Framing Climate Adaptation Opportunities: 

Four Case Studies on Increasing Resilience to Precipitation Extremes in Washington State

Prepared for the Climate Impacts Group by Kate DeCramer, Emma Diamond, Rajat Soni, and Daniel Wear

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Framing Climate Adaptation Opportunities:
Four Case Studies on Increasing Resilience to Precipitation Extremes in Washington State

Kate DeCramer • Emma Diamond • Rajat Soni • Daniel Wear

A capstone project submitted in partial fulfillment of the requirements for the degree of

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**Daniel Wear**  Daniel came to the Evans School from Chicago, where he worked at the National Audubon Society. His time spent with Audubon motivated Daniel’s decision to attend the Evans School, giving him the opportunity to understand the parallels between policy development, public service, and environmental management. When offline, you can find Daniel biking the mountains, islands, and valleys across the state or at the farmers market browsing.
Acknowledgements

Land Acknowledgement

As graduate students in the Master of Public Administration program within the Daniel J. Evans School of Public Policy and Governance at the University of Washington, we acknowledge that we are conducting work on the unceded ancestral lands of the Coast Salish peoples. The University of Washington and our team acknowledge the Coast Salish peoples of this land, which touches the shared waters of all tribes and bands within the Duwamish, Puyallup, Suquamish, Tulalip and Muckleshoot nations. Beyond this, the work of the following report considers impacts that cover the geographic region presently known as the State of Washington. This sacred land includes current and historical ancestral lands of the Chehalis, Chinook, Colville, Cowlitz, Duwamish, Hoh, Jamestown S’Klallam, Kalispel, Kikiallus, Lower Elwha, Lummi, Makah, Marietta Band, Muckleshoot, Nisqually, Nooksack, Palouse, Port Gamble, Puyallup, Quileute, Quinault, Samish, Sauk-Suiattle, Shoalwater, Skokomish, Snohomish, Snoqualmie, Snoqualmoo, Spokane, Squaxin Island, Steilacoom, Stillaguamish, Suquamish, Swinomish, Tulalip, Umatilla, Upper Skagit, Wanapum, and Yakama Nations.

Statement of Positionality

Our research, findings, recommendations, and analysis come from a background of both academic experiences and Eurocentric research methods. The opportunities afforded to us through the participation in formal academic education provided the basis of our research and our work. Our pedagogical training and context create implicit bias which we directly recognize. Furthermore, we acknowledge that we do not have a historical, generational, or place-based knowledge of significant portions of the geographic area known as Washington State.

Research Information

All information within the following report was gathered through secondary research and interviews with regional research practitioners.

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Secondary research refers to the collection of sources of data or information which has already been produced by others, including studies, government reports, surveys, peer-reviewed research, governmental and non-governmental websites and publications such as magazines and news articles among other sources.
While our research team was able to take deeper examinations into aspects of issues at hand, a majority of the information we utilize is attainable through primary research, reports, and articles available to the general public. Beyond a select set of interviews with subject matter experts, all information used in this report is widely available. Our findings section includes four climate goals we identified based on our ability to access data and information through secondary research. The climate goals presented are not exhaustive and do not necessarily reflect the most pressing potential climate impacts or community-identified impacts in Washington. The two-quarter (six-month) duration of the capstone project specified by the Evans School limited the depth into which the capstone team could interview, research and examine the complex multi-faceted aspects of their case studies.

Partner Support

*We would like to recognize the following partners for their valuable contributions to our project.*

**Jason Vogel, Ph.D.**  
*Deputy Director, Climate Impacts Group*

We thank Dr. Vogel for his thoughtful engagement and instruction around the implementation of the problem orientation framework and its application to problems highlighted in Washington State’s Integrated Climate Response Strategy. His feedback allowed us to think critically about how to identify climate adaptation problems and goals. Dr. Vogel’s support was essential in guiding our findings and recommendations.

**Joaquín Herranz, Ph.D.**  
*Associate Professor, Evans School of Public Policy and Governance*

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Zach Kearl, MPA  
Research Scientist, Climate Impacts Group

We thank Zach for his insights around his experience using the problem orientation framework. Zach’s guidance allowed our team to smoothly navigate the implementation of the framework and identify the best approaches for our work.

Additional Acknowledgements

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Executive Summary

Washington State’s Integrated Climate Response Strategy (WICRS) was the state’s response to the need for widespread climate adaptation in 2012. However, future analyses of the report found that it lacked a collaborative implementation strategy and widespread effectiveness. To address the challenge of communicating climate impacts to state agencies through a comprehensive report, the Climate Impacts Group (CIG) has asked the Evans consulting team to test using a problem orientation framework to identify policy problems and organize policy alternatives. After defining goals, trends, and conditioning factors, we used the problem orientation heuristic as a framework to articulate policy alternatives. Our process aimed to combat goal displacement and preconceived solutions that can be barriers to successful climate adaptation.

Research Questions

To frame our project, we focused on the following research questions:

How can the problem orientation framework be used to structure communication of climate change impact problems, goals, and alternatives?

What were the key challenges and insights we identified from using the problem orientation to identify climate adaptation goals and potential policy alternatives?

What recommendations do we have for the Climate Impacts Group on using the problem orientation framework to shape goals and organize information around climate impacts to Washington state agencies, stakeholders, and policymakers?

