IMPACTS OF CLIMATE CHANGE ON WASHINGTON'S ECONOMY

A Preliminary Assessment of Risks and Opportunities

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EXECUTIVE SUMMARY

In early 2006, Washington's Department of Community, Trade, and Economic Development and Department of Ecology commissioned the Climate Leadership Initiative (CLI) at the University of Oregon to analyze the current and likely future effects of global climate change on Washington's economy. The assessment was launched at a symposium at SeaTac airport on May 4, 2006 at which scientists, economists, and stakeholders shared and discussed current research on the topic. With oversight from a steering committee comprising economists and scientists from Washington universities, the private sector, and government, a CLI research team spent six months evaluating research and information about the economic effects of climate change in Washington and the Pacific Northwest.

The team reached three conclusions about the effects of climate change on Washington's economy:

1. **Climate change impacts are visible in Washington State and their economic effects are becoming apparent.**
2. **The economic effects of climate change in Washington will grow over time as temperatures and sea levels rise.**
3. **Although climate change will mean increasing economic effects, it also opens the door to new economic opportunities.**

Scientists expect the Pacific Northwest climate to warm approximately 0.5ºF every ten years over the next several decades, a rate more than three times faster than the warming experienced during the twentieth century. In Washington, scientists project that average annual temperatures will be 1.9ºF higher by the 2020s when compared with the 1970-1999 average, and 2.9ºF higher by the 2040s. Changes in total precipitation are not projected to be significant over that time period. Winters will bring more rain and less snow in the mountains.

Our assessment finds that impacts of climate change are visible, numerous, and becoming more pronounced. Key evidence includes:

- **Glaciers**: Mountain glaciers in the North Cascades have lost 18 to 32 percent of their total volume since 1983, and up to 75 percent of North Cascades glaciers are considered at risk of disappearance under temperatures projected for this century.
- **Snowpack**: The average mountain snowpack in the North Cascades (critical to summer streamflows) has declined at 73 percent of mountain sites studied.
- **Peak flows**: Peak stream flows are shifting earlier in the year in watersheds covering much of the state, including the Columbia Basin.
- **Wildfires**: The number of large (>500 acre) wildfires in Washington State has increased from an average of 6 per year in the 1970s to 21 per year in the early years of the 21^{st} century.

- **Rising sea levels**: Combining tectonic subsidence with rising sea levels, the South Puget Sound shoreline is likely to experience from 1 to 5 inches of sea level rise per decade, the largest global warming-linked rise in the state.

Our survey of economic effects in seven key sectors, industries, and regions of Washington revealed potentially costly impacts on forest resources, municipal water supplies, and other economic activities:

- Federal and state costs of fighting wildfires may exceed $75 million per year by the 2020s (a 2ºF warming), 50 percent higher than current expenditures.
- Water conservation expenditures to offset the decline in firm yield of Seattle's water supply due to climate change impacts could exceed $8 million per year by the 2020s and $16 million per year by the 2040s.
- Tourism and recreation revenues may be reduced in some localities due to forest closures and smoke intrusion associated with larger, more frequent wildfires.
- Hydropower revenues may be affected as stream flow regimes change in response to rising temperatures.
- Consumers could face water price increases in some basins that supply municipal water.
- Two key counties may experience a decline in dairy revenues by as much as $6 million by the 2040s due to the effects of higher-than-optimal temperatures on dairy cows.
- Water allocation restrictions or higher costs for water affecting farmers in the Yakima Basin may become more probable as the likelihood of drought years increases.
- New sea level rise projections could trigger costly re-design of some long-term investments in shoreline protection such as Seattle's Alaskan Way seawall and critical infrastructure such as bridges and culverts.
- Cumulative economic effects larger than the sum of individual sector or regional effects may occur due to interactions between industries and economic sectors.

Economic effects of climate change in Washington appear likely to grow as temperatures increase. At the same time, efforts within the state to reduce greenhouse gas emissions, as well as action to prepare for impacts that appear all but inevitable, will create economic opportunities. Among the key opportunities, this assessment emphasizes initiatives in transportation, biofuels, renewable power, energy efficiency, and carbon capture. These emerging industries can help the state achieve greenhouse gas mitigation and climate change adaptation goals, while enhancing Washington's capacity to export technology and expertise to trading partners around the nation and world seeking to meet the challenges of climate change.

The assessment is predicated on projections of gradual warming over the next several decades. However, abrupt changes in climate conditions could be triggered if certain temperature thresholds are crossed at the global level. By focusing now on greenhouse gas emissions reduction while taking prudent steps to prepare the state for climate change impacts, Washington can do its part to resolve global climate change and increase the likelihood that its citizens will prosper in a time of unprecedented changes.

INTRODUCTION

This publication offers a preliminary assessment of the effects of global climate change on the economy of Washington State. It also outlines economic opportunities that may be associated with climate change. We emphasize effects that Washington may experience within the first half of the twenty-first century, well within the lifetime of a majority of the state's residents or their children.

At a basic level, climate change is a classic example of what economists call an "externality." The benefits from climate-damaging activities (burning fossil fuels, deforestation, etc.) accrue to the individuals who engage in those activities, but the costs of those activities are "externalized" to individuals all around the world. Each individual has an economic incentive to "free-ride" on everyone else, and when everyone does this the result is a "tragedy of the commons" – global climate change. The challenges to economic analysis of the effects of this issue are complex: the problem is global, the causes are multiple, the effects extend far into the future, and the biophysical phenomena involved are bracketed by large uncertainties.

Although the drivers are global, the effects of climate change on Washington will be largely unique to Washington, for the state's economy, topography, natural resource endowment, and climate patterns are unique. As this assessment will show, some effects are visible today. The tools that scientists use to predict and detect them are becoming more powerful. Climate science, in particular, is rapidly improving its ability to "downscale" global climate trends, and to project the regional and local effects of planetary changes.

As regional projections improve, decision-makers can craft policies to address the effects with more confidence. The challenge for the state's decision-makers is two-fold: reduce the state's contribution to the problem by reducing emissions of heat-trapping gases responsible for climate change (i.e., mitigation), and prepare now for consequences of climate change on ecological systems, natural resources, shorelines, economic sectors and industries, built infrastructure and public health that appear inevitable (i.e., adaptation). Progress on one front or the other is not sufficient. As the director of a major study of the economics of climate change for the British government observes, "adaptation and mitigation are not alternatives; we must pursue both. But the costs of each will influence the choice of policies for both."[1]

Understanding those costs begins with a look at how climate changes affect economic activity. Climate changes can affect the quantity or quality of resources used directly as **inputs** in economic activity, like fresh water for drinking, irrigating crops, or generating electricity. Climate changes can accelerate the depreciation of **capital assets** like seawalls erected to protect shorelines from rising sea levels, and shorten the lifetime of capital investments. Climate changes can directly affect **human health** in ways that impact the workforce (e.g., through premature mortality, sick days, health care expenses, and insurance claims), impairing labor productivity and diminishing quality of life. And these general classes of effects can **interact** to produce larger cumulative economic effects than any single impact alone may suggest.

Washington State has a highly diverse and dynamic economy. The sheer size of the state's $268.5 billion economy serves to mask its vulnerability to climate-linked effects. Washington's gross state product is the sum of twenty-one economic sectors ranging in size from mining ($400 million in 2004) to real estate, rental, and leasing ($38.8 billion in 2004), and the degree of vulnerability of each sector to climate-related economic impacts is difficult to assess. National and international trade connections and inter-sector links spread the vulnerability to climate change effects.[2]

Economic analyses of the potential effects of climate change on national or state economies are sometimes assessed using general equilibrium models. Such models compare aggregate economic performance under different sets of assumptions. To the extent a timeframe is implied, such models tend to assume a smooth linear transition between two equilibrium states. But while the central trends of concern in global climate change (the emissions of greenhouse gases, concentrations of carbon dioxide in the atmosphere, and rising average global temperatures) increase in a linear fashion, societies experience climate as weather, a distinctly non-linear phenomenon.

Droughts, floods, and other extreme events are unlikely to be well characterized by general equilibrium models, nor are the possibilities of abrupt changes to the global climate system such as changes that could result in catastrophic sea level rise, although many scientists believe that the risks of both extreme weather and abrupt changes are growing. Furthermore, despite the Kyoto climate treaty and other efforts to date to limit greenhouse gas emissions, the world is not even close to a path toward a stabilized atmosphere. There exists no reasonable climate "endpoint" for which an economic equilibrium can be described.

Limiting the scale of analysis to particular industries, sectors, or regions of the economy holds more promise, particularly when such analysis can relate quantifiable resource impacts (e.g., water availability) directly to climate trends. At this scale, plausible estimates of potential costs and benefits associated with particular climate changes can be brought into focus. This assessment takes a sector and regional approach to economic analysis.

We begin this assessment with a look at regional temperature trends associated with global climate change, based largely on the work of the Climate Impacts Group at the University of Washington. We review the evidence that climate changes have already affected the state's ecological systems and natural resource endowment, presenting information about effects on snow and ice, flowing water, extreme heat, shorelines, and air and water chemistry.

On this foundation, we consider how impacts on the state's ecological systems and resource endowment may affect Washington's present and future economy. Following the definition of "leading indicator" as "an economic indicator that changes before the economy has changed,"[3] we focus on seven sectors, industries, and regions that offer evidence of climate change impacts. Given the resources and time available for the assessment, we have relied primarily on available research, sometimes extracting data or highlighting results that describe economic effects specific to Washington.

We follow the assessment of economic effects with a discussion of economic opportunities created by efforts to mitigate the causes of climate change and to prepare for its effects. Washington is connected to a world of trading partners that are also confronting new challenges of climate change. The state's ability to seize opportunities to export technology and expertise will influence its capacity to prepare for impacts here.

"The world we have known is history," warns James Gustave Speth, Dean of the School of Forestry and Environmental Studies at Yale University and former chairman of the President's Council on Environmental Quality.[4] Climate change is creating circumstances in which the planning and decision-making patterns of the past are of diminishing relevance for the future. Decision makers at all levels must be open to new ways of thinking and new possibilities, and they must be prepared for surprises. As warming increases, climate change will test Washington's decision makers like never before. Future Washingtonians have a major stake in the decisions made today.

CHAPTER ONE

CLIMATE CHANGE, PEOPLE, AND THE EVERGREEN STATE

In 1958, scientist Charles Keeling measured carbon dioxide at a concentration of 318 parts per million in air samples high on Hawaii's Mauna Loa volcano, a place remote from sources of air pollution. Keeling and his colleagues began to measure the gas each month, a practice continued at Mauna Loa and now replicated at many other sites around the world. The results are unequivocal. The atmospheric concentration of carbon dioxide has increased steadily over the last 48 years to climb past 380 parts per million. Today's level is 20 percent higher than when Keeling began his measurements (See **Figure 1-1**) and 36 percent higher than the concentrations that prevailed before human pollution became a factor during the Industrial Revolution of the 18th Century.

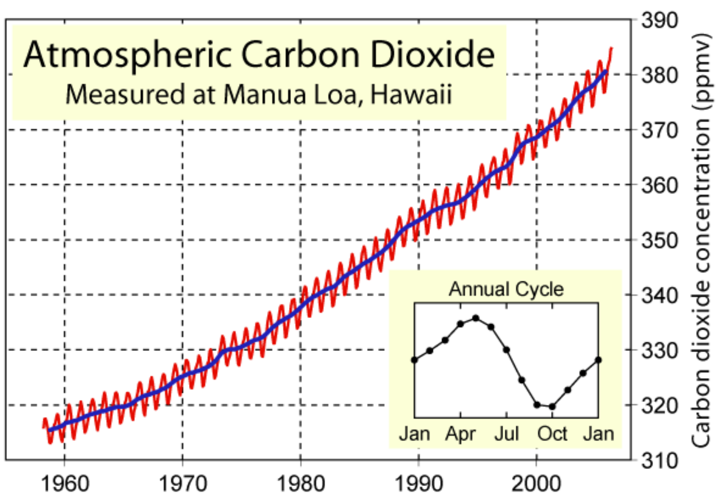

Figure 1-1. The Keeling Curve: Carbon Dioxide Concentrations Measured at Mauna Loa, 1958-2005. Source: Robert A. Rohde, Global Warming Art**,** based on data from the National Oceanic and Atmospheric Administration.[5]

The factor that has changed most over that period is human use of fossil fuels. Burning coal, oil, natural gas, and other fuels oxidizes carbon long stored deep underground in geological layers and transfers it to the atmosphere in gaseous form. The amount of carbon dioxide released by burning fossil fuels has increased steadily from negligible levels to more than 27 billion tons per year, or over four tons for each of the 6.4 billion people now living. Additional carbon dioxide is released by deforestation and land clearing. (Given the chemical formula of CO_2, 3.67 tons of carbon dioxide are released when each ton of carbon is oxidized.) (See **Figure 1-2**.)

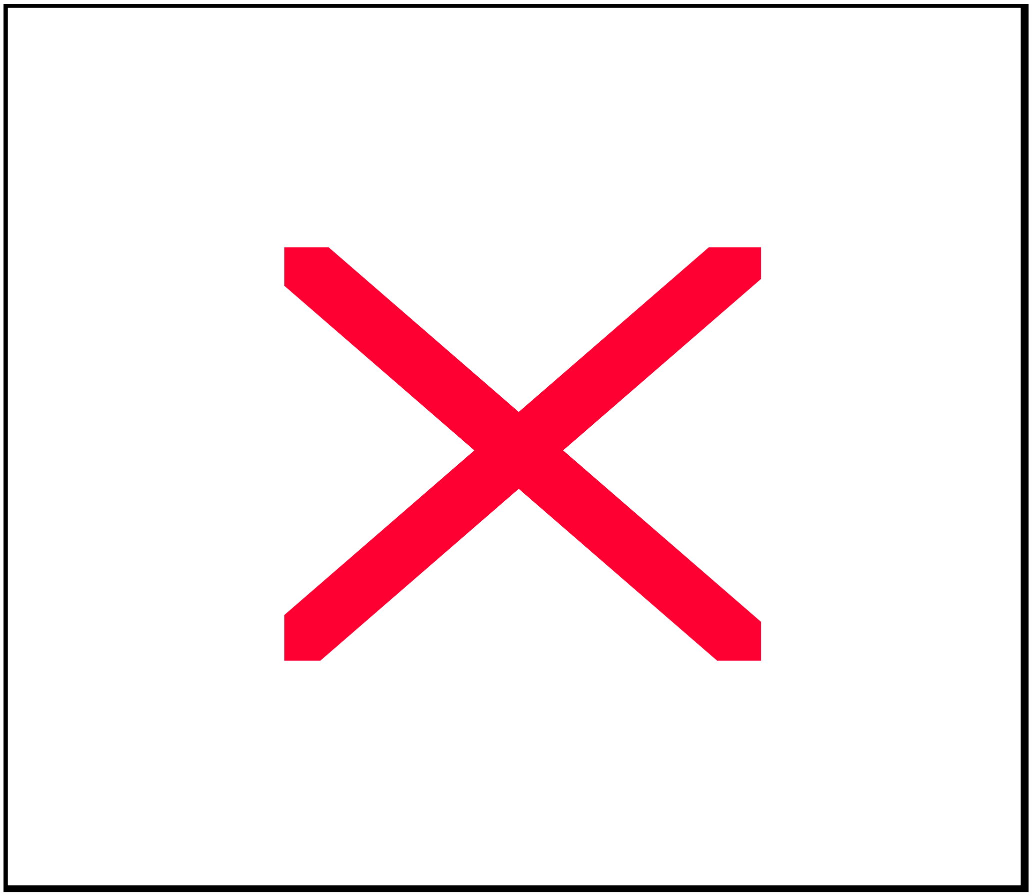

Figure 1-2. Global Carbon Dioxide Emissions, 1970-2003.
Source: Energy Information Administration, US Department of Energy.

The United States is the largest source of global greenhouse gas emissions, and Washington State contributes about 85 to 90 million tons per year to the global total from energy use, or about 0.3 percent of worldwide emissions. The state's trend line is similar to the global trend line. Since 1970, the amount of carbon dioxide released by vehicles, factories, power plants, and airplanes in Washington has increased by roughly 75 percent (see **Figure 1-3**), and Washington's emissions are projected to increase even more as the state's population grows.

On a per capita basis, Washington's yearly emissions of about 13.5 tons of CO_2 per person are more than three times larger than the world average of 4 tons per person, but over thirty percent lower than the U.S. average of 20 tons per person, largely reflecting the state's heavy reliance on electricity generated by dams. This reliance on hydro, though damaging to salmon and freshwater ecosystems, means that Washington residents lead somewhat less carbon-intensive lives than most Americans. But even if the emissions per person remained steady at 13.5 tons for the next twenty-five years, Washington's total emissions would grow

38 percent above present levels to 115 million tons, simply due to population growth.[6]

The result of this transfer of stored carbon to the atmosphere is a physical change in the earth's ability to capture the energy of sunlight and hold it as heat. Carbon dioxide (along with other trace "greenhouse gases" including methane, chlorofluorocarbons, nitrous oxide, and ozone) acts like a blanket of insulation that impedes the radiation of heat from the surface of the earth into space. As a result, temperatures rise at the earth's surface. The more carbon dioxide and other trace greenhouse gases released, the more effective the blanket.

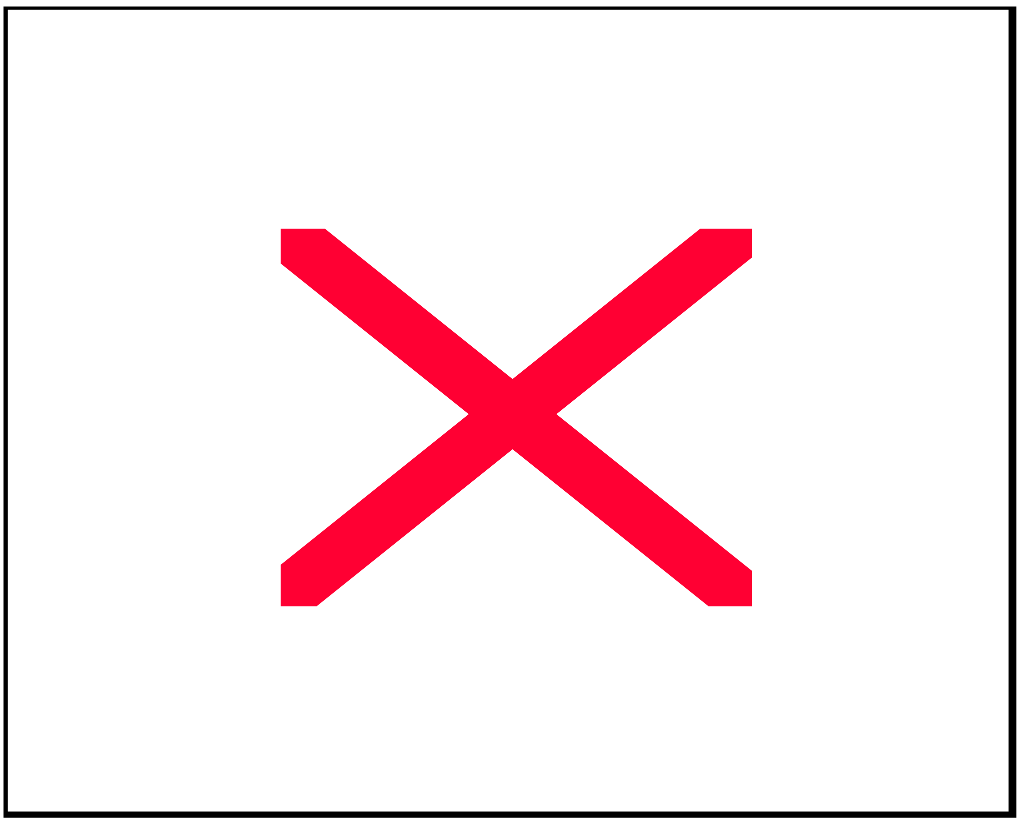

Figure 1-3. Carbon Dioxide Emissions in Washington State, 1970-2004.
Source: Department of Community, Trade, and Economic Development.[7]

Effects on Washington's Climate

Due to these global trends, a consistent warming pattern emerged from normal climate variability during the twentieth century. Washington experienced an average temperature increase of about 1.5º Fahrenheit, an increase one-third larger than the 1º-Fahrenheit rise in global temperatures recorded over the same time period.

Scientists expect the Pacific Northwest to continue to warm approximately 0.5 degrees Fahrenheit each decade over the next several decades, a rate of warming more than three times faster than the warming experienced during the twentieth century. Scientists project that, averaged across the region, annual temperatures will be 1.9º Fahrenheit higher by the 2020s when compared with the 1970-1999 average, and 2.9º Fahrenheit higher by the 2040s. (See **Table 1-1**.) These figures are averages; the projections span a range of warming from 0.7-3.2ºF for the 2020s and 1.4-4.6ºF for the 2040s. In the interest of simplicity, we have used the projected averages as benchmarks throughout this report.

Total precipitation is not projected to change significantly over the next several decades, with some indication of a very slight increase in the proportion of annual precipitation that falls during winter months. (See **Table 1-2**.) Consistent with the overall warming trend, a larger share of winter precipitation is expected to fall as rain, a shift with important implications for the state's mountain snowpack and freshwater supplies.

Table 1-1. Recent and Projected Temperatures for the Pacific Northwest

	1970-99	2020s	2040s
Annual	47.0° F	48.9° F	49.9º F
(increase)		*1.9° F*	*2.9° F*
Oct.-Mar.	36.1° F	37.8° F	38.6° F
(increase)		*1.7° F*	*2.5° F*
Apr.-Sept.	57.9° F	60.0° F	61.2° F
(increase)		*2.1° F*	*3.3° F*

Source: Climate Impacts Group, University of Washington[8]

Notes: Temperatures shown are averages across the Pacific Northwest, and may vary significantly from region to region. This table compares observed temperatures for the 1970-99 period with changes in temperature averaged across thirty-year periods centered on the 2020s (2010 to 2039) and 2040s (2030 to 2059) projected by ten global climate models using two emission scenarios that bound the range of scenarios evaluated by the Intergovernmental Panel on Climate Change (for a total of twenty projections of future climate). The future temperatures reported in this table are the averages calculated from changes projected by those climate models for the specified time periods.

These regional projections do not address how overall trends will influence localized climate events such as windstorms, heat waves, and storms bringing extreme rainfall or snowfall. Recent climate modeling results indicate that "extreme" events may become more common in some regions, including the western U.S., as rising average temperatures produce a more energetic climate system.[9] Even the change in average conditions could tip normal climate variability in a more destructive direction: drought conditions could become more frequent in some river basins as snowmelt-dependent streamflows decline.

The twentieth century temperature increases gave rise to a number of changes in the biophysical conditions of the State of Washington. Projections of continued future temperature increases suggest changes of greater magnitude are likely.

Ice and Snow

One of the most visible effects of rising temperatures is a significant reduction in ice and snow. Washington is one of only nine states in the continental U.S. with mountain glaciers. The hundreds of glaciers in the North Cascades and Olympic Mountains (at least 725 in the North Cascades alone) supply more than 30 billion cubic feet (~700,000 acre-feet) of summer runoff to the state's rivers each.[10]

Table 1-2. Recent and Projected Precipitation in the Pacific Northwest

	1970-99	2020s	2040s
Annual	28.0"	28.5"	28.5"
Oct.-Mar.	19.4"	20.2"	20.4"
Apr.-Sept.	8.5"	8.4"	8.2"

Source: Climate Impacts Group, University of Washington

Notes: Precipitation levels shown are averages across the Pacific Northwest, and may vary significantly from region to region. This table compares observed precipitation for the 1970-99 period with changes in precipitation averaged across thirty-year periods centered on the 2020s (2010 to 2039) and 2040s (2030 to 2059) projected by ten global climate models using two emission scenarios that bound the range of scenarios evaluated by the Intergovernmental Panel on Climate Change (for a total of twenty projections of future climate). The future averages reported in this table are calculated from percentage changes projected by those climate models for the specified time periods.

Like ice masses in virtually every mountainous region of the world, Washington's glaciers are now in retreat. According to the U.S. Geological Survey, the South

Cascade Glacier located northeast of Darrington has lost half its length and perhaps two-thirds of its ice volume over the past century.[11]

The retreat of North Cascade glaciers is "rapid and ubiquitous," according to a recent synthesis of annual surveys carried out since 1983 by the North Cascade Glacier Climate Project (NCGCP) (See **Figure 1-4**). Three lines of evidence support a region-wide conclusion that Pacific Northwest mountain glaciers are declining in response to rising temperatures. [12]

Taken as a whole, the Cascade glaciers included in the study have thinned by more than 31 feet, a loss of 18 to 32 percent of their entire volume. Forty-seven glaciers included in the NCGCP survey have shrunk in size, length, and volume. Four disappeared entirely: the David Glacier, Lewis Glacier, Spider Glacier, and Milk Lake Glacier. The data suggest that the loss of ice from Cascade glaciers is accelerating. Anticipating the impact of temperature changes projected for this century, project director Mauri Pelto foresees "the loss of up to 65-75 percent of North Cascade glaciers due to a 2ºC (3.6ºF) warming, but most will take more than 40 years to disappear."[13]

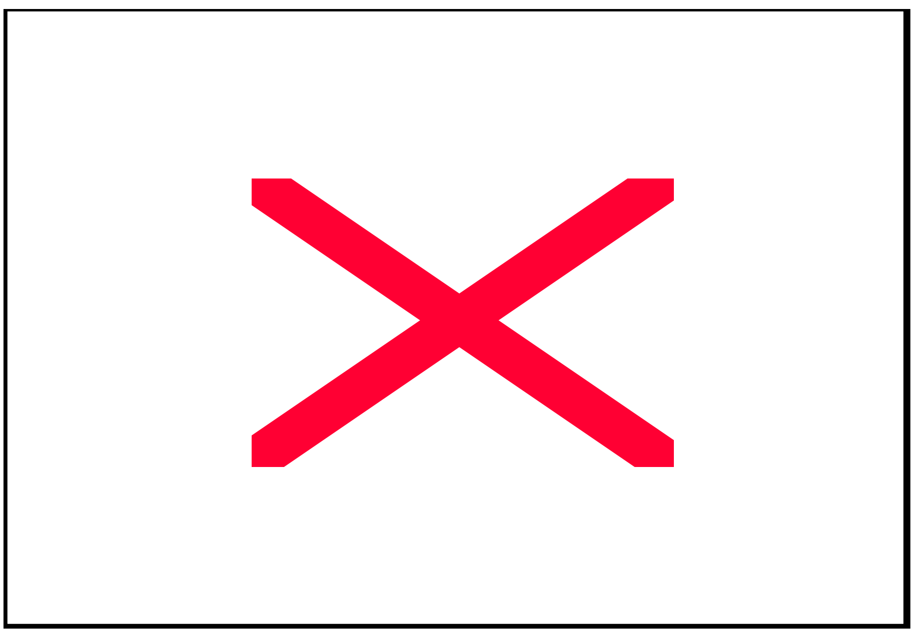

Figure 1-4. Decline of North Cascades Glaciers, 1984-2004.
Source: Mauri S. Pelto. 2005. "The Disequilibrium of North Cascade, Washington, Glaciers 1984-2004." *Hydrologic Processes.*

Glacial retreat of this magnitude has impacts beyond altered scenery and alpine recreation. One is a marked change in the way the alpine landscape interacts with sunshine. Ice fields and snowfields reflect sunlight, while darker rock surfaces and alpine vegetation absorb it. As snow and ice dwindle, the alpine zone warms, perhaps enough to accelerate the melting of remaining snow and ice and shift the dynamics of high-altitude vegetation.

