Overview of Climate Change Impacts in the U.S. Pacific Northwest

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Introduction

Understanding how global climate change may affect regional and local-scale processes is vital to developing the capacity to adapt to these changes. The following is a summary of projected climate change impacts for six diverse yet connected sectors of the Pacific Northwest (PNW) environment: hydrology and water resources, salmon and marine ecosystems, forests, coasts, agriculture, and human health. The information presented here draws largely from the work of the Climate Impacts Group at the University of Washington (water, salmon/marine ecosystems, forests, and coasts) with additional information from the U.S. Forest Service Research stations (forests), Washington State Department of Ecology (coasts), and the U.S. National Assessment (agriculture and human health).

Pacific Northwest Climate Change

20th century climate shows evidence of change. While natural climate variability has caused (and will continue to cause) fluctuations in PNW climate on seasonal and decadal scales, analysis of observed 20th century conditions shows evidence of longer term trends that are consistent with modeled projections of 21st century climate change *(Table 1, Figure 1)*. These trends include region-wide warming, increased precipitation, declining snowpack, earlier spring runoff, and declining trends in summer streamflow.

Warmer temperatures are projected with the most certainty. Greenhouse gases accumulating in the atmosphere have already raised global temperature beyond what can be expected from natural variability (*IPCC 2001*). Projections of future climate are based on estimates of (1) future global greenhouse gas and aerosol emissions, and (2) sensitivity to those changes. The uncertainty in (1) plays a larger role in temperature projections after mid-21st century; uncertainty in (2) is largely encompassed by examining a number of different climate models. For the PNW, an increase in average annual temperature of 2.7°F (range: 0.8-4.7°F) by the 2020s and 4.1°F (range: 2.7-5.8°F) by the 2040s is likely *(Table 2) (Mote et al. 2003)*.

Precipitation changes are less certain. Projected changes in annual precipitation are less certain than projected temperature changes. Most models project warmer, wetter winters and warmer, drier summers for the PNW *(Table 2)*. Studies of 20th century climate variability suggest, however, that the relatively small trends in precipitation projected with climate change may be less than the range of precipitation associated with natural decadal-scale variability *(Hamlet et al. 2004; Mote et al. 2004)*. Additionally, the increases in summer precipitation projected by some models do not fundamentally change the region's dry summers nor do they mitigate for increased drying of the soil column brought on by higher temperatures *(Hamlet and Lettenmaier 1999)*.

Impacts on other aspects of climate are uncertain. Climate models currently give little useful guidance about future changes in windstorms, cloudiness, or the behavior of patterns like El Niño/Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO)[2]. However, we expect that there will be wetter and dryer periods in the future (as in the 20th century), but that these periods will be superimposed on a warmer PNW. Thus, human systems (such as water resources systems) will have to be able to cope with both warm and dry *and* warm and wet conditions.

Projected Impacts of Climate Change

The temperature and precipitation changes

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[1] The Climate Impacts Group (CIG) at the University of Washington has conducted research on the impacts of climate variability and change on the Pacific Northwest (PNW) since 1995. For more information on the CIG and its research, please go to: www.cses.washington/edu/cig.

[2] ENSO and PDO have a major influence on PNW climate and natural resources on seasonal to decadal scales. For more information on the impacts of natural climate variability on PNW climate and natural resources, see *Mote et al. 1999.*

projected for the PNW have important implications for the region's water resources, salmon/marine ecosystems, forest resources, coastal environments, agricultural resources, and human health. In some cases, like snowmelt-driven hydrology, significant changes consistent with a warming climate are already occurring; in others, the results are still somewhat speculative.

☐ *Hydrology and Water Resources*

Limited reservoir storage and reliance on snowpack leaves the PNW vulnerable to climate variations affecting snowpack and streamflow. Most PNW watersheds are highly dependent on the accumulation of winter snowpack for meeting summer (April-September) water supply needs. Limited reservoir storage reduces the ability of watersheds to capture winter precipitation and spring runoff for use in the summer and early fall. Storage in the Columbia River Basin, for example, is only 30% of total annual flow *(Miles et al. 2000)*. While building more storage may be an option in some basins, many basins – including the Columbia River Basin – are essentially fully developed. Other approaches for managing climate change impacts will be required.

