Preparing for a Changing Climate

Washington State's Integrated Climate Response Strategy

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Executive Summary

Executive Summary

Rising levels of carbon dioxide and other heat-trapping gases have warmed the earth and are already causing wide-ranging impacts, from rising sea levels, to melting snow and ice, to more drought and extreme rainfall. Scientists project that these trends will continue and in some cases accelerate, posing significant risks to human health, our forests, agriculture, freshwater supplies, coastlines, and other natural resources that are vital to Washington State's economy, environment, and our way of life.

By taking action now to respond and adapt to changing climate conditions, Washington can significantly limit the damage and reduce the long-term costs of the climate-related impacts that are expected to grow in number and intensity in the decades to come. If no action is taken, potential costs to Washington from climate change impacts are projected to reach nearly $10 billion per year by 2020 from increased health costs, storm damage, coastal destruction, rising energy costs, increased wildfires, drought, and other impacts.[1]

The Need for Action

Our state and societies around the globe need to reduce greenhouse gas emissions to avoid worsening climate impacts and reduce the risk of creating changes beyond our ability to respond and adapt. Washington State is addressing this challenge and has adopted policies to reduce energy use, limit greenhouse gas emissions, and build a clean energy economy. Some changes in climate—and impacts on our state—are unavoidable, even if we reduce greenhouse gas emissions today.

This document, ***Preparing for a Changing Climate: Washington State's Integrated Climate Change Response Strategy***, lays out a framework to protect our communities, natural resources, and economy from the impacts of climate change and build our capacity to adapt to expected climate changes. It describes how existing and new state policies and programs can better prepare Washington to respond to the impacts of climate change. It calls on state agencies to make climate adaptation a standard part of agency planning and to make scientific information about climate change impacts readily accessible to decision makers in the public and private sectors. It also recommends that state agencies strengthen existing efforts and build partnerships to help local and tribal governments, private and public organizations, and individuals reduce their vulnerability to climate change impacts.

[1] Climate Leadership Initiative (2010).

Washington's Changing Climate and Risks

While Washingtonians have experience dealing with natural weather variability, climate change is moving us beyond a range where past experience can provide a reliable guide for what we might expect in the future.

- **Climate change could have severe consequences to human health** and will likely increase the number of people exposed to illness and injuries due to declining air quality and more frequent and severe heat waves, drought, wildfires, and flooding.

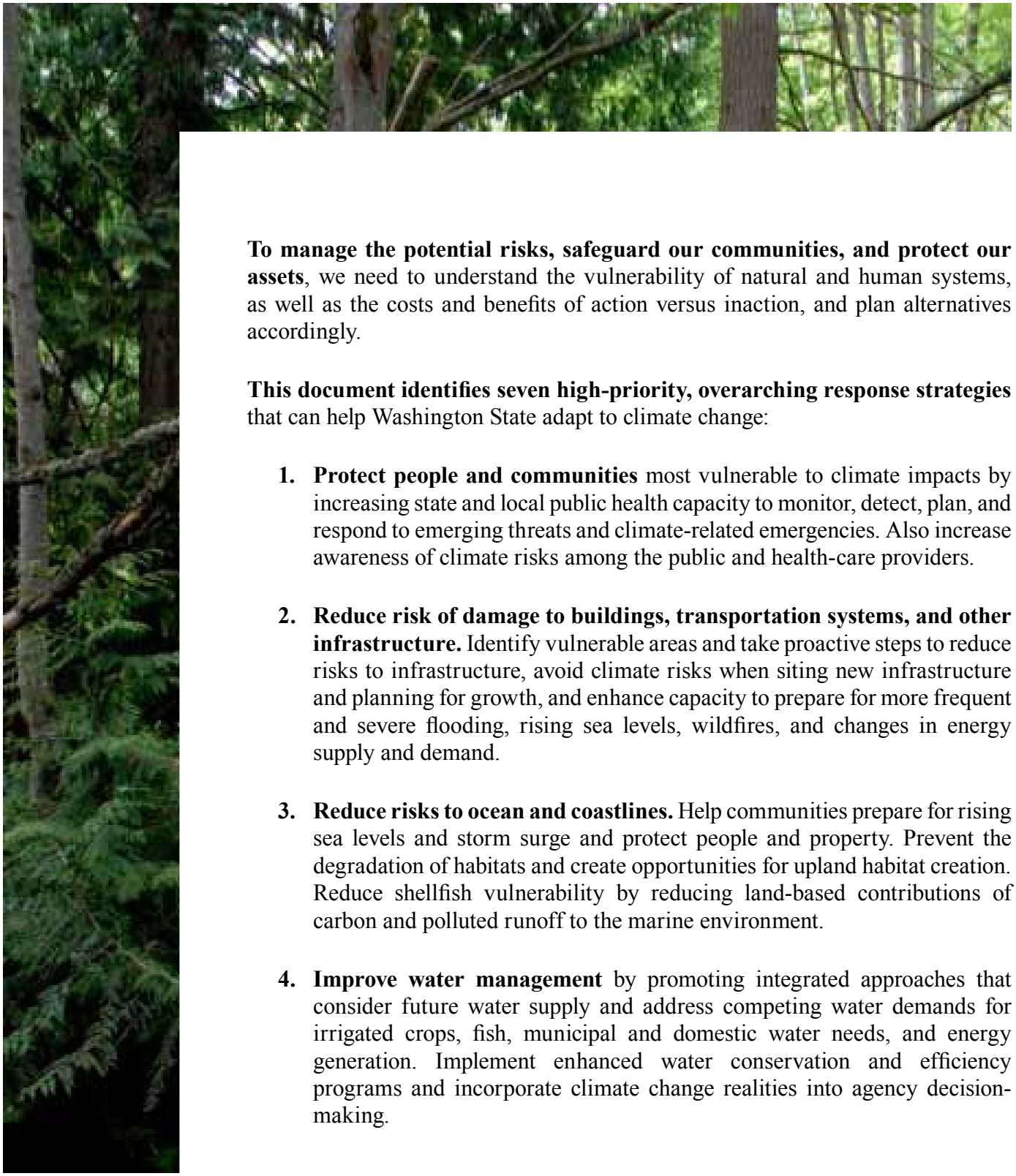
- **Our communities and transportation, energy, and other infrastructure could face increased damage costs and disruptions** from more frequent and severe flooding, wildfires, changes in energy supply and demand, and other climate impacts.

- **Coastal communities and ecosystems could face increased risks from sea level rise and storm surge.** Increasing ocean acidity poses risks to our shellfish industry and could alter the marine food web.

- **The quantity and quality of water available** for communities, irrigation, fish, hydropower generation, recreation, and other uses will be affected by declining snowpack, changes in seasonal streamflow, and increases in summer demand for water.

- **Fish, wildlife, and natural systems** will face increased stress. Climate change will more likely damage and destroy certain types of habitats, increase threats to certain species such as coldwater fish, alter natural patterns such as animal migrations or flower blooms, and alter the presence of pests and invasive species.

- **Washington's farms and forests will be threatened** by increased disease, pests, weeds, and fire, along with reduced summer water supplies. Climate change impacts could affect crop yields and benefit or damage different crops.



To manage the potential risks, safeguard our communities, and protect our assets, we need to understand the vulnerability of natural and human systems, as well as the costs and benefits of action versus inaction, and plan alternatives accordingly.

This document identifies seven high-priority, overarching response strategies that can help Washington State adapt to climate change:

1. **Protect people and communities** most vulnerable to climate impacts by increasing state and local public health capacity to monitor, detect, plan, and respond to emerging threats and climate-related emergencies. Also increase awareness of climate risks among the public and health-care providers.

2. **Reduce risk of damage to buildings, transportation systems, and other infrastructure.** Identify vulnerable areas and take proactive steps to reduce risks to infrastructure, avoid climate risks when siting new infrastructure and planning for growth, and enhance capacity to prepare for more frequent and severe flooding, rising sea levels, wildfires, and changes in energy supply and demand.

3. **Reduce risks to ocean and coastlines.** Help communities prepare for rising sea levels and storm surge and protect people and property. Prevent the degradation of habitats and create opportunities for upland habitat creation. Reduce shellfish vulnerability by reducing land-based contributions of carbon and polluted runoff to the marine environment.

4. **Improve water management** by promoting integrated approaches that consider future water supply and address competing water demands for irrigated crops, fish, municipal and domestic water needs, and energy generation. Implement enhanced water conservation and efficiency programs and incorporate climate change realities into agency decision-making.

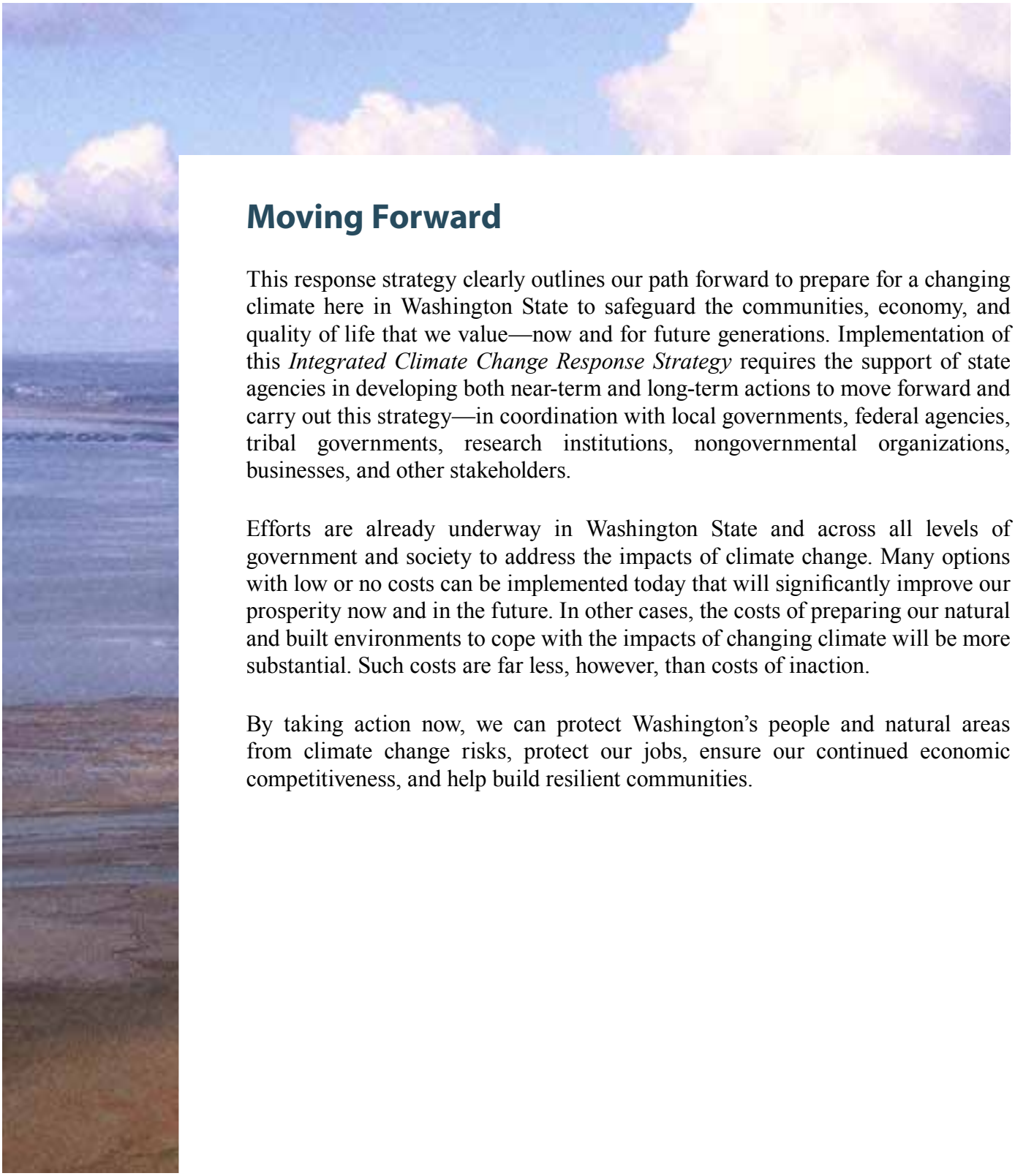
5. **Reduce forest and agriculture vulnerability** by enhancing surveillance of pests and disease. Promote and transition to species that are resilient to changing climate conditions, conserve productive and adaptive forest and farmland, and reduce forest and wildland fire risk in vulnerable areas.

6. **Safeguard fish, wildlife, habitat, and ecosystems** and improve the ability of wildlife to migrate to more suitable habitat as the climate shifts. Protect and restore habitat and sensitive and vulnerable species. Reduce existing stresses from development, pollution, unsustainable harvest, and other factors.

7. **Support the efforts of local communities and strengthen capacity to respond and engage the public.** Identify existing and new funding mechanisms to support adaptation work at the local level, and ensure a coordinated and integrated approach among levels of government and society. Support research and monitoring and ensure scientific information is accessible and responds to needs of decision-makers.

The response strategy describes these overarching strategies and presents additional strategies and actions in the following areas:

- Human health
- Ecosystems, species, and habitats
- Ocean and coastlines
- Water resources
- Agriculture
- Forests
- Infrastructure and the built environment
- Research and monitoring
- Climate communication, public awareness, and engagement



Moving Forward

This response strategy clearly outlines our path forward to prepare for a changing climate here in Washington State to safeguard the communities, economy, and quality of life that we value—now and for future generations. Implementation of this *Integrated Climate Change Response Strategy* requires the support of state agencies in developing both near-term and long-term actions to move forward and carry out this strategy—in coordination with local governments, federal agencies, tribal governments, research institutions, nongovernmental organizations, businesses, and other stakeholders.

Efforts are already underway in Washington State and across all levels of government and society to address the impacts of climate change. Many options with low or no costs can be implemented today that will significantly improve our prosperity now and in the future. In other cases, the costs of preparing our natural and built environments to cope with the impacts of changing climate will be more substantial. Such costs are far less, however, than costs of inaction.

By taking action now, we can protect Washington's people and natural areas from climate change risks, protect our jobs, ensure our continued economic competitiveness, and help build resilient communities.

1. Introduction

1. Introduction

Rising levels of carbon dioxide and other heat-trapping gases have warmed the earth and are already causing wide-ranging impacts, from rising sea levels to melting snow and ice to more drought and extreme rainfall. Scientists project that these trends will continue and in some cases accelerate, posing significant risks to human health, our forests, agriculture, freshwater supplies, coastlines, and other natural resources that are vital for our economy and the environment.

To avoid significant climate impacts and reduce the risk of creating impacts beyond our ability to respond and adapt, Washington State and societies around the globe need to reduce greenhouse gas emissions. Washington State is addressing this challenge and has adopted a portfolio of policies to reduce energy use, meet statutory greenhouse gas limits, and build a clean energy economy. This approach is summarized in the 2010 report to the Legislature, *Path to a Low-Carbon Economy—An Interim Plan to Address Washington's Greenhouse Gas Emissions*.[2] More work is needed to get the state on track to meet its statutory greenhouse gas limits for 2020 and beyond.

Some changes in climate are unavoidable even if greenhouse gas emissions are reduced. Climate impacts will likely be experienced through incremental changes in temperature and precipitation and through more frequent and destructive disaster events, such as catastrophic floods, wildfires, or coastal storms. In many cases, climate-related impacts will combine with existing stressors to increase harm to people, communities, infrastructure, economic activity, and natural resources. Both incremental changes and catastrophic events will be costly and will have direct implications for the health and welfare of our state. The state can significantly reduce the risks to our communities, economy, and the environment by taking action now to respond and adapt to changing climate conditions.

Guiding principles for Washington's climate change response strategy:

- Use best-available science.
- Build on principles of sustainability.
- Increase our resilience and protect the most vulnerable populations.
- Ensure integrated approaches that maximize mutual benefits and avoid unintended consequences.
- Emphasize collaboration and strengthen partnerships.
- Recognize the impacts of decisions made by other regions and countries.

[2] 2010 Comprehensive Plan, available at *http://www.ecy.wa.gov/climatechange/2010CompPlan.htm*.

Purpose of Response Strategy

In recognition of Washington's vulnerability to climate change impacts, the Washington State Legislature directed state agencies to develop this **integrated climate change response strategy** to enable state and local agencies, public and private businesses, nongovernmental organizations, and individuals to prepare for, address, and adapt to the impacts of climate change.[3] Governor Gregoire's May 2009 executive order reinforced this requirement, directing the Department of Ecology (Ecology) to collaborate with affected local, state, and federal agencies to develop recommendations, guidelines, and tools to address the impacts of sea level rise and changes in water resources.[4]

This document, *Preparing for a Changing Climate: Washington State's Integrated Climate Change Response Strategy,* satisfies these requirements. It offers recommendations on how existing state policies and programs can better prepare Washington State to respond to the impacts of climate change. It urges state agencies to make adaptation a standard part of agency planning and to make scientific information about climate change impacts accessible to public and private-sector decision makers. It also recommends that state agencies strengthen existing efforts to help local and tribal governments, private and public organizations, and individuals reduce their vulnerability to climate change. The response strategy underscores the need to build strong partnerships to support state, local, and tribal adaptation; coordinate activities across sectors; and engage stakeholders and the public.

Ecology prepared this response strategy in collaboration with the state departments of Agriculture, Commerce, Fish and Wildlife, Health, Natural Resources, and Transportation. A broad range of stakeholders with policy, management, and scientific expertise participated in four advisory groups and developed a set of recommendations for near- and long-term actions to prepare Washington for a changing climate. (See Appendix A for advisory group members and Appendix B for advisory group recommendations.) This response strategy builds on, summarizes, and integrates the recommendations of the four advisory groups. It also draws on the best available science on the impacts of climate change on Washington from the *Washington Climate Change Impacts Assessment* and other key sources, as well as Washington's initial adaptation plan developed in 2008 under Executive Order 07-02.[5]

[3] 2009 legislative mandate set in the State Agency Climate Leadership Act, *Senate Bill 5560*, codified in *RCW 43.21M.010-040*.

[4] Executive Order 09-05, *http://www.ecy.wa.gov/climatechange/2009EO.htm*.

[5] Climate Impacts Group (2009), available at *http://cses.washington.edu/cig/res/ia/waccia.shtml#report*. Leading the Way: Preparing for the Impacts of Climate Change in Washington, *http://www.ecy.wa.gov/pubs/0801008c.pdf*.

Response Strategy Outline

Chapter 2 of this response strategy identifies key climate risks and recommends a set of priority strategies to prepare for the impacts of climate change. The chapter outlines steps for agencies to make climate adaptation a standard part of agency planning efforts, programs, services, and operations. It also recommends major policies and programs that state and local governments can use to minimize climate-related risks and build resilience to climate impacts.

Chapter 3 summarizes the observed and projected changes in climate and the key risks for Washington's communities, economy, and the environment.

Chapters 4 through 10 of the response strategy lay out key climate impacts and priority response strategies for seven key sectors:

Chapter 4.	Human Health
Chapter 5.	Ecosystems, Species, and Habitats
Chapter 6.	Ocean and Coastlines
Chapter 7.	Water Resources
Chapter 8.	Agriculture
Chapter 9.	Forests
Chapter 10.	Infrastructure and the Built Environment

Chapters 11 and 12 of the response strategy outline recommendations to advance research and monitoring, raise awareness, engage the public, and build support for meaningful action.

2. Responding to Climate Change

2. Responding to Climate Change

Climate change will affect different regions, ecosystems, and sectors of the state's economy in many different ways, depending on the sensitivity of those systems to climate change, their ability to adapt to changing conditions, and the ability to manage associated risks. While the state and local communities have experience dealing with natural variability, climate change is moving us beyond a range where past experience is a good guide for what we might experience in the future. Climate-influenced conditions and events such as temperatures, sea levels, and storms can no longer be expected to remain within their historical ranges, and these trends are likely to continue well beyond the end of the 21st century.

Our state is already experiencing challenging economic conditions. The risks of not taking action to address climate change impacts now will only compound these economic challenges. In one study, potential costs to Washington from climate change impacts are projected to reach nearly $10 billion per year by 2020 and $16 billion per year by 2040.[6] These totals reflect increased coastal and storm damage costs, increased energy-related costs (reduced hydropower production and increased demand), increased wildfire costs, increased health-related costs, costs associated with reduced water availability, and other impacts.

Key climate-related risks include:

Increased injuries and disease. Increased injuries, sickness, and even deaths are expected from infectious diseases, heat stroke, and respiratory and cardiovascular disease due to higher temperatures, heat waves, declining urban air quality, and smoke from more frequent wildfires. More frequent extreme storms are likely to cause river and coastal flooding, leading to increased injuries and loss of life. These impacts come at a time when local and state funding for public health is rapidly eroding, and health costs are increasing.

Increased damage costs and disruptions to communities, transportation systems, and other infrastructure. Communities, infrastructure, and key economic sectors could all incur significant costs due to climate change. Damage and repair costs are projected to increase for Washington's roads, bridges, ports, rail, power and communication transmission systems, and communities due to extreme storms, flooding, erosion, landslides, sea level rise, and storm surges. Problems have already started. Interstate 5 in Washington's Chehalis Basin has been closed four times since 1990 due to flooding. The December 2007 storm caused approximately $23 million in damage to interstate and state highways in Washington as well as $39 million in damages to city and county roads. The I-5 closure resulted in $47 million in

[6] Climate Leadership Initiative (2010).

lost economic output to the state.[7] In Puget Sound counties, structures valued at approximately $29 billion are located in flood hazard areas, placing them at risk of flood damage. Ports, rail, highways, wastewater treatment plants, and other coastal infrastructure could require costly retrofits or relocation to accommodate rising sea levels and stronger coastal storms.

Reduced water supply. Washington's snowpack has historically held more than 6 trillion gallons of water. Increasing temperatures will significantly impact snowpack in the Cascade and Olympic Mountains, leading to reduced streamflows, reduced soil moisture, higher stream temperatures, and concerns for all water users, including agriculture, municipalities, and fish and wildlife. As temperatures rise, water demand increases, as does the potential for conflict among water users. At highest risk are agricultural water users in the Yakima and Columbia basins, along with coldwater fish species such as salmon, steelhead, and bull trout.

Loss of fish, wildlife, and natural systems. Climate change is projected to cause loss of habitat and force many species to move northward or higher in elevation. Species that cannot transition quickly enough will likely perish. Higher summer stream temperatures and reduced flow are projected to increase lethal stream conditions for salmon and other coldwater species. [8]Increased forest fires will destroy important habitat areas, leading to erosion and degraded water quality. Sea level rise is projected to eliminate valuable coastal habitats, and increased acidity in marine waters from carbon dioxide emissions and upland runoff is threatening the aquaculture and shellfish industry. Washington leads the country in production of farmed clams, oysters, and mussels with an annual value of over $107 million.[9] Wildlife recreation in Washington is a $4.5 billion industry responsible for more than 60,000 jobs in the state.[10]

Losses to agriculture and forest industries. Agriculture and forestry industries together contribute $50 billion annually to the state's economy. Increased disease, pests, weeds, and fire, along with reduced summer water supplies, are already affecting Washington's farms and forests. Many operations are experiencing higher costs and lower yields. Pests such as mountain pine beetle, potato tuber moths, and gypsy moths can now proliferate in Washington under warmer conditions. The area burned each year by forest fires in the Columbia River Basin is projected to double or triple by the 2080s. The average production of apples and cherries could decline by approximately $23 million per year by 2020.[11]

[7] Washington State Department of Transportation (2008a and 2008b).
[8] Mantua *et al*. (2010).
[9] Northern Economics, Inc. (2010).
[10] Washington Department of Fish and Wildlife (2011).
[11] Stöckle *et al*. (2010).

Priority Response Strategies

We know enough about future climate to understand the major risks, and many actions can be implemented now, at minimal budgetary cost, to reduce current risks and greatly reduce the need for costly actions in the future. Flexible approaches are needed that respond to risks and also recognize the range of the timing and degree of change as well as how people, wildlife, plants, and other systems will respond to these changes. In many cases, our existing laws and policies are the right vehicles for addressing the climate challenge with minor adjustments. In other cases, new policies will be necessary.

Responding to climate change impacts is typically referred to as "adaptation." Adaptation refers to taking steps to reduce the vulnerability of human and natural systems, increase the capacity to withstand or cope with changes in climate, and transform the system so that it is more compatible with likely future conditions. Many adaptation strategies are considered "no regrets" strategies because they help address existing stresses on our communities, economy, and environment from flooding, pests and diseases, wildfires, water shortages, and other variables while also reducing climate-related risks. "No regrets" climate adaptation actions can help advance priority goals that are beneficial to Washington State, including sustainable growth, public health, and economic competitiveness.

Seven overarching high-priority climate change response strategies identified for Washington are:

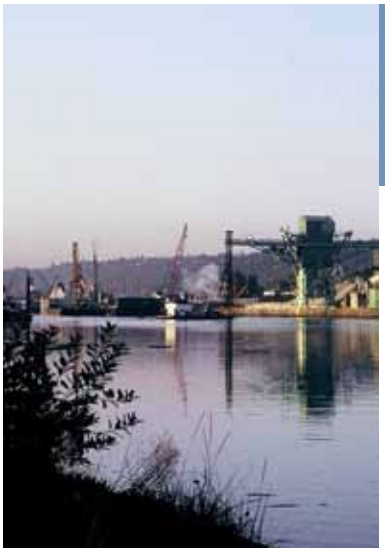
- Protect people and communities.
- Reduce risk of damage to buildings, transportation systems, and other infrastructure.
- Reduce forest and agriculture vulnerability.
- Improve water management.
- Safeguard fish, wildlife, habitat, and ecosystems.
- Reduce risks to ocean and coastlines.
- Support the efforts of local communities and strengthen capacity to respond and engage the public.

The following section describes these strategies in more detail. (See Appendix C for a complete list of strategies and actions.)

1. Protect people and communities from climate change impacts.

Enhance core public health capacity. Core public health capacity will need to be enhanced to increase surveillance, early detection, and response capabilities. Public health agencies should prepare to monitor and respond to diseases and carriers typically found in warmer climates, such as Rocky Mountain spotted fever, tularemia, and Lyme disease. Vulnerable and at-risk communities should be identified, especially for infectious diseases, heat stroke, and respiratory and cardiovascular disease caused by higher temperatures, heat waves, and smoke from more frequent wildfires. Public health agencies should raise awareness of new public health risks from climate change among health providers, health organizations, and the public.

Enhance emergency response capacity to address increasingly extreme floods and fires. State and local emergency response needs are expected to increase in flood- and fire-prone areas of the state. Police, fire and rescue, and wildland firefighting will have to prepare for increased activity, more challenging conditions, and additional costs. Populations that are vulnerable to increased incidence of floods and fires should be identified and educated about the increased risks, options to reduce risks, and appropriate responses in an emergency.



2. Reduce risk of damage to buildings, transportation systems, and other infrastructure.

Reduce flood damage by restoring floodplains and capturing more water. As extreme storms increase, the most effective and least costly approach to managing larger floodwaters is often to enhance floodplains' ability to accommodate flood flows and using "green infrastructure" approaches to manage stormwater. Reconnecting rivers with their floodplains and providing rivers room to flow often reduces downstream flood risks and damage. Natural approaches such as wetlands and soft armoring tend to be more environmentally beneficial than levees, dams, and other "hard" approaches to flood management.

Support local efforts to prepare for coastal flooding and storm surges. Provide information, guidelines, and technical support to coastal counties, cities, and tribes to help them evaluate the risks and vulnerability to sea level rise and coastal flooding in their communities. Roads, bridges, wastewater treatment plants, sewer and stormwater systems, gas and electric transmission

systems, communication systems, and other infrastructure could be at risk. Communities should consider options to reduce vulnerabilities without harming ecosystem functions.

Consider climate change impacts when siting new development and infrastructure. Consider future climate change risks when planning for new growth or permitting new structures, even if the location is not currently in FEMA's regulatory floodplain or other critical areas designation. Ensure the building design can accommodate projected impacts and does not increase risks for neighbors.

Plan for relocation if structures are damaged by floods or other impacts. If critical structures are at risk, communities should begin now to identify safer alternative locations for those structures. This will help prevent the typical response to rebuild structures in the same flood-prone location after the disaster.

3. Reduce forest and agriculture vulnerability to climate change impacts.

Enhance surveillance and eradication of pests and disease. Pests and disease can cause significant damage and economic losses, and these problems are projected to increase as the climate warms. Surveillance can identify new outbreaks and promote rapid response that will reduce damage and costs. These efforts should be coordinated among federal, state, tribal, and local agencies.

Promote identification of and transition to plant species that are resilient to new climate conditions. Support research and promote genetic diversity to ensure that agricultural and forest species living in Washington are able to survive under current and future climate conditions and emerging pests and diseases.

Conserve productive and adaptive farmland and forests. Encourage local governments to adopt land use regulations and incentives to minimize conversion of farmland and forests and to support land conservation incentive programs.

Reduce forest and wildland fire risk in highly vulnerable areas. Integrate wildfire management objectives with forest, shrub-steppe and grassland restoration objectives to enhance ecosystem health and resilience from pests, diseases, and invasive species that exacerbate fire risk.

4. Improve water management to address climate-related supply reductions.

Promote integrated water management in vulnerable basins. Projected changes in streamflow and runoff patterns will more likely increase the competition and conflicts among water users. Integrated water management will address existing and future water resources and ecosystem problems affecting fish habitat and agriculture, municipal, and domestic water supplies. This approach supports flexibility and adaptability under changing hydrological conditions. Models for this work include the water management efforts in the Columbia, Yakima, and Walla Walla basins.

Implement enhanced water conservation and efficiency programs. Reduce water demand, especially in water-limited basins, by monitoring water use and aggressively promoting and supporting water conservation and efficiency for agricultural, municipal, and industrial users.

Ensure sufficient cold water in salmon-bearing streams during critical seasons. Increasing stream temperatures can create barriers to migration and can kill coldwater fish such as salmon, steelhead, and bull trout. Shade, increased streamflow, and other measures can keep water temperatures cool and allow rivers to continue supporting coldwater fisheries.

Incorporate climate change realities into agency decision-making. Past hydrological data are an unreliable guide to project future conditions for water management decisions. Water resources managers will need to adapt their management and planning practice to reflect changing water availability. They need to take into account the change in timing and availability of water when planning for additional supplies, deciding whether water users may use their water rights for the amount allowed, and establishing instream flows for fish habitat and ecological purposes.

5. Safeguard fish and wildlife and protect critical ecosystem services that support human and natural systems.

Protect and restore habitat and improve the ability of species to migrate to more suitable habitat as the climate shifts. Identify and protect areas most suitable for current and future habitat as well as the connections between habitats. Land use planning policies, guidance, technical assistance, and incentive programs are effective ways for protecting, restoring, and acquiring habitat areas that provide refuge to species under stress from climate change.

Protect sensitive and vulnerable species and their habitats. Climate change will increase the stress on salmon and other culturally important species that are already sensitive or vulnerable. Climate risks and approaches to recover and protect vulnerable species should be incorporated into management and conservation plans and programs. This planning includes species recovery and management plans, water resources management plans, shoreline management plans, land use plans, and ocean management plans.

Reduce existing stresses on fish, wildlife, plants, and ecosystems. Fish, wildlife, plants, and ecosystems already face an array of existing stresses from human development, habitat loss and degradation, pollution, unsustainable harvest, and invasive species. Reducing existing threats is an important and effective way to help natural systems cope with the additional pressures from a changing climate. For example, reducing stormwater pollution improves water quality and aquatic habitat, increasing the resilience of aquatic species to additional stresses from climate change.

6. Reduce the vulnerability of coastal communities, habitat, and species.

Protect people, property, and infrastructure from coastal hazards and avoid new development in highly vulnerable areas. Rising sea levels, more extreme rainfall, and excessive runoff may increase risks to people, property, and infrastructure from coastal erosion and flooding. Communities should identify vulnerable areas and take steps to reduce threats, while also prioritizing actions that protect habitat and natural areas. Risks to coastal communities should be incorporated into land use and shoreline management plans, and regulatory tools, incentives, and technical assistance should be expanded or developed to incorporate climate risks.

Prevent coastal habitat degradation and destruction and seek opportunities for upland habitat creation as sea levels rise. Rising sea levels will cause a loss of valuable coastal habitats. As coastal flood risk increases, landowners should use natural approaches to reduce flood risks without harming species or habitat. Policies and incentives should be developed at the state or local level to reduce habitat degradation and destruction from hard armoring of coastlines. Incentives and regulatory tools should be modified or developed to guide development away from hazardous coastal areas to prevent costly flooding and to allow coastal ecosystems to be created in newly inundated areas.

