WRIA 7 Climate Change Impacts to Salmon Issue Paper
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Photo: Jason Walker

Prepared for:
Snohomish Basin Salmon Recovery Technical Committee

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1. Introduction

In the ten years since the adoption of the 2005 Snohomish River Basin Salmon Conservation Plan (Plan), there have been many successes and many challenges in the world of salmon recovery in our local basin and the greater Puget Sound. With each recovery project planned and implemented, we understand more about the complexity of this undertaking. Currently, one of the most pressing environmental concerns affecting salmon recovery in the Snohomish Basin is how climate change exacerbates unfavorable environmental conditions. Climate change science has been the focus of intense research, both global and regional, over the last decades. The research from the Puget Sound region, especially from the University of Washington's Climate Impacts Group (CIG) can help inform and guide potential reprioritization of salmon recovery actions in the Snohomish Basin within the context of climate change (Mauger et al., 2015). The message is clear: we must prepare for the current and future impacts of climate change and incorporate what we know about climate change into salmon recovery actions.

Climate change will likely impact the salmon recovery strategy in the Snohomish Basin. Predictions of climate impacts are varied, and their magnitudes uncertain, however CIG and others predict that regional precipitation patterns, while driven by year to year variations, will shift toward warmer, wetter falls, winters, and springs. Floods are likely to be more intense and more frequent. The prediction of warmer and rain dominated wetter winters will cause snowmelt from the mountains earlier and more quickly. The decrease in amount and early disappearance of the snow pack can intensify drought-like summer low flow conditions in currently snow-dominated watersheds. Increased average air temperatures will increase water temperature in both rivers and the ocean. Sea level rise, food web alteration and ocean acidification will impact nearshore and estuary areas. A changing climate can alter typical climate variability, causing environmental conditions that will greatly impact Snohomish Basin salmonids. It is expected that conditions currently considered on the upper range of variability to become more common. These conditions could mirror those observed in 2015, which had a warm, wet winter resulting in record low snow packs and followed by a dry, hot summer. This scenario created dire conditions for salmon. The full impact of 2015 on salmonids will not be understood for several years, but early indications are not encouraging. We know that some impacts from climate change are already occurring. These impacts, as well as others that have yet to be measured, are expected to become more prevalent in the future, and will affect all life stages of Pacific salmon (Mauger et al., 2015).

While we know the climate will change, the magnitude and timing of those changes are less certain. This issue paper is intended to help planners, citizens, policy makers and restoration practitioners involved in salmon recovery understand the impacts and help prioritize restoration and protection actions. For this paper, we rely on the science in the CIG *State of Knowledge* report (Mauger et al. 2015), which predicts climate change impacts into mid-century. This document is intended to highlight the best available science about climate change and the ways we expect it to influence salmon and their habitat in the Snohomish Basin. The key actions are recommendations for restoration priorities that build resilience for both salmon and the larger Snohomish Basin ecosystem, but we do not list prioritized projects. Attachments include references to the relevant literature; readers may refer to those for more information on topics of interest.

2. Climate variability, expected changes, and impacts to salmon

The Puget Sound's diverse landscape and climate have driven adaptation and biodiversity in our local flora and fauna. The Pacific Northwest climate naturally varies seasonally as well as year to year between cool and hot, wet and dry. We are familiar with the natural variability in our atmospheric weather and oceanic patterns, but ocean conditions also vary on inter-annual and decadal scales. Year to year variability is generally associated with the familiar El Niño Southern Oscillation (ENSO), which affects ocean temperatures as well as global precipitation and temperature. Longer-term decadal patterns are often described by the Pacific Decadal Oscillation (PDO; see section 8 for more information), a pattern defined by variations in sea surface temperatures and weather patterns in the North Pacific (NOAA, 2017).

The Puget Sound region is already experiencing some of the ways climate change is likely to worsen and prolong naturally occurring stressful environmental conditions. The rate of current greenhouse gas emissions is projected to make these extreme conditions more common in coming decades. We have already seen higher than normal air temperatures; by mid-century, annual average air temperatures are projected to rise between 2.3 and 3.3 degrees Celsius (4.2 – 5.9 degrees Fahrenheit), exacerbating surface water warming. Models used to inform the Climate Impact Group's *State of Knowledge* report show a decline in summer precipitation and increases in precipitation during fall, winter and spring. With more precipitation predicted to fall as rain at higher elevations, the region's snowpack is expected to decrease. Declining snow packs, consistent with future scenarios, have been observed through the National Resource Conservation Service (NRCS) snow telemetry monitoring (SNOTEL) (Figure 1).

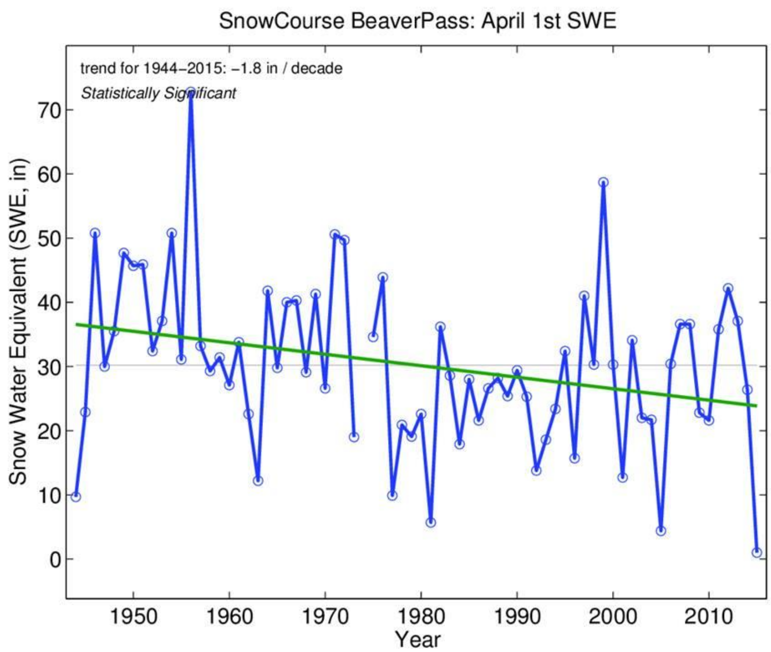

Figure 1. Snow pack for Beaver Pass in the North Cascades 1944-2015. The trend was statistically significant despite background variability with a decline of -1.8 inches per decade, 6% of the 71 year mean (https://cig.uw.edu/resources/analysis-tools/seattle-city-light-trends/).

In 2015, the water derived from snowmelt was recorded well below the 30 year median from December to July. However, the data from NRCS show that overall precipitation in the Snoqualmie Watershed was average in 2015, indicating that in this year precipitation shifted from snow to rain (NRCS, 2017;Figure 2.) 2015 was an extraordinary year likely near the high extreme of the current range of variability. It is an example of extreme conditions seen more often in recent years, and may represent a harbinger of more common future conditions. The data from NRCS and other sources show that typical snow-dominated elevations have experienced years with more rain and less snow, and that headwater areas typically dominated by rain-on-snow events will become rain-dominated. This suggests that our region will experience more precipitation as rain, less snow, more frequent and severe rain-driven flooding events, and more very low summer flows (Mauger et al., 2015).

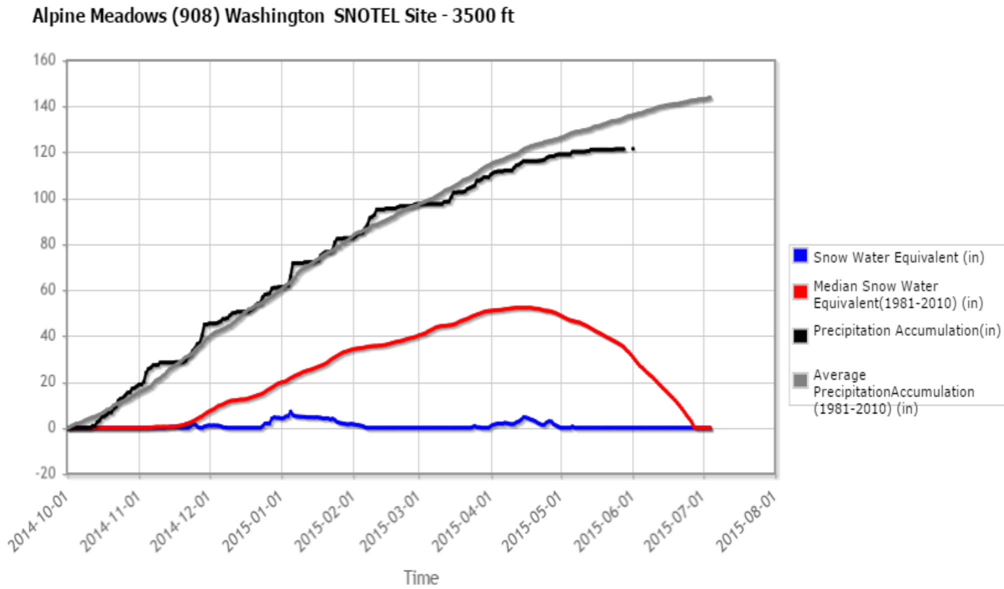

Figure 2: SNOTEL data from Alpine Meadows, just north of the North Fork Tolt River. This graph is representative of 2015 for all sites on the western slopes in the North Cascades (NRCS, 2017)

We expect climate change to challenge the survival of the region's iconic salmon species. Pacific Northwest salmon populations have declined over the last several decades, and climate change impacts are expected to further degrade salmon numbers in the years ahead, affecting salmon life histories, spawning, feeding, migration, growth, and health. It is urgent that we implement restoration projects and protect areas that preserve our basin's hydrologic patterns and habitat functions that support salmon in their various life stages. Salmon recovery partners in the basin must implement restoration and protection actions that are able to achieve their goals as climate change affects our natural system, and that help mitigate some of those effects. Climate effects should influence the way Snohomish Basin partners approach recovery now and in the future (Snohomish County, 2015).