Projected hydrologic impacts are diverse. Skillful modeling of hydrologic responses to past temperature and precipitation changes has facilitated the development of well constructed climate change scenarios for PNW water resources *(Hamlet and Lettenmaier, 1999; Payne et al. 2004; Snover et al. 2003)*. These scenarios show that the projected hydrologic impacts of climate change are diverse, affecting winter precipitation, snowpack accumulation, spring snowmelt, and winter/summer streamflows. While the specific magnitude of these impacts varies basin-by-basin, in general the warmer temperatures and increased winter precipitation projected by global climate models for the PNW by mid-21st century are expected to:

- Increase the amount of winter precipitation falling as rain rather than snow;
- Increase winter streamflow;
- Increase winter flood risks in transient (rain/snow mix) basins;
- Reduce the amount of water stored as snow, particularly in mid-elevation transient (rain/snow mix) basins *(Figure 2)*;
- Induce earlier snow melt and advance peak runoff earlier into the spring; and
- Decrease late spring and summer streamflows.

(Hamlet and Lettenmaier 1999; Mote et al. 1999; Miles et al. 2000; Mote et al. 2003; Palmer and Hahn 2002; Palmer et al. 2004)

Management implications are equally diverse. Climate change could affect how agencies manage PNW water resource systems for instream flows, irrigation, municipal water supplies, recreation, hydropower production, navigation, water quality, and flood control (Table 3). The greatest impacts are likely to be associated with water resources objectives dependent on summer streamflow *(Hamlet 2001)*. Projected lower accumulation in winter snowpack, combined with earlier melting of the snowpack, reduces the amount of water available as snow for spring reservoir refill and summer streamflows. The earlier snowmelt also lengthens the low-flow summer season. These changes, combined with increased demand for water and energy as a result of warmer summer temperatures and population growth, increase competition for water among multiple and often competing water uses.

Elevation matters. The projected effects of climate change will occur sooner (i.e., for smaller amounts of warming) and will be most pronounced in water systems fed by river basins in the mid-elevation transient snow zone. Areas with winter temperatures well below freezing may show only modest changes in streamflow timing for the same amount of regional warming, and hence will have delayed impacts. This is particularly true of the Canadian part of the Columbia River Basin which is at high elevation in the northern most part of the region.

Capacity to adapt to low flows is limited. Analysis of institutional capacity to adapt to hydrologic impacts finds that adaptability to drought presents one of the greatest challenges for PNW water resource systems *(Miles et al. 2000)*. Major limitations on adaptive capacity in the Columbia River system include low storage capacity and the system's inability to meet current demands; the large and fragmented arrangement of decision-making authorities for managing drought in the basin; and the number of agreements, legal requirements, and coordinating processes that must be dealt with when considering changes in policy. No official incorporation of climate change scenarios in long-range planning may also leave water resource systems more vulnerable to projected climate changes. These concerns highlight the need to improve planning and coordination processes and to develop regional drought contingency plans for the Columbia basin to reduce the PNW's vulnerability to low flow conditions. Such changes would benefit the region regardless of changes in climate, and would likely reduce low flow impacts associated with climate change.

There are opportunities to avoid some of the impacts by changing the way water systems are managed and operated. Despite the institutional concerns discussed above, technical opportunities to adapt to climate change have been examined for several PNW water resources systems. Payne et al. (2004), for example, found that changing flood control operating rules and allocating more storage for summer fish flows in the Columbia River Basin could ameliorate some of the impacts to the reliability of reservoir refill and summer fish flows caused by projected streamflow timing shifts. These adaptive measures, however, had tradeoffs in other important water resources objectives such as winter hydropower production.

☐ *Salmon and Marine Ecosystems*

PNW climate change includes many negatives for PNW salmon. PNW salmon are subject to a world of multiple stresses, including human impacts on streamflows and salmon habitat. Climate change adds another dimension to, and in many cases exacerbates, these stresses. Increased winter flooding, decreased summer and fall streamflows, and elevated warm season stream and estuary temperatures will clearly degrade in-stream and estuarine salmon habitat in the PNW. These changes will likely cause severe problems for the salmon stocks that are already stressed from degraded freshwater and estuarine habitat. Where winter temperatures are now cooler than optimal for juvenile salmon and/or incubating eggs, warming may improve stream productivity. However, such conditions are now limited to a very small number of inland, high elevation salmon bearing streams.