Methods

Based on Washington’s changing climate, the Climate Impacts Group (CIG) shared four large climatic change categories with our research team:

- Ocean Acidification
- Rising Sea Levels
- Changing Patterns of Precipitation
- Rising Temperatures
We chose to write and research four case studies within the category of **changing patterns of precipitation** to exemplify the use of the problem orientation framework in white paper format. The case studies focus on the impacts of changing patterns of precipitation on dryland wheat farming, soil stability and landslides, riverine flooding and sedimentation, and salmon survival in the Nooksack River watershed. The case studies provided us an opportunity to explore how to analyze climate impacts and actionable policy alternatives using the problem orientation framework. We were able to identify the following **climate adaptation goals**:

- **Reduce the economic vulnerability of dryland farmers in Washington state during instances of water scarcity.**

- **Protect downstream communities and infrastructure from the physical and economic impacts of flooding following the increased rates of high streamflow events.**

- **Mitigate climate impacts for salmon survival in the Nooksack River Watershed.**

- **Reduce the risk that landslides will disrupt economic activity, road and rail networks transport, and cause property damage.**

**Data**

To complete this research, we conducted extensive secondary research. We also led twelve semi-structured interviews with subject matter experts. We used the interviews with subject matter experts to fact-check our findings and help us identify areas to conduct further research.
Limitations

Certain limitations impacted our capacity to maximize our research throughout the project. Data we were searching for was sometimes not easily accessible or downscaled to the state or local level. Using the problem orientation framework also required iteration and narrow bounds on the research. This led us to select four main climate adaptation goals and set aside many other potential lines of inquiry.

Recommendations

After conducting the case studies, we reflected on the strengths and challenges of using the problem orientation framework. We recommend considering the following key insights to benefit future climate adaptation planning efforts:

- Using the problem orientation framework as an iterative process within a team context is crucial to ensuring that problem areas are current and address multiple perspectives.
- Identifying and defining a set of values prior to choosing more specific problems. This approach will tie the problems more closely to societal priorities and make it more likely that decision-makers can execute the identified alternatives.
- This will lead to a more consistent inclusion of environmental justice in both the research and policy proposals.
- Narrowing goal statements will help key stakeholders to apply the framework to proposed problems. Ensuring succinct and applicable goals will allow for the implementation of achievable policy alternatives.
- Mapping stakeholders throughout the research and problem orientation process will help prioritize the needs of and impacts to local communities. This strategy will help ensure a continued emphasis on underserved and BIPOC communities.
- Tailoring the structure of the framework as needed is important in ensuring successful research. Given that the framework is an approach to tell a broader story to policy makers, the structure of the problem orientation should remain flexible.
• Following the implementation and proposals developed through the framework, analysts should obtain feedback to consider the potential unintended harm or unanticipated benefits from the policy alternatives to additional stakeholders not originally considered. No given policy or solution will be all encompassing, therefore a better understanding of the impacts for each policy proposed is needed.
## Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIPOC</td>
<td>Black, Indigenous, and People of Color</td>
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<tr>
<td>CIG</td>
<td>The Climate Impacts Group at the UW College of the Environment</td>
</tr>
<tr>
<td>DOGAMI</td>
<td>Oregon Department of Geology and Mineral Industries</td>
</tr>
<tr>
<td>DOI</td>
<td>United States Department of the Interior</td>
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<tr>
<td>DNR</td>
<td>Washington State Department of Natural Resources</td>
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<tr>
<td>ENSO</td>
<td>El Niño and Southern Oscillation</td>
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<tr>
<td>FSA</td>
<td>Farm Service Agency of the USDA</td>
</tr>
<tr>
<td>FEMA</td>
<td>Federal Emergency Management Agency</td>
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<tr>
<td>FCI</td>
<td>Flooding Control Infrastructure</td>
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<tr>
<td>GHG</td>
<td>Greenhouse Gasses</td>
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<tr>
<td>IPCC</td>
<td>United Nations Intergovernmental Panel on Climate Change</td>
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<tr>
<td>LiDAR</td>
<td>Light Detection And Ranging</td>
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<tr>
<td>NFIP</td>
<td>National Flood Insurance Program</td>
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<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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<tr>
<td>NSEA</td>
<td>Nooksack Salmon Enhancement Association</td>
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<tr>
<td>NWS</td>
<td>National Weather Service</td>
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<tr>
<td>RCW</td>
<td>Revised Code of Washington</td>
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<td>PSE</td>
<td>Puget Sound Energy</td>
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<td>SPU</td>
<td>Seattle Public Utilities</td>
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<tr>
<td>SWE</td>
<td>Snow Water Equivalent</td>
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<tr>
<td>WDFW</td>
<td>Washington State Department of Fish &amp; Wildlife</td>
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<td>WGS</td>
<td>Washington Geological Survey</td>
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<tr>
<td>WICRS</td>
<td>Washington State’s Integrated Climate Response Strategy</td>
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<tr>
<td>WSDA</td>
<td>Washington State Department of Agriculture</td>
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<tr>
<td>WSDOT</td>
<td>Washington State Department of Transportation</td>
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<tr>
<td>USDA</td>
<td>United States Department of Agriculture</td>
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<tr>
<td>USDM</td>
<td>United States Drought Monitor</td>
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<tr>
<td>USFS</td>
<td>United States Forest Service</td>
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<tr>
<td>USFWS</td>
<td>United States Fish &amp; Wildlife Service</td>
</tr>
<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
</tr>
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Introduction
Chapter 1: Introduction

1.1 The Challenge of Statewide Climate Adaptation Planning

The Evans School of Public Policy and Governance Consulting Lab Team was asked by the Climate Impacts Group of the University of Washington College of the Environment to examine climate impacts facing stakeholders in Washington state. Our task was to find compelling ways to frame the nature of four distinct climate change adaptation problems that include current data on scientific trends and present a range of policy alternatives that directly address each of the four problems.