In drainage basins that contain significant amounts of glacial ice, the ice masses help sustain summer streamflows after the complete melting of a season's snowfall. Glaciers help maintain freshwater flows through the driest months of the year, and contribute to base flows irrespective of year-to-year fluctuations in precipitation. One river likely to see significant declines in late-summer flows due to glacial retreat is the Middle Fork of the Nooksack River. Fed by the Deming Glacier, the river is a contributor to the drinking water supply of Bellingham.[14]

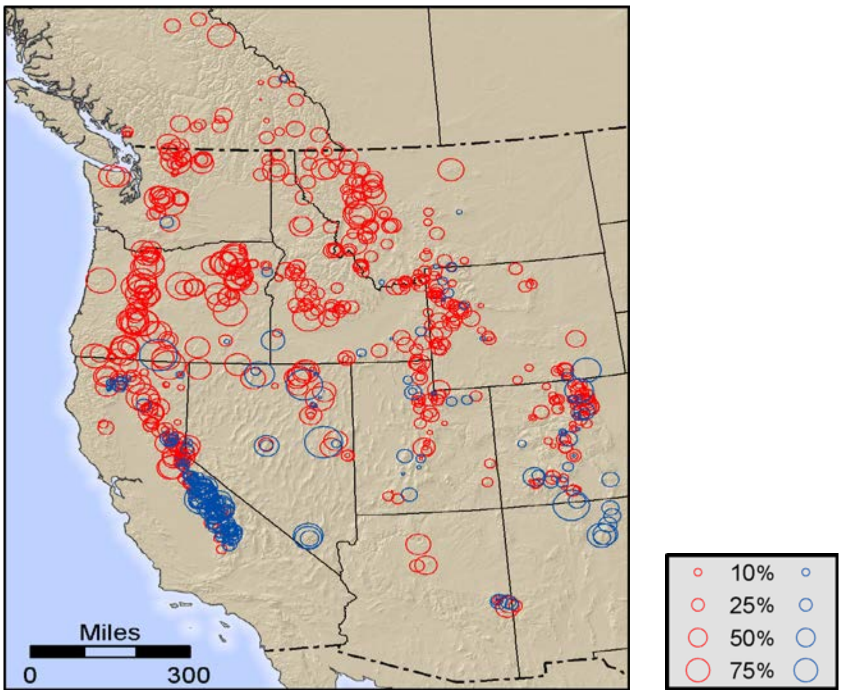

Figure 1-5. Mountain Snowpack Across the West 1950-2000.
Source: Casola et al., 2005, redrawn from Mote et al., 2005.[15] Red circles indicate locations where a decline in April 1 snow water equivalent (SWE) has been recorded relative to 1950; blue circles indicate locations where an increase in April 1 SWE has been recorded. SWE measures the quantity of water contained in snowpack if it were melted instantaneously.

Snowpack, a more transient form of water storage, is also showing the impact of warmer temperatures. Average precipitation has not declined since the middle of the twentieth century, but the mountain snowpack in the North Cascades has experienced some of the largest losses recorded in the West. The likelihood of significant snowmelt during winter months has increased, along with the frequency of winter precipitation that falls as rain rather than snow, quickly running off the land when it falls.

The April 1 mountain snow pack, an important indicator of summertime water availability in many river basins, declined at virtually every measurement location in the Pacific Northwest after 1950. (See **Figure 1-5.**) With the decline of snow storage, the proportion of annual river flow to Puget Sound during summer months has declined by 18 percent since 1948.[16]

Less snow means that glaciers are not replenished. Downstream effects include changes in the timing of peak flows of fresh water, power output, fish migration, and the availability of water through the summer dry season.[17]

Flowing Water

Another effect of rising temperatures is alterations to Washington's streamflows. The state's watersheds fall into three groups (see **Figure 1-6**). The **rain-dominant** group (shown in green), including many coastal rivers in western and southwest Washington, receive most of their precipitation as rain. Their rivers experience peak flows during winter months, tracking precipitation closely. **Snow-dominant** watersheds (shown in blue) like the Skagit and Spokane Rivers typically have headwaters at high elevations and receive mostly snow during the winter. Their rivers yield peak flows several months after the heaviest precipitation falls. "Transition" or **transient snowmelt** watersheds (shown in red) at intermediate elevations experience a mix of winter rain and snow that gives their rivers a flow pattern with a double peak, with relatively high winter flows and a late-spring pulse following the onset of snowmelt. Watersheds in the latter group, including the Cedar and Tolt rivers that supply Seattle's drinking water and the Quinault River on the Olympic Peninsula, are sensitive to slight temperature changes that shift the snow/rain balance in favor of rain.

In the decades ahead, snow-dominant watersheds like the Skagit and Yakima basins can expect higher winter flows and a flow pattern resembling the pattern of transient basins, while transient basins will lose their pronounced "twin peaks" pattern and release more of their yearly discharge during winter months. In short, many of the state's snow-dominant watersheds will acquire characteristics of transient snowmelt watersheds, while transient watersheds will behave more like today's rain-dominant watersheds.

The shift of some snow-dominant basins toward more transient conditions could present a mix of good news and bad news in terms of flood risk: a smaller snowpack could mean a reduced risk of early spring flooding (from rain-on-snow events), but soils saturated by the premature snowmelt could be more susceptible to flooding associated with late-spring rains. A great many factors will interact to determine how basins will function as the climate changes. The region got an indication of how complex and costly such interactions might be during the floods of February 1996.[18]

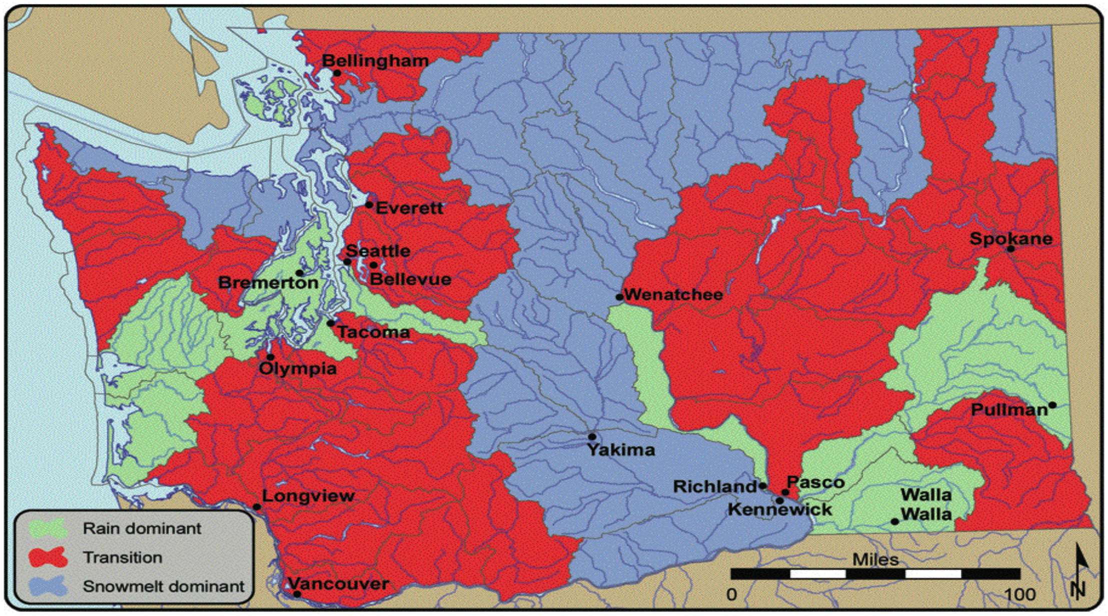

Figure 1-6. Susceptibility of Washington Drainage Basins to Climate Change Impacts on Snowpack. For the purpose of the figure, "rain dominant" watersheds store, on average, less than 10% of their cool-season (October-March) precipitation in snowpack, "transition" watersheds store 10% to 40% of their cool-season precipitation in snowpack, and "snowmelt-dominant" watersheds store more than 40% of their cool-season precipitation in snowpack. Source: Alan Hamlet and Robert Norheim, Climate Impacts Group. GIS analysis and cartography by Robert Norheim.[19]

Reduced summer flows in the state's snow-dominant and transient basins allow stream temperatures to rise, in some cases to levels sufficient to put cold-water fish species, including salmon and trout, at risk. In rivers unregulated by dams, stream temperatures are responsive to air temperatures, and hydrologists consider stream temperatures "highly likely" to increase in response to the projected increases in average air temperatures. Streams warmer than 68º Fahrenheit (20º Celcius) are lethal to many cold-water resident and anadromous (migratory) fishes such as salmon. [20]

Soils in every watershed class provide a significant water storage reservoir. The projected temperature changes would affect the role of the soil "water bank" in all three classes of watersheds. Soil moisture levels are the key to evapo-transpiration by natural vegetation and cultivated crops, shaping such attributes as ground-level microclimates, the need for irrigation, and susceptibility to fire. Soils are typically recharged by snowmelt during the winter and early spring, and release that moisture to vegetation and groundwater over the course of the growing season, reaching their driest condition by early October. Earlier snowmelt advances the date of soil recharge, meaning that soil moisture is exhausted earlier, imposing moisture stress on plants and trees during the hottest season.

Climate models suggest that the primary effect of rising temperatures west of the Cascades will be to accelerate soil drying and cause a pronounced reduction in soil moisture by late summer and fall. East of the Cascades the effect of warming may be somewhat different. There, levels of soil moisture during the summer months are more directly linked to precipitation patterns and even slight increases in summertime rainfall could increase soil moisture levels. This could bring some benefits for agriculture, but by extending the growing season, it could increase wildfire risks due to fuel buildup in some forest types.

Effects of Increased Heat

Increased heat has direct effects on the physical and built environment and on living things. While water can in theory be transported from areas of surplus to areas of scarcity, the effects of heat must be confronted where they occur. Although temperatures in Washington may increase gradually over the next decades, the averages may be accompanied by larger seasonal and regional variability.[21] Some parts of the state are likely to experience more pronounced warming sooner, and may have to contend with increasingly frequent intervals of extreme or excessive heat.

Higher temperatures affect the physiology of plants, animals, and people. Warmer summer average temperatures are likely to mean an increase in the frequency of extremely hot days (> 100 degrees F), a factor contributing to the incidence of heat cramps, heat exhaustion, and heat stroke, which occurs when the body's natural cooling mechanisms are overwhelmed. Urban areas pose special health risks during periods of extreme heat. Nighttime temperatures can remain at dangerous levels because pavement and buildings absorb heat during the day and release it at night. Elevated temperatures also stress animals, sometimes enough to impair the economic performance of livestock.

Insects respond in many different ways to elevated temperatures. Where freezing temperatures limit insect populations, insect reproductive success can be related to the length of the frost-free season. In some cases a full generation can be added by a delay in the onset of freezing temperatures. The codling moth, a significant pest of orchard crops in the Pacific Northwest, historically experiences two generations per year. Orchardists in the Columbia Gorge have observed the initial stages of a third cycle in codling moths in recent years, and expect that the moths will soon be able to complete a third cycle.[22]

Many insects expand their ranges as temperatures warm, among them vectors for human and animal diseases. This appears to be the likely mechanism in the transcontinental spread of mosquito-borne West Nile Virus and a factor in the spread of tick-borne Lyme Disease.[23] Such range expansions increase the expense of surveillance and monitoring, as well as the direct costs of medical treatment for disease outbreaks.

Possibly the most widespread direct impact of elevated summer temperatures is increased susceptibility of forests and non-forest vegetation to wildfire. A recent analysis of wildfire incidence in the Western U.S. since 1970 detected a sudden and dramatic increase in large (> 1,000 acre) forest fires beginning in the mid-1980s, a transition that the study's authors associate with unusually warm springs, extended summer dry seasons, drier (i.e., more flammable) vegetation, and longer fire seasons. The Pacific Northwest region is vulnerable to spring warmth, extended summers, and other factors identified as contributors to the regional wildfire trend. In particular, the researchers emphasize that "earlier snowmelt dates correspond to increased wildfire frequency." As noted, the snowmelt date has been shifting earlier in the year for decades in Washington.[24]

A continuing increase in wildfire size, intensity, and duration could transform Washington State's forests from a net sink of carbon dioxide (capturing more of the gas in vegetation than they release through respiration and burning) to a net source of the gas from burning. This positive feedback effect could accelerate the buildup of greenhouse gases and augment future global climate change.[25]

Sea Levels and Shorelines

Rising temperatures have also caused sea levels to rise. Globally, sea levels rose four to ten inches over the course of the past century as the world's oceans warmed slightly and expanded and as fresh water was added from the melting of mountain glaciers and land-borne ice masses. In the future, sea levels are expected to rise somewhat faster than the 0.75 inch-per-decade average change recorded during the twentieth century. Estimates published in 2001 projected that sea levels around the world would increase in a range between approximately 4 and 40 inches from 1990 to 2100.[26]

In the Pacific Northwest, rates of global sea level rise may be augmented by regional effects on the northeast Pacific Ocean linked to atmospheric circulation patterns, which could add 0-12" to sea level rise projections over the 1990-2100 period.[27] In addition, interactions with tectonic activity will exacerbate climate-induced sea level rise in areas with tectonic subsidence (sinking landmasses) and offset climate-induced sea level rise in areas with tectonic uplift (rising landmasses).

The rate of increase in sea levels over that time period is not linear; sea levels are expected to rise faster later in the 110-year interval. The calculations in this report assume a linear rate for purposes of simplicity, although that assumption may slightly overestimate sea level rise based on the 2001 projections, at least in the early part of this century. Ice masses in Greenland and Antarctica may contribute more to near-term sea level rise than previously estimated.[28] If confirmed, that finding would mean that sea levels will rise more, and more quickly, than the 2001 projections indicate.

In Washington sea level rise is so far difficult to detect. Different portions of the state's shorelines experience different vertical motions (sinking or rising landmasses) due to tectonic activity. The effect is to offset rising sea levels in some places while augmenting sea level rise in others.[29]

In general, some of the most densely populated areas of the state's shoreline along the southeast Puget Sound experience the highest subsidence rates, sinking at rates more than 1 millimeter per year. These areas are likely to experience the largest magnitude of sea level rise. Tacoma and nearby communities are likely to experience a sea level rise between 5 and 16 inches by the 2040s. Some areas, including Neah Bay and the San Juan Islands, by contrast, will experience little, if any, measurable sea level rise in that period (see Chapter 2, "Economic Impacts," for further discussion of the relative impacts in different parts of the state).

Washington's outer coast is comparatively sparsely settled, but far more vulnerable than Puget Sound communities to the storm surges and increased wave heights associated with sea level rise. The transient effects of past El Niño events may serve as guides to the more permanent impacts associated with sea level rise on the state's outer shores. During the El Niño of 1997-98, for example, tides recorded at the Toke Point tide gauge in Willapa Bay were the highest ever recorded. High water caused record coastal flooding and beach erosion.[30]

In the future, El Niño events and other regional-scale phenomena affecting sea levels will unfold against a background of rising global sea levels. Recent research on the distribution of global temperature change indicates that warming in the Western Equatorial Pacific may be greater than in the Eastern Equatorial Pacific, a temperature gradient believed to increase the likelihood of very strong "super" El Niño events. This research does not suggest changes in the overall frequency of El Niño episodes.[31] In addition to effects on tides and high water, El Niño events tend to be associated with drier winters in the Pacific Northwest, which can have significant implications for summer water availability.

Air and Ocean Chemistry

The current level of atmospheric carbon dioxide is 36 percent higher than the level that preceded the Industrial Revolution, and 30 percent higher than any previous measurement of the gas in the 650,000-year record of samples measured directly from glacier ice cores.[32] This build-up of the gas has altered the conditions under which plants grow.

Since carbon dioxide is "fixed" by plants into carbohydrates through the process of photosynthesis, changes this large could scarcely occur without measurable effects on crops, trees, and natural vegetation. But while the "fertilization effect" of carbon dioxide is a mainstay of plant physiology, many factors interact to control plant productivity. A change in one factor does not lead in a linear way to corresponding changes in growth rate, seed production, or agricultural harvests. No direct measurements of the fertilization effect of elevated carbon dioxide on natural or cultivated vegetation have been reported for Washington. Some models of vegetation response indicate an increase in carbon accumulation in forests and other ecosystems where fire suppression has been the general practice. As a rule, plants grow until they reach the limit of available water, particularly when temperatures are favorable. Due to fire control efforts, a large share of Washington's natural vegetation may now be near its water-limited carrying capacity, a condition in which it is more vulnerable to stress or dieback when sufficient water is not available. This is believed to contribute to the observed trend of large, long-burning wildfires.[33]

A more mundane impact of elevated carbon dioxide levels is the close correlation between carbon dioxide levels and pollen production by plants recognized for the potency of their airborne allergens. In controlled experiments, USDA plant physiologists found the pollen output of common ragweed at a carbon dioxide concentration of 370 parts per million (a level surpassed in 2001) to be roughly double the pollen output when plants were grown at pre-industrial concentration of 280 parts per million. At 600 parts per million, a level of carbon dioxide within the range of scenarios possible during the twenty-first century, pollen output doubled again to 20 grams per cubic meter.[34]

Common ragweed and giant ragweed, opportunistic annual plants typically found in disturbed areas, including vacant lots and industrial sites in some of Washington's most populous counties (King, Snohomish, Kitsap, Yakima, Benton, and Whitman).[35] In urban areas, ragweed pollen grains can combine with particulates from diesel exhaust to penetrate deep into lung tissue, believed to be an important mechanism in the rapidly growing incidence of asthma.

The sustained and accelerating change in the chemical composition of the atmosphere is also associated with changes in the chemistry of seawater (seeking equilibrium with the shifting mix of atmospheric gases). Scientists have confirmed, for example, that elevated carbon dioxide levels in the atmosphere promote the formation of carbonic acid due to absorption of carbon dioxide by seawater. Waters at the surface of the ocean (pH = 8.2) have become measurably less alkaline (by 0.1 unit) as a result, and pH levels may fall as much as 0.3 additional units during this century as atmospheric carbon dioxide levels continue to rise.[36]

The declining alkalinity of the marine environment, referred to as "acidification," interferes with biochemical steps that cold-water corals, plankton, snails, and other marine creatures employ to build shells from calcium carbonate. At best, the change in ocean chemistry slows the growth rate of shell-building organisms. At worst, it can promote the complete dissolution of their protective shells.

The Risk of Abrupt Climate Change

Climate scientists warn that while temperature trends seem to indicate gradual change, the earth's climate is not a linear system. Historical records reveal its vulnerability to abrupt changes. Nonlinear changes at a hemispheric or global scale could have profound impacts in Washington State.

Many nonlinear climate changes are possible. One is the disruption – by excessive fresh water released from the melting of the Greenland ice sheet -- of the so-called "thermohaline conveyor belt," a set of heat distributing currents including the Gulf Stream in the North Atlantic Ocean. Disrupting the Gulf Stream could reconfigure oceanic and atmospheric circulation patterns throughout the Northern Hemisphere. Another is an accelerated melt and break-up of the Greenland and/or West Antarctic ice sheets that could raise sea levels worldwide more and faster than now expected.[37]

Scientists link the likelihood of some "abrupt change" scenarios, particularly the break-up of ice sheets, to thresholds of global temperature change as low as 1.8ºF (1ºC) above present levels.[38] Crossing such thresholds, which appears inevitable given the current trajectory of emissions, could constitute what climate scientists term "dangerous anthropogenic interference" with climate. While we cannot project the effects of such nonlinear changes on Washington with confidence, they become more probable as average temperatures rise. There is evidence that current consensus views underestimate the pace of climate change.[39] Any form of abrupt climate change would dramatically alter economic impact scenarios.

Climate Science and Governance

The climate system, basically a planetary system for distributing heat, is adjusting to elevated levels of carbon dioxide and other greenhouse gases. Scientists believe that the warming measured so far is only about half the temperature change that would represent a thermal equilibrium associated with the current 380 parts per million of carbon dioxide. In other words, even with emissions cuts deep enough to stabilize carbon dioxide concentrations near the 380 parts per million reached in 2005, temperatures would continue to rise, snowfields and glaciers would continue to melt, and weather patterns would continue to change for many decades. Like a supertanker, the present accumulation of greenhouse gases in the atmosphere possesses massive momentum and inertia.

The climate challenge is one that Washington policymakers must grasp by two handles: reduce the state's contribution to the problem, and prepare for the effects. One response without the other is insufficient. Temperature, snowpack, streamflows, and sea levels are changing now, and these changes are certain to affect Washington over the next several decades.

In this assessment, we focus on climate projections for the 2020s and 2040s, well within the lifetimes of most Washingtonians, half of whom are younger than 37 years old.[40] We emphasize, however, that climate change will not stop by mid-century. More likely, without significant new policies, change will be accelerating then. Washington's climate has not simply begun to shift from one state (the "old climate" that has prevailed since territorial days) to a new stable state a few degrees warmer. The climate has begun to travel a slippery slope with no predictable end-point.

In this new world, the lessons of past climate surprises – droughts, floods, windstorms, and wildfires considered "anomalies" when they occurred – may prove pertinent to emerging circumstances. Washington's leaders may wish to study the lessons of such exceptional events, in an effort to understand the economic changes this exceptional era may bring.

CHAPTER TWO

ECONOMIC IMPACTS

Introduction

Estimating the potential impacts of climate change on a state's economy is a new field of inquiry, and one of urgent importance. Scientific uncertainties about how climate change will unfold compound the uncertainties of economic analysis, making a comprehensive and quantitative picture of future impacts a challenging goal. Macroeconomic models may someday be paired with climate models downscaled to regions of interest. Such tools have not been perfected.

As an alternative we have provided a synopsis of economic impacts in important sectors and regions of the state. Our analysis combines regional climate projections with well-documented examples of economic activity within the state. This approach is neither economy-wide nor strictly sectoral. Instead, we have sought examples of economic activities in which a parameter of climate change – for example, a change in temperature or a shift in the timing of precipitation – can be associated in a straightforward way with a probable impact on current economic activity.

Some of the subjects we examine (e.g., municipal water supplies, hydroelectric power generation) cross sector boundaries, making aggregate impacts difficult to assess. Some of the subjects (e.g., dairy) are subsets of a broader sector (agriculture), and may or may not be representative of sector-wide impacts. Some concern economic activities that are small components of Gross State Product with disproportionate significance to the state's identity (e.g., wine, snow sports).

We offer several caveats. First, although we have mostly focused on impacts likely by mid-century because regional climate projections are considered reliable over that period, climate changes will continue to unfold beyond that date. Our assessment of impacts for this early phase of climate change is unlikely to be, and is not intended to be, a reliable guide to impacts in the more distant future.

Second, climate projections are expressed as averages. The averages are based on projections that, in the case of temperatures, span a range of 2-3ºF for the time periods in question. Actual temperature and precipitation changes experienced at particular places in Washington will vary from the averages. Some parts of the state will warm more than the projections indicate, some less. Our assessment of impacts may not reflect the experience in particular locations.

Third, the climate projections appear to depict a relatively linear, gradual adjustment to future temperature and rainfall regimes, but scientists expect to encounter variability that is not well represented by the averages. Climate is a nonlinear system with thresholds that are poorly understood, and surprises are possible. Incorporating this uncertainty into our economic analysis in a quantitative way was beyond the scope of this project.

Finally, we encountered instances in which economic impacts appeared to be more sensitive to changes in the frequency of climate extremes (for example, heat waves and drought) than to changes in climate averages. In general, economic analyses tend to focus on average conditions, not the extremes, and may overlook or underestimate important impacts. Few climate models have the ability to simulate climate extremes with precision at the state level, and we know of no econometric models calibrated to analyze such findings.

With these caveats in mind, we turn to seven areas in which changes in temperature, water availability, snowpack, and other biophysical variables appear likely to affect the state's economy. Our findings indicate that climate change will continue to affect Washington's economy, and that impacts will grow, as temperatures rise. At the end of each section we offer sample policy questions related to how greenhouse gas reductions (mitigation) and/or preparation for the effects of climate change (adaptation) could be enhanced in the sector, industry, or region under consideration. Both mitigation and adaptation will be necessary to cope with the impacts of climate change. Note that the questions are by no means exhaustive. They are provided simply to illustrate the types of questions that should be considered when evaluating how to respond to the likely economic effects of climate change.

Impacts on Forest Resources

Climate change drivers

- **Average annual temperatures** are projected to increase 2°F by the 2020s and 3°F by the 2040s, compared with averages for 1970-1999. Higher temperatures will directly affect tree growth, water needs, pest impacts, and wildfire.
- **Average annual precipitation** is not currently projected to change significantly, but more winter precipitation will fall as rain.
- **Snowpack** is expected to melt earlier in the spring, extending the fire season.
- **Atmospheric carbon dioxide concentrations** are expected to increase, a change that may increase tree growth.

Key Points

- Climate change could impact the economic contribution of Washington's forests both directly (e.g., by affecting rates of tree growth and relative importance of different tree species) and indirectly (e.g., through impacts on the magnitude of pest or fire damage).
- Compared to an "average year" during the 20th century, an average year in the 2020s is projected to feature a 50 percent increase in the number of acres burned, and an average year in the 2040s is projected to feature a 100 percent increase in the number of acres burned.
- DNR's direct costs for fire preparedness and response are projected to rise proportionately, from $12 million (a conservative figure of the historic average) to over $18 million in the 2020s and to $24 million in the 2040s.
- If other state and federal expenditures related to fires also rise proportionately, direct state costs could increase from $26 million to over $39 million in the 2020s and to $52 million in the 2040s, and federal expenditures could increase from $24 million to over $36 million in the 2020s and to $48 million in the 2040s.
- The full range of economic impacts of wildfire, including lost timber value, lost recreational expenditures, and health and environmental costs related to air pollution and other forest changes, could be many times larger than the preparedness and control costs described above.
- Urban forests may also face growing wildfire risks as temperatures rise.
- Economic impacts unrelated to wildfires—e.g., from pests or changes in tree growth rates attributable to climate change—are unknown and may be either positive or negative.

Over half of Washington State (22 out of 43 million acres) is classified as forestland.[41] The state's forests support an array of economic activities from timber production to recreation and the protection of freshwater supplies and wildlife habitat. Nearly two-thirds of the state's forestlands are owned or managed by federal, state, local and tribal governments. Timber harvests on public lands account for 16 percent of the state's total harvest of approximately 3.6 billion board-feet.[42] Most wood products come from private commercial timberlands. In 2002, total employment in lumber, wood products, and pulp and paper was 43,700.[43]

Climate change could impact the economic contribution of Washington's forests both directly (e.g., by affecting rates of tree growth and relative importance of different tree species) and indirectly (e.g., through impacts on the magnitude of pest or fire damage).