Reduce shellfish vulnerability to ocean acidification by reducing land-based contributions of carbon and polluted runoff to the marine environment. Acidification is caused by both atmospheric carbon dioxide and land-based contributions of carbon from sources such as polluted runoff and leaking septic systems. While atmospheric carbon dioxide contributions can only be slowed by reducing carbon emissions, the pace of acidification in some parts of Puget Sound can be reduced by eliminating polluted runoff, leaking septic systems, and other sources of land-based carbon in the waters.

7. Support the efforts of local communities and strengthen capacity to respond and engage the public.

Identify existing and new funding mechanisms to support adaptation work at the local level. In some cases, climate adaptation can be integrated into existing programs with little or no cost or additional resources. In many cases, the cost of making changes and actively managing natural and built environments to cope with the impacts of changing climate may be substantial. However, these costs are far less than costs of inaction. State agencies should leverage existing federal and state funding as well as seek new sources of funding to implement high-priority adaptation projects at the state and local levels.

Develop an institutional structure to improve coordination and support an integrated approach. Successful climate change adaptation cannot be accomplished by a single agency or organization. An effective structure is needed to support cross-agency collaboration, ensure implementation of cross-cutting strategies, and link efforts across all governmental agencies, nongovernmental organizations, and other interests. An improved coordination mechanism is needed to determine and provide state input on research needs and priorities, develop mechanisms to track and monitor progress in implementing the strategies and actions, and ensure new information on climate impacts and effective responses is integrated.

Support information-gathering on climate impacts and ensure scientific information is easily accessible. Understanding of climate impacts and responses is growing rapidly and is continually being expanded. Tracking climate-related trends such as sea level rise, severe storms, and pest and disease invasions can help the state prepare and respond with the least cost and disruption. Tools need to be developed to make this information accessible and useful to the public and to decision makers at all levels.

Engage the public in determining appropriate responses to climate change. The state must provide leadership to ensure that communities, businesses, schools, and the public have accurate information and a forum to consider climate impacts and responses. Agencies should develop consistent messages, provide access to relevant information, and work with partners, stakeholders, and others to identify concerns and prioritize responses.

State Agency Climate Adaptation Planning

State government has an important role in responding to climate impacts. The Washington State Legislature mandated state agencies to lead by example in planning for and responding to the impacts of climate change:

> *State agencies shall strive to incorporate adaptation plans of action as priority activities when planning or designing agency policies and programs. Agencies shall consider: The integrated climate change response strategy when designing, planning, and funding infrastructure projects; and incorporating natural resource adaptation actions and alternative energy sources when designing and planning infrastructure projects.*[12]

This climate change response strategy establishes a framework for state action. The actions identified are broad and do not address who, when, and where to implement actions. Action plans with near- and long-term steps to implement the strategies and the broad actions should be developed by various lead agencies. In many cases, the advisory group reports identify more specific near-term actions that could be included in future action plans.

To advance the goals in the response strategy, the Department of Ecology should work with other key agencies to implement the response strategy and ensure that adaptation is integrated into agency policies, programs, and funding programs. Guidelines and information are needed to:

1. Educate agency leadership and staff on climate impacts and assess how climate change will affect their operations, services, and critical assets managed or owned by the agency, such as highways, forests, agricultural and habitat lands, water resources, and buildings.

2. Evaluate agency operations and programs, including existing enabling legislation, through a "climate lens," to determine what activities need to be adjusted to take into account climate variability and changes. This evaluation should consider such questions as the following:
   - *Is the policy, program, or investment sensitive to current and future changes in climate, such as observed or projected temperature, precipitation, streamflow, sea level, storms, or water quality?*
   - *Will climate impacts alter the effectiveness of the existing plan, policy, program, or project?*
   - *What is the level of risk and vulnerability to climate impacts?*
   - *Are adjustments or modifications needed to account for climate impacts and to help achieve the intended objectives?*

[12] Codified in RCW 43.21M.040.

3. Incorporate climate impacts and response into programs or projects managed by local governments and organizations that receive funding or are regulated by state government, and build local capacity to address climate change.

4. Develop a plan for near- and long-term actions to implement this response strategy.

Barriers Limiting an Effective Response to Climate Change

1. Inadequate information and experience.

- Outdated assumptions that future conditions will vary within historic bounds.
- Limited knowledge and experience in dealing with climate-related risks.
- Limited knowledge of effective response strategies.
- Lack of tools, maps, and guidance for communities to identify risks, assess vulnerability, and account for ranges of variability.
- Limited stakeholder awareness and engagement.

2. Inadequate institutional support for adaptation.

- Short-term perspectives and tendency to focus on near-term risks and benefits.
- Conflicting mandates and incentives.
- Fragmented decision-making and lack of coordination across levels of government and between governments.
- Legal barriers.

3. Lack of resources.

- Insufficient financial resources.
- Lack of human resources.
- Limited information on costs and benefits of climate change response strategies.

4. Public beliefs and attitudes.

- Skepticism about the science of climate change.
- Lack of understanding of the difference between weather and climate.
- Climate science is sometimes described in abstract technical terms that do not resonate.
- Lack of awareness of the near- and long-term risks of climate change and the benefits of acting.

Current Legal Framework for Climate Change Adaptation

We have a broad set of state, local, and federal laws that may be used to reduce risks of climate change on natural and human systems. This section highlights current statutory programs that can provide policymakers a solid foundation to address and reduce the impacts of climate change, though it is not a complete list.

State Comprehensive Emergency Management Plan and the State Hazard Mitigation Plan. RCW 38.52 requires that each political subdivision has a comprehensive emergency management plan that is based on the hazards the community faces. These plans are reviewed at the local level and updated at least every four years. Each of the plans is submitted to the state emergency management division for review to ensure consistency with the State Comprehensive Emergency Management Plan (CEMP). The CEMP, along with the State Hazard Mitigation Plan and its foundation document, the Hazard Inventory and Vulnerability Analysis, are the right vehicles to integrate and address climate risks and hazards.

Growth Management Act. The Growth Management Act's (GMA) policy foundation to control sprawl, protect our infrastructure investments, and conserve and protect our natural environment makes it central to planning for and reducing climate change impacts. Under the GMA, every county, city, and town is required to protect critical areas, including critical aquifer recharge areas, fish and wildlife habitat conservation areas, frequently flooded areas, geologically hazardous areas, and wetlands. Many local jurisdictions have been implementing a range of policies, programs, and regulations aimed at slowing down the impact of climate change on their communities.

Shoreline Management Act and Shoreline Master Programs. The Shoreline Management Act focuses on three basic policy areas: shoreline use, environmental protection, and public access. Local governments and Ecology work in partnership to develop Shoreline Master Programs for managing shorelines and help protect and restore important habitats, keep water clean, protect properties, and provide recreational opportunities to Washingtonians. This program continues to evaluate options to plan for storm surge, coastal flooding, and sea level rise. In 2010, Ecology released voluntary guidance for local governments on how to incorporate sea level rise into Shoreline Master Program updates.

Federal climate adaptation initiatives

In 2009, the Obama Administration convened the Interagency Climate Change Adaptation Task Force to develop recommendations on how federal policies, programs, and planning efforts can better prepare the United States for climate change. The Task Force released a set of recommended actions in support of a national climate change adaptation strategy in 2010, and federal agencies are currently working to implement several cross-cutting national strategies:

- National Action Plan for managing freshwater resources in a changing climate.
- National Ocean Policy Implementation Plan, which includes a series of actions to address resiliency and adaptation to climate change and ocean acidification.
- National Fish, Wildlife & Plants Climate Adaptation Strategy.

More information on federal implementation of the national adaptation strategy is available from:
www.whitehouse.gov/administration/eop/ceq/initiatives/adaptation/evolving-components

Federal agencies are also developing agency-specific plans to strengthen existing adaptation efforts and establish long-term priorities to respond to the challenges and opportunities that climate change poses to their missions, operations, and programs. By June 2012, under Executive Order 13514, agencies will submit their climate adaptation plans to the White House Council on Environmental Quality and the Office of Management and Budget.

For more information, see the Agency Climate Change Adaptation Planning section on CEQ's website:
www.whitehouse.gov/administration/eop/ceq/initiatives/adaptation

For more information and background on the U.S. response to climate change, see the America's Climate Choices reports developed by the National Academy of Sciences:
http://nas-sites.org/americasclimatechoices/

Coastal Zone Management Act. The Coastal Zone Management program is a voluntary state/federal partnership that encourages states to adopt their own management programs to meet the federal goals of protection, restoration, and appropriate development of coastal zone resources. Through the Department of Ecology, Washington State participates in the nationwide Coastal Zone Management (CZM) Program. Washington's CZM Program strives to preserve and protect coastal resources in the state. It sets up estuarine reserves that are jointly managed by the state and federal governments.

Watershed Planning Act. In 1998, the Washington State Legislature enacted a statewide Watershed Planning Program to encourage comprehensive, long-range water resource planning through voluntary collaborative efforts at the watershed level. Because of its statewide scope, high levels of support and participation, and its collaborative nature, the watershed planning program presents a useful vehicle for adaptation to impacts of climate change. Several of the planning groups have discussed the potential impacts of climate variability and change, and some have included these impacts in the technical assessments required for each watershed.

State Environmental Policy Act. The State Environmental Policy Act (SEPA) is intended to ensure that environmental factors are considered during decision-making by state and local agencies to encourage the development of environmentally sound proposals. SEPA requires the identification and evaluation of probable impacts for all elements of the environment and the development of mitigation measures that will reduce adverse environmental impacts.

Floodplain Management Act. The Floodplain Management Act requires the State to plan and prepare for flood hazards to improve public safety and prevent damages to property and infrastructure. Ecology partners with local governments to implement the act.

Clean Water Act and Water Pollution Act. The federal Clean Water Act requires the State to identify sources of pollution in waters that fail to meet state water quality standards (e.g., temperature) and to develop water quality improvement reports (including Total Maximum Daily Loads, or TMDLs) to address those pollutants. TMDLs establish limits on pollutants that can be discharged to the water body and still allow state standards to be met. Washington already has a significant number of water bodies, marine sediments, and groundwater polluted by an array of

pollutants. Regulatory tools—including water quality standards, National Pollution Discharge Elimination System (NPDES) permits, and section 401 water quality certification—as well as non-regulatory tools (such as Water Quality Financial Assistance) exist to clean up polluted waters, control stormwater pollution, prevent point source water pollution, and reduce nonpoint source water pollution.

Forest Insect and Disease Control Act (RCW 76.06). The law's primary goal is to expand and improve forest health problem detection, distribution of information and technical assistance to landowners, as well as coordination between all landowners. The law offers consultation regarding sources of risk to landowners such as insect infestations, diseases, tree overcrowding, and weather damage. The Department of Natural Resources (DNR) is responsible for implementation of the law. DNR monitors forest health to record the extent of insect and disease damage and gain advanced warning of outbreaks by certain pests.

Water resources laws. Several state water laws and programs are aimed at improving water management by seeking out new water supplies for both instream and out-of-stream uses; funding and incentivizing conservation, water use efficiency, reclaimed water, and shallow aquifer recharge; and enhancing water resources data and information.

Laws providing incentives. Several state and federal laws and programs are dedicated to ensuring protection for our state's forests, farmland, and aquatic resources; acquiring land to protect wildlife and ecosystems; and providing incentives for private landowner conservation. Specific examples include but not limited to the following:

- Washington Wildlife and Recreation Program
- Estuary Salmon Restoration Program
- Conservation Reserve Program
- Conservation Reserve Enhancement Program
- Forest Legacy Program
- Farmland Preservation Program
- Wetland Reserve Program
- Grassland Reserve Program

3. Observed Trends and Future Projections



3. Observed Trends and Future Projections

Climate change is pushing temperature and many climate-influenced conditions and events beyond their historical ranges. In Washington State, we are already experiencing trends that are consistent with a warming climate, from warmer temperatures to rising sea levels to melting snow and ice to more drought and extreme rainfall. (See Appendix D for a summary of Pacific Northwest climate change impacts.) Scientists project that these trends will continue and in some cases accelerate, posing significant risks to human health, our forests, agriculture, freshwater supplies, coastlines, and other natural resources that are vital for our economy and the environment.

Nine key indicators and projections of climate change affecting Washington State are discussed in more detail below:

- Increasing carbon dioxide levels.
- Warmer air temperatures.
- Drier summers and reduced snowfall.
- More frequent and severe extreme weather events.
- Rising sea levels.
- More acidic marine waters.
- Warmer water temperatures.
- Increasing frequency and severity of wildfires.
- Increasing frequency and severity of flooding.

Scientific projections of future climate in the Pacific Northwest

The Washington Climate Change Impacts Assessment reported scientific projections of future climate for the Pacific Northwest and assessed the potential consequences for eight key ecological and economic sectors. The assessment projects future climate for the Pacific Northwest using two scenarios of future greenhouse gas (GHG) emissions.

The scenarios provide plausible examples of what might happen given different assumptions about future technology, population growth, economic development, and other factors affecting greenhouse gas emissions. Scenarios can help us understand the likely range of future impacts and our vulnerability to climate change.

The **"A1B"** scenario represents a moderate GHG emissions scenario where global GHG emissions rise sharply until mid-century and slowly decline to the end of the century.

The **"B1"** scenario reflects a low emissions scenario where global GHG emissions rise slowly until mid-century and more rapidly decline to the end of the century.

GHG emissions are currently rising faster than what is projected in the A1B or B1 scenarios. This suggests that if current trends continue, climate impacts could be more severe than what is projected for the two scenarios.

http://cses.washington.edu/cig/res/ia/waccia.shtml#report

1 Increasing carbon dioxide levels

Climate change is caused by increasing levels of carbon dioxide and other greenhouse gases such as methane and nitrous oxide in the earth's atmosphere.

Observed trends: In 2010, atmospheric carbon dioxide levels were 392 parts per million (ppm), an increase of 41 percent over pre-industrial levels of 278 ppm and higher than any level in the past 650,000 years.[13]

Future projections: If current trends continue, carbon dioxide levels are projected to reach 600 to 1,000 parts per million by the year 2100.[14] Increasing levels of carbon dioxide and other greenhouse gases are causing global temperatures to rise and making the world's oceans become more acidic.

2 Warmer air temperatures

The *Washington Climate Change Impacts Assessment* projects potentially significant increases in average annual and seasonal temperatures in the Pacific Northwest.[15] Even at the low end of the projections, the changes in average annual temperature will be substantially higher than average conditions observed in the 20th century. Warming is expected in all seasons, with the greatest warming occurring during the summer months.

Observed trends: In the Pacific Northwest, average annual temperature rose 1.5°F between 1920 and 2003. The warming has been fairly uniform and widespread, with little difference between warming rates at urban and rural weather monitoring stations. Although the warmest single year on record was 1934, according to NASA the 2000s were the warmest decade since reliable modern records have been kept, going back to 1880.[16]

[13] NOAA/ESRL, http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html; IPCC (2007b).
[14] IPCC (2007a).
[15] Climate Impacts Group (2009).
[16] NASA (2010).

Future projections: Average annual temperature in the Northwest is projected to increase (relative to 1970-1999) approximately:

- 2°F by the 2020s (range of 1.1 to 3.4°F).
- 3.2°F by the 2040s (range of 1.6 to 5.2°F).
- 5.3°F by the 2080s (range of 2.8 to 9.7°F).[17]

Natural variability, including El Niño, La Niña, and the Pacific Decadal Oscillation (PDO), will continue to influence average temperatures, bringing colder or warmer than average years—or decades in the case of the PDO—to the Northwest, even as average global and regional temperatures increase over the long term as a result of rising greenhouse gas emissions.

Higher temperatures are expected to cause glacial and snowpack melt, sea level rise, more severe storms, increased wildfires, and increased diseases and pests.

3 Drier summers and reduced snowfall

Summers are expected to be drier, and winters are generally expected to be wetter, although some models project winter drying.[18] Because winter temperatures are projected to rise, Washington is expected to receive less snow and more rain on average in the future. As with temperature, natural variability will affect how we experience climate at any given point in time, producing wetter or drier than average years (or decades), even as climate change affects precipitation trends over the long term. Because of our region's large range of natural variation between wetter and drier years, it may be difficult to see how climate change is altering long-term precipitation trends for several decades.

Observed trends: Trends in annual precipitation in the Pacific Northwest vary depending on the time period, but overall, annual precipitation has increased. For the period 1920-2000, annual precipitation increased approximately 13 percent. Increases during this period were largest in the spring (37 percent), followed by winter (12 percent), summer (9 percent), and autumn (6 percent).[19] Cool-season precipitation also became more variable in the western U.S. from about 1973 to 2003.[20] Average snowpack in Washington's Cascades declined about 25 percent between 1950 and 2006, due in part to natural variability, with the largest decreases occurring at lower elevations.[21]

[17] Mote and Salathé (2010).
[18] Mote and Salathé (2010).
[19] Mote (2003).
[20] Hamlet and Lettenmaier (2007).
[21] Mote *et al*. (2008).

Future projections: For summer months, a majority of models project decreases in precipitation, with the average decline of 14 percent by the 2080s.[22] Some models project reductions of as much as 20 to 40 percent in summer precipitation.[23]

In winter, a majority of models project increases in precipitation, with an average of 8 percent increase by the 2080s under the moderate emissions modeling scenario (A1B). This figure is small relative to variability from year to year.[24] Although some models project modest reductions in fall or winter precipitation, others show very large increases (up to 42 percent).[25] Spring snowpack across the state is projected to decrease 29 percent by the 2020s, 44 percent by the 2040s, and 65 percent by the 2080s (relative to the 1971-2000 average) for the A1B scenario. Projected decreases in snowpack are slightly less for the low emissions modeling scenario (B1): a 27 percent decrease for the 2020s, a 37 percent decrease for the 2040s, and a 53 percent decrease for the 2080s.[26]

Snowmelt provides approximately 70 percent of annual streamflow in the mountainous regions of the western U.S.[27] Increased winter rain (as opposed to snow) and shifts to earlier spring snowmelt—both due to warmer winter temperatures—result in higher streamflows in winter and early spring. Late spring and summer streamflows are reduced in snow-dominated and transient watersheds (which receive a mixture of rain and snow).[28]

Lower summer streamflows could have major implications for fisheries, wildlife, water supply, and agriculture, particularly in drier regions of the state.[29] Although changes in total annual precipitation may be relatively small, reduced summer precipitation and warmer temperatures may lead to decreased soil moisture and higher rates of evapotranspiration. In some areas, these changes will likely lead to increased drought frequency and severity.[30]

[22] Mote and Salathé (2010).
[23] Mote and Salathé (2010).
[24] Mote and Salathé (2010).
[25] Mote and Salathé (2010).
[26] Elsner *et al*. (2010).
[27] Mote *et al*. (2008).
[28] Casola *et al*. (2005).
[29] Elsner *et al*. (2010).
[30] Mote and Salathé (2010).

4 Extreme weather events may increase

Climate change is expected to increase the frequency and intensity of extreme weather events such as floods, coastal storm surges, droughts, and heat waves.

Observed trends: The frequency of heavy downpours (defined as the top 1 percent of rainfall events) has increased by almost 20 percent on average in the U.S. and by about 12 percent in the Pacific Northwest.[31] Nationally, 8 of the top 10 years for extreme one-day precipitation events have occurred since 1990.[32] Record high temperatures have increased compared with low temperatures, and drought conditions have increased in many parts of the western United States.

Atmospheric rivers: Narrow regions in the atmosphere that deliver large masses of warm, moist air, transporting large amounts of water vapor across the Pacific Ocean and elsewhere.

Future projections: Climate models project an increased risk for more frequent extreme precipitation in the Northwest by the second half of the 21st century, although the patterns and level of intensity is highly variable.[33] More intense atmospheric rivers along the West Coast of the United States are also possible.[34] Increases of 5 to 10 percent in storm intensity are projected for the North Cascades and northeastern Washington, while increases in other areas of the state are not significant.[35] In the Seattle-Tacoma area, the magnitude of a 24-hour storm is projected to increase 14 to 28 percent during the next 50 years.[36]

Increased extreme heat events are projected for the 2040s, especially in south-central Washington and the western Washington lowlands.[37] Increases in the average annual number of heat events, average event duration, and maximum event duration are projected for the Seattle, Spokane, Tri-Cities, and Yakima regions.[38]

Extreme weather events can cause significant damage to structures and property, depending on the exposure and vulnerability of the specific location. In Puget Sound, development in floodplains heightens the exposure and vulnerability to floods resulting from heavy downpours. Coastal development heightens the exposure and vulnerability to coastal storm surges and sea level rise.

[31] U.S. Global Change Research Program (2009).
[32] U.S. EPA (2010).
[33] Salathé (2006); Rosenburg *et al*. (2010). Tebaldi *et al.* (2006).
[34] Dettinger (2011).
[35] Salathé *et al*. (2010).
[36] Rosenberg *et al*. (2010).
[37] Salathé *et al*. (2010).
[38] Jackson *et al*. (2010).

Heat waves and drought will increase fire risk, reduce summer water supply, and increase water temperatures to lethal levels for coldwater fish species.

5 Sea levels are rising, but the relative effect varies by location

Rising sea levels are primarily caused by two processes: additional water in the ocean from melting of glaciers and land-based ice sheets like Greenland and Antarctica; and thermal expansion of ocean waters due to warmer sea temperatures. Sea level is rising globally, but the relative effect varies by location with changes in land elevation and wind patterns.

Observed trends: Globally, oceans rose approximately 8 inches from 1870-2008, an average of 0.06 inches (1.5 mm) per year. However, the rate of change has accelerated in recent years. Between 1993 and 2008, average sea level rose approximately 0.12 inches (3 mm) per year, which is roughly twice as fast as the long-term trend.[39] In Washington, sea levels are not changing uniformly. Because the edge of the Juan de Fuca oceanic plate is slowly moving under the North American continental plate in western Washington, the Olympic Peninsula is rising at a rate of about 2 millimeters (0.08 inches) a year, while south Puget Sound is subsiding at about the same rate.[40] If these trends continue, relative sea level rise will be greatest in south Puget Sound and least on the northwest tip of the Olympic Peninsula.[41]

Future projections: In the Puget Sound region, the medium estimate for sea level rise is 6 inches by 2050 and 13 inches by 2100. For the central and southern Washington coasts, the medium estimate is an increase of 5 inches by 2050 and 11 inches by 2100. If uplift on the northwest corner of the Olympic Peninsula continues through the 21st century, sea level rise in that area could be lower than other areas of the state. The medium estimate for the northwest Olympic Peninsula is 0 inches by 2050 and an increase of 2 inches by 2100. However, the potential for continued accelerated ice melt from Greenland and Antarctica means that higher sea level estimates are possible for Washington's coastal regions. Increases of up to 3 feet for the northwest Olympic Peninsula, 3.5 feet for the central and southern coast, and 4 feet for Puget Sound by 2100 cannot be ruled out at this time due to large ranges for accelerating rates of ice melt from Greenland and Antarctica.[42]

[39] U.S. EPA (2010b).
[40] Mote *et al.* (2008).
[41] Huppert *et al.* (2009).
[42] Mote *et al.* (2008).

Rising sea levels, combined with increased storm surge, will increase the frequency and intensity of coastal flooding. Periodic floods will likely pose a greater and more near-term risk than permanent inundation of low-lying areas from increases in average sea level. Coastal erosion and habitat loss are also projected due to higher sea levels. For much of Puget Sound, 1 foot of sea level rise will likely turn a flood event expected to occur once in 100 years into an event that occurs every 10 years. If sea level rises 2 feet, a flood event expected to occur once in 100 years would turn into an annual event.

6 Marine waters are becoming more acidic

The global oceans have absorbed approximately 30 percent of human-generated carbon emissions since the Industrial Revolution.[43] When dissolved carbon dioxide mixes with seawater it forms carbonic acid. As marine waters have absorbed increasing amounts of carbon dioxide, the carbonic acid has caused ocean pH to decline, making seawater increasingly acidic.

Observed trends: Globally, ocean pH has declined 0.1 units relative to its pre-industrial measure of 8.2.[44] In the Hood Canal area of Puget Sound, observed pH is substantially lower, ranging from 7.39 to 7.56.[45]

Future projections: If carbon emissions continue their current trends, global ocean pH is projected to decline to approximately 7.8 by 2100.[46]

The biological effects of ocean acidification are not well understood and will vary among organisms, with some coping well and others not at all. Marine organisms that use carbonate to build shells or skeletons are expected to be affected by changes in seawater chemistry. The long-term consequences of ocean acidification for marine organisms are unknown, but changes in many ecosystems and the services they provide to society appear likely.[47]

[43] Canadell *et al*. (2007).
[44] IPCC (2007a).
[45] Feely *et al*. (2010).
[46] IPCC (2007a).
[47] National Research Council (2010).

7 Warmer water temperatures

Increased water temperatures are caused by warmer air temperatures and reduced summer water inputs. Water temperatures are increasing in freshwater rivers, lakes, and wetlands as well as in marine waters and nearshore systems such as estuaries.

Observed trends: Annual average water temperature in Lake Washington increased about 1.6°F from 1964 to 1998.[48] In marine systems, average sea surface temperatures have risen globally by 1.1°F since 1950.[49]

Future projections: Average statewide summer stream temperatures are projected to rise about 1.8°F by the 2020s and between 3.6°F and 9°F by the 2080s.[50] In many of Washington's streams and lakes, the duration of periods that cause stress to salmon because of warmer temperatures and migration barriers is projected to at least double and perhaps quadruple by the 2080s.[51] Prolonged elevated water temperatures and thermal stress for salmon are expected particularly in eastern Washington along the Upper Yakima River, the Columbia River at Bonneville Dam, and the Lower Snake River near Tucannon, as well as in western Washington along the Stillaguamish River near Arlington and in the Lake Washington/Lake Union area. Sea surface temperatures near the Washington coast are projected to increase 2.2°F by the 2040s.[52]

Increased water temperatures can be lethal for salmon and other coldwater species. Lakes may also experience a longer stratification period in summer,[53] which could increase eutrophication and lead to oxygen depletion in deep zones during summer, eliminating refuges for coldwater fish species.[54] Warmer ocean temperatures contribute to sea level rise, increased storm intensity, and greater stratification of the water column.[55]

[48] Arhonditsis *et al.* (2004).
[49] Nicholls *et al.* (2007).
[50] Mantua *et al.* (2010).
[51] Mantua *et al.* (2010).
[52] Mote and Salathé (2010).
[53] Euro-Limpacs (2011).
[54] Euro-Limpacs (2011).
[55] Hoegh-Guldberg and Bruno (2010).

8 Wildfires are increasing in frequency and severity

While forest fires occur naturally and provide important ecological benefits for many ecosystems, the frequency and severity of fires is expected to increase due to climate change. Warmer air temperatures, reduced snowpack, and reduced summer precipitation lead to reduced soil moisture and longer dry seasons that prolong the period in which fires could occur.[56]

Observed trends: Over the period 1987-2003, major wildfire frequency in the western U.S. increased fourfold compared to the period 1970-1986. The area of forest burned was six times greater in 1987 to 2003 than during the previous 16-year period from 1970 to 1986.[57]

Future projections: In the Pacific Northwest, wildfires are projected to burn twice as many acres yearly by the 2040s and three times as much forest area by the 2080s (relative to 1916-2006). The probability that more than 2 million acres will burn in a given year is projected to increase from 5 percent currently to 33 percent by the 2080s.[58] In forested ecosystems such as the western and eastern Cascades, Okanogan Highlands, and Blue Mountains, the area burned is projected to increase by a factor of 3.8 by the 2040s, compared to 1980-2006.[59] Regionally, the area burned by wildfire each year on average is projected to increase from about 425,000 acres currently to 800,000 million acres in the 2020s, 1.1 million acres in the 2040s, and 2.0 million acres in the 2080s.[60]

More frequent and severe wildfires will raise the risk of injury or death for firefighters and the public as well as increase the costs of firefighting. Increased property damage and reduced timber yields are also likely, as well as reduced air quality, loss of forested habitat areas for fish and wildlife, and reduced water quality due to erosion and sedimentation of water bodies.

[56] Westerling *et al*. (2006).
[57] Westerling *et al*. (2006).
[58] Littell *et al*. (2009).
[59] Littell *et al*. (2010). Compared to the period 1980 to 2006.
[60] Littell *et al*. (2010).

9 Floods are increasing in frequency and severity

In western Washington, flood risk is generally highest in late fall and winter when precipitation is greatest. In eastern Washington, flood risk is generally highest during the spring snowmelt. An increase in winter rainfall (as opposed to snowfall) as a result of climate change is expected to lead to more winter flooding in rain-dominated and transient (rain/snow mix) watersheds.

Observed trends: Flood risks are increasing primarily in rain-dominated basins and warmer, transient basins in western Washington,[61] which tend to experience average winter temperatures near 32°F. Flood risk in colder snow-dominated basins and cooler transient basins was largely unchanged during the 20th century. Since 1990, Puget Sound has experienced 16 federally declared flood disasters, and Interstate 5 has closed four times due to flooding.[62]

Future projections: As the climate warms, flood frequency is projected to increase in the months of January to March and decrease in April to May.[63] Flood frequency is projected to increase progressively from the 2020s through the 2080s, with the largest increases predicted for mixed rain-snow runoff basins located in Puget Sound, the west slopes of the Cascades in southwest Washington, and in the lower elevations on the east side of the Cascades.[64] Rain-dominated basins are projected to experience small changes in flood frequency.

Floods can cause widespread damage to communities and property. Increased frequency and severity of floods will likely lead to greater taxpayer costs for cleanup and rebuilding as well as economic disruption. Floods have caused numerous deaths and put emergency responders at risk during rescue operations.

[61] Hamlet and Lettenmaier (2007).
[62] Washington State Department of Transportation (2008b).
[63] Vano *et al*. (2010).
[64] Mantua *et al*. (2010).

4. Human Health

4. Human Health

Human health is naturally linked to the environment. As such, impacts of climate change will likely create a significant and emerging threat to human health in many ways, both directly and indirectly (see Figure 1). For example:

- Extreme temperatures, more frequent wildfires, and other severe weather events will likely increase the risks of heat-related illness, respiratory disease, and vector-borne diseases.
- Drought, flooding, and storm damage will likely alter drinking water supply and water quality conditions.
- Changes in water, air, food quality and quantity, ecosystems, agriculture, and the economy also indirectly expose humans to climate change impacts.

Vector: An organism or vehicle that carries pathogens from one host to another.

Climate change can affect human health in ways that affect families and the workforce, such as premature death and increased sick days, leaves of absence, health care costs, and insurance claims. These impacts also impair quality of life. The populations at greatest risk include children, the elderly, individuals suffering from respiratory and cardiovascular disease, and economically disadvantaged people.

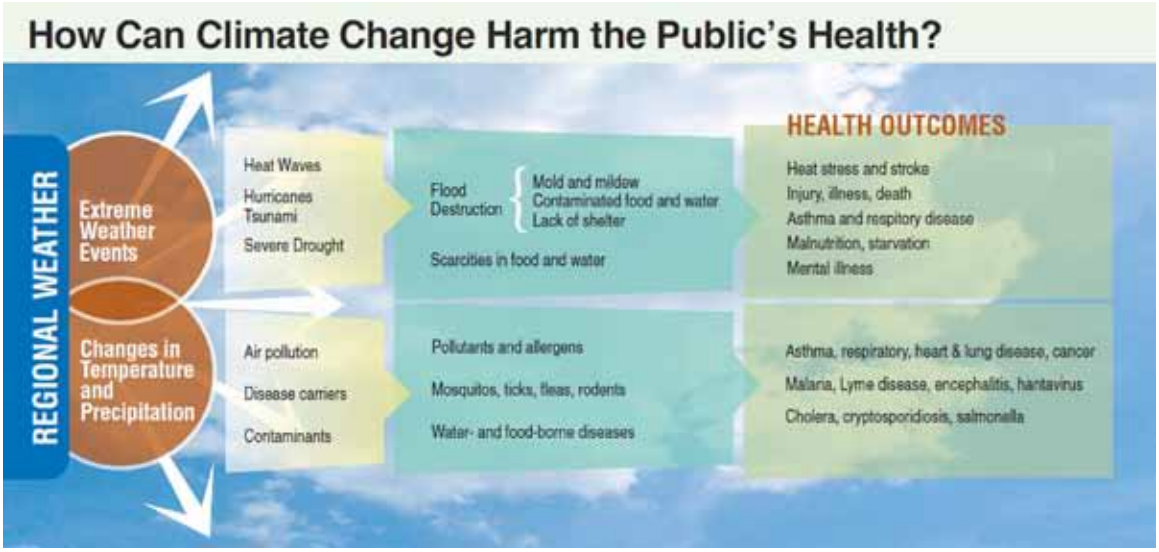


Figure 1. How climate change can harm human health[65]

[65] American Public Health Association citing U.S. Global Change Research Program

Much of the work to address and prepare for climate change effects on human health will happen in local communities and public health agencies, with focus on the adverse effects on vulnerable populations and sensitive communities.

