand Temperature Index Based on population weighted Heating and Cooling Degree Day Data (NOAA 2007)



3.4 Human Health

Impacts to human health also will vary regionally, as prevalence and susceptibility to certain diseases and health conditions vary with local climate, demographics and capacity to adapt to climate change (Rose et al. 2001). Many recent studies have linked high temperatures with increased mortality in the United States (Kalkstein 1993; Kalkstein et al. In Print), particularly in northern cities where residents are less accustomed to extremely warm weather (Table 1). Following extreme temperatures the death toll may increase as much as 85%, as it did in Chicago after a 5-day heat wave in 1995 (CDC 1995; Semenza et al. 1996, 1999). The impact of increased temperatures on morbidity and hospitalization is less clear than the mortality relationship, but a 1982 study by Jones et al. observed a 5% increase in hospital admissions during a 1980 heat wave in Kansas City (Jones et a. 1982). An 11% increase in hospitalizations was observed in Chicago following the 1995 heat wave (Semenza 1996). Increased incidence of death from heart diseases and diabetes, accidents, violence (including homicides), and suicide also have been associated with heat waves for a long time (Ellis 1972; Ellis et al. 1978).

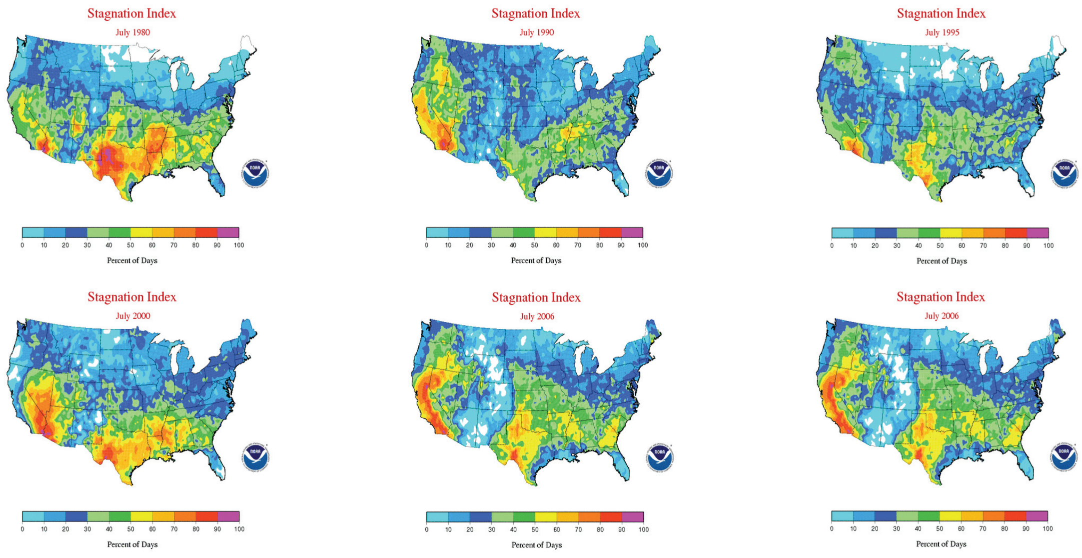
At the same time, warmer temperatures create ideal conditions for the development of stagnant air masses (Figure 2) that reduce air quality, trapping pollution and raising morbidity rates. Moreover, increased air pollution and allergens (CO_2 fertilization may lead to increased pollen production) may aggravate existing, and introduce new, respiratory ailments (Wayne et al. 2002). Stagnant air masses may also introduce travel hazards due to storms and unstable weather patterns (EPA 2003), and contribute to the spread of infectious diseases via habitat and genetic shifts in rodent and insect populations (Bradshaw and Holzapfel 2001). Although our health care infrastructure is capable of minimizing the worst effects of these impacts, the costs of adapting the infrastructure to changing conditions will be significant. In addition, any of these health-related impacts may lead to noticeable personal and insurance cost increases.

Table 1. Estimates of Total Heat-related Mortality for Average Summer on Three Climate Change Scenarios

	Present total	Estimated deaths on non-acclimatized (and climatized) basis for (*)					
City		A. GISS Trans A		B. GISS 2 × CO_2		C. GISS +2 °C	
Atlanta	18	45	(23)	159	(79)	203	(148)
Chicago	173	295	(145)	412	(622)	177	(88)
Cincinnati	42	93	(83)	226	(195)	378	(189)
Dallas	19	61	(61)	309	(244)	158	(79)
Detroit	118	201	(152)	592	(295)	302	(152)
Kansas City	31	33	(40)	60	(100)	330	(212)
Los Angeles	84	153	(81)	1654	(824)	164	(82)
Memphis	20	28	(14)	177	(88)	480	(229)
Minneapolis	46	96	(47)	142	(186)	209	(105)
New York	320	777	(386)	1743	(880)	577	(289)
Philadelphia	145	288	(142)	938	(700)	441	(220)
St Louis	113	325	(162)	744	(372)	749	(275)
San Francisco	27	44	(23)	246	(202)	66	(49)

(*) Full report has five scenarios: 1) Goddard Institute of Space Studies (GISS) Trans A (A in this table), 2) another modified scenario, 3) GISS 2 × CO_2 (B here), and 4) temperature rises of 3.6 °F (2 °C) (C here) and 5) 7.2 °F (4 °C). Source: Kalkstein 1993

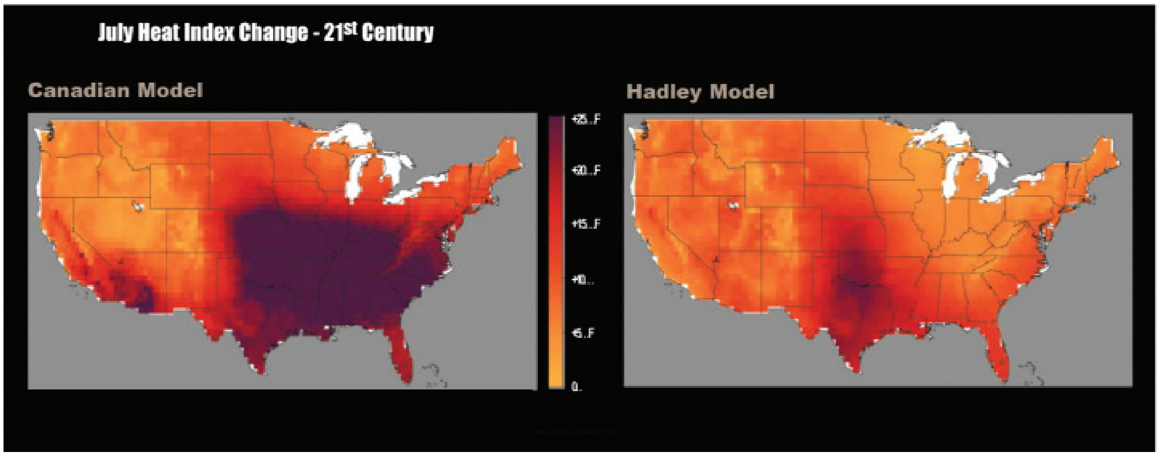
Figure 2. Air Stagnation Maps, June 1980-2006



The July heat index is predicted to increase by over 25ºF (13.9ºC) in some areas. The degree to which regions are likely to be affected by these increases varies, depending on the climate change model in use (see Figure 3). Both models, however, predict the greatest changes in the Southeastern region. For example, a day in Atlanta with the current heat index of 105ºF (40.6ºC) would reach a heat index of 115ºF (46.1ºC) under the Hadley Centre model, and 130ºF (54.4ºC) under the Canadian Climate Centre model (USGCRP 2001).

Figure 3. July Heat Index Increases in the United States.

July Heat Index Change – 21st Century. The color spectrum ranges from 0ºF to +25ºF in projected increase in average daily July heat index (USGCRP 2001).



Adaptation options include increasing the proportion of buildings (residences, offices and retail locations) with air-conditioning. Though it varies regionally, as of 2001, more than 70% of US residences have air-conditioning (27% in the Northeast, 88% in the South) (McGeehin and Mirabelli 2001). Other adaptation measures include changes in the built environment and use of materials that are less heat absorbing.

Hot Weather—Health Watch/Warning Systems (warning systems) have also been implemented in several US cities as a means of alerting residents of risky days.[1] First implemented in Philadelphia (called Heatline) in the summer of 1995, the warning systems have proven to be both effective and low cost (Kalkstein et al. 1996). A 2004 study by Ebi et al. quantified the costs of implementing the warning system in Philadelphia and compared those costs to the value of the lives saved (Ebi et al 2004). They estimated the total benefits from the system between 1995 and 1998 to be about $468 million.[2] The estimated wage costs for implementing the warning system were on the order of $5,000 per day on weekdays and $7,000 per day on weekends for Heatline operators and EMS crews. Other direct costs likely increased the costs of operation to $10,000 per day during a heat wave warning. With 21 warning days during 1995-98, the estimated costs of the Philadelphia system were about $210,000. The total cost of the system is likely much higher and includes expenses related to job absenteeism and lost economic productivity.

3.5 Forest Fires

More frequent and severe occurrence of forest fires may increase nationwide with climate change. Costs of suppressing fires increase with fire intensity and under certain climate conditions. Anticipated warmer and drier conditions in many areas, as well as earlier melting of snow-covered surfaces, are likely to extend the fire seasons and may increase fire intensity. A recent study analyzing wildfire trends in the western US found a six-fold increase

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[1] There are presently warning systems in Seattle, Washington; Dallas and Fort Worth, Texas; Phoenix and Yuma, Arizona; Washington, DC: Chicago, Illinois; St. Louis, Missouri; Cincinnati and Dayton, Ohio; New Orleans and Shreveport, Louisiana; Little Rock, Arkansas; Memphis, Tennessee; Lake Charles and Jackson Mississippi (NOAA 2004).

[2] 117 lives saved, $4 million per "statistical life" based on EPA estimates (Smith et al. 2001).

in the area of forest burned since 1986 compared with the 1970-1986 period. The average duration of fires increased from 7.5 to 37.1 days – mostly because of an increase in spring and summer temperatures and earlier thawing of snowpacks (Westerling et al. 2006). In general, there has been an increasing trend in the annual number of acres succumbing to fire in the National Forest System (NFS) since the early 1980s (USFS 2006). For example, with 1.2 million acres burned, 1987 marked the first year since 1919 when more than 1 million acres were affected. More than 1 million acres were ablaze again in 1988, 1994, and 1996 (USFS 2000). The most acres burned in 2006, when $1.5 billion in federal funds was used to protect over 9.3 million acres. Overall, over 7 million acres have burned every year for the past four years – with annual suppression costs amounting to $1.3 billion (USFS 2006).

Catastrophic forest fires account for 2.3% of the nation's insured losses (USFS 2006). The full cost of wildfires is vastly underestimated, however, since federal and state agencies only track suppression costs, structures lost, and acres burned. Other expenditures including loss of property and human life, public health needs, restoration of federal and private lands, impacts to local watersheds, or lost tourist revenue are not reported. There are additional indirect costs related to fires. For example, a study conducted for Alberta, Canada following a two-day forest fire in the town of Edmonton indicated that in addition to the $10 million spent on direct costs of fighting the fire, an additional expense of $10-12 million was accrued in lost wages, decreased productivity, and increased medical care (USFS 2006).

3.6 Insurance Claims

The increasing trends of adverse weather events, particularly in coastal areas, are predicted to continue (NAST 2001). Claims made to private and public insurers are expected to climb with them. From 1980 to 2005, private and federal insurance agencies distributed more than $320 billion in claims. Private insurers paid out 76% of the total, followed by the federal crop and flood insurance programs. The overall risk exposure of insurers' has grown considerably. The National Flood Insurance Program's exposure increased four-fold since 1980 to $1 trillion in 2005, and the Federal Crop Insurance Corporation's (FCIC) exposure grew to $44 billion (US GAO 2007a).[3]

In summary, the effects of climate change are expected to cross regional boundaries and exert negative impacts throughout the United States. These include stress to water supply networks, changes to the agricultural sector, threats to coastal infrastructure from storms and sea level rise, effects on energy supply and demand, increased risk to human health, more frequent and extensive forest fires, and additional impacts related to an increase in adverse weather events. Additional disconcerting trends relevant to specific regions in the United States are outlined in the rest of the report.

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[3] Expansion of FCIC's program contributed to the increase, as well as increases in portfolio holdings in hazard-prone areas.

4 Regional Summaries

4.1 Northeast and Mid-Atlantic

4.1.1 Overview

The Northeast and Mid-Atlantic regions include the most populated coastline in the country. Four out of the ten largest U.S. metropolitan areas are located within the region – New York, Washington DC/Baltimore, Philadelphia, and Boston (NOAA 2004). Figure 4 outlines predicted population changes in the region. Maryland and Virginia are predicted to experience the greatest percent of coastal population change in the United States. The major economic sectors include services, followed by manufacturing, finance, insurance and real estate, and trade. Agriculture, fisheries and resource extraction are also prominent industries in the region.

In the last century, the Northeast and Mid-Atlantic region has experienced significant increases in major weather events (from 12 to 20%), with the largest increases in very severe events. A warming of 4°F (2.2°C) has been observed along the coast from the Chesapeake Bay to Maine. Climate change scenarios for the next 90 years predict continued warming trends in the region, coupled with increases in precipitation levels (Barron 2001; Frumhoff et al. 2007).[4] The region's extensive coastal infrastructure – including transportation and energy supply networks and coastal developments – will likely endure the greatest portion of total economic impacts of climate change in the region.

4.1.2 Major Impacts

4.1.2.1 Coastal Infrastructure

Coastal developments, transportation facilities and infrastructure, as well as many energy and water supply systems are at risk of coastal storm surges. The Insurance Information Institute (2007) estimates that the value of insured properties vulnerable to hurricanes in the Northeast and Mid-Atlantic regions totaled nearly $4 trillion in 2004. One study estimated that a category 4 hurricane touching down in a major metropolitan area would inflict $50-66 billion in insurance losses alone (Barron 2001). Another assessment indicated that a sea-level rise of nearly 20 inches (50 cm) by 2100 would cause $23-170 billion in damages to coastal property throughout the US (Neumann 2000). With 34% of coastal properties located in the Northeast (NOAA 2004), the local costs of sea level rise are likely to amount to around $8-58 billion.