Impacts to PNW coastal ocean conditions are unclear. Early efforts to model ocean conditions indicate that warmer temperatures are likely to increase ocean stratification, which in the past has coincided with relatively poor ocean habitat for most PNW salmon, herring, anchovies, and smelt populations. Possible increases in winds may counter the increased stratification in ways that mitigate or even increase the wind-driven upwelling of critical nutrients *(Bakun 1990).*

Assessing impacts is challenging given complexities and uncertainties. Projecting climate change impacts on PNW salmon and coastal ecosystems is a challenging task. Salmon have complex life histories that may result in different responses to climate impacts across populations and geographic ranges. Furthermore, impacts of climate change on the marine environment, where salmon spend most of their life, are less well understood than impacts on inland freshwater environments. Changes in patterns and frequencies of natural climate variations (e.g., ENSO and PDO) are also important. For the factors that we can simulate with some confidence, the prospects for many PNW salmon stocks look bleak. Impacts to the PNW coastal marine fishery, which over the past 20 years has been worth $100 billion and $150 billion (dockside value), will be evaluated by the CIG using an ecosystem model driven by climate and fishing.

☐ *Forests*

Responses to climate change will vary. Forest responses to climate change will vary substantially within the region, even within forest stands, as climatic changes interact with topography, forest type, soil moisture, productivity rates, species distribution and competition, and disturbance regimes (e.g., fire, insects). A few broad patterns can be highlighted.

Impacts of climate change will be most apparent at forest interfaces and during seedling establishment. Climate change impacts are likely to be most obvious along interfaces between major biomes, such as forests and grasslands, or forest types, although die-back (should it occur) may be regional (rather than only at the interfaces). Forests are also vulnerable to climate impacts during stand initiation or open-canopied seedling establishment stages. Seedlings are especially sensitive to temperature extremes and to drought; establishment success and growth rates may be lower for present-day species seedlings under future climate conditions. Projections for increased frequency of summer drought as a result of climate change could make forest regeneration more difficult during these times. If seeding and planting do not succeed, the costs of replanting and of foregone production could be significant. *(Bachelet 2001; Keeton et al. 2004)*

Elevation matters. High elevation sub-alpine and alpine forests productivity may be enhanced by warmer winter temperatures and earlier snowmelt due to higher rates of seedling establishment and lengthening of the growing season. Upper elevational treeline will likely go up. In drier high-elevation sites, however, a longer growing season could allow summer soil moisture deficits to increase, potentially limiting productivity. In contrast, warmer temperatures and reduced snowpack in low elevations may limit forest growth by reducing the amount of water available for soil moisture recharge in the spring *(Ettl and Peterson 1995; Peterson and Peterson 2001; Peterson et al. 2002; Nakawatase 2003)*. Douglas-fir, the PNW's primary timber species, appears relatively sensitive to low soil moisture, especially on drier sites *(Case 2004; Hessl and Peterson 2004; Holman 2004).*

Species distributions are likely to change. Climate change is likely to cause plant communities to undergo shifts in their species composition and/or experience changes in densities in response to changes in temperature, precipitation, and disturbance regimes (e.g., drought, fire). Ecological models driven by several climate change scenarios project that cool coniferous forests in the western part of the PNW will contract and be replaced by mixed temperate forests over substantial areas. Dry forests in the eastern part of the region are likely to expand in response to projected increases in winter precipitation. Loss of biological diversity is possible if environmental shifts outpace species migration rates and interact with population dynamics to cause increased rates of local extinction. *(Mote et al. 2003)*

Changes in disturbance regimes are possible. Changes in fire frequency and/or severity are expected to have the largest effect on PNW forests. Several analyses suggest a longer fire season and greater likelihood of fires in forests east of the Cascades in the future (*Bachelet 2001; McKenzie et al. 2004*). Changes in fire frequency over the next century in forests west of the Cascades is less clear given that historic fire return intervals are greater than a century *(Neilson 2004*), although increased fire frequency in these forests could have significant ecological impacts. Changes in other disturbances, such as wind, insects, and disease, are also possible although the potential character of these disturbances under climate change are poorly understood. Interactions between multiple disturbances (e.g., between insects and fire) will be especially important *(Mote et al. 2003)*.

☐ *Coasts*

Climate change is likely to exacerbate current hazards. Global climate change is projected to exacerbate many of the same stresses and hazards currently facing the coastal zone. These include coastal erosion, shoreline retreat, bluff landsliding, and flooding.