Keeping the people of Washington healthy is of paramount importance. The challenge of adapting to the health impacts of climate change comes at a time when the entire public health system is examining and reshaping its approach to service. Local and state funding for public health is also rapidly eroding. For example, the loss of trained public health professionals ranges from as much as 25 to 40 percent in some jurisdictions.

The following sections describe the scientific understanding of the impacts of climate change on Washington's citizens and outline key strategies to support state and local efforts to protect human health and lower risks to our communities.

Impacts of Climate Change on Human Health

Climate change is expected to affect human health in at least five key ways:

- The risk of illness and death from extreme heat will increase.
- Asthma and respiratory problems will increase due to increasing levels of smog (ground-level ozone) and potential increases in other air pollutants.
- Diseases transmitted by food, water, and insects will increase.
- Illness, injury, and mental health problems from storms will increase.
- Drinking water supplies will change, and water quality could decline.

1 Illness and deaths from heat waves

Climate change is expected to increase the frequency, intensity, and duration of extreme heat events in Washington State. Excessive heat can lead to heat stress, heat stroke, and other health complications such as heart attack, stroke, respiratory illness, and death. Elderly people and people with existing health conditions are especially susceptible to heat-related illness.

Since extreme heat days are uncommon in the Puget Sound region, most homes lack cooling systems. Most people are not well prepared and do not take the necessary precautions. In the Seattle area, the number of heat-related deaths for people age 65 and older is projected to increase. In eastern Washington, increasing numbers of hot days (over 100°F) are expected to cause more heat-related illness, and agricultural workers are particularly exposed.[66]

[66] Jackson *et al.* (2010).

Ground-level ozone, or smog, is an air pollutant with harmful effects. Exposure to smog is linked to premature death, asthma, bronchitis, heart attack, and other cardiopulmonary problems.

2 Air quality and respiratory and cardiovascular disease

Climate change is expected to increase exposure to ground-level ozone and make it more difficult to meet the air quality standards necessary to protect public health.[67] In King County, average summer ozone concentrations are projected to increase 28 percent by the 2050s. In Spokane County, ozone concentrations are projected to increase by 17 percent by the 2050s.[68]

Larger and more frequent wildfires could also significantly affect air quality in Washington and increase concentrations of tiny atmospheric particles, which degrades air quality. Climate change could worsen our current challenges with asthma, increase pollen production, and prolong the pollen season.

Tiny Particles in the Air: Aerosols or Particulates

When you look up at the sky, you are looking at more than just air. Billions of tiny bits of solid and liquid are floating in the atmosphere. Those tiny floating particles are called **aerosols** or **particulates**.

The aerosols that are from air pollution are hazardous to human health. When these small particles go deep into a person's lungs, it can make him or her very ill.

3 Infectious disease

Climate change is expected to increase some diseases transmitted by food, water, and insects. Increasing temperature, precipitation, and extreme weather events can affect the replication, survival, persistence, habitat range, and transmission of disease-causing agents, worsening the following health concerns.

Tick-related disease. Longer, drier summers and changing distribution patterns of animal hosts could increase the distribution range of Dermacentor ticks, which are can carry Rocky Mountain spotted fever, tularemia, and Q fever, as well as cause tick paralysis. Milder winters in western Washington could cause an increase of Ixodes pacificus tick populations, which is the Lyme disease carrier in the western United States.[69]

[67] U.S. Environmental Protection Agency (2009).
[68] Jackson *et al.* (2010)
[69] Personal communication with Elizabeth Dykstra, DOH Public Health Entomologist, 2011.

Mosquito-borne diseases. The introduction of foreign mosquito-borne diseases remains a concern. The recently introduced species Ochlerotatus japonicus is a known carrier of filariasis and has been shown to transmit West Nile virus in the laboratory. Other types of diseases like western equine encephalitis and St. Louis encephalitis have occurred in Washington State and may be sensitive to climate change, though no cases have been reported since 1988.[70]

Waterborne illnesses. Outbreaks of waterborne diseases frequently follow heavy precipitation[71] and flooding.[72] Surface water used for drinking may be at greater risk of contamination.[73]

Harmful Algal Blooms (HABs). HABs are blooms of algae that can produce natural toxins with harmful effects, including illness and death. Humans are exposed to HABs through consumption of fish or shellfish, inhalation, or skin contact with contaminated water. Climate change may be contributing to the conditions that allow these algal blooms to flourish.

Rodent-related disease. Increased forest damages and losses due to beetle infestations and increasing risk of severe forest fires will alter the habitat and distribution of rodent populations. Loss of forest habitat may send more rodents into residential areas, increasing the risk of human exposure to the diseases rodents can carry, such as hantavirus.[74]

Food-borne illnesses. Research shows a significant correlation between food-borne illnesses and ambient temperature. Depending on the type of food-borne illness, for every degree centigrade (ºC) rise in temperature, the risk of food-borne illness can increase 2.5 to 6 percent.[75]

Washingtonians may also face higher risks from diseases originating in other parts of the world.

[70] Washington State Department of Health (2008).
[71] Curriero *et al*. (2001); Thomas *et al*. (2006).
[72] Wade *et al*. (2004).
[73] Rose *et al*. (2000).
[74] Personal communication with Elizabeth Dykstra, DOH Public Health Entomologist, 2011.
[75] Portier et al. (2010).

4 Injury and mental health problems from severe storms

More frequent and severe weather events such as storms and flooding are expected to result in injuries, illness, and deaths. These health problems include carbon monoxide poisoning from people using generators or barbeques indoors for cooking and alternative sources of heat during power outages.

Extreme weather events also result in more short- and long-term emotional trauma and mental health problems, including:

- Post-traumatic stress disorder.
- Depression.
- Sleep difficulties.
- Social avoidance.
- Drug or alcohol abuse.

The severity of the problems that come after an extreme climate event depend on how much support is available, both during and after, to the person affected by the event. During the recovery period, mental health problems and stress-related disorders can come from:

- Geographic displacement.
- Unemployment.
- Loss of property.
- Death or injury of loved ones.

Impacts of climate change on U.S. national security

According to the National Intelligence Council, global climate change will have wide-ranging implications for U.S. national security interests in the coming decades. Climate change could increase instability and conflict in vulnerable regions as a result of:

- Increasing drought and conflicts over water.
- Declining food security.
- Increased health problems.
- Increased displacement from flooding and rising sea levels.

These climate-driven impacts will worsen existing problems, such as poverty, social tensions, environmental degradation, and weakening of national governments.

For more information:

www.dni.gov/nic/special_climate2030.html

5 Drinking water supply and water quality

Climate change may affect the sustainability of water supplies in parts of the state in the coming decades. As temperatures rise, declining snowpack and changes in precipitation will affect streamflow timing and volume. These changes in streamflow could increase the risk of water shortages in many basins and also impair water quality. Sea level rise could cause increased saltwater intrusion into coastal aquifers. Expert opinion suggests that sea level rise will have only a minor effect on coastal aquifers, however, and the amount of freshwater available is not expected to change for coastal areas.

Vulnerable populations will bear the burden

For projected impacts of climate change on human health, the most vulnerable populations are children, the elderly, and people with existing respiratory, cardiovascular, or other chronic diseases.[76] People who work or exercise outdoors are also more exposed to the effects of heat.

Poor and disadvantaged people are particularly at risk from the impacts of climate change. Low-income individuals, people of color, and those that speak English as a second language often experience higher rates of chronic stress and have poorer health outcomes, regardless of the stressor. These individuals also may experience:

- Poorer existing health conditions.
- More barriers to health care.
- Unstable employment.
- Lower-quality housing.

In addition, the poor are more likely to:

- Have little or no access to healthy food.
- Have fewer transportation options.
- Live in neighborhoods with less social and financial capital, higher crime rates, and more safety concerns.

As a result, the impacts of climate change may further reduce the ability and capacity of low-income individuals and communities to adapt and to improve their quality of life.

[76] U.S. EPA (2010a).

Recommended Adaptation Strategies and Actions—Human Health

Much of the work to address and prepare for climate change effects will happen in local communities and public health agencies. The public health community has programs that reach across various populations and locations. Public health leaders have a key role to play in preparing communities to cope with the urgent consequences of climate change.

The following section describes five recommended strategies, along with accompanying actions. These strategies and actions are intended to help Washingtonians understand, respond, and adapt to the impacts of climate change. The strategies are not expected to introduce entirely new fields of work to public health but rather to bolster existing systems. By integrating climate adaptation strategies into the emerging public health system, the strategies:

- Help communities' most vulnerable populations.
- Communicate the health impacts of climate change.
- Enhance public readiness to take actions.
- Prioritize and implement operational changes that allow public agencies and communities to prepare for climate change.

Strategy A-1. Protect the communities that are most vulnerable to impacts of climate change.

Actions:

1. Identify people, communities, regions, infrastructure, and local economies that are most vulnerable to climate impacts. Provide tools that local health departments and communities can use to conduct community-wide assessments. Provide financial and technical support for local communities to develop and implement appropriate adaptation strategies to respond to current and future threats.

2. Enhance the capacity of state and local health organizations and communities to implement preventive actions that reduce public health risks related to climate change. The focus will be on ensuring efficient organizational structure, effective policies and programs, and adequate funding.

3. Work collaboratively with local health departments, community-based organizations, state and local planning organizations, and transportation agencies to:
   - *Improve community planning and design to support and promote healthy built environments and healthy living.*
   - *Expand and protect urban vegetation and open space.*
   - *Prevent construction of new critical infrastructure in vulnerable areas.*

4. Work with state and local agencies and organizations to:
   - *Enhance efforts to develop transportation options and evacuation routes to ensure safety of vulnerable people.*
   - *Develop and publicize shelters and responses to heat and flooding extremes.*
   - *Increase access to health care for at-risk populations.*
   - *Prepare for aftermath of extreme events.*
   - *Enhance preparedness for disease prevention of vector-borne and water-borne diseases following floods and storms.*

Strategy A-2. Enhance surveillance and reporting systems to monitor and support early detection of climate-related risks and swift responses to emerging health threats associated with climate change.

The ongoing and systematic collection of data is critical for monitoring changes in the magnitude of current public health threats and early detection of new or emerging threats. The following are the three areas where surveillance systems are critically important to public health preparation and adaptation:

- Zoonotic disease (diseases transmitted from animals to humans).
- Air quality monitoring.
- Notifiable conditions, a public health surveillance of those conditions that legally require reporting to local and state health departments.

Actions:

1. Maintain, rebuild, and increase overall efficiency of current surveillance systems—at the state level and in local health departments and health care organizations—to monitor and identify outbreaks of climate-related health diseases and illnesses.

2. Continue development of the Department of Health's Environmental Public Health Tracking network, and focus future efforts on expanding data and health indicators linked to climate change and healthy communities.

3. Enhance surveillance and electronic reporting from laboratories to support our ability to detect emerging health issues rapidly and implement timely and effective community responses.

4. Develop meaningful data sets to better understand changes in zoonotic disease patterns and disease vectors, air quality conditions, and harmful algae blooms. This information will assist our future efforts in preparing for and adapting to climate change-related conditions affecting our health.

5. Develop an early warning system to identify and predict when and where a harmful algae bloom or pathogen event may occur in our marine waters. This initiative will focus on:
   - *Characterizing environmental and biological factors that contribute to biotoxin or bacterial events.*
   - *The public health burden associated with these toxic events.*
   - *Potential policy and scientific solutions and/or information and data needs for mitigating human exposure from recreational, occupational, and seafood-related pathways during such events.*
   - *Increase collaboration between the Health and Agriculture departments on zoonotic disease surveillance improvements.*

Strategy A-3. Incorporate climate adaptation strategies into the Department of Health's *Agenda for Change*, with a focus on prevention, early detection, and swift responses to protect people from diseases and other health threats caused by changing climate conditions.[77]

Actions:

1. Identify, prioritize, and incorporate into health planning and regulations climate change mitigation and adaptation strategies. Include actions that promote healthy living and reduce greenhouse gas emissions and toxic pollutants. Collaboration with local governments can help incorporate healthy living strategies into land use planning and regulations, such as compact development that concentrates growth in compact walkable urban centers to avoid sprawl.

2. Refine existing emergency response and public health preparedness planning to enable local health and emergency response agencies to:

   - *Anticipate impacts of severe heat events, droughts, wildfires, and coastal flooding.*
   - *Develop early warning systems.*
   - *Quickly respond to extreme weather events.*
   - *Help local health departments assess their capacity to respond to health threats and to integrate climate preparedness into their hazard response plans and daily operations.*

[77] Washington State Dept. of Health (2010).

Strategy A-4. Engage and motivate citizens and organizations to take actions to build resilient communities.

Actions:

1. Collaborate with the Northwest Center for Public Health Practice and other academic partnerships to develop a web-based resource hub to provide information and technical resources on public health and climate change preparedness. This website should provide information in several languages to help meet the needs of communities most at risk.

2. Enhance the ability of local organizations to understand climate risks and reach vulnerable populations. Provide vulnerable populations with information on what they need to know and how to prepare for and address the risks of climate change.

3. Pursue partnerships with nonprofit organizations and businesses to develop climate change communication tools, messages, and social support networks that promote active community involvement and raise public awareness about the health problems related to changing climate.

4. Using the medical system, enhance awareness of the projected health problems that come from a changing climate and the services (response strategies) that are available—including the mental health system.

5. Distribute information on how a changing climate can affect human health to doctors, nurses, and emergency response personnel that provide direct services to vulnerable citizens. Expected impacts include increased asthma, heat exhaustion, and potential new diseases transmitted from animals to humans.

6. Pursue opportunities to engage with medical and academic institutions to raise awareness of the overarching mental health problems that come from the social and environmental disruptions related to emergencies. Potential partners include the state's mental health system, the Washington Medical Association, Washington State Department of Social and Health Services, University of Washington Medical School and School of Public Health, and the schools of social work at Washington State University, Portland State University, and Eastern Washington University.

7. Distribute alerts to the service providers of the medical and mental health communities during extreme weather events (and in advance, when possible), so they can be best prepared to serve members of their communities that may be adversely impacted.

8. Encourage the Washington State Public Health Association to dedicate time at the annual Joint Conference on Health to raise awareness and engage the public health and healthcare service providers about the health problems related to a changing climate. This conference also provides an opportunity to raise awareness about the tools and strategies that local communities can use to prepare for health problems associated with climate change.

9. Use existing programs within the Department of Health's Office of Drinking Water to educate and alert public water system operators and their customers about likely impacts of climate change and the need for enhanced emergency preparedness.

Strategy A-5. Build capacity and support to safeguard human health in the face of climate change.

Actions:

1. Expand training and education of health and social services providers, including mental health agencies, to build capacity to respond appropriately to human health risks of climate change.

2. Improve our understanding of human health impacts of climate change and extreme weather through continued interdisciplinary studies at the University of Washington, Washington State University, and with agency scientists. Further work needs to focus on better understanding the risks; identifying the areas and populations at greatest risk; and exploring new methods to address the identified risks.

3. Seek more reliable funding mechanisms that can support more localized forecasting and risk modeling to address the health implications of climate change from extreme heat events, flooding, other extreme weather events, and increased forest fires.

4. Pursue future funding opportunities, such as the Centers for Disease Control and Prevention (CDC) funds, to support the enhancement of critical public health infrastructure needed to promote healthy communities and to address the impacts of climate change.

5. Ecosystems, Species, and Habitats



5. Ecosystems, Species, and Habitats

Washington is home to nearly 600 mammals, birds, fish, amphibians, and reptiles. Among these are the iconic salmon, orca, and bald eagle, as well as game species such as elk, mule deer, ducks, and geese. Our diversity of fish, wildlife, and plants is supported by distinctive habitats and ecosystems, from the grasslands of the rolling Palouse prairie to the glaciated alpine tundra of the Cascade mountains, and from towering Douglas fir forests to the teeming Columbia River estuary.

Washington hosts a large number of imperiled species, listed by federal or state agencies as endangered, threatened, or a species of concern. Their populations have been reduced to the point that they require special attention and management to prevent extinction. Most of these species began their decline due to non-climate stressors such as habitat destruction, degradation, and fragmentation (breaking up of a habitat into smaller units); invasive species; or excessive hunting and fishing. Climate change adds a new stressor, however, that may further weaken already reduced populations and may cause formerly healthy populations to decline.

Ecosystem Products and Services

Washington's ecosystems also provide a wide range of products and services that benefit Washington residents, including food, clean water, flood and storm protection, recreation, and cultural heritage. These products and services support millions of dollars of economic activity and a significant number of jobs. Although it is difficult to calculate the full economic contributions of many ecosystem services, the economic value associated with some aspects of ecosystem services have been calculated for Washington. For example:

- Habitat in marine and coastal ecosystems in Washington State sustains commercial and recreational fishing that directly and indirectly supported over 16,000 jobs and $540 million in personal income in 2006.[78]
- Washington's biodiversity supported hunting, fishing, and wildlife viewing activities that added nearly $3.1 billion to Washington's economy in 2006.[79]
- The annual benefit of ecosystem services in the Puget Sound watershed is conservatively estimated to range between $9.7 billion and $83 billion.[80]

Climate change is eroding the valuable benefits and services our diverse ecosystems provide, and the impacts could be costly. The following sections describe the scientific understanding of climate change impacts on Washington's ecosystems, fish, wildlife, plants, and habitats. Following the discussion of impacts are recommended strategies and actions to support state and local efforts to protect these ecosystem assets and lower risks to our environment.

[78] Washington Department of Fish and Wildlife (2008).
[79] U.S. Department of the Interior, U.S. Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau (2006).
[80] Batker *et al*. (2010).

Impacts of Climate Change on Ecosystems, Species, and Habitats

Climate change is altering Washington's diverse ecosystems, and the effects are projected to harm many of the benefits we gain from ecosystems. Climate change will likely increase the stress on species that are already sensitive or vulnerable and will reduce the potential for their recovery and protection.

Climate change is expected to affect ecosystems, species, and habitats in at least six key ways:

- Degradation and loss of habitat.
- Increase in major ecosystem disturbances.
- Shifts in geographical ranges of some native plants and animals.
- Change in timing of life history events for plants and animals.
- Declines in species populations and loss of biodiversity.
- Spread of invasive species and disease.

1 Habitat degradation and loss

Changing conditions—such as rising air and water temperatures, increasing sea levels, and acidification of the oceans—will alter, and in some cases, destroy habitats. Existing land use activities and growing pressure from urban development and new infrastructure can increase habitat loss.

The human response to climate change also has implications for species and habitat. As sea levels rise, shoreline armoring may temporarily protect structures from flooding but will also likely eliminate coasts and beaches. Levees installed for flood protection may reduce the quantity, quality, and diversity of riparian habitat for fish.

Coastal areas. Rising sea levels will increase erosion of beaches and flood coastal marshes, tidal flats, and other important habitats for many species of fish and wildlife.[81] In a study of selected sites in Washington, researchers project that a 27-inch rise in sea levels would cause the loss of 58 percent of low tidal areas and 24 percent of freshwater tidal areas. Grays Harbor and Willapa Bay will likely experience the greatest loss of key habitats, although the Lower Columbia estuary will likely gain habitat.[82] Development of coastal areas and shoreline armoring (e.g., bulkheads, seawalls) prevent habitat areas from reestablishing inland.

Marine waters. Ocean waters are becoming warmer, altering the species found in our waters, affecting migration and breeding patterns, and increasing harmful algal blooms. Ocean acidification is a significant problem for species that depend on calcium carbonate to make shells or skeletons, including shellfish, corals, and some types of plankton. This acidification could result in the decline of species that provide the foundation of the marine food web and support commercial fisheries.

Streams and rivers. Warmer temperatures—coupled with resulting reductions in snowpack and water supply, along with increased agricultural and domestic water withdrawals—are projected to further stress the river systems, riparian areas, and springtime pools that are critical to the survival of plants and animals. Rising stream temperatures and lower summer streamflows will reduce the quality and quantity of freshwater habitat for salmon and other coldwater fish.[83]

Mountains. Alpine and subalpine habitats are declining primarily because warmer temperatures are allowing tree lines to advance upwards, thereby squeezing alpine systems. These trends are expected to continue, leading to a substantial decline or potential disappearance of high-elevation tundra and subalpine vegetation in the Olympic Peninsula by 2100. Species that live in these high-elevation systems would need to seek alternative habitats or perish.[84]

Aridlands. Washington's aridlands include habitats ranging from shrub-steppe grasslands, dunes, and the Palouse prairie. These habitats host numerous native plant and animal species. Many of these species already live near their physiological limits for water and temperature

[81] Glick *et al*. (2007).
[82] Ducks Unlimited (2010a, 2010b, 2010c, and 2010d).
[83] Mantua *et al*. (2010).
[84] U.S. Department of Agriculture, U.S. Forest Service (2011).

stress, and projected higher summer temperatures will further stress already vulnerable species. Increased temperatures will also benefit invasive species such as cheatgrass, which thrives in hot, open environments and crowds out native species.

2 Increase in major disturbances

Climate impacts may occur rapidly through major disturbance events such as wildfires, floods, drought, or disease or insect outbreaks. When climate change exceeds a species' physical or ecological tolerance thresholds, it can trigger rapid and potentially widespread responses. Disturbances are a natural part of ecosystem dynamics, and some disturbances are integral to maintaining healthy ecosystems. However, climate change is affecting when and how often disturbances occur and how large they are, and these events are likely to significantly alter many ecosystems and the animals and plants that depend on them.

In some cases, multiple climate-related disturbances can combine, such as when forest systems are stressed by increased temperatures, reduced snowpack, and reduced summer soil moisture—and then further weakened by mountain pine beetle or other insects or disease.

3 Shifts in geographic range

With higher temperatures and shifts in precipitation patterns, some native plants and animals will no longer be able to thrive in their current ranges. The ranges of many species in the U.S. have shifted northward and upward in elevation.[85] These changes are likely to continue. Shifts in geographic range depend on the availability and accessibility of appropriate habitat and the behavior of the species. Species that can shift their range will require migration corridors that are not restricted by natural landscape features or human development. Freshwater species are likely to be particularly susceptible to climate change impacts because their opportunities for migration and movement may be especially limited.

[85] U.S. Global Change Research Program (2009).

4 Change in timing of life history events

Shifts have already occurred in the timing of the seasons, animal migrations, and other life history events for plants and animals.[86] Spring now arrives on average of 10 days to two weeks earlier than it did 20 years ago in the U.S., the growing season is longer, and many migratory bird species are arriving earlier.[87] Climate change is likely to further alter the timing of life history events for plants and animals.

Of particular concern is the potential for interrupting lifecycle events among species, such as when a bird or insect relies on the timing of a flowering plant. If climate change prevents interactions needed for survival or reproduction, both species could perish.

5 Declines in species populations and diversity

While plants and animals can often accommodate a range of temperature, moisture, and other conditions, climate change is causing changes that occur at a faster rate, with greater intensity, in different patterns, or on a broader spatial scale than many species have previously experienced. Those species that cannot adapt are at risk of extinction.[88] Scientists estimate that 20 to 30 percent of the earth's plant and animal species assessed to date could be at increased risk of extinction if average temperatures increase 2.7°F to 4.5°F.[89]

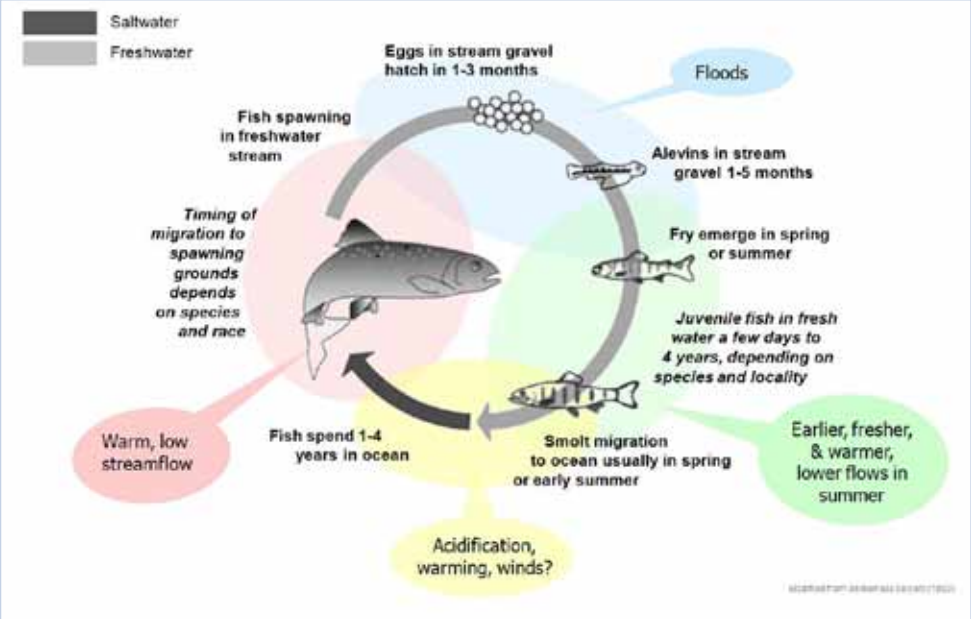


Figure 2. Effects of climate change across salmon life cycle[90]

[86] U.S. Global Change Research Program (2009).
[87] U.S. Global Change Research Program (2009).
[88] Noss (2001).
[89] IPCC (2007a).
[90] Littell *et al.* (2009).

Salmon, already disturbed by a variety of human activities, will be affected by climate change at every stage of their life cycle. Warmer stream temperatures, lower summer streamflows, and changes in the size and frequency of floods will put increasing stress on salmon (see Figure 2). The relative importance of climate factors will vary for different salmon stocks.[91]

The greater sage-grouse is another population that climate change will likely affect. As the impacts of climate change interact with other stressors such as disease and habitat degradation, these birds may be at increased risk of extinction. Under projected future temperature conditions, the cover of sagebrush within sage-grouse territory is anticipated to be reduced due to non-native grass invasions, making the areas prone to destructive fires.

6 Spread of invasive species and disease

Warmer temperatures allow insects and pathogens to expand their range and increase winter survival. Mountain pine beetle, western spruce budworm, blister rust, and needle blight are just a few of the insects and pathogens on the increase in our forests because of climate change. Insects and pathogens affect approximately 3 million acres of Washington's forests, leaving them susceptible to major tree die-offs or fires in the next 15 years.[92] Mountain pine beetle outbreaks in Washington's lodgepole pine and whitebark pine forests are of particular concern because the beetles are spreading rapidly and migrating to higher-elevation trees.

Cheatgrass, another invasive species thriving because of climate change, is replacing native shrubs and grasses and is transforming the remaining shrub-steppe and grassland habitats.[93] Vast areas of shrub-steppe lands have already been converted to cheatgrass over the past century. Once established, cheatgrass is extremely difficult to eliminate.[94] In concert with hotter temperatures and reduced moisture from climate change, cheatgrass tends to increase the size of wildfires, as well as cause the wildfire season to begin earlier and continue longer into the fall. Cheatgrass and other invasive species recover quickly and thrive after fires, at the expense of many native species. Consequently, more frequent fires can lead to irreversible loss of native shrubs and grasses, threatening the habitat of species dependent on the shrub-steppe environment.[95]

[91] Mantua *et al*. (2010).

[92] Seattle Times (2011) citing DNR. See http://seattletimes.nwsource.com/html/localnews/2016699269_barkbeetle06m.html.

[93] Bradley (2009).

[94] Bradley (2009).

[95] Bradley (2009).

Recommended Adaptation Strategies and Actions—Ecosystems, Species, and Habitats

The five strategies and accompanying actions included in this section are intended to sustain species and natural systems as well as the critical ecological services they provide for human health and well-being. The strategies focus on the conservation, restoration, and improvement of ecological functions and processes, and promote ways to help species and ecosystems recover from the impacts of climate change and extreme events.

Strategy B-1. Conserve habitat necessary to support healthy fish, wildlife, and plant populations and ecosystem functions in a changing climate, and protect connectivity areas between critical habitats to allow the movement of species in response to climate change.

Actions:

1. Identify opportunities and priorities for habitat connectivity, such as buffers, wildlife corridors, and a connected network of conservation areas in Washington. This action builds on the work of the Washington Wildlife Habitat Connectivity Working Group and the Western Governors' Wildlife Corridors Initiative.

2. Increase the quantity, quality, and size of conservation areas, buffers, and connectivity corridors using the full range of conservation tools available. This action will enhance key habitat areas, facilitate migration opportunities for species vulnerable to climate change, and increase connectivity in areas at high risk from climate impacts, such as coastal habitats at risk of sea level rise.

3. Encourage partnerships with federal, tribal, and local government, private landowners, and conservation organizations to implement landscape planning and foster adaptation strategies and actions that protect and restore habitat corridors across jurisdictional and land ownership boundaries.

The Western Governors' Wildlife Corridors Initiative: Multi-state collaboration to protect migration corridors

In 2007, the Western Governors' Association (WGA) launched the Wildlife Corridors Initiative as part of its focus on "Protecting Wildlife Migration Corridors and Crucial Wildlife Habitat in the West." The Initiative is a multi-state, collaborative effort to improve knowledge and management of wildlife corridors and crucial habitat. Its main objective is to develop policies and tools to help states integrate important wildlife corridor and crucial habitat values proactively into planning decisions, promote best practices for development, and reduce harmful impacts on wildlife. A 2008 report presents several recommendations, including establishing a regional climate change adaptation information clearinghouse relevant to wildlife corridors and crucial habitat. The clearinghouse should include data and analysis tools, visualization and interactive mapping tools, and state-of-the-art tools to integrate climate predictions with current and future wildlife corridors and crucial habitat.

The clearinghouse will ensure that decision makers can easily obtain the best and most up-to-date scientific and policy information.

www.westgov.org/wga/publicat/wildlife08.pdf

4. Identify high-quality habitats and conservation areas that are minimally affected by (or resistant to) climate change, able to sustain diverse and healthy populations, and can be used as refugia for species under stress from climate change. Prioritize these areas for protection and ecosystem management.

5. Protect and restore high-quality freshwater habitat through the reintroduction of beavers, wetland mitigation and creation, groundwater recharge, flow augmentation, and protection of coldwater springs.

Climate refugia are areas where climate change is likely to occur more slowly or to a lesser extent than other areas, due to physical landscape features, such as north-facing slopes, valleys or other low areas that act as sinks for cold air, or streams fed by deep coldwater springs. These areas provide refuge to species under stress from climate change.

Wildlife habitat connectivity through a climate lens

The Washington Wildlife Habitat Connectivity Working Group is a science-based partnership of land and natural resource management agencies, organizations, tribes, and universities. The Washington Department of Fish and Wildlife and the Washington State Department of Transportation co-lead the working group. The group is conducting detailed analyses aimed at identifying habitat and linkage areas that will most likely continue to provide connectivity as climate changes and to accommodate climate-driven shifts in species ranges.

The first products addressing habitat connectivity and climate change can be found on the Working Group website.

www.waconnected.org/climate-change-analysis

Strategy B-2. Reduce non-climate stressors to help fish, wildlife, plants, and ecosystems be more resilient to the effects of climate change.

Actions:

1. Use and improve existing regulatory and enforcement programs to build the resilience of natural systems to climate change, including such efforts as the following:
   - *Protect and restore the connections between rivers and their floodplains.*
   - *Reduce existing pollution and contamination of freshwaters.*
   - *Manage freshwater withdrawals.*
   - *Maintain and restore streamflows and lake levels.*
   - *Reduce forest fuel buildup.*
   - *Reduce other human-induced impacts in watersheds most vulnerable to climate change.*
2. Define priorities for land management in areas important to biodiversity to emphasize resilience to fire and decrease the likelihood of severe fires.
3. Take early action to eliminate or control non-native invasive species that take advantage of climate changes, especially where they threaten native species or current ecosystem function.
4. Restore riparian zones, estuaries, wetlands, and floodplains by implementing appropriate conservation, restoration, and other land stewardship actions and practices, such as mitigation banking.
5. Collaborate with local governments to reduce and reverse habitat fragmentation and loss through comprehensive land use policies, zoning regulations, critical area ordinances, and other regulatory and non-regulatory approaches.