Direct impacts from climate change arise because changing levels of temperature, soil moisture, atmospheric CO_2 concentrations, and other factors affect tree growth. Quantitative estimates for forests in Washington State are not available, but studies elsewhere suggest that impacts could be significant. According to a study of the Sierra mixed conifer timberlands in El Dorado County, California, climate change could reduce timber yields by 18-31 percent by the end of the 21st century, primarily because of increased summer temperatures.[44]

Climate change could affect Washington's forests in other important ways as well. One is by changing the range and affecting the life cycle of pests. Very little is known about the likely impacts here, and it is worth noting that some changes could be positive, i.e., climate change might shift existing pests out of Washington's forests instead of (or in addition to) attracting new pests to those forests. But the downside risk is likely to dominate: Washington's forests have evolved to deal with existing pests, so driving out these pests will probably matter less than the introduction of new pests. The pine beetle infestation that has decimated forests in British Columbia offers a sobering example of the risk posed by pests.

The most important way in which climate change could affect Washington's forests may be through fire. Indeed, recent research indicates that climate change has *already* affected fire in Washington's forests: Westerling et al. (2006) conclude that "large wildfire activity [in the western U.S.] increased suddenly and dramatically in the mid-1980s" and is "strongly associated with increased spring and summer temperatures and an earlier spring snowmelt."[45] A Washington-specific dataset including federal and state lands shows an average of 6 large wildfires (exceeding 500 acres) per year in the 1970s, rising to 10 in the 1980s, 14 in the 1990s, and 21 in the early years of the 21st century.[46]

Forest fires are likely to become more prevalent in the future because summer weather will continue to get hotter and drier. McKenzie et al. (2004) use 20th century data for Washington and other western states to estimate how the amount of rainfall and the average temperature in different years affects the number of acres burned in wildfires in those years. They then combine their results with climate projections to estimate how the pattern of forest fires is likely to change in the decades ahead. Compared to an "average year" (in terms of rainfall and temperature) during the 20th century, an average year in the 2020s will feature a 50 percent increase in the number of acres burned, and an average year in the 2040s will feature a doubling in the number of acres burned.[47]

Under this scenario, on the 13 million acres of private and state-owned forestlands (lands for which the state's Department of Natural Resources (DNR) bears fire-fighting responsibility), the average number of acres burned in an average year would increase from the current figure of 12,000 acres to over 18,000 acres with a 2°F warming and to 24,000 acres with a 3°F warming. Including the 12 million acres of federal forestlands (on which the US Forest Service and other federal agencies are responsible for fire-fighting) would multiply this impact by a factor of about ten, because fires on federal lands burn about 10 times more acres than fires on private or state-owned lands.[48]

An estimate of the economic impacts associated with this increase in forest fires begins with direct expenditures on fire suppression and control. DNR expenditures on fire control averaged $12 million between 1996 and 2005, and the average has risen substantially—to $20 million per year—during the first five years of the 21st century.[49] There are many reasons for this increasing cost, but a legislative study in 2005 highlighted that "increasing costs are closely tied to the number of acres burned."[50] Using the more conservative $12 million figure as the historic average, DNR's direct costs are projected to rise to over $18 million with a 2°F warming and to $24 million with a 3°F warming (Note: these estimates are in current dollars, not adjusted for inflation).

Two related items add to these costs. First, the state spends $14 million a year on related activities such as fire prevention and preparedness.[51] If these expenditures increase in proportion to DNR fire suppression expenditures, total state costs could increase from $26 million to over $39 million with a 2°F warming and to $52 million with a 3°F warming. Second, 2001 figures suggest that federal expenditures on fire suppression are approximately double state expenditures.[52] If federal expenditures increase in proportion to state expenditures and acreage is assumed to be the only contributor to cost, the federal total could rise from $24 million to over $36 million with a 2°F warming and to $48 million with a 3°F warming.

Forest fires impose other costs. These include the foregone value of timber harvest, recreation and tourism spending foregone due to forest closures and smoke impacts, and health and other environmental costs associated with air pollution. A 2003 analysis of Washington's Okanogan National Forest and Oregon's Fremont National Forest estimated such indirect costs to be 4-5 times larger than the direct costs of fire control.[53] The 2006 summer fire season illustrates some of the potential costs. The Tripod Complex fire in north central Washington generated smoke intrusion all the way to Montana and reduced hotel bookings in the Lake Chelan area during their most important summer revenue period.[54] The Conconully and Wooten State Parks were closed due to fires in 2006, the second year that Wooten had to close. The Wooten closure cost about $75,000 in foregone visitor expenditures and fees in 2006 and about $100,000 in 2005.[55]

Such losses are primarily local losses, reflecting discretionary expenditures that may simply be diverted elsewhere within the state or region. Net economic losses are more difficult to assess. Additional research in these areas, and on the differences in costs between state, federal, and private lands, would make valuable contributions to understanding the full economic effects of wildfires.

Our research has primarily focused on the consequences of increased wildland fires. Similar risks exist for forests and parklands in more urbanized areas of the state. Higher temperatures will increase the potential for fires in urban forests, just as they may increase the damage from pests and diseases in these forests. Urban forests provide essential services. From recreational opportunities to moderating temperatures and sequestering carbon dioxide, "green infrastructure" enhances the quality of life in urban areas. The risks and consequences of wildfire must be considered in these areas.

A final note about fires is pertinent. Westerling et al. (2006) conclude that the increase in western wildfires measured since the mid-1980s is more strongly correlated with increased spring and summer temperatures and an earlier spring snowmelt than with past or current management activities. This suggests that better (or different) management alone may not be sufficient to reverse the trend. Management will be necessary to protect people and property and to restore ecosystems, but it is unlikely to reduce the scale of wildfires experienced in Washington.

Mitigation Policy Questions

- What policies can enhance the capacity of wildland and urban forests to sequester carbon dioxide?
- To what extent can biomass-based energy production using forest byproducts reduce Washington State's carbon dioxide emissions?

Adaptation Policy Questions

- What types of management policies are appropriate in response to the projected increase in the scale and frequency of wildfires?
- If increased wildfires in Washington cannot be prevented, what policies can help reduce the risks of catastrophic fires, prevent damage in the wildland-urban interface, and reduce impacts on public health, tourism, and urban green infrastructure?

Impacts on Electricity

Climate change drivers

- **Average annual temperatures** are projected to increase 2°F by the 2020s and 3°F by the 2040s, compared with averages for 1970-1999. Higher temperatures will directly affect power demand by reducing demand for heating in winter and increasing demand for air conditioning in summer.
- **Average annual precipitation** is not currently projected to change significantly, but more winter precipitation will fall as rain.
- **Snowpack** is expected to melt earlier in the spring, depressing summer streamflows and increasing winter and early spring flows.

Key Points

- Climate change is likely to affect both the supply of electricity (due to a shift in the timing of peak hydropower generation) and demand for electricity (due to reduced consumption in the winter and increased consumption in the summer).
- The Northwest Power and Conservation Council estimates annual net impacts on power sales to range from a gain of $777 million to a loss of $233 million by 2020 and from a gain of $169 million to a loss of $730 million by 2040 compared to current sales, although it acknowledges that gains are likely overestimated and losses underestimated because estimates of growth in air conditioning are not yet incorporated into the Council's demand projections.
- Impacts of altered flow regimes on wild fish, and societal choices about the priority we place on them, may affect whether changes in flow regimes deliver more costs than benefits.
- Taking all factors into account, simulations of the power market by University of Washington researchers suggest a revenue impact of 5 percent or less, which at today's rates would total at most $165 million annually.

Electricity sales to residential, commercial, and industrial users in Washington State totaled $4.6 billion in 2003. Climate change is likely to affect both the supply and the demand sides of the state's electricity market.[56]

Washington's electricity market has three unusual economic features. First is the state's heavy reliance on hydropower. Dams generate 72 percent of the state's electricity—the national average is 7 percent. The rest of the state's electric generation comes from coal (11 percent, from a single 1,400 megawatt power plant in Centralia), nuclear power (8 percent, from a single 1,100 megawatt reactor near Richland), natural gas (7 percent), and non-hydropower renewable sources (2 percent).[57]

Second, Washington's power market is highly regulated. Public utilities such as Seattle City Light, which account for over half of all retail sales in the state, have a goal of breaking even, i.e., they charge their customers rates intended just to cover the cost of generating electricity. The Bonneville Power Administration, the federal entity that markets the power generated by many dams in the Columbia River basin, also has a cost-recovery mandate. Investor-owned utilities like Puget Sound Energy, overseen by the state's Utilities and Transportation Commission, earn back their cost plus a fair rate of return.[58]

Third, Washington's connection to the regional power grid has historically allowed the state to import power when grid-supplied electricity is cheap, and export power when it is expensive. The Pacific Northwest tends to purchase electricity from California and the Southwest during the winter (when their electricity demand is low and Northwest demand peaks due to heating and lighting), and sell surplus electricity to its southern neighbors during the summer (when their demand peaks because of air conditioning).

These three factors have helped keep consumer prices for electricity low. The retail price for power in Washington State was the 9th-lowest in the nation in 2003. Three things could change this favorable situation: population growth, growth of industrial demand, and climate change.

Most of the major sources of hydropower in the Pacific Northwest have been tapped, and while some of the Columbia River dams may be able to add turbines (and generating capacity) in the long term, marginal supplies of electricity today are most likely to come from fossil fuel-based power sources, particularly investor-owned natural gas-fired plants, with a smaller contribution from renewable power sources. If power demand grows with population (typical forecasts anticipate about one million additional residents every ten years), an increasing share of the state's electricity production may be exposed to volatile natural gas prices. Increased costs would be passed along to consumers.[59]

Climate change impacts are likely to affect both the supply of and demand for power in Washington. On the supply side, the main effect anticipated with a good degree of certainty is a shift in the timing of peak power generation. Assuming little change in total precipitation, earlier snowmelt (due to warmer temperatures) means more "fuel" flowing through the hydropower system during the winter and early spring (see Figure 2-1).

On the demand side, warmer winter temperatures will tend to diminish the state's demand for electricity, while hotter summer temperatures will tend to increase it, a shift illustrated by Figure 2-2.[60] According to current forecasts by the Northwest

Power and Conservation Council, winter demand is likely to fall considerably: the Council estimates a reduction of 300 average megawatts of demand (about one percent of Washington's generating capacity) for each 1°F rise in temperatures.[61] The 2.5ºF increases in average winter (October through March) temperatures projected for the 2040s would correspond to a 750-megawatt reduction in demand, comparable to half the generating capacity of the Centralia power plant.

Summer demand is likely to increase because of air conditioning and irrigation pumping, but the amount of that demand growth is unknown. The Council acknowledges that "air-conditioning penetration rates have increased significantly" since the development of the Council's demand forecasting model, and therefore that their "forecasted increases in [summertime] demand are too low and must be revised."[62]

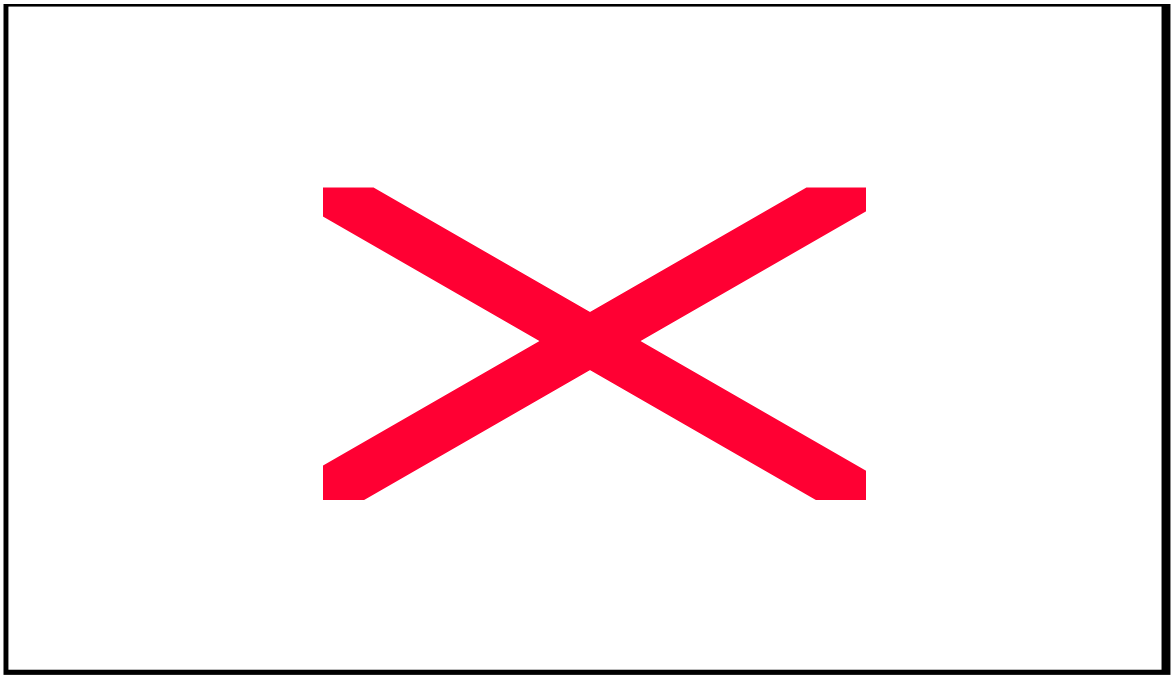

Figure 2-1. Streamflows at The Dalles Dam, Historic Flows With Projections for 2020s and 2040s. Source: John Fazio, Northwest Power and Conservation Council.

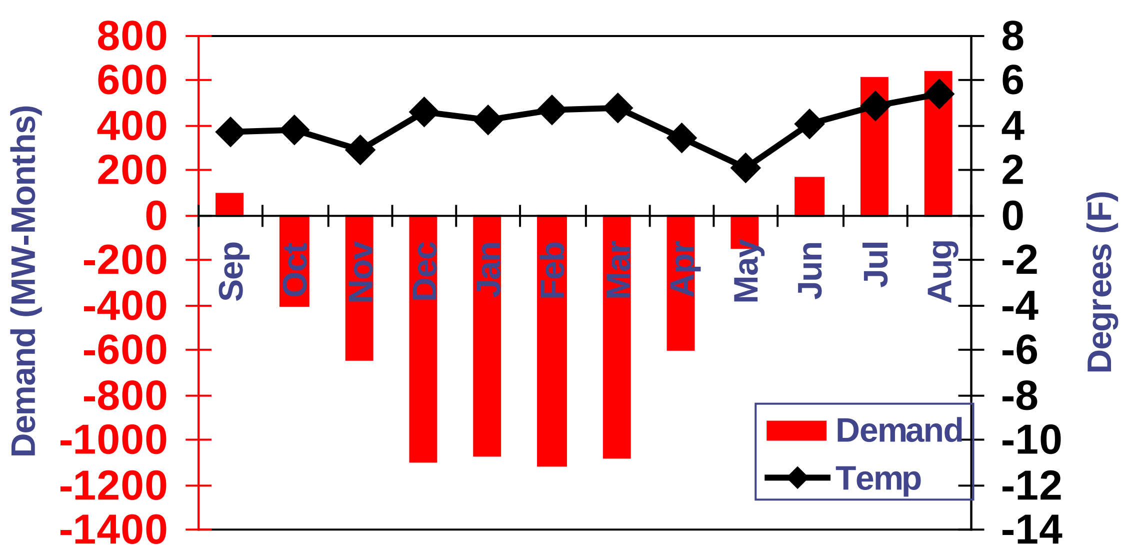

Figure 2-2. Monthly electricity demand and temperature changes, 2040 forecast compared with historic baseline. Source: John Fazio, Northwest Power and Conservation Council.

The most important variable in the state's power market is the total amount of precipitation entering the Columbia River Basin. Current models of the region's climate do not project a significant change in total precipitation during the next several decades. The Council estimates that annual net impacts on power sales from a range of plausible precipitation changes could run from a gain of $777 million to a loss of $231 million by 2020, and from a gain of $169 million to a loss of $730 million by 2040, compared with current sales. As the Council itself notes, these figures are likely to exaggerate gains and underestimate losses, since the Council's model does not incorporate assumptions about the growth of air conditioning.[63]

Assuming that average precipitation remains stable as regional temperatures rise, secondary effects include a shift in hydropower generation towards the winter and early spring; reduced power demand in the winter and increased demand in the summer; and potential changes to the ability to meet in-stream flow requirements for threatened and endangered salmon.

Even more than at present, wild fish may prove to be the wild card that determines whether changes in the flow regime deliver more costs than benefits to the power system and to Washington electricity consumers. As the Council notes in its *Fifth Northwest Electric Power and Conservation Plan*, "measures developed to aid fish and wildlife survival often diminish the generating capability of the hydroelectric system."[64]

Water for the summer flows critical to the survival and downstream migration of juvenile salmon must be stored behind reservoirs during the winter, reducing peak power generation and revenues. If river temperatures increase to levels lethal to juvenile and adult salmon during the summer, in-stream flow requirements may need to be adjusted to favor salmon survival. Less power is generated when stored water must be released through spillways rather than through (fish-killing) turbines. If power generation is restricted during a season when surplus power could otherwise be sold profitably, the system may incur further losses.

Taking many factors into account, simulations of the power market performed by researchers at the University of Washington under a variety of scenarios using the Columbia River Simulation Model (ColSim) showed that "hydropower revenue changes [i.e., losses] were less than 5 percent … primarily due to small changes in annual runoff."[65] Because hydropower accounts for such a large share of the state's electricity market, a 5 percent change would total $165 million.[66]

Washington's reliance on hydropower provides the state's electricity consumers with some protection from the volatility of fossil fuel prices and from potential regulatory controls (e.g., on carbon emissions). But hydropower is also more directly exposed to climate change impacts than other generating sources. A shift in timing of peak generation appears to be the supply-side impact most likely to affect electricity rates. A significant increase or decrease in total precipitation, though not currently projected, would have more dramatic effects on power supplies and electricity rates.

Mitigation Policy Questions

- What policies are available to restrain energy use during increasingly warmer summers, such as incentives for 'green building' practices, the use of energy efficient appliances including air conditioners, elimination of urban heat sinks by repainting surfaces with light colors, planting trees, and creating open spaces?
- What policies can favor the development of new power sources that maintain the price advantages of hydroelectricity while avoiding growth in greenhouse gas emissions?

Adaptation Policy Questions

- How can impacts on salmon stocks, many of which are already at risk, be minimized if Columbia River hydrosystem management priorities must shift in response to summer water availability issues?

Impacts On Municipal Water Supplies

Climate change drivers

- **Average annual temperatures** are projected to increase 2°F by the 2020s and 3°F by the 2040s, compared with averages for 1970-1999.
- **Snowpack** is expected to melt earlier in the spring, depressing summer streamflows and increasing winter and early spring flows.
- **Average annual precipitation** is not currently projected to change significantly, but more winter precipitation will fall as rain.

Key Points

- The potential impacts of climate change on municipal water supplies vary widely depending on populations served and water resources available, but both westside and eastside communities are likely to be affected.
- The "firm yield" of the Seattle water system is projected to decline by about 6.1 million gallons per day every ten years through the 2040s, assuming Seattle does not adapt to changing snowpack conditions by modifying its system operating rules.
- Water conservation, perhaps the most cost-effective response (estimated at an annual cost of $680,000 per million gallons per day saved), has potential that hasn't been fully tapped, but there is a limit to how much can be saved through conservation.
- Other alternatives are more costly to both consumers (water rates) and municipalities (investments in new storage capacity), though the relative costs of conservation and new supply projects are system-specific.
- Developing and implementing adaptation strategies can offer low-cost ways to add flexibility to supply systems.
- The uncertainties introduced by climate change increase the costs of water supply.

Municipal utilities across Washington State vary greatly in terms of the populations served and the water resources at their disposal. As such, it is not surprising that the projected impacts of climate change on municipal water systems vary and are specific to individual locations. This assessment focuses on a few locations. A more wide-ranging analysis is needed, especially for areas of the state outside the Puget Sound region.

Inside the Puget Sound region, our research identified some municipal water systems that have little cause for concern about climate change impacts. In

Everett, for example, the Sultan River provides so much water for the city's population of 100,000 that climate change is unlikely to constrain usage.[67]

In some of the most populous areas in Puget Sound, however, water resources are known to be a significant issue, especially when future population growth is taken into account. The importance of water resource availability can be seen in the recent actions of the Cascade Water Alliance (CWA), a coalition of cities and water districts in eastern and southern King County. Bellevue and other municipalities in the CWA currently depend on the City of Seattle for their water. However, they are now developing their own water supply system. Centered on the Lake Tapps reservoir in Pierce County, the new system will take decades to complete, at a cost estimated at $450 million.[68]

It is not clear what role (if any) concerns about climate change may have played in past CWA decisions, or what role those concerns will play in future decisions. What is clear is that climate change is likely to negatively impact municipal water systems in the Seattle area. The main concern in this area is not water *quantity*, i.e., total volumes, but rather water *availability*, i.e., timing. Figures 2-3 and 2-4 highlight the problem. Little precipitation falls in the mountain basins supplying Seattle's water during the summer, when water demand peaks.

Mountain snowpack acts as a natural reservoir, storing precipitation during the winter and releasing it during the spring and early summer. Constructed reservoirs act in concert with this natural phenomenon, providing water needed for consumptive uses during the summer. (These reservoirs can also help control flooding and release water, if needed, to maintain in-stream flows.)

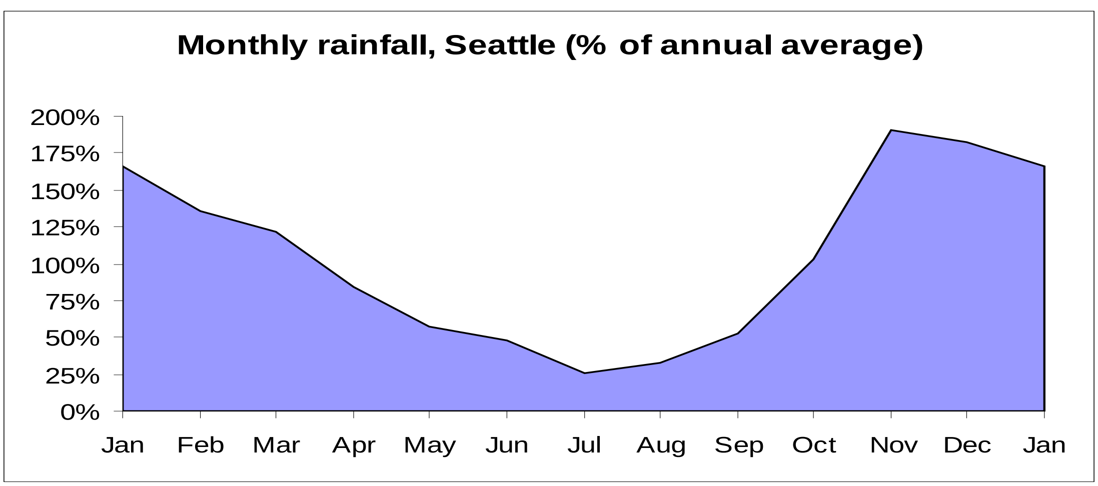

Figure 2-3. Monthly Rainfall in Seattle (above) shows monthly rainfall as a percentage of the annual average.

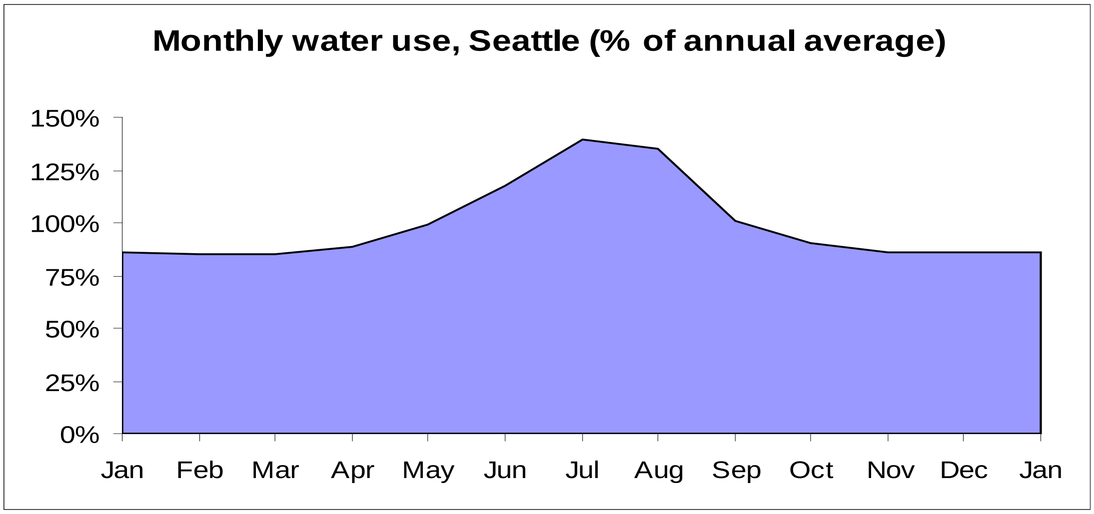

Figure 2-4. Monthly Water Use in Seattle (below) shows monthly water use as a percentage of the annual average. Sources: Richard Palmer, University of Washington, and the U.S. Census Bureau.[69]

From a water supply perspective, a key management goal for constructed reservoirs is to release stored water to bridge the "water gap" between the early summer and the fall, i.e., between the end of snowmelt run-off and the start of the rainy season. The resulting management strategy is clear: fill reservoirs to maximum capacity with snowmelt and precipitation and then manage draw-downs so that the reservoirs don't go dry before the rains return.

A direct impact of climate change on water supply will be on snowpack: warmer winters and springs means that smaller mountain snowpacks will melt earlier and release their stored water more quickly. An analysis of Seattle's Cedar and Tolt River watershed by Wiley and Palmer (2006) projects that a "50 year event" by historic standards—i.e., a snowpack so low that it only occurred once every 50 years—can become a common "5 year event" under climate conditions projected for the 2040s.[70]

These snowpack changes will increase the strain on water supply systems that rely significantly on snowpack. With less snowmelt during the late spring and summer months, the "water gap" will become more pronounced and will extend over a longer period. For example, Wiley and Palmer (2006) project that combined inflows to the Cedar and Tolt River reservoirs during the key June-September period will decline by 6 percent per decade.[71]

The ability of a water supply system to handle this increased strain depends on the system in question. Throughout the state, there are surface water systems, groundwater systems, and those that are a mixture of both. In addition, there are systems that rely on precipitation in the form of snowpack, precipitation in the form of rain, and those that are influenced by a combination of rain and snow. These factors, along with many others, including projected demand and ability to adapt, will affect the nature of the strain placed on water supply systems and their ability to adequately handle the strain. In some cases—as with Everett, discussed above—the system retains enough reserve capacity to fill the gap without difficulty. In other cases—such as the rapidly growing King County region—climate change may require more extensive use of adaptation strategies and eventually new investments.