Figure 4. NOAA's Projected Population Change in the Region

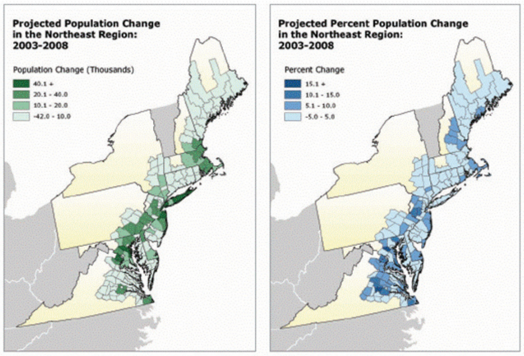

FIGURE 10. Projected population change in the Northeast Region: 2003-2008

Source: U.S. Census Bureau and W&PE, Inc.

FIGURE 11. Projected percent population change in the Northeast Region: 2003-2008

Source: U.S. Census Bureau and W&PE, Inc.

(Source: NOAA 2004)

Transportation infrastructure in the region is especially vulnerable. In the New York metropolitan area alone, there are 48 major transit facilities at 10 feet or less above sea level. All of the City's four airports also are at risk. The area's 2,200 bridges will likely be used as alternate routes and may become overstressed as a result (Zimmerman 2002). The scale of cost to repair or overhaul the system can be gleaned from the expenditures accrued after the attacks on September 11, 2001. Since that time, reconstruction costs of the transportation system in Lower Manhattan and the surrounding areas have amounted to over $7 billion (Zimmerman 2002).

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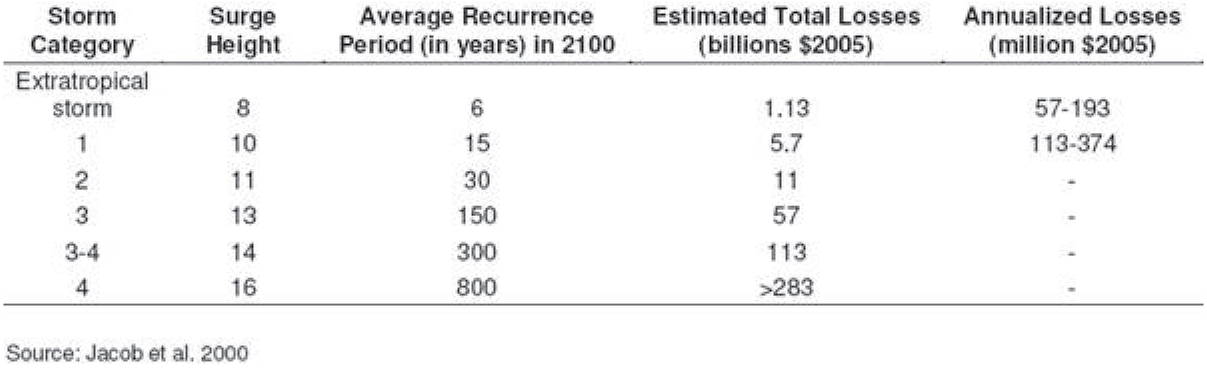
[4] Hadley Climate Model predicts a 25% increase in precipitation and a 5°F (2.8°C) average temperature rise. Canadian Climate Model predicts a 5-10% increase in precipitation and a 9°F (5°C) average temperature rise.

Table 2. Insured and Uninsured Losses from Coastal Surge, Flooding and Wind Damage in the Metropolitan East Coast Region



Storm Category	Surge Height	Average Recurrence Period (in years) in 2100	Estimated Total Losses (billions $2005)	Annualized Losses (million $2005)
Extratropical storm	8	6	1.13	57-193
1	10	15	5.7	113-374
2	11	30	11	-
3	13	150	57	-
3-4	14	300	113	-
4	16	800	>283	-

Source: Jacob et al. 2000

Similarly, flooding of the Boston subway system in 1996 inflicted over $92 million in damages (Frumhoff et al. 2007).

It is difficult to estimate how vulnerable roads are in the region. The length of rural and urban roads in the coastal states of the Northeast and Mid-Atlantic regions (all except Pennsylvania) extends 17,748 miles (US DOT 2005). Assuming that the density of urban roads is proportional to population density (77% of the population lives in coastal counties), then 7,439 miles of urban roads are potentially at risk.

In the Metropolitan East Coast Region, the expected insured and uninsured losses from coastal surge, flooding and wind damage expected with climate change range from $1.13 billion to over $283 billion, as outlined in Table 2 above. The estimated recurrence period is derived by averaging four commonly used climate change models (Jacob et al. 2000).[5]

Predictably, building protective structures along the coastline may become one option for mitigating the impacts. Constructing sea wall and bulkhead protection for just 25% of the length of the region's coastline would cost from around $300 million and just under $8 billion. Putting up dikes or levees to protect against a one-meter rise in sea level would run from $300 million to just over $1.5 billion for a quarter of the coastline.[6]

A major expenditure during a storm event is evacuation of the residents. According to NOAA (2004), the 2003 coastal population in the Northeast totaled 52.6 million people, comprising around 20.5 million households (US Census Bureau 2006).[7] Using data from a study that analyzed evacuation practices following the 1998 Hurricane Bonnie in North Carolina, the estimated direct costs of the evacuation ranged from $212 to $292 in 1998 dollars per household, depending on storm category (Whitehead 2000). Assuming the same evacuation trends and household costs, direct

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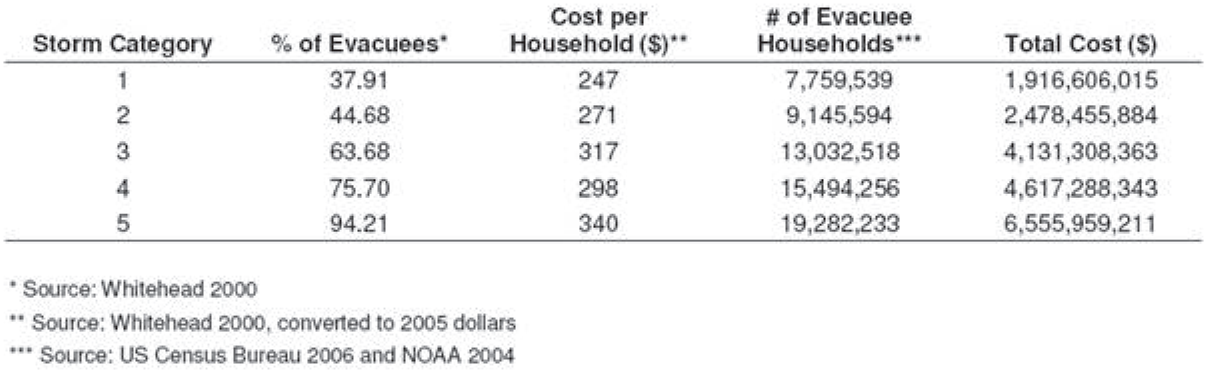
[5] The four scenarios used are: 1. HCGG=Hadley Centre Greenhouse Gases; 2. HCGS=Hadley Centre Greenhouse gases and Sulfate aerosols; 3. CCGG=Canadian Centre Greenhouse Gases; 4. CCGS=Canadian Centre Greenhouse gases and Sulfate aerosols.

[6] It is estimated that, in 2005 dollars, sea wall and bulkhead construction would cost $227-6,069 per linear foot and construction of dikes or levees to protect against 3.28 feet (1 meter) rise in sea level would cost $227-1,214 per linear foot (Neumann et al. 2000). NOAA puts the entire length of the region's coastline at 996 miles (or 5,258,880 feet) (CRS 2006).

[7] Census estimates the average number of people in a household to equal 2.57 (US Census Bureau 2006).

Table 3. Total Cost of an Evacuation in the Northeast States



Storm Category	% of Evacuees*	Cost per Household ($)**	# of Evacuee Households***	Total Cost ($)
1	37.91	247	7,759,539	1,916,606,015
2	44.68	271	9,145,594	2,478,455,884
3	63.68	317	13,032,518	4,131,308,363
4	75.70	298	15,494,256	4,617,288,343
5	94.21	340	19,282,233	6,555,959,211

* Source: Whitehead 2000

** Source: Whitehead 2000, converted to 2005 dollars

*** Source: US Census Bureau 2006 and NOAA 2004

costs of an evacuation effort for the Northeastern coastal region ranges from nearly $2 billion to over $6.5 billion. Table 3 summarizes the findings.

4.1.3 Other Impacts

Other industries in the region are expected to experience potentially deleterious effects stemming from global climate change as well. Changes in water quality and water temperature on the coasts may negatively affect the $63 billion ocean economy sector,[8] which employs 1.1 million people in the region (NOEP 2004; BEA 2005; Barron 2001; Frumhoff et al. 2007). The **skiing industry** also stands to become less viable. The region is home to 138 skiing facilities, whose annual revenues amount to nearly half a billion dollars (US Census Bureau 2002). The New Hampshire Department of Environmental Services estimates that direct and indirect spending in the New Hampshire skiing industry amounts to over 8 times the annual revenue (New Hampshire Department of Environmental Services 2005). If the same pattern holds for other states, direct and indirect spending for the industry in the entire region totals $4.05 billion. A decrease of 10-20% in skiing days will result in a loss of $405-810 million per year.

Other tourism industries, such as **snowmobiling and beach-related sectors**, which are primarily located in the vulnerable coastal communities, are likely to experience declines, as well (Frumhoff et al. 2007).

The **forest industry** will likely face declines in productivity as high as 17% (Barron 2001). Changes in forest composition and disturbances from pests, fire, and extreme weather events are likely to further jeopardize this economic sector, which generates over 300,000 jobs in New England and New York (Frumhoff et al. 2007). **Maple syrup** production may also suffer. Sap flow is predicted to fall by 17-39%, inflicting a loss of $5.3-12.1 million in annual revenue to this $31 million industry (Barron 2001).

Because the region spans a wide geographical and ecological area, economic effects on **agriculture** are expected to be mixed – at least for the short- to medium-term. For example, New York's agricultural yield may be reduced by as much as 40%, causing $1.2 billion in annual damages. On the other hand, Mid-Atlantic States' agricultural yields are likely to temporarily benefit from warmer temperatures (Barron 2001). The majority of annual losses suffered by the livestock industry will be due to warmer temperatures and heat stress on the animals. Annual losses of $50.8 million in Pennsylvania, $24.9 million in New York, and $5.4 million in Vermont mostly occur in the dairy industry, whose annual production value is $3.6 billion in the

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[8] This is defined as any economic activity, which directly or indirectly uses the ocean or the Great Lakes. Six sectors are included in the "ocean economy" – marine construction, living resources, minerals, ship and boat building, tourism and recreation, and transportation (NOEP 2004).

region (Frumhoff et al. 2007). Given the predicted disruptions from extreme weather events and warmer temperatures increasing the need for more irrigation, additional losses and the net effects on agriculture in the region are at present unknown. However, as an example of the potential magnitude, the 1999 nation-wide drought cost the Northeast region around $973 million in net farm-income losses (Frumhoff et al. 2007).

There are likely to be adverse **health impacts** on the population of the region. Floods and sea-level rise in estuaries and bays increase the presence of many water-borne pathogens, while higher temperatures may allow them to flourish and spread (Barron 2001). Heat-related illnesses and deaths may also increase. For example, it is estimated that an increase from the current 13 days above 90°F (32.2°C) to 16-32 days predicted by the climate change models may result in a five-fold increase in heat-related mortality in New York City (Barron 2001). The number of ozone-related deaths in the New York Metropolitan Region is predicted to increase by 53.8-63.8% by 2050, relative to 1990, assuming a scenario with continued high CO_2 emissions (30 gt/yr max) and significant population increases (15 billion by 2100; Kinney et al. 2006).

Additional effects to the infrastructure include those on **water and energy systems**. The Mid-Atlantic states are particularly vulnerable to potential disruptions to surface water recharges, since 95% of all water withdrawals are highly dependent on surface water flow (Barron 2001). Energy transmission infrastructure could itself be disrupted as a result of more severe weather occurrences or become overstressed during such events.

4.1.4 Missing Information and Research Needs

Economic impacts from climate change on coastal and urban infrastructures in the Northeast and Mid-Atlantic region likely dominate in magnitude the impacts on many of the other sectors of the region. At the same time, a reliable infrastructure is essential for performance of the other sectors. Consequently, prioritizing data collection and research may require a particular focus on the vulnerability of existing infrastructures in coastal areas (especially transportation and energy systems). Since infrastructures are often interdependent in their performance, research will need to account specifically for those interdependencies, lest important determinants of their individual performances are overlooked. For example, adequate flood control will be key to reliable transportation, reliable cooling water supply will be essential for electricity generation, and reliable electricity and water supply will contribute to public health. Similarly, investment and policy-making need to be cognizant of, and explicitly deal with, those interdependencies in order to reduce the region's overall vulnerability to climate change.

4.2 Southeast

4.2.1 Overview

The Southeast states – Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North and South Carolina, Tennessee, Virginia, and the Gulf Coast of Texas – may be some of the hardest hit by climate change in the US. By value, the region produces about one quarter of US agricultural products; half of US timber supplies; and much of the nation's fish, poultry, tobacco, oil, coal and natural gas (Burkett et al. 2001). As such, the state economies are intricately tied to the condition of their natural resources. Having undergone rapid population growth during the 1970s-1990s (30%), the region is expected to continue growing, perhaps another 40% between 2000 and 2025. The climate in the Southeast has gone through a warm period during the 1920s-40s, a cool period from 1950-1960, and is presently in another warm period that began in the 1970s. There has been a 20-30% increase in precipitation over the last 100 years. The Canadian Climate Centre (CCC) model scenarios show continued warming through the 2090s, whereas the Hadley Centre model scenarios project less warming (Burkett et al. 2001) and about a 20% increase in precipitation throughout the region by 2100. Both models predict an increase in the heat index greater in the Southeast than in other US regions, 8-15°F

(4.5°C-8.4°C) or more (Burkett et al. 2001). With warmer weather and warmer water in the Atlantic and the Gulf of Mexico, the region may experience an increased frequency and intensity of storms, sea level rise, and the loss of important agricultural areas, crops and timber species.

