11: Preparing for Climate Change

Preparing for Climate Change in Washington State

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Abstract

Climate change is expected to bring potentially significant changes to Washington State's natural, institutional, cultural, and economic landscape. Addressing climate change impacts will require a sustained commitment to integrating climate information into the day-to-day governance and management of infrastructure, programs, and services that may be affected by climate change. This paper discusses fundamental concepts for planning for climate change and identifies options for adapting to the climate impacts evaluated in the Washington Climate Change Impacts Assessment. Additionally, the paper highlights potential avenues for increasing flexibility in the policies and regulations used to govern human and natural systems in Washington.

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1. Introduction

Climate change is expected to bring significant changes to Washington State. As described in accompanying papers, Washington's natural, institutional, cultural, and economic systems (collectively referred to herein as "human and natural systems") face potentially unprecedented challenges from the combined effects of a changing climate, population growth, and growing demands on resources. Addressing these challenges will require a sustained commitment to preparing for the impacts of climate change (adaptation) and reducing greenhouse gases (mitigation).

This paper provides a starting point for climate change planning in Washington State by highlighting major considerations for adaptation planning as a whole and for the specific sectors analyzed as part of the Washington Climate Change Impacts Assessment (the Washington Assessment). Sections 2 and 3 explain what adapting to climate change means and why adaptation is necessary at the state and local level. Section 4 describes Washington State's efforts to date with state-wide adaptation planning and discusses possible adaptation strategies and actions related to the analyses conducted for the Washington Assessment. Section 5 suggests several approaches for incorporating rapidly evolving climate conditions and climate science into Washington State policy making. Finally, Section 6 describes next steps and research recommendations.

2. What Constitutes Climate Change Adaptation?

Adapting to climate and climate variability is not a new activity for human and natural systems. Reservoirs are constructed in response to seasonal variations in streamflow. Levees are built to reduce flood risk. Ecosystems shift over time to compensate for changes in temperature or sea level. The need for more systematic adaptation is increasing, however, as evidence that climate change is occurring continues to grow and as it becomes clear that substantive reductions in greenhouse gas emissions will not be made in time to avoid many projected climate change impacts (IPCC 2007).

The need to adapt to climate is based on the vulnerability of human and natural systems to climate impacts, which is a function of a system's

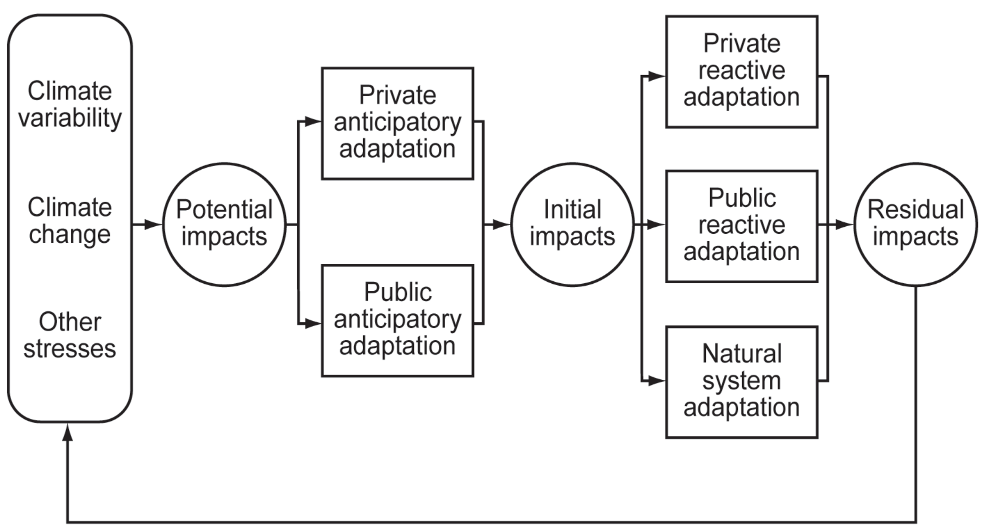

Figure 1. The role of anticipatory and reactive adaptation in addressing climate impacts (Klein 2003, figure used with permission)

sensitivity, exposure, and adaptive capacity to climate (Box 1). Breaking this down further, IPCC 2007 (Chapter 19) identified the following seven key components that influence vulnerability to climate change: 1) the magnitude of impacts (e.g., scale and intensity), 2) the rate and timing of impacts (e.g., fast vs. slow; near-term vs. long-term), 3) the persistence and reversibility of impacts, 4) the likelihood of impacts, 5) the potential for adaptation, 6) distributional aspects of impacts and vulnerabilities (e.g., across regions and population groups), and 7) the importance of the system(s) at risk.

It is important to note that vulnerability to climate impacts also may be affected by changes in non-climatic stresses such as population growth, increasing resource demands, changes in global economic markets, competition from invasive species, and development in or near sensitive habitats. Adapting to climate change likely will be more effective when adaptation efforts address both the climatic and non-climatic stresses affecting a system's vulnerability. For example, efforts to address climate change impacts on Pacific Northwest salmon likely will be more successful if other stresses related to habitat loss, hydropower operations, and salmon hatchery management practices are also considered part of the adaptation "portfolio."

But what does it mean to adapt to climate change? Definitions of adapting to climate change vary in detail but are generally based on the concept of making adjustments in physical, ecological, economic, and social systems to compensate for climate impacts (Smit et al. 2000, Adger et al. 2005, IPCC 2007). The goal of these adjustments is making human and natural systems more *resilient* to the impacts of climate change. A resilient system is one that has the capacity to "absorb and rebound from weather extremes, climate variability, or change and continue functioning" (Luers and Moser 2006; also Turner et al. 2003, IPCC 2007).

Adapting to climate change can be done in anticipation of climate change impacts (anticipatory adaptation) or in response to climate events (reactive adaptation), as illustrated in Figure 1. Anticipatory adaptation occurs when governments, businesses, and private citizens take proactive steps to reduce the negative consequences of projected climate change impacts. Anticipatory adaptation can also be used to maximize the benefits of climate change, such as a longer growing season or increased winter hydropower production.

Because it is impossible to anticipate perfectly how climate change will affect human and natural systems, and because natural systems cannot anticipate climate change impacts, reactive adaptation also will occur. Reactive adaptation may be an acceptable strategy in cases where the risks associated with responding reactively to climate impacts are considered acceptable. However, relying exclusively on reactive adaptation can be problematic (Smith 1997). First, reactive adaptation may be "too little too late" given that some climate change impacts, such as the loss of a species,

Box 1: Basic Concepts in Adaptation Planning

Sensitivity: The degree to which a system is affected, either negatively or positively, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise) (IPCC 2007).

Exposure: The nature and degree to which a system is exposed to significant climatic variations (IPCC 2001). Exposure to climatic stresses may vary by geography, elevation, length of time, and other factors.

Vulnerability: The extent to which a natural or social system is susceptible to sustained damage from weather extremes, climate variability, and change (and other interactive stressors) (Luers and Moser 2006).

Adaptive capacity: The ability of a system to adjust to climate stresses (including weather extremes, climate variability, and climate change) so that potential damages are reduced, consequences coped with, or opportunities maximized (IPCC 2007).

Table 1. Examples of adaptive capacity building (Luers and Moser 2006; Snover et al. 2007; UKCIP, undated)

Increase access to information about climate and climate impacts	• Increase staff access to science experts and peer-reviewed science and policy publications • Host brown bag seminars, department meetings, and scientific briefings for staff • Include climate impacts/adaptation information in websites, newsletters, fact sheets, utility inserts, brochures • Include information on climate impacts and adaptive planning activities in public meetings
Increase technical capacity to incorporate information on climate impacts	• Collect data and improve monitoring to fill critical information gaps • Conduct research, or partner with organizations to fund needed research on climate impacts • Increase training opportunities and access to technologies that support adaptation needs • Increase partnerships with organizations that can support adaptation needs • Hire expertise in areas that support adaptation needs • Dedicate new or existing staff time to overseeing adaptation activities
Increase legal and administrative capacity to adapt to climate change	• Develop adaptation planning strategy to guide adaptation activities • Assess regulatory, institutional, and cultural barriers to implementing adaptation actions • Modify regulations, policies, administrative procedures, etc. to remove or minimize identified barriers • Improve guidance/best management practices to incorporate adaptive planning objectives • Provide the necessary financial resources to support adaptive planning

may be irreversible. Second, reactive adaptation is likely to cost more than anticipatory adaptation (idem, Luers and Moser 2006, IPCC 2007, Repetto 2008). This may be particularly true when dealing with long-lived infrastructure that is difficult to retrofit or relocate in response to climate impacts, or when the potential to implement more cost-effective anticipatory adaptation measures becomes permanently constrained by present-day activities (IPCC 2007). Finally, reactive adaptation may run the risk of being short-sighted by focusing on resolving the crisis at hand, e.g., a single drought or coastal erosion event, and not addressing the underlying current and projected problems that contribute to the crisis, e.g., over-allocation of water resources or development in unstable coastal areas (Smith 1997). Consequently, adapting to climate change will ultimately involve both anticipatory and reactive adaptation actions.