The Climate Impacts Group (CIG)

The Climate Impacts Group (CIG) is a preeminent climate research organization. The organization provides research mostly focused on ecosystems and communities in the Pacific Northwest, but also addresses climate impacts across the wider western United States. The CIG’s research reports have guided a wide variety of stakeholders, academic researchers, policymakers, and the public on complex climate impacts in our biosphere. Their approach includes identifying climate-related information needs, providing rigorous and dependable scientific research, enhancing community understanding of climate challenges, and increasing policymakers’ capacity to plan and manage for change. The CIG’s work is developed for and in partnership with natural resource managers, planners, policymakers, non-governmental organizations, businesses, and the media. Their expertise incorporates climate and hydrologic modeling, impacts and vulnerability assessments, and adaptation planning.

Washington State’s Integrated Climate Response Strategy

This capstone project is motivated by the ten-year anniversary of Washington State’s Integrated Climate Response Strategy (WICRS) issued in 2012. In 2009, the Washington State Legislature passed the Washington State Climate Leadership Act which directed state agencies to produce a climate response strategy. WICRS was first published in April 2012, with the
Department of Ecology as the lead agency. The report identified the following seven priority high-level climate response strategies:

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

In 2017, the CIG and graduate students from the School of Marine and Environmental Affairs at the University of Washington examined the status of climate change adaptation across Washington state agencies. Their report found there was mixed awareness of WICRS and that the most commonly identified reason for not using WICRS was the lack of an implementation strategy. While state agencies may have been implementing adaptation strategies, there was no state-wide formalized process. Actions were not being tracked, evaluated, or reported comprehensively.

In preparation for a future possible statewide climate adaptation plan, the CIG is testing a new path using a different approach to identify climate adaptation strategies than the process used to develop WICRS. In collaboration with our team, the CIG is aiming to use a novel framework to identify policy problems stemming from climate impacts and adaptation strategies. A CIG team of Dr. Jason Vogel, Deputy Director, and Zach Kearl, Research Policy Analyst, guided our team as we identified climate adaptation problems and strategies using a problem orientation policy heuristic and framework developed by Dr. Vogel and his colleagues.

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d Adelsman and Ekrem

e Casola
The CIG is particularly interested in how the problem orientation framework shapes information around climate adaptation problems and policy alternatives. Our project may inform future statewide climate adaptation planning efforts through testing a new approach to identify problems and organize information around climate adaptation challenges.

1.2 Research Questions

Based on Washington’s changing climate, the Climate Impacts Group (CIG) shared four large climatic change categories with our research team:

- **Ocean Acidification**
- **Rising Sea Levels**
- **Changing Patterns of Precipitation**
- **Rising Temperatures**

We narrowed our focus to the category of **Changing Patterns of Precipitation** because we were interested in how changing precipitation patterns differently impact residents and ecosystems on the eastern and western side of Washington’s Cascades. Eastern Washington falls within the rain shadow created by the vertical spine of the Cascades. Moisture flowing onshore from the Pacific Ocean falls as precipitation in the mountains. The eastward air masses are largely dry. This orographic effect blocks the flow of atmospheric moisture eastward. Thus, the eastern parts of the state receive far less rainfall, even in normal circumstances, compared to the oceanic and temperate rainforest climate of western Washington. However, a full analysis and consideration of the impacts of Washington’s overall changing precipitation trends is beyond the scope of our report.

The Climate Impacts Group (CIG) shared the following parameters to guide our research. The following parameters guided us as we shaped our research questions.

- The CIG has asked us to **focus on climate resilience-related concepts**. This excluded research and analysis around climate change mitigation from the scope of our research.
- The CIG asked us to **use the problem orientation heuristic and framework to guide our research and shape our findings**. We adopted the problem orientation heuristic and

\[\text{\footnotesize Siler, Roe and Durran}\]
framework developed by Dr. Vogel.\textsuperscript{6} We explain the problem orientation in Chapter 2.5 (22).

- The CIG asked that we focus our research and \textit{writing to inform research scientists within the CIG} and policymakers within Washington state agencies.

\begin{center}
\textbf{Research Questions}
\end{center}

\begin{itemize}
\item 1. How can the problem orientation framework be used to structure communication of climate change impact problems, goals and alternatives?
\item 2. What were the key challenges and insights we identified from using the problem orientation to identify climate adaptation goals and potential policy alternatives?
\item 3. What recommendations do we have for the Climate Impacts Group on using the problem orientation framework to shape goals and organize information around climate impacts to Washington state agencies, stakeholders, and policymakers?
\end{itemize}

The research questions were vital to frame this analysis. We found that the problem orientation framework provided a unique approach to exploring complicated climate adaptation problems. Through our continued focus on how the problem orientation framework can be used to inform aspects of climate change issues, the following report addresses each of these research questions through applying the framework to four case studies.

\textsuperscript{6} Vogel, Cherney and Lowham
Background & Purpose
Chapter 2: Background & Purpose

2.1 Adoption and Impact of the Washington State Integrated Climate Response Strategy

Washington State’s Integrated Climate Response Strategy (WICRS) identified climate impacts upon:

- Human health
- Ecosystem, species, and habitats
- Oceans and coastlines
- Water resources
- Agriculture
- Forests
- Infrastructure and the built environment

Following these seven groups of climate impacts, the authors of WICRS recommended sector-specific action items and strategies for each stakeholder group to implement. While wide scoping, WICRS was unable to effectively connect issues across sectors, leading to a failure to implement many of the solutions presented in the 2012 report.