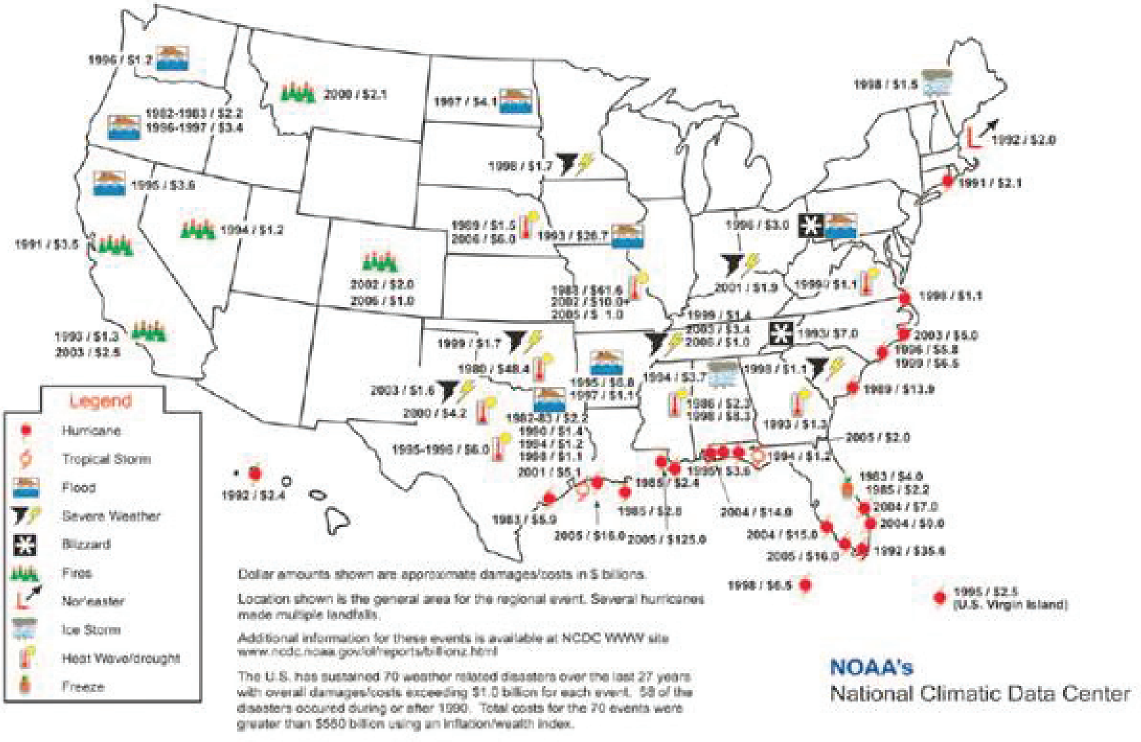
4.2.2 Major Impacts

4.2.2.1 Coastal Infrastructure

Since 1980, the United States has witnessed 70 natural disasters – including hurricanes, floods, heat waves, and droughts – each causing over $1 billion in damages (Figure 5). Fifty-eight of these events have occurred since 1990 and 29 have been in the Southeast. Total estimated damages from all of the billion-dollar events are more than $540 billion (Lott and Ross 2006).

Hurricanes and tropical storms are by far the most frequent and destructive of the natural disasters documented by the National Climatic Data Center at NOAA. Other disasters include non-tropical floods, heatwaves and drought, severe weather, fires, freezes, blizzards, ice storms and nor'easters, accounting for 24 of the 70 events and $308 billion in damages (Figure 6). The Southeast states were hit hardest by these natural disasters, with each state,

Figure 5. Billion Dollar Weather Disasters, 1980 - 2006



Dollar amounts shown are approximate damages/costs in $ billions.

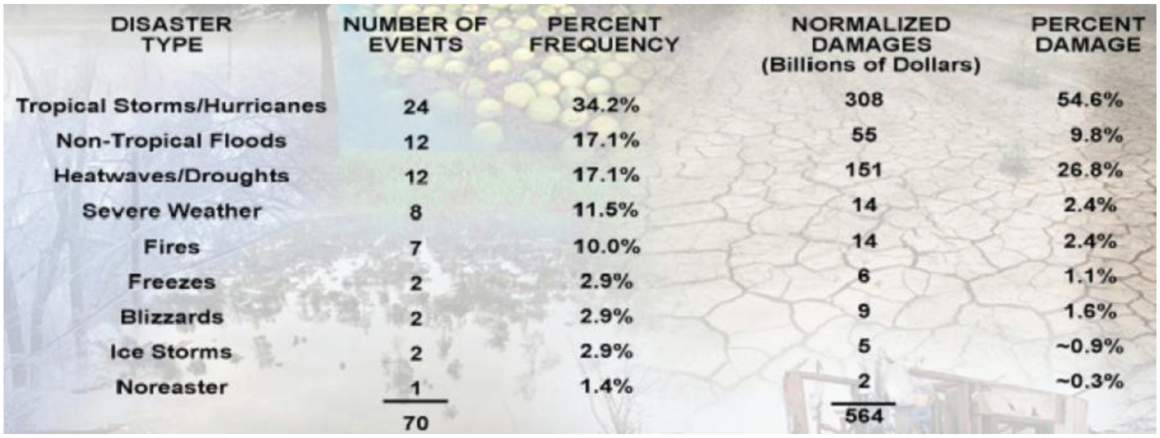
Location shown is the general area for the regional event. Several hurricanes made multiple landfalls.

Additional information for these events is available at NCDC WWW site www.ncdc.noaa.gov/ol/reports/billionz.html

The U.S. has sustained 70 weather related disasters over the last 27 years with overall damages/costs exceeding $1.0 billion for each event. 58 of the disasters occured during or after 1990. Total costs for the 70 events were greater than $560 billion using an inflation/wealth index.

(Source: NCDC 2007)

Figure 6. Billion Dollar Weather Disasters by Type



DISASTER TYPE	NUMBER OF EVENTS	PERCENT FREQUENCY	NORMALIZED DAMAGES (Billions of Dollars)	PERCENT DAMAGE
Tropical Storms/Hurricanes	24	34.2%	308	54.6%
Non-Tropical Floods	12	17.1%	55	9.8%
Heatwaves/Droughts	12	17.1%	151	26.8%
Severe Weather	8	11.5%	14	2.4%
Fires	7	10.0%	14	2.4%
Freezes	2	2.9%	6	1.1%
Blizzards	2	2.9%	9	1.6%
Ice Storms	2	2.9%	5	~0.9%
Noreaster	1	1.4%	2	~0.3%
	70		564	

(Source: NCDC 2007)

except Kentucky, experiencing at least 16 events that caused over $1 billion in damages each. Texas, Alabama, Georgia, Florida, and North Carolina each experienced 21-25 natural disasters from 1980-2006 (Lott and Ross 2006).

In 2005, the nation was made painfully aware of the damages possible from extreme storm events when Hurricanes Katrina and Rita struck. A total of 90,000 square miles was declared a federal disaster area following Hurricane Katrina, covering four states and 23 coastal counties and parishes. Eighty percent of the City of New Orleans was flooded, and more than 1,700 lives were lost. More than 350,000 homes were destroyed and another 146,000 seriously damaged. A total of 850,791 housing units were damaged. At an estimated $100,000 repair cost per unit, the total cost to rebuild what was lost could exceed $85 billion (Petterson et al. 2006). In addition to the urban infrastructure damaged by the storms, Petterson et al. (2006) estimated that 2,100 oil platforms and over 15,000 miles of pipeline were damaged. Lost revenue due to the damages amounted to almost $11 billion – 153 million barrels of oil (of an annual total of 547 million) at approximately $70 per barrel at the time of the hurricanes. The questions of what to rebuild, when, and at what cost have spurred debates locally, regionally and nationally, and have stirred deep-seated environmental justice concerns.

4.2.3 Other Impacts

Not all of the impacts from climate change in the Southeast pertain to coastal infrastructure. Forests, agriculture and fisheries, water quality, and energy may be subject to notable change and damages as well.

Forestry is a major economic sector in the Southeast. For example, the state of South Carolina boasts 60% forest cover and forestry is, after tourism, the second largest economic sector (South Carolina State Climatology Office 2007). Given the diversity of species and environmental conditions, short- to medium-term impacts on forests are uncertain. Sea level rise resulting in salt water intrusion may damage forests, particularly in southern Florida and Louisiana (Burkett et al. 2001). Higher temperatures, decreased soil moisture, and more frequent fires may stress forest ecosystems and ultimately may lead to a conversion from forest to savannah and grassland (Burkett et al. 2001). However, some species may see, at least temporarily, increases in productivity and forested acreage due to a longer growing season, CO_2 fertilization, and a switch from stressed to more acclimatized species. For examples, southern loblolly pine plantations may experience yield increases of 11% by 2040, and 18% by 2040, raising the expenses to $93 and $124 million respectively. Hardwood and mixed pine-hardwood forests (64% total forested area) will likely increase in acreage by 22% by 2040, and 25% by 2100, compared with 1990 base levels. (Burkett et al. 2001).

As increased storm frequency and intensity impact coastal infrastructure, they may also reduce **water quality** and harm **fish** populations. Fish and shellfish are at risk in warmer waters and when exposed to increased pollution following major storm events (Burkett et al. 2001). Much of this pollution will come from stronger storms stressing water management systems and causing sewer systems to overflow, as well as increased nutrient runoff from agricultural lands.

Energy demand will also change in the Southeast as temperatures increase, though not as much as in more northern regions. The majority of homes and offices already are equipped with air conditioning, and will face fewer expenses upgrading compared with cities in the Northeast that have fewer structures with central air conditioning. However, increased energy demand to meet cooling needs may add stress on the energy supply system and waste heat may exacerbate urban heat island effects and their associated human and environmental health impacts.

4.2.4 Missing Information and Research Needs

The high density of infrastructure in coastal regions of the Southeast, combined with high rates of sea level rise and subsidence, as well as exposure to hurricanes, make preparedness to coastal storms a high priority for research. As in the Northeast and Mid-Atlantic (and for that matter, much of the US), regional infrastructure systems are closely tied to each others' performance – for example, energy supply depends on cooling water availability; transportation on flood control; communication on energy; emergency preparedness on transportation, energy supply, resilient communication systems, water availability and more. Only a few of these interrelationships typically enter economic impact and cost assessment, and significant room persists to substantiate those relationships and make them an integral part of regional and local investment and policy decisions.

4.3 Midwest

4.3.1 Overview

Within the eight states of the Midwest region – Illinois, Wisconsin, Indiana, Ohio, Iowa, Minnesota, Missouri, and Michigan – lies the largest group of freshwater lakes in the country and the world. Long accustomed to utilizing this unique natural resource for shipping and manufacturing purposes, the Midwest produces 40% of the US industrial output and provides 30% of the US foreign agricultural exports. Observed climate change effects in the region include increases in temperatures – 4°F (2.2°C) in the North and 1°F (.6°C) in the South (Easterling and Karl 2001). A big concern in the region is drought-like conditions resulting from elevated temperatures, which increases levels of evaporation, contributing to decreases in soil moisture and reductions in lake and river levels.

4.3.2 Major Impacts

4.3.2.1 Manufacturing and Shipping

Around $3.4 billion and 60,000 jobs rely on the movement of goods within the Great Lakes-St. Lawrence shipping route annually (Easterling and Karl 2001). In 2004, over 42 billion ton-mileage[9] of overseas and Canadian goods was shipped through the Great Lakes, and 65 billion ton-mileage of goods destined for domestic distribution were carried as freight on the Lakes in 2004 (US ACOE 2004). Table 4 below outlines the geographic distribution of the domestic freight within the shipping route area, which is dominated by Lake Erie and Lake Hurron.

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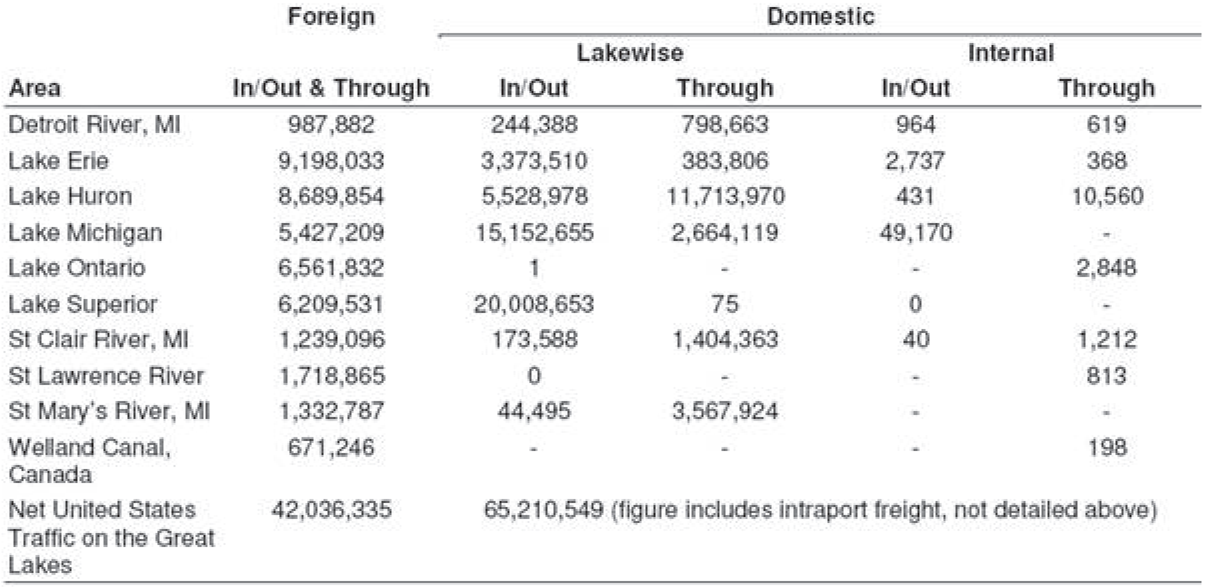
[9] Ton-mileage is obtained by multiplying the tons of commerce being shipped by the actual distance (in miles) moved on the water-route. It is a measure of total activity on the water channel (US ACOE 2004).