Whether anticipatory or reactive, adaptive planning involves two general categories of activity: building adaptive capacity and implementing adaptive actions (UKCIP, undated). Building adaptive capacity focuses on increasing institutional capacity to handle the impacts of climate change, i.e., to deliver adaptive actions. Building adaptive capacity recognizes that there are institutional, legal, cultural, technical, fiscal, or other barriers to planning for climate change that need to be addressed if a community is going to effectively adapt to climate change. Building adaptive capacity can occur regardless of the amount of uncertainty that exists around specific climate change projections (e.g. whether sea level rise increases

4 cm [2 in] or 34 cm [13 in]). As such, these steps represent "no regrets" strategies (Section 4.9) for adapting to climate change. General examples of activities that may build adaptive capacity are provided in Table 1; additional examples related to the eight sectors analyzed for the Washington Assessment are included in Table 2, located at the end of this paper.

Adaptation actions are actions taken to address specific climate vulnerabilities or opportunities. Examples of adaptation actions include improving drought planning, promoting new irrigation technologies to improve water use efficiency, managing forest density to reduce vulnerability to forest fires, and opening additional cooling centers during extreme heat events. A more extensive list of possible adaptation actions relevant to the eight sectors evaluated in the Washington Assessment is found in Table 2, located at the end of this paper.

Understanding what adaptation is also means understanding what it is not. Adapting to climate change is not about completely insulating communities and natural systems from all climate impacts; this is an unattainable goal. While many impacts can be anticipated and significantly minimized through adaptive planning, it is not possible to anticipate perfectly how climate will change and how these changes will manifest themselves at specific locations and points of time. Surprises are unavoidable. Consequently, the goal of adaptive planning is better framed as increasing the resilience of human and natural systems to climate impacts by eliminating or minimizing the negative consequences of climate change on these systems.

Second, adapting to climate change is not a one-time activity. Climate will continue to change as will Washington's communities, economies, social preferences, and policies and regulations. The assumptions that shape adaptation planning must be periodically revisited and adjusted to reflect these changes. Therefore, adapting to climate change must be seen as a "…continuous set of activities, actions, [and] decisions" undertaken by individuals, groups, and governments rather than a one-time activity (Adger et al. 2005).

3. Why Adapt to Climate Change at the State and Local Level?

State and local efforts to prepare for climate change are relatively new yet gaining ground quickly. As of September 2008, eight states – Washington, Oregon, California, Alaska, Florida, Maryland, New Hampshire, and Massachusetts – were developing state-level adaptation plans (Pew 2008). Six additional states (Arizona, Utah, Colorado, North Carolina, South Carolina, and Vermont) had recommended developing adaptation plans within their state mitigation plans. Numerous county and local governments around the country, including Washington's City of Olympia, King County, and City of Seattle, are also developing adaptation plans (Box 2).

Box 2. The CASES Database

Understanding how state and local governments are approaching the task of adapting to climate change is often helpful for building public and political support for adaptation, understanding the range of activities that constitute adapting to climate change, and learning from the experiences of other state and local governments who have started the process of adapting to climate change. Knowing which state and local governments are working on climate change adaptation and where to find information on their efforts can be challenging, however.

To help address this challenge and support state and local adaptation planning, the Climate Impacts Group is developing the CASES (Climate Adaptation caSE Studies) database. CASES is a user-driven, searchable database that will provide basic information on state and local adaptation planning efforts. Users will be able to query the database by location and/or any other combination of search options, including population size, impact concerns, and adaptation activities. CASES reports will include a summary of adaptation planning activities within a community and contact information for requesting additional information. The database is expected to "go live" with an initial set of case studies. Users will help grow the database over time by submitting case studies on their own adaptation work to the database. Funding for the development of CASES was provided by Washington State as part of the Washington Climate Change Impacts Assessment.

Adapting to climate change at the state and local level is prudent for several reasons (Snover et al. 2007, Smith 1997, Box 3). First, significant regional-scale climate change impacts are projected. Furthermore, because of lags in the global climate system and the long lifetime for key greenhouse gasses in the atmosphere, impacts over the next few decades are virtually certain. Impacts in the second half of the 21st century are also certain, but the magnitude of those impacts will be greatly influenced by the success or failure of efforts to reduce greenhouse gas concentrations both in the near-term and over time.

As described in accompanying papers, Washington State is projected to experience a wide range of climate change impacts (absent adaptation) by mid-21st century, including:

- An increase in average annual temperature of 1.8°C (3.2°F) by the 2040s (Mote and Salathé 2009, this report);
- A 37-44% decline in spring snowpack by the 2040s (Elsner et al. 2009, this report);
- A 13-16% decrease in summer hydropower production by the 2040s and a 363-555% increase in summer cooling demands, which is related to warmer summer temperatures as well as population growth and building trends (Hamlet et al. 2009, this report);
- Changing yields for dryland winter wheat (+13 to +24%), irrigated potatoes (-2% to -3%), and irrigated apples (+9%) by the 2040s *assuming continued availability of water to irrigated crops and benefits from the carbon dioxide (CO_2) fertilization effect* (Stöckle et al. 2009, this report). Average yield for cherries and apples decrease 40-50% by 2070 for junior water rights holders in the Yakima Basin despite the CO_2 fertilization effect when climate change-related declines in summer water supply are accounted for (Vano et al. 2009b, this report);
- A quadrupling of the duration of temperatures causing migration barriers and thermal stress for salmon (temperatures greater than

Box 3. Primary Reasons for Planning for Climate Change at the State and Local Level

1. Significant regional-scale climate change impacts are projected.
2. State and local governments, businesses, and residents are on the "front line" when it comes to dealing with climate impacts.
3. Decisions with long-term impacts are being made every day, and today's choices will shape tomorrow's vulnerabilities.
4. Significant time is required to motivate and develop adaptive capacity, and to implement changes.
5. Preparing for climate change may reduce the future costs of climate impacts and responses.
6. Planning for climate change can benefit the present as well as the future.

70°F) in the interior Columbia Basin by the 2080s (Mantua et al. 2009, this report);

- A tripling in the area burned by fire in the interior Columbia Basin risk by the 2040s (Littell et a. 2009, this report);
- Increasing coastal threats associated with higher mean sea level, increased coastal storm strength and flooding, increased beach and bluff erosion, and increased ocean temperatures and acidity (Huppert et al. 2009, this report);
- Projected increases in extreme rainfall magnitudes throughout the state by mid-century, although the projections vary substantially by both model and region (Rosenberg et al. 2009, this report); and
- An additional 156 deaths annually among persons aged 45 and above during heat events in 2045 in the greater Seattle, Washington, area alone, as well as an additional 132 deaths between May and September annually due climate change impacts on air quality (Jackson et al. 2009, this report).

The impact of these projected changes on Washington's human and natural systems could be significant if steps are not taken to eliminate, reduce, or otherwise accommodate the changes.

Second, Washington's residents, businesses, and local and state governments are on the "front line" when it comes to dealing with climate impacts. Climate change is driven by the global accumulation of greenhouse gases in the atmosphere but the impacts of this global-scale problem will be felt most acutely at the state and local level. State and local governments, businesses, and private citizens will be forced to deal with the physical impacts of climate change and the associated economic costs of lost productivity, damaged infrastructure, and increasing emergency response costs, among others. At its core, adapting to climate change is an inherent part of providing for the safety, health, and welfare of a community.

Third, decisions with long-term impacts are being made every day, and today's choices will shape tomorrow's vulnerabilities. State and local governments regularly make decisions that have long-lasting implications for climate vulnerability, including decisions related to land use planning and development, habitat management, flood control, erosion control, water supply, and infrastructure design. Excluding the potential impacts of climate change in these types of decisions can increase vulnerability to climate change. For example, developing property in an area that is likely to experience more flooding as a result of climate change increases the risk of flood damage to the new structures.

Fourth, significant time is required to motivate and develop adaptive capacity, and to implement changes. Evaluating and integrating information on climate change impacts into decision making does not happen quickly. Significant time is required to develop the necessary support for examining how climate change may affect specific resources or activities; for identifying and addressing where legal, institutional, and cultural barriers to using climate information in decision making exist; and for implementing strategies that reduce vulnerability to climate change impacts.

Fifth, preparing for climate change may reduce the future costs of climate impacts and responses. Efforts taken now to reduce vulnerability to climate change impacts may lead to future cost savings through damage avoidance and/or by avoiding the need to retrofit for climate resilience. For example, updating coastal setback requirements or modifying land use planning to eliminate certain types of land uses within the flood zone are likely to be more cost-effective when done proactively rather than reactively. The suite of adaptation choices also may be greater when preparing for, rather than reacting to, climate change.

Finally, planning for climate change can benefit the present as well as the future. Climate change is likely to intensify existing stresses by increasing the frequency, duration, and extent of events that contribute to present-day problems, such as flooding, drought, and forest fire risk. Most adaptation activities aimed at addressing projected climate change impacts are likely to provide benefits today, meaning that communities do not have to wait until the 2020s or the 2050s to realize the benefits of adaptation activities. For example, expanding an existing water conservation program in anticipation of increasing drought risk will help mitigate present-day droughts as well.

While the reasons for preparing for climate change are clear, adaptive planning to date has been inhibited by many real and perceived barriers. These include the following (Luers and Moser 2006; Snover et al. 2007; IPCC 2007; Ligeti et al. 2007; Repetto 2008; UKCIP, undated).