Seattle Public Utilities (SPU) estimates the "firm yield" of their system — i.e., the level of service expected to be maintained in 49 out of 50 years—to be 171 million gallons per day (MGD). [72] Current demand averages about 130 MGD. Demand has fallen in the past few years due to conservation efforts, economic forces, and changing regional priorities, and is forecast to remain essentially flat for the next 40 years (in part because Bellevue and other Cascade Water Alliance partners will be reducing their use of SPU water by 25 MGD as they shift to their own water supply system).[73] In the absence of climate change, firm yield would remain stable over time and SPU estimates that it would be able to meet demand "until well after 2060," the end of their forecast period.[74]

Taking climate change into account, Wiley (2004) projects that firm yield will fall by about 6.1 MGD per decade (about 3.4 percent per decade), reducing SPU's firm yield from its current level of 171 MGD to 159 MGD by 2020 and 147 MGD by 2040. A continuation of that trend (see Figure 3-5) would bring Seattle's water system to the point at which demand exceeds available supply by mid-century if no changes are made in how the system operates.[75] (The firm yield shown in Figure 3-5 assumes static operation of the supply system, which in reality is capable of responding dynamically to hydrologic conditions and to short- and long-term weather forecasts.[76] In addition, the demand forecast shown in Figure 2-5 assumes—conservatively—that there will no new conservation programs past 2030.)

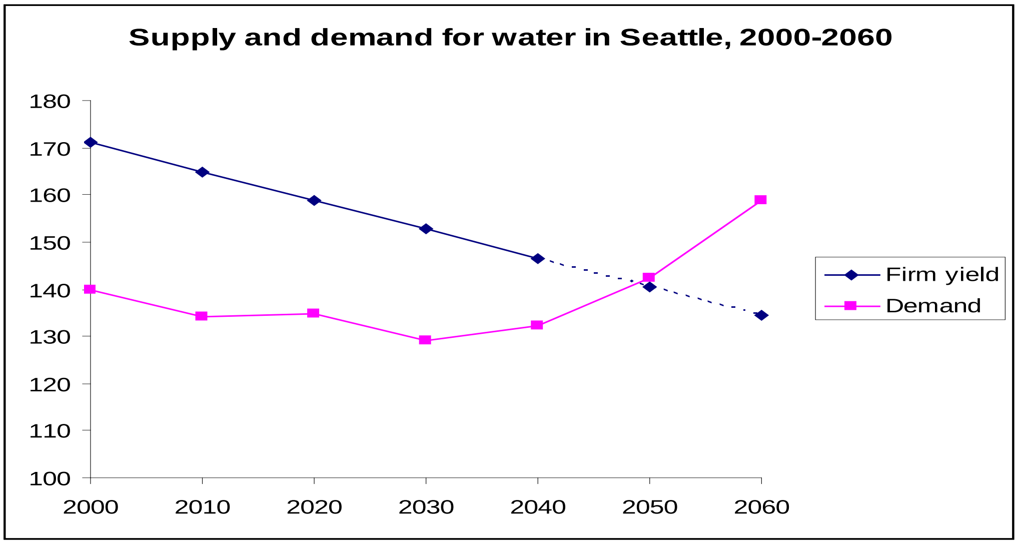

Figure 2-5. Supply and Demand for Water in Seattle, 2000-2060.
Sources: Demand is from Seattle Public Utilities. Firm yield is based on Matthew W. Wiley, University of Washington; the dotted line extends Wiley's analysis—which projects an approximately linear decline through 2040—for an additional 20 years.[77]

What are the economic impacts of water systems that approach capacity constraints? This is an extremely difficult question to answer because of the legal and political uncertainties that surround water policy. Local governments may address impending capacity constraints on the demand side (e.g., by promoting conservation measures) or on the supply side (e.g., by changing operations, building additional reservoirs, or developing alternative sources). Local governments may also develop and utilize adaptation strategies such as those adopted by SPU during the winter of 2004-05 to enhance the flexibility and resiliency of their existing supply systems. Without knowing which specific approaches will be adopted, it is not possible to offer more than a broad range of cost estimates.

For Seattle, the range of options (with estimates of associated costs where available) includes:

- Enhancing flexibility and resiliency of the supply system through operational adjustments. Although the costs are difficult to estimate, they are likely to be relatively low. The extent to which such adjustments can mitigate losses that would otherwise result from climate change is not clear.
- Additional conservation measures. Current conservation efforts by Seattle Public Utilities have an average annual cost of about $680,000 per MGD saved. Using this figure as a rough estimate of future costs indicates that offsetting the 6.1 MGD/decade loss due to climate change would require additional conservation expenditures of about $8.3 million per year by the 2020s (to offset a projected loss of 12.2 MGD) and $16.6 million per year

by the 2040s (to offset a projected loss of 24.4 MGD).[78] The costs of future conservation may be lower than these estimates because of technological improvements, or they may be higher because of increasing marginal costs after the "low-hanging fruit" gets picked. And of course at some point conservation efforts will be tapped out: beyond the conservation efforts that are already included the demand projections shown in Figure Water-3, SPU estimates that there is the "technical potential" for an additional 15 MGD of conservation savings by 2030, with an unknown amount available beyond that date.[79]

- Adding capacity. SPU's *2007 Water System Plan* includes an analysis of several supply alternatives, e.g., the Chester Morse Lake Dead Storage option. All together, these alternatives could generate an additional 68-123 MGD of firm yield, with an annualized cost (using a real discount rate of 5%) ranging from $40,000 to $1.4 million per MGD.[80]
- Raising water rates to reduce demand. The price elasticity of demand for water is in the range of -0.10 to -0.225, meaning that a 10% increase in water rates is likely to reduce demand by 1.0 to 2.25%.[81] The political feasibility of this option is unknown.

A final caveat: Perhaps more than in other areas, estimating long-term trends in water use is a difficult task. In 1997, for example, SPU forecast that demand would exceed supply in 2013.[82] Thanks to conservation measures and reduced demand from the Cascade Water Alliance members, that date was pushed back to "at least 2020" (according to the *2001 Water Supply Plan*) and it now appears to be at least a few decades beyond that, too.[83] Nonetheless, these estimates use the best available data, the data on the basis of which planning decisions are made. Given the multi-decade perspective required in such decision-making, the uncertainty introduced by climate change can only exacerbate other uncertainties and lead to increased costs.

Communities east of the Cascades face different challenges. Like the Puget Sound region, they face rising water demand as populations grow. Unlike the Puget Sound region, larger communities have resolved the conflict between limited surface water supplies and patterns of demand dominated by agricultural water uses by creating municipal water systems that integrate groundwater to a greater degree into their drinking water supply picture.

The cities of Spokane and Wenatchee, for example, rely exclusively on aquifers for municipal water supplies. Walla Walla depends on a mix of surface and groundwater sources, while Yakima serves 65,000 customers with a system comprising 90 percent surface and 10 percent groundwater sources.[84]

Subsurface water, considered "back-up supply" in Yakima and used when the federal Bureau of Reclamation imposes storage controls on water withdrawals from the Naches River due to low-snowpack assessments,[85] seems to offer a measure of protection against climate change impacts. But early snowmelt and reduced late-summer streamflows affect aquifer recharge. The director of the City of Spokane's Water Department, responsible for a system that draws from a sole-source aquifer, observes that "low river flows will ultimately affect groundwater levels as well."[86] While we were unable to assess the potential economic impacts of climate-linked changes to aquifer recharge, we note that the phenomenon could affect hundreds of thousands of eastern Washington residents that currently depend on subsurface sources for part or all of their municipal water supply.

Mitigation Policy Questions

- What policies have the best chance of maximizing the efficient use of water, and thus reducing demand and energy use for water pumping, in municipalities dependent on sources from low-elevation transient snowmelt basins?

Adaptation Policy Questions

- Given the sizable investment and long lead time necessary for planning and implementing supply side solutions, how can municipal water supply systems best determine if, where, and when additional storage should be pursued?
- How should demand and supply policies be balanced to determine the most efficient and effective course of action to ensure sufficient municipal water supplies, especially in the more populous regions in the Puget Sound?

Impacts on Agriculture

Climate change drivers

- **Average annual temperatures** are projected to increase 2ºF by the 2020s and 3ºF by the 2040s, compared with averages for 1970-1999. Higher temperatures will directly affect plant growth, water availability, and pests.
- **Average annual precipitation** is not currently projected to change significantly, but more winter precipitation will fall as rain.
- **Snowpack** is expected to melt earlier in the spring, depressing summer streamflows. This is likely to reduce water availability for agriculture.
- **Atmospheric carbon dioxide concentrations** are expected to increase, a change that may promote crop growth, but may also favor weeds.

Key Points

- Climate change will affect agriculture in a number of ways, some positive (e.g. longer growing seasons), some negative (e.g., reduced water supplies, increased water demand), and some of unknown impact (e.g., changed behavior of weeds, pests, and crop diseases). Impacts related to changes in water availability are likely to be of particular significance.
- Agricultural output in the Yakima Basin is highly sensitive to water availability, and to climate change impacts that increase the probability of water shortages. Expected annual crop losses with water shortage rise from an historic average of $13 million to $79 million by mid-century, or from 1.4 percent to 8.8 percent of the $901 million agricultural output during good years.
- Dairy production is sensitive to temperature changes, but Washington's average temperatures are likely to remain in a range in which direct impacts on milk output are small. Washington's two most productive counties would likely experience production declines no larger than 3-6 percent by the end of the century due to temperature effects alone.
- Effects of climate change on the winegrape industry are likely to be mixed. Warming could push some growing areas in Eastern Washington toward the upper limits of temperature tolerance ranges for some important winegrape varieties within the next half-century, while increasing the attractiveness of cooler areas such as the Puget Sound.
- Shifts in the global marketplace appear likely to be more significant for Washington farms than the direct economic impacts of changes in temperature and precipitation experienced in the state.

Agriculture is a $5.3 billion business in Washington State.[87] The top five commodities by value in 2004 were apples ($1.023 billion), milk ($861 million), wheat ($524 million), livestock ($476 million), and cherries ($237 million). Field crops, livestock, and fruits and nuts accounted for most of the state's farm production value.[88] Agriculture is practiced in almost every region of the state, under a wide variety of climate and resource conditions.

Climate change will affect agriculture in a number of ways, some positive (longer growing seasons), some negative (reduced water supplies, increased water demand), and some of unknown impact (e.g., changed behavior of weeds, pests, and crop diseases). Impacts related to changes in water availability are likely to be of particular significance in Washington.

A large factor determining the net economic impacts of climate change on Washington's agricultural sector will be the impacts experienced in other regions and expressed through the global and national marketplace. Washington's agriculture is highly export-dependent, and market shifts appear likely to be more significant for Washington farms than the direct impacts of changes in temperature and precipitation experienced here. Due to the extreme complexity of analysis required, we did not attempt to assess how such external factors might affect Washington agriculture.

The state's agricultural sector is too complex to attempt a comprehensive analysis of climate change impacts. With that difficulty in mind, we have chosen to present three short case studies to illustrate an array of possible impacts: a profile of the Yakima Basin, the state's highest-value agricultural region; a high value-added product; dairy production, which concerns the state's second most valuable agricultural commodity; and wine production, which features a high-value crop (winegrape harvest valued at $127 million in 2004).

Spotlight: Crops in the Yakima River Basin

Earlier this year, researchers at the Pacific Northwest National Laboratory studied the potential impacts of climate change on agriculture in the Yakima River Basin, which includes Yakima, Kittitas, and Benton Counties (Scott et al., 2006).[89] These three counties generated about $1.3 billion in agricultural production in 2004. This economic output is, however, dependent on water availability: these authors note that "economic losses in the Yakima Valley reportedly have been about $140–$195 million in a severe drought year such as 2001." This represents 10-15 percent of the valley's agricultural output by value.

Scott et al. analyzed a climate change scenario featuring a temperature increase of 3.6°F (slightly more than the average temperature increase projected for the 2040s) and a concurrent increase in carbon dioxide concentrations from 350 parts per million to 560 parts per million.[90] They analyzed dryland wheat and six irrigated crops (wheat, sweet corn, trellis apples, cabernet winegrapes, alfalfa, and potatoes) using the WSU CropSyst model, which estimates crop yields on the basis of factors such as temperature, carbon dioxide concentration in the atmosphere, and water availability. They then extrapolated their results to other crops, using the response of trellis apples, for example, as a proxy for the response of other types of apples, pears, and cherries.

For all seven of the crops studied, the CropSyst model estimated that climate change of the magnitude modeled would produce no significant impact on yields *assuming that water availability remained constant*.[91] Underlying this result was the coincidence that impacts from elevated temperature (which generally reduces yields) and the impacts from elevated carbon dioxide concentrations (which generally increases yields[92]) roughly offset each other for the crops included in their study.

For dryland agriculture, the assumption that water availability remains constant appears to be reasonable because climate change is not expected to significantly affect annual total precipitation, although warmer temperatures and earlier snowmelt will affect soil moisture in complex ways. In the context of their scenario, then—a 3.6°F increase in temperature combined with an increase in carbon dioxide concentrations to 560 parts per million—Scott et al. conclude that the net impact of climate change on dryland agriculture is likely to be close to zero. Another study (Thomson et al., 2005) suggests that dryland winter wheat production in the Yakima area may actually *increase* anywhere from 5-35 percent, mostly as a result of increased carbon dioxide concentrations.[93]

For irrigated agriculture, however, water availability is likely to decline in the key summer months (see Figure 2-6), and this tilts the balance strongly in the direction of negative impacts for irrigated crops. A complicating factor is that water allocations are not based on the concept of economic efficiency, which in case of drought would provide scarce water resources to those farmers who could use it most profitably. Instead, water allocation is based on the concept of "first in time, first in right": farms with "senior" water rights get their full water allocation before those with "junior" water rights get any. In case of drought, junior water-rights holders (who have a greater proportion of their acreage in high-value crops such as apples and winegrapes) are "pro-rationed," receiving only a fraction of their promised allocation, while senior water-rights holders (who have a greater proportion of their acreage in low-value crops such as alfalfa and sweet corn) are unaffected.[94]

The interaction between water law and history therefore magnifies the economic impact of water shortages in the Yakima River Basin, and current water law may amplify the impacts of climate change on irrigated agriculture more generally. In any case, water shortages in the Yakima River Basin are likely to become more common as losses in snowpack and earlier runoff reduce summer streamflows. Under the current climate, Scott et al. estimate that there is a 14 percent probability that junior water-rights holders will face pro-rationing of at least 50 percent. Under a 3.6°F warming, that probability increases from 14 percent to 54 percent. In other words, under the current regime of water rights, pro-rationing of at least 50 percent will occur on average every other year by mid-century, instead of the current rate of once every seven years.

The CropSyst model highlights that this reduced water availability will significantly reduce crop yields. In the case of irrigated wheat, for example, the difference between having 90 percent of full water and 40 percent of full water can be dramatic: 100 bushels per acre in the former case, only 50 in the latter case. For perennial crops, the values from the model are likely to be underestimates because they are single-year estimates that do not take into account possible carry-over impacts in later years.

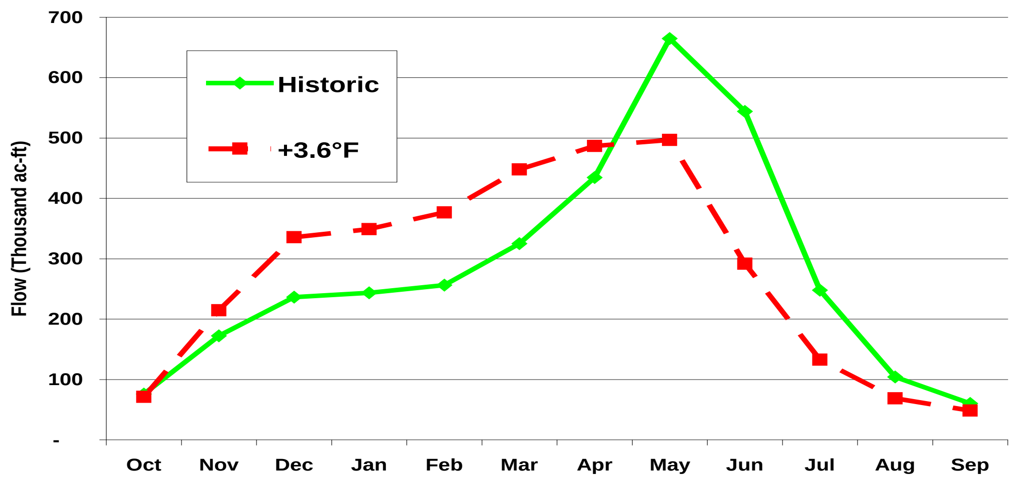

Figure 2-6. Average flow of the Yakima River at Parker, historic (1950-1999) and projection for a 3.6°F temperature increase.
Note that total annual flows are approximately constant. Source: M.J. Scott, L.W. Vail, C.O. Stöckle, A. Kemanian, and R. Prasad. 2006. "What Can Adaptation to Climate Variability in Irrigated Agriculture Teach Us About Dealing with Climate Change?" PNWD-SA-7396. Battelle, Pacific Northwest Division, Richland, WA.

Scott et al. conclude that climate change will increase the probability of water shortages and depress the production of irrigated crops in the Yakima River Basin. They use as their base scenario a "good year" without water shortages in which agricultural output for irrigated crops is estimated at $901 million.[95] Under historic conditions—i.e., in the absence of climate change—they estimate that water shortages reduced crop yields by at least 8 percent (by more than $50 million) in one year out of ten, and by at least 28 percent (by more than $250 million) in one year out of fifty.

With 3.6°F warming, the likelihood of "good seasons" decreases and the likelihood of "bad seasons" increases: 50-year droughts become 10-year droughts, and 10-year droughts become 2.2-year droughts. (In other words, the likelihood of a drought that reduces crop yields by at least 28 percent rises to 10 percent, and the likelihood of a drought that reduces crop yields by at least 8 percent rises to 45 percent.) Expected crop losses from water shortage rise from the historic average of $13 million per year to $79 million per year, or from 1.4 percent to 8.8 percent of the $901 million agriculture output during the "good year" base scenario.

The Yakima River Basin is among the driest places in the Pacific Northwest, and without irrigation it would face severe water constraints. The likely impacts of climate change on irrigated crops in Yakima highlight the potential impacts of climate change on agricultural areas dependent on water from low-elevation transient snowmelt basins, e.g., the Walla Walla, Methow, Wenatchee, and Okanogan valleys. In addition, the economic impacts on winegrape and dairy production illustrate the potential breadth and scope of climate change impacts on agriculture in Washington.

Spotlight: Dairy Production

Milk and other dairy products constitute the 2nd most valuable agricultural commodity (after apples) in Washington State. In 2004, the state had 237,000 dairy cows—the most productive in the nation at 62.6 pounds of milk per day, according to the National Agricultural Statistics Service—and its dairy farmers had sales of $861 million. Yakima and Whatcom counties dominate dairy production, together accounting for over half of the state total: Yakima leads the state with 66,000 dairy cows generating sales of about $240 million in 2004, and Whatcom is a close second, with 58,000 dairy cows generating sales of about $210 million in 2004.[96]

We analyzed potential climate change impacts on dairy production in both Yakima and Whatcom counties. (In addition to dominating dairy production, these two counties—Yakima in the hot, dry east side of the state, Whatcom in the cool, wet west side—help represent the range of conditions under which dairy farming takes place in Washington State.[97]) Our analysis was inspired in part by Hayhoe et al. (2004), a study that concluded that climate change could reduce milk production in California by 2 to 4 percent by mid-century and by 7 to 22 percent by the end of the 21st century.[98]

We based our analysis on a 1981 National Research Council study of temperature effects on dairy production.[99] A regression analysis of their data (see Figure 2-7) estimates that milk production per cow, which is about 60 lbs/day under optimal conditions, decreases by almost 1 lb/day for each degree that temperatures are sustained above 68°F.[100] (Cold temperatures also reduce milk production, by about 0.6 lbs/day for each degree that temperatures are sustained below 23°F, and both hot and cold temperatures affect cows' food consumption.[101])

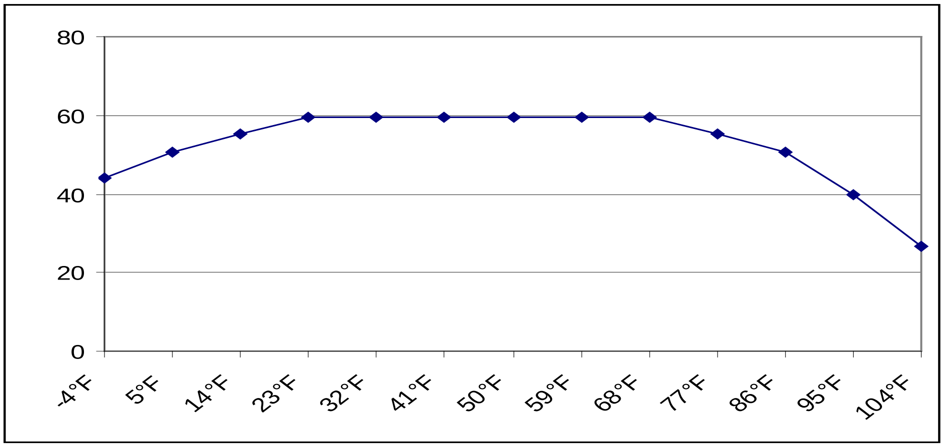

Figure 2-7. Milk production (pounds per day) at various sustained ambient temperatures. Estimates assume a 1300-lb cow producing a baseline of 60 lbs/day of 3.7% fat milk. Source: Adapted from National Research Council (1981).[102]

We combined these results with historic temperatures for Yakima and Whatcom counties and with projected temperatures for the same locations for the 2040s and 2090s. The historic data averaged ECHAM-5 daily temperatures for 1900-2000; projections came from the SRES-A2 scenario. Because our data only included daily highs and lows while the NRC study pertains to temperatures sustained for 6 hours, we made adjustments on the basis of the simplifying assumption that temperature follows a linear sawtooth with daily highs and lows spaced 12 hours apart. (The results of our study were not strongly affected by changes in this assumption.)[103]

Our results predict a decline in milk production in the two counties of 1 to 3 percent by mid-century and 3 to 6 percent by the end of the century, with larger declines in Yakima County than in Whatcom County. (See Table 2-1.) Our mid-century predictions are roughly in line with the California results from Hayhoe et al. (2004), but our end-of-century results are significantly less than the 7 to 22 percent reduction predicted by Hayhoe. We estimate lost sales of $6 million per year by the 2040s and $19 million per year by the 2090s (compared with current levels), although in both cases declining food intake by dairy cows would offset some of these losses.[104]

We suspect that the relative stability of dairy production in Washington compared to California is best explained by Washington's lower baseline temperatures in both the summer and the winter. In the summer, temperature increases will reduce milk production by less in Washington than in California because of Washington's lower baseline temperature. (This is especially true for Whatcom County.) In the winter, lower baseline temperatures in Washington mean that temperature increases will actually *increase* milk production by reducing the number of colder-than-optimal days.

	Dairy production (as % of current product)	Sales per year (in 2004 $m)	Lost sales per year (in 2004 $m)
Yakima—Current	--	$240	--
Yakima—2040s	98.0%	$235	$4.8
Yakima—2090s	94.5%	$227	$13.2
Whatcom—Current	--	$210	--
Whatcom—2040s	99.5%	$209	$1.1
Whatcom—2090s	97.1%	$204	$6.1

Table 2-1. Climate change impacts on dairy production in Yakima County and Whatcom County, 2040s and 2090s. Note that the economic value of lost sales will be at least partly offset by declining food intake by dairy cows.

Spotlight: Washington Wines

From modest roots in the 1960s, Washington's commercial vineyards and wineries have grown to a position of prominence in the state's agricultural sector. Washington State is the country's second-largest wine producer (after California), and at $127.5 million (2004 harvest), winegrapes are the state's fourth largest fruit crop by value.[105] The industry comprises some 400 wineries, 350 vineyards, and more than 30,000 vineyard acres heavily concentrated in the Yakima and Mid-Columbia valleys of Eastern Washington. The industry generated the equivalent of 14,000 full-time jobs and a total economic impact of $3 billion in 2005.[106]

The production of winegrapes is highly attuned to soil and microclimate conditions that favor specific grape varieties, and present conditions in Washington favor premium wines (priced above $8 per bottle). The motto of the Washington Wine Commission – "The Perfect Climate for Wine™" – expresses the confidence of an industry whose output has grown ten-fold in a quarter century. The sensitivity of premium winegrape varieties to climate factors makes climate change a natural concern to all levels of this multi-billion-dollar industry.

The effects of climate change are likely to be mixed across the state's nine recognized viticultural areas, with some areas benefiting from conditions that favor new varieties while other areas experience changes that are harmful to existing varieties. If growing-season temperatures reach averages projected for the middle of this century, for example, some growing areas in Eastern Washington may approach the upper limits of temperature tolerance for widely planted red-wine varieties including Merlot and Syrah, and may exceed the tolerance range for white-wine varieties including Chardonnay, Riesling, and Sauvignon Blanc.[107] (See Figure 2-8.) The great variety of microclimates in Eastern Washington viticultural areas makes generalization about impacts impossible.