Sea level rise impacts are varied. The Intergovernmental Panel on Climate Change "best estimate" of global sea level rise is 19 inches by 2100, with a range of 6 to 37 inches *(IPCC 2001)*. Local factors can strongly influence the impact of this change. The sea level rise that will be experienced along PNW coasts will depend on circulation changes in the Northeast Pacific and on local vertical land movements. In some places (south Puget Sound and the northern Oregon coast), land subsidence will exacerbate sea level rise; in other places (the Washington and southern Oregon coasts), uplift will ameliorate sea level rise *(Figure 3)*.

Coastal erosion, shoreline retreat, landslides are likely to increase. Coastal erosion, shoreline retreat, and landslides are projected to increase as a result of sea level rise and increased winter precipitation. Depending on uncertain changes in mean wind direction and wave climate, some coastal areas may experience accretion while others, even nearby, experience erosion. An increased frequency and/or magnitude of landsliding could be expected anywhere geologic conditions are conducive to landsliding, and are likely to be even more severe in areas subject to intensive development on unstable slopes.

☐ *Agriculture*

Projected impacts on agriculture are varied and uncertain. As with forests and salmon stocks, each crop or commodity may respond differently to changes in climate and atmospheric composition. In general, simulation models of specific crops indicate that a longer growing season improves agricultural productivity. Most PNW crops are expected to grow better in the future provided 1) enough water is available, and 2) other non-climatic conditions do not change *(NAST 2001)*. However, as noted previously, summer water supplies for irrigation are likely to decline in many areas of the PNW due to climate change while evaporative demand during the growing season is likely to increase *(Hamlet and Lettenmaier 1999).* Additionally, crop models typically assume no increased risk of pests, diseases, or weeds, most of which seem to fare better in a warmer climate *(NAST 2001).* It should also be noted that economic impacts to PNW agriculture are strongly related to uncertain future conditions in the global marketplace. Thus economic impacts to farmers may be only partly coupled to the ability to grow healthy crops in the PNW. CIG research is currently being conducted to better quantify the impacts to irrigated agriculture under global warming scenarios in the Snake River basin in partnership with the Idaho Department of Water Resources.

☐ *Human Health*

Impacts to human health uncertain. Little research has been done on the relationship between climate and human health in the PNW. In other northern locations like Chicago, a connection has been noted between extreme high temperatures and excess mortality *(NAST 2001).* Air pollution, which tends to be worst on hot stagnant days, may increase. Other factors, like reduced frequency of extreme cold, changes in other extreme weather events like heavy rainfall, poleward spread of tropical or subtropical diseases, changes in transmission of insect- or rodent-borne diseases, and changes in cloudiness which may affect suicide rate, cannot yet reliably be assessed.

Adapting to the Impacts of Climate Change

Human influences will continue to change atmospheric composition through the 21st century even as efforts are made to reduce greenhouse gas emissions (*IPCC 2001*). Given this, developing the capacity to adapt to the impacts of climate change is critical. This may require modifying existing policies, practices, and procedures to provide the flexibility necessary to adjust to short-term and long-term changes in climate *(Table 4).* In some cases, new policies may need to be developed or new infrastructure designed to mitigate projected impacts. In all cases, building adaptive capacity to climate change is expected to evolve over time. Decision makers should be open to regular re-evaluation of policies and practices in light of known and projected climate impacts.

Decisions made today will often shape future vulnerability to climate change. Recognizing and incorporating the impacts of climate change in planning may improve an organization’s ability to meet management objectives even as climate variability, climate change, and population growth affect resources. Although most PNW resource managers appear interested in the notion of a changing climate, few natural resource agencies in the PNW have begun any serious consideration of climate change impacts (*Mote et al. 2003*)[3]. Barriers to planning for climate change may include organizational, institutional, technical, legal, and infrastructure constraints. Operational and administrative policies that support the inclusion of climate change in planning provide important incentives for integrating climate impacts into resource management activities.

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[3] The City of Portland (Oregon) (*Palmer and Hahn 2002*) and the Tualatin River Basin (*Palmer et al. 2004*) completed a study on the impacts of climate change in 2002 and 2004, respectively. The City of Seattle (Washington), Bonneville Power Administration, and the Idaho Department of Water Resources are currently conducting climate change studies.