Information Barriers. Updated information on climate impacts and adaptation planning may be hard to find, out of date, and/or difficult to apply directly to state and local government management needs. For example, the geographic scope of available impacts assessments (such as a region of the country or a particular sub-basin) may not match the needs of individual decision makers, who would ideally like to know how climate change will affect their specific community or management domain with as much detail as possible. Additionally, the technical nature of climate information can make it difficult to interpret the relevance of available climate information to state and local planning needs.

Dealing with Uncertainty and Perceptions of Risk. Decision makers may feel there is too much uncertainty about the timing and extent of climate impacts, or the risks associated with implementing certain adaptation actions, to begin adapting to climate change. Additionally, decision makers may not feel that the impacts and associated risks are significant enough to require a change from "business as usual."

Issue Fatigue and Disconnected Time Horizons. Decision makers are often contending with multiple pressing issues related to present-day problems. Incorporating climate change impacts into already complex decision-making environments can be difficult, particularly given the long-term nature of the climate change problem. This challenge may become even more pronounced if projected impacts are not expected to occur until after a decision maker's term has expired or they have retired. Additionally, decision makers may find it hard to rationalize the near-term costs of specific adaptation options relative to the future (long-term) costs of inaction. The division of responsibilities between short-term and long-term planning, and the location of these responsibilities in different departments, may contribute to the problem of disconnected time horizons (Luers and Moser 2006).

Technical, Fiscal, and Human Resource Constraints. A lack of staff, fiscal, and technical resources for adaptive planning can limit adaptive planning efforts.

Regulatory and Institutional Barriers. Regulations, policies, and procedures may include provisions that limit the ability of institutions or individuals to implement adaptive actions. In some cases, regulatory programs or limits may actually promote actions that increase vulnerability to climate impacts (e.g., flood insurance programs that allow for development in floodplains). Institutional barriers may include problems coordinating across different levels of government, departments, or disciplines; lack of internal and/or external support for acting on climate change; and turnover of staff and elected officials. Institutional responses to risk taking also may create barriers. In general, staff are not punished when things go wrong if they followed existing guidelines. This encourages reliance on past information even when decisions made on the basis of past information may not be consistent with future needs.

Lack of "Peer" Examples for Adaptive Planning. In some cases, the perception that few, if any, "peer" communities (i.e., communities of similar size or geographic location) are planning for climate change may create a barrier to planning for climate change.

Reducing the barriers to adaptive planning will take time. Many may be addressed in substantive ways by building and maintaining adaptive capacity, as described in Section 2. Focusing early adaptation actions on low-regrets and no-regrets strategies (see Section 4.9) also may be effective for gaining early momentum on adaptive planning. Most important, however, is recognizing that while these barriers exist (and likely will always exist to some degree), the need to begin preparing for climate change impacts remains clear.

4. Adaptation Options for Washington State

Washington's commitment to adapting to climate change was formalized on February 7, 2007, when Governor Christine Gregoire signed the Washington Climate Change Challenge (Executive Order 07-02). In addition to establishing greenhouse gas reduction goals for the state, Executive Order 07-02 committed the state to determining what steps the State could take to prepare for the impacts of climate change. Five multi-stakeholder Preparation and Adaptation Working Groups (PAWGs) focusing on public health, agriculture, coasts and infrastructure, forestry, and water supply and management were assembled to develop the adaptation recommendations. The PAWG recommendations, released February 2008, varied by sector but addressed the following common themes (Ecology and CTED 2008):

- Enhancing emergency preparedness and response;
- Incorporating climate change and its impacts into planning and decision-making processes;
- Restoring and protecting natural systems and natural resources;
- Building institutional capacity and knowledge to address impacts associated with climate change;

- More effectively managing and sharing best available data; and
- Educating, informing and engaging landowners, public officials, citizens and others.

The Washington Assessment complements the State's effort with the PAWGs by providing updated and expanded details on the potential impacts of climate change in Washington. Adaptation options relevant to the scope of the analyses conducted for the Washington Assessment are described in the following sections and aggregated in Table 2, located at the end of this paper.

Note that the Washington Assessment does not provide a detailed list of specific policy changes that could be made, nor have the various studies in this report analyzed the effectiveness of the identified adaptation strategies and options on projected climate change impacts for each sector. The Washington Assessment should be viewed as starting point for initiating a more systematic review of adaptation needs, as recommended in Section 6**.** This could be done with continued involvement from the PAWGs and/or through a combination of intra- and inter-agency working groups convened to evaluate what adaptation options are needed and how they can be implemented.

4.1. Hydrology and Water Resources

Washington's water resources are highly sensitive to climate change, as described in Elsner et al. 2009, this report; Vano et al. 2009 a,b, this report. This sensitivity is largely dominated by the state's reliance on snowpack for much of its water supply. Although specific impacts will vary by watershed, climate change is projected to contribute to lower spring snowpack, higher winter streamflows, earlier peak spring runoff, and lower summer streamflows. These changes are most pronounced in relatively warm mid-elevation watersheds (such as those originating on the west slopes of the Cascades) where projected warming shifts more winter precipitation to rain rather than snow.

In the absence of adaptive responses, the projected hydrologic changes are expected to result in reduced water supplies in Seattle, Tacoma, and Everett, and increased impacts to irrigators with junior water rights in the Yakima basin (Vano et al. 2009a,b, this report). Regional hydropower production, flood control operations, and instream flow in the Columbia River basin will be materially affected by streamflow timing shifts that accompany regional warming, requiring operational changes (Lee et al. 2009) and different approaches to energy planning (Hamlet et al. 2009, this report).

Impacts on the high flow side of the spectrum are also projected. Increases in winter precipitation combined with regional warming are projected to increase flooding in many river basins in Washington (Mantua et al. 2009, this report). Changes in hydrologic extremes (floods and droughts) impact both human systems (Rosenberg et al. 2009, this report) and aquatic ecosystems (Mantua et al. 2009, this report), particularly in the context of Pacific Northwest salmon recovery activities.

Non-climatic factors are likely to compound projected hydrologic impacts. Patterns of development, such as location of new communities in a flood plain, may escalate flood risk by increasing community exposure to flooding. Loss of riparian habitat due to development, timber production, or other non-climatic factors may intensify projected impacts related to low streamflow, warmer summer water temperature, and damaging winter high flows.

Population growth will also add stress to water supplies. The majority of Washington's population (both current and projected) lives west of the Cascades in vulnerable areas affected strongly by loss of snowpack and increased flood risk. Likewise Washington's key agricultural areas are located in sensitive watersheds with limited reservoir storage. Finally, energy policies that place increased emphasis on renewable energy sources such as hydropower may effectively increase the stresses associated with projected losses in summer hydropower production (Hamlet et al. 2009, this issue).

The rapidly evolving impacts of climate change on the hydrologic cycle will require new approaches to water management, and greater flexibility in the way we conserve and manage our water resources and prepare for emergencies such as floods and droughts (Hamlet et al. 2009, in review). Strategies for adapting to reductions in summer water availability and increasing summer drought stress include expanding and diversifying existing water supplies, developing new or alternate water supplies, reducing demand/improving efficiency, implementing operational changes, increasing the ability to transfer water between uses and users, and increasing drought preparedness (Table 2, located at the end of this paper).

Adaptation actions to reduce increased winter flood risk include infrastructure changes such as strengthened dikes and levees, increased reservoir storage, restoration of hydrologic function in floodplains, operational approaches such as improved flood forecasting and adaptation of reservoir management policies, improved emergency management systems, and altered land use policies and flood insurance programs that take into account the changing risks of extreme events. Changes in ecosystem management and salmon habitat restoration plans will also be needed to adapt to changing high flow risks.

Most of the adaptation strategies identified in Table 2 are already familiar to water resources planners and managers, or are extensions of existing water planning and management strategies. This supports the argument that adapting to climate change can make use of existing tools and approaches (Snover et al. 2007), although which tools are used and how they are used may differ once projected climate change impacts are taken into account. It is worth noting that, in the context of water supply, demand management strategies such as conservation often emerge as low cost (often lowest cost) adaptation strategies, whereas adaptation strategies based on large scale infrastructure changes are often the highest cost (Hamlet et al. 2009, in review).

Barriers to adaptation in the water sector include institutional or legal constraints that ultimately prevent meaningful changes in water policy, water allocation, or water resources management from occurring (Gamble et al. 2003). Functional linkages between science (in this case climate change science) and water resources planning and management practice are frequently missing or are outdated. Perceptions of professional risk in the water resources management community are an obstacle to the acceptance of changes that are currently outside of accepted professional practice (e.g. scenario-based planning based on climate and hydrologic model simulations). Planning horizons are often too short to meaningfully encompass climate change impacts, and the policy sector is often unresponsive to the gradual nature of the changes. Instead changes in water management or water policy often follow crises. In the case of climate change impacts, these crises may occur decades in the future with the result that policy makers and planners ignore projected climate change impacts and focus on present difficulties. Polarization in communities focusing primarily on mitigation and those focusing primarily on adaptation has been a source of confusion in the media that limits the effectiveness of both groups. However, effective adaptations strategies can also have a positive impact on mitigation efforts (e.g., water conservation efforts may ultimately reduce the amount of total power required to treat and pump water). Together these efforts can result in greater flexibility in managing water resources into the future.