Warmer temperatures could increase the number of varieties suited to the state's cooler growing zones such as Puget Sound. Indeed, "cool climate regions (such as those in Western Washington) appear to benefit the most" from the projected warming, according to wine climatologist Gregory V. Jones of Southern Oregon University.[108] If true, this could signal a significant shift in the state's wine industry; at present, cool-climate areas in the Puget Sound and Columbia Gorge currently account for fewer than 400 vineyard acres, slightly more than 1 percent of the state's winegrape acreage.[109]

The Washington wine industry operates in a global marketplace, so a full assessment of the impacts of climate change on Washington wines must take external influences into account. One recent study (White et al., 2006) uses a high-resolution climate simulation model to examine how premium wine grape-producing regions in the United States could be affected by the climate changes projected for this century. The models used in the study predict a pronounced shift of premium winegrape production to higher elevations, toward the coast, and northward in latitude. The shift is likely to produce viable areas in "high humidity/precipitation regions" including the Pacific Northwest.[110]

That shift would bring costs as well as benefits. The authors note that higher humidity is associated with "higher risk of quality-reducing factors" including rot, mildew, and raindrop impacts that promote fungal dispersal. Thus growers in so-called "refugial premium winegrape production regions" appear likely to incur costs due to "extensive pathology control measures or . . . declines in winegrape quality."[111]

The authors also sound a cautionary note about temperature variability and the danger of relying on averages. While average temperature changes clearly produce shifts in the viability of different winegrape varieties, their simulation of future climate was sensitive enough to model changes in the frequency of extreme temperatures during the growing season. Temperature extremes had a decisive effect on the results: increases in the number of days above 95º F severely limited production of premium winegrapes. The modeled changes in the frequency of extreme temperatures by 2100 reduced their estimate of total area capable of consistently producing the highest quality grapes by more than 50 percent nationwide. Their conclusion: "Changes in the frequency of extreme temperatures may have a more extreme effect on biological and agricultural systems than changes in mean climate."[112]

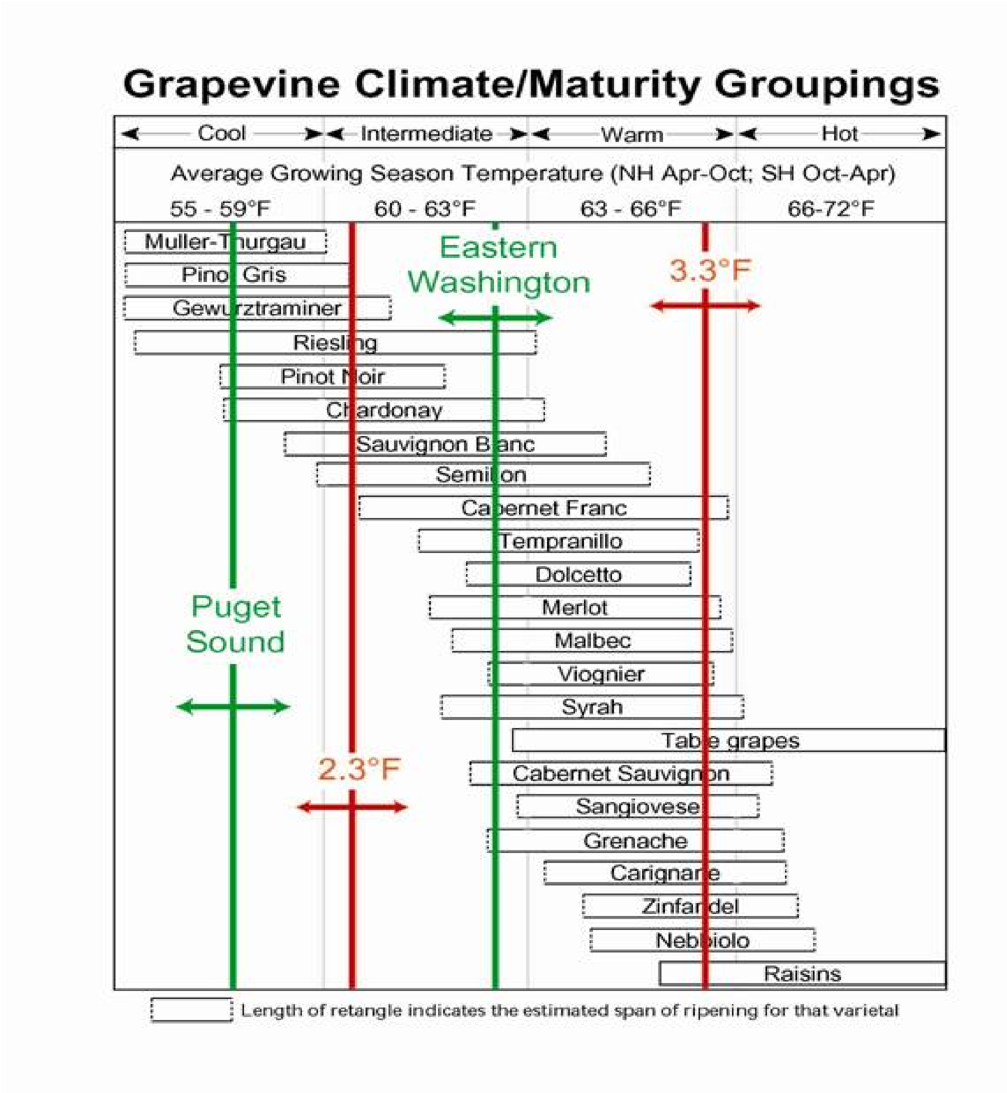

Figure 2-8. Grapevine Climate/Maturity Groupings, With Recent and Projected Ranges for Average Growing Season Temperatures in Puget Sound and Eastern Washington Growing Areas. Source: Gregory V. Jones, Southern Oregon University.[113]

Changes lie ahead for Washington's wine industry. They appear unlikely to be simple gains, although climate change impacts may be more severe in other wine-producing regions around the globe. Eastern Washington viticultural areas, where the industry is currently concentrated, are vulnerable to the impact of temperature changes and restrictions on irrigation. According to Jones, "the predicted warming of the next 50-100 years presents numerous potential impacts and challenges to the wine industry, including additional changes in grapevine phenological timing and ripening profiles that will lead to disruption of balanced composition in grapes and wine; alterations in varieties grown and regional wine styles; spatial changes in viable grape-growing regions; increased presence and/or intensity of pests and disease; and added water-related challenges (e.g., timing and availability)."[114]

Displacement of winegrape varieties and other impacts experienced by Washington's wine-producing regions will unfold during a period of unprecedented change for the global wine industry. "Refugial premium winegrape production regions" like the coastal Pacific Northwest may become destinations for new investment as Washington growers establish new vineyards and, possibly, as impacts elsewhere force the global industry to relocate capital. Local effects on land values and land use practices could be significant, with effects on production, revenue, and employment in Washington's wine industry as local microclimates shift and the global industry restructures in response to climate change.

Mitigation Policy Questions

- What policies can help farmers reduce energy use and thus greenhouse gas emissions through changes in machinery, irrigation practices, soil inputs and pest control, and other farming practices?
- What policies can help farmers take advantage of greenhouse gas sequestration opportunities (see Chapter 3)?

Adaptation Policy Questions

- Does the likelihood of significant economic impacts on irrigated crops in the Yakima Basin in water-short years favor planning for water demand (efficiency) or supply (storage) responses?
- Overall, how can the state help farmers plan and prepare for the likely impacts of climate change?

Impacts on Human Health

Climate change drivers

- **Average temperatures** are projected to increase 2°F by the 2020s and 3°F by the 2040s, compared with the average for 1970-1999. Summertime average temperatures are projected to increase slightly more than the annual average.
- **Average annual precipitation** is not currently projected to change significantly.

Key Points

- Although little firm data exists on which to base cost estimates, public health costs related to climate change effects could rise substantially.
- Changes in temperature and precipitation are linked to outbreaks of West Nile Virus, an infectious disease now present in Washington.
- Although it is not certain that West Nile Virus will spread in Washington as it has in other states, medical and non-medical direct costs in Colorado (estimated at $121.5 million over a five-year period) and medical, non-medical, and public health costs in Louisiana (estimated at $20.1 million for a single year) illustrate the magnitude of potential costs.
- Efforts to reduce global warming emissions may pay a "double dividend" by reducing the impact of asthma, a disease already estimated to cost Washington State over $400 million each year.
- Heat-related illnesses and mortality are likely to increase when temperatures exceed thresholds of 100º F.

In 2004, Health Care and Social Assistance expenditures accounted for $17.2 billion of Washington's Gross State Product, making it the state's fifth largest economic sector (6.6 percent of the state's total economic activity). Average temperatures, temperature extremes, and climate variability play a role in the incidence of infectious disease and the prevalence of a variety of health conditions that contribute to health care expenditures and outcomes.

The relationships between warming, weather, and health patterns are complex, making economic impacts intrinsically difficult to assess. Little firm data is available and therefore we have not quantified the likely public health costs of climate change. Some useful information can be gleaned, however, by looking at three areas of health impacts for which links to climate are relatively well documented: infectious disease, respiratory illnesses, and heat-related illnesses.

If the experience of other states offers a guide, the public health costs of climate change in Washington may soon begin to rise substantially.

Infectious Disease: West Nile Virus

Changes in temperature and precipitation affect the distribution of mosquitoes and other disease vectors, and thus have the potential to change the incidence of infectious disease. Higher temperatures and weather extremes associated with global warming may play a role in expanding the range of diseases spread by insect vectors.[115]

West Nile Virus (WNV) is a potentially deadly mosquito-borne infection that affects the nervous systems of birds, horses, and human beings. Symptoms include fever, meningitis, and encephalitis. West Nile Virus was not reported in the United States prior to 1999, when 62 people in New York developed nervous system diseases after exposure to the virus. Since then, the disease has spread to every state in the continental U.S.; 21,877 human cases of WNV have been reported through 2006, and the disease has caused 859 deaths.[116]

Washington State reported its first two human cases of the disease in September 2006.[117] (The virus had been detected in horses, birds, and mosquitoes in the state in 2004 and 2005.[118]) Based on the history of human infections in other states, a broader outbreak of WNV appears possible if and when conditions favor the disease and its mosquito vector. The trajectory of WNV outbreaks in other states can shed light on the costs Washington might incur if the disease spreads more widely in the human population.

Colorado, with a population approximately three-quarters the size of Washington's, provides a useful benchmark. No human cases of WNV were reported in the state prior to 2002, when fourteen cases of the infection were recorded. In 2003, this number leapt to 2,947 (including 63 deaths). In 2004, the number of new infections fell to 291, with 4 deaths; and in 2005 declined to 106 new cases (2 deaths). By October 24 of this year, 310 new cases and four fatalities had been reported in Colorado.[119] Colorado's experience illustrates the potential for rapid, non-linear changes in the incidence of this infectious disease.

Louisiana, with a population also about three-quarters the size of Washington's, is the only state for which the economic impacts of a WNV outbreak have been tallied. Louisiana reported its first case of the disease in 2001. In 2002, the caseload jumped to 329, with 24 deaths. Researchers with the Centers for Disease Control and Prevention assessed the total economic impact of the outbreak between June 2002, when the first cases of the year were reported, and February 2003, three months after the onset of the last human case reported in the prior year.[120]

These researchers estimated the single-year cost of the Louisiana outbreak to be $20.1 million, or $61,094 per case. Their estimate includes $10.9 million in medical and non-medical direct costs and $9.2 million in costs related to the public health response. Medical costs included the expenses of in-patient and outpatient care, while non-medical costs included an estimate of lost productivity plus transport and childcare costs incurred by infected individuals. The authors of this study comment that their total is "likely an underestimate, since some of the costs associated with illness or public health response were not available."[121]

A large component of the non-medical costs in the Louisiana study could be attributed to the 24 deaths; although the median age of those killed by the disease were 78, the total present value of foregone future earnings was estimated to be $5.4 million. This "value of foregone earnings" is an extremely conservative method of estimating the economic value of reducing mortality risks; applying the more common "value of statistical life" method, which values reduced mortality risks at about $7.5 million per life, would increase the total cost of the Louisiana outbreak to more than $190 million.[122]

While acknowledging differences between health-related costs in the respective states, the estimates for medical and non-medical costs incurred in Louisiana can be applied to Colorado's outbreak to give a rough estimate of cumulative economic impacts in that state over the past five years (See Table 2-2). The authors of the Louisiana study deliberately excluded public health costs from an extrapolation of their cost estimates to the nationwide WNV caseload, noting that "mosquito control capabilities vary tremendously from state to state." Thus cost estimates for Colorado, based on a per-case cost of $33,131 (medical costs = $13,374; non-medical costs =$19,757) offer a conservative estimate of total economic impact, exclusive of public health expenditures.

By this method, we estimate that the total economic impacts of West Nile Virus in Colorado over five years exceeding $120 million, with the direct and indirect costs of the outbreak varying by a factor of more than one hundred from year to year. If the state's 73 WNV fatalities since 2002 were valued using the "value of statistical life" method, the additional cost would be $548 million, yielding a total economic impact of approximately $670 million.

At least in terms of hospital costs and public health expenditures, these estimates appear to be within the correct order of magnitude. Colorado's Weld County (northeast of Denver) has been hard-hit by West Nile cases. According to the county's health department, during the outbreak's peak year of 2003, the hospitalization cost per patient was $31,034, and the cost per patient treated in emergency room and released was $1,216. The county also spent between $33,980 and $43,980 per year on "enhanced surveillance" activities during 2003 and 2004, and it continues to spend between $17,000 and $23,000 per year on surveillance activities including mosquito trapping and animal testing.[123]

Table 2-2. Estimated Cost of West Nile Virus in Colorado, 2001-2006

Year	WNV Cases	Cost
2001	0	$ 0
2002	14	$ 464,000
2003	2,947	$ 97,637,000
2004	291	$ 9,641,000
2005	106	$ 3,512,000
2006	310	$ 10,271,000
totals	3,668	$121,521,000

Sources: Based on WNV cases reported to the Centers for Disease Control and Prevention by October 24, 2006, and associated medical and non-medical costs from Zohrabian et al., 2004 (see note 76). Estimate does not include expenditures on public health and surveillance. Using the "value of statistical life" method to estimate the costs of mortality would yield a total economic impact approaching $670 million.

Washington's Department of Health has taken steps to prepare for West Nile Virus. The Department currently spends approximately $145,000 per year to conduct environmental surveillance for the virus,[124] and approximately $101,000 a year to conduct epidemiological follow-up and clinical testing on suspected human cases.[125] These figures do not include county-level expenditures on surveillance or public education efforts, which vary considerably from county to county. Colorado's experience suggests that the current annual expenditures of $246,000 in Washington would need to be scaled up considerably in the event of an outbreak.

Periods of drought followed by heavy rain have been associated with West Nile Virus outbreaks in Europe and in U.S. cities.[126] Warm temperatures are known to accelerate the growth of viruses in their mosquito hosts, and as water sites shrink, infected bird and mosquito populations become more concentrated, facilitating transmission of the virus. Drought may also reduce predation on mosquitoes. Factors not related to climate change are also believed to contribute to the severity of West Nile Virus outbreaks.[127]

Effective surveillance and public education may have helped to contain West Nile Virus outbreaks in states where the disease is now established. Investment in preventative steps such as mosquito control and a robust public infrastructure of detection and response, designed to be scaled up rapidly when an outbreak occurs, may be the price of living with this and other new infectious diseases.

Respiratory Illness: Asthma

Asthma, a respiratory disease characterized by wheezing, is one of the most common chronic health conditions in the U.S.[128] Asthma rates have steadily increased over the past twenty years, particularly among children.[129] In 2005, the American Lung Association estimated the direct costs of asthma (medical costs, emergency room visits, etc.) at $11.5 billion, and the indirect costs (work and school days missed, diminished productivity, diminished well-being, etc.) at an additional $4.6 billion.[130]

According to Washington's Department of Health, approximately 400,000 Washington adults and 120,000 youth currently have asthma.[131] The federal Centers for Disease Control (CDC) have identified Washington's asthma prevalence as among the highest in the nation, and the state's asthma rates are increasing faster than population growth.[132] Estimated costs of medical expenditures and lost productivity within the state are more than $400 million every year.[133]

Although no studies have formally examined the issue in Washington, qualitative evidence suggests that climate change could increase the economic burden of asthma in the state. Activities that emit greenhouse gases can cause or worsen the disease. Air pollutants from coal-fired power plants and automotive emissions, photochemical smog, and the particulates released by forest fires all aggravate asthma. Increased atmospheric carbon dioxide levels stimulate pollen production, which aggravates respiratory allergies. Heat waves and smog aggravate respiratory conditions. Flooding of homes fosters the growth of indoor fungus, a common allergen. Dust, a respiratory irritant, is more prevalent in regions with persistent drought.[134]

Reducing the risks of respiratory illness and asthma requires public investment. Environmental measures include reducing pollen counts by eliminating ragweed and other common weed allergens from parks and public spaces, limiting truck and bus idling, and improving public transportation systems to reduce air pollution.[135]

Measures to reduce greenhouse gas emissions may pay a "second dividend" in Washington by reducing the risk of asthma and other respiratory illnesses. Energy conservation and efficiency, certain renewable sources of electricity, and climate-friendly technologies all improve air quality. Reducing the economic burden of respiratory illnesses may be an important social component of the return on investments in emissions reduction.

In addition, efforts to reduce greenhouse gas emissions could lead to substantial cost savings in certain urban areas of the state by keeping smog below limits that trigger Clean Air Act violations. Higher summer temperatures are likely to result in more smog in urban areas. As temperatures rise, the Seattle metropolitan area and other urban areas may come even closer to violating Clean Air Act standards. The costs of non-attainment to the Seattle area and to those businesses and industries that will be required to obtain air permits could be substantial. Efforts to reduce greenhouse gases may help reduce the risk of triggering these costs.

Heat-related Illnesses

Heat waves have occurred with more intensity and frequency during the last twenty years, and cases of heat-related mortality and illness appear to be on the rise. From 1999 through 2003, a total of 3,442 deaths were attributed to exposure to extreme heat in the United States.[136] A recent study in the journal *Environmental Health Perspectives* calls heat "the primary weather-related cause of death in the United States."[137]

Nakai, Itoh, and Morimoto (2004) found that heat-related deaths were more likely to occur on days with a peak daily temperature above 100º F (38º C), and the number of deaths increased as a function of the number of hot days.[138] Their data suggest that even a small rise in temperature above certain thresholds may lead to a significant increase in heat-related mortality, a finding supported by studies in Spain showing that the increase in mortality rates can be detected at temperatures as low as 75º F (24º C).[139]

The summer of 2006 featured record-breaking heat in Washington State and elsewhere throughout the United States. Temperatures exceeded 100ºF east of the Cascade Range and the upper 90s over much of Western Washington. Seattle's high of 97º on July 21 broke the previous record set in 1994. In Eastern Washington, highs included 112º in Pasco and 107º in Ephrata, Walla Walla, Wenatchee, and Omak.[140]

Although these record temperatures are theoretically high enough to cause heat-related illnesses, Washington's incidence of heat-related illness and death is typically low, and expenses in recent years have been modest. In 1998, for example, the state reported approximately 60 heat-related hospitalizations and three deaths. Hospital charges for heat-related admissions in 1998 were approximately $6,250 per patient.[141] In 2005, there were approximately 30 hospitalizations and no reported deaths.[142] Washington did not report any heat-related mortality during the 2006 heat waves, when more than 140 people died of heat-related causes in California.

The Centers for Disease Control describe air-conditioning as "the number one protective factor against heat-related illness and death."[143] In Washington, more frequent and longer heat waves are likely to increase the demand for air conditioning, which is costly and energy-intensive. In a state with historically low levels of penetration by air conditioning, public health may prove to be a factor as important as personal comfort in the growth in electricity demand.

A multi-faceted approach to prevention and response appears essential. Early warning systems for climate extremes including meteorological forecasts and accurate modeling are critical and relatively inexpensive. Prevention and response programs for elderly and other high-risk populations without air conditioning also seem important.

Mitigation Policy Questions

- What policies can help reduce the contribution of greenhouse gases to urban smog as summer temperatures rise, and can such policies measurably reduce the risks of asthma?
- Can the energy-saving and GHG-reduction potential of green building, energy efficiency, the use of renewable energy, and product efficiency standards (e.g., air conditioners) be maximized simultaneously?

Adaptation Policy Questions

- What policies can help the state prevent and prepare for the possible human health impacts of climate change?
- What policies can support the development of efficient and effective climate-change-related disaster response and management plans?

Impacts On Shorelines

Climate change drivers

- **Sea levels** in the northeast Pacific Ocean are projected to rise between 3 inches and more than 40 inches above current levels by the end of this century. Local measurements of sea level rise around Washington State may exceed or fall short of the expected range due to geological motions (rising and sinking) that affect different parts of the state's shoreline.
- **Catastrophic sea level rise** due to accelerated melting of land-borne ice in Greenland and Antarctica could cause sea levels to rise by as much as 80 feet over a period of centuries.

Key Points

- Sea level rise impacts in Washington will vary throughout the state. A region particularly vulnerable to early impacts is the South Puget Sound between Tacoma and Olympia.
- A two-foot rise in sea levels would inundate 56 square miles and affect at least 44,429 people, a portion of the state's population larger than the current population of Olympia.
- At the upper bound of current projections, Tacoma could experience two feet of sea level rise within 50 years.
- Engineering re-design of Seattle's Alaskan Way seawall to account for new sea level rise projections might add 5 to 10 percent to total project costs, or $25 to $50 million.
- Low-lying agricultural areas protected from tidewater by dikes and tidegates (e.g. Willapa Bay, Skagit River Delta) will be among the first areas in the state affected.
- Public ports within reach of tidewater will feel the affects of sea level rise.
- Impacts on the outer coast are likely to include accelerated erosion and increased vulnerability to storm surges and high tides.

Washington State's 3,026-mile shoreline[144] (including coastal bays, Puget Sound, and more than 300 islands) gives the state a large exposure to the risks and impacts of rising sea levels. Sea level rise attributable to the thermal expansion of seawater (caused, in turn, by the transfer of heat from the warming atmosphere to the oceans) is well understood. The potential impacts, and even the timing of those impacts, are complex.

Melting ice in Greenland, Antarctica, and mountain glaciers contributes to near-term sea level rise. In the past, that contribution has been considered slight.[145] Additional sea level rises of much larger magnitude due to the melting and break-up of land-borne ice masses is believed to be possible, and scientists are reassessing its probability based on recent evidence.[146]

Geological forces and the physical diversity of the Washington shoreline complicate the issue. Parts of Washington are sinking relative to sea levels (thereby augmenting the rise) while other parts of the state are rising (and offsetting the impact of rising waters).

Thus, while projections of sea level rise due to thermal expansion of the oceans and the melting of land-borne ice can be made with considerable confidence, the extent and timing of impacts depend largely on location. Figure 2-9 shows the relative magnitude of vertical motions occurring in different parts of Western Washington. The South Puget Sound shoreline between Tacoma and Olympia is subsiding about an inch (24 mm) per decade, and thus will experience rising sea levels sooner than other places. Seattle is also subsiding, although at a lesser rate.[147]

While the impacts vary, it is worth noting that even portions of the state's shoreline affected by uplift rather than subsidence are not rising fast enough to stay ahead of sea levels for more than a few decades. Neah Bay, on the outer Olympic Peninsula, will rise more rapidly than sea levels for several decades if the global rise is at the low end of the projected range. But even that location could experience as much as 30 inches of sea level rise by the year 2100 if sea levels increase at the upper bound of current projections.[148] Figure 2-10, a visual summary of relative rates of change in sea level at several Washington locations, shows that the rate of sea level rise is expected to increase over time.

A change this pervasive along the state's shoreline will have economic impacts. Like the underlying physical phenomena, impacts will vary by location depending on both physical and economic factors. Low-lying agricultural areas protected from tidewater by dikes and tidegates (e.g., Willapa Bay, Skagit River delta) will be among the first areas affected, and should be among the first to be assessed for impact.

In addition to private residential, agricultural, and commercial real estate along shorelines, public ports within reach of tidewater will encounter the effects of sea level rise. Shipping terminals, marinas, docks, and recreational facilities associated with coastal port districts are places where impacts will reach more deeply into the state's economy through effects on commercial and recreational activities.

Low-lying areas of Washington State, particularly in South Puget Sound, are vulnerable to the levels of sea level rise likely to be experienced by the 2040s.

Taking subsidence into account, applying the upper and lower bounds of sea level rise projected by the Intergovernmental Panel on Climate Change in 2001 and adding a regional correction for atmospheric effects on the northeastern Pacific Ocean, Tacoma can expect sea levels to rise between 5 inches and 20.6 inches by 2045 compared with present levels. Using the upper bound of the projections, Tacoma could experience a two-foot sea level rise within 50 years.[149]

Significant portions of downtown Olympia and the Port of Olympia, with subsidence rates similar to Tacoma's, are built on fill just a few feet above current sea level. A 1993 analysis by the city's Public Works Department compared areas of the port that could expect inundation by normal high tides if sea levels were four feet higher than present levels (a level possible by 2100 at the upper bound of current projections plus subsidence) with areas considered vulnerable today to a 100-year flood. Under that scenario, normal high tides would cover the area inundated by today's once-in-a-century flood. The report concluded, "Without protective measures, a four-foot rise in sea level would submerge most of the port peninsula except for islands in the filled area." The report went on to note that downtown Olympia and structures and facilities along the shoreline of Budd Inlet and Capitol Lake would be vulnerable to inundation during major tidal floods.[150]

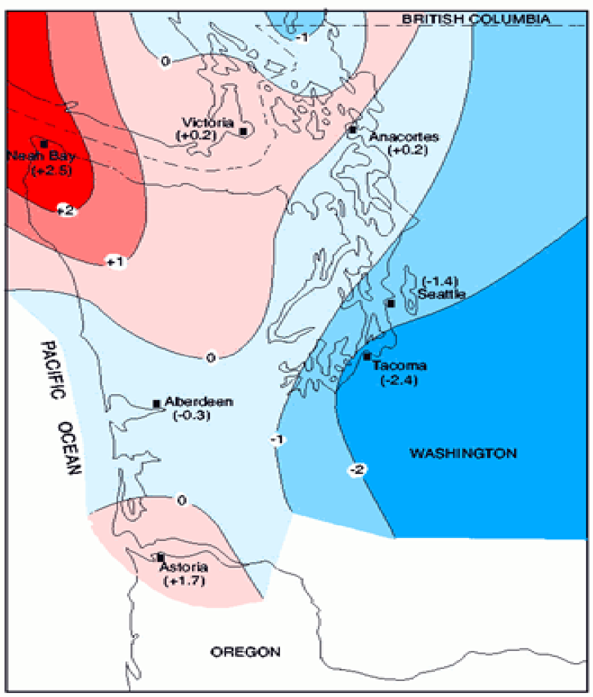

Figure 2-9. Broad Zones of Tectonic Uplift and Subsidence in Western Washington. Areas shown in blue are sinking relative to sea levels; areas shown in red are rising relative to sea levels. (Estimates are in millimeters of subsidence or uplift per year.) Source: Climate Impacts Group, modified from Hugh Shipman, 1989. "Vertical Land Movements in Coastal Washington: Implications for Relative Sea Level Changes,"

Washington State Department of Ecology, Olympia, WA.

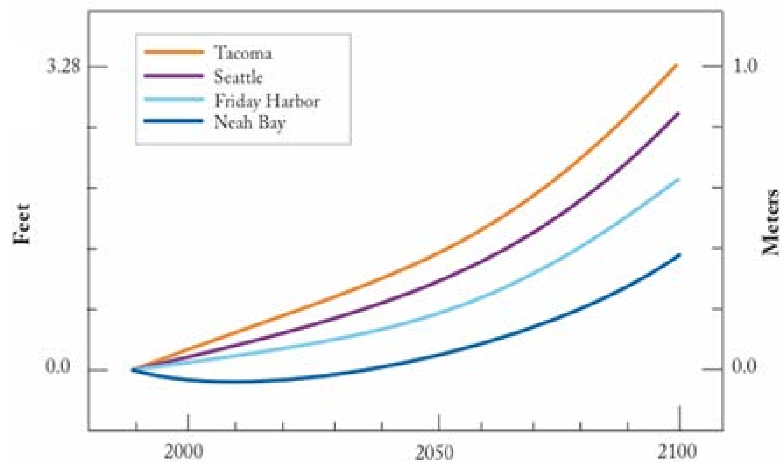

Figure 2-10. Sea Level Rise Anticipated In Several Washington Locations between the Years 1990 and 2100. Source: Climate Impacts Group.