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Tables

Indicator	Observed 20th century changes	Projected mid-century changes
Temperature	Region-wide warming of about 1.5°F (1920-2000) *(Figure 1)* ▪ Warming has been fairly uniform and widespread, with little difference between warming rates at urban and rural weather monitoring stations. ▪ 1990s the warmest decade on record (warmer than any other decade by 0.9°F) ▪ Most warming occurring during winter	▪ 2020s: average increase of 2.7°F ▪ 2040s: average increase of 4.1°F ▪ Temperature changes benchmarked to the decade of the 1990s. For scenario ranges, see Table 2
Precipitation	Region-wide increase in precipitation since 1920 ▪ Median value: +22% ▪ Changes upwards of 60% in northeast Washington and British Columbia)	Uncertain, although most models project wetter winters and drier summers (see Table 2)
April 1 snowpack	Substantial declines (>30%) at most monitoring stations below 6,000 feet.	Continued decrease in April 1 snowpack in mid- and low-elevation basins. ▪ Projected decrease in April 1 snowpack for the Cascades Mountains in Washington and Oregon relative to 20th century climate: o - 44% by the decade of the 2020s (based on +3°F average temp change) o - 58% by the decade of the 2040s (based on +4.5°F average temp change)
Timing of peak spring runoff	Advanced 10-30 days earlier into the spring season during the last 50 years ▪ Greatest trends occurred in the PNW	Earlier peak spring runoff expected on the order of 4-6 weeks
Summer streamflow	Declining in sensitive PNW basins ▪ May-September inflows into Chester Morse Lake (WA) in the Cedar River watershed as a fraction of annual flows have decreased 34% since 1946 ▪ Losses in June-Sept flows at Dworshak Dam (ID) on the order of 10% in 82 years	Continued and more wide-spread declines ▪ April-September natural streamflow in the Cedar River (WA) projected to decrease 35% by the 2040s (based on a 2.5°F increase in average temp) ▪ July-October streamflows in the Tualatin Basin (OR) projected to decrease 10-20% by the 2040s; total average annual runoff projected to be less than the historic average

Table 1: Observed and Projected Impacts of Climate Change in Major Climate/Hydrologic Indicators *(Sources: Mote et al. 1999; Miles et al. 2000; Mote 2003a,b; Snover et al. 2003; Stewart et al. 2004; Wiley 2004)*

	Temperature change	***Precipitation change***	
Decades	*Avg. annual (°F)*	*Oct-Mar*	*Apr-Sept.*
2020s			
Low	0.8 °F	+ 2%	- 4%
Average	*2.7 °F*	*+ 8%*	*+ 4%*
High	4.7 °F	+ 18%	+ 14%
2040s			
Low	2.7 °F	- 2%	- 7%
Average	*4.1 °F*	*+9 %*	*+ 2%*
High	5.8 °F	+ 22%	+ 9%

Table 2. Projected changes in average annual PNW temperature and precipitation for the decades of the 2020s and 2040s. The projections are based on analysis of eight climate models driven by an increase in equivalent carbon dioxide of approximately 1% per year. Changes are benchmarked to the decade of the 1990s (Mote et al. 2003)

Projected Hydrologic Impact	**Potential Management Implications**
Increased winter streamflow	- Increases the risk for more winter flooding in low (rain dominant) and mid-elevation (rain/snow mix) basins, possibly requiring more active management of floods and floodplains - Increases the potential for more streambed scouring events (affecting salmon redds), possibly impacting salmon recovery and management activities - Increases the potential for more winter hydropower production, possibly increasing revenues
Reduced snowpack	- Reduces the amount of water available for spring reservoir refill and summer streamflows, potentially requiring operations adjustments to meet summer water demands (with implications for summer hydropower production and salmon) - Reduces the risk for spring flooding in large snowmelt dominant basins - Likely to increase competition for summer water uses
Earlier snowmelt and earlier peak runoff	- Increases length of the summer low flow season, potentially increasing competition for summer water - May have implications for salmon management and recovery where there is a mismatch between salmon migration patterns and peak flows
Reduced summer streamflow	- Increases frequency of significant low flow events and potential for drought, potentially increasing competition for water and stressing abilities to meet water quality parameters and instream flow requirements (re: warmer water temperatures)