Figure 3 and Table 1 below summarize projected climate changes and their impacts to salmon. Figure 3 summarizes the anticipated timing of climate impacts seasonally and their effects on the associated salmonid freshwater and estuary life stages. Table 1 shows each climate impact's effects on salmon - as well as examples of geographic locations where the climate impacts will likely be observed. Together, this table and figure can be used to understand, in brief, how and where projected climate impacts will affect salmon in the Snohomish Basin.

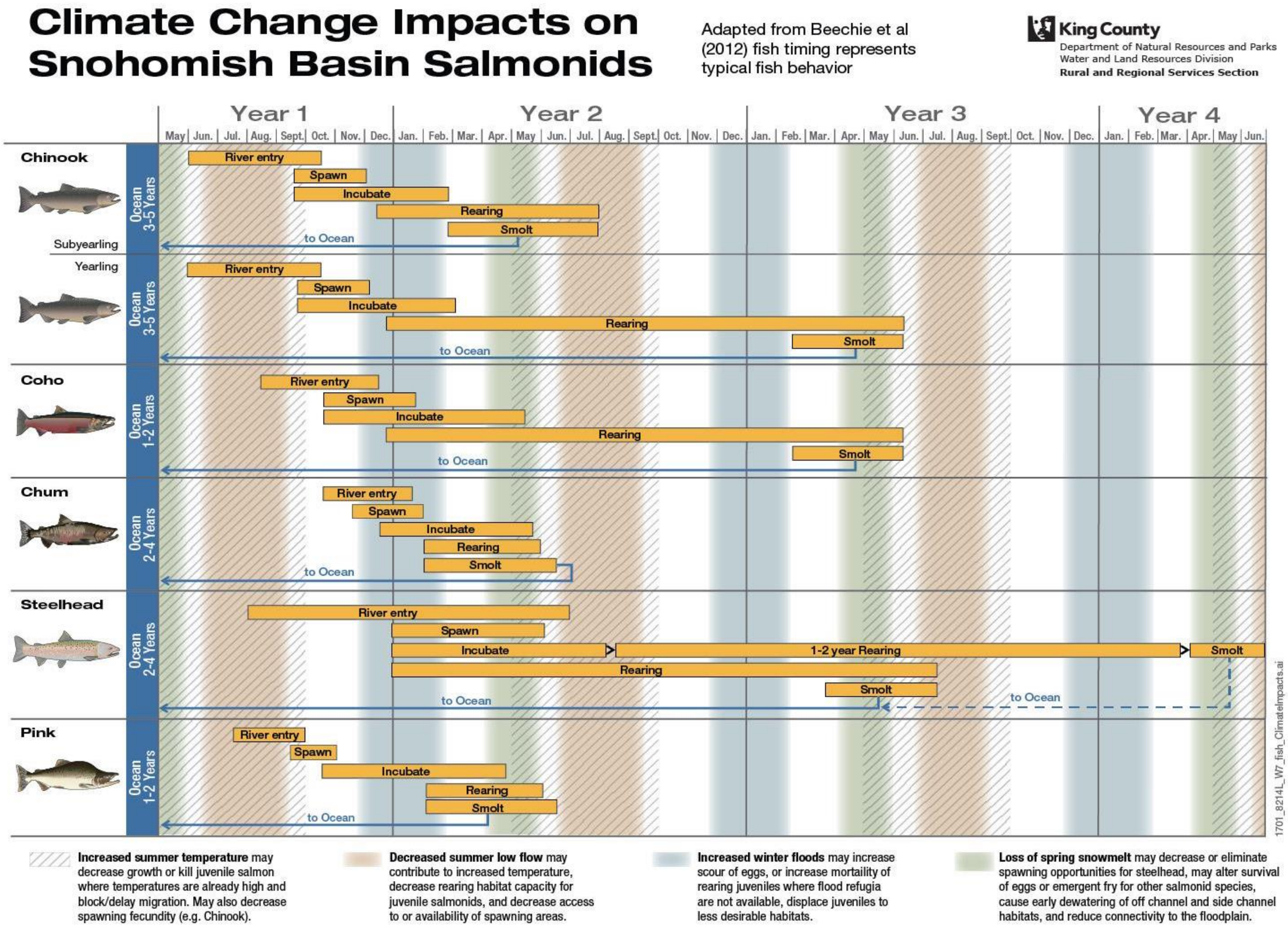

Figure 3: Salmonid freshwater and estuarine life stages and impacts of climate change (adapted from Beechie et al., 2012.)

Table 1: Broadly anticipated climate effects, potential impacts to salmon and critical geographic areas of occurrence.

Climate impact	Salmon impact	Primary geographic area
Hydrology	Shifting timing of life cycle transitions (Figure 2); scouring/smothering redds; stranding; increased disease; loss of thermal refugia; loss of flood refugia; migration barriers due to extreme low and/or high flows	Mainstem spawning reaches – Lower Tolt, Lower Raging, Snoqualmie at Fall City reach, Snoqualmie at Carnation reach, middle Pilchuck, mainstem Skykomish
Temperature	Can be lethal above certain temperatures; sub-lethal effects above 17 C include developmental abnormalities, altered growth rates, non-fertilization of eggs; altered food web; migration timing; altered predator/prey relationship; increased disease	Temperature will be a concern for the whole watershed. Areas likely to feel the greatest impacts include: the Mainstem Skykomish, Snoqualmie, Snohomish. Lower Cherry Creek, lower/mid Raging River, Woods Creek
Stormwater	Increased water pollution causing decreased oxygen, food web alteration, pre-spawn mortality	Older developed areas in Patterson and Tuck Creeks and the cities of Everett and Monroe, Marysville, Lake Stevens, Snohomish
Sedimentation	Lethal conditions created by turbidity and smothering of interstitial spaces in redds and gill damage; interference with migration cues; altered /decreased habitat	Areas susceptible to major changes of geomorphic processes such as the headwaters of Skykomish, Snoqualmie, Raging and Tolt Rivers.
Sea level rise	Shifting habitat range; loss of estuarine habitat; altered food web; could create passive gains in habitat depending on nearby infrastructure constraints, elevation, and vegetation gradients	The Puget Sound nearshore including the Snohomish basin nearshore (Everett to Mukilteo) and estuary
Marine	Altered food webs; decreased food availability; decreased ocean survival; diminished dissolved oxygen affecting metabolism; altered migration patterns	Puget Sound, Salish Sea, and Pacific Ocean

3. Hydrology

Climate impacts

Winter hydrology

Climate scientists anticipate that more winter precipitation will fall as rain and less as snow, with the Snohomish Basin becoming rain-dominant by the end of the 21st century (Figure 4). This will change when and how water enters the stream network. Storms are predicted to be more intense, creating higher peak flows in the winter (Figure 4). These storm events are anticipated to become more frequent, occurring 8 days per year in 2080 compared to 2 days per year historically. Winter stream flows are projected to increase by 28%-34% by the 2080s and flows associated with a 100yr flood will likely increase 18-55%. By the 2040s the historical 100yr flow will become a 30yr flow. Some of these shifts have already been detected. This increase in flow from increased rain is directly related to a decrease in snowpack. Shifting hydrologic patterns will have many impacts on salmon and salmon habitat. The average annual rainfall is projected to increase slightly with climate change, but this increase will be small, considering natural variability (The Nature Conservancy and the Climate Impacts Group). Overall, precipitation regimes will shift in timing and elevation/type of precipitation, resulting in more intense and frequent peak winter flows (Mauger et al., 2015).

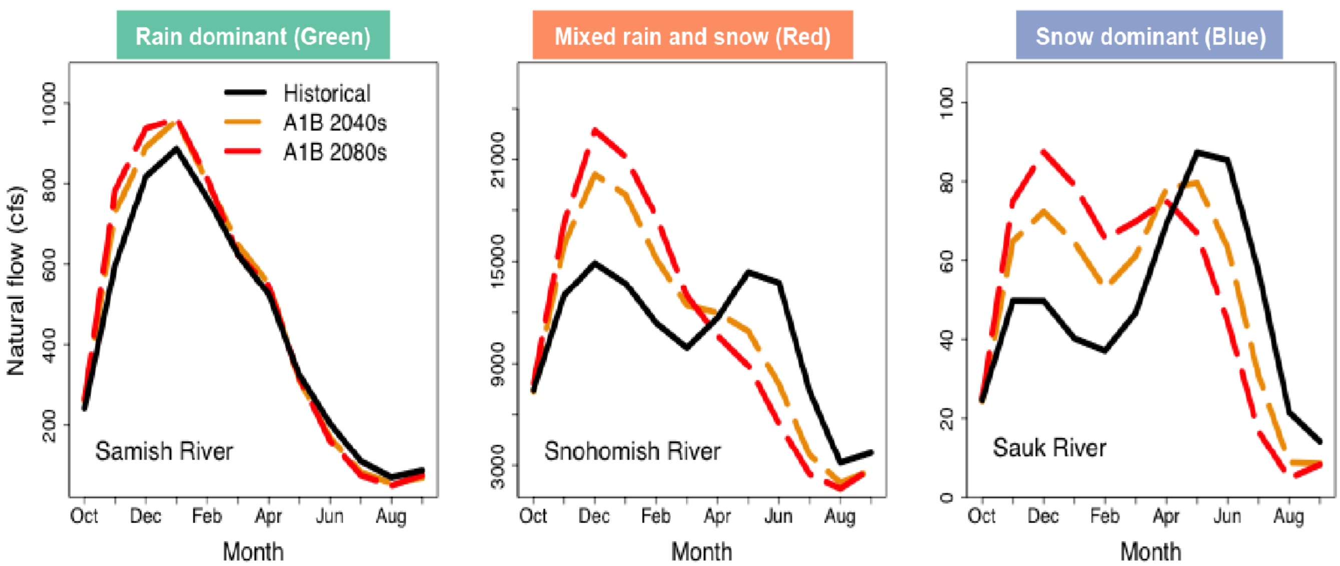

Figure 4. Streamflow is projected to increase in winter and decrease in spring and summer for all basin types, with the biggest changes occurring in "mixed rain and snow" watersheds. Results are shown for the Samish river, a warm basin (left); the Sauk River, a cold basin with source waters at high elevations (right) and the Snohomish River, a middle-elevation basin with substantial area near the current snowline (middle; Mauger et al., 2015).