4.2. Energy

As shown in Hamlet et al. 2009 (this report), energy demand for heating and cooling is projected to increase due to the combined effects of population growth and warmer regional temperatures. Heating energy demands are projected to increase in the region by 35-42% by the 2040s despite reductions in heating days[1] due due to warming. Cooling energy demands in the region are expected to increase significantly, rising 363-555% by the 2040s relative to the late 20th century.

Increased heating energy demands will affect both direct fossil fuel use (e.g. natural gas use for space heating) and demand for electrical power from hydropower and other sources. Growing cooling energy demands, on the other hand, will primarily increase demand for electric power since air conditioning technology is predominantly powered by electricity. Increasing cooling energy demands will also indirectly affect fossil fuel use associated with non-renewable power sources as the energy industry looks to increase capacity in response to growing demands. Increases in air conditioning use in the Pacific Northwest are likely to intensify these impacts and increase peak electrical power loads in summer.

Climate change will also affect hydropower production. Hydropower accounts for roughly 70% of the electrical energy production in the Pacific Northwest and is strongly affected by climate-related changes in annual streamflow amounts and seasonal streamflow timing. Winter (December-February) regional hydropower supplies are projected to increase by about 4% by the 2040s, which will offset increases in heating energy demand to a certain extent. However, summer (July-September) regional hydropower

[1] Cooling and heating degree days are measurements used in the energy market to estimate demand. In the United States, a cooling degree day is counted for each degree the average temperature for a day moves above 75°F (24°C). For example, if the average temperature for the day was 80°F (27°C), that would count as 5 cooling degree days. One heating degree day is counted for each degree that average daily temperature falls below 65°F (18°C).

supply is projected to *decrease* by about 15% by the 2040s, exacerbating the projected growth in cooling energy demands. Total annual hydropower production is expected to decline by about 3% (*idem*).

Adapting to these changes will be needed, especially in summer. Impacts in summer are expected to be much more severe due to strongly increasing demand for electrical power, expected increases in air conditioning use and associated peak demands, and substantially reduced supplies from regional hydropower resources during the peak air conditioning months. Adaptation options for increasing energy supply include expanding the capacity of conventional, alternative, and renewable energy supplies in both winter and summer in anticipation of increased demand, and increasing local transmission capacity and peaking generation capacity in anticipation of projected increases in peak summer loads (Table 2, located at the end of this paper). Changes in water management policy to allow for increased summer hydropower generation may partially compensate for lost generating capacity. Increasing summer hydropower production may also help offset projected impacts to salmon (Mantua et al. 2009, this report) by increasing summer streamflow volumes as more water is passed through hydropower dams to generate electricity. The increase in summer production would potentially come at a loss for winter production, however, as reservoir levels are drawn down for summer production rather than being carried over into winter. Regional capacity constraints in the winter may be eased by importing energy from California and the Southwest, where excess capacity is expected to increase with winter warming.

Reducing energy demand in winter and summer will also be critical adaptation strategies. Options include establishing more stringent energy efficiency standards for new construction and appliances (including increased state-wide heating and air conditioning efficiency and insulation standards), promoting increased use of high efficiency air conditioning technology (e.g. geothermal air conditioning systems), reducing heat island effects in urban settings via "green roofs" or other approaches, implementing water and energy conservation programs, and increasing application of renewable energy sources such as solar hot water heating and photovoltaic panels in residential and commercial buildings.

Barriers to adaptation in the energy sector include limited (and fully allocated) hydropower resources and current limitations on the ability to increase renewable resources to meet projected changes in demand. Although increased hydropower production in summer may be technically feasible, losses of summer recreation opportunities on reservoirs and tradeoffs with winter hydropower production are likely to occur. The need to balance greenhouse gas mitigation activities with the need for increased generation capacity will require difficult tradeoffs between acquiring additional capacity to meet projected demand and portfolio standards for renewables imposed by the policy sector.

4.3. Agriculture

Stöckle et al. (2009, this report) indicate that, with the possible exception of winter wheat, the main agricultural commodities in eastern Washington will be affected by future climate, even as soon as the next few decades.

However, elevated atmospheric carbon dioxide (CO_2) may compensate for the effect of warming and result in yield gains. Adapting agriculture to changing conditions will be critical to managing climate change and capturing the potential benefits of elevated CO_2. Changes in the relative importance of the region's commodities, adoption of new crops and varieties, changes in management, and research will play an important role for adaptation.

Adapting to evolving future climatic conditions is among the significant long-term challenges for the agriculture in the state. Conventional or biotechnology-based plant breeding research will be needed for this task. Overall advances in agricultural technology will be also needed to reduce costs and improve crop yields and quality. Research in automation, sensors, and overall improvement of decision-making tools for management will also be important (Table 2, located at the end of this paper). Maintaining a state-of-the art monitoring network and information center for evaluating the manifestations of climate change and guiding basic and applied research for adaptation would be beneficial.

Apples and other temperate tree fruits are projected to benefit from warmer weather combined with elevated CO_2, but management and varieties will need to constantly adapt to harvest the benefits of future conditions. Eventually, warming will affect over-winter chill requirements of temperate tree fruits requiring substitution. In the case of annual crops, modification of planting dates and use of varieties better adapted to the available growing season will be required, particularly in the case of potatoes. For annual and tree fruit crops, the search for more effective and environmentally friendly approaches for controlling more aggressive (or new) insects and weeds will be needed.

Impacts to Washington agriculture will also depend on changes to agricultural areas outside of Washington, which was beyond the scope of Stöckle et al. (2009, this report). It is difficult to predict the economic environment under which agriculture will operate as we move through the century. Increasing global population is projected to reach nine billion people by mid-21st century and the rapid development of highly populated countries such as China and India will ensure increasing demand for agricultural products. The diversification of the state's agriculture may be an important factor for adaptation. Conventional and biotechnology-based breeding may further help the competitive position of existing commodities in the state as well as facilitate adaptation to climate change as already discussed. Finally, consequences of climate change appear less severe for higher latitude regions like Washington than agricultural areas further south, potentially increasing the competitive position further.

4.4. Salmon

As shown in Mantua et al. (2009, this report), the hydrologic processes that influence the timing, volume, and temperature of streamflow in Washington State are highly sensitive to projected changes in future climate. Changing thermal and hydrologic regimes will likely have a wide range of impacts on freshwater ecosystems, favoring some species while having negative impacts on others. While the magnitude of streamflow and stream temperature impacts varies by location, many salmon populations are expected to experience greater thermal stress in the summer due to warmer summer water temperatures and lower summer streamflows. In watersheds where streamflow is now strongly influenced by a mix of rainfall and snowmelt-driven runoff, winter flood events are predicted to increase. Winter floods can reduce the reproductive success of salmon by damaging eggs while they are incubating in nests (redds), and by reducing the overwinter survival for rearing fry and parr. Taken together, the analysis points to reduced reproductive success for many salmon populations in Washington State (*idem*).

While salmon populations are affected by many non-climatic stresses (e.g., dams, other habitat loss, hatcheries, harvest and pollution), Mantua et al. (2009, this report) clearly demonstrates that adaptation in the salmon sector will require addressing factors that influence the timing, volume, and temperature changes projected for Washington's lakes and streams. Potential adaptation options for offsetting water temperature increases include reducing out-of-stream water withdrawals during periods of high temperature and low streamflow; identifying and protecting thermal refugia provided by ground-water inflows, undercut banks, and deep stratified pools; and restoring vegetation in riparian zones that provide shade and complexity for stream habitat (Table 2, located at the end of this paper). Protecting and/or restoring instream flows in summer is also a key adaptation option for reducing the future impacts of climate change.

Adaptation strategies for reducing the risk posed by flooding in fall and winter include protecting and restoring off-channel habitat in floodplains. In watersheds with large storage reservoirs, there may be opportunities to change reservoir operations in ways that compensate for climate change impacts on summer water temperature and seasonally low streamflow by augmenting flows with relatively cold water released from reservoirs at key times. However, climate change is also likely to increase the demand for surface water in summer for such uses as irrigated agriculture and municipal water supplies. This situation will require strategic policy thinking that recognizes the trade-offs that will have to be made between ecosystem protection and other water resource uses, and development of clear decision guidance to avoid protracted and potentially costly conflicts. Modified flood control operations in watersheds with dams may also provide a means for reducing the projected impacts of climate change on flooding.

4.5. Forests

Littell et al. (2009, this report) show that climate change will have potentially profound impacts on Washington's forest ecosystems. Warmer temperatures and declining snowpack are projected to increase water stress on forests, increase forest fire risk, and increase in the frequency of mountain pine beetle outbreaks. Productivity of Douglas-fir, a commercially important species, will vary more with water stress east of the Cascades and possibly at middle to upper elevations, where stands are more sensitive to drought than at the most productive lower-elevation sites west of the Cascade crest. However, productivity is ultimately projected to decline statewide later in the century with increased temperatures and drought stress.

Eastside forests will be the most vulnerable in the short term, as they are already periodically affected by severe disturbances worsened by drought stress. Both fire and insect disturbance may vary in extent and severity due to non-climatic factors such as stand dynamics and fuel buildup (or reduction) from fire management. Forest management will need to anticipate new landscape patterns that emerge from climate-disturbance interactions.