Changes in hunting and fishing opportunities

In 2008, the Theodore Roosevelt Conservation Partnership (TRCP) and a number of other national hunting and fishing groups produced a successful publication, Seasons' End: Global Warming's Threat to Hunting and Fishing, detailing the predicted impacts of global climate change in the habitat and distribution of fish and wildlife in the United States.

In the 2010 sequel, Beyond Seasons' End: A Path Forward for Fish and Wildlife in the Era of Climate Change, the TRCP and its partners provide recommendations to address the effects of climate change. Since the publication of these reports, the need for adaptation strategies to help fish and wildlife cope with our changing climate has become increasingly clear.

www.trcp.org/issues/climate-change

Mitigation banking is the restoration, creation, enhancement, or preservation of a wetland, stream, or habitat conservation area, for the purpose of providing compensation for unavoidable impacts to ecosystem resources that a proposed project would adversely affect.

Strategy B-3. Manage species and habitats to protect ecosystem functions and provide sustainable cultural, recreational, and commercial use in a changing climate.

Actions:

1. Incorporate climate change considerations into existing and new management plans for protecting sensitive and vulnerable species, using best available science regarding projected climate changes and trends as well as vulnerability and risk assessments. Modify protection and recovery plans to accommodate migration as well as longer-term shifts in species range associated with climate change and its effects.

2. Conduct and refine species and habitat vulnerability assessments (such as the Pacific Northwest Climate Change Vulnerability Assessment for Habitats and Species) and other scientific studies to determine appropriate management approaches.

3. Conserve genetic diversity by protecting diverse populations and genetic material across the full range of species. Such efforts may include identifying areas for seed collection across different elevations and across the ranges of target species.

Assessing the Vulnerability of Species and Ecosystems to Projected Future Climate Change in the Pacific Northwest

The Pacific Northwest Vulnerability Assessment project is designed to assist conservation and natural resource managers in understanding the potential effects of climate change on the species and ecosystems they manage. The project has six specific objectives:

- Downscale future climate simulations for the Pacific Northwest.
- Simulate potential future vegetation and habitat changes using vegetation models.
- Model potential shifts in the distributions of 12 or more focal animal species selected based on discussions with land managers from the region.
- Assess the vulnerabilities of species, ecosystems, and managed lands to projected changes in climate, vegetation, and species distributions.
- Summarize uncertainties in the simulated future climate, vegetation, and species distribution changes.
- Work with managers to incorporate research results into management plans.

An important component of this project involves collaborations with managers, scientists, and decision makers to integrate the research results into management and conservation plans, such as state wildlife action plans.

http://esp.cr.usgs.gov/info/nccwsc/vulnerability/index.html

Strategy B-4. Integrate climate adaptation considerations for species and ecosystems into natural resource and conservation planning, land use and infrastructure planning, and resource allocation and public investment initiatives.

Actions:

1. Incorporate climate change considerations for species, habitats, and ecosystem processes into planning and regulatory activities related to implementation of the Growth Management Act, Shoreline Management Act, Watershed Management Act, State Environmental Policy Act, and other state goals and policies.

2. Ensure that land and water resources managers at the state and local levels integrate adaptation options into plans, programs, and practices. These options should address and limit the impacts of climate extremes, such as severe storms, floods, droughts, and heat waves, without causing harm to fish, wildlife, habitats, and ecosystem functions.

3. Engage with cities and counties to support incorporation of climate change considerations into activities, guidelines, and both regulatory and non-regulatory programs that protect or conserve habitats and species. The changes should consider the impacts of climate change on habitats and species and potential for safeguarding priority habitats and species from the effects of climate change and catastrophic events.

4. Update natural resource protection plans, land use plans, and water resources management plans to address climate change considerations for species and ecosystems and to support habitat resilience in a changing climate.

5. Develop criteria and guidance to consider impacts of climate change on species and ecosystems when funding new infrastructure and economic development, mitigating impacts from ongoing degradation associated with human development, and compensating private landowners for conservation practices.

Strategy B-5. Build capacity and support for the adoption of response strategies that help protect and restore ecosystem function and services at risk from climate change.

Actions:

1. Establish an interagency, multidisciplinary forum (such as an interagency climate change task force) to strengthen existing partnerships and build new collaborations across jurisdictions. The forum would facilitate sharing new research and approaches to address climate impacts to ecosystems and to ensure that the needs of species, habitats, and ecosystems are considered in other areas such as agriculture, forests, infrastructure, and human health.

2. Increase coordination and participation in existing regional and national research and policy forums—such as the National Climate Assessment, Climate Science Centers, Regional Integrated Science and Assessment partnerships, and Landscape Conservation Cooperatives—to ensure that regional efforts recognize Washington's unique and important natural resources.

3. Develop and integrate messages about the benefits of ecological services at risk from climate change into education programs and curriculum related to natural resources management.

4. Initiate and support efforts to quantify the benefits of ecological services and natural systems at risk from climate change. Compare lifetime cost-effectiveness of nature-based versus engineered options for climate response to help identify cost-effective adaptation options.

5. Develop programs to engage citizens in monitoring impacts of climate change on our shorelines, forests, rivers and streams, and other natural systems and in sharing their observations, case studies, stewardship efforts, and other activities using multimedia resources.

6. Coordinate development and maintenance of integrated long-term, large-scale monitoring of early-warning indicators of species responses, including range shifts, population status, and changes in ecological systems functions and processes. Reconsider monitoring approaches to ensure that indicators track changes associated with climate change.

7. Develop applied tools for decision makers and land managers to maximize the adoption of climate adaptation strategies for species and ecosystems. Such efforts may include:

   - *Guidance, tools, and technical assistance to local governments to enable them to identify, designate, and protect locally important habitats, corridors, and species at risk from a changing climate.*
   - *Incentives, tools, and information to increase the contribution of working lands to ecological resilience.*
   - *Tools to promote nature-based alternatives to engineered adaptation options such as flood control, erosion control, and protection of water quality and quantity.*

6. Ocean and Coastlines

6. Ocean and Coastlines

Washington State has a unique array of coastal and estuarine environments along the Pacific Ocean and Puget Sound. Around 70 percent of Washington residents live in counties that border the coast.[96] Coastal tourism, marine industries, and Washington's robust commercial fishing industry provide important jobs that sustain coastal communities. Washington's coastal areas and marine waters are not only an important economic engine for the state but also are central to the quality of life we enjoy. They provide vital recreational, transportation, and cultural benefits to Washington residents and support a stunning array of wildlife.

Climate change imposes pressures on coastal environments already experiencing environmental stressors from human activities and population growth. Rising sea level, storm surge, ocean acidification, and other climate impacts will pose serious risks for coastal communities and wildlife.

Because Washington has more than 3,000 miles of marine shoreline and a growing coastal population, understanding and planning for the effects of climate change on these environments is of paramount importance. The following sections describe the scientific understanding of the impacts of climate change on Washington's coasts and outline key strategies to support state and local efforts to protect these areas and lower risks to our communities and ecosystems.

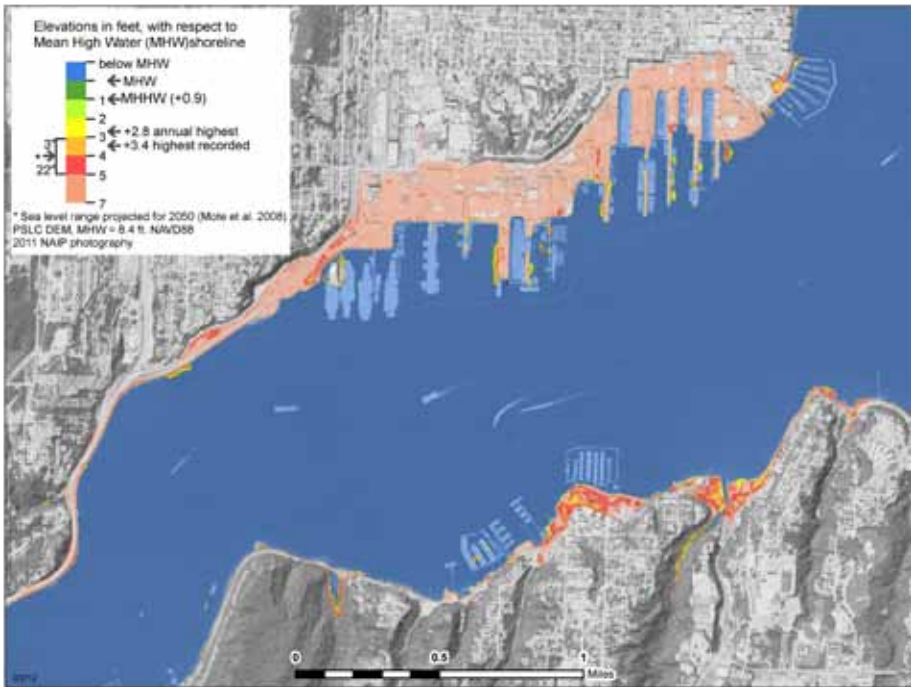
[96] U.S. Census Bureau (2010).

Impacts of Climate Change on Ocean and Coastlines

Climate change will affect coastal and marine environments in distinct ways:

- Sea level rise and storm surge will increase the frequency and severity of flooding, erosion, and seawater intrusion—thus increasing risks to vulnerable communities, infrastructure, and coastal ecosystems.
- Increased ocean acidity will affect marine ecosystems and Washington's commercial shellfish industry.[97]
- Warmer marine temperatures could alter the magnitude, frequency, and duration of harmful algal blooms and cause harmful effects to humans and animals.[98]
- Together, these impacts will have profound effects on Washington's coastal and marine areas and the resources they provide to our communities, wildlife, economy, and our way of life.

1 Sea level rise



Source: Washington State Department of Ecology

Global sea level is rising as a result of melting glaciers and ice caps and the expansion of warming ocean waters. Long-term tide gages and recent satellite measurements show that global sea levels rose approximately 8 inches from 1870-2008, an average of 0.06 inches per year. In the past decade, global sea level has risen at an accelerated rate of around 0.14 inches per year. Globally, sea level is expected to rise for several centuries due to current and projected greenhouse gas emissions and the oceans' delayed response to increasing global temperatures. [99] Current projections for global sea level rise by the end of this century are in the range of 3 to 4 feet or more, [100] well above the 7 and 23 inches that the Intergovernmental Panel on Climate Change projected in 2007.[101]

[97] Huppert *et al*. (2009); Feely *et al*. (2010).
[98] Huppert *et al*. (2009).
[99] IPCC (2007). Synthesis report
[100] Rahmstorf (2010).
[101] IPCC (2007a).

Sea level rise is expected to vary across regions of Washington State depending on several factors, such as changes in local land levels caused by tectonic movement, sedimentation patterns, and changes in wind patterns. Projections of sea level rise in Washington developed by Ecology and the University of Washington's Climate Impacts Group (see Table 1) indicate that Puget Sound and the central and southern outer coast (on the Pacific Ocean) are likely to experience more sea level rise than the northwest Olympia Peninsula. Through movement of the earth's crust, the northwest Olympic Peninsula is rising at a rate that is likely to offset rising sea levels in that region for most of the 21st century.[102]

Year	Puget Sound	Northwest Olympic Peninsula	Central and Southern Outer Coast
2050	+3 to +22 inches	-5 to +14 inches	+1 to +18 inches
2100	+6 to +50 inches	-9 to +35 inches	+2 to +43 inches

Table 1. Projected sea level rise estimates for Washington
Source: Mote et al. (2008).

Washington, Oregon, and California are jointly funding a National Academy of Sciences study to evaluate sea level rise on the West Coast for the years 2030, 2050, and 2100. The study will provide updated projections of sea level rise for Washington. The final report will be published in summer 2012 and will cover both global and local sea level rise factors and estimates.

2 Flooding and damage to coastal communities

Rising sea levels will increase the frequency and severity of coastal flooding, increase erosion, and result in greater levels of storm damage along developed shorelines. The hazards associated with coastal areas will grow, and the demand for protection and reconstruction will increase. Coastal defenses may become necessary in places where they do not yet exist. Existing defenses—including seawalls, and dikes—may become more vulnerable and need to be repaired or expanded.

At the same time, pressure for people to retreat from vulnerable areas and maintain natural coastal ecosystems will increase. Communities will face increasingly complicated decisions about balancing demands for stabilizing the shorelines with calls for protecting habitats and publicly accessible shorelines.

Hardened or armored shorelines

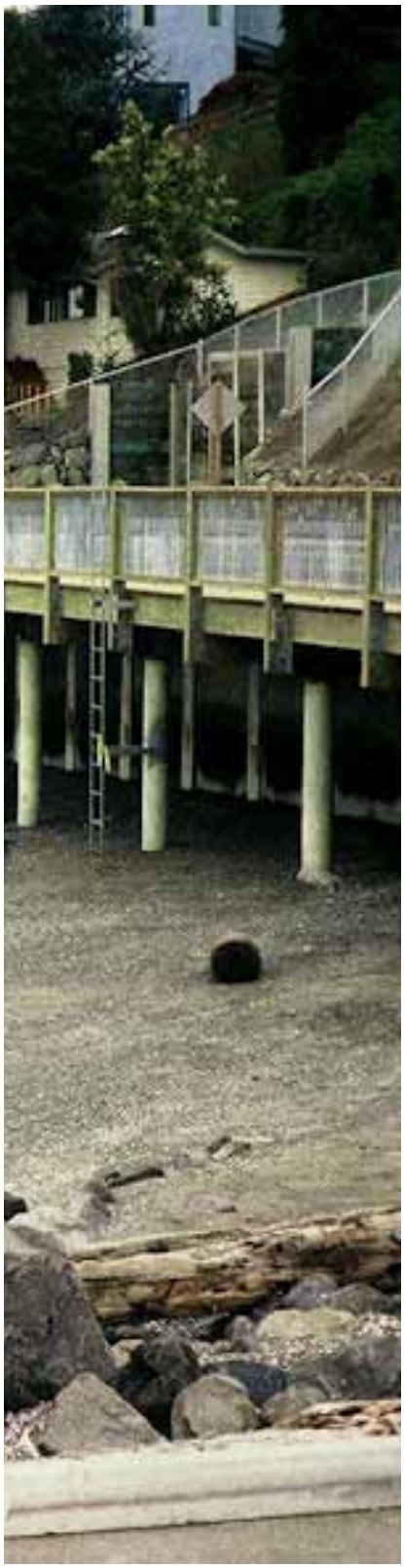
Many shorelines have been hardened with concrete, steel, gabions, or armor stone to prevent erosion. Such reinforcement usually results in the elimination of shoreline vegetation and cover that is important to fish and other wildlife.

[102] Mote *et al*. (2008).

With increased vulnerability to coastal hazards, many communities will need to increase their attention to emergency management, hazard mitigation, and the costs of preparing for and recovering from natural disasters.

Levels of risk vary by location, and many specific impacts, such as the following, are possible:

- Coastal roads will be subject to more frequent closures and more frequent repairs.
- Shoreline parks will be subject to increased damages and closures. Access to the water and to natural shorelines will become more difficult as water levels rise and people construct hardened shorelines in response.
- Intrusion of seawater could damage equipment and strain the capacity of wastewater and stormwater systems. Backflow of water through stormwater pipes could cause localized flooding in low-lying areas. Drainage of low-lying areas will become more difficult, and stormwater management may require installation of tide gates, control works, and pump systems.
- Higher water tables and increased flood events may increase corrosion of underground utilities.
- Contaminated sites within shoreline areas may be affected by changes to water tables and increased flooding, spreading contaminants to Puget Sound and coastal marine waters.
- Sea level rise may affect fuel storage facilities and pipelines. Large oil handling facilities constructed their tanks, containment areas, and pipeline conveyance systems based on current water levels. Changes to the water level could alter the stability of the ground or the flow of groundwater, increasing the chance of a spill reaching Washington waters.
- Increasing storm severity off the Pacific Northwest coast could increase the risk of vessel incidents and oil spills.
- Puget Sound river deltas will be more vulnerable to longer-duration flooding, high water tables, and increased salinity, which could affect coastal agriculture and restoration projects.



3 Increase in erosion

Rising sea level is expected to increase shoreline erosion and the vulnerability of low-lying coastal areas to storms and flooding. On bluffs, which compose much of Puget Sound's shoreline, rapid erosion rates may put upland structures at risk and increase the likelihood of landslides. On spits and barrier beaches, erosion is likely to accelerate, and the potential for flooding and storm damage to low-lying areas will increase. Residential communities built on spits are common both in Puget Sound and on Washington's ocean coast. High-tide storms and chronic erosion already pose significant threats to many of these communities, and these threats will increase in the future. Extreme high tides can damage structures and utilities, contaminate water supplies, and cut off emergency access.

Rising sea level, erosion, and changes in surface water runoff patterns will alter coastal sediment transport systems from current trends that are in relative equilibrium. These changes could result in the delivery of a large volume of eroded sediment to new areas, or to existing areas in newly increased quantities, disrupting both ecosystem services and human infrastructure. Examples include ports that will require more frequent dredging and aquaculture areas and other nearshore habitats (like eelgrass beds) that are impaired by additional sediment.

In addition, small bays that now have inlets with sheltered salt marsh habitats could close from sediment buildup, with significant impacts to the associated salt marsh and coastal ecosystem. These changes will cause additional loss of those habitats, along with others inundated by rising sea levels.

4 Disruptions and damages to ports and harbors

The ports of Seattle and Tacoma are important gateways for international trade, and are the third largest load center for containers in North America. Other major ports in Washington include the Ports of Everett, Bellingham, Olympia, Grays Harbor, Vancouver, Longview, and Port Angeles. Rising sea levels could affect port operations, damage seawalls and structures, and flood low-lying port land and surrounding transportation networks. The severity of impacts will depend on the local rate of sea level rise, the proximity to rivers subject to flooding, and the dependence of the port on vulnerable transportation links.

Marinas and waterfront recreation facilities could also require more frequent repairs and modifications. Changes in the water level and coastal erosion could submerge or undermine fuel tanks for marinas and other facilities, which often locate their tanks close to their operations.

5 Loss of coastal habitats

Beaches and nearshore areas provide critical habitat for innumerable species of fish and wildlife.

In their natural state, beaches and bluffs are fairly resilient to modest increases in sea level rise. Erosion may increase, but beaches can shift landward, preserving their associated habitats. In addition, increased erosion provides sediment to nearby beaches that makes them more resilient to rising water levels. On developed and armored shorelines, however, erosion is prevented, and higher sea levels will squeeze out beaches and nearshore habitats.

One of the challenges of rising sea level is that it will increase the pressure to harden the shoreline. Armoring of shorelines to protect upland development prevents the natural migration of sediment that maintains beaches and coastal marshes, resulting in more rapid beach erosion; loss of critical habitat for young fish, shorebirds, shellfish, and other species; and ultimately decreased resilience of coastal environments.

Rising sea levels may diminish and even destroy coastal marshes and wetlands. Some coastal wetlands may be able to migrate landward as sea level rises, but where dikes or natural topography prevent this movement, wetlands may be lost. In addition, salt marshes may be able to expand vertically as water levels rise but only if natural sources of sediment are maintained.

Nearshore environments along the Pacific coast and Puget Sound will likely face dramatic shifts in the extent and diversity of marshes, swamps, beaches, and other habitats.[103] With 27 inches of sea level rise, impacts to coastal ecosystems could include:

- Loss of two-thirds of the low tidal areas in Grays Harbor and Willapa Bay.
- Loss of 11 to 56 percent of freshwater tidal marsh in Grays Harbor, Willapa Bay, and Puget Sound.
- Loss of 40 percent of freshwater tidal areas in Whatcom, Skagit Bay, and Snohomish.[104]

[103] Glick *et al*. (2007).
[104] Ducks Unlimited (2010a, 2010b, 2010c, and 2010d).

6 Saltwater intrusion into coastal aquifers and rivers

Sea level rise could cause an increase in saltwater intrusion in coastal aquifers known to be hydraulically connected to saltwater bodies. The San Juan Islands and several coastal areas are susceptible to seawater intrusion. Groundwater is the main source of freshwater supplies for the Islands. The small amount of yearly precipitation keeps the islands' groundwater system in a fragile balance between the recharge rates and the groundwater pumping. Increased pumping rates may upset this balance and result in seawater intrusion into nearshore aquifers. Expert opinion suggests that sea level rise will have only a minor effect on coastal aquifers, however, and the amount of freshwater available is not expected to change for coastal areas. [105]

7 Increasing ocean acidity

The world's oceans absorb carbon dioxide (CO_2) from the atmosphere. As the oceans soak up excess carbon emissions, the chemistry of the seawater changes—both locally and globally. This absorption alters the ocean's natural acid-base balance. This move toward a lower pH value is called ocean acidification.

Washington State is particularly vulnerable to ocean acidification. Washington's coastal waters experience seasonal upwelling where waters that are naturally low in oxygen and rich in CO_2 rise to the surface. Coastal waters also receive excess nitrogen from human activities that can stimulate algae blooms. As these blooms die and sink, bacteria decompose them, depleting oxygen from the surrounding water. The combined effects of upwelling, nitrogen inputs, and low oxygen zones mean that Washington is likely to see the impacts of ocean acidification on marine organisms earlier than other coastal areas.

Ocean acidification and climate change

Ocean acidification is related to but distinct from climate change, though they share a common cause—increasing carbon dioxide in the atmosphere. Climate change encompasses the effects associated with changes in the Earth's temperature, which cause global warming and changes in weather patterns.

Ocean acidification refers to the lowering of ocean pH resulting from its increased absorption of carbon dioxide from the atmosphere. Ocean acidification does not include the warming of the ocean.

[105] Huppert *et al*. (2009).

Many animals and plants rely on calcium carbonate to form their skeletons or shells. The trend toward more acidic conditions can reduce the calcification in shellfish species including oysters, clams, scallops, mussels and other species. Acidified waters are suspected of contributing to a recent crisis in larval supplies in the Northwest's shellfish industry. The effects of ocean acidification are serious and real, putting at risk Washington's:

- Shellfish aquaculture.
- Commercial and tribal harvesting of wild shellfish resource.
- Important fish species that use marine plankton as a vital food source.

A decline in the shellfish and marine food web could also have serious economic consequences. Washington leads the country in production of farmed clams, oysters and mussels with an annual value of over $107 million a year.[106] Washington shellfish growers directly and indirectly employ more than 3,200 people and provide an estimated total economic contribution of $270 million each year. In addition, tourists and residents purchase more than 300,000 licenses to harvest clams and oysters from Washington waters, providing more than $3.3 million per year in state revenue.

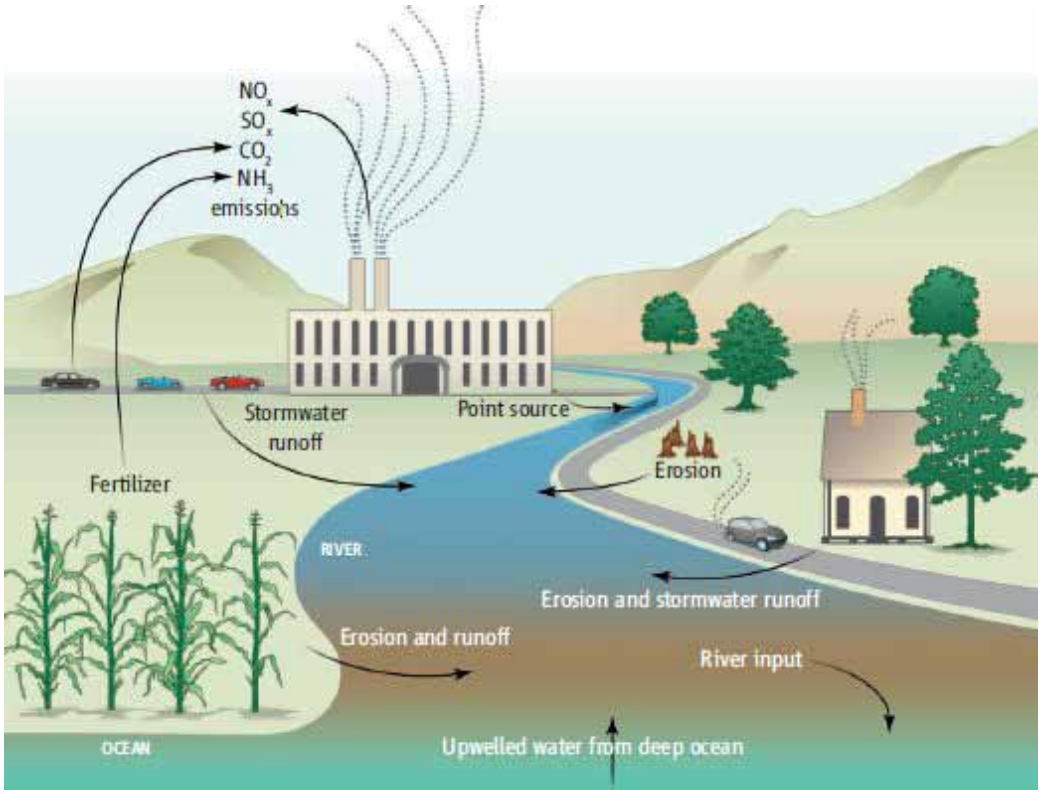


Figure 3. Contributors to ocean acidification[107]

[106] Northern Economics, Inc. (2010).
[107] Kelly *et al*. (2011).

8 Algae blooms and coastal hypoxia

Harmful algal blooms (HABs) are overgrowths of algae that can produce potent toxins. These toxins harm humans and other animals that eat contaminated fish or contact contaminated water. Warmer water and air temperatures promote algae blooms and may also promote earlier and longer-lasting blooms. Increase in nutrient rich runoff from rivers could also increase the frequency of algae blooms in coastal waters.[108]

Hypoxia: low oxygen concentration

More spring runoff and warmer coastal waters will worsen the seasonal reduction in oxygen resulting from excess nutrients. **Dead zones**—areas with low oxygen—are likely to increase in size and intensity as temperatures rise unless efforts to control runoff are strengthened.[109]

[108] Huppert *et al*. (2009).
[109] U.S. Global Change Research Program (2009).

Recommended Adaptation Strategies and Actions—Ocean and Coastlines

We already have some excellent tools and strategies for better managing our shorelines. The strategies and accompanying actions described below will help us better prepare for and adapt to climate change impacts on Washington's Pacific Coast, Puget Sound, and coastal communities by:

- Limiting new development in highly vulnerable areas.
- Protecting the shoreline from rising sea levels using green or "soft" alternatives to traditional "hard" shore armoring, seawalls, and dikes.
- Accommodating rising sea levels through engineering and construction practices or raising the height of piers or buildings.
- Managing retreat from highly vulnerable sites.
- Restoring and maintaining wetlands, preserving sediment transport processes, and preserving habitat for vulnerable species.
- Enhancing monitoring and research of ocean chemistry changes and effects on marine ecosystems.

Managed retreat:

Managed retreat is the deliberate process of altering barriers or other defenses to allow flooding of a presently defended area. Such efforts can reduce both coastal flooding and erosion. Managing this flooding process helps to reduce risk and negative impacts.

Strategy C-1. Lead by example by developing a state framework to guide decision-making and protect people, assets, and natural areas from coastal hazards.

Actions:

1. Evaluate and propose revisions of laws and rules that govern land use, shoreline management, and other programs to effectively address sea level rise and other climate change impacts.

2. Develop guidance and require state agencies to integrate current and anticipated coastal climate impacts into planning, policies, programs, and investment decisions related to:

   - *Land use.*
   - *Transportation.*
   - *Shoreline management.*
   - *Economic development.*
   - *Facility siting and design.*
   - *Conservation and restoration.*
   - *Emergency preparedness.*

3. Require all projects that the state funds, permits, or approves in vulnerable coastal areas to consider the effects of sea level rise and other coastal hazards. Evaluate alternatives to reduce vulnerability and protect communities and coastal ecosystems.

4. Identify essential public infrastructure at risk and develop a decision-making process to determine when to protect, retrofit, relocate, or manage retreat.

5. Revise oil spill response plans to consider climate change. The plan revisions should include geographic-specific response strategies based on risk assessments and considerations of changes in infrastructure and logistical support.

6. Recommend an institutional arrangement to align state agencies' coastal adaptation strategies and actions, help prioritize actions across state agencies, and enhance emergency preparedness and response to extreme weather events.

Strategy C-2. Avoid development in highly vulnerable areas and promote sustainable development in appropriate, less vulnerable areas.

Actions:

1. Provide guidance, updated maps, tools, and information to help local jurisdictions assess risk and vulnerability and incorporate best available information on sea level rise, climate impacts, and adaptation options into their planning, regulations, project siting, and permitting.

2. Identify incentives and regulatory tools to reduce exposure to risk and discourage new public development in coastal areas at high risk from erosion, landslides, flooding, and storm surges. The tools should include:
   - *Acquisitions and easements.*
   - *Transfers of development rights.*
   - *Setbacks.*
   - *Rebuilding restrictions.*
   - *Tax incentives and fees.*

3. Update various planning guidelines and provide incentives to local governments to consider impacts of climate change and adaptation actions when amending shoreline master programs, land use management plans, and other plans.

4. Develop policies and information to guide insurers in dealing with properties in vulnerable areas. Inform property purchasers and investors regarding sea level risks that may affect coastal property.

5. Assess damage costs and remove incentives that encourage rebuilding in at-risk areas.

6. If rebuilding is the only option, construction techniques and building code amendments should be adopted to increase resilience and reduce risk to development projects.

Swinomish Climate Change Initiative

In 2008, the Swinomish Indian Tribal Community started work on a landmark two-year Climate Change Initiative to study the impacts of climate change on the resources, assets, and community of the Swinomish Indian Reservation and to develop recommended actions to adapt to projected impacts.

With expert assistance from scientists at the University of Washington Climate Impacts Group, in 2009 the Tribe issued the *Impact Assessment Technical Report*, an assessment of projected impacts. The report identified potential impacts from sea level rise and storm surge on infrastructure and tribal land. Detailed maps were developed highlighting coastal inundation risk zones on tribal lands and in neighboring areas.

In 2010, the Swinomish published the *Climate Adaptation Action Plan* outlining actions to help build a climate-resilient community that can meet the challenges of anticipated climate impacts in the years to come.

www.swinomish-nsn.gov/climate_change/climate_main.html

Strategy C-3. Accelerate efforts to protect and restore nearshore habitat and natural processes.

Actions:

1. Identify priority conservation and restoration areas that can increase natural resiliency and protect vulnerable communities. Identify regulatory and non-regulatory mechanisms that local jurisdictions can use to conserve and protect those areas.

2. Develop guidelines for state agencies, local governments, watershed groups, nongovernmental organizations, and others to address sea level rise in coastal habitat restoration and protection. Direct state agencies to use the guidelines to incorporate sea level rise into state-managed and supported coastal restoration and protection projects.

3. Identify feasible state level policy options to avoid or minimize shoreline hardening, especially in Puget Sound. Policy options should seek to streamline state and local permitting processes to provide incentives for green shoreline and soft armoring practices.

4. Develop a program to promote green shoreline programs for Puget Sound and some urbanized coastal areas. This program can be built on the lessons learned from pilot projects currently in progress in San Juan County and Lake Washington (City of Seattle), as well as the green shores initiative in British Columbia.[110] Develop and provide state and local jurisdictions with green shoreline design manuals for different types of shoreline along Puget Sound and the Pacific coast.

5. Incorporate future sea level rise in the prioritization, design, and post-project maintenance of toxic clean-up sites near the shoreline.

[110] For more information on green shores in Canada, visit www.greenshores.ca

Strategy C-4. Build local capacity to respond to coastal climate impacts by providing tools to assess vulnerability and advancing research, monitoring, and engagement efforts.

Actions:

1. Complete a coast-wide (including Puget Sound) sea level rise vulnerability assessment. Update periodically as new and improved scientific information becomes available.

2. Identify and provide local jurisdictions with information, web-based tools, training, case studies, locally effective adaptation policies and actions, and other resources needed to build resilient coastal communities. Case studies could address, for example, how communities are using the National Oceanic and Atmospheric Administration's (NOAA) Digital Coast, which provides data, tools, and training to help manage coastal resources.