Summer hydrology

A diminishing snowpack will lead to lower summer flows beginning earlier in the year. In conjunction with this impact, a significant decline in summer rain is predicted for our region, with an estimated 22% less summer rain likely by the 2050's (Mauger et al., 2015). Less snow and less summer rain will exacerbate and extend drought-like conditions and the duration of low flow impacts (e.g., warmer stream temperatures, disconnected streams, less available habitat) on the streams and rivers.

Salmon Impacts

One of the most obvious impacts climate change will have on salmon survival is altered hydrologic patterns (Snohomish County, 2015). These changes will have both episodic and catastrophic impacts on the survival of salmonid populations due to outright mortality, impacts on availability of spawning and rearing habitat, and flow and thermal barriers to migration. The hydrologic disruption brought by climate change will alter the timing and magnitude of high and low stream flows and corresponding temperatures. The timing of corresponding life cycle transitions is strongly influenced by environmental conditions the timing of juvenile and adult migrations could shift as well (Taylor, 2008). Shifts in the timing of juvenile out-migration become discordant with seasonal cycles in marine and ocean conditions that support growth during the smolt phase(Figure 3).

Winter impacts on salmon

The larger, more frequent winter floods predicted will increase the risk of redd scouring, reducing the number of viable eggs incubating in the gravel through the winter. A significant shift in flood regimes has already been observed. These flows will also bring increased sediment loads that can smother redds, further reducing egg survival. Higher winter flows will decrease the amount of slower water habitat available to juvenile fish, increasing the risk of "flushing" juveniles rearing in the freshwater out to the estuary or ocean too soon, decreasing salmonid survival rates.

Summer impacts on salmon

Longer, drier summers could disrupt migration and spawning due to insufficient water in the system to cue adult migration and spawning. Less water will also limit the amount of spawning habitat available to adults returning to rivers during base flow periods. The declining snowpack will reduce the duration and volume of spring snowmelt. Dry summers and high air temperatures will mean decreased spring and summer flows and warmer water, like the one observed in the Snoqualmie Watershed in 2015 (King County, 2016).These predicted low flows may delay some adult salmon migrations until the fall rains, possibly delaying spawning times closer to flood season. Low flows can also disconnect stream systems, stranding fish in areas with poor habitat and water quality and preventing access to important spawning areas. By limiting the amount of suitable habitat available for salmon, low flows concentrate fish in a few areas, which increases the spread of disease, competition for food, predation, and likelihood of stranding.

Local context

The majority of the basin will feel the effects of higher winter flows and lower summer flows. Leveed reaches, even partially, disconnected from their floodplains will exhibit the greatest effects. Areas with a high proportion of levees, such as the lower Tolt and Raging Rivers, the lower Skykomish River, Snoqualmie at Fall City Reach, the Snoqualmie at Carnation Reach, the Snohomish River, middle Pilchuck River and lower Sultan River will experience some of the largest impacts from the change in frequency and intensity of winter flows. With these hydrologic changes, though, even unleveed spawning reaches will be less hospitable to salmon.

Lower summer flows will affect many basin streams and rivers. Small tributaries will likely experience low flow disconnection to the mainstem more frequently. Larger tributaries are also at risk. For instance in the Snoqualmie Basin, the Raging River, Tuck, Aldair and Cherry Creeks are also at risk of disconnection.

Key Actions

- Research and implement innovative restoration practices (e.g., beaver introduction) where appropriate, to dampen the effects of shifting hydrology. Work toward resilience by encouraging natural processes that may moderate expected shifts.
- Identify how habitat boundaries, such as floodplains, are changing. Protect shorelines at risk of being armored as climate change advances. Protect habitat outside current habitat boundaries to allow channel migration. Secure land that increased flooding and sea level rise is likely to inundate.
- Headwaters are critical to providing cool, plentiful water. Monitor land use closely to minimize impacts to hydrology. In particular, where headwater streams are disconnected from their floodplains (e.g. South Fork Snoqualmie), work on reconnection to restore processes of water storage as well as continuing to plant and protect forests.
- Restore areas that provide flood storage and slow water during frequent, “ordinary” flood events (e.g., those that occur every one to five years) by reconnecting the floodplain (e.g., removing/setting back levees). This will be important above and adjacent to spawning grounds to counter the increased risk of higher flows scouring spawning areas.
- Work to protect floodplains by working with regulations to limit development in the floodplains.
- Remove and fix barriers like culverts and floodgates to ensure access to tributaries, connect oxbows, and protect pools to restore low flow refugia and reconnect local hydrology.
- Work with dam operators like Seattle Public Utilities and Snohomish Public Utility District to use reservoirs to ameliorate hydrologic impacts, especially during low flow periods.
- Protect and expand late successional forest development on federal lands and currently protected areas (regulatory buffers, etc.). Plant and protect working forests from conversion to other land uses, and expand forested areas
- Work with forestry managers and researchers to investigate and better understand the effects of forest management, including stand rotations and selective logging on basin hydrology (Perry and Jones, 2016; Hall, Beechie and Press, 2014; Cafferata and Reid, 2013).

4. Temperature

Climate impacts

Air temperatures are expected to increase 2.3-3.3 degrees C by 2050 (Mauger et al., 2015). This warming will affect water temperatures during increasing periods of low flow, when they are highly influenced by air temperature (Figure 5). This phenomenon was documented in the 2015 Snoqualmie Water Temperature Study (King County, 2016) where air temperatures and extreme low flows influenced both stream and mainstem water temperatures.

Warmer temperatures will accelerate snow and glacial melt in the summers, and decrease accumulation and glacier mass balance in the winters. Watersheds dependent on these sources will benefit from the cool meltwater until the source is gone. For instance, in the Skagit Watershed, glaciers account for 2.4% coverage and up to 25% of the summer low flow in the mainstem Skagit River (Riedal and Larrabee, 2016). The Snohomish has less than 0.3% coverage, suggesting the influence to summer base flows in the Snohomish River will be less than in the Skagit, but this warrants further exploration. More importantly, during low flow periods, groundwater will likely have a greater influence on streams as a water source and temperature regulator (King County, 2016. Unpublished raw data). The Puget Sound region has already experienced warming air temperatures over the last century: the frost-free season has lengthened by thirty days, with nighttime temperatures warming by 1.1 degrees C (Mauger et al., 2015). Increased air temperatures will mute diurnal and seasonal cooling in streams, resulting in warmer water.

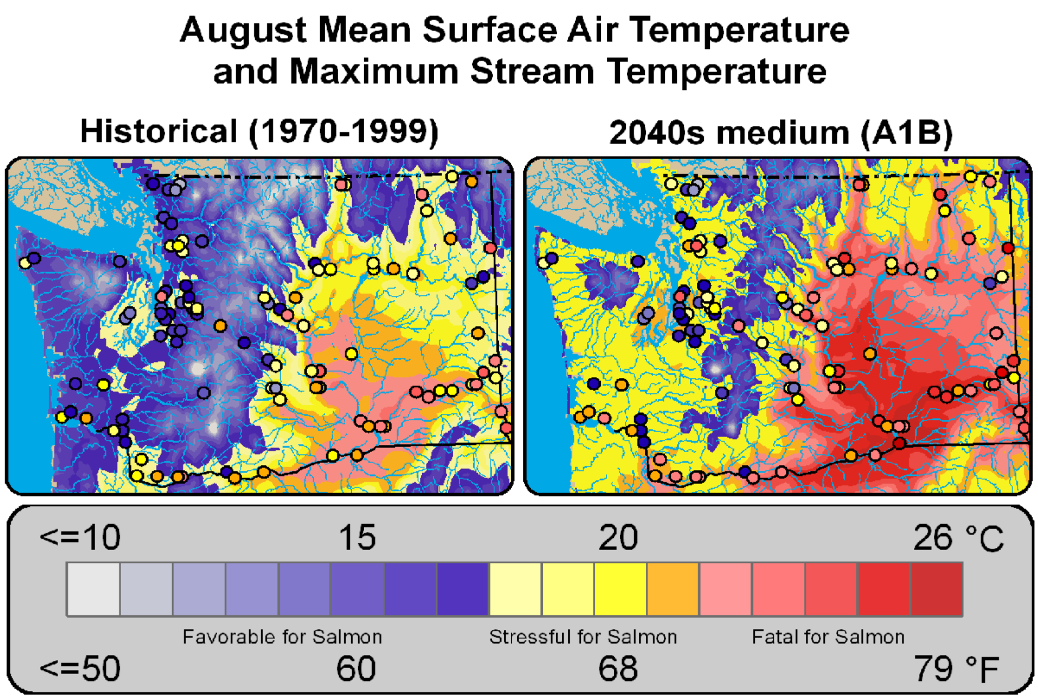

Figure 5: August mean surface air temperature (colored patches) and maximum stream temperature (dots) for 1970-1999 (left) and the 2040s (right, medium emissions scenario, (A1B)). The area of favorable thermal habitat for salmon declines by the 2040s in western Washington, and in eastern Washington many areas transition from stressful to fatal for salmon. Circles represent selected stream temperature monitoring stations used for modeling stream temperatures. Excerpted from *The Washington Climate Change Impacts Assessment*, University of Washington, Climate Impacts Group, June 2009.