Adaptation options for the forest sector can be viewed differently at different scales (Millar et al. 2007, Joyce et al. 2008). For example, regional adaptation involves planning that is sufficiently flexible to facilitate appropriate local actions but also capable of organizing regional responses to broader impacts. Examples of regional-scale adaptation strategies include a stronger emphasis on maintaining mixed landscape structure, maintaining species diversity and within-species diversity, increasing forest resilience to drought stress and severe disturbance by managing density, improving information used in forest management to facilitate planning for projected conditions, and evaluating the barriers and opportunities that limit or facilitate local adaptation (Table 2, located at the end of this paper).

Local adaptation must be tailored to local conditions to succeed. One must identify specific management objectives, such as reduced risk of fire or insect outbreaks, characteristics of landscape pattern, or habitat needs for threatened species; assess the capacity to alter conditions to meet the objectives, e,g, by achieving target densities or basal area; and then implement the appropriate treatments that will allow objectives to be met. For example, targeted thinning may increase the resilience of drier forests in which fire suppression has caused a shift toward fuel structures susceptible to crown fires. In wetter forests where 20th century timber management has decreased age class diversity and altered patch structure, targeted thinning could simultaneously create appropriate fuel breaks and increase canopy and age-class diversity. In water-limited forests, tailoring stand density to the expected water conditions of the future will likely increase resilience to insect attack and climate change in general.

Two of the key barriers to adaptation in the forest sector are mixed land ownership (and management mandates/missions) and the need for a wide range of ongoing ecosystem services from forests. For example, federal forests (both wilderness and multiple-use), state forests, and private forests have different mandates for management, making integrated planning at the spatial scales of landscapes and watersheds more difficult. The global timber economy and local forest-reliant communities make adaptation decisions more complex and introduce unexpected pitfalls. On the other hand, barriers might in some cases be turned into opportunities; for example, if national economic priorities called for carbon-smart biomass use that also provided incentives for thinning vulnerable forests to densities more resilient to climatic change. Ongoing dialogues among stakeholders directed toward anticipating both climatic and non-climatic stressors will be needed.

4.6. Coasts

Climate change is projected to bring higher mean sea level, increased coastal storm strength and flooding, increased beach and bluff erosion, and increased ocean temperatures and acidity to Washington's coastal environment (Huppert et al. 2009, this report). Current projections for changes in mean sea level range from 4 cm (2 in) to 34 cm (13 in) by 2100 in moderate scenarios, but could reach an extreme of 128 cm (50 in) by 2100 if the accelerated melt rates observed in Greenland and Antarctica between 2002 and 2006 were to continue through the 21st century (Mote et al. 2008). How these changes affect a given location or coastal use will vary depending on the physical characteristics of the coast and the influence of human activities in that area (e.g., whether the beach is armored or not).

Adaptation strategies must recognize the dual nature of coast impacts. Adapting to coastal impacts will require adapting to more frequent or more severe short-term problems such as increasing episodic coastal flooding and storm damage while also taking into account the long-term problem of increasing mean sea level, which threatens to permanently inundate low-lying areas. Adaptation to climate change can take three forms. Accommodation involves altering current uses of the coastline in response to changes in coastal oceans and environment, such as by raising the height of piers and placing shoreline buildings on pilings. Protection involves fending off the impacts by building structures like seawalls and dikes that keep the sea from intruding on coastal structures. Retreat involves avoiding the harmful effects of rising sea level by abandoning coastal sites and moving to higher ground (Table 2, located at the end of this paper).

Beaches, Bluffs, and Sand Spits. Washington's beaches, bluffs, and spits are vulnerable to increased flooding and increased shoreline erosion due to sea level rise. Building on these properties will be increasingly risky. Bulkheads and rock walls can temporarily reduce upland erosion caused by wave action, but they can do little to prevent continued erosion and sliding of the seaward bank, since waves rebound off the breakwater and increase the rate of beach erosion. Beach armoring can cause two negative effects that act to reduce the beach area: stopping the sediment from bluff erosion from adding to the beaches and moving the sand offshore (Johannessen and MacLennan, 2007). Flood zone designations could be modified to incorporate the expected sea level rise. Coastal communities may also choose to reduce development in coastal hazard areas. Alternatives to bulkheads should be considered where shoreline erosion is a problem. Setback policies and the redesignation of property lines that are to move with rising mean high water, called rolling easements by Titus (1998), can also be employed to accommodate sea level rise. Ultimately, however, communities and residents may decide to retreat upland from their current location as the sea level rises (Chrisman-Glass, 2009).

Ports and Harbors. For most port facilities, the slow speed of changes in mean sea level in combination with 30 to 40 year re-building cycles gives port facilities the flexibility to adapt by raising and shifting piers and docks over time. However, a much greater challenge is preserving a port's ability to function in the freight transportation network if sea level rise causes flooding of adjacent transportation corridors (highways, railroads) or storage areas. Because most Washington ports are inside of Puget Sound, they are protected from acute storm damage caused by waves. Some ports will have to deal with episodic flooding, in estuaries at river mouths. For example, the Port of Tacoma may have increasing problems with access to container and other terminal yards when the Puyallup river floods. Maintaining access to port facilities may require new dikes or raising existing dikes to prevent significant flooding of the lands needed by freight handling facilities. Because the set of interests is great, and property ownership in the region is complex, adapting to these risks will require a broad, well-coordinated plan of action by Port authorities, railroads, cities, counties, and state and federal agencies.

Shellfish Aquaculture. Shellfish aquaculture will need to adapt to three basic threats: (a) sea level rise causing a shift of shallow tidelands towards the upland shore, much of which is privately owned; (b) increased sea surface temperatures and acidification which may affect shellfish survival and growth; and (c) increased frequency of harmful algal blooms (HABs). One adaptive response to shifting tidelands is shifting shoreline property lines as the mean high water mark moves inland. In fact, some U.S. states already follow this principle. In Texas, when large hurricane or other events cause significant erosion of shorelines, the private property lines are shifted upland to preserve public beaches and tidelands.

Breeding or shifting to more tolerant strains of shellfish may facilitate adaptation to increased temperatures and acidification, although we do not have sufficient information regarding these factors to confidently predict whether this approach would be successful. Finally, the potential for more HAB outbreaks will require closer monitoring of shellfish tissue and water quality by the State Department of Health and NOAA. If reliable, qualitative predictions of HAB risks can be developed and managers can then be more prepared to respond quickly if HAB risks are "high" (Moore et al., 2008). This approach to adaptation is being discussed currently among scientists.

4.7. Urban Stormwater Infrastructure

Flooding is a pervasive problem in urban areas, often leading to property damage, public health threats (when combined with sanitary sewage), and disruptions to transportation systems. One need only look at the last three years to appreciate the devastation such events can cause in Washington State (Mapes 2009).

Although the link between flooding and precipitation is obvious, it is important to recognize that floods are not exclusively dependent upon climatic factors. Of equal (if not greater) significance are patterns of urban development - both in the watersheds that give rise to runoff volumes in response to large storms and across the floodplains that have always conveyed high waters. These considerations, and their relationship with changing precipitation patterns, are not specifically addressed in this report. However, the results of Rosenberg et al. (2009, this report) indicate that the magnitudes of extreme precipitation events have increased in the Puget Sound over the past 50 years, with more ambiguous changes in other parts of the state. Furthermore, simulations of future precipitation suggest that these magnitudes could continue to increase over the next 50 years, although specific projections vary widely by simulation, and actual changes may be difficult to distinguish from natural variability.

The existing literature proposes a variety of possible adaptation actions that could be employed, in part or in whole, to address the impacts of climate change on urban stormwater infrastructure (e.g., Crabbé and Robin 2006, Waters et al. 2003, Table 2, located at the end of this paper). The most common actions advocate recasting design storms and/or design flows and resizing pipes or stormwater facilities to reflect a new (or anticipated) discharge. This approach presupposes a known target discharge, presumably based upon a defensible, broadly accepted model of future climate. A key finding of Rosenberg et al. (2009, this report) is that such knowledge does not presently exist. Even if more confident projections do indicate that current systems will be undersized (and the evidence in the Puget Sound region is that some may already be), the costs associated with upgrading our infrastructure are likely to be prohibitive, particularly in densely developed areas where there may be limited space to put more robust systems in place.

More practical management options (with or without specific recommendations for redesigning infrastructure) are those that emphasize local-scale on-site management of stormwater volumes, which are capable of reducing discharges that flow into these downstream conveyance systems. These strategies, collectively termed "Low Impact Development" in the Puget Sound (PSAT 2005), "Green Infrastructure" by the EPA (PGI 2008), and "Sustainable Urban Drainage" in the United Kingdom (Woods-Ballard et al. 2007), are likely to perform most successfully in the face of a changing climate. In part, this is because their designs are inherently resilient, typically accommodating large stormwater volumes. Total storm volumes also are projected to change more modestly than storm intensities in this region (Salathé et al. 2009, this report). Examples of these "facilities" include green roofs, permeable pavements, vegetated swales, rain gardens, and pocket wetlands. Such approaches provide greater intrinsic opportunities for adaptation than those that depend solely on precise determination of rainfall depths and durations, particularly given the widely varying projections of future short-term rainfall intensities.

Fundamentally, accounting for future increases in stormwater runoff is still a matter of risk, with or without the consideration of climate change. Where large capital projects are proposed, robust decision-making can factor in both historical and projected trends in precipitation to help determine what is cost-effective over the design lives of the projects. Specific design adjustments, however, necessarily will vary with location and the risk tolerance of the decision maker.