3. Assist coastal planners with activities such as:
   - *Simulating potential impacts of long-term sea level rise on wetlands and shorelines.*
   - *Analyzing risks and potential losses from floods, sea level rise, and storm surges.*
   - *Mapping hazard areas.*
   - *Assessing and evaluating the risks from sea level rise and other climate change impacts in local jurisdictions.*
   - *Enhancing sustainable development in coastal areas.*
   - *Identifying community exposure to climate change—considering land cover, land use, zoning, structures, vacant lots, parcel values, and social disruption.*

4. Identify potential funding mechanisms and help local governments seek funding to incorporate climate adaptation into plans, policies, and projects.

Washington's Coastal Planning for Climate Change Training

The Coastal Training Program's Planning for Climate Change course is designed for planners to increase awareness about climate impacts to Pacific Northwest shorelines and specific action steps to prepare for climate change.

The Coastal Training Program provides practical, science-based training to professionals who make decisions about coastal management in Washington State. The program is administered through the Padilla Bay National Estuarine Research Reserve, which is part of the Department of Ecology and NOAA.

www.coastaltraining-wa.com

5. Assist local jurisdictions in raising awareness about the impacts of sea level rise and the need for adaptation actions by providing educational materials, participating in local events, and engaging the communities in efforts such as the King Tides, Washington Beach Program, and water quality monitoring programs.

6. Collaborate with local partners—including local governments, tribal governments, federal agencies, universities, nonprofits, NOAA Sea Grant, and National Estuarine Research Reserves—to monitor the effectiveness of climate adaptation tools and options and to identify changes that are needed.

7. Expand essential data collection and monitoring programs to improve our understanding of climate impacts, including:
   - *The impacts of sea level rise and storm surge on the shoreline.*
   - *Changes in erosion.*
   - *Unstable bluffs.*
   - *Saltwater intrusion and inundation of freshwater areas.*

8. Develop an inventory of dikes, levees, tide gates, clean-up sites, nearshore fuel storage facilities, and other facilities. Provide this information to local jurisdictions and others to plan for and adapt to rising sea levels and coastal hazards and to aid investment decisions in coastal areas. Ensure that the inventory products and maps are widely available to planners, agencies, tribes, and other users.

Strategy C-5. Enhance our understanding and monitoring of ocean acidification (pH) in Puget Sound and coastal waters as well as our ability to adapt to and mitigate effects of seawater acidity on shellfish, other marine organisms, and marine ecosystems.

Actions:

1. Support the work of the newly created Blue Ribbon Panel on Ocean Acidification, convened under the auspices of the Washington Shellfish Initiative. The Panel will focus on documenting the current state of scientific knowledge and ways to advance our scientific understanding of the effects of ocean acidification. The Panel will recommend actions to respond to increasing ocean acidification, reduce harmful effects on Washington's shellfish and other marine organisms, and adapt to the impacts of acidified waters. A report will be submitted to the Governor, NOAA's administrator, regional research groups, and other policymakers in October 2012.

2. Expand collaboration with NOAA Fisheries, other federal agencies, nonprofit organizations, academic groups, and the shellfish industry to enhance monitoring to track biological and chemistry changes in the Pacific Ocean, Puget Sound, and coastal areas of Washington, including key areas such as Hood Canal and Willapa Bay.

Washington Shellfish Initiative

In December 2011, Washington became the first state in the nation to have the Governor endorse an agreement among federal and state government, tribes, and the shellfish industry to respond and expand Washington's shellfish resources, promote clean-water commerce, and create family-wage jobs.

The agreement builds on the National Shellfish Initiative created by the National Oceanic and Atmospheric Administration (NOAA) to stimulate coastal economies and improve the health of ailing estuaries through increasing commercial shellfish production and native shellfish populations and habitats in our nation's waters.

As a part of the Washington Shellfish Initiative, and with strong support from the NOAA administrator and scientists, Governor Gregoire has convened a Blue Ribbon Panel on Ocean Acidification of leading tribal, local, state, and federal policymakers; scientific experts; public opinion leaders; and industry representatives.

For more information:

www.ecy.wa.gov/water/marine/oceanacidification.html

NANOOS: Creating customized ocean information and tools

The Northwest Association of Networked Ocean Observing Systems (NANOOS) is a partnership of federal and state agencies, local governments, tribes, nongovernmental organizations, industry, and educational institutions involved in a wide range of decisions about our oceans and estuaries.

NANOOS is the regional association of the national Integrated Ocean Observing System (IOOS) in the Pacific Northwest, primarily Washington and Oregon. The system operates several buoys in the Puget Sound monitoring hypoxia (low oxygen concentrations), algae blooms (indicated by chlorophyll), and climate effects (especially on temperature, salinity, and underwater sunlight penetration).

A pilot project between NANOOS and the National Estuarine Research Reserve System is providing real-time water quality data for shellfish growers in the Pacific Northwest, which can help oyster growers determine whether oysters have enough oxygen.

www.nanoos.org

3. Coordinate with state and federal agencies to improve monitoring by evaluating and adopting improved pH measurement protocols to support fine-scale data analysis and tracking of small changes in pH. Create a new baseline data set.

4. Continue to actively address problems of pollutants in marine waters (which add to acidity problems) by studying toxics and nutrients entering Puget Sound. Develop models to determine the effects of nitrogen discharges on dissolved oxygen levels in Puget Sound. Evaluate trends in water quality over time and detect emerging issues.

5. Continue to explore how Clean Water Act authorities can be used to prevent or reduce localized effects from ocean acidification and climate change.

7. Water Resources

7. Water Resources

A reliable supply of water is vital for the communities, businesses, industries, ecology, and quality of life in Washington State. Washington communities rely to varying degrees on our snow-fed water supply to provide safe and clean drinking water. Our $2.5 billion irrigated agriculture industry, which helps drive the local and state economy, relies on water to irrigate crops. That same water also feeds rivers and streams that support salmon, a state icon and valuable commercial fishery. Washington's abundant hydropower resources supply two-thirds of the electricity for the state.

The impacts of climate change will intensify our current challenges in managing water resources in Washington. The state's water resources are already under stress from:

- Excessive water withdrawals.
- Increasing conflicts among water users and demands on water resources.
- Increasing water quality degradation.
- More frequent and intense droughts and floods.
- Loss of species, habitats, and ecosystems.

Climate change impacts will vary across different watersheds in Washington. More frequent and extreme precipitation events will likely strain our urban stormwater systems and increase the amount of polluted runoff flowing into Puget Sound. Flood risk will increase for some basins in the state, putting people and infrastructure in harm's way.

Climate change will increase the variability—widening the range—of future supply and demand of water. As climate change shifts the timing and volume of streamflow and reduces snowpack, lower flows during the summer will make it more difficult to maintain an adequate supply of water for communities, agriculture, and fish and wildlife. Lower summer flows and higher stream

temperatures will continue to degrade our water quality and place further stress on salmon.

Our current management systems for water are designed around past patterns of temperature and precipitation. Preparing for and adapting to the impacts of climate change will require new management approaches that take into account how future conditions are likely to change. Many initiatives are in place and partners are engaged in addressing these challenges and anticipating future needs, using approaches such as:

- Conservation and demand management.
- Technical innovations.
- Water transfers, markets, and water banks.
- Infrastructure improvements.
- Enhanced information systems and hydrologic forecasting.
- Water management and efficiency practices.

However, no single project or initiative can adequately address the challenges we face and the tradeoffs we need to make. Our region needs well-coordinated adaptation strategies at the state, local, and regional levels to improve resiliency, reduce risks, and increase water sustainability. Long-term integrated planning and investing in comprehensive actions at a region or basin level will help prepare Washington for future changing climate and balance our water management objectives related to:

- Water availability and demand.
- Water quality.
- Agriculture.
- Fish and wildlife.
- Flood and storm control.
- Hydropower.
- Navigation, recreation, and tourism.

Washington's quality of life depends on adequate, reliable amounts of clean water. The sections below describe the scientific understanding of the impacts of climate change on Washington's waters, followed by key strategies and recommended actions to protect these waters and lower risks to our communities and ecosystems.

Impacts of Climate Change on Water Resources

Climate change has already altered and will continue to alter the snowpack and streamflows in the western United States, affecting where, when, and how much water is available for all uses.[111] Projected climate change impacts include:

- Reductions in the amount of water naturally stored in snowpack and glaciers, due to rising temperatures and increasing winter runoff.
- Declining late summer streamflow, increasing demand for water, and more intense competition for scarce water resources.
- Increases in winter precipitation, posing additional challenges for managing reservoirs for flood control, fish, and hydropower.
- Reduced water quality due to lower late summer streamflow, warmer summer temperatures, and increased winter flooding.

1 Declining snowpack and loss of natural water storage

During the winter, when the majority of precipitation occurs, snow accumulates in upper elevations and forms a "natural reservoir" that stores water during times when demands are relatively low. As the climate warms, more precipitation falls as rain and less as snow, leaving less water naturally stored in snowpack and glaciers. The snow melts earlier in the spring, and less water is available to feed our streams in the late summer when demands for water are highest.

Widespread declines in spring snowpack have already occurred across the western U.S., especially since the 1950s.[112] Greater losses in snowpack have been observed in mid-elevation mountain ranges such as the Cascades, where sensitivity to changes in temperature is high. Snow is melting earlier, and peak runoff occurs from 1 to 4 weeks earlier across much of the western U.S. than in the 1950s.[113]

These patterns are expected to continue and further alter the hydrologic behavior of many watersheds in Washington. Spring snowpack across the state is projected to decrease 29 percent by the 2020s, 44 percent by the

[111] Hidalgo *et al*. (2009).
[112] Mote *et al*. (2005).
[113] Stewart *et al*. (2005)

2040s, and 65 percent by the 2080s (relative to the 1971-2000 average) under a moderate emissions modeling scenario (A1B). The low emissions scenario (B1) shows slightly less severe projected decreases of 27 percent for the 2020s, 37 percent for the 2040s, and 53 percent for the 2080s.[114]

2 Changes in seasonal streamflow

Increasing temperature, declining snowpack, and earlier snowmelt are expected to shift streamflow timing. The impact will differ by basin type (see Figure 4), however. Hydrologic modeling shows that:

- **Mixed rain- and snow-dominated basins**, such as the Yakima River, are likely to shift to rain-dominated basins. Peak streamflow will shift earlier in the spring and late summer streamflow will decline.
- **Snow-dominated basins**, such as the Columbia River, are likely to see reduced peak spring streamflow, increased winter streamflow, and reduced late summer flow.
- **Rain-dominated basins**, such as the Chehalis River, will likely see relatively little change in streamflow timing. However, they will likely experience higher winter streamflow, due to the potential for more winter precipitation.

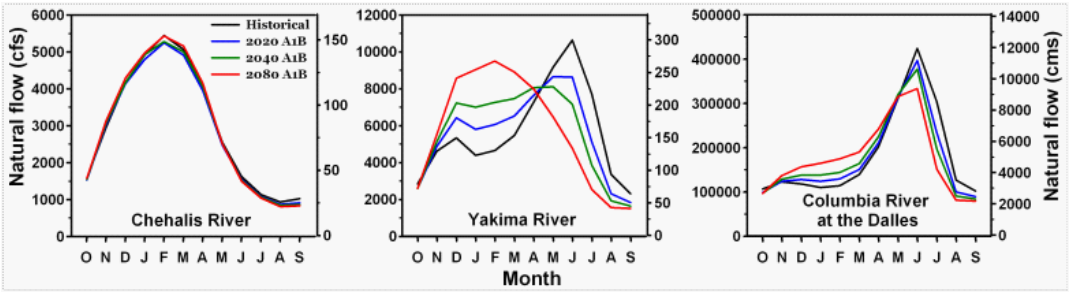


Figure 4. Projected average monthly streamflow for a rain-dominated watershed (Chehalis River), a mixed rain-snow watershed (Yakima River), and a snowmelt-dominated watershed (Columbia River). Hydrographs represent monthly averages of simulated daily streamflow for 1916-2006 and three future periods: 2020s, 2040s, and 2080s. (Elsner et al. 2010)

[114] Elsner *et al*. (2010).

In the winter, average runoff is projected to *increase* by:

- 11 to 13 percent by the 2020s.
- 16 to 21 percent by the 2040s.
- 26 to 35 percent by the 2080s.[115]

In the summer, average runoff is projected to *decrease* by:

- 16 to 19 percent by the 2020s.
- 22 to 29 percent by the 2040s.
- 33 to 43 percent by the 2080s.[116]

Yearly precipitation changes are expected to be small overall. Seasonal patterns are expected to intensify, however, with most (but not all) models projecting more winter precipitation and less summer precipitation. Extreme precipitation events are also projected to increase in Washington. Future changes in precipitation due to climate change may be difficult to distinguish from natural variability, given the wide range of natural variability in annual and seasonal precipitation in the Pacific Northwest.

3 Higher drought risk and more competition for scarce water resources

Climate change is expected to increase the risk of summer water shortages and increase demand for water, which will intensify competition for water for both instream and out-of-stream uses.

Yakima Basin: Water shortages are projected to occur more frequently in the Yakima Basin, and the reservoir system will likely face difficulty supplying water to all users, especially those with junior water rights. The average production of apples and cherries could decline by approximately $23 million in the 2020s and by $70 million in the 2080s.[117]

Salmon in the Columbia Basin: Lower summer streamflow and higher stream temperatures will substantially reduce the quality and extent of freshwater salmon habitat.[118] By the 2080s, the duration of stream

[115] Relative to 1916-2006. Elsner *et al*. (2010).
[116] Relative to 1916-2006. Elsner *et al*. (2010).
[117] Stöckle *et al*. (2010).
[118] Mantua *et al*. (2010).

temperatures that cause thermal stress and migration barriers for salmon is projected to at least double and possibly quadruple for most streams in the interior Columbia Basin.

Hydropower: Summertime hydropower production is likely to decline by 9 to 11 percent by the 2020s. Meanwhile, summer demand for energy will increase significantly due to higher electricity needs from air conditioning as well as population growth.[119]

Puget Sound water supplies: Urban water supply systems in Puget Sound will collect less water in their reservoirs in late spring and early summer. Climate change impacts could result in water demand increases of as much as 12 percent by 2060.[120] Many of the region's water utilities have adapted in the past to fluctuations in water supplies and are actively implementing and planning long-term adaptations to respond to climate change challenges.

Small water systems and groundwater: Increased drought risk could alter drinking water supplies for small public, private, and independent water systems. Many communities in rural areas rely on groundwater, which could be affected by climate change. Reductions in spring and summer streamflow could limit surface water supplies, triggering heavier reliance on groundwater. On the "plus" side, warmer, wetter winters could increase the amount of water available for groundwater recharge.[121] The impacts of climate change on groundwater sources of supply are not well understood, however, and this area needs further study.

Forests: Drought stress is likely to reduce forest productivity in eastern Washington. The area of severely water-limited forests is projected to increase 32 percent by the 2020s and an additional 12 percent in the 2040s and 2080s.[122] Drought-stressed forests may be more susceptible to mountain pine beetle outbreaks.[123]

Wildfires: Warmer temperatures and reductions in summer precipitation will likely increase the areas burned by wildfire. Wildfires disrupt the watershed processes through erosion, warmer water temperatures, increased stormwater runoff, and loss of forest canopy. These changes will likely alter the soil's capacity to retain water and recharge aquifers.[124]

River navigability: Reductions in summer water levels could also affect the navigability of rivers and lakes in the region, although the risk is not well understood.

[119] Hamlet *et al*. (2010).
[120] Water Supply Forum (2009).
[121] U.S. Department of the Interior, U.S. Bureau of Reclamation (2011).
[122] Littell *et al*. (2010).
[123] Littell *et al*. (2010).
[124] U.S. Global Change Research Program (2009).

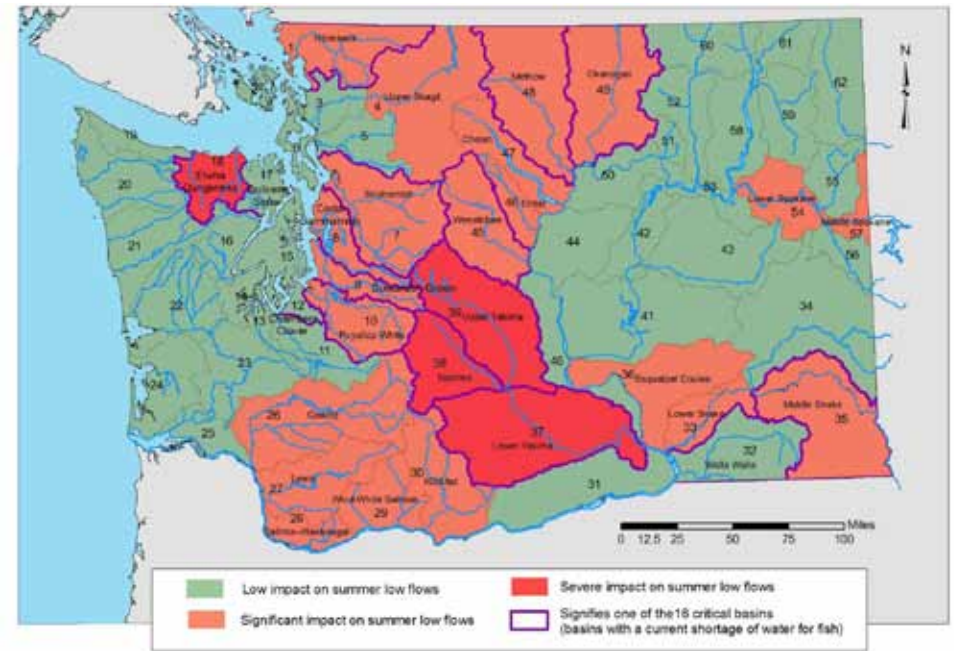


Figure 5. 2040 Projected climate change impact on summer flows by watershed. Climate change will intensify current water needs of people, fish, and farms in at least 45 percent of the state, shown in red on the map.

Source: Washington Department of Ecology

4 More severe winter flooding

Washington already faces challenges from severe flooding, and the damages can be very costly. Projected increases in winter runoff, increases in winter precipitation, and more intense precipitation will increase the frequency of flooding, particularly for mixed rain/snow-dominated basins sensitive to changes in temperature. For many large rivers near major population centers in western Washington, the magnitude of the 100-year flood under natural conditions is projected to increase by 20 to 30 percent by the 2040s (see Figure 6).[125] Low-lying, rain-dominated basins show modest increases in winter flood frequency due to projected increases in winter precipitation and extreme precipitation events.

Flood frequency east of the Cascades is typically driven by rapid spring snowmelt, particularly in snow-dominated basins. In general, snow-dominated basins are expected to experience

[125] Hamlet *et al*. (2010).

minimal changes in flood event frequency due to anticipated climate changes, and spring flood event frequency could decline in some eastern Washington basins because of declines in spring snowpack.

More frequent flooding poses challenges for managing reservoirs for flood control, fish, and hydropower production. More flooding will strain existing flood control infrastructure, such as reservoirs, dikes, levees, tide gates, and dams. Flooding, erosion, and rising snow/freeze-thaw levels increase the flow of sediment to lower elevations in watersheds, potentially changing the width and depth of stream channels. Low-lying buildings, roads, energy facilities, wastewater facilities, and other infrastructure in or near floodplains or along coastal areas will be at a higher risk of flood damage. The risk of erosion, landslides, and mudslides could also increase. In Puget Sound and lower elevation basins in the interior Columbia basin, winter flood risk will likely increase the risk of streambed scouring of spawning habitat.[126]

[126] Mantua *et al*. (2010).

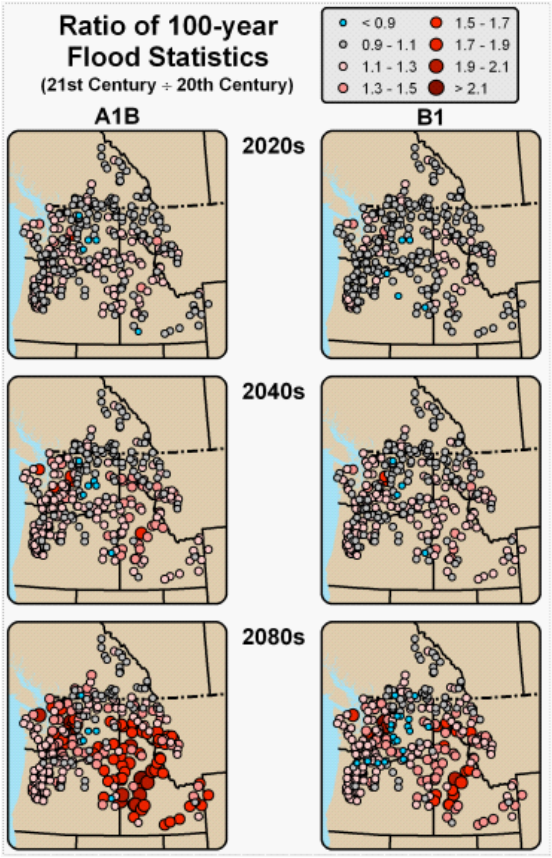


Figure 6. Maps of the ratio of the 100-year flood magnitude (future/historical) for three future time intervals, under two climate scenarios. (Higher ratios, shown with larger dots in red, indicate more intense flooding events projected for the future). (Source: Tohver and Hamlet 2010)

5 Declining water quality

Projected increases in temperature, winter flooding, and prolonged low summer flows will pose challenges for water quality. High runoff during the wet winter months will increase the flow of polluted runoff into waterways. Stormwater flows over the land and carries with it pollutants from the ground or paved surfaces, such as car oils, antifreeze, brake lining dust, pet and farm waste, fertilizers, and pesticides. Stormwater is the leading contributor to pollution of urban waterways in Washington, and this polluted runoff endangers sensitive species and habitats.

Winter flooding could also strain the capacity of urban drainage infrastructure and result in more frequent overflows. In coastal communities, marine water could inundate wastewater and stormwater systems and could discharge water into the streets from flooded storm drains.

Warmer and drier summers, and elevated stream temperatures could potentially impact the established water quality standards for rivers and streams and the effluent limits (amount discharge to the water body) set on existing wastewater treatment facilities.

Recommended Adaptation Strategies and Actions—Water Resources

Many water resources managers and users are already engaged in efforts to improve Washington's ability to respond to climate change. The recommended strategies and actions below are aimed at reducing climate risks and vulnerabilities, while accommodating non-climate demands of a growing population, ecosystem restoration, clean energy production, and protection from drought and floods.

Strategy D-1. Manage water resources in a changing climate by implementing Integrated Water Resources Management approaches in highly vulnerable basins.

Actions:

1. Ensure that long-range plans developed for highly vulnerable basins—including the Columbia, Yakima, and Walla Walla river basins—account for climate change impacts. Consider the risks and vulnerabilities to water resources and infrastructure, agriculture, forest, and other sectors. Integrate adaptation actions into basin plans to enhance water supply reliability, improve water quality, and improve instream flows and fish passage at existing reservoirs.

2. Promote broader recognition that an integrated approach is feasible and beneficial, by documenting lessons learned and conclusions from the implementation of integrated water resources management plans in the Columbia, Yakima, and other river basins.

3. Expand the models of the Columbia River Program, the Yakima River Integrated Water Management Plan, and the Walla Walla flexible water management system to other basins (such as the Dungeness and Wenatchee river basins), sub-basins, and aquifers, based on:

   - *Existing and emerging water management issues.*
   - *Need for integrated planning.*
   - *Community and stakeholder engagement.*
   - *Legal and institutional framework.*
   - *Capacity to develop and implement an integrated plan.*

4. Develop guidance for analyzing whether and how to incorporate projected climate information and adaptation actions into planning, policies, and investment decisions. The analysis would help state, local, federal and tribal governments and water organizations understand how changes in watershed hydrology, ecosystems, water quality, and species and habitat conditions in a given watershed may affect activities such as:

   - *Water allocation decisions.*
   - *Water delivery.*
   - *Water systems operations.*
   - *Water quality standards.*
   - *Stormwater and floodplain management.*
   - *Infrastructure safety.*
   - *Ecosystem restoration and species recovery.*
   - *Environmental preservation and restoration efforts.*

5. Incorporate climate change realities—recognizing that past hydrological data are no longer a reliable guide to project future conditions—into agency decision-making to:
   - *Approve new or change existing water rights.*
   - *Adopt instream flows for fish habitat and ecological purposes.*
   - *Decide whether water users are able to use their water rights for the amount allowed, when purchasing or banking trust water rights.*
6. Use the watershed-based framework created under Watershed Planning (RCW 90.82) to establish a well-coordinated water and land use policy that takes an integrated approach to planning. Such plans should reduce risks to rural and urban communities from extreme weather events (such as intensive flooding and frequent droughts).
7. Integrate climate change adaptation into ongoing efforts that address management of stormwater, wastewater, water quality, water reuse, and potable water demand—to ensure that planning decisions and investments made now are not increasing future vulnerability and causing unintended consequences. Require consideration of the impacts of extreme weather events in planning, siting, and designing of water, wastewater, and stormwater infrastructure and related facilities.

Integrated Water Resources Management in the Yakima Basin

Water shortages are a chronic problem in the Yakima River Basin. Demand for water to irrigate crops, provide drinking water and ensure salmon and steelhead survival is greater than available supply.

In 2009, Ecology and the U.S. Bureau of Reclamation brought representatives from the Yakama Nation, irrigation districts, environmental organizations, and federal, state, and local governments to develop a consensus-based solution to the basin's water problems. The group agreed upon a proposed approach to improving water management in the Yakima River Basin—an Integrated Water Resources Management (IWRM) plan.

The IWRM Plan, the most comprehensive effort to date in the Yakima Basin, includes seven elements: reservoir fish passage, structural and operational changes to existing facilities, surface water storage, groundwater storage, habitat and watershed protection and enhancement, enhanced water conservation, and market reallocation of water. The new plan has brought together once-conflicting water interests to support the plan.

Yakima River Basin Integrated Water Resource Plan:

www.usbr.gov/pn/programs/yrbwep/2011integratedplan/plan/integratedplan.pdf

Strategy D-2. Improve water supply and water quality in basins most likely to be affected by changing climate.

Actions:

1. Strengthen and increase the capacity of natural systems to respond to droughts, streamflow changes, and flooding by encouraging local governments to adopt land use policies and best practices. Examples include practices that reduce impervious surfaces to protect surface water quality, improve infiltration, and reduce stream erosion and sedimentation. These policies and practices would:
   - *Direct development away from vulnerable areas.*
   - *Decrease flood risk.*
   - *Expand the protection and restoration of prime agricultural and forest lands, aquifer recharge areas, wetlands, floodplains, and wildlife habitat and corridors.*
2. Encourage the state Department of Natural Resources and the U.S. Forest Service to develop and implement forest management practices that would improve water-holding capacity in watersheds and help protect water quality from increased temperature, erosion, and associated pollutants.
3. Support new surface and aquifer storage by capturing winter and spring runoff to make up for summer low flows, where feasible and environmentally sound; and increase storage capacity in existing reservoirs. Doing so could improve water supply reliability, and enhance instream flows, if and when stored water is released during low flow conditions.
4. Conserve water and support water reuse, retention, and infiltration by designing development sites to minimize water needs (such as drought-tolerant landscaping), retaining graywater and stormwater on site and using reclaimed water, and expanding adoption of low-impact development (LID).
5. Foster the development of climate-ready water utility initiatives. Highlight existing utility efforts to evaluate and incorporate climate information into planning, and support the development of peer-to-peer information sharing. Assist water and wastewater utilities,

along with stormwater and floodplain managers, in implementing climate change adaptation and mitigation strategies, with the goal of fostering more resilient water systems. Provide water system planners and operators with the knowledge, capacity, resources, and skills necessary to adapt to a changing climate and continue to fulfill their public health and environmental missions.

6. Support the development and delivery to water utilities of early-warning or rapid-response information, to address challenges and disaster risk to water systems from extreme climate events, such as devastating floods, droughts, fires, and storms.

7. Aggressively pursue reallocation and redistribution of water in critical basins, through water transfers, water transactions, water markets, and water banks with the goal of increasing streamflows for fisheries and improving habitat conditions.

8. Work with federal and local partners to improve the performance of existing water infrastructure, such as reservoirs, to respond to extreme events that may result from climate change and to improve local water supplies.

Columbia River Basin

A temperature-sensitive cycle of snow accumulation and melting dominates surface water flows in the Columbia River Basin. Average temperatures are 1.5ºF higher in the Columbia River Basin than they were a century ago, and annual average temperatures are expected to increase by 2.5 ºF in the next 50 years. This warming could fundamentally change the patterns of rain and snow in the Columbia River Basin. The changes in water supply and demand are important features of Washington State University's 2011 Forecast.

The forecast found that climate change will shift water availability away from the irrigation season when demands are highest. Water supply at Bonneville Dam is forecasted to decrease nearly 21 percent between June and October, while increasing up to 36 percent between November and May.

Current out-of-stream diversion demands for municipal and agricultural irrigation are projected to increase by 2030. This increased demand is likely to exacerbate water supply issues in some locations, and during the summer, will make it more difficult to meet all demands, including instream demands for fish. The forecast information will guide the state in developing a water management plan and in making strategic capital investments in water infrastructure to meet eastern Washington's environmental and economic needs.

www.ecy.wa.gov/programs/wr/cwp/wsu_supply-demand.html

River Management Joint Operating Committee (RMJOC)

Climate change will alter how the Columbia River and its tributaries will be managed for flood control, power generation, and protection of endangered fish. The U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, and the Bonneville Power Administration began a climate change initiative in 2008.

In 2011, the three federal agencies produced the "Climate and Hydrology Datasets for Use in the River Management Joint Operating Committees' Longer-Term Planning Studies – Part IV Summary." The data sets show how climate change could alter hydrology and water supplies in the Columbia River Basin and how climate change could affect the operation of the Columbia River and its tributaries.

www.bpa.gov/power/pgf/ClimateChange/Final_PartIV_091611.pdf

Strategy D-3. Implement water conservation and efficiency programs to reduce the amount of water needed for irrigation, municipal, and industrial users and to improve basin-wide water supply.

Actions:

1. Adopt the most up-to-date water conservation technologies, water-efficient practices, and alternative water supplies whenever possible and where they:
   - *Provide the most beneficial and least costly way to decrease water demand across all sectors.*
   - *Reduce stress on existing water supplies.*
   - *Increase the benefits to aquatic ecosystems.*

   Because of the connection between water and energy use, new energy-efficient technologies may provide opportunities to reduce both energy and water use, along with greenhouse gas emissions.

2. Expand and accelerate improvements of irrigation infrastructure, starting with aging systems in basins most vulnerable to droughts and climate change. Local conservation districts and various funding agencies—such as the Natural Resources Conservation Service (NRCS), Ecology, U.S. Bureau of Reclamation (USBR), and the Bonneville Power Administration (BPA)—must continue to help irrigation organizations and landowners improve water delivery and distribution systems. These improvements can be done through projects such as:
   - *Lining ditches.*
   - *Piping.*
   - *Re-regulating reservoirs.*
   - *On-farm conservation.*
   - *Pump exchange (replacing water from one source with water from another).*
   - *Water use management projects.*

Climate Change in the Methow Valley

A team of USGS, local stakeholders, and consultants are looking at long-range water-related issues in the Methow Basin, anticipating changing climatic conditions. The major issues include water availability and providing riverine habitat for several endangered fish species.

The team is developing a decision analysis tool for water users and the public, interested in whether water will be available for irrigation in the future, whether the current fish populations can be supported with declining summer runoff, and whether there will be enough lowland snow to support the tourism industry of cross-country skiing. The tool will also enable decision makers and water managers to make more targeted decisions on specific restoration activities in the basin.

wa.water.usgs.gov/projects/methow/cc.htm

3. Expand and accelerate implementation of water conservation and efficiency standards for industries and businesses.

4. Expand the U.S. Geological Survey (USGS) and the National Weather Service (NWS) Methow Basin project—"Future Runoff Scenarios for Decision Makers for the Methow River, Washington"—to other watersheds to understand and quantify how hydrologic systems respond to land use, water use, and climate changes.[127] (This effort includes using the interactive web-based database being developed for the Methow.)