2.2 Alternative Perspectives for Communicating Climate Impacts and Defining Climate Adaptation Goals

To research and write this report and our case studies, we used a novel framework within the category of a policy research approach to clarify policy problems and alternatives. However, there are many other different analytical frameworks and approaches used in the climate adaptation space. Examining climate impacts upon our natural environment and society involves a range of complicated problems and intricately connected issues across natural, economic, political, social, and cultural contexts. There are numerous analytical models that we could have selected to examine, present and communicate climate change impacts to policymakers and the public.

Below we summarize an example of different approaches to climate impact analysis and adaptation planning below. Collaborative and competitive groups use approaches that suit their goals, mandates and
constituencies. Frameworks can vary widely based on underlying philosophies and values. These frameworks are not solitary; many are combined or overlap when policymakers encounter the complexity of real-world problems and people. Teams and working groups are often heterogeneous, coming from organizations with divergent missions and orientations. Ultimately, the following perspectives present multiple analytical possibilities when considering climate impacts:

- **Economists** prefer quantitative, econometric cost valuations and benefit-cost analysis that explain our climate problem in terms of numeric impacts with utilitarian goals that can normalize the nature of the problem across several domains and variables like geography, political organization, moral preferences and cultural traditions.

- **Politicians and governmental agency staff** focus on electoral or constituent realities with an eye to short-term election cycles and voter prerogatives, legislative process, implementation challenges, constrained budgets, competing public priorities, and legal constraints. They examine climate problems in terms of policy windows that can open and close with shifting political power and public pressure, often unrelated to the underlying science governing these problems.

- **Actuarial researchers** take a risk-based approach focusing on applied risk analysis using concepts central to the insurance industry which rely on databases of past historical weather patterns and atmospheric conditions, powerful mathematical models of potential anthropogenic climate forcings, and other statistical parameters to inform future insurability constraints for high-value assets, as well as calculations for asset depreciation, useful life, and replacement value.

- **Conflict-resolution specialists** see climate problems and priorities as a competition among stakeholders for scarce vital physical and economic resources necessary for society

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\(^{\text{i}}\) Ahmad and Warrick
in strained habitable environments. These specialists examine whether these climate stresses will lead to increasing cross-border military conflict, civil war, internecine violence, local and global social instability, and mass migration and relocation of affected populations.

Different stakeholders or practitioners have developed different analytical approaches to understanding climate adaptation problems. These approaches maintain both similarities and differences from the problem orientation framework within the policy research approach we utilized.

2.3 The Timescale of Climate Change Policies and Key Research Parameters

After selecting an approach or combination of analytical approaches, policymakers make critical assumptions and choices on climate priorities along a temporal axis. Stakeholders have to decide whether policy goals should be centered around:

- **Reduction**: Long-term cause mitigation
- **Resiliency**: Medium-term impact avoidance and adaptation
- **Rescue**: Short-term self-preservation involving emergency response to avoid immediate loss of life and acute economic calamity

Examining climate impacts across all three of the above goals: reduction, resiliency, and rescue, is beyond the scope of this analysis. Instead, our analysis contains three key parameters that shaped our research questions for this report:

The CIG has asked us to focus on resilience-related concepts. Therefore we did not examine the problems, goals or alternatives from the standpoint of reducing the long-term sources of anthropogenic climate forcings, such as greenhouse gas (GHG) emissions or removing carbon pollution from the atmosphere though complicated capture-technologies (sequestration). We also did not examine economic solutions or policies that focus on every potential loss of life scenario, however personally tragic and distressing these events are to those affected.

The CIG has asked us to use the problem orientation framework. Using four case studies, we applied the problem orientation framework
developed by Vogel et al.\textsuperscript{j} to identify climate adaptation policy problems, goals, and policy alternatives. Vogel et. al described the problem orientation heuristic as involving several distinct, yet interconnected, components, which we summarize in Chapter 2.5 (22).\textsuperscript{k}

The CIG has asked us to focus our research and writing to communicate to an audience of new employees at the Climate Impacts Group and members of state agencies to help inform decision-making around climate adaptation planning. While many stakeholders in the state of Washington have the power and position to affect policy decisions and many stakeholders are affected by those policy decisions, we were tasked specifically with conducting research and writing case studies to inform research scientists within the CIG and policymakers within Washington state agencies.

2.4  Key Challenges of Climate Adaptation Planning

Among some climatologists and policymakers, there is growing recognition that national, state, and local policy contexts combined with climate change creates climate vulnerabilities. Some examples of policy problems exacerbated by climate change impacts include:

- \textbf{Aging, path-dependent infrastructure}
- \textbf{Inadequate investment in flood/drought preparedness}
- \textbf{Building in high-risk floodplains}
- \textbf{Poverty and economic inequality}
- \textbf{Systemic racism and community underinvestment}

\textsuperscript{j} Vogel, Cherney and Lowham

\textsuperscript{k} It is important to note that the problem orientation framework is not domain specific to climate problems. It is a decision-analytical tool that can be applied to examining any problem.

\textsuperscript{l} The problem orientation heuristic is ethically agnostic. The framework does not adopt any specific moral dimension to the outcome of the analysis. One could use the problem orientation process to examine a virtuous goal with laudable moral dimensions. Likewise the heuristic can examine a nefarious goal that would be viewed as appalling, illegal, immoral or wrong. Furthermore, the problem orientation framework allows the analyst to use features from many of the other frameworks described here when considering the nature of problems, goals, and alternatives that could inform decisions on how to address climate impacts.
While climate change is a key driver of climate vulnerabilities, focusing solely on climate mitigation falsely narrows the focus of what is within the power of government to change. Some policymakers and researchers argue that climate adaptation draws attention to the many causes of climate vulnerability including bad water or forest management, unplanned urbanization, and social injustices that leave the poor and marginalized at risk. In fact, blaming disasters solely on climate change overlooks the poor policy and planning decisions that make these events much worse. This means that there is not one problem to solve – climate change – although reducing greenhouse gas emissions is key to long-term cause mitigation. Medium-term climate impact avoidance and adaptation includes many policy problems within the jurisdiction of local, state, and federal governments to address.