Salmon Impacts

Warm water temperatures in fresh, estuarine, and marine waters can cause lethal and sub-lethal effects for salmon. Water temperatures above 23 degrees Celsius can kill salmonids within a few seconds to hours (Ecology, 2000). This has a direct, observable impact on salmon populations, especially if those water temperatures are observed throughout a system or persist for several days, as they did in the Snoqualmie River system during the summer of 2015.

Also detrimental are the many potential sub-lethal effects of warmer water that lead to lower growth, increased stress, reduced fitness and survival. Generally, adult salmon avoid swimming through water warmer than 16 degrees Celsius, which can disrupt adult migration for spawning. Temperatures of 21-22 degrees Celsius can block migration and result in pre-spawn mortality (Mantua et al., 2010). When salmonids hold and migrate at higher temperatures, there is an increase in outright mortality or sub-lethal effects such as egg abnormalities (Richter and Kolmes, 2005).

Juveniles in the system can also experience sub-lethal thermal stress from warm water. Warmer stream temperatures decrease the concentration of dissolved oxygen available to fish. Hypoxic conditions associated with warm water can create aquatic “dead zones.” Even if fish can leave these zones, some important food sources for fish cannot move and will die. Mortality can occur if the fish cannot find refuge from hypoxic dead zones.

Slight increases in water temperature can alter food web dynamics, fish metabolism and energetic requirements, shift conditions to favor warm water, non-native species and the predator-prey relationship by increasing how often fish must eat (Crozier, 2015). Food available for salmon in the basin will change as warmer water causes preferred foods like mayfly, stonefly, and caddisfly nymphs to either die off or become metabolically insufficient for salmon; replacement prey may not be as beneficial to salmon (Hamilton et al., 2010; Beauchamp, 2009). As water temperature increases, juveniles will likely have a lower corresponding metabolic benefit, and may eventually stop feeding even if food is available.

A prime example of the controlling effects of stream temperatures on migration occurred in 2015, where high temperatures in the Skykomish River caused unusually high numbers of Chinook salmon to enter the Sultan River, a thermally manipulated tributary of the Skykomish. The Sultan River is controlled by a dam, which Snohomish County PUD manages to maintain adequate flows and cool temperatures during the hot summer months. These management practices created a thermal refugia in 2015 where salmon not natal to the Sultan river sought refuge from high temperatures in the mainstem Skykomish. Habitat above the Sunset Falls trap and haul operation was also a thermal refugia in 2015, when approximately half of the estimated Skykomish River Chinook and Coho escapements were passed above the falls. This proportion was much higher than most years, and supports the need to maintain possibility at this natural barrier to anadromy as climate changes increase demand for thermal refugia.

Local context

Increased water temperatures will be a problem in many areas of the watershed. In extreme low-flow, hot summers, tributary headwaters such as Griffin Creek and Patterson Creek appear to maintain cooler temperatures, but can still exceed state 7-day average temperature standards (King County, 2016). When these streams join the Snoqualmie floodplain, they heat up further, especially with only small riparian buffers to shade the river. While the streams heat up in these reaches, they are generally still cooler than the Snoqualmie River and provide potential cold water refugia as long as the salmon can reach them. Several larger streams (e.g., Tuck and Ames Creek) and many smaller unnamed tributaries have physical blockages that can reduce juvenile salmonid access to these cooler habitats.

Key Actions

- Identify, protect and enhance processes and habitats that provide cool water. Protect cool headwater streams. Locate groundwater sources and seeps and protect natural processes that create critical habitats like wetlands, tidal flats, marshes and estuaries; this will help ensure that water can be stored, recharged, and delivered at a moderated pace and temperature.
- Protect and restore Snohomish Basin tributaries, which are cooler than the mainstem rivers and can provide salmon with cold water refugia. Emphasize opening access to floodplain tributaries, including small stream systems. Continue work to moderate mainstem temperatures.
- Remove and fix barriers, culverts and floodgates to ensure access to tributaries and estuary; connect

oxbows and protect pools to restore cold water refugia.

- Monitor land use changes, particularly tree removal and new development, to quantify and mitigate for impacts to temperature.
- Increase the rate of planting and protecting riparian buffers to help stabilize in-stream temperatures and reduce sediment and toxin load.
- Work with dam operators such as Seattle Public Utilities and Snohomish Public Utility District to use reservoirs to help ameliorate temperature impacts, especially during low flow periods.
- Maintain and improve access to resilient habitat refugia such the trap and haul operation at Sunset Falls.
- Work with forestry managers and researchers to investigate and better understand the effects of forest management, including stand rotations and selective logging on basin hydrology (Perry and Jones, 2016; Hall, Beechie and Press, 2014; Cafferata and Reid, 2013).

5. Stormwater

Climate impacts

With predicted increases in heavy rainfall events in fall and winter, stormwater runoff will increase pollutant discharge into rivers and streams and, ultimately, Puget Sound. Pesticides, heavy metals, bacteria, motor oils and other pollutants already contribute significantly to stormwater pollution in our region. Stormwater can impact the river system by washing toxics into streams, and adding nutrients that alter frequency, timing, and intensity of algal blooms and decrease oxygen levels.

Stormwater will also increase the “flashiness” of the hydrograph, meaning higher peak flows during storms. These flows can scour stream beds and banks, flushing out habitat-forming debris and organic matter important to macroinvertebrate communities and small fish.

Salmon impacts

Stormwater impacts to salmon are varied, causing both lethal and sub-lethal conditions, in particular for coho salmon. The Washington State Department of Ecology and several federal agencies have identified stormwater runoff as a primary obstacle to salmon recovery. Toxics, like copper and polycyclic aromatic hydrocarbons (PAHs), can cause disrupt spawning and cause mutations in salmonid eggs and rearing juvenile salmon. Stormwater washes in excess sediment and eutrophic nutrients that can cause dissolved oxygen to decrease, creating hypoxic conditions for both fish and macroinvertebrates, disrupting the food chain (MacIntyre, 2015).

A direct, observable impact of untreated stormwater is pre-spawn mortality, when adult salmonids die before they are able to spawn. Pre-spawn mortality will likely increase as there are more frequent and heavier rain events.

Local context

Stormwater will most seriously affect older suburban and urban areas like the Patterson and Tuck Creek subbasins and the cities of Everett and Monroe, Marysville, and Lake Stevens. Most of the older developed areas did not initially have any stormwater controls and the early stormwater control methods/requirements are generally considered inadequate by today’s standards. These areas are not yet retrofitted to minimize stormwater runoff. While the issues of stormwater are complex, treating and retaining water on site before it runs off into streams and rivers may reduce fish exposure to chemicals and stressful hydrologic and water quality conditions.

The population in the Snohomish Basin is expected in the next several decades, with a net population growth of 24% expected by 2040 in comparison with 2015 (Puget Sound Regional Council, http://www.psrc.org/data/forecasts/) This increased population will create a demand for development of homes and infrastructure which in turn will create the potential for greater stromwater runoff. While stormwater currently is not the most pressing issue for salmon in the Snohomish Basin, it could become one depending on how future population growth and development plays out.

Key Actions

- Study and prioritize areas that need stormwater retrofits and accelerate those actions.
- Implement Green Stormwater Infrastructure that slow conveyance and increase storage, such as bioswales, rain gardens, and replacement of impervious surfaces with plantings and/or pervious surfaces.
- Plant more trees in suburban catchments.
- Monitor land use changes, particularly tree removal and new development, to quantify and mitigate for impacts to temperature.

6. Sedimentation

Climate impacts

Sedimentation of our rivers and streams is expected to increase in the future, especially in winter, when heavy rains and less snow will increase erosion, soil saturation, and landslide potential. The heavier rains will also swell stream flows and likely increase bank erosion which can move more sediment downstream increasing accretion in depositional areas. The higher incidence of rain-on-snow and higher intensity rain events will likely cause increased frequency and intensity of flooding, erosion, and landslides on hillslopes which increase sedimentation in streams and rivers.

Heavier and more frequent rain events can worsen erosion and landslide potential in areas with natural land cover. Developing natural land, especially paving surfaces and reducing plant cover, will only increase these risks.

As Snohomish Basin headwaters experience more runoff due to shrinking snowpacks, winter storms will likely erode exposed areas with little plant cover. This sediment will eventually settle out in low gradient stream and river sections. This process of increased aggradation can exacerbate flooding as bed elevations in leveed channels fill and increase public demand for dredging, which can destroy habitat, to lessen flooding impacts.