Table 4. Ton-mileage of US Freight Carried on the Great Lakes, 2004



	Foreign	Domestic			
		Lakewise		Internal	
Area	In/Out & Through	In/Out	Through	In/Out	Through
Detroit River, MI	987,882	244,388	798,663	964	619
Lake Erie	9,198,033	3,373,510	383,806	2,737	368
Lake Huron	8,689,854	5,528,978	11,713,970	431	10,560
Lake Michigan	5,427,209	15,152,655	2,664,119	49,170	-
Lake Ontario	6,561,832	1	-	-	2,848
Lake Superior	6,209,531	20,008,653	75	0	-
St Clair River, MI	1,239,096	173,588	1,404,363	40	1,212
St Lawrence River	1,718,865	0	-	-	813
St Mary's River, MI	1,332,787	44,495	3,567,924	-	-
Welland Canal, Canada	671,246	-	-	-	198
Net United States Traffic on the Great Lakes	42,036,335	65,210,549 (figure includes intraport freight, not detailed above)			

Any decline in water levels along the system could jeopardize this relatively inexpensive and effective method of transporting manufactured goods. If water levels drop significantly, a scenario described by the Canadian Climate Centre Model, dredging may be the only alternative to salvage this system. It is estimated that between 7.5 and 12.5 million cubic yards would need to be dredged annually at a cost of $85-142 million (Great Lakes Regional Assessment Group 2000). System connectivity is predicted to become 25% impaired, causing a loss of $850 million annually (Easterling and Karl 2001). Increased incidences of drought will likely place an additional stress on the water conveyance system. For example, a 1988 Midwest drought cost the region over $49 billion, in part because riverine commercial shipping had to be replaced by more expensive railroad transport due to the Mississippi River's reduced water levels (Easterling and Karl 2001).

4.3.3 Other Impaacts

Forestry is an integral part of the economic structure in the Midwest. Over 90% of forestland is used for commercial forestry, resulting in economic activity valued at $41.6 billion (Great Lakes Regional Assessment Group 2000). The sector employs 200,000 people and produces $27 billion in forest products. Many of the economically valuable timber species – aspen, jack pine, red pine, and white pine – may be lost due to warming of the climate (Easterling and Karl 2001). The virgin pulping/wood fiber industry may be eliminated entirely as the forested landscape shifts toward oak and hickory species.

Potentially negative impacts are expected to the $5.7 billion **dairy industry**, since milk production by dairy cows is temperature sensitive and declines once temperatures advance beyond a certain threshold (Great Lakes Regional Assessment Group 2000). The **agriculture** sector also may experience losses similar to the 1988 drought, which cut production of grain by 31% and production of corn by 45% (Easterling and Karl 2001). The variability and spectrum of potential impacts make it difficult to predict the economic effect on agriculture. Some of these impacts include: increases in soil erosion, increases in severe weather events, increases in use of herbicides, and an extended growing season with associated changes in water demand and quality, as well as impacts on ecosystems and fisheries (see, e.g. Donaghy et al. 2006).

The region is well-known to **outdoor recreation** enthusiasts and most portions of the industry are likely to suffer because of climate change. For example, the distribution of prominent game and other bird species (e.g. waterfowl, warblers, perching bird species) may be altered, affecting hunting and bird-watching. In Michigan, Minnesota and Wisconsin alone, $4.7 billion was spent in 1996 on hunting, and bird-watching generates $668 million in retail sales and supports 18,000 jobs. **Skiing** is likely to be affected as well. Lighter than usual snowfall during the 1997-1998 season resulted in business losses of $144 million (Great Lakes Regional Assessment Group 2000). **Boating** is another favorite pastime – 4 billion boats are owned in the region. Reduced water levels may require dredging to ensure access to the 1,883 marinas, at a total annual cost of $68 million (Great Lakes Regional Assessment Group 2000).

4.3.4 Missing Information and Research Needs

One of the major impacts of climate change in the region will be on shipping and, as a result, the manufacturing base that depends on reliable supply of inputs into the production process, as well as shipment of products to markets, will be affected. Little information is currently available to assess the broader logistics and supply chain implications of climate change in the region, as well as the associated costs to businesses in transport and manufacturing sectors, employment and costs to end consumers. Data collection and research to fill this knowledge gap and guide policy and investment decision-making will need to combine climate science with business decision-making and regional economic impact assessment. Information on re-routing the shipments and the cost incurred by the industry would be helpful in evaluating the larger picture.

4.4 The Great Plains

4.4.1 Overview

The Great Plains region includes Texas and New Mexico in the south and all the states spanning to Montana and North Dakota to the north.[10] Its economic base is formed primarily by the service sector, but includes manufacturing, government, finance, and insurance and real estate industries (Joyce et al. 2001). Although agriculture's overall economic contribution to the gross regional product is fairly small (see Table 5), 90% of the land in the region is used for agriculture (Ojima 2002). The region has already witnessed increased temperatures and precipitation, as well as decreased snowpack (Joyce et al. 2001). The average temperatures are predicted to increase by around 3°F (1.7°C) by 2030 and increases up to 11°F (6.1°C) by 2090 may be expected. Although average precipitation may slightly decline by 2030, it is predicted to increase by almost 5 inches per year by 2090 (Ojima 2002). Despite predicted precipitation increases, higher temperatures throughout the region are likely to result in net soil moisture declines because of water loss through evaporation (Joyce et al. 2001). Competing uses for water could result in re-prioritization of land use and economic sectors.

4.4.2 Major Impacts

4.4.2.1 Agriculture and Water

The agricultural sector in the region contributes $22.5 billion annually in market value of products – 35% of which is attributed to crops and the rest to livestock (Ojima 2002). The sector already uses 40% of the total water in the region and, although there is some evidence that productivity of certain crops may temporarily benefit from warmer temperature, decreased availability of water for agricultural purposes may pose a more significant economic hurdle (Joyce et al. 2001). Long-term increases in temperatures may overwhelm agricultural coping mechanisms. The consumptive demand for water of some crops (especially grass and alfalfa) may increase by 50% by 2090, further straining water resources in the region (Joyce et al. 2001). One study estimated that net agricultural income will decrease by 16-29% by 2030 and by 30-45% by 2090 because of

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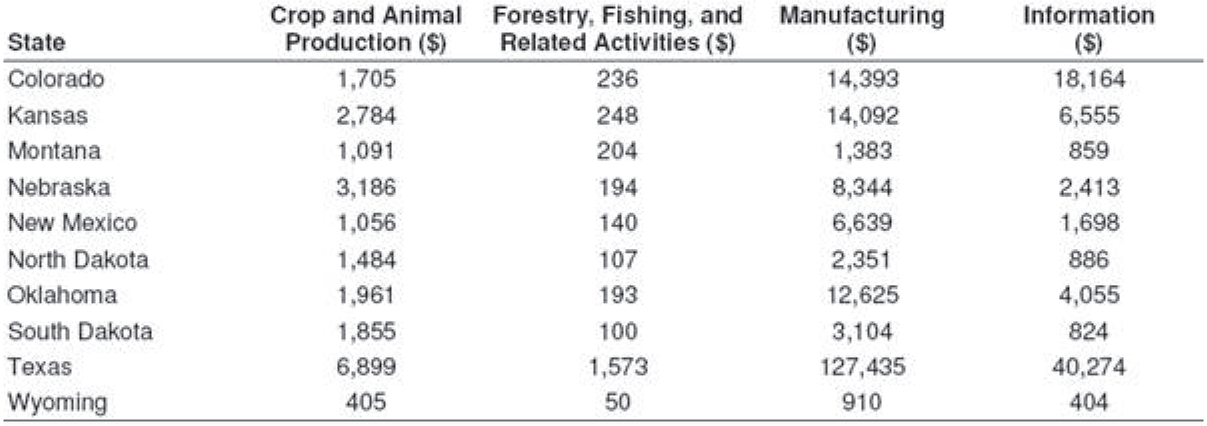
[10] CO and WY are also included in the "West" Assessment; and MT is also included in the "Pacific Northwest" assessment.

Table 5. Selected Industries and Their Contribution to State Domestic Product in Millions of Dollars, 2005



State	Crop and Animal Production ($)	Forestry, Fishing, and Related Activities ($)	Manufacturing ($)	Information ($)
Colorado	1,705	236	14,393	18,164
Kansas	2,784	248	14,092	6,555
Montana	1,091	204	1,383	859
Nebraska	3,186	194	8,344	2,413
New Mexico	1,056	140	6,639	1,698
North Dakota	1,484	107	2,351	886
Oklahoma	1,961	193	12,625	4,055
South Dakota	1,855	100	3,104	824
Texas	6,899	1,573	127,435	40,274
Wyoming	405	50	910	404

Source: BEA 2005

conflicting water uses around the San Antonio Texas Edwards Aquifer region (Chen and McCarl 2000). If similar trends hold for the entire region, the agricultural sector stands to lose $3.6-6.5 billion by 2030 and $6.75-10.13 billion by 2090on an annual basis.

The agricultural sector is vulnerable to projected increases in disturbances, such as drought and invasive species. A year-long drought in 1995 cost the Southern Great Plains agricultural sector $5.81 billion (Joyce et al. 2001). Stressed ecosystems are more susceptible to invasive species; control costs and weed-associated losses due to invasives amount to $15 billion annually nationwide. The region is home to 23.4% of the nation's crop and animal production (BEA 2005). Under the assumption that costs to control invasive species are distributed evenly throughout the country, the region expends $3.51 billion annually in invasive species control costs. This figure may increase dramatically, as damaging invasive species migrate north with warmer temperatures.

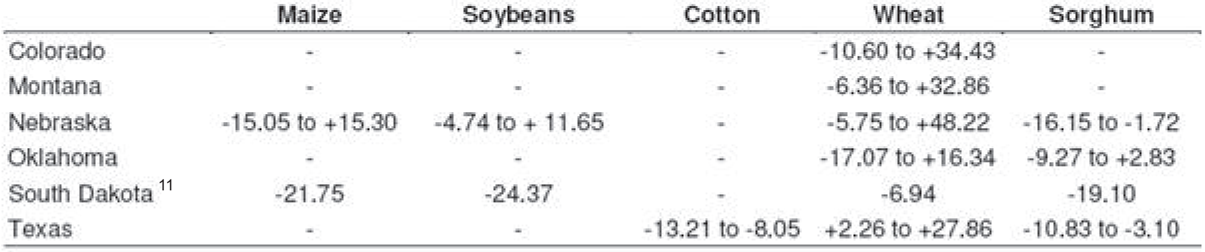
Changes in crop productivity are likely to be both positive and negative, at least in the short- to medium-term. However, in the long run, if temperatures continue to increase and water availability continues to change seasonally and in total, even some of the better adjusted crop types may no longer be able to cope. The Southern and Plains regions are likely to experience a decline in productivity – by as much as 70% for soybeans and 10-50% for wheat (Reilly et al. 2003). Crops in other areas may temporarily increase their yields (see Table 6). The crops around the Edwards Aquifer Region, however, are expected to have lower yields (Chen and McCarl 2000). Table 7 outlines the predicted changes.

An additional burden on the agricultural sector may be an increased resilience of insects to pesticides. Pesticide use and the associated costs are estimated to increase by 10-20% for corn; 5-15% for potatoes; 2-5% for cotton and soybeans; and 15% for wheat (although pesticide expenditures for wheat may also decrease by 15%; Reilly et al. 2003).

4.4.3 Other Impacts

Water demand for municipal uses will likely increase as regional temperatures continue to rise. A study of the San Antonio Texas Edwards Aquifer region estimates municipal water demand to increase by 1.5-3.5% (Chen and McCarl 2000). As supplies of freshwater diminish, quality of water is likely to suffer. Increased contamination of water has been estimated to raise the cost of water treatment by 27% from around $75 to $95 per million gallons in Texas (Dearmont et al. 1997).

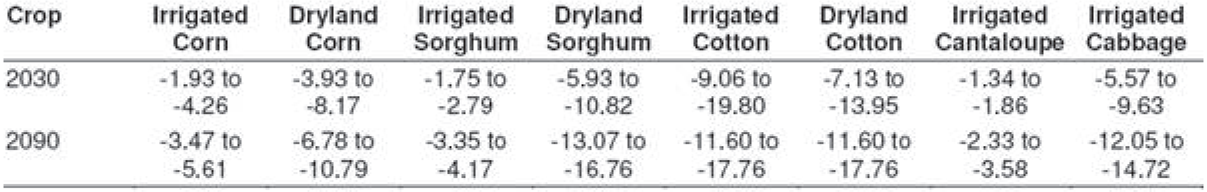
Table 6. Predicted Percentage Changes in Yield Variability for 2090 in Selected States
Under the Canadian Climate Centre and Hadley Centre Models



	Maize	Soybeans	Cotton	Wheat	Sorghum
Colorado	-	-	-	-10.60 to +34.43	-
Montana	-	-	-	-6.36 to +32.86	-
Nebraska	-15.05 to +15.30	-4.74 to + 11.65	-	-5.75 to +48.22	-16.15 to -1.72
Oklahoma	-	-	-	-17.07 to +16.34	-9.27 to +2.83
South Dakota [11]	-21.75	-24.37	-	-6.94	-19.10
Texas	-	-	-13.21 to -8.05	+2.26 to +27.86	-10.83 to -3.10

Source: Reilly et al. 2003

Table 7. Predicted Percentage Changes in Crop Yield in the Edwards Aquifer Region
Based on the Hadley Centre and Canadian Climate Centre Models



Crop	Irrigated Corn	Dryland Corn	Irrigated Sorghum	Dryland Sorghum	Irrigated Cotton	Dryland Cotton	Irrigated Cantaloupe	Irrigated Cabbage
2030	-1.93 to -4.26	-3.93 to -8.17	-1.75 to -2.79	-5.93 to -10.82	-9.06 to -19.80	-7.13 to -13.95	-1.34 to -1.86	-5.57 to -9.63
2090	-3.47 to -5.61	-6.78 to -10.79	-3.35 to -4.17	-13.07 to -16.76	-11.60 to -17.76	-11.60 to -17.76	-2.33 to -3.58	-12.05 to -14.72

Source: Chen and McCarl 2000

Higher incidences of **severe weather** events are likely to cause major damage to the region's infrastructure. For example, a 1999 outbreak of tornadoes in the Great Plains caused $1.16 billion in damages and 54 deaths; and an extreme flooding event in 1998 in southeast Texas inflicted $1.16 billion in damages and caused 31 deaths (Joyce et al. 2001).