Jesse Ribot, of American University, and Myanna Lahsen, of Linkoping University in Sweden explain: “While politicians may want to blame crises on climate change, members of the public may prefer to hold government accountable for inadequate investments in flood or drought prevention and precarious living conditions.” We found this framing of the intersecting and compounding problems of climate change and various policy contexts critical to our research and this report. It is within this context that a tool to identify specific climate adaptation policy problems and alternatives is particularly useful.

2.5 The Problem Orientation Framework

The CIG team provided an explanatory research article to the Evans Consulting Lab project members introducing the problem orientation framework. A core idea presented in the work is the following conception of the aim of policy sciences:

*The policy sciences aim to maximize the functional value of knowledge as opposed to developing generalized causal relationships or theory. A major component is a focus on problems instead of preconceived solutions or methodological approaches.*
emphasizes practical insights into real world problems and the invention and evaluation of alternatives to resolve those problems, as opposed to generalized theory development or methodological orthodoxy.\(^p\)

It is this focus on problems and their definitions that opens the opportunity to see climate change adaptation issues in a new light and form new ways to address problems between numerous stakeholders. Clearly identifying specific problems is especially valuable when a problem like climate change is concerned. Here, the overwhelming scope of the challenge may cause policymakers to doubt their ability to make meaningful changes or collaborate effectively outside their domain of expertise. The problem orientation heuristic offers an analytical framework to aid policymakers in trusting that problem-focused analysis can lead to new insights and possibilities to address the complexities of climate impacts.

Our research group reconfigured the problem orientation framework into the following four-part analytical process:

**Clarify Goals**

The authors explain that goal clarification involves the “complex, overlapping and sometimes contradictory goals of the relevant community engaged in or affected by a decision process.”\(^q\) This is particularly true in the climate impact space, where numerous stakeholders are being affected by climate impacts, and are experiencing these effects in different ways. The goal clarification process in the climate impact space thus requires a willingness to embrace objectives that may be in tension with one another.

**Describe Trends**

Vogel et al. explain that information on trends is necessary to “evaluate progress or lack of progress.” Specifically “information on trends might include the biophysical, social, and decision-making aspects of a given issue.” As a result, Vogel et al., explain “describing trends requires careful consideration of the relevance of any piece of information to the identified goals - otherwise analysts have no logical basis for determining what information actually matters in identifying or resolving a problem.” For

\(^p\) Vogel, Cherney and Lowham

\(^q\) Ibid.
example, in the climate space, the Intergovernmental Panel on Climate
Change (IPCC) is careful to provide guidance on confidence level\(^7\) in various
trends in atmospheric climate conditions. In some cases, a trend may have
high confidence in a global context but medium or low confidence in a
regional or local context. Thus trend analysis is particularly important when
applied to climate impact related goals in a specific defined area such as
Washington State.

**Identify Conditioning Factors**

There are two components within the concept of conditioning
factors. First, a policy analyst should seek to “understand why the identified
trends have occurred and what factors underlie any discrepancies between
trends and goals.” Second, the analyst should “take trends data and project
[...] them into the figure based on an understanding of the factors
conditioning those trends.” Thus an analyst can come to appreciate the
factors on the trends observed both from the status quo and looking into the
future.

**Suggest Policy Alternatives**

With the previous steps complete, the policy analyst may now
consider an array of policy options that influence the conditioning factors
and might drive trends in a desirable direction in order to achieve the goals
originally identified. Vogel et al. recommend “[i]t is best practice to present a
range of alternatives along with their benefits and drawbacks for decision
makers to choose based on their own criteria.” This flexible and open-
minded approach is critical when addressing the range of challenges of
climate change adaptation in Washington State.

**Identifying the Impacts of Changing Patterns of Precipitation**

Given our interest in major trends accelerated by climate change
reflected in the geological variations of the state of Washington, we focused
on the category of Changing Patterns of Precipitation. The eastern and
western portions of Washington are bisected by the northern Cascade
range. Washington’s western regions experience significant rainfall, leading

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\(^7\) Glossary Definition: IPCC defines confidence levels as a likelihood of an event
occurring, with higher confidence levels meaning there is a likelihood of the projection
being correct eight or nine times out of ten according to Lewis and Gallant.
to complex environmental policy challenges around flooding, infrastructure, and water quality. In eastern Washington, water supply and availability are limited particularly during summer months, leading to complex regulation of water rights.\textsuperscript{5}

Climate change is accelerating both precipitation trends, increasing precipitation during winter months in western Washington and decreasing water availability across the state, with particular impacts during summer months in eastern Washington. We were interested in researching policy problems caused by changing water availability due to these divergent policy challenges. At their simplest levels, the climate change adaptation problems we identified narrowed down to “too much water” and “too little water” during different seasons.