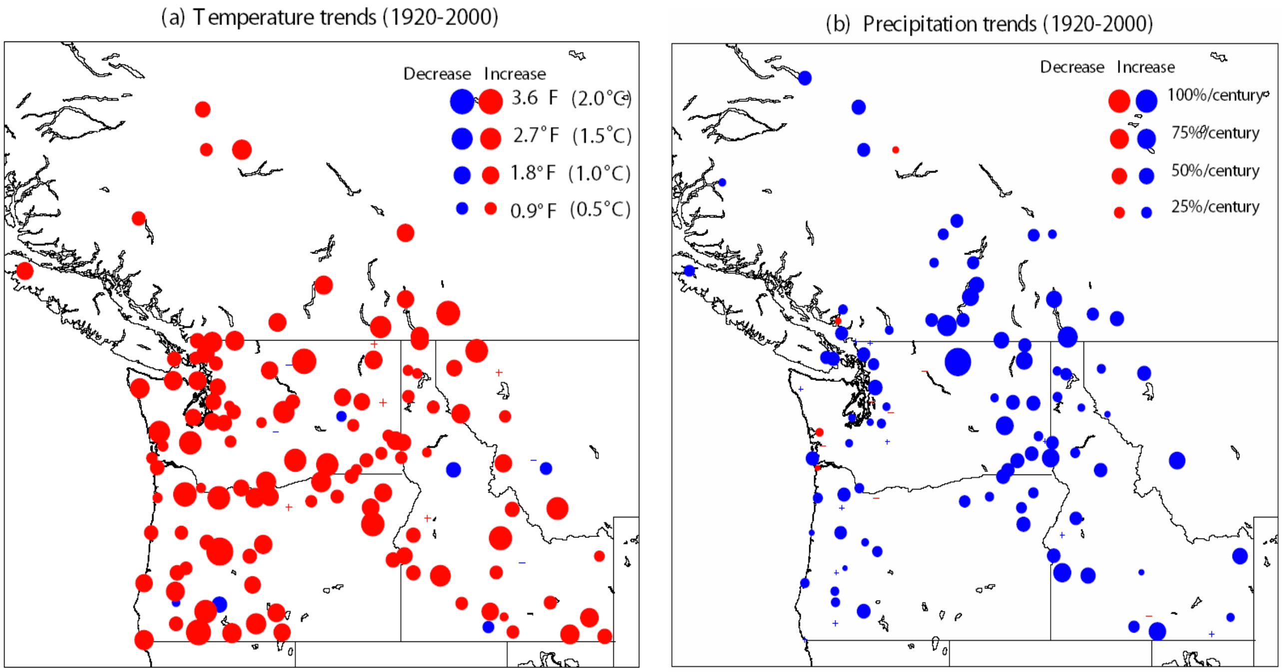
Table 3. Summary of potential management implications associated with projected climate change impacts on PNW water resources *(Sources: Hamlet and Lettenmaier 1999; Mote et al. 1999; Miles et al. 2000; Mote et al. 2003)*

Sector	Possible Adaptive Strategies
Hydrology and water resources	▪ Diversify sources of water supply (including new technologies such as reverse osmosis) ▪ Increase usable storage (including surface water, off stream storage, and aquifer storage and recovery) ▪ Connect regional water systems ▪ Expand conservation and demand management strategies ▪ Install high efficiency delivery systems for irrigated agriculture ▪ Develop advanced wastewater treatment ("gray water") ▪ Use water banking and water markets (through state or other programs) to facilitate the reallocation of water resources ▪ Reduce development in the floodplain ▪ Expand the use of climate information (e.g. seasonal forecasts) in water resources planning and management ▪ Renegotiate transboundary water agreements for the Columbia River system ▪ Actively monitor trends in snowpack, streamflow and other conditions affecting hydrology and water resources to anticipate problems
Salmon and marine ecosystems	▪ Maintain biodiversity through conservation and restoration of freshwater and estuarine habitat ▪ Ensure that fishery practices are sustainable and do not excessively impact any one stock ▪ Manage hatchery programs to minimize harm done to wild stocks ▪ Recognize the lag time associated with impacts of natural variability in one season on the viability of stocks in the following seasons; high spawning returns during a drought may lead to lower juveniles during the following season (fishery and hatchery targets may need adjusting accordingly)
Forest ecosystems	▪ Maintain biodiversity ▪ Plant tree species known to have a broad range of environmental tolerance ▪ Expand or adjust protected areas to incorporate greater geomorphic or landscape diversity to allows for shifts in species distributions ▪ Adapt tree planting to reflect changes in summer growing conditions ▪ Manage forest density to reduce susceptibility to drought stress (e.g., using prescribed fires) ▪ Develop the ability to plan and implement at longer time frames and larger spatial scales in decision rules ▪ Develop management systems to provide for more retention of sequestered carbon ▪ Actively monitor trends in forest conditions, including drought stress and pests ▪ Establish (or enhance) structural and lot development requirements in forested areas to reduce potential for fire damage
Coasts	▪ Reduce development in coastal hazard areas ▪ Preserve ecological buffers to allow for inland beach migration ▪ Enhance shoreline protection where retreat and accommodation are not possible ▪ Incorporate climate change impacts into design requirements for coastal structures ▪ Increase monitoring and control of invasive species