Uncertainty about the timing and magnitude of sea level rise has economic costs. The City of Seattle, which maintains five seawalls, is preparing to rebuild the Alaskan Way seawall protecting downtown Seattle from the waters of Elliott Bay. The current proposal, with a design life of 75 years and a budget of about $500 million, was engineered to accommodate a sea level rise of 11 inches. If revised projections show sea levels likely to exceed that amount within the design life of the seawall (or by roughly the year 2080), the project may need to be redesigned. The cost of such a redesign is unknown, but one generic estimate suggests 5 to 10 percent of total project costs, or $25 to $50 million.[151]

Even a modest rise in sea levels, one too small to threaten property or infrastructure in areas of the state with steep shorelines, could bring surprisingly large impacts due to the sheer length of shoreline affected. Without addressing the issues of subsidence or uplift, the Department of Ecology has mapped the impact of modest (2') and catastrophic (10' and 20') sea level rise on the state's present-day shoreline. According to a Geographic Information System (GIS) analysis of this impact, a two-foot rise in sea levels would be sufficient to inundate a total area of 35,848 acres (56 square miles). At least 44,429 people – more than the current population of Olympia – live in areas that would be affected by this inundation.[152]

Impacts on the state's outer coast include accelerated coastal erosion and increased vulnerability to storm surges and high tides. This vulnerability would be compounded by an increase in average wave heights, a physical effect associated with more intense storms. The heights of storm waves measured at buoys hundreds of miles off the Oregon and Washington coasts have increased as much as 8 feet over the past 25 years, and such waves deliver 65 percent more force when they come ashore.[153]

Catastrophic sea level rise is a real long-term risk that policymakers should take seriously. But policymakers should also take steps to address the numerous impacts Washington State will encounter incrementally as sea levels rise over the next several decades such as increased erosion and deterioration of coastal infrastructure. Like other aspects of climate change, sea levels appear to be rising faster than earlier models had projected. Steps to prepare natural and built features of the state's shoreline for probable impacts are now prudent.

Mitigation Policy Questions

- Will the state lose any potentially significant carbon sequestration zones (e.g., riparian forests, croplands) due to inundation in the relatively near term?

Adaptation Policy Questions

- How can areas most susceptible to sea level rise, such as low-lying agricultural areas, ports, and properties within reach of tidewater, be assessed for potential risk?
- What process and criteria are appropriate to make determinations about where dikes, revetments, sea walls and other sea level protection mechanisms are appropriate?
- How can the engineering and financial implications of "accelerated depreciation" of coastal infrastructures by sea level rise be managed?

Impacts on Snow Sports

Climate change drivers

- **Average winter temperatures** (October through March) are projected to increase 1.7ºF by the 2020s and 2.5ºF by the 2040s, compared with averages for 1970-1999. Higher temperatures will affect snow accumulation and snowmelt at ski areas.
- **Winter precipitation** will include more rain and less snow as temperatures rise.

Key Points

- Snow sports areas accounting for over 40 percent of average visits to Washington ski areas during the past ten years are based at low elevations at which climate change impacts on snow cover are likely.
- The frequency of warm winters would increase to more than 50 percent at some ski areas, given winter temperature changes projected for the 2020s and 2040s.
- Population projections for Puget Sound cities suggest potential for growth in demand for winter recreation opportunities that could offset the economic impact of deteriorating snow conditions.

Although winter sports including downhill skiing, snowboarding, and other winter recreation at mountain resorts are a relatively small part of Washington's economy, snow sports make up a high-profile industry that will be among the first in the state to experience the effects of climate change. Snow sports in Washington State, are potentially vulnerable to the projected shift in winter precipitation from snowfall to rain as average temperatures warm. Some ski areas based at low elevations, including destinations that are among the state's most popular, may experience direct climate change impacts.

A small but high profile part of the state's $2.2 billion Arts, Entertainment, and Recreation and $6.5 billion Accommodations and Food Services economic sectors, the Washington snow sports industry defies generalization. The state's sixteen ski areas, for example, vary in size from day-use areas to destination resorts, and have base elevations from less than 3,000 feet to more than 4,500 feet.[154]

Total visits to Washington ski areas surpassed two million in 2005-06, a record year, and the average over the preceding ten years was 1.65 million visits per year.[155] Washington's ski areas are privately owned and financial information is proprietary, making estimates of economic impact imprecise at best. Based on general patterns for the industry nationwide and on surveys done in the Rocky Mountains and the Inland Northwest, annual revenue from recreational activities at Washington areas (season passes, ticket sales, ski lessons, equipment rental, etc.) probably falls within a range of $50 million to $150 million.[156] This range does not include expenditures by visitors on food, retail sales, accommodations, and other categories, nor does it include the costs of transportation.

A complete picture of the industry's economic contribution to the state would also include estimates of goods and services purchased by ski areas themselves, and the economic impact of wages paid to their seasonal and full-time employees. Such a complete economic assessment of the Washington snow sports industry has not been performed.

Past studies of the potential impact of climate change on skiing and snowboarding in the Pacific Northwest have used climate models to examine how warmer temperatures might affect the length of the operating season and the likelihood of rainy days at particular areas.[157] Such results, while important, are not considered to be predictive of economic results because the industry's revenues are not constant throughout the winter season. Revenues vary with storms, holidays, and other factors.

Such studies do clearly show that impacts of warmer temperatures are greatest at lower elevations, and impacts on snow cover increase with temperature. Four areas based at less than 4,000 feet elevation (The Summit at Snoqualmie, Mount Baker, Mount Spokane, and 49 Degrees North) accounted for over 40 percent of average visits to Washington ski areas during the past ten years (more than 683,000 in an average year). Climate studies suggest that impacts on snow cover are likely to be greatest at these elevations.

A recent study by Oregon State University researchers (Nolin and Daly, 2006) mapped the area of temperature-sensitive or "at-risk" snow in the Pacific Northwest.[158] The authors define at-risk snow cover as snow that accumulates at temperatures near the melting point, where it is vulnerable to the increased likelihood of rainfall and to more rapid melting rates. They used data only from the core winter months (December through February) in this analysis. Assuming a threshold temperature of 32ºF (the actual snow/rain transition can occur slightly above or below the freezing point), the area of at-risk snow in Washington State mapped by this study includes 12.5 percent of the snow-covered area of the Cascades, and 61 percent of the snow-covered area in the Olympic Mountains.

Few Washington ski areas have terrain that falls directly within the "at-risk snow" zone as conservatively defined by this study, but a number of ski areas can expect an increase in the frequency of warm winters. In this study, a "warm winter" is defined as one during which average monthly temperatures for at least one month of the December-February period exceeds a rain-versus-snow threshold temperature of 32ºF (0ºC). More rain falls at these temperatures, and snow melts faster and earlier. Under projected climate warming scenarios, the frequency of warm winters will increase such that ski areas that have a very low frequency of warm winters under current climate conditions may double or triple the incidence of warm winters by mid-century.

Monthly averages hide significant variability in temperature, and year-to-year variability in average temperature is large. The authors calculated the relative frequencies for average temperatures at intervals across a range between 28.2ºF and 32.0ºF, based on temperature records for 1971-2000. The results allow the authors to evaluate changes in the expected frequency of warm winters along a gradient of degrees of warming between 0ºF and 3.8ºF.

Table 2-3. An Increase in Probability of "Warm Winters" at Four Washington Ski Areas at Two Levels of Projected Warming

		Probability of Warm Winters		
Area	1996-2006 Average Visits	1971-2000 Average	1.8ºF Warming	2.7ºF Warming
The Summit At Snoqualmie *(base: 2,840')*	430,347	0.27	0.43	0.53
Mount Spokane *(base: 3,818')*	67,747	0.27	0.50	0.53
Mount Baker *(base: 3,549')*	125,497	0.03	0.03	0.13
Bluewood *(base: 4,543')*	42,012	0.03	0.33	0.40

Sources: Table 2 in Nolin and Daly, 2006. Note: a 1.8ºF warming corresponds roughly to the average winter temperature change projected for the 2020s, and a 2.7ºF warming corresponds roughly to the average winter temperature change projected for the 2040s. See Table 1-1, Recent and Projected Temperatures for the Pacific Northwest.

Results for four ski areas that span the elevation range are shown in **Table 2-3.** The table shows how the relative frequency of warm winters would increase with winter temperature changes of the magnitude now projected for the 2020s and 2040s. According to this model, The Summit at Snoqualmie, which experienced such "warm winters" during 27 percent of the years between 1971 and 2000, could expect such conditions in over 50 percent of winters under a warming scenario of 2.7ºF, comparable to the average winter warming projected for the 2040s. Mount Spokane would experience a similar increase in the relative frequency of warm winters.

Results for Mount Baker and Bluewood show that altitude is not the only factor at work. Local topography and weather patterns play an important role. Mount Baker is a low-elevation area with typically abundant snowfall and a low relative frequency of warm winters. Bluewood, located in the Blue Mountains of southeastern Washington, has the second-highest base elevation in the state and is renowned for dry powder snow, but could see the frequency of "warm winters" increase more than ten-fold as temperatures increase to levels now projected for the 2040s.

While the economic impacts of such changes cannot be projected, the potential deterioration of snow cover at lower elevations and the increasing relative frequency of warm winters will pose new challenges to an industry already characterized by financial variability.

The snow sport industry employs a variety of snow grooming and other methods to provide an attractive and consistent visitor experience under all snow conditions. Many Washington ski areas, owned by resort chains with properties elsewhere in North America, benefit from their parent organizations' ability to spread the financial burden imposed by fickle weather in particular locations. Population projections for the state, and for Puget Sound population centers in particular, suggest potential for steady growth in demand for winter recreation opportunities.

Some in the snow sports industry have already made great efforts to adopt sustainable practices and to educate their clientele about global warming.[159] The industry's role in raising awareness of the problem among thousands of Washington residents and tourists who visit the slopes each year will only grow as the direct impacts on snow cover and snow quality become visible at some of the state's most popular mountain areas. If and how these impacts may affect revenues for the industry remains unknown.

Mitigation Policy Questions

- Can policies foster increased energy efficiency in ski and snow sport facilities, especially in locations where increased use of snowmaking machines may be financially attractive?
- Can alternative transportation and fuels policies help reduce greenhouse gas emissions from vehicle transportation to and from ski and snow sport areas?

Adaptation Policy Questions

- What if any steps needed to help the ski industry adjust to increased temperatures and diminished snowpack?
- Under what conditions can artificial snowmaking offset declines in natural snowcover, and how should the potential costs and environmental effects (e.g. water use) be addressed?
- Is relocation to higher elevations a viable strategy for low-elevation areas?
- Can diversification with a greater focus on off-season activities offset winter-season revenue losses**?**

Other Economic Impacts

The economic impacts of climate change can be analyzed only to the extent that data are available on the relationship between climate change and various economic activities or regions of the state, or on similar relationships in other states that can be used to illustrate the likely effects in Washington. These conditions currently do not exist for all of the likely economic impacts of climate change in Washington. In this section we discuss some additional likely economic impacts of climate change in Washington; although we could not quantify the impacts at this time, we have included the topics because of their potential significance.

A. Impacts on Salmon and Other Fisheries

Climate Change Drivers

- **Average annual temperatures** are projected to increase 2°F by the 2020s and 3°F by the 2040s, compared with averages for 1970-99. Higher temperatures will increase stream temperatures, with direct impacts on freshwater fish.
- **Snowpack** is expected to melt earlier in the spring, depressing summer streamflows and increasing winter and early spring flows.

Economic impacts relating to salmon and other commercial fisheries are likely to focus in two areas. The first concerns commercial fisheries in Alaska. The Alaska fishing fleet is based in Seattle, so impacts on commercial stocks of salmon and other species in Alaska may affect both producers and consumers in Washington. A complex mix of biophysical changes in ocean conditions, estuaries, and freshwater habitat as well as policy decisions regarding harvest quotas and other issues will determine the impacts of climate change on salmon, halibut, pollock, and other commercially important fisheries in Alaskan waters, and therefore on the Washington-based Alaskan fleet. We were unable to find quantitative estimates of the potential economic impacts of climate change on Alaskan fisheries.

The other area concerns endangered salmon stocks in Washington State. Rising temperatures associated with climate change will exacerbate the problems already faced by these fish, leading to direct as well as indirect economic losses. Reduced snowpack and increased wildfires are likely to put many high elevation streams, which currently serve as refuges and intact spawning grounds for endangered salmon, at greater risk. Elevated water temperatures resulting from lower flows and higher air temperatures may create lethal conditions for salmon in the summertime, when farmers and municipal users may be seeking additional water supplies from the same rivers. Changes in ocean conditions may also affect salmon in unknown ways.

We were unable to quantify the direct economic losses related to Endangered Species Act listings and resulting restrictions on fishing, water use, and other activities. We were also unable to quantify the economic impact stemming from "existence value," i.e., the value that Washington state residents get simply from the presence of salmon in Washington waters. Although fisheries also have commercial and recreational values, these tend to be limited by dwindling runs and fishing restrictions, so existence values tend to dominate empirical studies.

For example, Anderson et al. (1993) combined existence values (from contingent valuation studies) with commercial, recreational, and capital values to determine that climate change of 2° to 4°F would reduce the value of Yakima River spring chinook salmon by $3.8 million, from $7 million to $3.2 million. If the state undertook various "enhancements" to improve the fishery, thereby raising the base value of Yakima River spring chinook to $30.6 million, climate change would reduce that value by $19.5 million.[160]

In another study, Goodstein and Matson (forthcoming) estimate existence value for wild fish in the Pacific Northwest. Based on their results, a reduction of wild salmon populations by one-third would correspond to a loss of between $222 million and $2.2 billion for Washington State; a reduction by two-thirds would correspond to a loss of between $445 million and $4.5 billion.[161] These estimates cannot be directly tied in to our climate change work because of uncertainty about the impact of climate change on the state's salmon populations.

In addition to the methods described above, there are other ways to quantify the economic effects of climate change on Washington's fisheries. No matter what approach is used, the bottom line is that the effects are almost certain to be negative.

B. Impacts on Flooding

Climate change drivers

- **Average annual temperatures** are projected to increase 2°F by the 2020s and 3°F by the 2040s, compared with the 1970-1999 average. This will directly affect spring melting and peak runoff dates.
- **Average annual precipitation** is not currently projected to change significantly, but more winter precipitation will fall as rain.
- **Sea levels** in the northeast Pacific Ocean are projected to rise between 3 inches and more than 40 inches above current levels by the end of this century. Local measurements of sea level rise around Washington State may exceed or fall short of the expected range due to geological motions (rising and sinking) that affect different parts of the state's shoreline.

Washington State may experience increased winter flooding and resulting economic costs due to climate change, but the probability of increased flooding is unknown. Hamlet and Lettenmaier (2006) argue that 20th century temperature changes "have resulted in substantial changes in flood risks" over much of the western United States. Temperature-induced changes in flood risk vary by geography, however, increasing in some areas and decreasing in others. These authors also note an increase in "the variability of cool season precipitation after about 1973," and suggest that this increase in variability is the result of climate change or other "large-scale climatic influence."[162]

Flood damage in Washington costs an average of $40 million a year.[163] Major storms can generate significant impacts. For example, the City of Seattle attributes costs of $20 million to landslides caused by major storms during the winter of 1996-97.[164] Although we could not assess the frequency or impact of more severe storms, policymakers should prepare for the possibility that the economic costs of flooding will increase as temperatures warm and climate change proceeds.

Increased flooding has implications for stormwater management. Local governments may need to reconsider design standards for stormwater collection systems, bridges, culverts, wastewater treatment and other critical infrastructure in order to control the effects of higher volumes of storm-related runoff. Early efforts to estimate the costs and feasibility of retrofitting stormwater runoff and combined sewer overflow systems in urban areas will be important.

The possibility of increased flooding also has implications for floodplain management in rural settings. Early efforts to anticipate the potential consequences of flooding and to devise management strategies to protect roads, bridges, and other public infrastructure as well as buildings, crops, and other private economic assets are likely to prove economically advantageous. New economic and ecological benefits of floodplain restoration may become apparent.

C. Cumulative Indirect and Linkage Effects

This chapter has considered the present and likely future economic impacts of climate change in discrete sectors, industries and regions of Washington. However, the state's economy is complex. Changes in one economic sector or region of the state may trigger changes in other sectors. The state's economy is interconnected with national and global markets. Changes in one region of the country (or world) often trigger feedbacks that alter supply and demand in other regions. Such feedback processes can cascade through the economy, producing more extensive cumulative indirect economic effects than a sectoral analysis alone can describe.

For example, the need to ensure sufficient water supplies to communities dependent for water upon transition snowmelt basins during years of poor snowpack could send ripple effects throughout the state's economy. Water providers may seek to augment supplies by building new diversion or storage infrastructure, with effects on other water users and on salmon recovery goals. Municipalities might seek to pump more groundwater, which could have implications for other economic sectors or for the environment. If regulations prohibit additional storage, the amount of water available for industrial uses could be limited. Given the water demands for some high tech industries and other businesses, efforts by one sector to augment water supplies could have ripple effects through other sectors of economy.

Another sector-specific example of cumulative effects can be found in the winegrape industry. As previously discussed, rising temperatures may open opportunities for planting Pinot Noir grapes in cooler regions of Western Washington. Because the Northwest wine industry operates in a global marketplace, such a shift in regional production of a premium winegrape variety may generate economic effects in the Washington wine industry and beyond. These changes are likely to affect jobs and incomes in communities where Pinot Noir vines are introduced, which could trigger changes in other sectors in the region through the effects of indirect and induced expenditures attributable to the new industry.

Direct impacts due to increased costs, reduced output or lost market share are relatively easy to identify. By comparison, the complexities of today's economy make it much more difficult to assess cumulative indirect and linked economic effects. No rule-of-thumb can provide the type of credible analysis needed for effective policy making. For this reason, Input-Output models and, at a larger scale, Computable General Equilibrium (CGE) models are often used to analyze structural adjustments within the economy resulting from the combination of environmental, market, and behavioral changes.

We did not use a CGE model for this assessment because of data, time, financial constraints, and other factors. We therefore cannot project how the cumulative economic effects of climate change may unfold in Washington. It should be assumed, however, that such effects would occur. Even without detailed information on cumulative impacts, it is evident that the implications for Washington of the sector, industry and region-specific economic impacts outlined here are significant and will increase the warmer it gets. Rapid attention and early action by policymakers to respond to climate change is likely to reduce the costs substantially, while delay is almost certain to lead to higher costs.

CHAPTER THREE

ECONOMIC OPPORTUNITIES

Introduction

The preceding chapter described how climate change is likely to affect certain industries, sectors, and regions of Washington's economy. Given the potential costs of climate change, the question arises as to how the state can best respond. Three categories of response can be described:

- *Pursue policies* that reduce greenhouse gas (GHG) emissions in the state so as to reduce Washington's contribution to the global causes of the economic effects discussed in the previous chapter. Efforts to reduce (mitigate) GHG emissions will be needed across the globe in order to prevent warming from becoming worse and to avoid climate thresholds. Emission reduction policies will have costs. However, they might also yield economic benefits to the state. In addition, mitigation is a good risk-management response to the possibility of future federal action to reduce carbon emissions because the sooner the state pursues mitigation the easier the transition to a low-carbon economy will be.

- Anticipate *business opportunities* resulting from the need to respond to climate change and promote economic adjustment away from practices and products that may be harmed by climate change. New technologies, processes and services will be needed to reduce emissions and to prepare for the effects of climate change. Similarly, businesses that currently are either heavily dependent on fossil fuels, generate high levels of greenhouse gases, or negatively impact ecological sinks that absorb emissions may find themselves at risk in the future. Helping these businesses reduce their GHG emissions or shift to other activities will help prevent serious economic impacts in the future.

- *Anticipate* and *take action to prepare for* the future effects of climate change through forward-looking planning and policy measures. No matter the scale or speed of GHG mitigation efforts occurring at the international, national or state levels, some warming is now inevitable and will increase over time. Although temperature increases cannot be prevented, the state can control how it prepares for climate change. Taking active steps to prepare for the effects of warming can in many cases help prevent harm from occurring and in other ways minimize the damage and/or make repair and restoration easier and less costly.

Each of these responses to climate change is important. Because an assessment of the economic effects of mitigation policies warrants a major study in itself, although vital, this chapter does not take this approach. Instead, the chapter focuses on the later two responses. In specific, the first section discusses in some detail the business opportunities that are emerging to respond to climate change. The second part discusses in qualitative terms a way to think about anticipating and preparing for the effects of climate change.

Business Opportunities Resulting From Climate Change and Adjustment Away From Business Activities That May Be Harmed By Climate Change

A recent study of California's economy concluded that a combination of policies aimed at reducing greenhouse gas emissions could generate a net increase in Gross State Product and in employment.[165] The economic model used in the California study has not been adapted to Washington's economy. At this point, we cannot say whether the economic benefits of responding to warming will outweigh the costs. However, one overarching message from the California study could hold true for Washington: Climate action may offer potential business opportunities.

One climate-related business opportunity is cost savings resulting from improved vehicle and energy efficiency. Improved efficiency reduces the amount of money leaving the state to pay for imported petroleum and other fossil fuels. This money can be redirected to other spending or savings by businesses and residents. Another opportunity lies in expanding local production of products and technologies that reduce GHG pollutants. Pressure is likely to continue to grow to reduce emissions as governments around the globe become increasingly concerned with climate change. New products and processes will be needed to accomplish this goal.

Alternative energy and energy efficiency appear to hold the most promise to achieve both GHG emission reductions and cost savings. Two detailed studies examining the costs, savings and climate impacts of emissions reduction strategies in Washington found that the majority of energy and emissions savings would be derived from these two sources. In both studies, economic benefits were largely due to reduced expenditures on fuels. (See **Table 3-1. Greenhouse Gas Emissions Reductions and Net Benefits** for highlights from one study.)

The Climate Protection Advisory Committee (CPAC) review of the impacts of seven emission reduction strategies for four counties in the Puget Sound area found cumulative savings of $1.5 to $2.1 billion (net present value) between 2005 and 2020 from all seven emissions reduction strategies. Of that amount, the greatest savings, $1.17 billion, were expected to derive from standards to restrict emissions of carbon dioxide from new vehicles (which Washington recently adopted). Maximizing energy efficiency in buildings was predicted to save $700 million. Those two strategies are expected to achieve the following carbon dioxide emissions reductions: 3.1 million metric tons of carbon dioxide equivalent (MMT CO_2 e) and 3.5 million MMT CO_2 e respectively out of 16.6 MMT CO_2 e total reductions considered possible by 2020.[166]

In the following section of this chapter we discuss strategies identified in the CPAC report for their contribution to greenhouse gas emissions reduction that can also generate business opportunities. The business opportunities exist in the form of savings from reduced fuel imports and from the sale and export of Washington products, services, and technologies that generate fewer GHG emissions than the status quo.

Table 3-1. Greenhouse Gas Emissions Reductions and Net Benefits from Two Key Strategies Evaluated by the Climate Protection Advisory Committee.

	GHG Emissions Reductions (MMT CO_2 e)		Net Economic Benefits (2002$)	
Action	2010	2020	2010	2020
Full, sustained efficiency programs, building codes and appliance standards	1.4	3.5	$55 million	$137 million
Adopt California Standards for Tailpipe Emissions (Pavley, LEV II)	0.2	3.1	$10 million	$439 million

Source: Puget Sound Clean Air Agency, Climate Protection Advisory Committee, 2004.[167]

Energy Efficiency

Increased energy efficiency offers business and households the potential for direct savings from implementing energy efficiency measures. Efficiency also provides business opportunities by companies that capitalize on the growing demand for energy efficiency (and thus lower GHG emitting) products, services and technology. In the past 25 years, the Pacific Northwest has avoided the need for 3000 average megawatts of electric power through efficiency, which, in the process, lowered the region's carbon emissions by about 13 million tons in 2004 and saved the region's consumers $1.25 billion the same year.[168]

Consumers accrue additional savings when electricity providers invest in affordable energy efficiency measures in place of purchasing new energy supplies. Additionally, some efficiency measures create non-energy savings, such as the water savings achieved by more efficient clothes washers. Reduced energy use also precludes the need for additional energy distribution and transmission infrastructure, resulting in further savings. Efficiency measures include any technology or practice or service that maintains a level of service, but consumes less energy in doing so. Examples include efficient heating and cooling equipment, lights, motors, transformers, building shells, and others. Solar hot water heaters capture solar heat that is otherwise "wasted," thereby offsetting the use of electricity or gas to produce the same heat.

While the wholesale market price of electricity has fluctuated widely over the past decade, the cost of conservation has stayed fairly level at about $20 per megawatt-hour, cheaper than most forms of energy production.[169] The Council calls for the majority of growth in energy demand, 2,800 average megawatts, to come from conservation over the next 20 years. The Council considers another 1,100 average megawatts of conservation to be technically achievable, but not cost-effective. The average levelized cost of this 2,800 average megawatts conservation resource is 2.4 cents/kWh (with some measures costing more and some less), which is about half the cost of power generated by new hydropower, natural gas, wind, or coal plants. This suggests that increased conservation could be more cost-effective (and create less CO2 emissions) than new power plant construction.[170] Cost-effectiveness, of course, correlates with the cost of electricity: higher electricity prices or carbon taxes increase the amount of conservation considered cost effective.

Smart energy, the computerization of power generation, transmission and end use, maintains service while consuming less energy. The field holds particular economic potential for Washington. In some applications smart energy provides end-users with information so that they may reduce their use at times of peak load and in others increases the efficiency of the grid. Digital metering could allow for

Spotlight on Product Efficiency Standards

Washington is one of only ten states with standards for the minimum energy efficiency of specific products. Standards can bring down the cost of efficiency technologies and ensure that all market levels of a product, not just the high-end, include the improvements.

Washington has enacted standards for 12 products not covered by federal standards, from commercial ice-makers to clothes-washers, expected to result in a net savings of $465 million over 14 years, with returns to businesses and households from 30 percent to over 100 percent. With those standards in place between 2006 and 2020 the state is expected to reduce its CO_2 emissions by a cumulative 7 million tons, its annual water use by 1.7 billion gallons, natural gas equivalent to 3 percent of the current statewide commercial sector use, and electrical use sufficient to power more than 90,000 homes.[1] Congress, spurred by multiple states adopting state efficiency standards, adopted federal minimum standards for all of but three of Washington's product standards.

Additional savings may be possible. As of July 2006, standards had been developed by other states for 13 products not yet included in Washington's list. The products range from ceiling fans to walk-in refrigerators and freezers.[1] If the state enacted standards for walk-in refrigerators and freezers, Washington could save $8.3 million and 26,200 metric tons of carbon on a yearly basis by 2020.

electrical meters to be read over phone or Internet lines. With such instant, easy-to-access information, power can be bought and sold by utilities in real time.

This sector is expected to receive $3 billion in Pacific Northwest investments and $500 billion in worldwide investments by 2020.[171] Pacific Northwest National Laboratory estimates that the application of smart grid technology could save the nation a cumulative $80 billion by 2020 by alleviating the need for an additional infrastructure to meet increasing demand.[172]

In addition to revenues, the energy efficiency industry creates jobs. In 2004, the industry employed almost 4,300 people through 133 organizations in Washington and earned revenues of nearly $900 million dollars.[173] In 2004, Washington's smart energy sector consisted of approximately 48 organizations with a total of 1,826 employees and total revenues of $475 million.

Improved Transportation Efficiency

Depending on the cost of the measures, economic benefits can be obtained from reduced transportation emissions. One way this can occur is cost savings from reduced consumption of imported fossil fuels. Improved vehicle emissions controls help achieve these savings. Washington has already taken a major step to reduce GHG emissions by adopting California's tailpipe emissions standards. By 2016, the standards are expected to lower GHG emissions by about 30 percent as compared to the 2002 fleet.[174] Using an estimate of $1.74 per gallon (constant 2004 dollars) for the cost of gasoline, the standards are expected to save Washington residents $2 billion by 2020, primarily in fuel costs.[175] This represents a substantial amount of money that would normally have been sent out of state to pay for imported fossil fuels. Leaving these funds in the pockets of Washington residents and businesses will open the door to other investment opportunities.