\section{2.6 Our Research Process}

Each state approaches climate adaptation planning and policy research differently. During top-down strategic planning, policymakers identify long term strategies and goals.\textsuperscript{1} A top-down strategic climate adaptation goal stated in Washington State's Integrated Climate Response Strategy is to “protect people and communities from climate change impacts.” Conversely, bottom-up climate adaptation starts with a specific geographically bounded entity, and asks, for example, how might projected environmental changes due to climate change here affect communities and ecosystems? In addition, our capstone project took a bottom-up research approach, focusing on context-specific local adaptation practices.

\textsuperscript{5} Western Regional Climate Center
\textsuperscript{1} CORDIS EU
Climate Impacts from Changing Patterns of Precipitation

We identified the following climate impacts due to increased precipitation:

- Impacts of inland and riverine flooding on communities and infrastructure
- Consequences of sedimentation buildup in water supplies
- Potential risks of landslides on public roadways
- Financial loss to agricultural producers during flood events
- Damages caused by fertilizer runoff from agricultural lands during extended precipitation events

We identified the following climate impacts due to decreased availability of water:

- Scarcity of water causing increased water demand and financial loss among agricultural stakeholders
- Low streamflow availability and increasing water temperatures further endangering salmon
- Decreased water supply for hydroelectric power generation
Research Design & Methods
Chapter 3: Research Design & Methods

3.1 Climate Impact Criteria and Selection

The problem orientation framework can be used to organize any policy problem. In partnership with the CIG, we reviewed the following climate impacts:

- Increased coastal flooding
- Coastal erosion
- Large catastrophic wildfires
- Severe heat waves
- Riverine flooding
- Drought

We determined that the larger topic of changing patterns of precipitation in Washington would be the central theme for guiding our topic choices. This led us to research select impacts within that category: riverine flooding, erosion, peak streamflows, and drought. There are many more than four potential goals within the category of changing patterns of precipitation. But by selecting four goals within the larger category of changing patterns of precipitation, we were able to explore climate adaptation planning through different sets of values – economic values, health, and environmental values – as well as different impacts from a scarcity or surplus of water. Through research, we identified the following four climate adaptation goals:

- Reduce the economic vulnerability of dryland farmers in Washington state during instances of water scarcity.
- Protect downstream communities and infrastructure from the physical and economic impacts of flooding following the increased rates of high streamflow events.
- Mitigate climate impacts for salmon survival in the Nooksack River Watershed.
- Reduce the risk that Cascade landslides will disrupt economic activity, road and rail networks transport across the state, and cause property damage.

3.2 Applying the Problem Orientation Framework

In Chapter 2.5 (22), we outlined our iterative research process using the problem orientation model by tracing a decision-analytic process from goals to alternatives. For each climate impact, we used the following four-
step process to apply the problem orientation framework to our selected resiliency and goals:

1. **We clarified goals** for each climate impact by specifically addressing effects on human health, infrastructure, agriculture, and the environment. We gathered empirical evidence to support why the climate impacts of inland and riverine flooding, erosion, early peak streamflows, and drought are a concern to Washington state and described the factors that policy alternatives must consider.

2. **We described trends and projections** to assess historical, current and future directions regarding the climate impact. Trends included both quantitative and qualitative and came from a variety of sources. The process of describing trends emphasized why a climate impact matters to the public and therefore needs to be addressed by decision makers.

3. **We identified conditioning factors** to understand why trends are occurring, what affects their rate of change, and who may be particularly vulnerable to impacts.

4. **We presented a range of policy alternatives** from current research and case studies for climate adaptation to provide a variety of potential solutions to decision makers.

### 3.3 Literature Review

During the initial phase of understanding the problem orientation framework, we conducted a literature review. The primary goal was to compare research methodologies that have been used to frame climate impacts. Comparing the problem orientation framework to other heuristics helped us identify its unique benefits. Within the literature review, we compared climate adaptation and climate communication frameworks. This comparison of how different frameworks shaped regional climate adaptation plans, paired with the application of the problem orientation framework to a non-climate centric program, provided multiple examples of successful implementation of frameworks to develop policy recommendations from highly scientific findings.
3.4 Research Methods

Secondary Research

The findings presented in our report are mainly derived from examining reports published by stakeholders including the Climate Impacts Group (CIG), the Environmental Protection Agency (EPA), the Internal Revenue Service (IRS), the International Panel on Climate Change (IPCC), Washington Department of Agriculture, Washington Department of Ecology, Washington Department of Health, the United States Department of Agriculture (USDA), the Washington Department of Natural Resources (DNR), the Washington Geological Survey and numerous others. Beyond these sources, we also gathered information to inform trends through collecting recent news sources, journal publications, and academic research. The variation in the sources we used allowed us to find parallels between quantitative data provided through historical data comparison and anecdotal or qualitative experiences and findings.

Interviews with Subject Matter Experts

To gain insight into the impacts of changing patterns of precipitation, we interviewed subject matter experts to deepen our understanding of trends and conditioning factors, identify policy alternatives, and pinpoint further research related to our goals. All interviews were semi-structured and conducted virtually for conversations of 20-60 minutes. We interviewed subject matter experts from the following organizations, among others:

- Washington State Department of Natural Resources (DNR)
- The IMPACT Center at the School of Economic Sciences, Washington State University
- Seattle Public Utilities (SPU)
- Trout Unlimited
- United States Geological Survey (USGS)
- University of California, Merced
- University of Washington School of Urban Planning
- United States Department of Agriculture (USDA)

Appendix A: Interviews of Subject Matter Experts
The interviews were a vital addition to our research process. Through implementing the problem orientation prior to the interviews, we were able to identify specific questions that had arisen within the broader problems we were studying to then ask the subject matter experts. The interview conversations themselves provided additional avenues for further research. Typically, the subject matter experts we interviewed were able to provide confirmation of our research findings or advice on how to further scope our inquiries.