4.8. Human Health

Jackson et al. (2009, this report) analyzed climate change impacts on heat- and air quality-related mortality. The analysis found that excess deaths have resulted from heat events for residents in the greater Seattle area (King, Pierce and Snohomish counties). This pattern was not demonstrated for Spokane County, the Tri-Cities (Benton and Franklin counties), and Yakima County, perhaps because of the relatively small populations in these regions, but also because people in these regions may have already implemented successful adaptations. With increasing temperatures predicted throughout the state during the 21st century, increasing excesses in mortality due to heat seems likely in all of these regions unless appropriate prevention and intervention strategies are implemented. More heat events are also likely to result in increased illness and hospitalization, and loss of income and productivity through illness and death. Climate change will also likely degrade air quality. Ground level ozone concentrations are projected to increase in King and Spokane counties due to increases in warm season air temperatures (May-September). These increases could easily overwhelm air quality improvements made over the last several decades.

Persons who are particularly vulnerable to heat stress and poor air quality include the elderly, the very young (such as infants), the infirm, the economically disadvantaged, and those who labor outdoor. Effective adaptation strategies must take into account the particular needs of these groups. For example, the elderly are at increased risk to heat stress due to the combined effects of chronic illness, medication use, social isolation, and lack of mobility. Effective adaptation actions could focus on notifications and door-to-door transportation services to cooling centers (Table 2, located at the end of this chapter). Adaptation options for vulnerable groups such as outdoor laborers may prove more problematic. While the state has guidelines for preventing heat-related illness, the major challenge is the effective implementation of these practices in the face of the practical realities of farming and of the economic forces that can drive workers to exert themselves beyond healthy limits.

Washington faces serious barriers to the adoption of truly effective adaptation strategies. Growing population and urbanization likely will increase the frequency of extreme heat events by reducing the number of trees and extent of green space, as well as through extensive use of asphalt and concrete, creating what is known as the urban health island effect (i.e., temperatures in urban centers are increased relative to surrounding areas). In the case of air quality, the major problem is pollution from vehicular derived emissions. It is not clear what the proper combination of incentives and disincentives might be to move communities toward low or zero emission vehicles, or to transition large numbers of people to mass transit. Many other factors will influence future air quality, including decisions about land use and forestry practices, transportation, industrial emissions, fire management, and regulatory standards. All of these have implications for energy consumption and emissions, which will in turn impact air quality.

Addressing these challenges will require partnerships among scientists, policymakers, and the public. More immediately, public health measures could include improved use of early warning systems for extreme heat events and alert systems for high air pollution days; offering free public transportation on high ozone or particulate matter days; and increased public education that focuses on the risks and signs of heat exposure, and that emphasizes behavior changes that can reduce exposures to air pollutants.

4.9. No Regrets, Low Regrets, and Win-Win Strategies

As Washington decision makers begin assessing how to move forward on adapting to climate change in Washington State, strategies for prioritizing early actions on climate change will need to be considered. One approach is identifying "no regrets," "low regrets," and "win-win" (or "co-benefit") strategies (de Loë et al. 2001,Willows and Connell 2003, Snover et al. 2007, Luers and Moser 2007).

No regrets, low regrets, and win-win strategies describe approaches to acting on climate change that balance the need for adaptive action with uncertainty and risk. No regrets actions provide benefits in current and future climate conditions even if no climate change occurs. For example, improved drought planning provides benefits for managing present-day drought regardless of what happens to drought risk in the future. However, if drought risk increases as projected with climate change, the benefits from improved drought planning will be even greater.

Low regrets actions provide important adaptation benefits at relatively little additional cost or risk. For example, a community planning flood levee upgrades may increase the height of the levees in anticipation of greater flood risk if the benefits of the increased levee height exceed the marginal cost of the increase.

Finally, win-win (or co-benefit) actions reduce the impacts of climate change while providing other environmental, social, or economic benefits. For example, implementing coastal setback requirements or rolling easements[2] (Titus 1998, Chrisman-Glass 2009) to address the potential threats of sea level rise on coastal properties may also provide benefits to nearshore habitat by giving these habitats room to migrate inland as sea level rises.

Implementing no regrets, low regrets, and win-win strategies can help build early momentum on adaptation planning while also producing potentially significant cost savings. Care must be taken, however, not to consider a community adapted to climate change based solely on the implementation of no cost or low cost adaptation actions. Implementing no cost or low cost adaptation actions is likely to address the "low hanging fruit", potentially leaving important determinants of vulnerability to climate change as issues that must still be resolved. Adapting to climate change will require difficult choices; making and implementing these choices will take time, underscoring the need to begin adaptive planning sooner rather than later.

5. Policy Formulation in a Changing Climate

As noted in Section 2 and reflected in Section 4, climate change will require building adaptive capacity and delivering adaptive actions to address the challenges and opportunities presented by climate change. These two general categories of activity can happen simultaneously, although in

[2] Setback, or retreat, policies generally condition the use of property in areas vulnerable to erosion and flooding and prohibit new construction seaward of a setback line. A "rolling easement" is a device that allows publicly owned tidelands to migrate inland as the sea rises, thereby preserving ecosystem structure and function. Thus, rolling easements transform static property lines into ones where private property must yield the right of way to naturally migrating shorelines.

some cases it may be necessary to address specific capacity needs before certain adaptation actions can be fully undertaken.

One component of increasing adaptive capacity is increasing flexibility in institutions and decision processes so the public and private sector can more readily adjust to climate impacts as they occur. The need for more flexibility is well recognized in climate change literature (Smith and Lenhart 1996; Fankhausera et al. 1999; Smith et al. 2000). Though Washington agencies currently enjoy some flexibility when determining, issuing, and applying regulations, more flexibility may be needed to accommodate uncertainties associated with climate change as well as uncertainties in non-climatic stresses, such as changes in population growth, economic trends, resource demands, the legal landscape, and economic trends. Without more flexibility, the institutions, laws, and policies used to govern human and natural systems may become increasingly constrained in their ability to effectively manage climate change impacts.

This section briefly considers some of the broader, systemic options for increasing flexibility in Washington State policy-making. These options include, but are not limited to, building social capital; broader use of market mechanisms, conditional permitting, adaptive management, and the precautionary principle; and increasing legislative flexibility in the courts.

With the possible exception of building social capital, which is a fundamental component for all government action, none of the options provided are offered as "one size fits all" answers to increasing flexibility and building adaptive capacity. When, where, and under what conditions these options are applied will vary in ways yet to be determined depending on 1) the nature of the decisions being made and the individuals or institutions implementing those decisions, 2) how risks are perceived, and 3) existing barriers to adaptive planning, among other factors. Additional research is needed in this area.

More importantly, increasing flexibility is an objective that needs to be pursued judiciously. Important questions must be considered: What does "increased flexibility" really mean? Where and when is it required? What are the potential consequences of increasing flexibility? In some cases, the needed flexibility may exist but there may be a lack of political will to implement the needed changes. These questions are not easily answered and will need to be evaluated as adaptive planning progresses in Washington State.

5.1. Building Social Capital

Social capital can be defined as the social skills, informal networks, levels of trust, and values within an organization, community, or society that allow people to work together for mutual benefit (Putnam 2000, Pelling and High 2005, Luers and Moser 2006). Adger (2003) describes social capital as the "necessary glue for adaptive capacity, particularly in dealing with unforeseen and periodic hazard events." Building social capital between public agencies and their stakeholders may be one of the most beneficial, and yet most difficult to evaluate, courses of action for increasing flexibility in decision-making processes. The means for building social capital will vary but include transparency in decision making (e.g. Washington State's commitment in 2007 to keep PAWG and related mitigation working group meetings open to the public via toll free conference call lines), outreach and education, and building sustained partnerships.

Social capital must also be built between regulatory agencies. Climate change impacts reflect a complex combination of both climatic and non-climatic stresses that often extend beyond the jurisdiction of individual agencies. Effectively addressing the complex challenges presented by climate change will likely require more coordinated responses between agency jurisdictions. A diverse set of institutions and agencies must learn to integrate their practices and work collaboratively in areas that were previously the responsibility of one particular agency. It will be necessary to build cooperative mechanisms and mandates into current agency structures to facilitate efficient information, jurisdiction, and resource sharing.

5.2. Market Mechanisms

Market mechanisms provide an alternative approach to technological mandates and environmental regulation for achieving environmental protection. Market mechanisms often use market-based approaches in conjunction with government policy to provide financial incentives for innovation or behavior change. Market mechanisms are the core of environmental trading programs designed to limit activities found to have negative impacts on the environment (e.g., the emerging carbon trading market), or to facilitate the transfer of limited resources between users (e.g., water markets).

Market mechanisms provide flexibility by generally allowing users to choose individualized pathways toward meeting regulatory goals, although it is common for limits to be placed on some aspects of the market system. In the context of climate change, market mechanisms selectively apply (in theory) the best practices of the current economic system to leverage efficiency, innovation, and capital to achieve adaptation goals. Water markets, for example, may aid climate change adaptation by providing incentives for improved water use efficiency. Surplus water is then available, at the discretion of the water rights owner, to sell or lease to municipal governments or conservation organizations for meeting growing demands for municipal and industrial water supply and habitat conservation (Adler 2008, Medellin-Azuara et al. 2008). A study of climate change impacts on California's water supply assessed the economic value of this optimization of water use through markets at $142 million/year in 2050 (Medellin-Azuara et al. 2008).