Salmon impacts

Studies have shown that high levels of suspended solids can kill salmonids by burying redds after spawning and potentially harm juvenile fish by decreasing dissolved oxygen or smothering their gills. Even when suspended sediments are not at a level that causes direct mortality, there is potential for chronic sub-lethal and behavioral effects. Sub-lethal effects can include reduced foraging capabilities, stunted growth, stress, lowered disease resistance and interference with migration cues (Bash et al., 2001).

Local context

For a time, erosion will increase in areas that shift from snow dominated to rain-on-snow dominated weather patterns, mostly found in the Snohomish Basin's upper headwater areas like the Skykomish and Upper Snoqualmie watersheds. Since less than 0.3 percent of the Snohomish Basin is glacier-covered, sedimentation from glacial melt will not be a significant factor in the basin, but there could be local sediment impacts in areas with glacial-fed streams. (Mauger et al., 2015) More frequent rain events will likely bring sedimentation impacts from erosion and landslides or other unstable landforms.

Key Actions

- Restore functional riparian buffers quickly to help reduce sediment load.
- Protect intact buffers to reduce sediment load and minimize erosion.
- Study and understand sedimentation changes in the mainstem areas e.g., sediment budget(s)
- Set back levees in aggrading reaches to allow natural channel migration/avulsion and limit increases in flood-exacerbating bed elevations.
- Identify landslide-prone slopes- and implement hydrologic protections that decrease the likelihood of mass-wasting events.

7. Coastal

Climate change impacts are not limited to the freshwater areas of the Snohomish Basin; they will also bring changes to the ocean and tidal areas of the basin. Effects to the ocean environment are harder to predict and quantify than freshwater effects, but there will be impacts to salmon survival. The most notable changes expected in Puget Sound's coastal and marine ecosystems are sea level rise and ocean acidification.

Sea level rise

Climate impacts

Sea level in Puget Sound rose 20 centimeters from 1900-2008 and sea level rise (SLR) will continue, though it is hard to predict exactly how much (Mauger et al., 2015). Sea level is projected to rise 0.6 meters by 2100 (The Nature Conservancy, 2016). Sea levels are projected to increase everywhere in the Pacific Northwest, with the possible exception of Neah Bay. SLR will have a myriad of effects on the marine nearshore, including bank erosion, landslides, and "coastal squeeze."

The phenomenon known as coastal squeeze will occur in areas where people will be faced with pressures, from the sea (e.g. sea level rise and storm surge), from the watershed (e.g., increased sedimentation and flooding) and from settlement patterns (Figure 6).

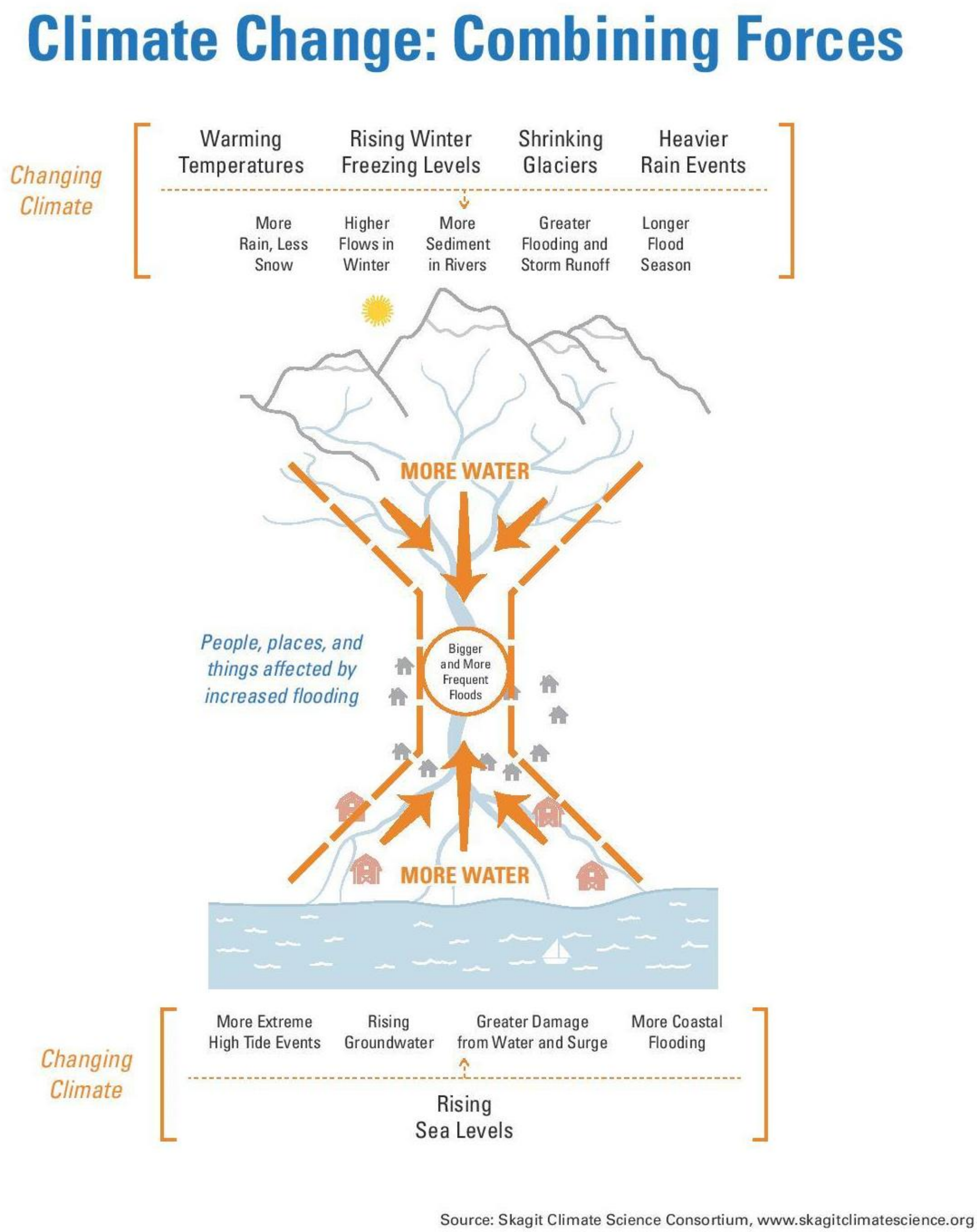

Figure 6: Infographic developed by the Skagit Climate Science Consortium (www.skagitclimatescience.org) that describes the phenomenon of coastal squeeze showing where climate impacts will be felt in the Puget Sound lowlands.

Nearshore

The risk of erosion and landslides along marine shorelines will increase in areas with and without bulkheads in the nearshore. SLR will overtop existing bulkheads and cause toe erosion of the banks (this will also happen in areas without bulkheads), which is likely to increase landslides. The predicted 22% more rain in the winter will increase the risk of destabilizing nearshore slopes and increase landslides. Bank erosion is beneficial for salmon because the sediment it supplies is critical to a productive nearshore environment. Increased landslides could threaten property and heighten the demand for building new bulkheads and enlarging existing bulkheads, continuing to decrease this important habitat-forming sediment input.

Projected increases in winter rain will increase rivers' peak flows (Stillaguamish Tribe of Indians, 2014). When combined with sea level rise, this means water could get trapped in the nearshore and estuarine areas, causing coastal squeeze. This squeeze will increase flood inundation of these areas, leading to inundation of coastal septic systems and wells, increased sedimentation in the estuary and nearshore, and more coastal bluff erosion. In the Skagit River floodplain, the area flooded during a 100-year event is projected to increase by 74% (on average) by the 2080's, factoring in the combined effects of sea level rise and larger floods. A similar study found that a 10-year event would flood 19 - 69% more area in the lower Snohomish River floodplain by the 2080's (Mauger et al., 2015).

Coastal squeeze will also have impacts beyond flooding. In undeveloped nearshore systems, beaches and coastal marsh shorelines "migrate" inland with increases in sea level. However, in heavily armored areas like the Snohomish Basin, beaches and coastal marshes tend to be restricted by infrastructure; so bulkheads cannot move inland when seas rise. In these cases, rising sea level will degrade beach habitats along the shoreline; eventually the habitats will disappear or become nonfunctional for juvenile salmonids and the two primary beach spawning forage fish (Pacific sand lance and surf smelt, see Figure 7).