We clarify that interviewees were providing informational background only. The experts were not speaking in an official capacity on behalf of their organizations or agencies, or any collaborators or affiliations past or present. The interviewees should also not be understood to be characterizing their already published research in a different manner. Where there may be a question, we refer the reader to their published work as provided in the Bibliography (116). References to interviews merely indicate how consultations were useful to our understanding of the problems we examined and should not be deemed authoritative positions by the interviewees on the issues we analyzed. Our interviewees inclusion in this report also does not constitute their endorsement of any particular statement, graphic, or visual aid presented in this report.
Four Climate Impact Case Studies
Chapter 4: Four Climate Impact Case Studies

4.1 Summary of Findings

In this chapter, we introduce four case studies, each corresponding to a goal we identified using the problem orientation framework. Each case study explores some opportunities and challenges of increasing the resilience of Washington communities, infrastructure, ecosystems, or the economy in the face of a specific climate impact. Each case study is detailed, but not exhaustive.

4.1.1 Reading the Four Case Studies

Insights From Using the Problem Orientation

Across the four case studies, we found the problem orientation framework to be a useful tool to identify and communicate information related to the localized challenges of a changing climate. Using the problem orientation helped us see how a climate trend—such as increasing water scarcity in the spring and summer—has complex impacts on a range of sectors.

- **Identifying stakeholders** we were able to see which stakeholders had significant power to shift resources, change the policy context, or authority to change the status quo. We also had some success identifying which stakeholders were more vulnerable to climate impacts, although there is room for the
problem orientation to build in this step more explicitly and to greater effect.

- **Gathering and understanding trends** related to our specific climate impact helped us quantify and understand climate adaptation problems, both in scientific terms and within a policy context.

- **Delineating conditioning factors** helped us see the ways in which the problem was getting worse or better.

- **Focusing on policy alternatives that directly changed a conditioning factor**, we were able to ensure that our suite of potential solutions linked directly to the goal we identified.

Following the four case studies, we explore additional insights and challenges we encountered, as well as limitations we experienced during the research process.

### 4.1.2 Stakeholder Table

Provided below is a table of all our stakeholders across the four case studies. **Table 1** (35-36) This visual representation indicates where stakeholders have authority or are impacted across our four case studies. Additionally, each individual case study concludes with a table of key stakeholders. (50, 60, 73, 88) We included stakeholder tables to orient the key organizations and groups that are impacted by a specific climate impact or can affect a potential policy alternative. Because our case studies include technical and scientific language, we also included a **glossary**. (131) We intend the glossary to be used as a resource to enhance the reader’s understanding of the science, law and social policy relevant to each case.
<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Sector</th>
<th>Mandate</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agronomists (Economics)</td>
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<td>Economics and Commerce</td>
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<td>Private</td>
<td>Infrastructure Planning and Recommendation</td>
<td>● ●</td>
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<td>Transport</td>
<td>Passenger Rail Transit</td>
<td>●</td>
</tr>
<tr>
<td>Business Communities (Chambers of Commerce, etc.)</td>
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<td>Civil Society &amp; Econ. Development</td>
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<td>Transport</td>
<td>Rail Transportation/Logistics</td>
<td>● ●</td>
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<td>Utility</td>
<td>Power Supply</td>
<td>● ●</td>
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<td>U.S. Government</td>
<td>Power Supplier/Water Wholesaler/Dam, Reservoir &amp; Canal Management</td>
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<td>Governance/Public Administration</td>
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<td>Land Ownership</td>
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<td>Food &amp; Crop Production</td>
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<td>Interstate and Federal Roadways</td>
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<td>Research</td>
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<td>Safety Advocacy</td>
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<td>Stakeholder</td>
<td>Sector</td>
<td>Mandate</td>
<td>Relevance</td>
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<td>Tribal Governance, Sovereign Relations</td>
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<td>Tribal Sovereignty &amp; Natural Resources Management</td>
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<td>Power</td>
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<td>Sport &amp; Recreation</td>
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<td>Public Transportation</td>
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<td>Specific to Commission</td>
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<td>US Forest Service (USFS)</td>
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<td>Support for WA Farm &amp; Food Economy</td>
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Droughts in Washington state are becoming more frequent, severe, and more likely to continue from one year to the next due to climate change. Wheat is predominantly farmed on non-irrigated properties in the state and consequently is extremely vulnerable to drought in the spring, summer, and fall. Wheat is also one of the state’s top agricultural exports, but during times of drought, wheat yields have fallen up to 50% with losses centered in eastern Washington. Washington’s current state-level drought designations – a Drought Advisory and a Drought Emergency – unlock federal funds that help reduce the economic vulnerability of wheat farmers. However, state-level drought designations are determined by water supply, not soil moisture levels or projections. Adopting a similar policy to Oregon’s county-by-county emergency drought declaration in Washington may increase access to federal aid for Washington wheat farmers, as well as provide benefits to other stakeholders.

Case Study: The Impacts of Climate Change on Wheat Farming in Washington State

Reduce the economic vulnerability of dryland farmers in Washington state during instances of water scarcity.

Droughts in Washington state are becoming more frequent, severe, and more likely to continue from one year to the next due to climate change. Wheat is predominantly farmed on non-irrigated properties in the state and consequently is extremely vulnerable to drought in the spring, summer, and fall. Wheat is also one of the state’s top agricultural exports, but during times of drought, wheat yields have fallen up to 50% with losses centered in eastern Washington. Washington’s current state-level drought designations – a Drought Advisory and a Drought Emergency – unlock federal funds that help reduce the economic vulnerability of wheat farmers. However, state-level drought designations are determined by water supply, not soil moisture levels or projections. Adopting a similar policy to Oregon’s county-by-county emergency drought declaration in Washington may increase access to federal aid for Washington wheat farmers, as well as provide benefits to other stakeholders.