Agriculture	▪ Change planting dates ▪ Change planting varieties ▪ Improve agricultural water use efficiency
Human health	▪ Improve disease surveillance and protection ▪ Reduce air pollution ▪ Provide opportunities for cooling (warming) during extreme heat (cold) days

Table 4. Summary of potential adaptation strategies for managing climate change impacts in the PNW. This table represents a sampling of possible adaptation strategies. The appropriateness of these and other strategies will vary on a case-by-case basis. The utility of adaptation strategies for agriculture are complicated by interactions between the environment, economics, and farm policy (NAST 2001). Adaptation strategies for human health impacts are complicated by the complexities of determining cause-effect relationships between human health and environmental factors. *(Sources: Mote et al. 1999; NAST 2001; Hamlet 2003; Mote et al. 2003)*

Figures


(a) Temperature trends (1920-2000)

(b) Precipitation trends (1920-2000)

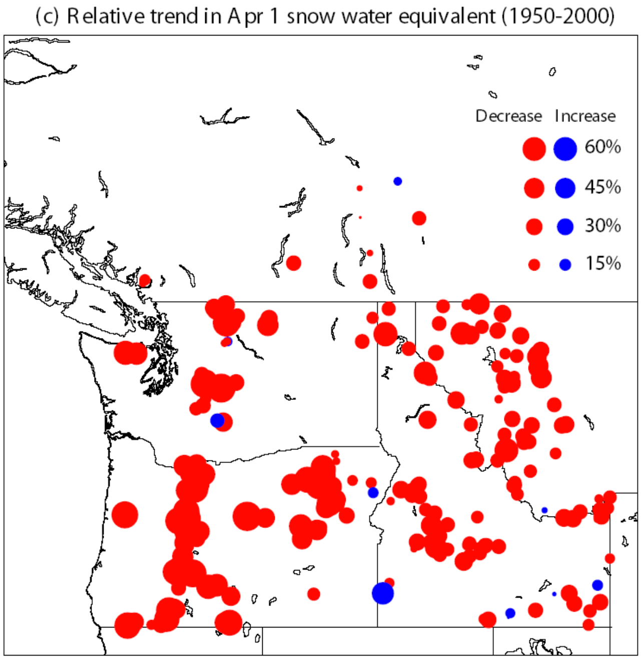

(c) Relative trend in Apr 1 snow water equivalent (1950-2000)

Figure 1. 20th century trends in (a,b) average annual PNW temperature and precipitation (1920-2000) and (c) April 1 snow water equivalent (1950-2000). These figures show widespread increases in average annual temperature and precipitation for the period 1920 to 2000 and decreases in April 1 snow water equivalent (an important indicator for forecasting summer water supplies) for the period 1950 to 2000. The size of the dot corresponds to the magnitude of the change. Snow water equivalent is a common measurement for the amount of water contained in snowpack were it melted simultaneously. *(Figure source: Climate Impacts Group, University of Washington)*