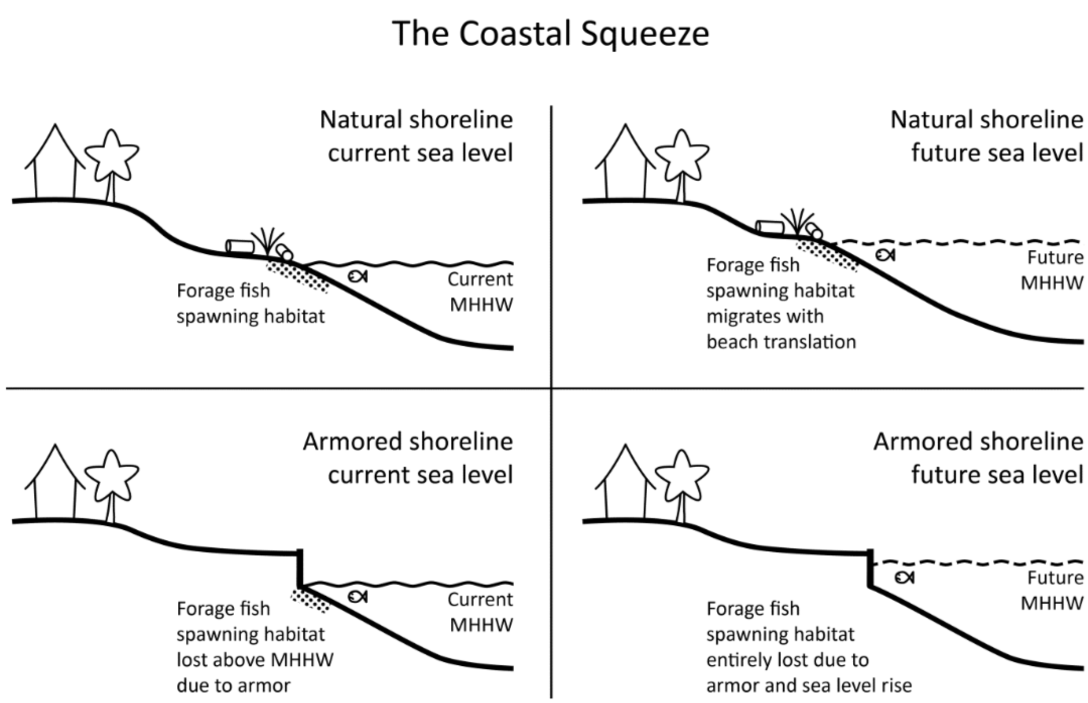

Figure 7: Coastal squeeze in nearshore graphic (Coastal Geologic Services)

Estuary

SLR is expected to change estuary habitats over time. In areas where the nearshore can migrate landward, current estuary habitats will become nearshore habitats and the estuary boundaries will move further inland. The basin is likely to lose its critical freshwater and transition marshes, particularly in the tidally influenced areas of the delta. Recent collaborative work by the Tulalip Tribes, National Fisheries Conservation Center, and Marine Conservation Institute developed a Sea Level Affecting Marshes Model (SLAMM), which projects marsh transitions among sea level rise scenarios. This work suggests that if habitat is allowed to transition naturally with these changes unencumbered by barriers like levees, there may also be opportunities to expand salt marsh habitat (Georgian et al., 2016). These habitats may move further upland as SLR occurs, depending on space available. As SLR causes shifts in habitat types, it will also move the salt wedge further upstream into areas that are currently freshwater.

Salmon impacts

Based off the SLAMM modeling efforts, sea level rise is likely to harm salmon through the loss of transitional estuarine and marine habitat as well as nearshore beach habitat for forage fish (Georgian, 2016). According to the CIG *State of Knowledge* report, SLR will increase the area of salt marsh and transition marsh, shifting the ranges of habitat used by salmon. Given that the Snohomish marine area is developed, with many bulkheads, tide gates, and culverts, it will likely lose habitat area and types to coastal squeeze.

Increased erosion from SLR and landslides is already bringing requests for more and bigger bulkheads along the nearshore to protect development; additional SLR will likely increase these requests (pers. comm. Kollin Higgins, King County, 2016). Additional bulkheads will cut off the sediment supply needed by forage fish, such as surf smelt and sand lance, which are key salmonid prey. Also, marine riparian vegetation is removed when new bulkheads are built. Both of these issues will reduce the quantity/quality of forage fish and other salmon food sources, further challenging the viability of salmon populations. Additional bulkheads will intensify the effects of coastal squeeze.

Local Context

Impacts of SLR and coastal squeeze will be focused on the Snohomish Basin coastal areas.

Key Actions

- Identify how habitat boundaries, such as floodplains, nearshore and estuaries, are changing. Improve consistency and effectiveness of regulatory protections. Protect marine and freshwater shorelines at risk of being armored as climate change exacerbates impacts. Protect land that will be inundated by increased flooding and sea level rise.
- Improve regulatory protection, especially in all unarmored marine areas. Encourage bulkhead removal or soft armoring replacement where necessary and possible, but especially at historic feeder bluffs.
- Buy land that will be directly impacted by sea level rise, remove existing infrastructure if necessary to allow marine shoreline migration and bluff erosion.
- Work with partners to understand vulnerability of estuary infrastructure under SLR, including levee maintenance and drainage needs, transportation corridors and wastewater facilities.

8. Marine and Ocean Conditions

Climate impacts

Salmon spend much of their lives in the North Pacific feeding from the ocean's food web. There are a number of complex large-scale cyclical variations in climate that naturally influence ocean conditions including the North Pacific Gyre Oscillation (NPGO), and the El Niño Southern Oscillation (ENSO), and the Pacific Decadal Oscillation (PDO). Interactions between these phenomena are very complex. PDO is a climate *index* based on multi-decadal patterns in sea surface temperatures that is strongly correlated with salmon populations. As an indicator, PDO has warm and cool phases. Over the past century, these phases oscillated irregularly over a period of 10-40 years with more recent short-term (3-5 year) events (Figure 8, NOAA, 2017; NOAA, 2016; Peterson et al., 2015). These phases are correlated with Northwest climate and ecology and variations in northeast Pacific marine ecosystems. Specifically, PDO is correlated with patterns in atmospheric pressure, prevailing winds, currents, coastal upwelling impacts, winter land-surface temperature and precipitation and stream flow as well as historic salmon landings from Alaska to California (Mantua et al., 1997).

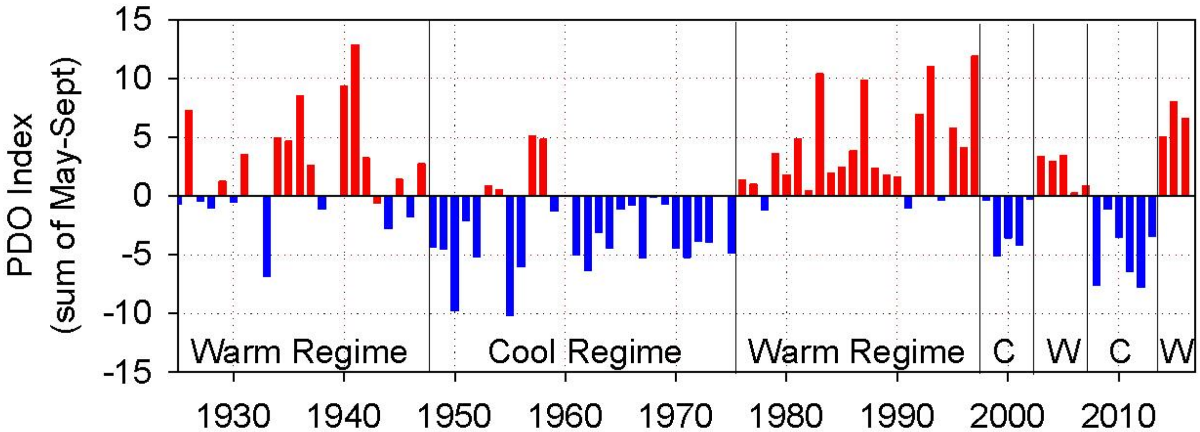

Figure 8. Time series of shifts in sign of the Pacific Decadal Oscillation (PDO), 1925 to present. Values are summed over the months of May through September. Red bars indicate positive (warm) years; blue bars negative (cool) years. Note that 2008 and 2012 were the most negative values recorded since 1956 (NOAA, 2017)

These warm and cool phases are correlated with composition, abundance, and distribution of plankton communities, the basis of the ocean food web. PDO is hypothesized to alter the source of ocean water off the West Coast. In cooler phases, northerly winter winds bring cold water and boreal zooplankton communities from the Gulf of Alaska south into the California Current. Northerly winds cause coastal upwelling which generally brings cold, salty, nutrient-rich water to the surface. These conditions increase phytoplankton production that support zooplankton communities dominated by cold-water, lipid-rich copepods. These conditions are correlated with good salmon survival. When the PDO shifts to a warm phase, warm southwesterly winds result in more water from the warmer, fresher, North Pacific Current and its associated tropical and sub-tropical warm water lipid-deplete copepods. These conditions are correlated with poor salmon survival for populations in the lower 48 states (Figure 9).

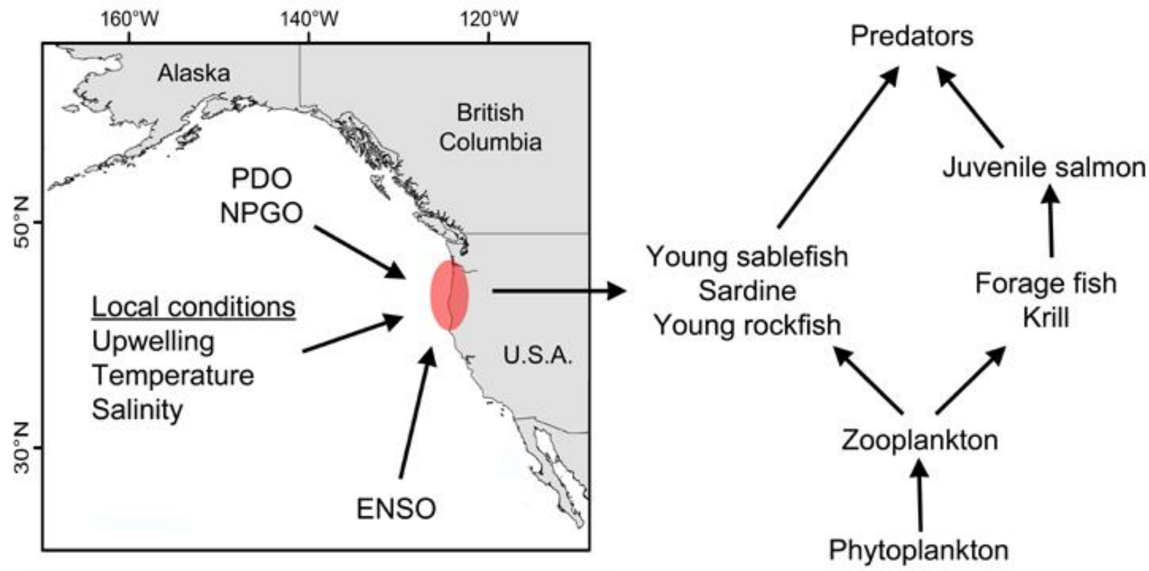

Figure 9. Illustration of how basin-scale and local-scale physical forces influence the northern California Current and resultant food web structure. PDO = Pacific Decadal Oscillation. NPGO = North Pacific Gyre Oscillation. ENSO = El Nino-Southern Oscillation (Peterson et al., 2015)