Increased fuel efficiency in passenger vehicles is another way transportation-related cost savings can be achieved. Plug-in hybrids with a 40-mile range could cut fuel use per vehicle by 50 percent and CO_2 emissions by up to one third. The payback period could come close to three years for 40-mile range plug-ins, if gasoline reaches $4 per gallon and batteries attain the low end of their feasible price range.[176] Clearly the widespread adoption of this technology could result in dramatic fuel savings for Washington. At present, EDrive, an engineering firm based in California, appears to be leading the charge to produce retrofitting technology.

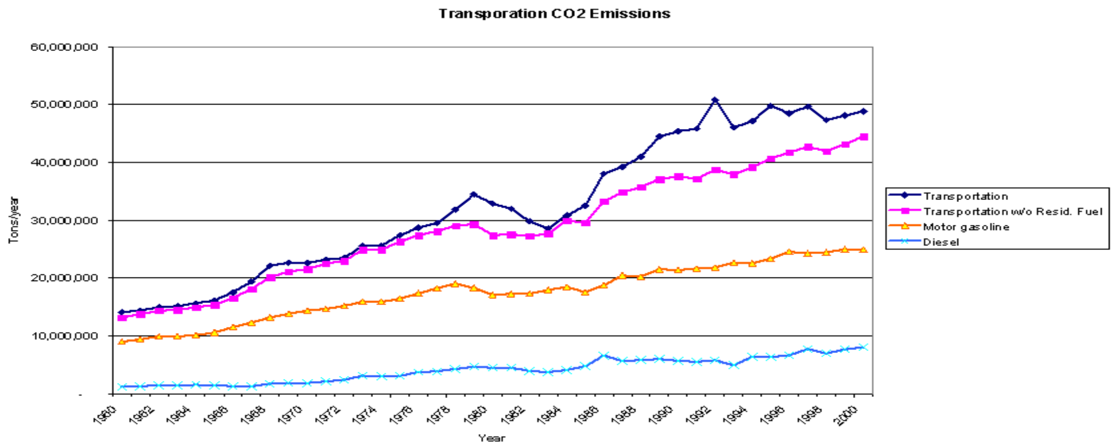

Figure 3-1. Transportation Emissions of Carbon Dioxide in Washington, 1960-2002. Source: Greg Nothstein, Department of Community, Trade, and Economic Development.

Reducing the number of miles driven in a given period (called vehicle miles traveled or VMT) offers still another way to achieve cost savings while reducing GHG emissions. V miles traveled have increased on a total and per-capita basis in Washington. Vehicle miles traveled stood at 8,834 miles per capita in 2004.[177] A variety of smart growth policies can mitigate the expected annual 1.9 percent increase, with corresponding fuel savings although perhaps without a net economic benefit. (See Figure 3-2 for past trends.) A five percent reduction in vehicle miles traveled by 2020, relative to forecast "business-as-usual" trend, achieved through increased use of mass transit, carpooling, telecommuting, growth management, and land use planning, could save nearly 120 million gallons of gasoline. The Tellus Institute, which performed the analysis, did not calculate the costs of measures needed to achieve those savings, due to the complexities involved. This makes it impossible to determine whether the result would be a net cost or benefit, even knowing that the benefits of the fuel savings were estimated to total $1 billion (net present value in 2004) from 2005 to 2020 for Washington. Washington, California and Oregon would eliminate the emission of 8 million metric tons of CO_2 through 2020 with that 5 percent reduction in vehicle miles traveled.[178]

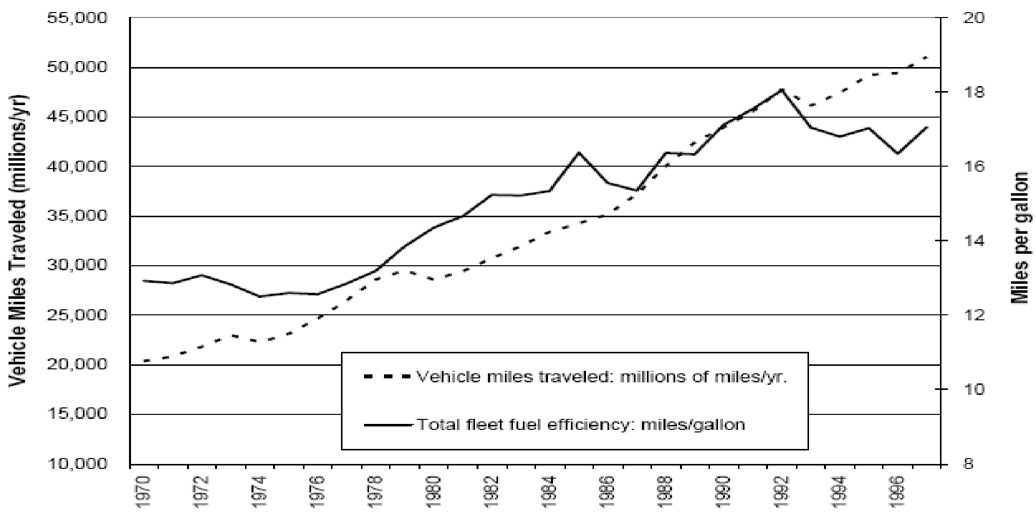

Figure 3-2. Total Vehicle Miles Traveled and Vehicle Fuel Efficiency for Washington State, 1970-1997. Source: Department of Community, Trade, and Economic Development.[179]

Freight and transportation related fuel costs and GHG emission could also be reduced by switching to more fuel-efficient modes of travel. For example, although the energy intensity of passenger rail systems varies, light rail systems can achieve 78 passenger-miles per gallon, whereas heavy rail can only reach 57 passenger-miles per gallon.[180] Additionally, moving freight by rail is about 50 percent more fuel efficient than transporting goods by truck, particularly in the case of long-haul delivery.[181]

Improvements in airplane efficiency are an area where Washington stands to gain from fuel savings and also from the development of new technologies. Boeing is making major advances in airplane fuel efficiency with the upcoming 787 jet (formerly the 7E7), which will be 20 percent more fuel-efficient than similar-sized planes. With the airline industry losing $180 million a year in revenues for every one-cent increase in fuel costs, Boeing's leadership in this area could prove to be an economic boon.[182] Aircraft, spacecraft and launch vehicles were the top-valued export passing through Washington ports in 2004, valued at $17.5 billion. As long as aircraft are designed and built in Washington, innovations in this field are particularly significant for the state.[183]

Renewable Sources of Electricity

Potential exists in Washington for growing primary and secondary energy sources that produce fewer greenhouse gas emissions than fossil fuels and even, down the road, reduce costs. It is possible that Washington may avoid future costs imposed by carbon taxes or cap and trade systems, should they occur, by moving early to reduce GHG emissions by investing in renewable energy infrastructure. This opportunity will expand as existing generating capacity reaches the end of its operating life and energy demand increases. Washington currently relies primarily on large-scale hydropower (66 percent) for electricity, which does not contribute significant GHG emissions. The next largest portion of the electricity portfolio is coal (18 percent), which contributes 80 percent of Washington's electricity-related GHG emissions.[184] Natural gas provides 6 percent of the state's electricity and most of the remainder of the state's electricity related GHG emissions. Although wind power capacity has been rapidly expanding and is expected to continue to grow, it makes up just one percent of the current electricity portfolio.[185] (See Figure 3-3 for Washington's utility fuel mix.) This suggests ample growth potential exists in renewables.

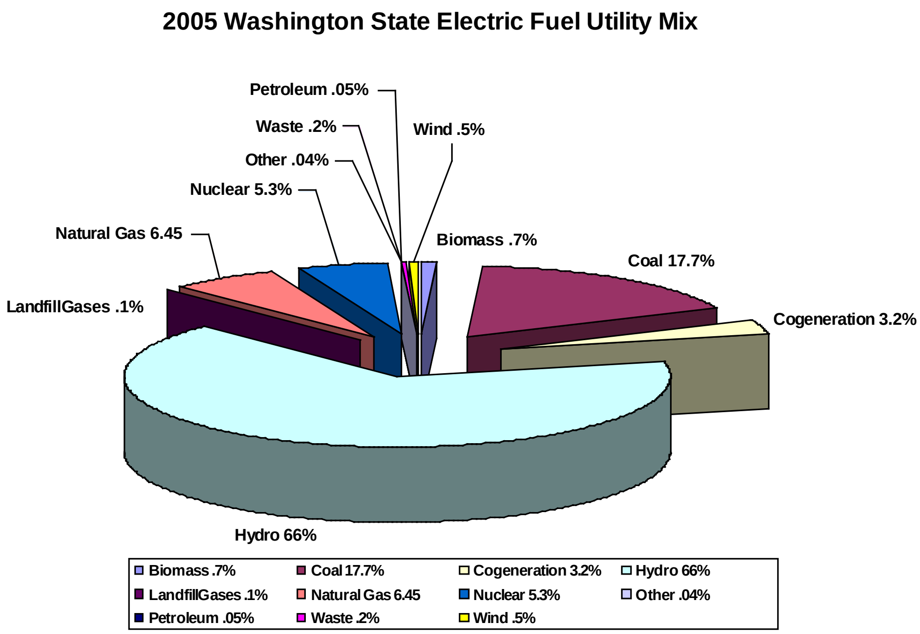

Figure 3-3. Washington Electric Utilities Fuel Mix, 2005.
Source: Department of Community, Trade, and Economic Development.[186]
Note: The Washington Utility Fuel Mix is the aggregate fuel mix of all Washington electric utilities including BPA direct sales to end users in the state of Washington. These figures do not include approximately 2 million MWhs of electricity market purchases by 16 large industrial customers.

The greatest potential for business development in the state of Washington in the renewable energy sector appear to lie in wind, fuel cells and solar, with components of the latter two being developed and researched in the state. Possibility of future activity exists in tidal and wave energy, geothermal, small-scale hydro and biomass. However, these require improved technology in order to become cost-effective and reliable.[187]

At present, all of these renewable energy sources can draw a premium from customers enrolled in voluntary "green power" programs due to their low GHG emissions and minimal environmental impact as compared with conventional fuel sources. Existing renewable portfolio standards in California require utilities to purchase green power and therefore create revenue for energy supplies that can meet green power standards. Total revenue from green power programs in Washington in 2005 was nearly $2.5 million, which reflects a 57 percent increase in sales and an 11 percent increase in customer participation from 2004.[188]

The Washington clean energy industry (which includes renewables; energy efficiency; and smart energy) can supply 60 percent of the growing power need for the entire region (namely Oregon, Montana and Idaho), according to the Northwest Power and Conservation Council (Council). Over the next 20 years, the Council calls for an increase of almost 7,000 aMW of power resources for the region, which is about a 40 percent increase over existing capacity. For all citizens of the state and region, potential benefits include a more stable energy supply with resulting lower energy costs.

The renewable energy sector is growing and significant potential remains untapped. Washington's solar industry, for example, is a $150 million sector and home to industry leaders in the production of solar grade silicon, which currently poses a bottleneck in the worldwide manufacturing of photovoltaics. Washington also houses major manufacturers of inverters, the component that translates the power into usable energy, and companies involved in crystal growth. At present, no company manufactures solar modules in Washington, meaning that the state is missing a significant piece of the value chain.[189]

Washington holds enormous potential for further development of wind projects, with more than a million acres of windy land. Recent estimates of Washington's capacity for wind energy range from 1,900 average megawatts to 7,000 average megawatts.[190] The lower figures represent the mid-term potential considering energy needs, equipment costs, visibility impacts and advances in turbine technology.

Wind projects provide significant economic benefits to rural communities, as well as creating electricity cost-effectively and without producing greenhouse gases. Those benefits come in the form of landowner revenues, property taxes, premiums on "green power," and higher levels of job creation than exist for conventional power generation projects. However, the state is not involved in wind turbine manufacturing, lessening the overall gains from this form of power.

The fuel cell industry in Washington possesses the advantages of the existing aerospace and electronics industry expertise, the state's reputation as a gateway to Asian markets and the activity already taking place in the fuel cell industry in the state and the region. Vancouver, British Columbia has an emerging fuel cell cluster, which could serve as a resource for the existing research organizations and fuel cell companies in Washington if the relationship is properly developed. However, initial cost, useful life, as well as the cost and storage of hydrogen continue to pose market barriers. In addition, the Washington fuel cell industry faces competition from many other states as well as countries such as Japan, Germany, Korea, and Canada.

Job creation offers another benefit from the growth of the renewable electricity sector. The renewable energy sector generates more jobs per unit of installed power, per unit of power produced, and per dollar invested than does the fossil fuel industry, according to a review of 13 reports by Kammen et al. While jobs in the fossil-fuel industry typically are in operations and maintenance, more jobs in the renewables sector are in construction, manufacturing, and installation.[191] The distinction between operation and maintenance jobs versus jobs in manufacturing is important because of the difference in training needs to ensure that jobs stay within the state. It is also important to note that construction jobs are temporary, while operation and maintenance jobs are more likely to be permanent.

In 2004 Washington's renewable energy industry had total revenues of $783 million and the average wage of approximately $57,000 was more than 25 percent higher than annual average Washington or national wage.[192] In 2003, the WSU Energy Extension program predicted that a 15 percent to 25 percent linear growth in the industry would create between 1,960 and 4,300 jobs over the next decade.

Biofuels for Transportation

Biofuels produced in Washington may offer significant opportunities for economic growth as well as emissions reductions, particularly if the feedstock is grown in the state and if sufficient quantities are produced for export. Biofuels can provide farmers with an additional income from oilseeds used in crop rotations. However, even a conversion of all corn and soy agricultural lands in the United States to biofuels feedstock production would only meet 12 percent of national gasoline needs and 6 percent of current national diesel needs.[193]

Biofuels, however, can also be made from agricultural residue. A recent inventory of biomass in the state shows that Washington produces over 16.9 million tons of dry equivalent biomass that could be used for producing electricity or biofuels. Economic and technical challenges in collection and processing preclude use of the full amount at present, as only about 15% is in the form of concentrated waste streams.[194]

State and federal policies combined with increased publicity for and increased access to biodiesel have pushed demand. Washington state regulations require 2 percent biodiesel blended with all diesels by December 2008 or sooner – a requirement that will increase to 5 percent once Washington can grow the feedstock and possesses the crushing capabilities to meet a 3 percent requirement.[195]

A 2 percent biodiesel blend would elevate Washington's biodiesel consumption to somewhere upwards of 20 million gallons per year, since the state uses nearly 1 billion gallons of diesel annually.[196] Currently, Midwestern plants fill the void in supply, but Washington stands a good chance of leading the West Coast in this arena, as at least one large-scale biodiesel plant (100 million gallon capacity) is already under development. Imperium Renewables, the plant owner, says the company plans to use a blend of feedstocks at the Grays Harbor plant, contingent on price, including imported palm, soy, and canola oils. The canola could be grown locally, although it must compete with other feedstocks to be viable for the plant and must be cost effective as compared with other crops to be worthwhile for farmers.[197] It is impossible for us to estimate just what portion of feedstocks will be locally grown. The plant is expected to create 250 to 350 construction jobs and 50 permanent jobs.[198]

Until Washington begins using more biodiesel, it is likely that the Grays Harbor plant will produce sufficient biodiesel to export to Oregon and California.

Biological Sequestration

The maintenance or expansion of carbon "sinks," biological systems that absorb atmospheric carbon dioxide and keep it out of the atmosphere, offers another means of reducing GHG emissions and generating economic opportunity in Washington. Both topsoil and forests can serve as carbon sinks with specific management practices such as no-till farming and longer rotations on timberland. These practices can generate additional revenue streams for land and resource owners through the sale of carbon credits to offset emissions of carbon dioxide by utilities, industry, and others in the Pacific Northwest and beyond. However, these forms of carbon storage can be temporary, because if the soil is tilled or the forests logged or burned, GHGs are released into the atmosphere, and what once was a sink becomes a source of carbon.

Like energy efficiency measures, the amount of sequestration that is practical as well as technologically and economically feasible depends on policies and cultural values, which largely dictate the price of carbon offsets and the alternative opportunity costs of the land. The costs of sequestration thus vary from site to site.

One study found that riparian (streamside) forests contain about 70 tons of carbon per acre. According to this study, owners of riparian land in Western Washington could sequester 110 million tons of carbon in these forests over 50 years. Compensating landowners at a rate of $2 per ton would cost an estimated $230 million over that time period.[199] With carbon now valued at approximately $4 per ton on the Chicago Climate Exchange (and about $20 per ton on the more mature European exchange, due to countries' participation in the cap-and-trade system mandated by the Kyoto climate treaty), it is likely that the sale of carbon credits by Washington's private forest landowners holds even greater financial potential.

Matt Delaney, a forestry carbon consultant in Oregon, reports that typically forest-based carbon sequestration deals in his state involve a one-time payment of $800 to $1,000 an acre for a carbon lease agreement that spans a term of 50 to 100 years. Of the 7.8 million acres of private forestland in Washington, 3.2 million acres are non-industrial private forests.[200] If just one-third of these non-industrial forests were managed to sequester carbon at a value of $1,000 an acre, the forests could provide up to $1.06 billion for landowners over 50 to 100 years from the sale of carbon credits.

The full economic potential for carbon sequestration on cropland in Washington is not yet clear. Karl Kupers, carbon sequestration specialist for the Pacific Northwest Direct Seed Association (PNDSA), loosely estimates that there are over a million acres of farmland that could generate additional revenue through carbon credits from no-till farming practices. These practices also save some fuel costs, but require a switch in equipment.

Many farmers are reluctant to adopt the new practices because of the cost of acquiring new equipment and the fear of reduced crop yields. Studies are underway to determine the benefit per ton of carbon sequestered required to offset the costs to farmers switching to carbon sequestering practices.

Some of the money for such a program in forestry or agriculture could come from outside of the state through carbon-offset programs. For example, the PNDSA leases carbon credits from no-till farming in Eastern Washington to a Louisiana energy company for $2.50 a ton for ten years. By contracting 77 growers representing 6,470 acres of cropland, PNDSA conservatively estimates they could store a total of 3,000 tons of CO_2 per year. Kupers says that prices for carbon credits, and therefore revenue to farmers adopting no-till practices, would be likely to increase with mandated CO_2 emission reductions.

Additional economic and environmental benefits of no-till farming accrue from the reduction of wind erosion, which improves air quality and thus human respiratory health, and from a dramatic reduction in soil and chemical runoff into waterways. The latter results in reduced expenses for silt removal in waterways and improvement of habitat for salmon and other aquatic species.[201] Similarly, forest management practices that improve carbon storage in living forests, such as practices that favor biodiversity, can also protect against pest infestations and reduce forest fire risks. Such practices could yield benefits, as yet uncalculated, by reducing the expense of adverse impacts.[202]

Anticipate Future Costs and Prepare for the Impacts of Climate Change

Almost all climate change research to date has focused on determining the causes and rates of climate change, the degree of potential impacts, and the best strategies to mitigate greenhouse gas emissions.[203] Little effort has been given to the assessment of strategies for preparing for the effects of global warming. No matter how aggressive efforts are at the global scale to reduce greenhouse gas emissions, the present accumulation of greenhouse gases in the atmosphere represents a commitment to a temperature increase of close to 2^0F. Preparing for the effects of this change is therefore a prudent step to prevent and reduce the impacts. It may also lead to economic opportunities.

This section discusses ways to think about preparing for climate change. It offers an approach for considering potential future impacts and outlines strategies for responding to them. Little research has been done on preparing for climate change. We have therefore been compelled to provide a general qualitative rather than detailed quantitative overview of the issue. More research on the economic costs and benefits of preparation for climate change in Washington is needed.

Previous chapters of this report have described the current and likely future biophysical and economic effects of climate change In Washington. The impacts are summarized in general terms below. When anticipating the future costs of climate change it may be useful to consider these impacts:

- *Direct economic output* is likely to be affected in many other sectors of the economy. Some sectors may see costs rise, some may see benefits, and others may find that their resource base deteriorates. For example, forest products industry may be affected by the increased frequency and scale of fires. Reduced water availability, increased temperatures, and possibly additional pests may affect certain agricultural sectors. The interaction between the affected sectors is likely to generate cumulative effects on the entire economy.

- *Increased depreciation of capital* can be expected due to a variety of direct climate change effects as well as global and national market changes triggered by warming. For example, public infrastructure such as roads, bridges and stormwater systems may need to be replaced at accelerated rates because they will be exposed to weather conditions or water levels for which they were not designed.[204] Businesses may find that capital expenditures expected to depreciate over a long time period may need to turn over faster as markets adjust to new climatic conditions.

- *Adverse effects on human skills and health* such as increased illnesses may occur due to increased summer heat waves, higher pollen counts and increased diseases caused by pathogens such as West Nile virus and respiratory conditions such as asthma.[205] These effects may increase employee illness and absenteeism and thus economic productivity. They may also increase the costs of health care.

- *Government may face increased challenges* resulting from the changes described above. Many economic sectors, industries and regions will be affected. The possibility exists that some industries may shift to different regions of the state or leave the state entirely to adapt to new climate conditions, which may affect local employment and tax bases. The effects of climate change elsewhere in the world such as increased storm intensity, drought, or heat waves, may precipitate an influx of both voluntary in-migrants and "environmental refugees" moving to Washington, amplifying the challenges of dealing with population growth. Flooding due to sea level rise or more intense or frequent storms may pose new challenges to government related to questions of liability, insurance, property abandonment, and increased costs to maintain public services.

Vulnerability and Opportunity Assessment

A Vulnerability and Opportunity Assessment is a planning tool that can be used to plan for the effects of climate change. The process embeds climate change in future planning. It also identifies opportunities to prevent or reduce the potential damage or losses that may occur from climate change before they occur. Vulnerability/Opportunity assessments are a form of risk assessment. They utilize current and future projections of economic and climatic conditions as well as decision support tools to analyze potential impacts, project economic and environmental costs and benefits of different response strategies, and incorporate chosen strategies into future planning.

Vulnerability/Opportunity assessments usually begin with two steps: a) a decision to incorporate climate change into future planning and decision making, and; b) an inventory of existing systems that may be at risk of adverse climate impacts. The systems to consider should include: [206]

- *Built systems.* Roads, bridges, sewage treatment, stormwater collection, water purification, waste disposal, communication and other forms of public infrastructure, commercial and residential buildings, and other aspects of the human-constructed environment. It is particularly important to consider climate change in any large, long-term infrastructure investment, such as the Seattle seawall and water storage and conveyance systems. Safe and reliable built systems are important for a well-functioning economy.

- *Human systems.* Emergency and medical response, disaster management, health care, social welfare, food delivery and security, public safety, equipment and building maintenance, agriculture and forest research, cooperative extension, and other systems that depend on human coordination and response. Human systems provide the management and repair apparatus and safety nets for a well-functioning economy. For example, agricultural research must be robust to monitor and respond to pests, plants, diseases and changes in water flows and temperature.

- *Natural systems.* Watersheds, lakes, groundwater and aquifers, wetlands, forests, soils, coastal and marine ecosystems, plants and animals and other elements of ecological systems. Resilient ecosystems and biodiversity form the critical sources and sinks that support life on Earth and provide the basis for all human economic activity.

In a vulnerability/opportunity analysis, the current condition of each system is compared to relevant climate scenarios, such as those discussed in this report, to determine the degree of probability and severity of adverse effects. This means determining the likelihood of adverse effects occurring and, if realized, the likely seriousness of the consequences (e.g. slight, modest or severe damage). For example, roads, bridges, culverts and other infrastructure can be assessed to compare the conditions they were initially designed to withstand against likely future increases in storm frequency and intensity, or sea level rise.

Steps in a Vulnerability/Opportunity Assessment

1) Develop/utilize climate impact scenarios
2) Assess risks to existing systems
3) Assess existing systems against climate scenarios
4) Estimate the gaps between existing capacity and what will be needed under different climate scenarios
5) Identify and assess strategies for closing gaps
6) Chose strategy and implement

Over the past few years it has become increasing possible to examine climate impacts on a finer scale such as that needed for regional vulnerability/opportunity planning purposes. The Climate Impacts Group at the University of Washington and other researchers has made great strides in teasing out regional trends from global climate data. However, it still may be difficult to obtain the fine resolution data required for local analysis. In this case estimates can be used based on regional data. Investment in further research is needed continue to produce the refined level of data required to complete localized vulnerability/opportunity assessments.

Once potential vulnerabilities are identified, strategies can be examined for closing the gaps. The economic and environmental costs and benefits of the various strategies are assessed. Finally, the most cost-effective strategies are chosen and implemented. For example, upgraded cleaning schedules may be deemed the most efficient way to ensure that certain culverts can carry water during regular storm events while plans may be adopted to install larger culverts in other locations that must carry higher water volumes during major storm events.

Case Study: Olympia Sea Level Rise Plan

In 1991 a Global Warming Task Force was created in Olympia. Through a six-year study they found that even moderate projections of sea level rise could have catastrophic effects on the city's coastal land. In order to act rapidly to prevent future risks, Olympia's task force recommended a number of options that include renewed waterfront zoning measures, increasing building standards, acquiring coastal land as a buffer, initiating storm water and flood controls, relocating sewer lines and relocating the principal water-source to a safer location. Since completing the research the city is investigating where best to direct its resources. A100-year plan is being prepared which will consider various options. In the meantime, new municipal projects are being designed with climate change impacts in mind. For example, flood-proofing has been a priority in the construction of the new city hall.

Quantitative methods for measuring risk can be used in a vulnerability analysis where the probability is expressed as the event frequency per unit of time or activity, and the consequences are expressed as loss of dollar value or through other metrics such as illness days or lost recreational days that don't readily lend themselves to agreed-upon dollar values (e.g. Risk= Probability of occurrence x Consequence of occurrence). Qualitative decision-making tools can also be used such as a "Fault Tree Analysis" that graphically represents logical combinations of causes that may lead to a defined negative outcome.

At least six strategy options can be considered when deciding how to close the gap between current conditions and future climate risks. [207] The examples provided under each option below are by no mean exhaustive. They are provided simply to illustrate the type of activity that can occur under the strategy option.

- *Status Quo*: This approach assumes that no action will be taken to reduce vulnerability to climate-related damage. It is accepted that losses will be absorbed and that damaged areas will be rebuilt, restored or abandoned.

- *Prevent the Loss:* Preemptive actions are taken to reduce vulnerability and blunt the effects of climate change. For example:
    - Critical infrastructure, especially those expected to last 50 or more years such as the Seattle seawall, can be engineered to account for sea level rise expected over that time period.
    - Stormwater collection systems can be rebuilt and expanded and road culverts enlarged on normal replacement schedules to accommodate more extreme precipitation events.

- Routine maintenance practices for public infrastructure can incorporate climate change so that, for example, debris is regularly removed from culverts to ensure stormwater flows smoothly.
- Urban heat sinks can be eliminated by repainting surfaces with light colors, planting trees, and creating open spaces.[208]

- *Spread the Loss*: Policies and programs can be instituted to share and spread climate-related losses across the population. For example:
  - The insurance commissioner could establish programs to provide added protection for wind, rain, or drought damage (although care must be taken to ensure this does not delay permanent adaptation).
  - Short term financial support can be provided to communities that may be affected by smoke intrusion, public health impacts, lost tourism and recreational opportunities, or lost timber jobs due to increased forest fires.