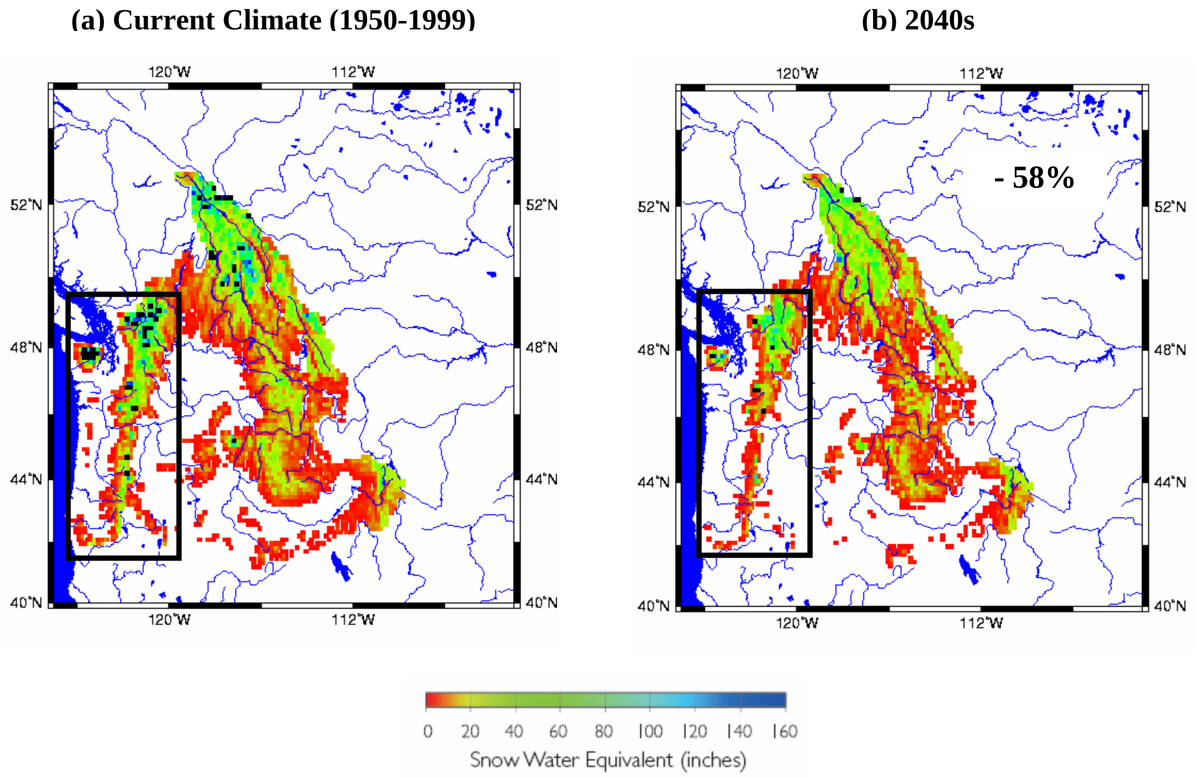


Figure 2. Climate change impacts on spring snowpack in the PNW. Simulated average April 1 snow water equivalent for (a) 20th century climate (1950-1999) and (b) the decade of the 2040s as a result of climate change. A 58% reduction in April 1 snowpack is projected for the Cascades Mountains (box) by the 2040s. The simulation of future snowpack used a "middle-of-the-road" climate change scenario averaging temperature and precipitation changes from four global climate models. *(Figure source: Climate Impacts Group, University of Washington)*

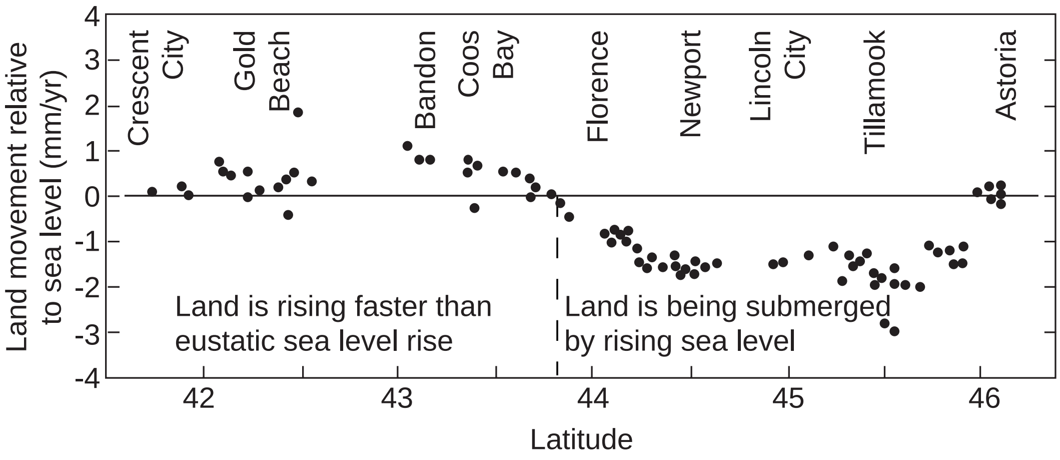


Figure 3. Vertical land movements in Oregon relative to mean sea level (*Komar 1992*). Figure courtesy of the Oregon Department of Geology and Mineral Industries.