5. Expand and accelerate implementation of municipal water efficiency improvements to reduce amount of water used per person or household. Improvements could include:

   - *Water rate setting.*
   - *Water-smart landscape programs.*
   - *Rebates to install or upgrade water-efficient irrigation systems.*
   - *Regulations to reduce waste of water used outdoors.*
   - *Water-efficient development codes and policies for new development.*
   - *Rainwater harvesting from roofs.*
   - *Education and public outreach campaigns.*

6. Seek more reliable funding mechanisms to help water providers implement climate-ready plans and practices.

[127] USGS/NWS. http://wa.water.usgs.gov/projects/methow/summary.htm

Strategy D-4. Build the capacity of state, tribal, and local governments; watershed and regional groups; water managers; and communities to identify and assess risks and vulnerabilities to climate change impacts on water supplies and water quality.

Actions:

1. Provide local communities and watershed groups with water forecast projections using best available data, tools, and models to assess watershed vulnerability and determine priority risks that require a response. Provide examples of management strategies that will build resilient watersheds and communities.

2. Help watershed groups and communities identify vulnerable areas and assets at risk. Develop climate-readiness plans using approaches that would most sustainably and effectively prepare for and adapt to changes in the watershed.

3. Provide tools and incentives to watershed groups to implement watershed protection and restoration plans focusing on:
   - *Controlling stormwater on a regional or watershed basis.*
   - *Reducing flood peaks.*
   - *Reducing sedimentation.*
   - *Increasing recharge of aquifers.*
   - *Restoring instream flows.*

Climate Ready Water Utilities

Extreme weather events, sea level rise, shifting precipitation and runoff patterns, temperature changes, and resulting changes in water quality and availability contribute to a complex scenario of climate challenges that may have significant implications for drinking water, wastewater, and stormwater utilities.

Seattle Public Utilities (SPU) worked closely with the University of Washington's Climate Impacts Group to examine the effects of climate change on SPU's system performance and to project future changes in water supply and demand. SPU used this information to analyze a range of adaptation options and identified several "no-regrets" options that provide benefits regardless of the magnitude of climate change.

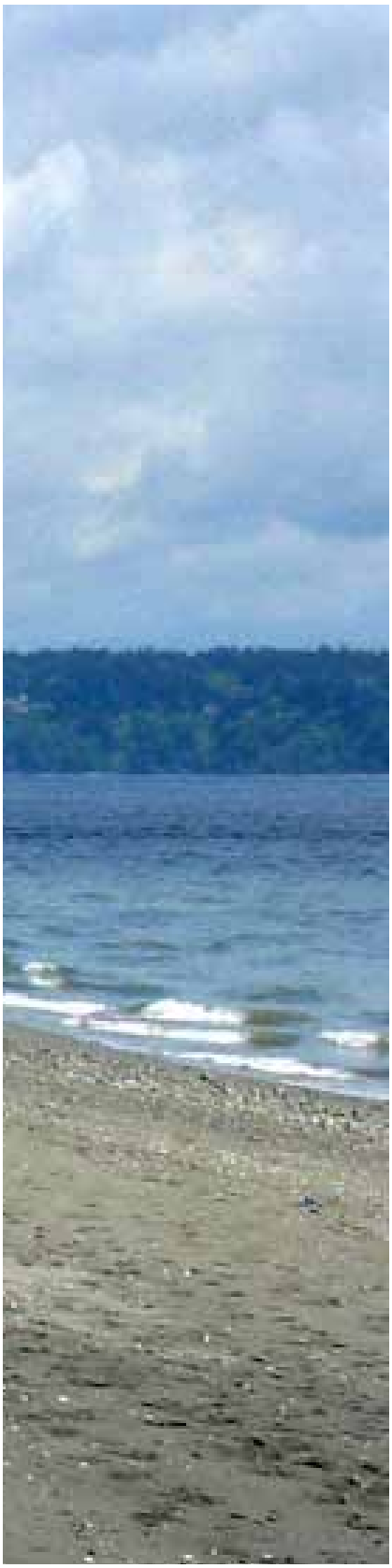
EPA's Climate Ready Water Utilities (CRWU) initiative provides resources for water utilities to adapt to climate change:

water.epa.gov/infrastructure/watersecurity/climate/

Climate Change Vulnerability Assessments: Four Case Studies of Water Utility Practices:

cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=233808

4. Collaborate with the scientific community and water management entities to develop and disseminate best available data, information, and tools on:
   - *Hydrologic changes and hazards, such as extreme floods and droughts.*
   - *Projected impacts and risks of climate change on long-term water budgets and on ecological resources in a given basin.*
   - *Alternatives to respond to these changes effectively.*
5. Expand the central clearinghouse of data and case studies to support climate change and adaptation planning. Provide information and examples of effective strategies to prepare for climate impacts, including:
   - *Operational changes.*
   - *Engineering and design options.*
   - *Green infrastructure approaches.*
   - *New infrastructure investment.*
   - *Planning.*
   - *Land use controls.*
6. Inform utilities about the Climate Ready Water Utilities Initiative and tools such as the Climate Resilience Evaluation and Assessment Tool (CREAT). Support water utilities, working with the University of Washington's Climate Impacts Group (CIG) and the Climate Impacts Research Consortium (CIRC), to incorporate information on climate impacts into models used in water, wastewater, and stormwater systems planning and site design.



7. Continue to invest in improvements and expansion of online data-sharing systems to provide farmers, water utilities, and other customers with timely information on weather, soil conditions, crop water requirements, as well as water efficiency and conservation practices.

8. Improve information on water use by expanding use of meters and implementing methodologies using satellite imagery and other technologies.

9. Improve understanding of climate change impacts on water resources by supporting expansion and refinement of regional climate impact assessment tools and models developed by CIG, CIRC, U.S. Geological Survey (USGS), and other scientific entities. These tools are intended to cover climate change impacts on surface waters, groundwater recharge and groundwater availability and the interaction between climate, hydrology, and vegetation.

10. Explore cooperative work with regional Climate Science Centers, NRCS, USGS, CIRC, and the Climate Impacts Group. Continue and expand existing monitoring networks, such as streamflow gages.

8. Agriculture

8. Agriculture

Washington's agriculture industry is important to the nation and the world. The combination of diverse climate, soils, and topography creates opportunities for growing a wide variety of crops. Agriculture is practiced in almost every region of the state, and it is the key economic driver and employer in most counties of the state. Washington's agriculture is highly diversified, with more than 300 commodities produced commercially. Washington is the ninth largest grower of crops in the U.S. and first in the production of nine commodities.[128] Further, Washington is the nation's third largest exporter of food and agricultural products.

Total farmland was about 15 million acres in 2007, with more than 1.8 million acres under irrigation. Washington's 39,500 farms and ranches produced crops and livestock valued at $7.9 billion in 2010, up from $7.1 billion in 2009. Field crops, livestock, and fruits accounted for most of the state's farm production value. Moreover, farming supports a wide range of economic activities, including a large food processing and distribution industry. The food and agriculture industry contributes 12 percent to the state's economy and employs 160,000 people.[129]

Biofuels such as ethanol and biodiesel are increasingly produced as alternative liquid fuels to replace petroleum-based gasoline and diesel and reduce greenhouse gas emissions. The resulting increase in wheat and other grain prices has benefited some farmers. However, biofuel production has contributed to increased costs and feed shortages for cattle, hogs, and other livestock industries, reducing profitability and increasing consumer prices.

[128] See agr.wa.gov/Marketing/International/Statistics.aspx; OFM (2011).
[129] See agr.wa.gov/AgInWA/Crop_Maps.aspx

Agriculture is sensitive to changing climate conditions and weather extremes, such as droughts, floods, and severe storms. Understanding the implications of climate change on agriculture is important for policymakers, governmental agencies, and agriculture producers. This information will help them to plan and make decisions that sustain productivity and ensure the economic viability of the sector in a changing environment.

The following sections describe the scientific understanding of the impacts of climate change on Washington's agriculture and outline key strategies to support state and local efforts to protect the agricultural sector.

Impacts of Climate Change on Agriculture

Climate change will affect agriculture in a number of ways, depending on the sensitivity of specific crops to the interaction of rising temperatures, changes in water availability, increasing carbon dioxide levels, and more frequent and severe events. Longer growing seasons, warmer temperatures, and higher carbon dioxide concentrations may increase productivity for some crops. But limited water availability along with more weeds, pests and diseases, extreme heat, drought, and flooding will likely negatively affect some crops and livestock.

Different crop zones across Washington support different commodities and agricultural practices, and these zones are likely to have different responses to climate changes. Changes in climate may affect which crops can grow efficiently in the state. For example, some cooler parts of Washington could see an increase in premium grape-growing acreage due to warming.[130] Climate impacts in other regions of the world may also affect Washington's agriculture sector and our global competitiveness.

Some of the key impacts of climate change on agriculture are:

- Changes in crop productivity.
- Decreases in water availability.
- Increased stress from extreme events.
- Reduced livestock productivity.
- Increased stress from invasive weeds, diseases, and pests.
- Global economic impacts from climate change.

1 Changes in crop productivity

Changing climate conditions is expected to alter the geographic regions in which specific crops can be grown. Crop productivity will be affected by several factors, including changes in average temperature and extremes, elevated carbon dioxide levels, availability of water, and stress from weeds, pests, and invasive species. Research on selected crops in Eastern Washington indicates that climate impacts will generally be mild over the next couple decades. Elevated carbon dioxide levels will likely offset some of the negative effects of climate change and result in yield gains for some crops. However, climate impacts will likely be increasingly harmful over time.[131]

[130] See news.stanford.edu/news/2011/june/wines-global-warming-063011.html
[131] Stöckle *et al*. (2010)

The vulnerability of cropping production systems in Washington is highest for crops that have very small windows for optimum performance, for perennial crops, and for farming systems currently on the margin of climatic production zones.

The decrease in snowpack and changes in streamflow patterns will limit the availability of water for irrigated crops. For example:

- The Yakima Basin reservoir system will be less able to supply water to all users, especially those with junior (newer) water rights.
- Average apple and cherry yields are likely to decline by 20 to 25 percent by the 2020s for junior water rights holders, due to lack of irrigation water. The value of apple and cherry production in the Yakima Basin is likely to decline by about $23 million, or 5 percent by the 2020s. [132]

2 Increased stress from extreme events, such as extreme heat, drought, and flooding

Extreme events, such as droughts and heavy downpours, are likely to reduce crop yields and affect livestock productivity. Excessive rainfall can flood cropland, delay spring planting, affect crop quality and quantity, and increase susceptibility to root diseases. It can also cause erosion and increase runoff of agricultural chemicals to surface and groundwater. Low-lying agricultural areas such as the Skagit River delta could be at higher risk of flooding as sea levels rise. [133]

More frequent and severe droughts will limit the water available for crops at the same time that warmer temperatures will increase water demand.

[132] Vano *et al*. (2010).
[133] U.S. Global Change Research Program (2009).

3 Reduction in livestock productivity

Heat and humidity stress pose a significant threat to livestock well-being, especially in confined conditions such as dairy, beef, pig, and poultry operations. A large number of animal mortalities have been reported in recent heat waves, with some states reporting losses of 5,000 head of cattle in a single heat wave in one summer. Heat stress and mortality will likely increase as temperatures rise in Washington. [134]

Warmer temperatures will also affect production efficiency and result in:

- Decreases in voluntary feed intake, leading to reduced weight gains and lower milk production.
- Increases in the energy requirements to maintain healthy livestock.
- Allowing greater proliferation and survival of parasites and disease pathogens.[135]

Studies show that the negative effects of hotter summers will outweigh the positive effects of warmer winters for agricultural production.

Climate change has already disrupted western U.S. rangelands and livestock populations, and the effects are expected to be more severe in the future.[136] Production of animal feed will likely be extended into late fall and early spring. However, quality of animal feed will be negatively affected, water will be limited, species of plants will shift, and plant productivity will decline.[137]

[134] U.S. Global Change Research Program (2009).
[135] U.S. Global Change Research Program (2009).
[136] U.S. Climate Change Science Program and U.S. Dept. of Agriculture (2008).
[137] U.S. Global Change Research Program (2009).

4 Increased stress from invasive weeds, diseases and pests

With higher temperatures and changing precipitation patterns, Washington will likely become increasingly susceptible to invasion by new agriculture pests, invasive weeds, and carriers of human and livestock disease. Warmer temperatures will allow invasive weeds and pests to expand their ranges northward, spreading weeds and pests not previously seen in Washington. These new insects will be able to survive the winter and complete additional life cycles in the longer growing season. [138]

Increases in weeds, insects, and diseases will most likely:

- Increase the cost of crop production.
- Decrease yields and crop quality.
- Increase the costs of controlling weeds.
- Increase risks to food safety, human exposure, and the environment.

For example, in recent years the potato tuber moth has become a major pest in eastern Washington. This invasion is believed to be due to warmer winter temperatures that increase moth survival during the winters, with fewer dying off. Warmer temperatures result in earlier emergence (5 to 10 days) of adults in the spring, an increase in the percent of additional generation that growers would have to control, an increase in control costs, and the potential that moth would develop resistance faster to insecticides.

[138] U.S. Global Change Research Program (2009).

Economic impacts on Washington agriculture

Washington's agriculture industry will likely experience both economic benefits and disruptions from global climate change and global markets. For example, several staple crops consumed in developing counties, such as cereal grains, are major commodities grown in Washington State.

If global climate predictions are realized, the Pacific Northwest will likely be looked upon to provide food to other parts of the world experiencing crop failures due to rising sea levels, heat waves, droughts, floods, and increased pests.

Also, as the purchasing power of people in the most populous countries increases, demand for high-value food crops grown in Washington will also increase.

While these global changes may increase demand for Washington's commodity exports, rising costs of energy and transportation may reduce this opportunity.

5 Economic impacts from global climate change

Other global and local factors will affect Washington's agriculture sector and how it responds to climate change. For example:

- The Pacific Northwest may be called upon to provide food to other parts of the world that are more vulnerable, have food shortages, and are less able to adapt to changes in climate.
- The impact of climate change on the hydropower system will affect the food processing industry. The freezing of fruits and vegetables is Washington's primary food processing industry. This industry is energy-intensive and has depended on the relatively low cost of hydropower in the region.
- Potential impacts of climate change on the state's transportation infrastructure and the cost of fuels will very likely affect Washington agricultural exports. Washington ships about 70 percent of its harvest out of the state, with the nearest major markets over 1,000 miles away. The current global distribution of goods depends on well-developed infrastructure that provides fast, low-cost transportation.

Recommended Adaptation Strategies and Actions—Agriculture

Washington's farmers and ranchers have been successful in increasing agricultural productivity. This success is due in large part to their ability to adapt to changing growing conditions through changes in management practices and in crops or animal selection. However, projected changes in temperature and precipitation and an increase in extreme events (such as drought, heat waves, and heavy downpours) are likely to challenge the effectiveness of current farming practices—affecting crop growth, yields, and livestock productivity.

How the agriculture sector responds to climate change will likely not only affect food production and livestock products but also may impact ecosystems and fish, wildlife and native plants. The four strategies recommended here focus on a number of economically profitable and socially and environmentally acceptable practices. The strategies aim to help farmers anticipate and respond to opportunities and challenges of climate change and extreme weather events. The strategies are grouped according to the following separate but related areas of concern:

- Protection of productive agricultural land.
- Reduction of impacts of severe droughts and floods.
- Prevention and control of invasive species.
- Engagement of agricultural communities in research, data sharing, and adaptation policies and actions.

Strategy E-1. Maintain and enhance agriculture productivity by helping farmers and ranchers transition toward sustainable agriculture.

Actions:

1. Conserve and protect productive and adaptable farmlands by supporting county and city policies and programs that limit sprawl and conversion of agricultural lands to development and facilitate locally-grown food and community garden plots.

2. Maintain agricultural land in production and compensate farmers for the environmental benefits of conservation projects implemented on their lands. Examples of projects include ones that:
   - *Preserve and restore wetlands, riparian corridors, and wildlife habitat.*
   - *Improve water quality.*
   - *Sequester carbon (keep carbon in the soil)*

3. Compensate farmers using mechanisms such as purchases, leases, and establishment of conservation markets. Support the agricultural community in accessing funding programs within various state, federal, and local agencies and conservation organizations.

Conservation markets give economic values to environmental benefits and are sold to purchasers, typically land developers required to mitigate impacts of their development projects.

4. Protect the productivity of agricultural soils from water runoff, erosion, wind storms, and excessive heat through such management practices as:
   - *Direct-seeding.*
   - *No-till farming.*
   - *Reduced-volume irrigation systems.*
   - *On-farm water conservation and storage.*
   - *Biological and organic soil amendments, such as manure and compost.*
   - *Integrated pest management practices.*
   - *Cover-crops and fall-planted crops.*

5. Facilitate access by farmers and growers to technical and financial assistance to implement the practices.

6. Help growers select more economically and ecologically resilient crops, such as:
   - *Pest-resistant crops.*
   - *Drought-tolerant crops.*
   - *Diversified variety of crops.*
   - *Soil and water holding crops, such as alfalfa seed.*

7. Safeguard livestock against the impacts of climate change, and protect livestock by:
   - *Modifying facilities to reduce heat stress.*
   - *Limit the enclosure of livestock during hot weather and allow livestock access to pastures.*
   - *Ensuring properly managed grazing.*
   - *Improving herd performance through good genetic stock.*
   - *Adapting the reproduction season to fit the climate and sources of feed and forage.*
   - *Establishing a herd health program in impacted areas.*
8. Ranchers can be provided with assistance from conservation districts, Washington State University's cooperative extension service, and other agricultural organizations.

Dryland Farming and Climate Change

To address questions related to climate change and dryland agriculture, the region's land-grant universities—Washington State University, Oregon State University, and the University of Idaho—recently received a $20 million grant from the U.S. Department of Agriculture.

Known as Regional Approaches to Climate Change in Pacific Northwest Agriculture (REACCH PNA), this grant will support 20 scientists at the three universities and the USDA's Agricultural Research Service to begin a comprehensive evaluation of the impacts of predicted climate change on the region's cereal grain production.

reacchpna.uidaho.edu/reacchpna

Strategy E-2. Reduce impacts of severe droughts and extreme weather events on irrigated agriculture.

Actions:

1. Increase the ability of the state, local governments, irrigation districts, and other entities to obtain the most up-to-date forecasts of droughts and extreme events. Integrate these forecasts into drought planning and decision-making by policymakers, water users, and water managers. Improve and update existing data provided through federal agencies such as the National Oceanic and Atmospheric Administration, Natural Resources Conservation Service, and National Weather Service as well as universities including the WSU AgWeatherNet Program.

2. Prepare for and respond more effectively to droughts. This may require revising the statutory authority for drought emergency declarations by the Governor**.** The declaration triggers several drought response activities.

3. Identify highly drought-vulnerable basins, provide advance warning of drought and extreme events, develop drought plans, and enable decision makers to reduce risks and damages from droughts.

4. Enhance water conservation and efficiency activities at the farm and district levels in highly drought-vulnerable basins by expanding technical and financial cost-share assistance programs. These programs help growers reduce irrigation needs and runoff, such as improving water conveyance, improving groundwater infiltration and soil retention/capture, and planting drought-tolerant crops.

5. Improve water reliability and increase water supplies through continued support for integrated basin water management planning and by fostering voluntary transfer of water. (Changes to current statutes may be needed to provide incentives to increase participation of existing water right holders in water transfer programs.)

6. Expand and improve the effectiveness of the state's water right transfer program by seeking statutory changes that provide flexibility and incentives to current water right holders interested in transferring their water to other users.

Strategy E-3. Prevent, eradicate, and control pests, diseases, and weeds potentially harmful to public health, the environment, and agriculture production.

Actions:

1. Implement tracking and monitoring, pest and weed control, and eradication actions. State and federal agencies, county noxious weed boards, and county pest and disease boards should conduct these efforts collaboratively.

2. Provide information to the agricultural community to enable farmers and growers to modify agricultural practices and to adapt to new pests and diseases.

3. Increase awareness and protect pollinator (bees) habitat by incorporating conservation of bee habitat into land management and farm practices that minimize land use impacts on pollinators—including tillage, pesticide use, burning, grazing, cover-cropping, and roadside management.

4. Develop and enhance emergency response plans to manage significant pest outbreaks that harm human health, the environment, and the economic viability of the agriculture sector. These plans should include streamlined approval mechanisms of new biological and chemical tools as well as monitoring.

Strategy E-4. Promote opportunities to engage the agricultural sector and rural communities in developing and implementing new policies, technologies, and practices addressing the impacts of climate change.

Actions:

1. Increase participation of farmers, producers, farm organizations, industry leaders, and rural communities in research, changes to public policies, and implementation of new policies and programs that promote:
   - *Ecosystem services.*
   - *Environmental health.*
   - *Economic profitability.*
   - *Social and economic equity.*
2. Create or enhance existing networks to facilitate rapid transfer and adoption of new knowledge and technologies to help farmers adapt to changing climate, promote sustainability, and benefit the environment, rural communities, and farmers.
3. Engage the agricultural community in research to assess vulnerability of various annual (e.g., cereal grains) and perennial crops, and select crop varieties capable of adapting to expected climate changes.

9. Forests

9. Forests

Climate change is expected to affect Washington's forested landscapes in multiple ways. Forests cover 22 million acres in Washington, or over half of the total area of the state. Approximately 44 percent of forest land is in federal ownership; 13 percent is in state and local ownership; and 43 percent is privately owned.[139]

Washington's forests, timber supply and forest-related industries contributed approximately $16 billion to Washington's economy in 2005 and employed 45,000 people with a total payroll of $2 billion. [140] Forestry is the major employer in many rural communities in the state. The Washington State Department of Natural Resources manages about 2.1 million acres of forested state trust lands, producing about $200 million each year in revenue for designated public beneficiaries such as schools, universities, counties, and other public institutions.

Forests provide environmental and social benefits that Washington residents value, including clean water and air, fish and wildlife habitat, natural open space, and recreation opportunities. Forests also absorb and store carbon dioxide, and timber practices can produce biomass for energy production, in addition to primary forest products.

Biomass fuel:

Plant material, wood, vegetation, or agricultural waste used as a fuel or energy source.

Forests are sensitive to climate variability and change. Warmer temperatures, earlier spring snowmelt, changes in precipitation patterns, and more frequent and severe extreme weather events are expected to change patterns of fire, insects, tree growth, and regeneration in the state. Understanding and accounting for future climate helps support long-term planning to manage and preserve healthy forests and the economic and environmental benefits they provide.

The following sections describe the scientific understanding of the impacts of climate change on Washington's forests and outline key strategies to support state and local efforts to protect forests and lower risks to our communities and ecosystems.

[139] Campbell *et al.* (2010).
[140] Partridge and MacGregor (2007).

Impacts of Climate Change on Forests

Climate change could fundamentally change the nature of forests in Washington, particularly in ecosystems where water shortages are greatest. Disturbances such as droughts, insects, disease, and fire are a natural part of ecosystem dynamics, and some disturbances are integral to maintaining healthy ecosystems. Climate change is affecting when and how often disturbances occur and how large they are, however. These events are likely to significantly alter many forest ecosystems and the animals that depend on them. Climate change is likely to reduce forest health and productivity and alter the geographic range of certain tree species.

Many impacts will likely occur first in forests on the east side of the Cascade mountains, but forests west of the Cascades also will likely experience significant changes in disturbances and species distribution before the end of the 21st century. Human factors—such as changes in land use patterns, population growth, and land and water management practices—also affect forests and could increase the vulnerability of forests to the impacts of climate change.

The key impacts of climate change on forests include:

- Larger and more frequent wildfires.
- Increase in mountain pine beetle outbreaks.
- Changes in geographic range, growth, and productivity.

1 Larger and more frequent wildfires

Fire plays a critical ecological role in many of Washington's forest types, particularly in the fire-adapted dry forests east of the Cascades. However, over a century of fire suppression, extensive logging, and overgrazing have resulted in forest conditions in many areas that are currently at an increased risk of unnaturally severe and extensive disturbance from fire, insects, and disease.[141]

[141] Hessburg and Agee (2003); Hessburg *et al*. (2005); Franklin *et al*. (2008).

Drier, hotter conditions are expected to increase the frequency and magnitude of wildfires. The annual area burned by fire in the Columbia Basin is projected to double or triple from an average of about 425,000 acres annually (1916–2006) to:

- 800,000 acres in the 2020s.
- 1.1 million acres in the 2040s.
- 2.0 million acres in the 2080s.[142]

Widespread areas of dead or damaged trees due to insect infestations make forests vulnerable to large, severe forest fires.

Fire regimes in different ecosystems in the Pacific Northwest have different sensitivities to climate. In forested ecosystems such the western and eastern Cascades, Okanogan Highlands, and Blue Mountains, the area burned is projected to increase by a factor of 3.8 by the 2040s, compared to 1980-2006.[143] In some drier areas, the year-to-year variation will also likely increase. In wetter regions in western Washington, the relationship between fire and climate is weaker, and future fire projections are less certain. However, rising summer temperatures, lower soil moisture, and higher evaporation rates could result in large disturbances in western Washington forests that have not traditionally been considered "fire-prone."[144]

Large, severe wildfires have serious economic and social consequences. On average, $26 million is spent annually (2002-2011) suppressing wildfires in Washington.[145] The true costs of such wildfires may be from 2 to 30 times greater, however, if we account for the myriad adverse environmental and social impacts.[146]

[142] Littell *et al*. (2010).
[143] Jamison (2012).
[144] Littell *et al*. (2010).
[145] Cline (2010), as cited in DNR (2010).
[146] WFLV (2010).

Impacts of wildfires to plants, wildlife, rivers, human health, and property

Increases in fire frequency could result in shifts in vegetation toward more fire-tolerant species or otherwise alter plant communities that depend on a given fire regime to persist.[147] These shifts could disturb wildlife populations that depend on affected forest habitats, and key wildlife migration corridors may be cut off.

Increased incidence of fire could also reduce the land's ability to absorb and slowly release rainwater, increasing erosion and sediment in rivers. Forest fires could also contribute to human health problems, primarily smoke inhalation, and to damage to houses and public facilities.

2 Mountain pine beetle outbreaks

Mountain pine beetle outbreaks in Washington's lodgepole pine and whitebark pine forests are of particular concern because they are spreading rapidly and migrating to higher elevation trees, killing trees in their path. Temperatures currently leave forests vulnerable to mountain pine beetle outbreaks in large areas of the Olympic Mountains, northern Rocky Mountains, in a mid-elevation band on the west and east sides of the Cascade Mountains, and to a lesser degree in the Blue Mountains of southeastern Washington.[148]

With warmer temperatures and more drought stress, mountain pine beetle outbreaks are projected to increase in frequency. Warmer temperatures allow for more winter survival of insects and pathogens as well as faster insect growth. Warmer conditions also shift their ranges, and drought stress makes trees more susceptible to attack. Mountain pine beetle outbreaks will reach higher elevations as temperatures warm. At lower elevations, the mountain pine beetle could become less of a threat, however, and the total susceptible area for outbreaks could decline. Other insect species may emerge in areas that are no longer suitable for the mountain pine beetle.[149]

[147] Noss (2001).
[148] Littell *et al*. (2010).
[149] Littell *et al*. (2010).

3 Changes in geographic range, growth, and productivity

With increases in temperature and decreases in water availability, the climate will become unsuitable for certain tree species. Conifers such as Douglas-fir, yellow cedar, and western hemlock dominate Washington's landscape, and climatic and elevation gradients strongly influence their distribution. Growth and vigor is expected to decline in Douglas-fir, lower-elevation ponderosa pine, and western hemlock forests.

Douglas-fir: Douglas-fir productivity varies with climate across the region and will potentially increase in wetter parts of the state during the first half of the 21st century, but productivity is expected to decrease in the driest parts of its range. The area that can support Douglas-fir in Washington is projected to shrink by 32 percent by the 2060s and by 55 percent by the 2080s.[150] This decline will be most pronounced at lower elevations, especially in the Okanogan Highlands and the south Puget Sound/southern Olympics.

Pine forests: About 85 percent of the current habitat for pine will shift outside the climatically suitable range for one or more pine species.[151] This shift will be especially apparent in pine forests in the Columbia Basin and eastern Cascades as early as the 2040s, particularly in parts of the Colville National Forest, Colville Reservation, and central Cascades.[152]

The area of severely water-limited forests is projected to increase by at least 32 percent in the 2020s and an additional 12 percent in the 2040s and 2080s. Geographic patterns of forest productivity will likely change; statewide productivity may initially increase due to warmer temperatures but will then decrease due to increased drought stress.[153]

[150] Littell *et al*. (2010). Actual quote: About 32% of the area currently classified as appropriate climate for Douglas-fir would be outside the identified climatic envelope by the 2060s, and about 55% would be in the 50%-75% range of marginal climatic agreement among models. Only about 13% of the area currently suitable for Douglas-fir would be suitable in >75% of the statistical species models.
[151] Littell *et al*. (2010).
[152] Littell *et al*. (2010).
[153] Littell *et al*. (2010).

Recommended Adaptation Strategies and Actions—Forests

Washington's forests and rangelands provide a significant source of revenue to the state, along with tremendous environmental, social, and ecological benefits such as watershed protection, wildlife habitat, recreation, carbon storage, and biomass for energy production. Forests reduce erosion, recharge aquifers, regulate streamflows, moderate water temperatures, and protect water quality. Urban forests play a significant role in protecting public health from rising temperatures, air and water pollution, flooding, and precipitation runoff. Climate change will not only affect forest health and productivity—it will also affect our ecosystems and the range of goods and services they provide. The following four strategies focus on ways to protect, manage, and restore our forests.

Strategy F-1. Conserve and restore healthy, resilient forests across ownership boundaries and large geographic ranges to minimize the threats from climate change and extreme weather events.

Actions:

1. Develop a comprehensive approach that integrates objectives and actions for preservation of working forests, wildfire management, insects and diseases control, and forest health protection and restoration. Developing the integrated approach needs to occur in partnership with tribal, federal, state, and local resource protection agencies; public land management agencies (Department of Natural Resources, U.S. Forest Service, Bureau of Land Management and others); private forest landowners; nongovernmental organizations; and other stakeholders.

2. Develop a coordinated plan for fire hazard reduction and suppression for at-risk forests to assist policymakers, communities, and jurisdictions with land-management decisions so that forest fire threats are reduced. Information on existing and projected forest health and fire hazard conditions should be widely shared with forest landowners, managers, decision makers, and the public.

Statewide Forest Resource Assessment and Strategy

The 2008 federal Farm Bill required state forestry agencies to conduct a Statewide Forest Resource Assessment and Strategy as a condition of receiving forest landowner assistance funds. Washington State Department of Natural Resources (DNR) completed the forest resource assessment and strategy in June 2010. The assessment identified wildfire hazard reduction and forest health restoration as major issues, with the greatest risk of wildfire in eastern Washington, mountain gap wind zones, and the San Juan Islands.

DNR recently completed its 2010-2014 Strategic Plan (see box on the next page) to guide the agency's focus and new initiatives. Several issues identified in the Statewide Forest Resource Assessment are addressed in the Strategic Plan and can be seen as an expression of agency-wide priorities.

www.dnr.wa.gov/Publications/em_wa_statewide_a_cover_contents_intro_section.pdf

3. Reduce development pressures on forestlands by working with local governments to protect forestlands from conversion, such as through zoning and transfers of development rights. Facilitate implementation of best practices, and engage private landowners through market and investment opportunities.

4. Secure sustainable funding and expand financial and technical assistance to forest landowners. Use an "all-lands" approach for allocating public funding to forest landowners to implement new and modified practices that reduce risks from:
   - *Forest fires.*
   - *Pests and diseases.*
   - *Erosion and sediment loads into rivers.*
   - *Loss of habitat.*
   - *Loss of soil moisture.*

Transfer of development rights (TDR) allows owners of property zoned for low-density development or conservation use to sell development rights to other property owners located in "receiving" zones, such as designated urban areas, that can accept additional density.

5. Advocate at the federal level for:
   - *Increased funding for the Land and Water Conservation Fund, Forest Legacy Program, and Environmental Quality Incentives Program, which will benefit several states including Washington.*
   - *Passage of the Community Forestry Conservation Act, a bill to authorize tax-exempt revenue bonds for working forest conservation.*

DNR's 2010-2014 Strategic Plan: The Goldmark Agenda

The DNR Strategic Plan, known as the Goldmark Agenda, identifies preserving forest cover and protecting working forests from conversion as major goals for the Department. DNR has established several initiatives to support small forest landowners to maintain their land as working forests, advance policies and incentives to maintain private working forest lands and associated jobs, consolidate DNR-managed working forests into strategically positioned blocks that help provide compatible management for neighboring forest lands, and permanently maintain DNR-managed working forests at greatest risk of conversion.