TYPES OF ADAPTATION MEASURES

CATEGORY	MEANING	EXAMPLE
Status Quo	Do nothing to reduce vulnerability & absorb losses	Rebuild, or abandon affected structures
Prevent the Loss	Adopt measures to reduce vulnerability	Engineer structures for big winds, floods, drought
Spread or Share the Loss	Spread the burden of losses across different sectors	Establish public funding for emergency food and shelter
Change the Activity	Stop activities that are not sustainable under new climate regime and substitute others	Prevent development in low lying coastal areas, rebuild wetlands
Change the Location	Displace the infrastructure or system	Relocate infrastructure out of risk zones
Enhance Adaptive Capacity	Enhance the resiliency of the system to improve its ability to deal with stress	Preserve or rehabilitate natural systems, increase emergency response capacity

Modified from *Adapting to Climate Change*, Canadian Climate Impacts and Adaptation Research Network

- *Change the Activity*: Activities that are not sustainable under new climate conditions can be prohibited and activities that make sense due to the new conditions can be initiated. For example:
  - Land use plans can be changed so that development is restricted and seashore setbacks are adopted in areas such as the south Puget Sound likely to be impacted by sea level rise and in river floodplains such as the lower Snohomish that are susceptible to flooding in major storm events.
  - Wetlands can be restored to increase the buffering effects they provide against large storms.
  - Public policies that encourage activities that may be at risk of harm due to climate change, such as building in floodplains or areas at risk of sea level rise, can be changed to eliminate the incentives.

- *Change the Location*: Infrastructure and built structures can be relocated to safer locations. For example:
  - Roads, bridges, stormwater collection, communication and other public infrastructure systems can be relocated out of low-lying coastal areas, floodplains, avalanche zones and other at-risk locations.

- o Buildings constructed in 100 and 500-year floodplains can be relocated to higher ground.

- *Enhance Adaptive Capacity:* The resiliency of built, human, and natural systems can be enhanced to improve their ability to respond to climate change. For example:
  - o Early warning systems and emergency response systems can be enhanced to anticipate extreme temperature or storm conditions and trigger special care for sensitive populations such as the elderly, infirm, and children.
  - o Building codes can be adopted to increase energy and water efficiency so that when supplies are more constrained in 40 years demand will have been reduced.
  - o Forests, wetlands, and other natural systems can be preserved and restored so that as warming intensifies they have greater capacity to survive fires, drought, heat waves and other events and buffer their effects.
  - o Water storage, conveyance and treatment systems can be improved to ensure secure water supplies and delivery in the future when snowpack and summer streamflows are reduced.

> ***Case Study: King County Proposed Flood Control District***
>
> King County recognizes that its extensive system of levees may be at risk due to climate change. Five hundred aging levees and revetments line 115 miles of riverbank and protect thousands of homes, downtown and industrial sections, and more than $4 billion dollars in infrastructure. King County's Global Warming Team, which was given permanent status in May 2006, found that climate change would increase the likelihood of more serious and frequent flooding in the region. Subsequently, King County has proposed the creation of a flood control district that would finance major levee upgrades and buyout homes and businesses that are located in the floodplains. If approved by the County Council, the district would spend up to $335 million on local flood-control projects.

The environmental costs and benefits of each option should be determined through careful analysis. They will be location and time specific. However, for comparison purposes it may be helpful to look at the outcomes of the CLIMB report completed for the Boston, MA region, which is one of the few detailed studies completed on the topic in the nation. It found that the "Status Quo" option would result in the greatest amount of damage and the highest costs to government and residents. In contrast, the study found that investing now in measures to prepare for the impacts of climate change would significantly reduce the amount of damage and lower the costs of preparation.

'Multiple Benefit' Options

Some of these strategy options may prove beneficial to pursue even without their contributions to reducing the costs of climate impacts. For example, coastal development policies may address ongoing risks associated with storm surges and tsunamis in addition to reducing the risks of sea level rise. Restoring floodplains may buffer the effects of extreme flood events and also be beneficial for water management under current conditions. Careful analysis should be completed to identify these "multiple benefit" or so-called "no regret" options.

Economic Opportunities

Economic opportunities may also emerge through many of these strategies to prepare for climate change. Because the risks of climate change may be experienced in similar forms in other states and nations, new processes and technologies produced in Washington may have appeal to national and worldwide markets as well as to local consumers. For example:

- Reduced summer water supplies may spur the need for technologies to increase water use efficiency, from waterless and low-flow toilets to water-efficient agricultural practices and water efficient products. Only California, Nebraska and Texas in 2003 had more farms than Washington implementing irrigation improvements, illustrating the fact that Washington agriculture is already a leader in advanced irrigation technologies and techniques.[209] Reduced water supplies around the globe may present Washington with an opportunity to export their expertise and products.

- Shifts in growing zones may create opportunities for high-value crops that were previously grown only in warmer climates. For example, varieties of winegrapes that previously could not be successfully grown in Washington may in the future find the climate in parts of the state more hospitable. Similarly, if California's dairy cows experience heat-related reductions in output, the Washington dairy industry may have the opportunity to fill the void in the national market (although the state's dairy industry may also feel some of the effects).

- Increased risk of forest fires may lead to a need for large-scale thinning, especially in the wildland-urban interface. Biomass from thinning projects can be efficiently used for energy or heat production in large or small

Case Study: Lake Chelan Air Quality Advisory

Chelan-Douglas County recently rewrote their Natural Event Action Plan (NEAP) for air quality and weather predictions due to wildfire. They define several wildfire health advisory levels, contingent up on the severity of air quality conditions. The Chelan Douglas County Health District then faxes these health advisories to local radio stations, school districts, hospitals, day care, nursing homes, and local government agencies. Each advisory includes specific recommendations for individuals to reduce potential health risks. The success of this protocol hinges upon the communication between various governmental agencies. For example, in times of emergency, close contact must be maintained between agencies responsible for transportation, communication of information, fire control, and public health.

> applications, such as in lumber mills or rural schools close to where the wood is harvested. If burned cleanly, this can provide a source of carbon neutral renewable energy using local feedstocks. The Washington Department of Ecology reports that the state contains woody biomass sufficient to produce 43 percent of Washington's current residential electricity consumption, although much of that material may not exist close enough to population centers to make it cost-effective, due to transportation costs. Washington businesses and communities not only can capitalize on the state's abundant biomass as a source of fuel, but also on the chance to develop technology and products within this growing sector.

In sum, if done effectively, the costs of preparation may be small in comparison to the costs of inaction. Many preparation activities may also prove beneficial no matter how climate change unfolds in the future, and some may generate economic opportunities for local entrepreneurs.

CHAPTER FOUR

CONCLUSIONS

Our assessment supports three overall conclusions about the economic impacts of climate change in Washington:

- **Climate change impacts are already visible in Washington State and their economic impacts are becoming apparent**
- **The economic impacts of climate change in Washington will grow over time assuming temperatures and sea levels continue to rise**
- **Although climate change will mean increasing economic impacts, it also opens the door to new economic opportunities**

1. Climate change impacts are already visible in Washington State and economic impacts are becoming apparent.

Biophysical impacts of climate change can be observed today in Washington's mountain glaciers and snowpack, in the timing of river flows, and in the incidence of wildfire. Evidence from other states suggests that outbreaks of West Nile Virus, an infectious disease new to Washington, may be linked to changes in temperature and precipitation.

The economic effects of these biophysical changes are beginning to emerge from the "noise" of a dynamic economy and a naturally variable climate. Initial measurable economic consequences include increased costs of wildfire response and some restrictions on recreational use of public lands, shifts in the timing of hydropower generation, and increasing competition for irrigation water in some basins. Other difficult-to-measure consequences may also be occurring.

2. The economic impacts of climate change in Washington will grow over time assuming temperatures and sea levels continue to rise.

Our research indicates that the economic impacts of climate change will increase as the state's climate becomes warmer and, possibly, more variable. Wildfires are expected to grow larger and more frequent as temperatures rise; it is logical to expect the cost of forest fires and fire management to increase. Declining snowpack and rising summer temperatures will affect the supply and demand for irrigation water, imposing new costs on farm communities. Streamflow shifts will affect the management and costs of municipal water supplies in Puget Sound, the state's most populous area, and possibly other regions. Rising sea levels will affect coastal infrastructure and properties. Costs linked to drought (associated with longer, hotter summers) and flooding (associated with warmer, more rainy winters) appear likely to increase.

It is also probable that the impacts of climate change elsewhere in the United States and around the world will affect Washington's economy by changing market conditions for products currently produced or consumed in the state, and by increasing the state's relative attractiveness to in-migrants. Net economic effects of these changes are unknown. The potential for abrupt climate change would dramatically accelerate economic impacts aspects throughout all aspects of the state's economy in ways that cannot currently be determined. In sum, the almost certain increasing scope and breadth of the economic impacts suggests that Washington policymakers should act earlier rather than later to reduce the state's contribution to climate change and to prepare the state for impacts that cannot be prevented.

3. Although climate change will mean increasing economic impacts, it also opens the door to new economic opportunities.

Climate change will impose larger impacts on Washington's economy the warmer it gets. It also, however, opens the door to new ways of thinking and new economic opportunities.

Although the existing and likely future impacts are the result of phenomena unfolding at a global scale beyond the control of state policymakers, Washington can control how it responds to these impacts through its planning, policy, and economic development mechanisms. As is already occurring, state agencies can incorporate climate change into planning and policy development and public outreach efforts. Public infrastructure such as dams, reservoirs, seawalls, roads, communication networks, and electrical production and transmission systems can be re-evaluated in light of potential impacts. Policies that may have been economically efficient under historic conditions, such as the way water is allocated and the current Columbia River storage and flow regime, can be reevaluated to address new circumstances.

In addition, local and global efforts to reduce greenhouse gas emissions and prepare for the impacts of climate change as they unfold offer opportunities for job and income growth in Washington. Energy efficiency measures can shift money that currently leaves the state as payments for imported fuels and feedstocks into local savings and investments. Renewable power and energy efficiency technologies developed in Washington can capture expanding global markets for low-carbon goods and services. Early action on policy development can help the state to secure these and other economic opportunities during a period of likely unprecedented change.

Through effects on water availability, climate change is likely to influence the prices of certain factors – kilowatt-hours of electricity, acre-feet of irrigation water, hundred-cubic-foot quantities of water for residential and municipal use – that influence costs in virtually every sector of Washington's economy. By changing ambient temperatures and sea levels, climate change will affect major public investments in infrastructure including storage reservoirs, seawalls, bridges, and roads, shifting schedules for replacement and affecting the ways such long-term projects are financed. Through effects on regional air quality, allergens, and disease vectors, climate change will influence the baseline of health conditions affecting the state's labor force.

Major uncertainties cloud efforts to understand the impacts of climate change on Washington's economy. Little is known about how greenhouse gas mitigation policies and actions adopted at the state, regional, national, and global levels might influence the capacity of the Washington economy to prepare for impacts experienced in the state. Much remains unknown about how climate change will play out, in particular the role that biophysical feedbacks may play in amplifying the impacts of higher temperatures. The climate system may contain thresholds that, once crossed, lead to changes more rapid and less predictable than any the scientific consensus now anticipates. Finally, we know too little about cumulative effects, economic linkages, and trade-offs to anticipate with any confidence how impacts on particular industries, sectors, or regions may influence, and be influenced by, impacts elsewhere.

Our analysis suggests key questions that deserve the sustained attention of the state's policymakers:

1. Given pervasive changes that bring both costs and opportunities to Washington, can government devise ways to bank the benefits in order to build capacity to defray the costs of more disruptive impacts? For example, can the state find ways to steer savings from reduced energy use into new spending that further improves energy efficiency, rather than consumption that boosts energy demand?
2. What impacts of climate change can the state's major trading partners anticipate, and how are those impacts likely to affect markets for Washington's goods and services?
3. What are the anticipated impacts of climate change on areas outside the state that currently supply the largest number of in-migrants to Washington, and what effects could those impacts have on in-migration, population growth, and economic development here?
4. What areas of resource law, like the appropriation doctrine in water law, are likely to sharpen rather than alleviate conflicts among parties with competing claims, under anticipated climate conditions?
5. How is climate change likely to alter the lifestyles of Washington residents, in particular their expectations relating to housing, transportation, and energy use?
6. Will public investment priorities need to be reordered as the state's climate changes?

There are many other questions, and few definitive answers. Issues as complex as global climate change rarely grow simpler with the passage of time. The earlier policy interventions are made, the more likely they can achieve their goals. Policy options are likely to be more costly, and may be precluded altogether, the longer intervention is delayed.

Due to its position in the U.S. and global economy, Washington's decision to prepare for the economic impacts of climate change will have multiple effects. The state has an opportunity act to address the problem, protect Washington residents from harm, and set an example of leadership. That would be a legacy worthy of the name.

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[72] See page 2-21 of the draft 2007 Seattle Water System Plan, http://www.seattle.gov/util/About_SPU/Water_System/Plans/2007WaterSystemPlan/index.asp.
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[75] Based on Matthew W. Wiley. 2004. *Analysis techniques to incorporate climate change information into Seattle's long range water supply planning*, University of Washington master's thesis, http://www.tag.washington.edu/papers/papers/Wiley_Thesis_2004.pdf, p. 126. Because Wiley's analysis is based on a historic yield of 183 MGD, we took his percentage changes and applied them to SPU's historic yield of 171 MGD.
[76] An example of the dynamic nature of system operations is the winter of 2004-05. Low snowpack in that winter—the lowest on record—reduced the probability of floods from snowmelt. Due to this reduced probability of flooding, SPU water managers captured more water in storage earlier than normal. This adaptation provided Seattle with enough water to return to normal supply conditions by early summer. This experience illustrates that by adapting its operating rules to changing conditions, Seattle may be able to mitigate some of the impacts from the projected reductions in snowpack due to climate change.
[77] Demand, in million gallons per day (MGD), is from Seattle Public Utilities, "Official Yield Estimate and Long-Range Water Demand Forecast," May 2006,

http://www.seattle.gov/util/About_SPU/Water_System/Plans/index.asp, p. 7. (The fall in demand projected for the next few decades is associated with increased conservation efforts and reduced demand from the Cascade Water Alliance. For the year 2000 we used the year 2005 forecast.) Supply is "firm yield" in million gallons per day (MGD). The data point for the year 2000 is from the SPU study cited above. Supply numbers for other years are based on Matthew W. Wiley. 2004. *Analysis techniques to incorporate climate change information into Seattle's long range water supply planning*, University of Washington master's thesis, http://www.tag.washington.edu/papers/papers/Wiley_Thesis_2004.pdf, p. 126. Because Wiley's analysis is based on a gross yield calculation that differs from that used by SPU, we took his 6.1 MGD/decade loss estimate and applied it to SPU's historic yield of 171 MGD. We also extended his analysis, which ends in 2040, for two additional decades.

[78] Cost of current commitments from Seattle Public Utilities staff, personal communications, October 2006. See also Seattle Public Utilities, *Water Conservation Potential Assessment (Revised May 2006)*, http://www.seattle.gov/util/About_SPU/Water_System/Reports/Conservation_Potential_Report/index.asp, p. ES-3.

[79] Seattle Public Utilities staff, personal communications, October 2006.

[80] See page 2-32 of the draft 2007 Seattle Water System Plan, http://www.seattle.gov/util/About_SPU/Water_System/Plans/2007WaterSystemPlan/index.asp. Annualized cost is determined by calculating the annual value of a perpetuity that combines design and construction costs and annual operating costs.

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[84] Information on mix of water sources from public works departments in Walla Walla, Wenatchee, and Yakima, personal communications, October 3, 2006. Spokane information from Brad Blegen, Water Department Director, City of Spokane, personal communication, September 29, 2006.

[85] Yakima management strategy described by Jeff Bond, Public Works Department, City of Yakima, personal communication, October 3, 2006.

[86] Brad Blegen, Water Department Director, City of Spokane, personal communication, September 29, 2006.

[87] National Agricultural Statistics Service. 2002. Online: http://www.nass.usda.gov/census/census02/profiles/wa/cp99053.PDF

[88] Values from Table NT-10, "Field Crops – Total Crop Value," Table NT-12, "Fruit, Nut, and Berry Crop – Total Crop Value," and Table NT-13, "Livestock and Related Products – Total Value," *2005 Washington State Data Book*. Online: http://www.ofm.wa.gov/databook/default.asp

[89] M.J. Scott, L.W. Vail, C.O. Stöckle, A. Kemanian, R. Prasad. 2006. "What Can Adaptation to Climate Variability in Irrigated Agriculture Teach Us About Dealing with Climate Change?" PNWD-SA-7396. Battelle, Pacific Northwest Division, Richland, WA. Unless otherwise noted, this paper is the source of the information presented in this section.

[90] Note that these two variables are not necessarily linked in this way: a temperature increase of 3.6°F could occur with carbon dioxide concentrations that are higher or lower than 560 parts per million. Also note that Scott et al. do not present results for a smaller temperature increase similar to what is projected for the 2020s, and that their study also does not consider the unknown but potentially significant impacts stemming from changes in weeds, pests, and crop disease.

[91] Michael Scott, unpublished WSU CropSyst Model runs for 2°C (3.6°F) warming. From "Climate change impact on agriculture in eastern Washington," presentation to a symposium on economic impacts of climate change in Washington State, Sea-Tac Airport, May 4, 2006.
[92] For a contrary view—that increased carbon dioxide concentrations may not stimulate yields—see M. Rebecca Shaw et al. 2002. "Grassland Responses to Global Environmental Changes Suppressed by Elevated CO2," *Science* 298: 1987-1990.
[93] Allison M. Thomson et al. 2005. "Climate Change Impacts For The Conterminous USA: An Integrated Assessment (Part 3. Dryland Production Of Grain And Forage Crops)," *Climatic Change* 69:43-65. For a contrary view—that increased carbon dioxide concentrations may not stimulate yields—see M. Rebecca Shaw et al. 2002. "Grassland Responses to Global Environmental Changes Suppressed by Elevated CO2," *Science* 298: 1987-1990.
[94] Michael Scott, personal communication, September 28, 2006.
[95] This $901 million estimate is different than the $1.3 billion estimate cited at the beginning of this section in part because it doesn't include dryland crops, cattle, or dairy products, and in part because the estimate was done in a different way (using average prices, yields, and acreage from 2000-2005 instead of just 2004 data).
[96] All data from National Agricultural Statistics Service. Relative ranking and dairy productivity from "The Pride of Washington State" (October 2005), online at http://www.nass.usda.gov/Statistics_by_State/Washington/Publications/wabro.pdf. Number of dairy cows and value of state dairy production from http://www.nass.usda.gov/Statistics_by_State/Washington/index.asp.Value of county dairy production estimated from statewide figures and the proportion of dairy cows in each county.
[97] For Yakima County we used coordinates of latitude 46.35, longitude -120.18, approximately Granger. For Whatcom County we used coordinates of latitude 48.83, longitude -122.5.
[98] Katharine Hayhoe et al. 2004. "Emissions pathways, climate change, and impacts on California." *Proceedings of the National Academy of Sciences* 101(34): 12422-27. Online: http://www.pnas.org/cgi/content/full/101/34/12422.
[99] National Research Council. 1981. *Effect of Environment on Nutrient Requirements of Domestic Animals* Washington, D.C.: National Academy Press. Online: http://www.nap.edu/catalog/4963.html#toc, pp. 76 and 79.
[100] In the NRC study, "sustained temperature" means a temperature that is maintained for at least 6 hours. Because our data only included daily highs and lows, we made the simplifying assumption (following advice from Eric Salathé, University of Washington, personal communication, June 13, 2006) that temperature follows a linear sawtooth with daily highs and lows spaced 12 hours apart. The results of our study were not strongly affected by changes in this assumption.
[101] Dry matter intake decreases by about 0.4 lbs/day for each °F that temperatures are sustained above 68°F, and *increases* by about 0.1 lbs/day for °F that temperatures are sustained below 41°F.
[102] National Research Council. 1981. *Effect of Environment on Nutrient Requirements of Domestic Animals*. Washington< D.C.: National Academy Press. Online: http://www.nap.edu/catalog/4963.html#toc, pp. 79.
[103] Climate data and sawtooth advice from Eric Salathé, University of Washington, personal communication, June 12 and 13, 2006; see, e.g., E.P. Salathé. 2004. "Downscaling Simulations of Future Global Climate with Application to Hydrologic Modeling." Accepted in *International Journal of Climatology*.
[104] For Yakima County, food intake and milk production in the 2090s were respectively projected to be 95.7% and 94.5% of their average levels for 1900-2000. (The same figures for the 2040s were 98.5% and 98.0%.) For Whatcom County, food intake and milk production in the 2090s

were respectively projected to be 97.4% and 97.1% of their average levels for 1900-2000. (The same figures for the 2040s were 99.4% and 99.5%.)

[105] Table NT-12, "Fruit, Nut, and Berry Crop – Total Crop Value,", from Office of Financial Management, *2005 Data Book*, Olympia, Wash. Online: http://www.ofm.wa.gov/databook/resources/nt12.asp

[106] From "Washington Wine Facts," Washington Wine Commission, Seattle, Wash., Online: http://www.washingtonwine.org/facts.cfm

[107] Based on data on grapevine climate/maturity groupings from Gregory V. Jones, Southern Oregon University, including projections of average growing season temperatures for 2049 by the HadCM3 climate model, A2 scenario, downscaled to the Puget Sound and Eastern Washington growing areas.

[108] Gregory V. Jones. 2006. "Climate Change and Wine: Observations, Predictions, and Potential Impacts," presented at the Association of Washington Wine Grape Growers annual meeting, Kennewick, Wash., February 9.

[109] Based on vineyard acreage figures for the state's 9 recognized "American Viticultural Areas" from the Washington Wine Commission, Online: http://www.washingtonwine.org/appel.cfm

[110] M.A. White, N.S. Diffenbaugh, G.V. Jones, J.S. Pal, and F. Giorgi. 2006. "Extreme heat reduces and shifts United States premium wine production in the 21st century," *Proceedings of the National Academy of Sciences*, Vol. 103, No. 30, pp. 11217-11222. Online: http://www.pnas.org/cgi/doi/10.1073/pnas.0603230103

[111] White et al., "Extreme heat reduces and shifts United States premium wine production in the 21st century," p. 11220.

[112] White et al., "Extreme heat reduces and shifts United States premium wine production in the 21st century," p. 11220.

[113] The climate-maturity groupings shown in this figure are based on relationships between phenological requirements and climate for high- to premium-quality wine production in the world's benchmark regions for each variety. The dashed line at the end of the bars indicates that some adjustments may occur as more data become available, but changes of more than +/-0.5-1.0ºF are highly unlikely. Climate data include recent (1950-2004) and projected average growing season temperatures for the Puget Sound and Eastern Washington growing areas. The figure and the research behind it are works-in-progress, used with permission of the author, Gregory V. Jones, Ph.D.

[114] Gregory V. Jones. 2006. "Climate Change and Wine: Observations, Predictions, and Potential Impacts," presented at the Association of Washington Wine Grape Growers annual meeting, Kennewick, Wash., February 9.

[115] Paul Epstein and Evan Mills, eds. 2005. *Climate Change Futures: Health, Ecological and Economic Dimensions.* Cambridge, MA: The Center for Health and the Global Environment, Harvard Medical School.

[116] Centers for Disease Control and Prevention, Division of Infectious Vector-borne Diseases. "West Nile Virus" information online: http://www.cdc.gov/ncidod/dvbid/westnile/surv&control.htm.

[117] "Pierce County man is state's first confirmed case of West Nile virus infection," news release, Washington State Department of Health, September 13, 2006. Online: http://www.doh.wa.gov/Publicat/2006_news/06-143.htm "Pierce County woman is state's second confirmed West Nile virus case," news release, Washington State Department of Health, September 25, 2006. Online: http://www.doh.wa.gov/Publicat/2006_news/06-150.htm

[118] Washington Department of Health. "West Nile Virus Statistics." Online: http://www.doh.wa.gov/. Accessed August 2006.

[119] Statistics on Colorado cases since 2002 from the "Statistics, Surveillance, and Control" page on the Centers for Disease Control West Nile Virus Website. Online: http://www.cdc.gov/ncidod/dvbid/westnile/surv&control.htm
[120] A. Zohrabian, M.I. Meltzer, R. Ratard, K. Billah, N.A. Molinari, K. Roy. R.D. Scott II, and L.R. Petersen. 2004. "West Nile Virus Economic Impact, Louisiana, 2002." *Emerging Infectious Diseases*, Vol. 10, No. 10, pp. 1736-1744. Online: http://www.cdc.gov/ncidod/EID/vol10no10/03-0925.htm
[121] Zohrabian et al. 2004, "West Nile Virus Economic Impact, Louisiana, 2002."
[122] The "value of statistical life" (VSL) technique is discussed in Chapter 7 of the EPA's "Guidelines for Preparing Economic Analyses," on-line: http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html Their recommend VSL (in 2006 dollars) is $7.5 million.
[123] Sara Evans, Weld County Department of Public Health and Environment, Greeley, Colo., personal communication, September 25, 2006.
[124]Dorothy Tibbetts, Manager, Zoonotic Disease Program, Washington State Department of Health, personal communication, August 2006.
[125] Jim Robertson, Division of Epidemiology, Health Statistics and the Public Health Laboratory, Washington Department of Health, personal communication, August, 2006.
[126] P.R. Epstein & C. Defilippo. 2001. "West Nile virus and drought." *Global Change & Human Health* 2, pp. 105-107 and T.P. Monath & T. F. Tsai. 1987. "St. Louis encephalitis: Lessons from the Last Decade."*Am. J. Trop. Med. Hyg.* 37, pp. 40-59.
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[128] US Department of Health. Online: http://www.hhs.gov. Accessed August 2006.
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[130] Christine Rogers. 2005. "Carbon Dioxide and Aero-Allergens." In Paul Epstein and Evan Mills, eds. 2005. *Climate Change Futures: Health, Ecological and Economic Dimensions.* Cambridge, MA: The Center for Health and the Global Environment, Harvard Medical School.
[131] Washington Department of Health. "Asthma Program." Online: http://www.doh.wa.gov/CFH/asthma/default.htm Accessed August 2006.
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[140] "Relief from heat wave in sight." *Spokane Spokesman-Review*, July 24, 2006. Online: http://www.spokesmanreview.com/breaking/story.asp?ID=7076. Accessed August 2006.
[141] Comprehensive Hospital Abstract Reporting System (CHARS), Center for Health Statistics, Washington State Department of Health, August 2006.
[142] Comprehensive Hospital Abstract Reporting System (CHARS), Center for Health Statistics, Washington State Department of Health, August 2006 (Note: CHARS does not cover private alcoholism hospitals, no-fee hospitals, US military hospitals, US Veterans Administration (VA) hospitals, or Washington State psychiatric hospitals. Eligible hospitals provide data for hospital units that are Medicare-approved, including psychiatry, rehabilitation, and bone marrow units.)
[143] U.S. Centers for Disease Control, "Extreme Heat: A Prevention Guide to Promote Your Personal Health and Safety." Online: http://www.bt.cdc.gov/disasters/extremeheat/heat_guide.asp
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