4.4.4 Missing Information and Research Needs

The agricultural sector of the Great Plains, because of its dominance in the region and its dependency on water resources, may be significantly affected by climate change. Major research efforts are under way to estimate the cost and benefits to agriculture from changes in temperatures and precipitation patterns. Whether climate change may be beneficial to the agricultural sector overall, however, depends on a range of issues, from the ability of crops to react to the full range of possible changes in the climate, to the technologies and practices employed in growing food, to the range of climate conditions that are considered. In the short- to medium-term, production of several crops will show increased yield. However, for the more distant future, some of those crops, too, may be stressed as temperatures increase and water becomes scarce. One of the areas in need of significant attention by researchers is the identification of long-term transition strategies for the agricultural sector to make it less vulnerable to climate change. Exploration of how best to develop transition strategies into action at the regional, local and farm level is needed.

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[11] Note: For South Dakota, the Canadian Center Model was used to estimate loss of productivity for maize and wheat production only; and the Hadley Centre Model was used to assess soybeans and sorghum production only.

4.5 West

4.5.1 Overview

The Western region of the country stretches from desert plateaus of Arizona and New Mexico to the mountainous ranges of Colorado and Northern California, all the way north to Wyoming. Climatically sensitive sectors – agriculture, mining, construction, and tourism – account for nearly one-eighth of the region's economy.[12] The sprouting population of the region greatly influences the flow and allocation of resources. Temperatures have already increased 2-5°F (1.1-2.8°C) within the past century and the snow season is now shorter by 16 days in California and Nevada (Smith et al. 2001). The Central Valley of California, southeastern California, south-central Utah, northeastern Arizona and western Colorado all experienced more drought as compared with the rest of the region (Smith et al. 2001). The predicted impacts of climate change on the region include wetter winters and drier summers, as well as sea level rise of 6-37 inches by 2100 (Smith et al. 2001). Similar to the Great Plains, meeting the competing needs and uses for water resources will be a major challenge as decreased winter snowpack contributes to changes in water flow, both in quantity and timing.

4.5.2 Major Impacts

4.5.2.1 Water System and Agriculture

The use of water in the area is highly regulated and apportioned between many stakeholders through interstate and international agreements. This system is the product of past population and climatic pressures. The Colorado River Compact of 1922, for example, handles the water-distribution networks among several States in the West, including Arizona, California, Nevada, New Mexico, and Utah (Konieczki et al. 2004). Many argue that the system is already overstressed (Smith et al. 2001). Satisfying the legal requirements currently in place, meeting additional demand, maintaining the physical infrastructure, and juggling competing uses will become more challenging and costly if climate change advances and stores of water are depleted. Major climate change models predict winter snowpack will decline and snowmelt will occur earlier, resulting in greater runoff.[13] Storing water in aquifers for later withdrawal, which is the practice currently used to manage the resource, may be compromised (Smith et al. 2001).

The demand for water is rising in the region. Withdrawals for all purposes – domestic, agricultural, and industrial – have increased 58% to 62.8 million acre-feet from 1950 to 2000 in Arizona, California, Nevada, New Mexico, and Utah. Domestic water use has grown 410%, with population growth reaching 250%. Ground-water withdrawals increased dramatically in most States – 324% in Nevada, 147% in New Mexico, 208% in Utah, and 52% in California, although they decreased 15% in Arizona (Konieczki et al. 2004). While the demand for water has steadily increased, there is evidence that the supply is drying up. For example, the total annual streamflow of the San Pedro River in southeastern Arizona has experienced a drop of about 66% from 1913 to 2002 (Thomas 2006).

One study predicts that in the years 2070-2099, an additional 254,000 acres now producing crops will have to be fallowed because of water shortages around the Central Valley, which will generate an annual loss of $278.5 million (9% of net revenue). However, during especially dry years – which are estimated to occur 15% of the time – 29.1% of the land will have to be fallowed, resulting in an annual loss of $829 million (26.4% of total revenue). Considering multiplier effects on the overall well-being of the economy and applying an output multiplier of 2.1, the estimated economy-wide loss will be $6 billion during dry years (Hanemann et

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[12] Economic sector sensitivity to climate change is determined by modeling historical economic and weather data and analyzing how economic output in each of the sectors fluctuates as a result of weather variation (Lazo et al. 2006).

[13] Runoff is the portion of precipitation that escapes managed water cycles in uncontrolled surface streams, rivers, drains, or sewers.

al. 2006). On an individual farm level, decreased supplies of water will likely reduce the value of affected farmland by around 36% of the overall area-weighted, per-acre value of the farm, which on average equals $1,700 (Schlenker et al. 2005). Other agricultural activities may be impacted, as well. The value of wine production in California is $3.2 billion (California Climate Change Center 2006). Grape quality will likely diminish with higher temperatures, causing losses to this sector (PNAS 2007). A decline in dairy cow productivity is correlated with higher temperatures as well. An annual loss of $287-902 million is expected to this $4.1 billion industry in California (PNAS 2007).

Agricultural water use is only part of the picture; urban and industrial uses and needs should be considered also. It is estimated that the predicted growing population in California will raise urban demand for water by 62% by 2085. Meeting this increased demand will run the state $316 million per year. However, for 35% of the driest years, the costs are likely to be on the order of $5 billion per year (Hanemann 2006). Some climate scenarios suggest that the amount delivered to the West Side of the San Joaquin Basin may be reduced by 50% (Hidalgo 2006). Other studies indicate decreases in deliveries of 11 and 14.5% (depending on the provider - Central Valley Project and State Water Project, respectively) to the region between 2035-2064, and 27.3 and 31.4% between 2070-2099 (Hanemann 2006). Considering that the annual agricultural receipts for the Central Valley total more than $4.9 billion (California Water Plan Update 2005), reducing water deliveries to this profitable sector will likely affect the whole area.

Water procurement in Arizona, Nevada, and New Mexico is already a controversial issue. Strained supply of water will likely increase the cost of living in the major metropolitan areas of those states.

4.5.3 Other Impacts

Sea level rise and flooding are likely to affect Southwest coastal areas. For example, to protect the San Francisco Bay Area and the stretch of coast south of Santa Barbara from a 3.28 feet (1 meter) rise in sea level, an initial investment of $1.52 billion, plus $152 million in annual maintenance costs, will be required (Smith et al. 2001). The probability of a major flood event there is predicted to increase to a 2-in-5 chance of an event occurring in the next 50 years (Franco et al. 2005).

Energy infrastructure will also be affected. Under extreme heat events, the increase in net energy expenses in California is expected to rise by $2 billion (Franco et al. 2005). Other studies predict yet more severe increases in energy expenditure for residential and commercial buildings. Under the mildest warming scenario of 2.7°F (1.5°C), the annual costs are predicted to increase by $1.37 to 3.7 billion by 2100. Under scenarios of an extreme 9°F (5°C) warming, annual costs increase by $8.11 and 18.7 billion (Mendelsohn 2003). Another potential source of expenditure may come from the need to obtain energy from sources other than hydropower, which relies on high water levels. If energy generated from hydropower sources is reduced by 10%, making up the deficit through other supplies will cost $3.5 billion/year for California (Franco 2005).

About 45% of land in California is covered with **forest.** Thirty-five percent of this is commercial forest. Effects of climate change are predicted to reduce the productivity of mixed conifer stands by 18%, and productivity of pine plantations by 30%. Additional stresses on forests, such as the expected 55% increase in forest fires, will also damage this resource (California Climate Change Center 2006). Economic damages inflicted from increased incidences in fires will likely be far-reaching. The 1991 Oakland fire caused losses of about $2.2 billion (in 2005 dollars), and the 2003 wildfires in San Diego and San Bernardino Counties damaged $2 billion worth of property and infrastructure (Insurance Information Institute 2007).

The recreation industry is also likely to suffer. **Skiing**, for example, is worth around $1 billion for the entire region (US Census Bureau 2005a), not considering indirect spending. Climate change is predicted to alter precipitation patterns and decrease snowpack, thereby decreasing the number of snow days that will likely dramatically affect this industry.

4.5.4 Missing Information and Research Needs

The West will likely experience significant climate impacts on the hydrological cycle, water supply systems, and water demand in the years to come. There is very active research into the associated climatological, agricultural, technological, socioeconomic, institutional and legal implications. However, few efforts, if any, exist to systematically estimate costs of meeting water demands for the various uses in the region. Identification of costs of alternative strategies could provide the basis for investment and policy that increase the resilience of the region in light of climate change.

4.6 Pacific Northwest

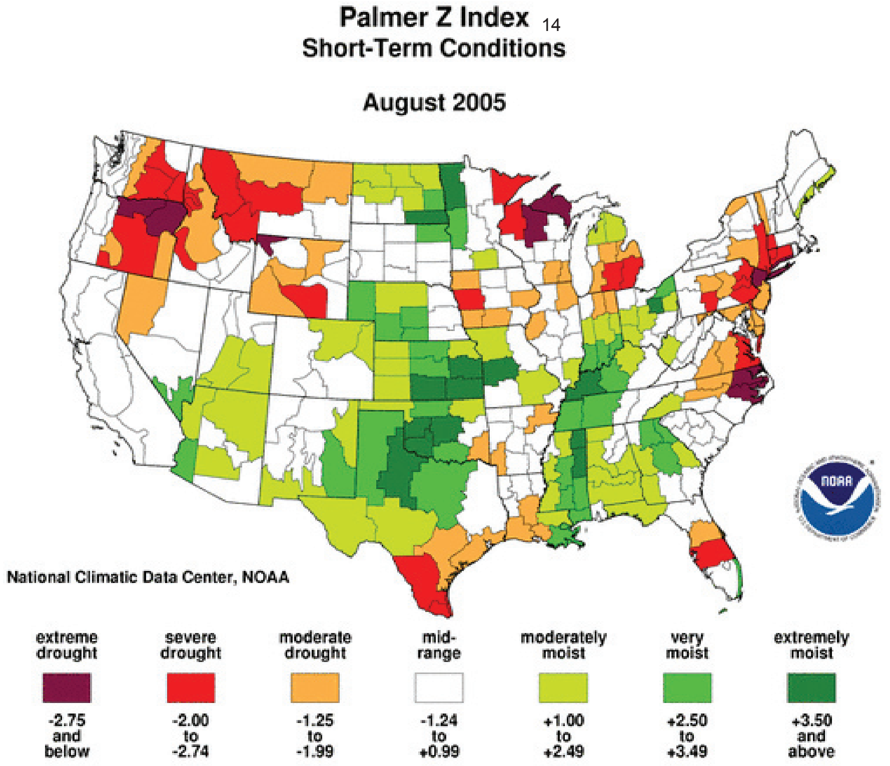
4.6.1 Overview

A large region consisting of Washington, Oregon, Idaho and Montana, the Pacific Northwest has undergone rapid urban growth (twice the national average) since the 1970s. Much of the region is forested and approximately 50% of the land area is federally owned (Parson et al. 2001a). The economy is characterized by a heavy reliance on agriculture, fisheries, and natural resource extraction (forestry and mining). Tourism, particularly visitation to national parks, also makes a significant contribution to the regional economy. The greatest threats from climate change come from increased temperatures and decreased precipitation in summer, contributing to water shortages and increased forest fires.

The climate of the Pacific Northwest is heavily influenced by the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), bringing alternating warm-wet and cool-dry seasons to the region. The past century has seen an increase in average air temperatures of 1-3°F (.6-1.7°C), roughly uniform across the seasons. The warming trend is anticipated to continue, with temperatures rising another 3°F (1.7°C) by the 2020s and 5°F (2.8°C) by the 2050s. Precipitation has increased, on average, 11% in the region over the last century, with the greatest increases in northeast Washington and southwest Montana (up to a 50% increase). The future direction and magnitude of changes in precipitation are uncertain, but likely between a small decrease (of 7% or 2 inches, mostly during summer) and a slightly larger increase (of 13% or 4 inches, mostly during winter; Parson et al. 2001a).

Despite the modest increases in precipitation, higher temperatures have, and are likely to continue to contribute to decreased snowpack and earlier spring melting that could lead to severe droughts (Figure 7), jeopardize regional water supplies and make forests more vulnerable to fire and pest outbreaks (Parson et al. 2001a; Epstein et al. 1997).

Figure 7. US Drought, 2005



(Source: NOAA 2007)

4.6.2 Major Impacts

4.6.2.1 Water Supply

Despite increases in winter precipitation, in many places a large percentage of the traditionally snow-covered areas of the northwestern United States have experienced a decline in spring snowpack, especially since the middle of the 20th century (Mote et al. 2005). The largest decreases have occurred at lower elevations where snowpack is most sensitive to temperature and in regions where winter temperatures are mild. The peak streamflow in Pacific Northwest basins dominated by snowmelt has advanced by 1–2 weeks (Groisman et al. 2004; Hodgkins et al. 2003), thereby providing less river runoff during late spring and summer.

Climate projections suggest a 30% decline in snowpack over the Northern Rockies and a 50% decline over the Cascades by 2050 with a doubling of CO_2 (Parson et al. 2001a). This would lead to a 10% reduction in annual average stream flows and reduced peak spring flows across the region (Parson et al. 2001a). A 2004 study by the University of Washington Climate Impacts Group estimates that by 2090, snowpack will be 72% below the 1960-90 average, which would not only diminish water supplies but could lead to a loss of lower elevation skiing destinations (Jolly et al. 2004). The secure supply, or firm yield, of water to the region may fall by as much as 6.1 million gallons per day for every ten years of climate change (Washington Department of Ecology 2006).

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[14] The Palmer Z Index measures the variance from normal climate moisture (NCDC 2007). Red color indicates dryer conditions than normal, and green corresponds to more moist conditions.

As supplies decrease, water demand will continue to grow because of continued population and economic growth in the region. In Washington State, the growth in annual demand attributable to population growth will be about 4.1 billion gallons by 2020 and 5.5 billion gallons by 2040 (Washington Department of Ecology 2006). This growth in demand will be exacerbated by climate change, adding another 5-8% onto the already large 50% projected increase in demand on summer municipal water supplies by 2050 (Parson et al. 2001a). According to the study by the Washington Department of Ecology (2006), impacts from climate change - such as a decrease in snowpack duration - will alter the hydrology of water storage in the state by 1.3 billion gallons annually. With the projected demand for water increasing by 1.5 billion gallons annually, a 2.8 billion gallon per year increase in storage capacity will be required. This number could jump to 5.5 billion gallons in a particularly dry year. Combined with increases from population growth, the total increase in water demand may be as large as 8.0 billion gallons in 2020 and 9.6 billion gallons in 2040 (Washington Department of Ecology 2006).