There are notable limitations associated with adopting new market mechanisms. First, rights must be well-defined, enforceable, and transferable for markets to be effective. Second, determining how marketable rights are priced and whether those rights include the value of ecosystem services such as clean water, habitat preservation, and other public goods that may be affected by market activities can be difficult. Other important questions to be answered include who owns the rights; who benefits from the sale if there are payments for public goods; and how low-income buyers or sellers fare under new markets (Ruhweza and Waage 2007). Perhaps most importantly, developing new markets requires buy-in from businesses, policy makers, and consumers alike. Businesses, consumers, regulators, and government entities would need to fundamentally adjust to "free goods" becoming "scarce assets". Education in the new models will be crucial.

5.3. Conditional Permitting

Conditional permitting increases regulatory flexibility by allowing specified activities or uses to occur within defined limits. Conditional permitting, or conditioned rights, is a common tool of governance. For instance, intellectual property rights expire after pre-determined periods of time because it is thought that perpetual patents negatively impact economies and encourage monopolies. Nuisance law requires that landowners refrain from activities interfering with another's use and enjoyment of their own land. Climate change may create new needs and opportunities for conditional permitting, including, for example, setback policies and rolling easements in coastal areas.

5.4. Adaptive Management

The term "adaptive management" has been used traditionally to describe an approach to natural resource management that is based on the understanding that ecosystems function in ways that are unpredictable and therefore uncertain (Holling 1978, Walters and Holling 1990, Tarlock 1994)[3]. Climate change adds to this uncertainty. Management of these systems is improved under an adaptive management framework by allowing for changes throughout a program's implementation as new information is acquired.

Precedent for expanding adaptive management in Washington law is found in Washington State's Growth Management Act (GMA). The GMA suggests the use of adaptive management as an interim approach for managing scientific uncertainty, stating that "management, policy, and regulatory actions are treated as experiments that are purposefully monitored and evaluated to determine whether they are effective and, if not, how they should be improved to increase their effectiveness" (WAC 365-195-920). The Code goes on to note that effective implementation of an adaptive management program requires a willingness by cities and counties to fund the research component of an adaptive management program, modify decisions on the basis of new information, and commit to the "appropriate timeframe and scale necessary to reliably evaluate regulatory and nonregulatory actions affecting critical areas protection and anadromous fisheries" *(idem)*.

Washington's GMA code highlights two fundamental components to adaptive management. The first is the concept of iteration, or the idea that an adaptive management program should incorporate cyclical feedback

[3] More generally (and particularly in the context of climate change), adaptive management can also refer to implementing adaptation actions now to address the obvious risks of climate change while deferring action in other areas where the risk of deferring action is acceptable (UKCIP, undated). In this case, as with the more traditional definition of adaptive management, consistent monitoring and reevaluation of new information is integral to determining when action must ultimately be taken.

rather than operate in a strictly linear manner. This cyclical feedback loop will place greater emphasis on the use of "Best Available Science."

The second important component is social and institutional learning through a strong monitoring, evaluation, and reporting program. Monitoring, evaluation, and reporting are essential for adapting management practices to a changing climate as many of the changes themselves likely will be incremental and discernible over longer periods of time. Monitoring, evaluation, and reporting are important tools for identifying when current policies or programs become ineffective, obsolete, or require tweaking to fulfill their mandates. An additional benefit is that new information can improve the baseline used in future decision making. Monitoring can also provide good quality, publicly available data that others can use to learn from predecessors and thus lower costs (Ruhl 2005). Consequently, specific attention should be paid to ensuring that monitoring and assessment are maintained as part of an adaptive management approach.

The practice of adaptive management has not been without challenges, however. Noted problems include difficulties developing acceptable predictive models for policy comparison (often complicated by a lack of data on key process or difficulties validating data); difficulty implementing large-scale management experiments because of the costs and risks; a mismatch between the length of the adaptive management process and short funding cycles; agency and stakeholder impatience with the slow pace of adaptive management; and a lack of leadership for monitoring and coordinating efforts (Halbert 1993, McLain et al. 1996, Walters 1997, Levine 2004). Consequently, adaptive management to date has been more influential as an idea rather than as a practical management tool (Lee 1999).

5.5. The Precautionary Principle

What we know, and don't know, about climate change impacts on Washington State involves risk. Under circumstances involving great risk - whether related to climate change or other hazards - a more precautionary approach may be warranted, even if some of the cause and effect relationships are not fully established scientifically (Barrieu and Sinclaire-Desgagné 2006).

The precautionary principle provides flexibility by allowing decision makers to take a more proactive stance on risk reduction. The precautionary principle differs from adaptive management in its inherent acceptance of scientific uncertainty at the outset. The approach asks "how much harm can be averted" rather than "how much harm is allowable" (Seattle Precautionary Principle Working Group 2004).

Washington State has at least two programs that recognize the precautionary principle concept. The Department of Ecology's Persistent Bioaccumulative Toxins (PBT) program explicitly adopted the precautionary principle as one of the policy's ten guiding principles for addressing PBTs (Gallagher 2000). The GMA, previously noted for its suggested use of adaptive management, also suggests a "precautionary or no risk approach" in situations when there is incomplete scientific evidence about whether a development or land use action could harm established critical habitat areas (WAC 365-195-920(1)). However, the language in the statute is advisory language that does not impose any serious mandate on the decision makers.

It is worth emphasizing that the precautionary principle does not necessitate a "zero-risk" or "zero-harm" response (Seattle Precautionary Principle Working Group 2004; Foster et al. 2000). Rather, the approach advocates considering a range of alternatives that balance known and unknown risks against a number of decision criteria, including scientific information, the costs and benefits of the actions (or non-action), and risk tolerance.

5.6. Legislative Flexibility and the Courts

Courts review agencies' interpretations of statutes, promulgation and application of rules and standards, and the constitutionality of agencies' founding and enabling acts. Consequently, courts play an important role in determining the flexibility that state and local agencies have in responding to environmental uncertainty. Legislatures, in turn, can influence how the courts assess the flexibility that agencies have in responding to environmental uncertainty by giving agencies broad enough statutory authority to respond to new contingencies.

Courts have shown a willingness to allow agencies flexibility in the face of uncertainty. For example, in *Postema v. Pollution Control Hearings Board* (142 Wash.2d 68, 91, 11 P.3d 726 (2000)), the Supreme Court of Washington held the Department of Ecology did not need to engage in formal rulemaking in order to apply new standards based on changes in science or technology. The federal precedent cited in *Postema* indicates that courts may give some latitude to agencies responding to evolving circumstances as new contingencies are encountered. However, to help achieve this judicial tolerance of agency flexibility, the legislature must be careful to give an agency broad enough statutory authority to respond to new contingencies.

6. Conclusions

Adapting to climate change will ultimately require more systematic integration of governance levels, science, regulation, policy, and economics to effectively deal with the wide range of impacts projected for Washington State. This integration will be shaped through formal mechanisms such as the development or modification of laws, regulations, and policies, and through legal proceedings in the courts. Integration also will evolve through more subtle changes in institutional culture, channels of communication, and modes of interaction that build trust between government agencies and their stakeholders.

This paper discusses fundamental concepts for planning for climate change and identifies options for adapting to the impacts evaluated in the Washington Assessment. Additionally, the paper highlights potential avenues for increasing flexibility in the policies and regulations used to govern human and natural systems in Washington. The paper should not be viewed as an ending point for the discussion on adaptation needs in Washington State, however. That discussion is, in fact, just beginning.

Areas of future research to support adaptive planning include research on institutional capacity needs and regulatory barriers to adaptation in Washington agencies. Improving institutional capacity to better understand

and incorporate climate change impacts into planning is a “no regrets” strategy that yields benefits regardless of how much warming is realized or whether precipitation decreases or increases, for example. An analysis of institutional capacity should assess how the Department of Ecology and other state agencies might be able to improve institutional capacity for adapting to climate change. This includes looking at:

- specific information needs;
- additional training/skills needs;
- specific regulatory, institutional, or other barriers to addressing climate change impacts; and
- additional coordination needs between departments and agencies, including federal, regional, and local agencies.

Identification of regulatory/policy barriers will be particularly beneficial. From this initial analysis, a series of white papers discussing identified barriers and options for addressing these barriers could be developed.

Additional research on the use of “best available science” in decision making is also suggested. Washington Administrative Code (WAC) 365-195-900–925 (procedural criteria for the Growth Management Act) is the only place where best available science is specifically elaborated upon in Washington law. The WAC is designed to assist local governments in evaluating science and deciding when they are in possession of the best science available. The recurring need for updated information on climate impacts and other related information will place a heavier reliance on the use of best available science in the policies used to govern human and natural systems. An evaluation of the successes and failures in using best available science in programs like the Growth Management Act may provide useful guidance on how to best integrate evolving climate change science into decision making. Finally, additional research on building social capital and the potential application of market mechanisms, conditional permitting, and other mechanisms for increasing flexibility in Washington State policy-making is needed.