While regional climate in the Pacific Northwest is driven by these natural variations in climate and ocean conditions in the Pacific, we don't know how climate change will affect them. Climate change is expected to increase ocean temperatures in the northeast Pacific by 1.8C by 2040 (Mauger et al., 2015), which experts hypothesize will result in a 1-4% increase in marine mortality. Weather patterns in 2014 and 2015 caused +2-4C temperature anomalies over a large area of the northeast Pacific Ocean labeled "the Blob," which may portend extreme climatic variations that will become more common in the future. Salmon returns in 2015 were some of the worst on record. Fish that did return to freshwater experienced high mortality from Blob-related drought and subsequent warm and low stream flows exacerbated by blob-related low snowpacks from unusually warm and wet winter precipitation (Peterson et al., 2015).

Juvenile salmon originating in the Snohomish Basin migrate through the Puget Sound on their way to the ocean, feeding from the marine food web. Scientists hypothesize that since the 1980s, changes in the Puget Sound's physical environment, productivity, and juvenile salmon food availability caused a decline in juvenile Chinook and coho marine survival. In 2014, The Salish Sea Marine Survival Project (SSMSP) was created to study the complex relationships between marine survival and marine conditions in the Salish Sea. While NOAA has monitored marine indicators for over a decade in the Pacific Ocean, comprehensive monitoring has just begun in the Puget Sound. Continued monitoring through organizations like SSMSP is essential to understand the effects of marine conditions on marine survival, and salmon resiliency throughout the region, especially as climate change influences conditions that may cause shifts in migration timing.

Salmon Impacts

It is clear that PDO cycles affect salmon survival. However, the impacts of climate change on the natural stochastic variations that determine ocean conditions are not known, and the effect of ocean conditions on salmon is not well understood. While there are informative correlations between survival and ecosystem indicators, changes in any indicator can confound relationships between others. The ways in which salmon are impacted will depend on their life stage while in the ocean ecosystem, how long they spend in the ocean, and other ocean variables like plankton communities. Further study is important to understand how climate change will affect salmon, and might already be doing so.

Local context

Effects of ocean conditions will be felt most strongly in the Pacific Ocean, as well as the Puget Sound nearshore including the Snohomish Basin nearshore and estuary. Ocean conditions are also intrinsically related to weather patterns that affect terrestrial freshwater habitats in the ways described in previous sections.

Ocean acidification

Climate impacts

Ocean acidification, due to the absorption of carbon dioxide (CO_2), is projected to increase 150-200% by 2100 based on current CO_2 emission scenarios (TNC, 2016). Warmer air temperatures will likely cause sea surface temperatures to increase as well (Mauger et al., 2015). Together these factors can have a wide range of impacts on marine ecosystems.

Salmon impacts

As the ocean acidifies, marine species that form calcium-based shells (like shellfish) will be most affected, but acidification is also expected to change food availability for salmon during their smolt and ocean life cycle phases. For instance, acidification will reduce the availability of crab larvae, an important food source for juvenile salmonids, as well as herring, an important food for adult salmonids. The role affected species play in supporting Puget Sound salmon raises concerns about how acidification could affect the entire Puget Sound and ocean food web (Ecology, 2012).

Key Actions

- Protecting and restoring areas of carbon uptake – including eelgrass and tidal marshes.
- Increase monitoring and study of areas of carbon uptake, pH regulation, as well as biogeochemical balances and the relationships between marine food webs, acidification, pollution, temperature and climate change in the Puget Sound.
- Increase monitoring efforts of marine conditions, especially within the Puget Sound and Salish Sea to understand connections between Puget Sound salmon survival and patterns in marine conditions.

9. Discussion

Significant change is expected in the Puget Sound region over the next 20-30 years, with a net population growth of 24% expected by 2040 in comparison with 2015 (Puget Sound Regional Council, http://www.psrc.org/data/forecasts/). The Puget Sound coastal shoreline counties account for 68% of the Washington State population - 4,779,172 out of 7,061,530 (Alberti et al., 2016). Nearly half of these people live in King County. By 2030, the Puget Sound population is estimated to exceed 5.7 million – an 18.2% increase from 2014 estimates as compared to a 12.7% national growth rate predicted in the same time frame (Alberti et al., 2016). This rapid and extensive growth has direct implications to the Snohomish Basin, with climate change multiplying impacts and stressors to both natural as well as built environments in the Basin.

People moving to the area will need homes to live in, clean drinking water, transportation systems, agricultural products, and strong economies. These needs increase the complexity of addressing the impacts of climate change for endangered anadromous species. Where and how people live in Puget Sound, the patterns of development and transportation systems, along with our economies, all contribute to how salmon will survive and -- hopefully -- recover in the Puget Sound region.

To address these competing forces, planning processes are likely to become more complex, interdisciplinary, and integrated. We need solutions that benefit many interests and sectors while addressing the anticipated changes coming to our watershed and region. Salmon recovery will need to be part of a holistic solution that addresses the pressures the Basin faces in the form of transportation, development and other land use changes.

Currently, the Basin is actively working on more complex planning processes as shown by the formation of the Snohomish Sustainable Lands Strategy (SLS) and the King County Farm Fish Flood (FFF) effort. Both efforts acknowledge the importance of finding multi-benefit solutions that address broader ecosystem function and human interests (e.g., agricultural lands and fish habitat). While these examples deal with three lenses, salmon recovery, flooding and farms, the work to recover salmon will need to expand beyond these to be successful. It will be imperative for salmon recovery specialists and agencies to participate in planning efforts, such as transportation corridors, infrastructure renewal and improvements and growth management to bring the salmon recovery lens. This will allow for better comprehensive and creative problem solving that will benefit all. This work will be challenging and incredibly complex but necessary if we are to achieve our goals in this changing environment. Efforts to further integrate and address the impacts of climate change are already underway. This work will need to continue and accelerate as the pace of population growth and climate change increases.

10. Conclusion

Salmon life history types are varied. Over the centuries, species have evolved with slight differences across the species and within salmonid types to better withstand and adapt to habitat, climate and ocean conditions. The Plan has identified recovery actions that address viable salmonid population (VSP) criteria, such as life stage diversity, abundance, productivity, and spatial structure. By addressing these criteria, we hope to give salmon the best chance for recovery. However, climate impacts will directly affect these VSP criteria. For instance, water temperatures across the basin will likely increase, making some areas inhospitable to salmon, and causing dire conditions for unique life history types such as yearling Chinook. Climate impacts could potentially decrease suitable summer habitat, impacting the spatial diversity in the system, or increased winter scouring could affect population abundance and ultimately productivity.

The summer of 2015 illuminated what may be expected in years to come. Along with large-scale strategies at a global, national and state level to dampen these impacts, work must be done at the basin level. For salmon recovery, restoration and protection actions must amplify the species' natural ability to adapt. To give salmonids the best chance of survival, we must continue implementing the Plan strategy of restoring and protecting diverse and varied habitat types.

The proposed actions (Table 2 and 3) are not new, for the most part; they are described in other Snohomish Basin planning documents like the Salmon Plan and the Snohomish Basin Protection Plan (Forum, 2015). What has changed is the urgency and potentially the prioritization of salmon recovery strategies. We must think beyond direct habitat needs (which are still important) to decrease the intensity of climate impacts likely in 10, 20, and 50 years.