The water supply problem is further complicated because the Columbia River – one of the region's primary sources – is nationally one of the most developed and heavily managed river systems for purposes of electricity generation, flood control, water supply, irrigation, wildlife habitat, navigation and recreation. There is little to no room to increase supply. Instead, water conservation measures will need to be put into place. Such measures could cost more than $8 million per year by the 2020s, perhaps $16 million by the 2040s (Washington Department of Ecology 2006).

4.6.2.2 Forests

The indirect effect of climate change on forests is also related to projected water shortages throughout the region. While average precipitation levels are predicted to increase, the actual rainfall events are projected to vary seasonally, resulting in wetter winters and drier summers. This variation, in turn, decreases water availability. As trees become more stressed from lack of water they are more vulnerable to pest outbreaks, disease and fire. At the same time, younger and thicker managed forest ecosystems are more vulnerable to catastrophic fire than are older, thinner pine stands (Parson et al. 2001a). These factors are contributing to an overall increase in the number of acres of forest burned each year in the Pacific Northwest and in the US as a whole (USFS 2000). Other climate change effects, such as increases in spring and summer temperatures and earlier melting of snowpacks, were found to have contributed to the six fold spike in the area of forest burned since 1986, compared with the 1970-1986 period. Moreover, the average duration of fires increased from 7.5 to 37.1 days since 1986 (Westerling et al. 2006). In 1987, 1.2 million acres of forest burned throughout the US, the first time since 1919 that more than one million acres burned in one year. 1988, 1994 and 1996 also saw one million or more acres burned. In 2000, 2.14 million acres burned (mostly in the West), raising fire suppression costs to $1 billion, or about $480 per acre (USFS 2000).

State and federal spending on fire suppression in the state is projected to increase to more than $93 million per year by the 2020s with a 2°F (1.1°C) warming in the Pacific Northwest – 50% more than current spending (Washington Department of Ecology 2006). A 50% increase in the number of acres burned is expected by 2020, and a 100% increase by 2040, raising the suppression bill to $124 million.[15] As an order of magnitude estimate, these numbers are useful, but may in fact turn out to be low if both the number of acres burned and the cost of suppression per acre continue to increase, as they have done in the past (Table 8).

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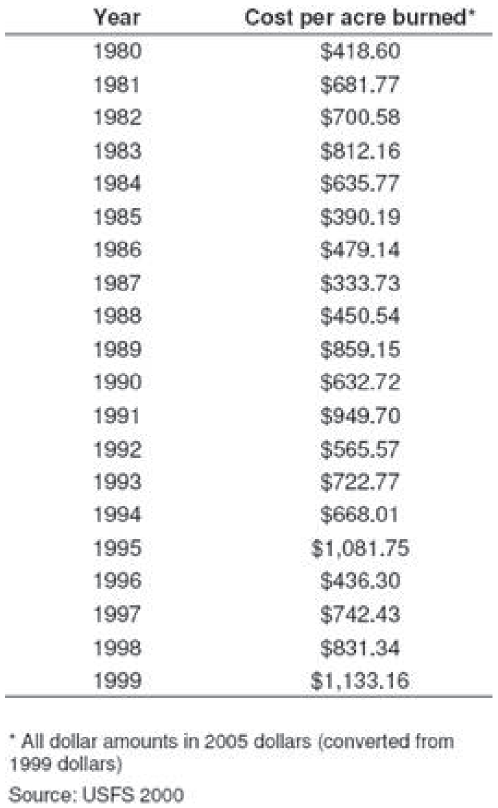
[15] Dollar figures for fire suppression in the State of Washington are based on present expenditure for 1) Department of Natural Resources direct costs for fire preparedness ($12 million), 2) other state expenditures ($26 million), and 3) federal expenditures on fire preparedness and suppression ($24 million; Washington Department of Ecology 2006).

Table 8. Service Expenditures for Emergency Fire Suppression



Year	Cost per acre burned*
1980	$418.60
1981	$681.77
1982	$700.58
1983	$812.16
1984	$635.77
1985	$390.19
1986	$479.14
1987	$333.73
1988	$450.54
1989	$859.15
1990	$632.72
1991	$949.70
1992	$565.57
1993	$722.77
1994	$668.01
1995	$1,081.75
1996	$436.30
1997	$742.43
1998	$831.34
1999	$1,133.16

* All dollar amounts in 2005 dollars (converted from 1999 dollars)

Source: USFS 2000

4.6.3 Other Impacts

In addition to impacts to the water supply and forests of the Pacific Northwest, the region's **coastal infrastructure** may likely be at risk from sea level rise, and climate change is projected to affect agriculture, electricity supply and demand, and human health.

As air and water temperatures warm, sea level is expected to rise in the Pacific Northwest. Although this will not affect the high rocky shores, there are numerous cities and towns in tidal areas, such as the Puget Sound in Washington. Sea level rise will be compounded by land subsidence. Currently, land in the Puget Sound is subsiding 0.3-0.8 inches per year (Parson et al. 2001a). A two-foot rise in sea level would inundate approximately 56 square miles in Washington, affecting more than 44,000 people (Washington Department of Ecology 2006). This kind of change could happen in Tacoma within the next 50 years. In order to protect coastal settlements, expensive infrastructure will need to be designed and re-designed, built and re-built. One estimate of the costs of redesigning the Alaskan Way seawall increases project costs 5-10% ($500 million) when protection from sea level rise is considered (Washington Department of Ecology 2006).

Agriculture in the Pacific Northwest may benefit from a longer growing season, but these benefits may be offset by higher maximum temperatures and water shortages. Expected annual crop losses from water shortages are projected to rise from $13 million at present to $79 million by mid-century (1.4 to 8.8% of $901 million total output). Higher temperatures are also expected to reduce dairy output 3-6% and may allow new insect pests, weeds and crop diseases to flourish (Washington Department of Ecology 2006).

Warmer temperatures, particularly in urban areas, mean shifts in **energy** demand peaks (higher and earlier in the summer, lower in the winter) and decreases in air quality that may affect human health. Although the overall change in energy revenue and expenditure in the Pacific Northwest may be marginal (less than +/- 5%)[16], peak shifts may pose supply problems, especially to the extent that peak power is provided by hydroelectric plants that will be affected by decreased streamflows.

Human health may be affected by increased air pollution that increases asthma and other respiratory diseases; warmer weather may also support the introduction of infectious diseases into previously unaffected areas. Some of these problems will be magnified during periods of electricity supply interruptions, raising the vulnerability of particularly the elderly, sick and less affluent. Asthma already costs the state of Washington over $400

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[16] The Washington Department of Ecology (2006) estimates impacts to the state energy budget of +/- 5%, or $165 million annually. This proportional change may be relevant to other states in the region.

million per year and over $120 million was spent on medical and non-medical direct costs in Colorado over a five-year period to combat West Nile Virus, a mosquito-borne disease making its way through the United States (Washington Department of Ecology 2006).

4.6.4 Missing Information and Research Needs

Perhaps the most striking impacts of climate change on the Pacific Northwest concern those on forests and wildfires. Many of the other impacts, such as on water supply and infrastructure will be, in principal at least, similar to those in other regions. Nevertheless, few studies exist on each of those impacts, and where quantification of cost has been attempted, prior research often simply estimated and presented those costs on the basis of percentage changes or overall decreases or increases in, for example, energy demand, agricultural production, and water availability. Rigorous and detailed economic analysis of impacts is sparse. Significant opportunities exist to fill the void in quantitative assessments for the region.

4.7 Alaska

4.7.1 Overview

Alaska's ecology, climate, geography, and its size give it characteristics distinct from the lower 48 states. With its almost year-round cold temperatures, upwards of 85% of the state rests upon permafrost, a layer of frozen soil that ranges from 10-300 feet deep in some places (Parson et al. 2001b). Its $40 billion economy is supported primarily by resource (oil and gas) extraction, fisheries, and government and military employment (Table 9). The Alaska Permanent Fund distributes petroleum revenues to state residents, $300-2000 per person each year since 1982 (Alaska Permanent Fund Corporation 2007).

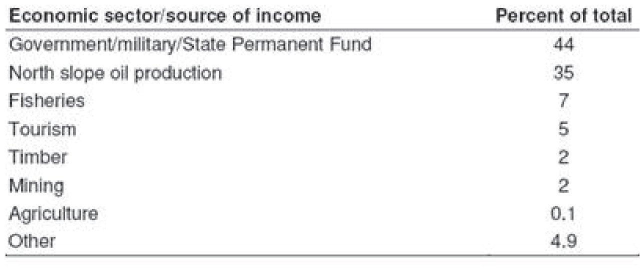
The nation's largest state, Alaska covers an area of 570,380 square miles and supports a population of approximately 641,724 – only a 2% increase from 2000 (US Census Bureau 2005b). The majority of Alaska's population resides along the southern coast, including Anchorage, the largest city and the only one with a population greater than 100,000 people. Unlike the arctic interior of the state, these coastal regions (and almost 34,000 total miles of tidal shoreline including the islands) are vulnerable to sea level rise and storms. Precipitation varies widely, even in this relatively small area of the state, with some localities receiving 10 inches of precipitation annually and others up to 100 inches. The state's transportation infrastructure is limited and relies heavily on a system of ferries and airports. The Alaska Highway is the principal roadway through the state and the Alaska Railroad runs from Seward to Fairbanks.

4.7.2 Major Impacts

4.7.2.1 Public Infrastructure

The northernmost state in the US, Alaska has experienced and is projected to experience climate change double that experienced in other US regions. Since the 1950s, the average air temperature has risen 4°F (2.2°C), 7°F (3.9°C) in the

Table 9. Economic Sectors/Sources of Income for Alaska

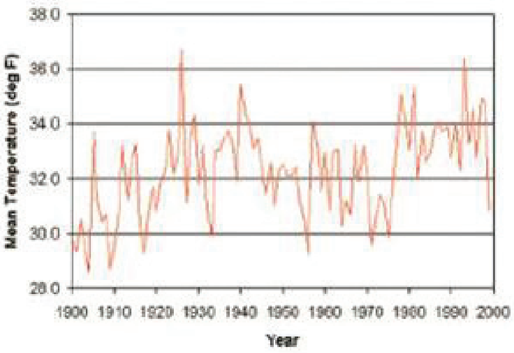


Economic sector/source of income	Percent of total
Government/military/State Permanent Fund	44
North slope oil production	35
Fisheries	7
Tourism	5
Timber	2
Mining	2
Agriculture	0.1
Other	4.9

Source: Parson et al. 2001b

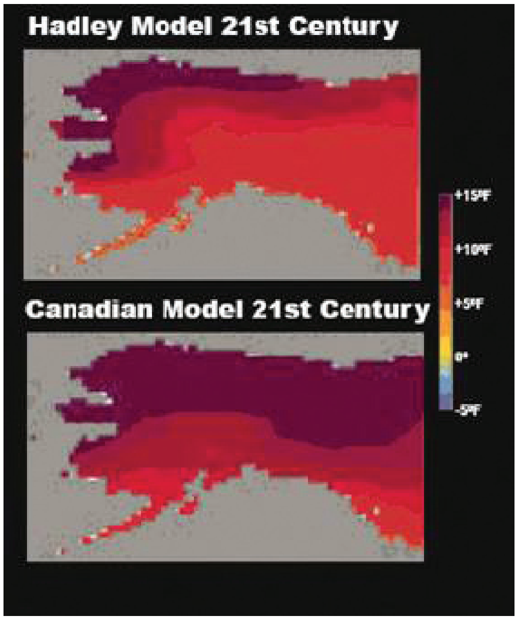
winter. Much of the warming occurred during a major climate regime shift around 1977 (Figure 8). Warming is expected to continue – 1.5-5°F (.9-2.8°C) by 2030 and 5-18°F (2.8-10°C) by 2100 – and will be strongest in the winter months (Figure 8, Figure 9). Observed average precipitation increased 30% between 1968 and 1990 (Figure 10). This trend is expected to continue, with an additional 20-25% increase in the north and northwest. Precipitation may decrease somewhat in the southeast.

Figure 8. Alaska Average Annual Temperature



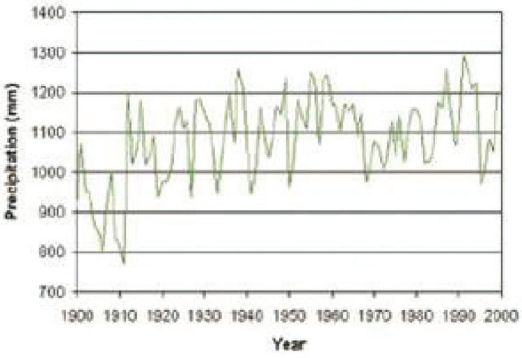
(Source: Parson et al. 2001b)

Figure 9. Alaska Winter Temperature Change by 2100



(Source: Parson et al. 2001b)

Figure 10. Alaska Precipitation 1900-2000



(Source: Parson et al. 2001b)

With higher temperatures, much of the additional precipitation will be falling as rain and Alaska's extensive permafrost layer will be subject to major changes in freeze-thaw cycles. Thawing permafrost will place the state's infrastructure – its network of roads, rail, airports, and energy and water supply which depends on permafrost as a foundation – at risk. Warmer temperatures and warmer oceans may also lead to more intense coastal storms and sea level rise that will affect coastal cities and towns.