Washington State faces unprecedented economic challenges, however. A significant budget deficit looms and deep cuts will be required to balance the state budget. Despite these challenges, preparing for climate change can continue from its important beginnings in the 2007 PAWG process. Many of the actions recommended by the PAWG process as well as others provided within this report require nominal fiscal resources. These include, but are not limited to, identifying and eliminating legal and administrative barriers to planning for climate change; increasing technical capacity within state and local governments to incorporate climate information into decision making; and public outreach and education. Furthermore, many adaptive actions may create cost savings through damage avoidance (e.g., by modifying development plans in areas likely to experience greater flooding) or delayed infrastructure upgrades (e.g., by reducing per capita water use through improve conservation and water use efficiencies). Finally, many of the changes required to develop a more climate-resilient Washington will take time to implement. Waiting for climate change to “arrive” will be too late in some cases and significantly more costly in other cases.

Table 2. Options for adapting to the impacts identified in the Washington Climate Change Impacts Assessment enhancing or supplementing Washington's Preparation/Adaptation Working Group recommendations, released February 2008

Sector	Adaptation Strategy	Examples of Adaptation Actions and Activities that Build Adaptive Capacity
Hydrology and Water Mngmt.	Expand and diversify existing water supplies	• Connect regional water systems to utilize overall water supply more efficiently • Enhance existing groundwater supplies through aquifer storage and recovery • Purchase existing water rights to meet changing supply needs • Add capacity to existing reservoirs by raising dam height
	Develop new or alternate water supplies	• Develop new sustainable groundwater sources • Construct new surface water reservoirs • Develop advanced wastewater treatment capacity for water reuse ("gray water" or "purple pipe") • Implement new technologies such as reverse osmosis for desalination (coastal areas only) • Encourage rainwater harvesting to provide water supply for residential and commercial buildings
	Reduce demand/ improve efficiency	• Increase water conservation measures • Price water to encourage conservation in summer • Reduce outdoor landscape water demands (e.g., promote drought tolerant landscaping) • Update building codes to require highest efficiency plumbing fixtures (e.g. dual flush toilets) • Provide financial incentives (e.g., tax breaks, rebates) for switching to more efficient manufacturing processes, irrigation practices, and appliances • Reduce system losses (repair pipes, line irrigation canals)
	Implement operational changes	• Rebalance flood control rule curves and reservoir refill schedules • Allocate increased storage for instream flow • Improve hydrologic forecasting and use of forecasts • Increase use of optimization in reservoir management to rebalance systems • Shift hydropower generation schedules to emphasize summer energy production • Revise maintenance schedules to conserve water (e.g. seasonal pipe and reservoir flushing schedules) • Use existing flood irrigation systems to recharge soil moisture and groundwater during winter
	Increase ability to transfer water between uses and users	• Use water banks, water pools, and water markets to facilitate the reallocation of water resources in times of shortage • Remove obstacles to flexible water reallocation in existing water law and water policy • Factor in climate change impacts in renegotiations of transboundary water agreements where applicable
	Increase drought preparedness	• Improve drought forecasting capability • Update drought management plans to recognize changing conditions • Increase emergency aid assistance for droughts • Improve coordination between stakeholders during drought
	Reduce winter flood impacts	• Strengthen dikes and levees where appropriate • Increase reservoir storage • Revise flood control rule curves • Restore hydrologic function in floodplains • Improve flood forecasting and emergency management systems • Alter land use policies and flood insurance programs to incorporate the changing risks of extreme events

Table 2. Options for adapting to the impacts identified in the Washington Climate Change Impacts Assessment enhancing or supplementing Washington's Preparation/Adaptation Working Group recommendations, released February 2008

Sector	Adaptation Strategy	Examples of Adaptation Actions and Activities that Build Adaptive Capacity
Energy	Increase energy supply	• Increase the capacity of conventional, alternative, and renewable energy supplies in both winter and summer • Increase local transmission capacity and peaking generation capacity in anticipation of projected increases in peak loads in summer • Increase winter transfers of excess energy capacity in California and the Southwest, where excess capacity is expected to increase with warming. • Implement changes in reservoir management policies to increase hydropower production in summer.
	Decrease energy demand	• Establish more stringent energy efficiency standards for new construction and appliances, including increased state-wide heating and air conditioning efficiency and insulation standards • Implement energy conservation programs • Implement water conservation programs (reduces energy use via reductions in hot water use) • Promote use of high-efficiency heating and air conditioning technologies (e.g., geothermal air conditioning systems) • Promote use of "green roofs" and other strategies to reduce urban cooling loads • Promote the use of renewable energy sources such as solar hot water heating and photovoltaic panels in residential and commercial buildings to reduce summer energy demand and peak loads.
Agriculture	Adjust production to reflect changing conditions	• Change planting dates • Change planting varieties to include crops that are better suited to projected climate conditions • Improve approaches to insect and weed management
	Improve agricultural water supply and use	• Promote new irrigation technologies to improve water use efficiency • Promote water conservation • Use market forces to distribute water • Diversify and expand water supplies and infrastructure
	Improve information and technology used in managing agriculture	• Maintain well-funded monitoring network and information center for data collection on impacts to agriculture • Support research on biotechnology-based breeding to increase the number of crop varieties that are suitable for projected climate conditions • Increase research on automation, sensors, and overall improvement of agricultural management practices to reduce costs and compensate for yield losses
Salmon	Reduce summer stream temperatures and protect (and sustain) minimum instream flows in summer	• Reduce out-of-stream withdrawals during periods of high temperature and low streamflow • Identify and protect thermal refugia provided by groundwater flows, undercut banks, and deep stratified pools • Restore riparian zones that provide shade and complexity for stream habitat • Modify reservoir operating rules to mitigate impacts on summer low flows and water temperature
	Reduce peak winter flows	• Protect and restore off-channel habitat in floodplains • Modify reservoir operating rules to mitigate impacts on winter flooding

Table 2. Options for adapting to the impacts identified in the Washington Climate Change Impacts Assessment enhancing or supplementing Washington's Preparation/Adaptation Working Group recommendations, released February 2008

Sector	Adaptation Strategy	Examples of Adaptation Actions and Activities that Build Adaptive Capacity
Forests	Maintain mixed landscape structure	• Expand or adjust protected areas to incorporate greater diversity of topographic and climatic conditions to allow for shifts in species distributions in response to climate change • Tailor timber harvest or prescribed burning to create a mosaic of patch sizes and age classes • Avoid creating monoculture forests or forests lacking structural diversity (e.g., homogeneous stands or large clearcuts)
	Maintain species diversity and within-species diversity	• Expand or adjust protected areas to incorporate greater diversity of topographic and climatic conditions to allow for shifts in species distributions in response to climate change • Plant tree species or varieties known to have a broad range of environmental tolerances • Reduce potential for invasive species
	Reduce the impact of climatic and non-climatic stressors	• Manage forest density to reduce susceptibility to severe fire, insects outbreaks (whether natives or invasives), and drought, by establishing or enhancing structural prescriptions • Manage forests for changing fire regimes so that the risk of extreme fire events in minimized
	Improve information used in forest management	• Incorporate understanding of elevation-specific climate sensitivities into management strategies • Actively monitor trends in forest conditions, including drought stress, insects, and invasive species
Coasts	Accommodate coastal impacts	• Incorporate climate change impacts into design requirements for coastal structures • Modify flood zone designations to incorporate projected sea level rise • Increase (or initiate) use of setbacks and rolling easements to allow for inland migration of wetlands, salt marshes, and other critical habitat systems, including shallow tidelands used in shellfish production. • Reduce sources of nutrients that contribute to harmful algal blooms (HABs) and increase HAB monitoring to help ensure continued viability of recreational and commercial shellfish harvests
	Protect high value coastal uses	• Construct new dikes/raise existing dikes to protect high-value areas • Increase partnerships across government levels to manage impacts to ports and supporting transportation systems
	Retreat from high-risk coastal areas	• Reduce development on beaches and bluffs likely to be threatened by sea level rise. • Where protection of property is not feasible, abandon coastal sites and move to higher ground
Urban Stormwater Infrastructure	Increase resiliency of stormwater management strategies	• Where long-lived capital projects depend on a specified design capacity, integrate specific design adjustments appropriate for the location of the project, the risk tolerance of the decision maker, and anticipated costs of increasing capacity or volume. • Promote the use of stormwater-management strategies that emphasize the management of stormwater volumes (e.g., Low Impact Development strategies), rather than strategies that that depend on precise determination of rainfall depths and durations (e.g., engineered stormwater detention ponds)

Table 2. Options for adapting to the impacts identified in the Washington Climate Change Impacts Assessment enhancing or supplementing Washington's Preparation/Adaptation Working Group recommendations, released February 2008

Sector	Adaptation Strategy	Examples of Adaptation Actions and Activities that Build Adaptive Capacity
Human Health	Reduce impacts of extreme heat events	• Open additional cooling centers during extreme heat events and improve transportation services to cooling centers for vulnerable populations • Increase public education on risks associated with heat stress and ways to reduce impacts • Improve use of early warning systems for extreme heat events • Increase use of shade trees to reduce temperatures in urban areas • Improve guidelines for providing cooling to outdoor laborers, as well as guidelines for when outdoor work or activities should be postponed or avoided
	Reduce the impacts of ozone/particulate matter pollution	• Increase public education on risks associated with high air pollution and ways to reduce impacts • Improve use of early warning systems for poor air quality days • Increase availability and use of mass transit to reduce auto emissions (e.g., free or reduced public transportation fees on high ozone or high particulate matter days)

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