Biodiversity and **habitat conservation** connect with the agency's strategic priorities for **natural area conservation** and **climate adaptation**. In addition, **upland water quality, quantity, and Puget Sound restoration** are central to DNR's responsibilities to regulate forest practices and manage state trust lands sustainability.

www.dnr.wa.gov/Publications/em_strategic_plan_2010_goldmark_agenda.pdf

Strategy F-2. Maintain and protect forest species and genetic diversity across the landscape to ensure long-term conservation of our forest genetic resources and help buffer against impacts of climate change.

Phenology:
Study of periodic biological phenomena, such as breeding, flowering, and migration, especially as related to climate.

Actions:

1. Ensure forest landowners continue to manage for native species and structural diversity. Use current reforestation practices to maintain species and genetic diversity across their forest lands.

2. Build disease resistance in five-needle pines and other tree species with serious disease issues, in cooperation with existing U.S. Forest Service efforts.

3. Maintain and expand participation in tree breeding, testing, and selection programs, such as those operated by the Northwest Tree Improvement Cooperative and the Inland Empire Tree Improvement Cooperative. Ensure that testing by cooperative members incorporates greater geographic diversity and adaptive traits such as cold-hardiness and drought-tolerance.

4. Create a gene conservation plan for tree species in Washington based on vulnerability assessments to climate change of various eastern and western Washington tree species. The U.S. Forest Service has completed a vulnerability assessment for western Washington.

5. Create a cooperative tree seed bank within Washington State Department of Natural Resources to provide for recovery from large-scale disturbances, such as fire or insect outbreaks. This effort may begin with a "virtual" seed bank created with cooperative agreements among landowners who maintain seed inventories and are willing to make their seed available in the event of major disturbance.

6. Build on existing monitoring and evaluation programs to detect problems with tree growth, phenology, reproduction, or tree health.

Strategy F-3. Protect, expand, and manage urban forests to help communities reduce impacts of rising temperatures and extreme precipitation runoff events.

Actions:

1. Expand the Urban Forests Assistance Program (authorized under the Washington State Urban and Community Forestry Act) to help mitigate the impacts of climate change, such as the following:
   - *Airborne pollution.*
   - *Higher water temperatures in urban streams.*
   - *Urban heat island.*
   - *Heat waves.*
   - *Severe stormwater runoff.*
   - *Flooding.*
   - *Erosion.*

Urban Heat Island:
A metropolitan area that is significantly warmer than its surrounding rural areas.

2. Secure sustainable funding sources to build the Urban Forest Assistance Program's capacity to increase participation by cities, towns, and communities in planting and sustaining healthy trees and vegetation in urban areas.

3. Support cities and towns in developing education and community programs to enhance community awareness of the benefits that trees provide—including public health, environmental, ecological, and economic improvements. Support communities in adopting sound tree protection and management ordinances in all communities faced with threats from heat waves, flooding, and landslides.

4. Promote urban forests by engaging cities, communities, neighborhoods, local and state park officials, and volunteers in:
   - *Planting trees more tolerant of heat and drought conditions.*
   - *Implementing effective options for tree watering and maintenance.*
   - *Selecting pest- and disease-resistant trees.*
   - *Removing invasive species.*
   - *Monitoring the health of the trees.*

Strategy F-4. Build capacity and support for maintaining, enhancing, and restoring resilient and healthy forests.

Actions:

1. Build on existing or create new pilot projects, experiments, and research to better understand how forests are likely to respond after severe disturbance events. For example, would a combination of thinning and prescribed fires help vulnerable forests better adapt to fire?

2. Strengthen existing partnerships and build new collaborations across jurisdictions to share knowledge and information on climate change impacts and adaptation across all sectors and across broad landscapes of varying ownerships and jurisdictions. This approach is referred to as an all-lands approach.

3. Increase coordination and collaboration with federal and tribal governments, the scientific community, and private conservation groups to ensure that research and management strategies address Washington's forest needs and recognize the important social, economic, and environmental benefits of forests.

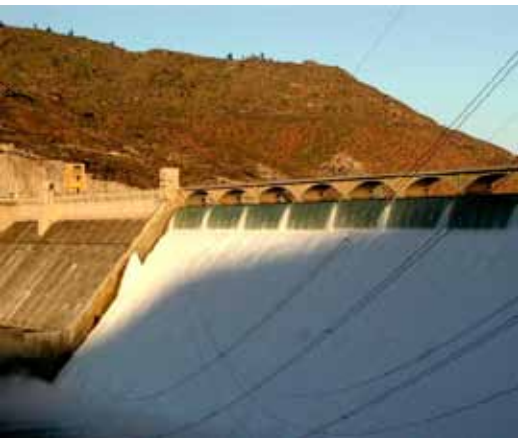
4. Improve forest health and reduce forest hazard conditions by providing information to landowners, policymakers, and the public about wildfires, pests, and diseases—and benefits that forest ecosystem services provide.

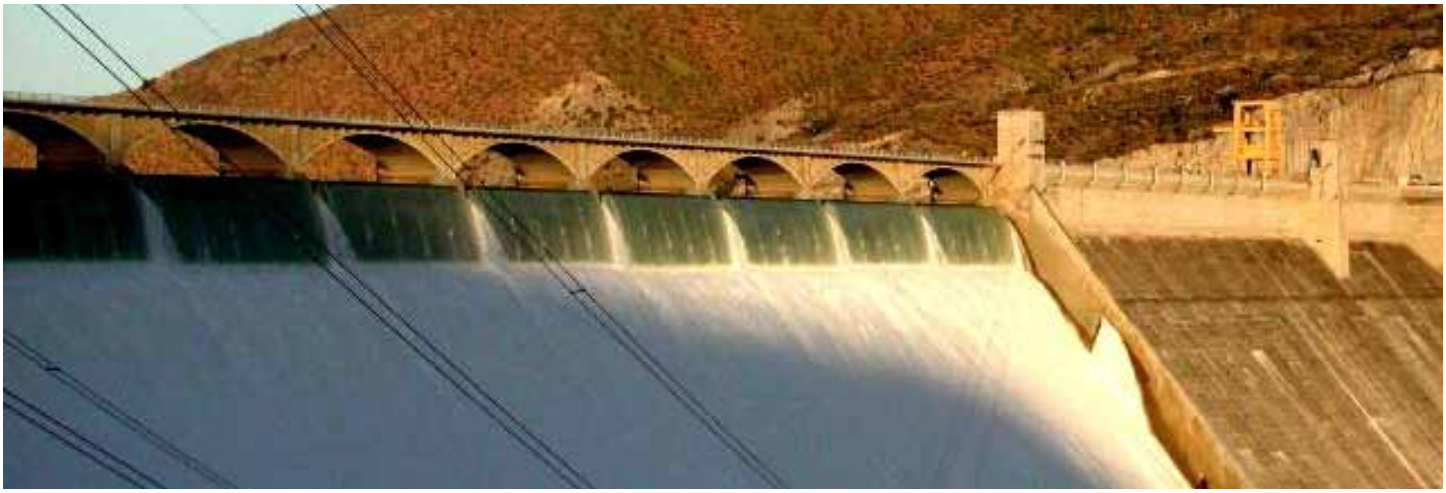
5. Improve understanding and communication of impacts and adaptation responses by engaging all levels of government, stakeholders, and the public in adaptation planning and decision-making affecting forests.

6. Integrate messages about the benefits of forest ecosystem services into education programs and curriculum related to natural resources management, environmental protection, urban planning, economics, and other programs.

7. Coordinate development and maintenance of integrated long-term, large-scale monitoring of early-warning indicators of species responses, including range shifts, population status, and changes in ecological systems functions and processes.

10. Infrastructure and the Built Environment





10. Infrastructure and the Built Environment

Maintaining safe and reliable infrastructure is critical for Washington's economy, environment, and way of life. This chapter addresses climate impacts and strategies to prepare our transportation, energy, communities, and communications infrastructure for a changing climate. Coastal and water infrastructure are addressed more fully in Chapter 6, **Ocean and Coastlines**, and Chapter 7, **Water Resources**.

Washington's infrastructure is vulnerable to a changing climate. Infrastructure systems are designed and maintained based on our past and current experiences. For example, bridges are built to allow logs and other debris to pass under during anticipated high flows. Climate change is moving us beyond the range where past experience is a good guide for what we might experience in the future. Climate change could both create new challenges and exacerbate our current challenges in managing infrastructure systems for coastal erosion, flooding, unstable slopes, higher temperatures, and extreme events.

Climate impacts could:

- Increase maintenance and repair costs.
- Affect public safety.
- Interrupt critical evacuation routes and energy supplies.
- Cause travel delays and disruptions.
- Disrupt economic activity.
- Degrade our quality of life.

The impacts of climate change will vary across the state depending on geography, topography, and the capacity of different communities to adapt. Recognizing the risks associated with climate change is an important first step toward better planning of new infrastructure investments and mitigating potential damage to existing infrastructure.

Because infrastructure is designed to last for decades, it is important to consider climate change in planning and design. The high costs and length of time it takes to alter infrastructure means that, for responsible asset management, we must begin to take into account future climate conditions now. The work we do to prepare for and adapt to our changing climate will protect taxpayer investments and our vital infrastructure systems for conditions both today and in the future.

The following sections describe the scientific understanding of the impacts of climate change on Washington's infrastructure and built environment and outline key strategies to support state and local efforts to protect them and lower risks to our communities.

Impacts of Climate Change on Infrastructure and the Built Environment

Climate change is expected to increase the risk of flooding and damage to infrastructure and communities, resulting in travel delays and disruptions to transportation, energy, communities, and communications systems.

- Sea level rise and storm surge will increase the risk of flooding, erosion, and damage to coastal infrastructure.
- More extreme precipitation will increase the risk of flooding, landslides, and erosion, which may damage or disrupt infrastructure systems and overwhelm drainage structures.
- Warmer temperatures and heat waves could strain energy and transportation systems—though they also offer benefits such as reduced snow and ice removal costs.
- Prolonged low summer flows could affect river navigation.
- Lower summer streamflow will reduce summer hydropower production at a time when warmer temperatures will increase electricity demand for cooling.
- Larger and more intense forest fires could damage buildings, roads, and other infrastructure.

Our infrastructure is an interconnected network, which will require an integrated approach to addressing climate change impacts. Utility lines are often strung along bridges or within the road right-of-way. Parts of our energy distribution systems, like fuel delivery for vehicles and for heating rely on road networks.

Many climate impacts are common to all types of infrastructure. For example, rain or sea-level inundation could flood underground equipment and instruments associated with power stations, telecommunication and cable boxes, and traffic signals for all modes of transportation. Increased flooding and landslides would affect operations and maintenance of many types of infrastructure.

1 Transportation systems

Climate change impacts pose significant challenges to our transportation system. Sea-level rise and storm surge will increase the risk of major impacts to vulnerable transportation infrastructure along coastlines. Airports, rail lines, roads, and other structures in low-lying coastal areas will be at a higher risk of temporary or permanent flooding and erosion.[154] Closures and travel delays could increase, especially in densely populated areas near the coasts. Evacuation routes along the coast could be washed out. Washington's seaports and the connected distribution networks will face higher risks of flooding. Together, these impacts could significantly affect communities and economic activity along the coasts.

Extreme weather events are becoming more frequent and intense, and they pose major challenges for transportation. Heavy downpours have increased by 25 percent in magnitude in the Puget Sound region over the past 50 years, and they are projected to continue to increase.[155] When combined with changes in streamflow, population growth, and development pressures, this change could increase the risk of flooding, weather-related accidents, delays, and traffic disruptions.[156] In 2007, flooding closed a 20-mile section of Interstate-5 in the Chehalis Basin for four days, resulting in $47 million in lost economic output to the state. The 2007 storm caused approximately $23 million in damages to interstate and state highways in Washington as well as $39 million in damages to city and county roads.[157] More severe flooding will increase the risk of damage to bridges and could overwhelm drainage structures, such as culverts.[158] The risks to public safety will increase, along with the risk of major economic impacts from closures and delays.

More heavy downpours and more precipitation falling as rain instead of snow could increase the risk of landslides and slope failures, leading to more frequent road closures and higher maintenance costs.[159] In 2010, nearly 130 Amtrak Cascades passenger trains were delayed or canceled because of mudslides and hillside washouts. In 2011, the number of

[154] U.S. Global Change Research Program (2009).
[155] Rosenberg *et al*. (2009)
[156] U.S. Global Change Research Program (2009).
[157] Washington State Department of Transportation (2008a).
[158] Washington State Department of Transportation (2008a).
[159] Washington State Department of Transportation (2008a).

delays and cancelations had doubled by October.[160] Along the 466-mile route for Amtrak Cascades, more than 60 areas have been identified as at risk for mudslides. The closures also affect Sound Transit's Sounder, the Amtrak Coast Starlight long-distance train, and BNSF (Burlington Northern Santa Fe Corporation) Railway freight trains. These types of events will potentially become more common.

An increase in extreme heat can negatively affect pavements, rails, striping, and other materials. Infrastructure impacts include:

- Heat-related buckling of pavements and rails.
- Traffic-related rutting of pavements.
- Thermal expansion of bridge joints.

Rising temperatures could benefit our transportation system by reducing road closures and costs for snow and ice removal. The temperature changes for our region are unlikely to cause catastrophic failures; rather, the change in conditions can be addressed through selection of materials that can withstand the new temperature norms.

Larger and more severe wildfires will increase risks to traffic operations and safety by obscuring visibility for drivers. Large fires can sometimes create enough smoke to require closure of roadways, limiting mobility and creating economic impacts.[161] Fires and insect damage can also have a secondary impact of reducing vegetation coverage, leading to increased erosion and landslides that can erode or cover roadways during or following heavy rains and snowmelt.[162]

Climate risks to our transportation infrastructure will vary by location. Effectively preparing for climate change requires an improved understanding of the areas and assets at high risk. The Washington State Department of Transportation (WSDOT) recently completed work to pilot a risk assessment model developed by the Federal Highway Administration. As part of the pilot, WSDOT completed a qualitative assessment and initial screening of state-owned transportation infrastructure vulnerable to climate impacts. The results of the assessment will be used to help prepare for future conditions and incorporate climate information into decision-making. (See box on page 162 for more information.)

[160] See wsdotblog.blogspot.com/2011/10/wsdot-takes-mudslides-head-on-to.html
[161] Hamlet *et al*. (2011).
[162] Hamlet *et al*. (2010).

2 Energy systems, supply, and use

Climate change is expected to alter the supply and demand for energy in Washington State (see Table 2). Shifts in the amount and timing of streamflow are expected to lead to substantial changes in seasonal hydroelectric power generation, which supplies two-thirds of the state's electricity needs. Winter hydropower production is projected to increase, and summer hydropower production is projected to decline.

Extreme heat wave events are likely to increase in frequency, generating an increase in the peak demand for electricity for air conditioning and industrial cooling in the summer. The increase in summer demand will coincide with a decline in summer hydropower availability.

Warmer temperatures will decrease demand for heating in the winter, which is primarily from natural gas. Because of expected growth in population, however, the overall demand for winter heating is still projected to increase.

Year	2020s	2040s	2080s
Summer hydropower generation	Decrease 9-11%	Decrease 13-16%	Decrease 18-21%
Winter hydropower generation	Increase 0.5-4%	Increase 4-4.2%	Increase 7-10%
Annual hydropower generation	Decrease 1-4%	Decrease 2.5-4%	Decrease 3-3.5%
Winter demand for energy for heating*	Decrease 11-12%	Decrease 15-19%	Decrease 24-32%
Summer demand for energy for cooling*	Increase 92-118%	Increase 174-289%	Increase 371-749%

Table 2. Projected changes in hydropower generation and energy demand compared to 1917-2006 (not including population growth).

**Figures are for a fixed year 2000 population. Population growth is projected to increase winter demand for energy for heating and summer demand for energy for cooling.*

Source: Hamlet et al. (2010).

Climate change is also likely to affect the potential to generate electricity from other renewable energy sources besides hydropower—such as wind, solar, and biomass (plant-based sources)—although these effects are not well understood.[163]

Sea level rise, storm surge, and extreme weather events could increase the risk of flooding and damage to energy production and delivery systems, such as power plants, transmission lines, pipelines, and oil refineries. More storm activity could increase the cost of power and infrastructure maintenance and lead to more, longer blackouts and disruptions of services. Extreme heat could affect transmission efficiency. Declines in summer streamflows could also threaten supplies of cooling water for thermal power plants.

3 Communities and development

Climate impacts will also affect local communities and the infrastructure they depend on. Commercial and residential buildings near floodplains or along the coast could face higher risks from flood damage. Heavier downpours could strain the capacity of stormwater systems, creating backups and flooding and increasing the risks of combined sewer overflows that pollute rivers, lakes, and Puget Sound. Climate risks will vary by location and will affect decisions about land use and development patterns.

4 Communications infrastructure

Along the coasts, inundation from sea level rise and flooding may affect access chambers, vaults, and other underground communications facilities. Increased storm activity may raise the cost of telecommunications supply and infrastructure maintenance, due to increased frequency and length of network outages and disruption of communication services.

[163] U.S. Global Change Research Program (2009).

Recommended Adaptation Strategies and Actions—Infrastructure and the Built Environment

Moving forward to protect our infrastructure minimizes risk and helps ensure that infrastructure, services, and operations remain effective in both current and future climate conditions. The five adaptation strategies and actions presented below emphasize building on existing work to identify risks and vulnerabilities and taking proactive measures to prepare for risks.

Adaptation approaches vary based on the risk and importance of the infrastructure, and efforts may include:

- Protecting infrastructure by strengthening dikes and levees and by using other hard or soft structural approaches.
- Strengthening infrastructure to better withstand climate impacts (such as flooding or extreme heat) through improved materials, design, and construction techniques.
- Raising or elevating infrastructure to protect it from flooding.
- Relocating, decommissioning or abandoning selected infrastructure where the costs of protection and maintenance outweighs the benefit.
- Care must be taken to avoid approaches that have negative impacts on fish and wildlife or cause unintended consequences.

To protect infrastructure, we must also integrate consideration of climate change impacts and adaptation into existing planning, operations, and investment decisions at the state and local levels. These include plans related to:

- The Growth Management Act.
- The Shoreline Management Act.
- Emergency preparedness and response.
- Transportation.
- Energy.

Because land use drives the location of substantial public investment, care should be used in planning where future development occurs. Availability of data, mapping, resources, and the policy guidance would allow each local government to determine the appropriate set of decisions for its situation and likely impacts.

Adaptation responses require coordination among multiple jurisdictions and private entities that own and operate infrastructure, respond to emergencies, and engage in long-range planning related to land use, transportation, energy, and emergency preparedness.

Strategy G-1. Protect vulnerable infrastructure and ensure it is safe, functional, and resilient to climate impacts.

Actions:

1. Develop a common framework and methodology for transportation infrastructure risk assessment at a regional scale and for all transportation modes and operations.

2. Encourage local, regional, tribal, and federal governments and private entities to prepare detailed inventories and climate vulnerability assessments to identify critical and vulnerable infrastructure within their jurisdictions.

3. Work with ports to determine short- and long-term strategies to protect port infrastructure and transportation linkages to ensure movement of commerce and international trade.

4. Encourage owners and operators of critical energy infrastructure to evaluate vulnerability to the impacts of climate change, including risks of damage and the potential for disruptions and outages from flooding, sea level rise, extreme heat, erosion, and extreme weather events.

5. Adopt regulatory and incentive programs to encourage state, tribal, and local transit organizations; public works departments; utilities; and other partners to demonstrate awareness and, where possible, consistency with efforts to address vulnerable systems.

6. Work with the insurance industry to identify and implement mechanisms to reduce risks to property owners from climate-related hazards and to educate consumers on ways to reduce exposure to risk.

Washington's Transportation Infrastructure

The Washington State Department of Transportation is one of five entities that the Federal Highway Administration funded to "test drive" its draft vulnerability and risk assessment conceptual model for transportation infrastructure.

WSDOT conducted the statewide assessment on state-owned and managed infrastructure, using data from the University of Washington's Climate Impacts Group. Through workshops and the FHWA model, WSDOT found vulnerable infrastructure across the state. Most of our newer bridges are resistant to climate changes—some can withstand a sea level rise of up to 4 feet or more.

In some areas, however, road approaches to bridges appear more vulnerable than previously thought. From the data and maps that came out of the workshops, WSDOT can see where climate changes are likely to intensify the threats already facing our transportation facilities.

www.wsdot.wa.gov/SustainableTransportation/adapting.htm

Strategy G-2. Guide future development away from areas at risk.

Actions:

1. Gather and provide the best available scientific information on climate impacts and areas at high risk from flooding, seawater inundation, landslides, extreme heat, and wildfires. Provide information for a range of climate scenarios, for all regions in the state and on a basin-by-basin basis, using consistent data from the UW Climate Impacts Group and other reputable sources. Make the information available and readily accessible to citizens, businesses, local governments, tribes, and others to assist in making informed decisions to prepare for and adapt to climate impacts.

2. Develop guidance as well as regulatory and incentive programs to encourage state and local governments to limit new development in high-risk areas and to incorporate projected climate change impacts and adaptation actions into long-term planning, policies, and investment decisions. These policies and plans include regional or countywide planning policies, comprehensive plans, shoreline master plans, development regulations, and urban growth area expansions.

3. Determine how to consider potential climate impacts and adaptation options for non-project and project actions, as part of the State Environmental Policy Act.

4. Encourage the federal government to accelerate modernized flood mapping and implement fundamental reforms to the National Flood Insurance Program to incorporate risks from climate change.

5. Limit new development in floodplains and coastal areas vulnerable to sea level rise and return some coastal and floodplain areas to natural conditions.

6. Encourage local jurisdictions to identify and implement ordinances and other approaches to reduce wildfire risks.

Strategy G-3. Reduce or avoid climate risks by considering climate in the planning, funding, design, and construction of infrastructure projects and by promoting improved design and construction standards in areas vulnerable to climate risks.

Actions:

1. Develop a framework to guide the state's planning and investments to:
   - *Protect, repair, elevate, or decommission vulnerable infrastructure.*
   - *Protect safety and key evacuation routes.*
   - *Protect critical transportation facilities and corridors for the movement of people and freight, both within Washington and to nearby states and Canada.*
   - *Address potential financial, social, and environmental impacts.*
2. The framework should identify a process to decide when the state will not invest in at-risk projects with a long lifespan.
3. Require incorporation of climate impacts and response strategies in the state's long-range transportation plans; mode-specific plans for highways, rail, aviation, and ferries; and regional transportation plans.
4. Develop transportation design and engineering guidance to minimize climate change risks. The design guidance should be used when siting and designing new transportation infrastructure and project-related infrastructure, such as stormwater treatment and flow control, wetlands protection and mitigation, and fish passages. The guidance should provide information on techniques and materials resistant to increased heat and other climate impacts.
5. Require consideration of climate risks and response strategies in the site selection, design, and construction of state-funded infrastructure projects.
6. Advance the adoption and enforcement of progressive building codes and design standards to reduce vulnerability of structures to climate-related hazards.

7. Provide incentives to incorporate climate risks and response strategies in the design of commercial and residential buildings. Promote strategies and technologies, including those that:
   - *Reduce energy and water use.*
   - *Accelerate deployment of smart-grid technologies—using electronic control, metering, and monitoring to reduce energy use (see box on page 167).*
   - *Maximize rain and snow seepage into the ground, which reduces runoff and replenishes groundwater, using green infrastructure and low-impact development approaches.*
   - *Collect rainwater onsite.*
   - *Maximize open spaces to reduce urban heat effects.*
8. Identify and provide financial incentives to property owners to reduce exposure to risk, such as low-cost loans or financial incentives to rebuild—or relocate—according to improved construction standards, increased setbacks, or elevation of the structure.

Green infrastructure encompasses the preservation and restoration of natural landscape features, such as forests, wetlands, floodplains, and natural drainage features. At the site scale, it involves low-impact development (LID) and sustainable building features, such as rain gardens, green roofs, permeable pavement, rainwater harvesting, urban forestry, and preservation of green open spaces such as parks and wetlands.

Benefits of green infrastructure include:

- Better management of stormwater runoff.
- Lower incidence of combined sewer overflows (CSOs).
- Water capture and conservation.
- Flood prevention.
- Storm surge protection.
- Defense against sea level rise.
- Accommodation of natural hazards.
- Reduced ambient temperatures and urban heat island effects.

For more information:

www.ccap.org/green_infrastructure.html

Strategy G-4. Enhance the preparedness of transportation, energy, and emergency service providers to respond to more frequent and intense weather-related emergencies.

Actions:

1. Incorporate information about climate impacts into state and local emergency planning efforts, including the Comprehensive Emergency Management Plan, the State Hazard Mitigation Plan, and the Hazard Identification and Vulnerability Analysis.
2. Bolster contingency plans for key critical transportation, energy supply and distribution networks, telecommunications, and water infrastructure at risk.

3. Identify and protect critical evacuation routes. Coordinate emergency evacuation planning among adjacent cities and counties.

4. Improve systems to provide engineers, public works, and maintenance staff with early warning of problems, engage onsite protections in advance of an emergency, and provide early warning to the public. Revise existing systems—or develop better systems, such as using sensors and smart technologies—for monitoring:

   - *Bridge abutments.*
   - *Land slopes.*
   - *Stormwater runoff and drainage systems.*
   - *Real-time flood levels and storm surge.*
   - *Other climate impacts on infrastructure.*

5. Adjust routine operations, maintenance and inspection, and capital budget expenses to prepare for more frequent and intense storms, floods, landslides, wildfires, and extreme heat events.

6. Seek more reliable funding mechanisms to ensure that local governments can safeguard vulnerable populations, especially during heat waves. Provide incentives to prepare for energy supply interruptions and develop backup systems in schools, clinics, and emergency shelters.

7. Foster interaction with communication service providers to improve reliability of emergency services during extreme weather events, encourage communication companies to identify alternative means of communication during emergencies, and seek incentives for new technology to diversify and decouple communications from electric grids or otherwise improve their resilience.

Strategy G-5. Build capacity of the energy sector to respond to climate-related disruptions and meet potential increases in energy demand and changes in supply.

Actions:

1. Continue to consider climate-related changes in energy supply and demand, system reliability, and in the State Energy Strategy and the Northwest Power Plan. Encourage utilities to consider potential climate impacts in integrated resource plans.

2. Require consideration of climate risks in relicensing existing and siting new energy projects.

3. Aggressively increase energy efficiency and conservation efforts.

4. Encourage additional research into the impacts of climate change on alternative energy sources. Identify how future climate impacts could affect the state's renewable energy goals , and work with utilities to ensure that renewable energy and energy conservation goals are met.

5. Encourage the development of small energy sources on site (e.g., solar panels) to increase reliability by having redundant systems and to reduce risks associated with the long-distance transmission of energy.

6. Construct stronger, more resilient transmission and distribution systems to improve system reliability and to create additional capacity and redundancy.

7. Adjust reservoir management to account for climate impacts—either too little water or too much water—in considering multiple objectives for energy production, agriculture irrigation, flood management, fish flows, and other needs.

What is Smart Grid?

Smart Grid is an advanced telecommunications and electric grid with sensors and smart devices linking all aspects of the current grid—from generator to consumer—and delivering enhanced operational capabilities that:

- Provide users with the information and tools necessary to respond to electricity grid conditions, including price and reliability, through the use of electric devices and new services.
- Ensure efficient use of the electric grid, optimizing current assets while integrating emerging technologies such as renewable energy and storage devices.
- Enhance reliability by protecting the grid from cyber attacks, increasing power quality, and promoting early detection and self-correction of grid disruptions.

For more information:

www.pnwsmartgrid.org/

11. Research and Monitoring

11. Research and Monitoring

In the Pacific Northwest, a wide body of research exists on the impacts of climate change. The Climate Impacts Group (CIG) at the University of Washington has taken several steps to improve science/policy interactions through multiple methods and interdisciplinary approaches. In 2009, CIG completed a comprehensive assessment on the impacts of climate change on Washington and the implications for nine key economic sectors in the state. CIG also worked with several water management agencies in Washington to determine the effects of climate change on water resources, including development of hydrologic climate scenarios for nearly 300 streamflow locations in the Columbia River Basin and selected coastal drainages in western Washington.

Over the past few years, universities, regional organizations, federal and state agencies, local communities, tribes, and nongovernmental organizations formed several new partnerships. These collaborations are working to improve regional climate science projections, expand and coordinate scientific research and monitoring, and provide best available information to policymakers, managers, and the public.

State agencies need to be involved with various regional research organizations to ensure that scientific research agendas developed by the organizations can apply toward reducing Washington State's vulnerability to climate change and climatic extremes. Identifying the need for additional research and scientific information involves interactions with local experts, decision makers, and other groups, such as water users and managers, forest fire managers, and the conservation community.

Support is needed for additional research and monitoring to expand our understanding of the impacts of climate change; develop tools to ensure that climate information is accessible, relevant, and useful for decision makers and resource managers; and allow managers to track how climate change is progressing and how natural and human systems are responding. Tools that effectively incorporate past and future climate changes into land and water management are critical to making good decisions affecting natural and built systems. Also, new and improved partnerships are needed to tailor scientific information to local decision-making needs.

Improving our capacity to respond to climate change may require new monitoring networks or the expansion or adjustment of existing monitoring systems. Monitoring information can be used to refine and test the models and assumptions we use for projecting future climate changes. Monitoring networks that agencies and others currently manage are typically not well-coordinated and integrated, nor are they adequately funded to clearly focus on climate change and climate variability. Better integration is needed to ensure that monitoring data are easily accessible and can be shared.

Recommended Strategies and Actions—Research and Monitoring

Strategy H-1. Improve scientific knowledge and ensure that climate science is responsive and applied to the needs of policymakers, managers, planners, and others.

Actions:

1. Solicit input from local governments, tribes, businesses, nongovernmental organizations, and other stakeholders to identify needs for data, information, and resources that would foster their understanding of the risks and consequences of climate change at the regional, state, and local levels.

2. Participate in current research efforts conducted by the UW Climate Impacts Group, Northwest Climate Science Center, Regional Integrated Science and Assessment Center - Climate Impacts Research Consortium (CIRC), the North Pacific and Great Northern Landscape Conservation Cooperatives, and others to ensure the scientific research agenda recognizes Washington's distinctive natural resources and addresses priority needs of the state.

3. Support the periodic update of the U.S. National Climate Assessment for the Northwest and CIG's comprehensive regional climate scenarios for Washington State.

Understanding Washington's marine waters

The Puget Sound Assessment and Monitoring Program is an extensive network of regional scientists who monitor key indicators of water and sediment quality, nearshore habitat, and the health or abundance of fish, seabirds, shellfish, and marine mammals. With more than 25 years of water quality monitoring—including temperature, pH, and sediment—we are in a unique position to assess status and trends in our waters. This long-term monitoring lets us know if our waters are healthy or impaired and tracks trends over time.

Ecology's Marine Monitoring Unit conducts a variety of marine observations, including monthly sampling at 40 core monitoring stations. Ecology uses a floatplane to take photos of Puget Sound water conditions during routine transit flights between the Kenmore base and Olympia.

"Eyes Over Puget Sound" is the result, and the effort provides an example of how we are optimizing our resources to monitor Puget Sound. "Eyes Over Puget Sound" combines high-resolution photo observations with satellite images, data collected en route on ferries traveling across Puget Sound and to Vancouver Island, and measurements from moored instruments.

For more information:
www.ecy.wa.gov/programs/eap/mar_wat/mwm_intr.html
www.ecy.wa.gov/programs/eap/mar_wat/eops/

Strategy H-2. Partner and collaborate with state, federal, tribal, and local governments and various organizations to enhance existing monitoring systems, and develop new systems where needed to monitor the impacts of climate change and the efficacy of adaptation responses.

Actions:

1. Establish an extensive network of sentinel site monitoring stations at locations that are not expected to be subject to local land use changes. Include continuous monitors that track multiple measures, such as temperature, water quality and stream flows, at sentinel sites and at selected long-term ambient monitoring sites.

2. Take measurements in and around streams to:
   - *Assess hydrologic effects to stream channels from extreme storm events, including measuring the geometry and sediment composition of stream channels.*
   - *Assess biological integrity with regard to climate change impacts, such as monitoring of sediment-tolerant/intolerant organisms (taxa) and heat-tolerant/intolerant organisms.*
   - *Assess the stresses to riparian vegetation from dropping water tables and changing temperatures.*
   - *Evaluate signals in hydrology such as those developed by The Nature Conservancy through the Indicators of Hydrologic Alteration (IHA) software.*[164]

3. Work with the U.S. Geological Survey to implement a robust, multi-purpose groundwater monitoring program in Washington State, which will be part of the national groundwater climate response network (CRN).[165]

4. Implement monitoring programs designed specifically to test the effectiveness of adaptation actions and the assumptions underlying proposed adaptation actions. Encourage each agency or partner to monitor the implementation of its respective actions.