A recent study by Larsen et al. (2007) attempted to quantify the potential impacts of climate change on Alaska's public infrastructure. In total, climate change is expected to add $5-10 billion to an already $32-56 billion infrastructure maintenance budget through 2080,[17] depending on the climate

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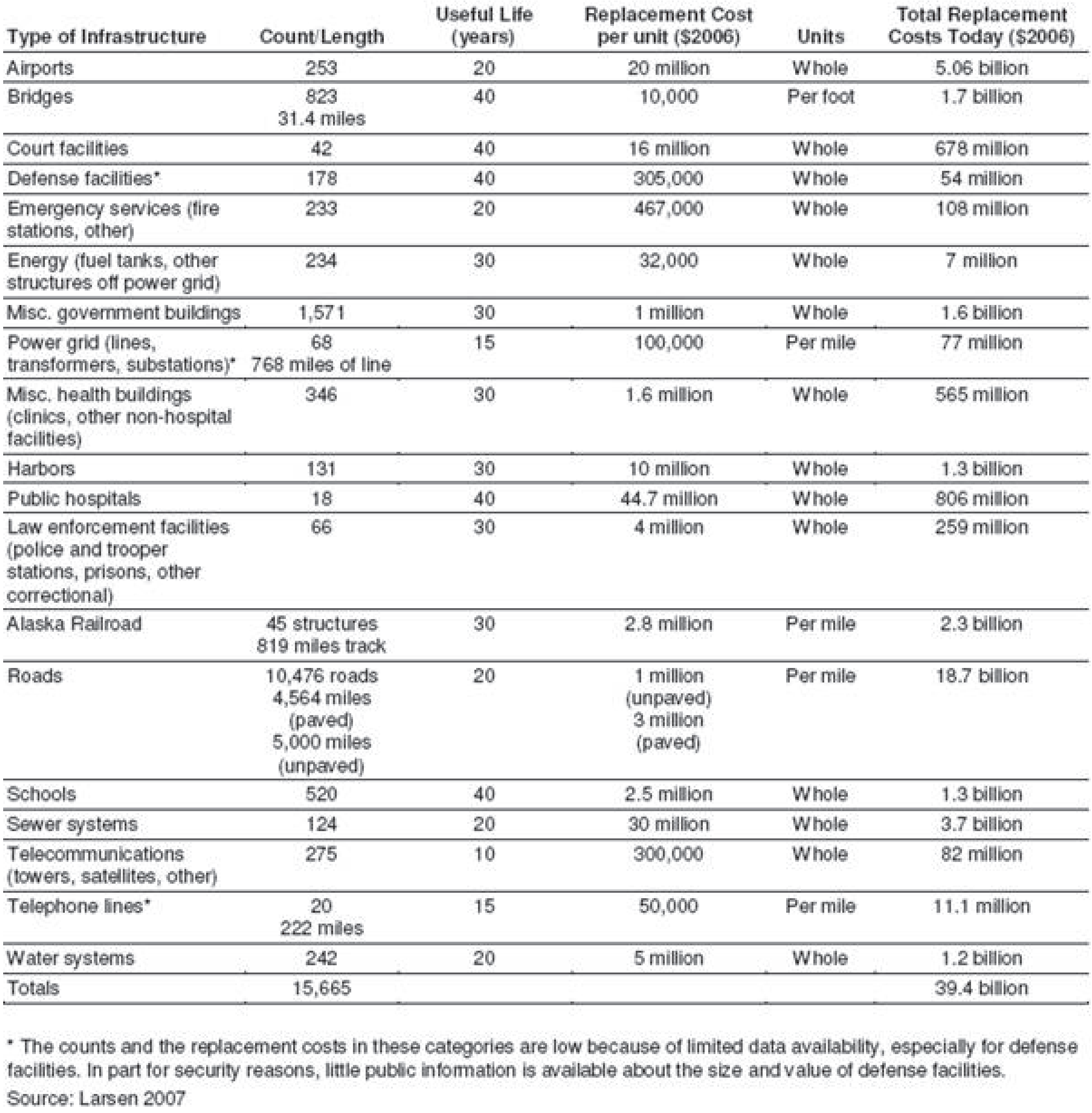
[17] Alaska's budget for infrastructure damage (to buildings, roads, airports, pipelines, etc.) is already about $35 million per year. The most resources are directed towards rebuilding heaved roads. At about $2 million per mile, annual road repair amounts to approximately 1.4% of the total state budget (Cole et al. 1999).

change scenario under consideration (Arnold 2007; Rosenberg 2007). The study by Larsen et al. (2007), the first of its kind for Alaska and one of the most thorough state-level assessments in the US, used estimates of lifetime and replacement costs for 19 types of infrastructure elements along with climate change scenarios to project future costs (Table 10). Larsen et al. (2007) observed that climate of change may benefit construction, land and sea transportation in the long-run by allowing the use of more conventional construction techniques and opening new shipping and travel routes; however, short-term damages will be significant and will likely persist through the century, generating major costs and service disruptions.

Table 10. Estimated Life Expectancies and Replacement Costs for 19 Types of Public Infrastructure

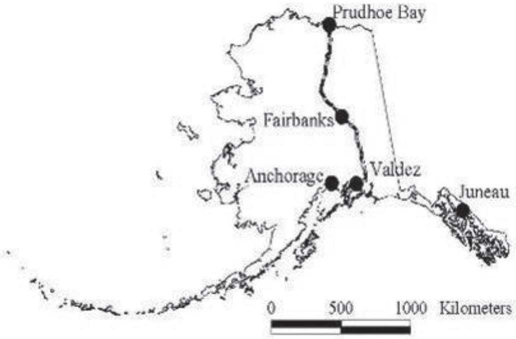


Type of Infrastructure	Count/Length	Useful Life (years)	Replacement Cost per unit ($2006)	Units	Total Replacement Costs Today ($2006)
Airports	253	20	20 million	Whole	5.06 billion
Bridges	823 31.4 miles	40	10,000	Per foot	1.7 billion
Court facilities	42	40	16 million	Whole	678 million
Defense facilities*	178	40	305,000	Whole	54 million
Emergency services (fire stations, other)	233	20	467,000	Whole	108 million
Energy (fuel tanks, other structures off power grid)	234	30	32,000	Whole	7 million
Misc. government buildings	1,571	30	1 million	Whole	1.6 billion
Power grid (lines, transformers, substations)*	68 768 miles of line	15	100,000	Per mile	77 million
Misc. health buildings (clinics, other non-hospital facilities)	346	30	1.6 million	Whole	565 million
Harbors	131	30	10 million	Whole	1.3 billion
Public hospitals	18	40	44.7 million	Whole	806 million
Law enforcement facilities (police and trooper stations, prisons, other correctional)	66	30	4 million	Whole	259 million
Alaska Railroad	45 structures 819 miles track	30	2.8 million	Per mile	2.3 billion
Roads	10,476 roads 4,564 miles (paved) 5,000 miles (unpaved)	20	1 million (unpaved) 3 million (paved)	Per mile	18.7 billion
Schools	520	40	2.5 million	Whole	1.3 billion
Sewer systems	124	20	30 million	Whole	3.7 billion
Telecommunications (towers, satellites, other)	275	10	300,000	Whole	82 million
Telephone lines*	20 222 miles	15	50,000	Per mile	11.1 million
Water systems	242	20	5 million	Whole	1.2 billion
Totals	15,665				39.4 billion

* The counts and the replacement costs in these categories are low because of limited data availability, especially for defense facilities. In part for security reasons, little public information is available about the size and value of defense facilities.

Source: Larsen 2007

Figure 11. TAP Pipeline

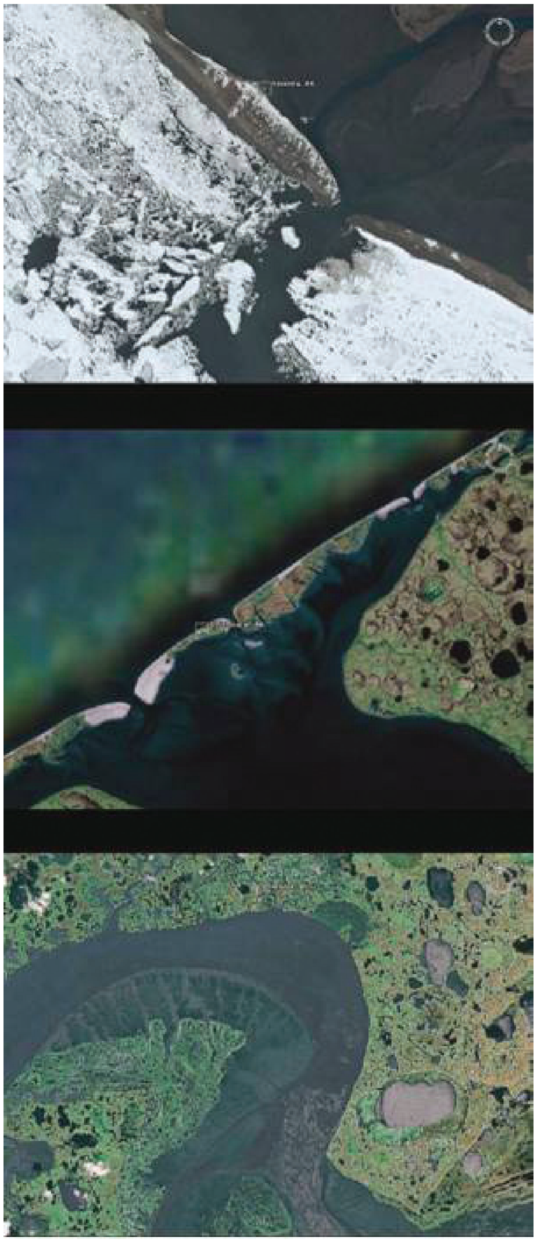


(Source: McBeath 2006)

McBeath (2006) evaluated potential climate impacts on the Trans-Alaska Pipeline (TAP). An 800-mile, 48-inch diameter warm oil pipeline, the TAP crosses nearly the entire state, north to south from Prudhoe Bay oil field to the Port of Valdez (Figure 11). The pipeline cost approximately $8 billion to construct, and approximately $800 million of those construction costs were due to the need to elevate the pipeline above permafrost over half its length. Since its construction, the thawing of permafrost has reduced structural integrity, which leads to spills (McBeath 2006).

In addition to disruptions to Alaska's infrastructure network from thawing permafrost, significant impacts are predicted for human settlements, particularly coastal towns and villages vulnerable to sea level rise and more frequent and intense storms. Cost estimates of shoreline protection and village relocation continue to rise. In 1998, the Army Corps of Engineers estimated construction costs of $5-7 million (converted to 2005 dollars) for a sea wall in Shismaref, located along Alaska's northwest coast, and costs of $64 million (converted to 2005 dollars) to relocate the town of Kivalina, 100 miles north (US ACOE 1998). The most recent estimates by the US Army Corps of Engineers (US ACOE) are up to $450 million in relocation costs for Shismaref, Kivalina and the village of Newtok – see Figure 12 for their locations. (Larsen et al. 2007).

Figure 12. Alaska's Coastal Towns



(Source: Google Earth 2007)

4.7.3 Other Impacts

Other sectors of Alaska's economy could be negatively affected by climate change, especially **forestry** and **fisheries**. In the long run a warmer climate may bring benefits to forestry and agriculture, but short-term vulnerabilities pose significant costs resulting from thawing permafrost and unstable soils, increased fire and insect outbreaks.

Roughly one-third of the state (129 million acres) is forested, and, of this, 4 million acres are located outside of protected areas; these support commercial harvests and road construction.[18] Increased occurrence of fire and pest outbreaks put both natural and managed **forests** at risk. An example of the kind of damages that may be expected in warmer and more vulnerable forests is the spruce bark beetle outbreak. In 1992 the outbreak – the largest documented in North America – damaged over 2.3 million acres on Kenai Peninsula. Additional insect outbreaks in the 1990s damaged over 800,000 acres of forest (Parson et al. 2001b). If an outbreak of this scale were to hit the state's commercial forests, upwards of 50% of the harvestable forestland area could be lost, causing a $332 million loss to the industry.[19]

Forest fires have also been increasing in recent history, their intensity associated with warm and dry periods in the climatic record. As of 1970, approximately 2.5 million acres burned each year. This number jumped to 7 million acres per year by the 1990s (Nash and Duffy 1997). In 1996, a 37,000 acre forest and peat fire caused $96 million in direct losses and destroyed 450 structures (including 200 homes). Based on a median housing value of about $200,000 (US Census Bureau 2005b) today, damage to the housing stock of this magnitude would cost nearly $40 million. As climate changes, more and more settled areas near forests will be at risk.

In 1995, Alaska's **fisheries** brought in 2.1 million tons of fish and $1.64 billion in revenue to fishermen, accounting for 54% of total US catch by volume and 37% by value. The total value of fisheries has since risen to approximately $2.8 billion and employs over 20,000 workers (Parson et al. 2001b). Changes in ocean temperatures, expected to be slower than temperatures over land, may affect spawning and migratory behaviors of many commercially valuable species. Sea level rise may impact harbor infrastructure, requiring retrofits and upgrades to docks. Higher temperatures may increase cooling needs for storage and processing of catch. All of these impacts are likely to add cost to an already vulnerable industry and will likely negatively impact the state economy.

4.7.4 Missing Information and Research Needs

The information contained in this report and indeed the state of knowledge on potential climate impacts to Alaska's resource extraction industries is sparse. Additional research should be directed to (and data openly shared) risks to oil and natural gas extraction, forestry and fisheries. The research efforts underway to quantify the potential impacts to Alaska's public infrastructure should continue and be intensified.

4.8 Hawaii and US Affiliated Islands

4.8.1 Overview

Hawaii and the US affiliated islands cover a large area throughout the Pacific and the Caribbean, including Puerto Rico and the US Virgin Islands in the Caribbean, the Hawaiian Islands, American Samoa, the Commonwealth of the Northern Mariana Islands, Guam, the Federated States of Micronesia, the Republic of the Marshall Islands,

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[18] The productivity of these 4 million acres of forest land is roughly 50 cubic feet per acre per year (Parson et al. 2001b).

[19] Calculation based on forestry's contribution to the state economy. $33.2 billion Gross State Product × 2% contribution of timber × 50% loss in forested area = $332 million. (Bureau of Economic Analysis 2007).

and the Republic of Palau in the Pacific. The economies of these island states and territories are dominated by agriculture, fishing and processing, tourism, and some high-tech industries (Carter et al. 2001). They have unique geological features and rich economic and cultural diversity. These island states will be most vulnerable to sea level rise and storms that will threaten coastal infrastructure and drinking water supplies.

Over the past century, average temperatures have increased 1°F (.6°C) in the Caribbean and 0.4°F (.2°C) in the Pacific. Global average sea level has risen 4-8 inches over the last century, though with significant local variation. The rate of sea level rise in the Gulf of Mexico is presently 3.9 inches per century. Their climates are significantly affected by ENSO, storm surges, and extreme lunar tides. Future trends in air temperature are much less important than sea level rise, changes in ENSO, storm cycles, and ocean temperature and circulation (Carter et al. 2001).