Table 2. Summary of actions to be taken for each climate impact

Climate impact	Strategies and Actions
Hydrology	● Research and implement innovative restoration practices (e.g., beaver introduction) where appropriate, to dampen the effects of shifting hydrology. Work toward resilience by encouraging natural processes that may moderate expected shifts. ● Identify how habitat boundaries, such as floodplains, are changing. Protect shorelines at risk of being armored as climate change advances. Protect habitat outside current habitat boundaries allowing channel migration. Secure land that will be inundated by increased flooding and sea level rise. ● Headwaters are critical to providing cool, plentiful water. Monitor land use closely to minimize impacts to hydrology. In particular, where headwater streams are disconnected from their floodplains (e.g. South Fork Snoqualmie), work on reconnection to restore processes of water storage as well as continuing to plant and protect forests. ● Restore areas that provide flood storage and slow water during frequent, “ordinary” flood events (e.g., those that occur every one to five years) by reconnecting the floodplain (e.g., removing/setting back levees). This will be important above and adjacent to spawning grounds to counter the increased risk of higher flows scouring spawning areas. ● Work to protect floodplains by working with regulations to limit development in the floodplains. ● Remove and fix barriers like culverts and floodgates to ensure access to tributaries, connect oxbows, and protect pools to restore low flow refugia and reconnect local hydrology. ● Work with dam operators like Seattle Public Utilities and Snohomish Public Utility District to use reservoirs to ameliorate hydrologic impacts, especially during low flow periods. ● Protect and expand late successional forest development on federal lands and currently protected areas (regulatory buffers, etc.). Plant and protect working forests from conversion to other land uses, and expand forested areas ● Work with forestry managers and researchers to investigate and better understand the effects of forest management, including stand rotations and selective logging on basin hydrology (Perry and Jones, 2016; Hall, Beechie and Press, 2014; Cafferata and Reid, 2013)
Temperature	● Identify, protect and enhance processes and habitats that provide cool water. Protect cool headwater streams. Locate groundwater sources and seeps and protect natural processes that create critical habitats like wetlands, tidal flats, marshes and estuaries; this will help ensure that water can be stored, recharged, and delivered at a moderated pace and temperature. ● Protect and restore Snohomish Basin tributaries, which are cooler than the mainstem rivers and can provide salmon with cold water refugia. Emphasize opening access to floodplain tributaries, including small stream systems. Continue work to moderate mainstem temperatures. ● Remove and fix barriers, culverts and floodgates to ensure access to tributaries and estuary; connect oxbows and protect pools to restore cold water refugia. ● Monitor land use changes, particularly tree removal and new development, to quantify and mitigate for impacts to temperature. ● Increase the rate of planting and protecting functional riparian buffers to help stabilize in-stream temperatures and reduce sediment and toxin load. ● Work with dam operators such as Seattle Public Utilities and Snohomish Public Utility District to use reservoirs to help ameliorate temperature impacts, especially during low flow periods.

	● Maintain and improve access to resilient habitat refugia such the trap and haul operation at Sunset Falls. ● Work with forestry managers and researchers to investigate and better understand the effects of forest management, including stand rotations and selective logging on basin hydrology (Perry and Jones, 2016; Hall, Beechie and Press, 2014; Cafferata and Reid, 2013)
Stormwater	● Study and prioritize areas that need stormwater retrofits and accelerate those actions. ● Implement Green Stormwater Infrastructure that slow conveyance and increase storage, such as bioswales, rain gardens, and replacement of impervious surfaces with plantings and/or pervious surfaces. ● Plant more trees in suburban catchments. ● Monitor land use changes, particularly tree removal and new development, to quantify and mitigate for impacts to temperature.
Sedimentation	● Increase the rate of planting and protecting functional riparian buffers to help stabilize in-stream temperatures and reduce sediment and toxin load. ● Protect intact buffers to reduce sediment load and minimize erosion. ● Study and understand sedimentation changes in the mainstem areas e.g., sediment budget(s) ● Set back levees in aggrading reaches to allow natural channel migration/avulsion and limit increases in flood-exacerbating bed elevations. ● Identify landslide-prone slopes- and implement hydrologic protections that decrease the likelihood of mass-wasting events.
Sea level rise	● Identify how habitat boundaries, such as floodplains, nearshore and estuaries, are changing. Improve consistency and effectiveness of regulatory protections. Protect marine and freshwater shorelines at risk of being armored as climate change exacerbates impacts. Protect land that will be inundated by increased flooding and sea level rise. ● Improve regulatory protection, especially in all unarmored marine areas. Encourage bulkhead removal or soft armoring replacement where necessary and possible, but especially at historic feeder bluffs. ● Buy land that will be directly impacted by sea level rise, remove existing infrastructure if necessary to allow marine shoreline migration and bluff erosion. ● Work with partners to understand vulnerability of estuary infrastructure under SLR, including levee maintenance and drainage needs, transportation corridors and wastewater facilities.
Ocean acidification	● Protecting and restoring areas of carbon uptake – including eelgrass and tidal marshes. ● Increase monitoring efforts of ocean and marine conditions to better understand connections between patterns in ocean conditions and survival of salmon.

Table 3. Summary of strategies and actions, the climate impact they address, and co-benefits

Strategies and Actions	Climate Impact	Co-benefits
Research and implement innovative restoration practices (e.g., beaver introduction) where appropriate, to dampen the effects of shifting hydrology. Work toward resilience by encouraging natural processes that may moderate expected shifts.	Hydrology, temperature	Water quality, public health, reduced flooding, public education
Identify how habitat boundaries, such as floodplains, are changing. Protect shorelines at risk of being armored as climate change advances. Protect habitat outside current habitat boundaries allowing channel migration. Secure land that will be inundated by increased flooding and sea level rise.	Hydrology, temperature, Sea level rise	Water quality, ecosystem benefits, public education
Headwaters are critical to providing cool, plentiful water. Monitor land use closely to minimize impacts to hydrology. In particular, where headwater streams are disconnected from their floodplains (e.g. South Fork Snoqualmie), work on reconnection to restore processes of water storage as well as continuing to plant and protect forests.	Hydrology, temperature	Water quality, public health, public safety, reduced flooding
Restore areas that provide flood storage and slow water during frequent, “ordinary” flood events (e.g., those that occur every one to five years) by reconnecting the floodplain (e.g., removing/setting back levees). This will be important above and adjacent to spawning grounds to counter the increased risk of higher flows scouring spawning areas.	Hydrology, temperature	Water quality, reduced flooding
Work to protect floodplains by working with regulations to limit development in the floodplains.	Hydrology, temperature	Ecosystem benefits
Remove and fix barriers like culverts and floodgates to ensure access to tributaries, connect oxbows, and protect pools to restore low flow refugia and reconnect local hydrology.	Hydrology, temperature, sedimentation	Public health, public safety, reduced flooding, ecosystem benefits
Protect and expand late successional forest development on federal lands and currently protected areas (regulatory buffers, etc.). Plant and protect working forests from conversion to other land uses, and expand forested areas	Hydrology, temperature, sedimentation	Water quality, public health, public safety, ecosystem benefits, reduced flooding

Work with forestry managers and researchers to investigate and better understand the effects of forest management, including stand rotations and selective logging on basin hydrology (Perry and Jones, 2016; Hall Beechie and Press, 2014; Cafferata and Reid, 2013)	Hydrology, temperatures	Water quality, ecosystem benefits
Identify, protect and enhance processes and habitats that provide cool water. Protect cool headwater streams. Locate groundwater sources and seeps and protect natural processes that create critical habitats like wetlands, tidal flats, marshes and estuaries; this will help ensure that water can be stored, recharged, and delivered at a moderated pace and temperature.	Temperature	Water quality, ecosystem benefits
Protect and restore Snohomish Basin tributaries, which are cooler than the mainstem rivers and can provide salmon with cold water refugia. Emphasize opening access to floodplain tributaries, including small stream systems. Continue work to moderate mainstem temperatures.	Temperature	Water quality, ecosystem benefits, public health, reduced flooding
Remove and fix barriers like culverts and floodgates to ensure access to tributaries, connect oxbows, and protect pools to restore cold water refugia.	Hydrology, temperature, sedimentation	Ecosystem benefits, reduced flooding
Monitor land use changes, particularly tree removal and new development, to quantify and mitigate for impacts to temperature.	Temperature, stormwater	Water quality, ecosystem benefits
Increase the rate of implementation of functional riparian buffer restoration to help stabilize instream temperatures and reduce sediment and toxin load.	Temperature, sediment	Water quality, ecosystem benefits, public health, public safety, reduced flooding
Maintain and improve access to resilient habitat refugia such as the trap and haul operation at Sunset Falls	Temperature	Ecosystem benefits
Study and prioritize areas that need stormwater retrofits and accelerate those actions.	Stormwater	Water quality, public health, reduced flooding, public education
Implement Green Stormwater infrastructure that slow conveyance and increase storage, such as bioswales, rain gardens and replacement of impervious surfaces with plantings and/or pervious surfaces. Especially in urban and suburban areas.	Stormwater	Water quality, public health, ecosystem benefits, reduced flooding, public education
Plant more trees in suburban catchments.	Stormwater	Water quality, reduced flooding, ecosystem benefits

Study and understand sedimentation changes in mainstem areas e.g., sediment budget(s)	Sedimentation	Water quality, public health, ecosystem benefits
Set back levees in aggrading reaches to allow natural channel migration/avulsion and limit increases in flood-exacerbating bed elevations.	Sedimentation	Ecosystem benefits
Identify landslide-prone slopes and implement hydrologic protections that decrease the likelihood of mass-wasting events	Sedimentation	Ecosystem benefits
Protect marine and freshwater shorelines at risk of being armored as climate change exacerbates impacts. Protect land that will be inundated by increased flooding and sea level rise.	Sea level rise	Public safety, ecosystem benefits, reduced flooding, reduced landslide hazard, public education
Improve regulatory protection, especially in all unarmored marine areas. Encourage bulkhead removal or soft armoring replacement where necessary and possible, but especially at historic feeder bluffs	Sea level rise	Water quality, public safety, ecosystem benefits, reduced flooding, public education
Buy land that will be directly impacted by sea level rise, remove existing infrastructure if necessary to allow marine shoreline migration and bluff erosion.	Sea level rise	Water quality, public safety, ecosystem benefits, reduced flooding, public education
Work with partners to understand vulnerability of estuary infrastructure under SLR, including levee maintenance and drainage needs, transportation corridors and wastewater facilities.	Sea level rise	Public safety, ecosystem benefits, reduced flooding
Protect and restore areas of carbon uptake, including eelgrass and tidal marshes.	Ocean acidification	Water quality, public health, ecosystem benefits, public education
Increase monitoring efforts of ocean and marine conditions to better understand connections between patterns in ocean conditions and survival of salmon	Ocean acidification	Water quality, public health, ecosystem benefits,

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