5. Collaborate with various agencies to monitor the spread of pests and diseases and to increase the overall efficiency and sensitivity of current surveillance systems.

Sentinel sites are monitoring stations for which long-term monitoring data are available.

[164] See http://conserveonline.org/workspaces/iha.
[165] See http://pubs.usgs.gov/fs/2007/3003/pdf/2007-3003-lowres.pdf.

Strategy H-3. Support development and use of applied tools for decision makers and land and water managers to help them understand the risks and consequences of changing climatic conditions on communities, infrastructure, and natural systems; and select effective adaptation options to build resilience.

Actions:

1. Share existing tools with local governments, state and tribal agencies, and local communities to help them understand key vulnerabilities to climate impacts and what actions can be taken. Examples include the Climate Ready Water Utilities Toolbox, Georgetown Climate Center sea level rise tool, and other tools. Incorporate climate change considerations into existing planning tools that evaluate the effects of alternative land use policies, such as ENVISION, INVEST, and models from the Natural Capital Project.[166]

2. Maintain the state's climate adaptation clearinghouse and link to other clearinghouses to improve the availability of information.[167] Leverage and link existing efforts to support climate adaptation efforts at the state, tribe, and local levels.

Climate Adaptation Clearinghouse

The Washington Department of Ecology's climate adaptation clearinghouse contains links to information on the impacts of climate change, regional and federal adaptation efforts, and resources to help communities plan and adapt.

www.ecy.wa.gov/climatechange/ipa_resources.htm

[166] See *www.naturalcapitalproject.org*
[167] See *www.ecy.wa.gov/climatechange/ipa_resources.htm*

12. Climate Communication, Public Awareness, and Engagement



12. Climate Communication, Public Awareness, and Engagement

To date, the public dialogue on climate change has largely focused on greenhouse gas emissions and reduction strategies. Moving forward, the public discussion needs expand to prepare Washington for the unavoidable consequences of climate change and extreme weather events. Without an informed public conversation, the adaptation strategies and actions will lack the support they need for effective implementation.

Building support to reduce climate risks is proving to be difficult as policymakers, local communities, and the public are currently challenged with urgent issues such as the economy and jobs. The risks that climate change will result in more frequent and severe floods, wildfires, droughts, and other extreme events make it necessary for policymakers and scientists to step up efforts to increase public awareness and build grassroots action.

Climate change is creating a new and dynamic decision environment. Citizens, governments, and businesses need an accurate understanding of the problem and its causes, the likelihood and severity of the impacts, how the risks may affect them personally and collectively, and the costs and benefits of taking action. Communication, education, and outreach are powerful tools that government agencies, private organizations, and nonprofits can use to dispel misconceptions and to bring climate impacts and hazards to the attention of the public.

Recent surveys of Washington's local government officials, planners, and stakeholders highlight the need for more outreach and education about impacts of climate change—for accessible information on how climate change could affect their communities and for insight into effective mechanisms to build resilience and engage the public.

The state Legislature directed Ecology to identify "methods to increase public awareness of climate change, its projected impacts on the community, and to build support for meaningful adaptation policies and strategies." The recommended strategies and accompanying actions described below are intended to:

- Raise awareness about risks and consequences of changing climate trends on various economic sectors, natural resources, and human health.
- Foster dialogue between state and local community leaders, scientists, resource managers, and policymakers on what we can do to prepare for and respond to the threats of changing climatic conditions.
- Engage and motivate organizations and individuals to take action.
- Explore opportunities for collaboration among government agencies, the private sector, and nongovernmental organizations to shape and strengthen future efforts to adapt to climate.

Recommended Strategies and Actions—Climate Communication, Public Awareness, and Engagement

Strategy I-1. Create coordinated and cohesive communication messages and tools on climate change impacts and adaptation, and ensure they are effectively distributed to a wide variety of people and professionals across all levels of government and the public.

Actions:

1. Continue to leverage partnerships between state agencies and research organizations to develop clear and consistent messaging on climate change impacts and adaptation. The messages must connect to other priority issues and resonate with people's core values, such as health, safety, and the economy.

2. Develop targeted climate change risk communication training for use communication staff within by state agencies and other entities.

3. Conduct targeted outreach to state and local elected officials, leaders, and staff to share information and outreach materials, improve the understanding of risks, and inform decision-making.

4. Develop communication materials focused on vulnerable communities that are at high risk and have a low capacity to respond, paying particular attention to low-income and underserved populations.

5. Develop risk maps and decision-support tools to identify climate change risks for specific geographic areas throughout the state.

6. Support additional research to identify how people perceive climate risks, what messages resonate with people, and how people learn and respond to information about climate change.

Strategy I-2. Leverage existing education and outreach networks and integrate communication about climate change.

Actions:

1. Build on existing networks and integrate climate change into current state agency education and outreach efforts related to public health, land use, ecosystems, water resources, coastal management, agriculture, forests, and infrastructure.

2. Use a variety of channels to communicate about climate change, such as:
   - *Web sites, agency listservs, newsletters, and news releases.*
   - *Social media, including Facebook, Twitter, and video clips.*
   - *Meetings of climate educators and climate communicators group.*
   - *Presentations at public events.*
   - *Publications including Frequently Asked Questions (FAQs).*

3. Promote effective integration of climate change education into K-12 educational programs and school curricula.

4. Bolster the network for climate educators, such as hosting peer-to-peer networking events and summits to share and exchange information, experiences, and best practices.

5. Encourage universities and community colleges to integrate climate considerations into vocational and educational training programs. For example, provide training for engineering students to incorporate more frequent and severe weather, flooding, sea level rise, or other climate impacts into design.

6. Build on the existing climate education website hosted by state agencies to provide information on existing tools, materials, and best practices in teaching and learning about climate change.

7. Partner with extension programs to incorporate climate information into community outreach efforts and programs. Build on successful models such as the Washington State University Extension's Carbon Masters program, the Master Gardeners program, and others.[168]

8. Provide peer-to-peer professional training opportunities and encourage sharing of information among levels of government, nongovernmental organizations, and professional associations.

[168] See http://carbonmasters.wsu.edu/ and http://mastergardener.wsu.edu/

Strategy I-3. Engage the public in climate change conversations and solutions for addressing impacts.

Actions:

1. Develop a framework for citizen engagement and action, modeled after the framework developed in 2007 as part of the Governor's climate change challenge.[169]

2. Develop compelling, visual stories and social media to connect climate change impacts to concerns people already have, convey the benefits of addressing climate change, and demonstrate how actions currently underway can address impacts of climate change.

3. Partner with scientists, community leaders, and organizations credible to target audiences and those affected directly by the impacts of climate change when delivering messages on climate change to citizens.

King Tide Photo Initiative

"King tides" occur naturally when the sun and the moon align, causing an increased gravitational pull on the Earth's oceans. The Washington Department of Ecology invites residents and visitors to take photos of Washington's king tides. Documenting how very high tides affect the natural environment and our coastal infrastructure will help us visualize what sea level rise might look like in the future.

In 2010 and 2011, Washington's King Tides Photo Initiative gathered over 400 photos.

Ecology's King Tide website:
www.ecy.wa.gov/climatechange/ipa_hightide.htm

[169] See *http://www.ecy.wa.gov/pubs/0801005.pdf*

4. Engage the news media and provide information to help citizens make informed choices.

5. Develop "citizen science" initiatives that engage the public in making observations and collecting and recording data on climate change and its effects on communities and the environment. Build on successful initiatives, such as the Washington King Tides Photo Initiative,[170] Washington Sea Grant citizen science initiatives,[171] National Phenology Network, and Audubon's Christmas Bird Count.

6. Improve Ecology's climate change clearinghouse to make the information more accessible and easier to understand. Build off successful models in other states, such as the Cal-Adapt website [172] and link to existing tools, case studies, projects, and portals, such as the Climate Adaptation Knowledge Exchange (CAKE) and the Georgetown Climate Center's Adaptation Clearinghouse.[173]

[170] See http://www.ecy.wa.gov/climatechange/ipa_hightide.htm
[171] See http://www.wsg.washington.edu/citizenscience/projects.html
[172] See http://cal-adapt.org/
[173] See www.cakex.org and www.georgetownclimate.org/adaptation/clearinghouse

Climate Adaptation Knowledge Exchange (CAKE)

Climate Adaptation Knowledge Exchange (CAKE), a joint project of Island Press and EcoAdapt, is aimed at building a shared knowledge base for managing natural systems in the face of climate change. It includes a virtual library of adaptation resources, case studies, a directory of individuals and organizations working on climate adaptation, and tools to help make adaptation decisions.

CAKE website:

www.cakex.org

The Adaptation Clearinghouse

The Adaptation Clearinghouse, developed by the Georgetown Climate Center, seeks to assist state policymakers, resource managers, academics, and others who are working to help communities adapt to climate change. The clearinghouse contains resources, tools, and case studies to help planners understand climate risks and effective response strategies.

Adaptation Clearinghouse website:

www.georgetownclimate.org/adaptation/clearinghouse

Glossary, Bibliography, and Photo Credits



Glossary and Acronyms

Adaptation: Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Adaptive capacity: The ability of a system or species to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Adaptive management: A systematic approach for improving resource management by learning from management outcomes. Adaptive management is an iterative approach in which managers, scientists, and stakeholders work together to evaluate a problem, select and implement strategies, monitor conditions, evaluate the effectiveness of the strategies, and adjust future actions accordingly.

Armored (or hardened) shorelines: Many shorelines have been hardened with concrete, steel, gabions, or armor stone to prevent erosion. Such reinforcement usually results in the elimination of shoreline vegetation and cover that is important to fish and other wildlife.

Biodiversity: The range of organisms present in a particular ecological community or system. It can be measured by the numbers and types of different species, or the genetic variations within and between species.

Combined sewer overflow (CSO): An overflow of stormwater, untreated waste, toxic material, and debris from a combined sewer system that collects sewage and stormwater runoff in a single pipe system. During periods of heavy rainfall or snowmelt, the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant. For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other water bodies.

Dike: An embankment for controlling or holding back water.

Ecosystem: A biological environment consisting of all the living organisms or biotic component, in a particular area, and the nonliving, or abiotic component, with which the organisms interact, such as air, soil, water and sunlight.

Estuary: A partly enclosed coastal body of water with one or more rivers or streams flowing into it, and with a free connection to the open sea.

Green infrastructure: Encompasses the preservation and restoration of natural landscape features, such as forests, wetlands, floodplains, and natural drainage features. At the site scale, it involves low-impact development (LID) and sustainable building features, such as rain gardens, green roofs, permeable pavement, rainwater harvesting, urban forestry, and preservation of green open spaces such as parks and wetlands.

Hardened (or armored) shorelines: Many shorelines have been hardened with concrete, steel, gabions, or armor stone to prevent erosion. Such reinforcement usually results in the elimination of shoreline vegetation and cover that is important to fish and other wildlife.

Hypoxia: Low oxygen concentration; used in this context regarding oxygen concentrations in waters such as Puget Sound.

Low-impact development: A planning and design approach to help manage stormwater using on-site natural features to manage rainfall and infiltrate, filter, store, evaporate, and detain runoff close to its source.

Maladaptation: When the negatives of an adaptation action or strategy outweigh the benefits, it becomes a maladaptation. Maladaptation may include strategies that benefit one sector or community at the expense of others; strategies that decrease near-term harm but increase long-term vulnerability; strategies that result in increased greenhouse gas emissions or otherwise increase the rate or extent of global or regional change; economic actions or strategies that reduce incentives to adapt or set paths that limit choices available to future generations.

Managed retreat: The deliberate process of altering barriers or other defenses to allow flooding of a presently defended area. Managing this flooding process helps to reduce risk and negative impacts.

Mitigation banking: The restoration, creation, enhancement, or preservation of a wetland, stream, or habitat conservation area, for the purpose of providing compensation for unavoidable impacts to ecosystem resources that a proposed project would adversely affect.

Phenology: Study of periodic biological phenomena, such as breeding, flowering, and migration, especially as related to climate.

Refugia (or climate refugia): Areas where climate change is likely to occur more slowly or to a lesser extent than other areas, due to physical landscape features, such as north-facing slopes, valleys or other low areas that act as sinks for cold air, or streams fed by deep coldwater springs. These areas provide refuge to species under stress from climate change.

Resilience: The ability of a population or system to bounce back to a condition similar to its previous state following disturbance or change, with core functions and processes intact.

Riparian zone (or riparian area): The interface between land and a river or stream.

Risk: A combination of the magnitude of potential consequences of climate change impacts and the likelihood that the consequences will occur.

Scenario planning: A method used to create and evaluate alternate futures, and to make decisions that are effective and robust across a range of possible futures.

Stormwater runoff: Stormwater is rain and snow melt that runs off surfaces such as rooftops, paved streets, highways, and parking lots. As water runs off these surfaces, it can pick up pollution such as: oil, fertilizers, pesticides, soil, trash, and animal waste. From here, the water might flow directly into a local stream, bay, or lake. Or, it may go into a storm drain and continue through storm pipes until it is released untreated into a local waterway.

Sustainability: The conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations. Sustainability is important to making sure that we have and will continue to have the water, materials, and resources to protect human health and our environment.

Transfer of development rights (TDR): A mechanism that allows owners of property zoned for low-density development or conservation use to sell development rights to other property owners located in "receiving" zones, such as designated urban areas, that can accept additional density.

Urban heat island: Developed areas that are hotter than nearby rural areas. Buildings, roads, and other infrastructure change the landscape and replace open land and vegetation with impermeable dry surfaces. These changes cause urban regions to become warmer than their rural surroundings, forming an "island" of higher temperatures in the landscape. Heat islands can affect communities by increasing summertime peak energy demand, air conditioning costs, air pollution and greenhouse gas emissions, heat-related illness and mortality, and water quality.

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variations to which a system is exposed, its sensitivity, and its adaptive capacity. Vulnerability to climate change can be exacerbated by the presence of other stresses.

Zoonotic disease: A disease that can be transmitted from animals to people or, more specifically, a disease that normally exists in animals but that can infect humans.

Acronyms

BLM	Bureau of Land Management
BPA	Bonneville Power Administration
CAKE	Climate Adaptation Knowledge Exchange
CDC	Centers for Disease Control and Prevention
CIG	Climate Impacts Group at the University of Washington
CIRC	Climate Impacts Research Consortium
CREAT	Climate Resilience and Assessment Tool
CRN	Climate Response Network
CSC	Climate Science Center
CZM	Coastal Zone Management
DNR	Washington Department of Natural Resources
ESRL	Earth System Research Laboratory
EQIP	Environmental Quality Incentives Program
FEMA	Federal Emergency Management Agency
FLP	Forest Legacy Program
GHG	Greenhouse Gas
GMA	Growth Management Act
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
LCC	Landscape Conservation Cooperative
LID	Low-impact development
LWCF	Land and Water Conservation Fund

NFIP	National Flood Insurance Program
NGO	Nongovernmental organization
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NW	Northwest
NWS	National Weather Service
OA	Ocean acidification
PSU	Portland State University
RCW	Revised Code of Washington
RISA	Regional Integrated Sciences and Assessments
Risk MAP	Risk Mapping, Assessment, and Planning (a FEMA program)
SLR	Sea level rise
TDR	Transfer of development rights
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
UW	University of Washington
WACCIA	Washington Climate Change Impacts Assessment
WSDA	Washington State Department of Agriculture
WSU	Washington State University

Bibliography

American Public Health Association. Climate Change and Public Health Fact Sheet. Available at http://www.apha.org/NR/rdonlyres/0BB28118-6236-4586-99DE-294C00199628/0/APHAClimChg_PHissue_4d.pdf.

Arhonditsis, G.B., M.T. Brett, C.L. DeGasperi, and D.E. Schindler. 2004. Effects of climatic variability on the thermal properties of Lake Washington. Limnology and Oceanography 49(1): 256–270.

Batker, D., M. Kocian, J. McFadden, and R. Schmidt. 2010. Valuing the Puget Sound Basin: Revealing Our Best Investments. Earth Economics. Tacoma, WA.

Bradley, B.A. 2009. Regional analysis of the impacts of climate change on cheatgrass invasion shows potential risk and opportunity. Global Change Biology 15: 196–208.

Campbell, S. K. Waddell, and A. Gray (tech. eds.). 2010. Washington's forest resources, 2002–2006: five-year Forest Inventory and Analysis report. Gen. Tech. Rep. PNW-GTR-800. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Canadell, J.G., C. Le Quere, M.R. Raupach, C.B. Field, E.T. Buitenhuis,, P. Ciais, T.J. Conway, N.P. Gillett, R.A. Houghton, and G. Marland. 2007. Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity, and efficiency of natural sinks. Proceedings of the National Academy of Sciences of the United States of America 104.

Casola, J.H.; J.E. Kay, A.K. Snover, R.A. Norheim, and L.C. Whitely Binder. 2005. Climate impacts on Washington's hydropower, water supply, forests, fish, and agriculture. A report prepared for King County (Washington) by the Climate Impacts Group, Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, WA.

Climate Impacts Group. 2009. The Washington Climate Change Impacts Assessment. M. McGuire Elsner, J. Littell, and L. Whitely Binder (eds). Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle, WA.

Climate Leadership Initiative. 2010. Additional Analysis of the Potential Economic Costs to the State of Washington of a Business-as-Usual Approach to Climate Change: Lost Snowpack Water Storage and Bark Beetle Impacts.

Curriero, F.C., J.A. Patz, J.B. Rose, and S. Lele. 2001. The association between extreme precipitation and waterborne diseases outbreaks in the United States, 1948-1994. American Journal of Public Health 91(8):1194-1199.

Dettinger, M. 2011. Climate Change, Atmospheric Rivers, and Floods in California - A Multimodel Analysis of Storm Frequency and Magnitude Changes. J. Am. Water Resour. Assoc. 47: 514-523.

Ducks Unlimited, Inc. 2010a. SLAMM Analysis of Grays Harbor, Washington. Unpublished technical report, Vancouver, WA.

Ducks Unlimited, Inc. 2010b. SLAMM Analysis of the Lower Columbia River, Washington and Oregon. Unpublished technical report, Vancouver, WA.

Ducks Unlimited, Inc. 2010c. SLAMM Analysis of Willapa Bay, Washington. Unpublished technical report, Vancouver, WA.

Ducks Unlimited, Inc. 2010d. Update of Puget Sound SLAMM Analysis. Unpublished technical report, Vancouver, WA.

Elsner, M.M., L. Cuo, N. Voisin, J. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

Euro-Limpacs. 2011. Climate Change and Freshwater.

Feely, R.A., S.R. Alin, J. Newton, C.L. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy. 2010. The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. Estuarine, Coastal and Shelf Science 88(4): 442-449.

Feely, R.A., S.C. Doney, and S.R. Cooley. 2009. Ocean acidification: Present conditions and future changes in a high-CO2 world. Oceanography 22(4): 36–47.

Franklin, J.F., M.A Hemstrom, R. VanPelt, J.B. Buchanan, and S. Hill. 2008. The Case for Active Management of Dry Forest Types in Eastern Washington: Perpetuating and Creating Old Forest Structures and Functions. Washington Department of Natural Resources.

Glick, P., J. Clough, and B. Nunley. 2007. Sea-level Rise and Coastal Habitats in the Pacific Northwest: An Analysis for Puget Sound, Southwestern Washington, and Northwestern Oregon. National Wildlife Federation.

Hamlet, A.F., and D.P. Lettenmaier. 2007. Effects of 20th century warming and climate variability on flood risk in the western U.S. Water Resources Research 43, W06427.

Hamlet, A.F., S.Y. Lee, K.E.B. Mickelson, and M.M. Elsner. 2010. Effects of projected climate change on energy supply and demand in the Pacific Northwest and Washington State. Climatic Change 102(1-2): 103-128.

Hamlet, A.F. 2011. Impacts of climate variability and climate change on transportation systems and infrastructure in the Pacific Northwest. A White Paper prepared for the Western Federal Lands-Highway Division by the Climate Impacts Group, University of Washington, Seattle, WA.

Hamlet, A.F., P. Carrasco, J. Deems, M.M. Elsner, T. Kamstra, C. Lee, S-Y Lee, G. Mauger, E. P. Salathe, I. Tohver, L. Whitely Binder. 2010. Final Project Report for the Columbia Basin Climate Change Scenarios Project. *http://www.hydro.washington.edu/2860/report/*.

Hessburg, P.F. and J.K. Agee. 2003. An environmental narrative of Inland Northwest United States forests, 1800-2000. Forest Ecology and Management 178: 23-59.

Hessburg, P.F., J.K. Agee, and J.F. Franklin. 2005. Dry mixed conifer forests and wildland fires of the inland Northwest USA: Contrasting the landscape ecology of the pre-settlement and modern eras. Forest Ecology and Management 211: 117-139.

Hidalgo, H.G., T. Das, M.D. Dettinger, D.R. Cayan, D.W. Pierce, T.P. Barnett, G. Bala, A. Mirin, A.W. Wood, C. Bonfils, B.D. Santer, and T. Nozawa. 2009. Detection and Attribution of Streamflow Timing Changes to Climate Change in the Western United States. Journal of Climate 22: 3838-3855.

Hoegh-Guldberg, O, and J.F. Bruno. 2010. The impact of climate change on the world's marine ecosystems. Science 328: 1523-1528.

Huppert, D.D., A. Moore, and K. Dyson. 2009. Impacts of climate change on the coasts of Washington State. Chapter 8 in The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate. Climate Impacts Group, University of Washington, Seattle, WA.

IPCC. 2007a. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA.

IPCC. 2007b. Climate Change 2007: Summary for Policymakers. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA.

IPCC. 2007c. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment, Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.

Jackson, J.E., M.G. Yost, C. Karr, C. Fitzpatrick, B. Lamb, S.H. Chung, J. Chen, J. Avise, R.A. Rosenblatt, and R.A. Fenske. 2010. Public health impacts of climate change in Washington State: Projected mortality risks due to heat events and air pollution. Climatic Change 102(1-2): 159-186.

Jamison, R. 2012. Personal communication by e-mail. Received on January 26, 2012 from Rachael. jamison@dnr.wa.gov.

Kelly R.P., Foley M.M., Fisher W.S. Feely R.A., Halpern B.S. Waldbusser G.G., and M.R. Caldwell. 2011. Mitigating Local Causes of Ocean Acidification with Existing Laws. Science 332(6033): 1036-1037.

Littell, J.S., M.M. Elsner, L.C. Whitely Binder, and A.K. Snover (eds). 2009. The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate - Executive Summary. In The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate, Climate Impacts Group, University of Washington, Seattle, WA.

Littell, J.S., E.E. Oneil, D. McKenzie, J.A. Hicke, J.A. Lutz, R.A. Norheim, and M.M. Elsner. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change 102(1-2): 129-158.

Mantua, N.J., I. Tohver, and A.F. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102(1-2): 187-223.

Mote, P.W., A.F. Hamlet, M. Clark, and D.P. Lettenmaier. 2005. Declining mountain snowpack in western North America. Bulletin of the American Meteorological Society 86(1): 39-49.

Mote, P.W. 2003. Trends in temperature and precipitation in the Pacific Northwest during the twentieth century. Northwest Science 77(4): 271-282.

Mote, P.W., and E.P. Salathé. 2010. Future climate in the Pacific Northwest. Climatic Change 102(1-2): 29-50.

Mote, P.W., A.F. Hamlet, and E.P. Salathé. 2008. Has spring snowpack declined in the Washington Cascades? Hydrology and Earth System Sciences 12: 193-206.

Mote, P.W., A. Petersen, S. Reeder, H. Shipman, and L.C. Whitely Binder. 2008. Sea Level Rise in the Coastal Waters of Washington State. Report prepared by the Climate Impacts Group, Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle, WA and the Washington Department of Ecology, Lacey, WA.

NASA. 2010. NASA Research Finds Last Decade was Warmest on Record, 2009 One of Warmest Years. News Release 10-017. *http://www.nasa.gov/home/hqnews/2010/jan/HQ_10-017_Warmest_temps.html*

National Research Council. 2010. Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean. Washington, DC: The National Academies Press. *http://dels.nas.edu/Report/Ocean-Acidification-National-Strategy/12904*

Nicholls, R.J.,[M. L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C. E. Hanson (eds)]. 2007. Coastal systems and low-lying areas. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. 315-356.

Northern Economics, Inc. 2010. Assessment of Benefits and Costs Associated with Shellfish Production and Restoration in Puget Sound. Prepared for Pacific Shellfish Institute.

Noss, R.F. 2001. Beyond Kyoto: Forest Management in a Time of Rapid Climate Change. Conservation Biology 15(3): 578-590.

Office of Financial Management (OFM). 2011. Washington State 2011 Data Book. *www.ofm.wa.gov/databook/default.asp*.

Partridge, C. and B. McGregor. 2007. The Future of Washington Forests. Washington Department of Natural Resources, Olympia, WA.

Pierce, D.W., T.P. Barnett, H.G. Hidalgo, T. Das, C. Bonfils, B.D. Santer, G. Bala, M.D. Dettinger, D.R. Cayan, A. Mirin, A.W. Wood, and T. Nozawa. 2008. Attribution of Declining Western U.S. Snowpack to Human Effects, Journal of Climate 21: 6425-6444.

Portier CJ, Thigpen Tart K, Carter SR, Dilworth CH, Grambsch AE, Gohlke J, Hess J, Howard SN, Luber G, Lutz JT, Maslak T, Prudent N, Radtke M, Rosenthal JP, Rowles T, Sandifer PA, Scheraga J, Schramm PJ, Strickman D, Trtanj JM, Whung P-Y. 2010. A Human Health Perspective On Climate Change: A Report Outlining the Research Needs on the Human Health Effects of Climate Change. Research Triangle Park, NC: Environmental Health Perspectives/National Institute of Environmental Health Sciences. *www.niehs.nih.gov/climatereport*

Rahmstorf, S. 2010. A new view on sea level rise. Nature Reports Climate Change 4. *http://www.nature.com/climate/2010/1004/full/climate.2010.29.html*

Rose, J.B., S. Daeschner, D.R. Easterline, F.C. Curriero, S. Lele, J.A. Patz. 2000. Climate and waterborne disease outbreaks. Journal of the American Water Works Association, 92(9): 77-87.

Rosenberg, E.A., P.W. Keys, D.B. Booth, D. Hartley, J. Burkey, A.C. Steinemann, and D.P. Lettenmaier. 2010. Precipitation extremes and the impacts of climate change on stormwater infrastructure in Washington State. Climatic Change 102(1-2): 319-349.

Salathé, E.P. 2006. Influences of a shift in North Pacific storm tracks on western North American precipitation under global warming. Geophysical Research Letters 33, L19820.

Salathé, E.P., L.R. Leung, Y. Qian, and Y. Zhang. 2010. Regional climate model projections for the State of Washington. Climatic Change 102(1-2): 51-75.

Seattle Times. 2011. Climate change, beetle may doom rugged pine. *http://seattletimes.nwsource.com/html/localnews/2016699269_barkbeetle06m.html*

Stewart, I.T., D.R. Cayan and M.D. Dettinger. 2005. Changes toward earlier streamflow timing across western North America. Journal of Climate 18(8): 1136-1155.

Stöckle, C., R.L. Nelson, S. Higgins, J. Brunner, G. Grove, R. Boydston, M. Whiting, and C. Kruger. 2010. Assessment of climate change impact on eastern Washington agriculture. Climatic Change 102(1-2): 77-102.

Tebaldi, C., K. Hayhoe, J.M. Arblaster, and G.A. Meehl. 2006. Going to the Extremes: An Intercomparison of Model-Simulated Historical and Future Changes in Extreme Events. Climatic Change 79(3-4): 185-211.

Thomas M.K, D.F. Charron, D. Waltner-Toews , C. Schuster, A.R. Maarouf, and J.D. Holt. 2006. A role of high impact weather events in waterborne disease outbreaks in Canada, 1975-2001. International Journal of Environmental Health Research 16(3): 167-180.

Tohver, I., and A.F. Hamlet. 2010. Impacts of 21st century climate change on hydrologic extremes in the Pacific Northwest region of North America. Chapter 7 in Final Report for the Columbia Basin Climate Change Scenarios Project, Climate Impacts Group, Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle.

U.S. Bureau of Reclamation. 2011. SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water, Report to Congress.

U.S. Climate Change Science Program and U.S. Dept. of Agriculture. 2008. The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity. SAP 4.3. *http://www.climatescience.gov/Library/sap/sap4-3/default.php*.

U.S. Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau. 2006. National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.

U.S. EPA. 2009. Assessment of the Impacts of Global Change on Regional U.S. Air Quality: A synthesis of climate change impacts on ground-level ozone. EPA/600/R-07/094F.

U.S. EPA. 2010a. Climate Change and Health Effects. EPA 430-F-10-003. *http://www.epa.gov/climatechange/downloads/Climate_Change_Health.pdf*.

U.S. EPA. 2010b. Climate Change Indicators in the United States. EPA 430-R-10-007. *http://epa.gov/climatechange/indicators.html*.

U.S. Global Change Research Program. 2009. Global Climate Change Impacts in the United States, T.R. Karl, J. M. Melillo, and T.C. Peterson, (eds.). Cambridge University Press.

Vano, J.A., M. Scott, N. Voisin, C. Stöckle, A.F. Hamlet, K.E.B. Mickelson, M.M. Elsner, and D.P. Lettenmaier. 2010. Climate change impacts on water management and irrigated agriculture in the Yakima River basin, Washington, USA. Climatic Change 102(1-2): 287-317.

Vano, J.A., N. Voisin, L. Cuo, A.F. Hamlet, M.M. Elsner, R.N. Palmer, A. Polebitski, and D.P. Lettenmaier. 2010. Climate change impacts on water management in the Puget Sound region, Washington, USA. Climatic Change 102(1-2): 261-286.

Wade, T.J., S.K. Sandhu, D. Levy, S. Lee, M.W. LeChevallier, L. Katz, and J.M. Colford, Jr. 2004. Did a Severe Flood in the Midwest Cause an Increase in the Incidence of Gastrointestinal Symptoms? American Journal of Epidemiology 159(4): 398-405.

Washington State Department of Health, Reshaping Governmental Public Health in Washington State: An Agenda for Change, October 2010. *http://www.doh.wa.gov/PHSD/doc/AgendaForChange.pdf*

Washington Department of Fish and Wildlife (WDFW). 2011. Fish, Wildlife, and Washington's Economy. *www.wdfw.wa.gov/publications/01344/wdfw01344.pdf*.

Washington Department of Fish and Wildlife (WDFW). 2008. Economic Analysis of the Non-Treaty Commercial and Recreational Fisheries in Washington State. Prepared by TCW Economics with assistance from The Research Group. *http://wdfw.wa.gov/publications/00464/wdfw00464.pdf*.

Washington State Department of Transportation (WSDOT). 2008a. Storm-Related Closures of I-5 and I-90: Freight Transportation Economic Impact Assessment Report, Winter 2007-2008: WA-RD 708.1. *http://www.wsdot.wa.gov/research/reports/fullreports/708.1.pdf*.

Washington State Department of Transportation (WSDOT). 2008b. Flooding in the Chehalis River Basin: Synthesis. *http://www.wsdot.wa.gov/NR/rdonlyres/C7DB2042-AAA9-4D93-8686-42B9D18E71EB/64822/ChehalisFloodingTSRAPFeb20083.pdf*.

Water Supply Forum. 2009. 2009 Regional Water Supply Outlook. *http://www.watersupplyforum.org/home/outlook/*.

Westerling, A.L., Hidalgo, H.G., Cayan, D.R., and Swetnam, T.W. 2006. Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity. Science 313 (5789): 940-943.

Western Forestry Leadership Coalition (WFLV). 2010. The True Cost of Wildfire in the Western U.S.

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Appendices



Appendices

These appendices are available on the Department of Ecology's website at:
www.ecy.wa.gov/climatechange/ipa_responsestrategy.htm

Appendix A. Advisory Group Members
Appendix B. Advisory Group Final Reports and Recommendations
Appendix C. Priority Response Strategies and Actions
Appendix D. Summary of Projected Changes in Major Drivers of Pacific Northwest Climate Change Impacts