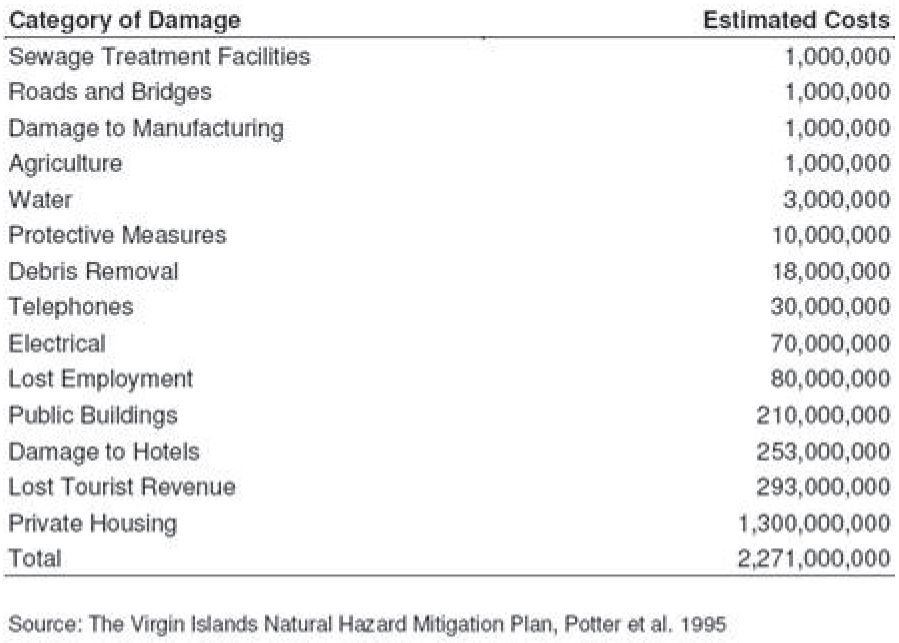
4.8.2 Major Impacts

4.8.2.1 Coastal Infrastructure

Climate change will likely stress already deficient infrastructure on the islands. According to the American Society of Civil Engineers, 47% of Hawaii's bridges are structurally deficient or functionally obsolete (ASCE 2005). The state also has 77 high hazard dams, whose failure would lead to loss of life and property damage. Repairs (not including those due to climate change) to Hawaii's drinking water infrastructure could exceed $146 million over the next 20 years; its wastewater infrastructure, $1.74 billion. The biggest threats to this already burdened infrastructure will be sea level rise and tropical storms.

There have been a number of destructive hurricanes to hit the US islands in recent years. Hurricane Marilyn, in the US Virgin Islands, caused as much as $4 billion in damages (see Figure 13,

Table 11. Breakdown of Estimated Damages from Hurricane Marilyn in the US Virgin Islands



Category of Damage	Estimated Costs
Sewage Treatment Facilities	1,000,000
Roads and Bridges	1,000,000
Damage to Manufacturing	1,000,000
Agriculture	1,000,000
Water	3,000,000
Protective Measures	10,000,000
Debris Removal	18,000,000
Telephones	30,000,000
Electrical	70,000,000
Lost Employment	80,000,000
Public Buildings	210,000,000
Damage to Hotels	253,000,000
Lost Tourist Revenue	293,000,000
Private Housing	1,300,000,000
Total	2,271,000,000

Source: The Virgin Islands Natural Hazard Mitigation Plan, Potter et al. 1995

Potter et al. 1995; National Hurricane Center 1996). Hurricane damages in Hawaii from 1957-1995 topped $2.7 billion (Pielke 2001). Hurricane Iniki, the most powerful hurricane (category 4) to hit Hawaii, caused 7 deaths, $2 billion in damages, and leveraged $295 million FEMA disaster relief in 1992 (Hamnett et al. 1999; Carter et al. 2001). It was part of the strong 1991-1994 El Niño cycle that produced some 11 powerful tropical cyclones in the Central Pacific.

Hurricane Georges hit Puerto Rico in 1998, bringing 26 inches of rain in 24 hours that caused major flooding, landslides, infrastructure and agricultural damages, and left 12 people dead. Puerto Rico lost 75% of its water and sewer infrastructure. Ninety-six percent of its electrical power network, 50% of its utility poles and cables, and 33,100 homes were damaged or destroyed. Road damages exceeded $25 million, and damage to public schools was about $23-29 million. Its agricultural areas were also affected, with 75% of the coffee crop, 95% of the plantain and banana crops, and 65% of all poultry production temporarily lost (USGS 1999; NOAA 1999). In total, Hurricane Georges cost Puerto Rico $2.3 billion in damages; damages to the US mainland damages were $6.9 billion (Carter et al. 2001).

With storms and sea level rise come beach erosion, which occurs 150 times faster than the rate of sea level rise (Carter et al. 2001). Some Caribbean islands are already losing 9 feet of coastline each decade due to erosion and the projected rate of sea level rise would erode more than 33 feet of coastline per decade in the foreseeable future.

4.8.3 Other Impaacts

Climate impacts on coastal infrastructure, particularly roads, bridges, docks, water supply systems, and hotels will reduce the attractiveness of islands to **tourism**, as well as impact local ecosystems, from tropical forests to coral reefs. Changes in temperature and precipitation may make additional locations unattractive to visitors.

4.8.4 Missing Information and Research Needs

Although the climatic and socioeconomic situation differs considerably among Hawaii and the various US affiliated islands, by virtue of their size and location, they all exhibit vulnerability to sea level rise. With the bulk of their infrastructures, populations and economic activities located along coast lines, these islands will benefit from adaptive capacity that reduces vulnerability to gradual sea level rise as well as helps prepare them for extreme events. A series of case studies for various islands, strategically chosen, may provide a basis on which to identify, in those locations and many of the others, investment and policy options that reduce vulnerabilities and cost.

5 Conclusions and Recommendations

The nation already experiences a wide range of adverse economic impacts of climate change itself, as well as changed environmental conditions whose frequency and severity are consistent with those under a changed climate. Examples include sea level rise and its impacts on coastal economies; droughts and heat waves with their impacts on agriculture, forestry, energy systems and public health; and severe rainfall events with their impacts on transportation and other infrastructure systems.

Directly or indirectly, Climate change will continue to affect all sectors and regions of the country, though not all of them equally or at the same time. There will temporarily be winners and losers from climate change, but the long-term economic cost of climate change rapidly exceeds benefits and places major strains on public sector budgets, personal income and job security. Because of the higher economic costs of climate change, we conclude that delayed (or inaction) action on global climate change will likely be the most expensive policy option. **A national policy for immediate action to mitigate emissions coupled with efforts to adapt to unavoidable impacts will significantly reduce the overall costs of continued climate change.**

Providing adequate information and support for climate change policy requires that models and assessments of mitigation and adaptation options reflect both the costs of environmental investments and policy as well as the benefits of such policies. To achieve such a balanced perspective, in turn, necessitates a concerted effort by the scientific and stakeholder communities along the following three dimensions:

1. Adequate choice of methodologies.
2. Expansion of regional and sectoral case studies.
3. Implementation of adaptive and anticipatory management.

5.1 Choice of Methodologies

Much of the economic analysis of climate change impacts and adaptation has been guided by the notion that adaptation options can be carried out incrementally and that their extent must be limited to the point at which the cost of an extra unit of adaptive measures equals the cost of that extra unit. This is the traditional microeconomic approach to identifying, for example, optimal levels of production, now applied to the production of "care" for environmental goods and services. As such, it rests on more than 100 years of economic theory, has led to myriad economic assessments of optimal investment and policy, and, unfortunately, is utterly inadequate to address all but the narrowest of climate mitigation and adaptation issues. Many of the assumptions underlying the traditional microeconomic approach do not hold in the climate change context, such as the assumption of homothetic consumer preferences, concave benefit functions and infinitesimally divisible levels of action.[20] In fact, a recent report by the U.S. Government Accountability Office on climate change and federal land management stressed precisely this point by asserting that "resource managers lack specific guidance for incorporating climate change into their management actions and planning efforts. The report further concludes that in light of the missing information managers cannot plan for upcoming changes and are left only to respond to already-observed climate change impacts (US GAO 2007b).

An alternative approach treats mitigation and adaptation actions as investments in natural, human-made and social capital, with the goal of maintaining or enhancing the services they provide. A methodological approach consistent with that viewpoint will need to rest in portfolio choice theory. It needs to include methods and tools from the theory of investment and finance under risk and uncertainty.

The current, rather inadequate, theoretical and conceptual foundation is resulting in a hodge-podge of empirical and modeling studies with often incongruous results. We recommend that one consistent assessment be carried out across major regions of the US and across major sectors in those regions. Key features of that assessment should be:

(a) Recognition of the complementary and non-marginal

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[20] For a concise presentation of standard economic approaches to adaptation cost estimation see Callaway et al. 1998; for a non-technical rebuke of those assumptions see Dore and Burton 2000.

nature of investments in climate change solutions: Adequate preparation to deal with climate impacts requires that investments into human-made infrastructures (such as dikes and levies) are coupled with corresponding investments in social capital (such as local knowledge about disaster preparedness and institutions to manage infrastructures and communicate with local populations) and natural capital (such as flood plains and coastal ecosystems). Investment in one, without corresponding recognition of the performance of the other factors that influence overall "system performance," will likely be misguided and wasteful. And since investment in either will likely need to be significant (non-"marginal") to have any noticeable impact, the methodological approach needs to adequately capture the investment decision as one of portfolio choice, rather than be based on traditional benefit cost analysis.

(b) Use of cutting-edge data acquisition and visualization: The spatial nature of infrastructures, settlements, economic activity and climate impacts all call for the use of the best available spatial data, such as satellite imagery and Geographic Information Systems. The recursive nature of climate impact and socioeconomic adjustment, in turn, calls for the application of computer modeling tools that help play out the dynamic nature of adaptation to climate change. Although pilots are trained on flight simulators to improve safety of their equipment and passengers, investment and policy-making often lacks corresponding tools for information processing and learning. Adequate capture and visualization of cutting-edge scientific information will be an important contributor to proper investment and policy decision-making.

(c) Modular, hierarchical approach to filling knowledge gaps: The extent of the problem and dearth of consistent and detailed information will require an approach that allows scientists to first cover large regions and highly aggregate sectors, but then to remove and replace initially coarse assessments with finer ones as new data and information are generated. Sequential movement towards higher-resolution studies that will require strict adherence to research protocols as new modules are developed. A detailed listing of underlying assumptions will be needed to enhance follow-up research and enable comparison to other cases or locations.

(d) Tight coupling of environmental, economic and social information for specific sectors and regions: The interdependencies among sectors and regions in the US, and the potentially significant ripple effects of the cost of climate impacts and the benefits of adaptation require that data, models and analyses adequately reflect those interdependencies. This will be a clear break from current practice, where focused sectoral and regional assessments are typically carried out in isolation of each other, or – when they are connected – the studies are of such coarse temporal and spatial resolution as to offer only very general guidance for investment and policy-making.

5.2 Regional and Sectoral Case Studies

Adaptation actions typically are carried out in individual sectors within specific regions with the goal of reducing the vulnerabilities of environmental, social and economic systems at particular locations. As a consequence, an assessment of the benefits of various adaptation actions and options will require place-specific information. Therefore, we highly recommend to successively move from the large regional assessments currently available to ever finer scales of resolution of the actions taken across the US. To ensure that the different regional and sectoral case studies remain comparable and that knowledge can be effectively transferred from one place to another will require, as discussed above, that a consistent methodology be applied and that data acquisition, analysis and reporting follow protocols that are common and consistent across case studies.

One novel approach to organizing the potentially large number of the very heterogeneous case studies is akin to the development of open source software. There, many different developers and users provide modules to an evolving product whose features reflect changes in the state-of-technology and user preferences, while at the same time providing consistency and coherence for the system as a whole to optimally function.

A consistent nation-wide, regional and sectoral case studies approach will enable systematic comparison of the underlying reasons why, in some cases, a particular adaptation strategy was chosen, yet not in others, and why some of these strategies were successful while others failed. On the basis of detailed comparative studies, general guiding principles and policies may be derived that are meaningful nationally. Such an approach to policy design would be quite different from the one where a universally applicable economic theory is combined with broad legal direction to inform policy with the understanding that regional and sectoral processes will follow suite to generate locally appropriate investment in mitigation and adaptation actions.

Because improved understanding of climate impacts, and the costs and benefits of those impacts, is in the national interest, the **federal government should organize and finance a set of region- and sector-specific studies that help guide climate policy and investment, using appropriate methodologies.** Fortunately, large amounts of data and studies are already available in the scientific literature, as well as reports by various agencies and non-governmental entities, that can provide solid starting points for the assessment of mitigation and adaptation benefits. It will be prudent to systematically evaluate those assessments and build on them; it will not be necessary to start from scratch in many cases. Although Congressional oversight of the process of information assembly and new analysis would be necessary, the intellectual power of the nation's labs and universities should be set free to do this cutting-edge research.

5.3 Adaptive and Anticipatory Management

The climate is not constant, and the local economies and societies that attempt to adapt to it are not static. We are neither ignorant of the risks associated with climate change, nor has the nation implemented the necessary strategies to mitigate, prepare for, and adapt to climate change. A new management approach is required that helps society and the economy adapt to the changes in environmental, technological, social and economic circumstances, and that responds to new knowledge that is gained as management approaches are implemented.

Consequently, management ideally anticipates likely future conditions and sets in place strategies that answer to those conditions when they are met. Since considerable uncertainty will always prevail about possible future environ-mental, technological, social and economic condi-tions, management and policy need to identify robust strategies – portfolios of investment and policy decisions that lead to desired outcomes under a wide range of potential future states of the world.

Advanced computer simulation may provide one piece of valuable input into the identification of robust strategies. To date, the climate change research and policy communities have benefited much from computer models developed in the natural sciences to better understand the biogeochemical cycles, especially the cycles of carbon and other greenhouse gases, and how those cycles are altered under different socioeconomic activities. No comparable funding has been provided or similar effort has been made to improve the tools for quantitative analysis of the human activities that lead to climate change, their interdependency with changes in the natural world, and the associated mitigation and adaptation options.

Computer models can only provide one kind of input into the management process. Another very important contribution must come from the various stakeholder communities which are affected by climate change and which ultimately choose among alternative mitigation and adaptation actions. The choice of methodology and case study approaches outlined above may render stakeholder involvement a more doable and more productive component in the assessment process and may foster implementation of sustainable climate mitigation and adaptation strategies.

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