Problem Statement

Droughts cause significant risks to the economic viability of dryland farmers in Washington State. According to the United Nations, climate change will impact agriculture more than most industries. Drought is also one of the nation’s most costly natural disasters. Water scarce years reduce the yields, quality, and marketability of crops. Economists at the Washington State Department of Agriculture estimated that the economic damage from the 2015 extreme drought in Washington state averaged between $633 million to $773 million dollars statewide. Damages include destruction related to irrigated crops, like apples and potatoes, and dryland crops, like wheat. Dryland crops differ from irrigated crops because they derive their water from precipitation.
In June 2021, an unprecedented heat dome across the Pacific Northwest exacerbated an existing drought in Washington state, which extended into September. Heat and drought stress led to a combined 40% reduction in winter and spring wheat yield for the region. It was the worst drought in Eastern Washington since 1977; many wheat farmers in eastern Washington lost half of their crops. Estimates are not yet available for the total economic losses due to the 2021 drought, which will likely have continued impacts on the 2022 growing season. Dryland crops that rely on soil moisture, like wheat, may be particularly impacted by drought.

**Figure A1: Map of Washington State Wheat Producing Counties**

**Why Should We Care About Wheat?**
Wheat contributes 1% of the state’s overall economy. The economic benefits are primarily centered in eastern Washington.
Washington state typically contributes the fourth largest wheat crop in the U.S., which is a major national producer of the world’s wheat. Fig. A1 (38) Among recent years, wheat contributed approximately 1% of Washington state’s total economy. In the areas of eastern Washington where farmers choose to plant wheat, they do so because it is the highest value crop per acre based on soil and moisture conditions. Whitman County in eastern Washington typically produces more wheat than any county in the United States. Fig. A2 In 2020, state wheat exports yielded $663 million, behind only fish, seafood, and frozen French fries. While Washington is the nation’s top exporter of apples, in 2020 apple exports yielded $26 million less than wheat exports.

Wheat production in Washington state is under-appreciated compared to more highly visible crops like apples and hops. Wheat can also often seem distant from the economic concerns in western Washington because wheat farming is concentrated in eastern Washington. The IMPACT Center, located in the School of Economic Sciences at Washington State University in Pullman, seeks to address economic, social, political, and technical problems that affect the competitiveness of Washington’s agriculture and related sectors. The IMPACT Center found that in 2019, “Every dollar from wheat exports resulted in another $2.75 in economic activity throughout the state, much of it in the rural communities where the grain producers operate.”

**Why Washington Wheat Is at Risk**

Dryland wheat farming is more vulnerable to drought impacts than any other activity impacted by drought in Washington state. This is because wheat is highly exposed to drought, extremely sensitive to drought, and has a low adaptive capacity. The following sections outline the trends and conditioning factors that contribute to dryland wheat’s extreme drought vulnerability.
High Exposure to Drought

Washington wheat producing counties are highly exposed to drought because droughts are more frequent, intense, and typically last longer in eastern Washington than western Washington. The rain shadow effect caused by the Cascade Mountains creates a sharp decline in precipitation on the eastern side of Washington state. The semi-arid climate of eastern and southeastern Washington has been conducive to growing dryland wheat, which requires between 12-24 inches of precipitation for successful crop growth. At a certain point, soil becomes saturated and cannot retain additional moisture. Beyond that point, every inch of precipitation is increasingly beneficial to growing dryland wheat. Less than 12 inches of precipitation stunts crop growth and reduces the quality of the crop. In the last decade, droughts have particularly impacted wheat crop growth in eastern Washington in 2014, 2015, and 2021.

Extreme Sensitivity to Drought

Precipitation is the primary limiting factor of production for most of the dryland wheat-growing region in Washington state. Without rain, wheat cannot grow because there is no other mechanism of improving soil moisture on non-irrigated farmlands. This is because 90% of Washington state’s wheat farmers do not have water rights, therefore do not have legal access to irrigated surface water or irrigated groundwater. Dryland wheat in Washington is particularly sensitive to soil moisture levels at multiple times of year because there are two different main types of wheat planted in the state: winter and spring wheat. They both are impacted by droughts at different and overlapping seasons.
A drought lasting into fall reduces the likelihood of winter wheat’s successful planting and can reduce the next season’s harvestable yields. This is because winter wheat is planted in September and relies on soil moisture levels in September and October to start growing before winter wheat lies dormant over the cold winter months. An early spring drought reduces the likelihood of the growth of both winter and spring wheat, but impacts are greater on spring wheat because wheat farmers plant spring wheat in March and early April. Spring wheat seeds rely on soil moisture levels during these early spring months to begin growth. Spring of 2021 was the driest March – April in Washington state since 1926.18 Dryland farmers and ranchers in
eastern Washington were among the first to feel the effects of the 2021 drought because they rely on spring moisture in the soil.¹⁹

**Low Adaptive Capacity to Drought**

Dryland agricultural producers in the semi-arid areas of interior Washington have less ability to adapt to climate change than producers in Western Washington with greater access to irrigated water, more frequent precipitation, and milder climates.²⁰ There are multiple causes of dryland wheat’s low adaptive capacity, outlined below.

Dryland farmers need to make critical decisions on crops prior to the planting and growing seasons but have limited and uncertain information on future precipitation levels. If wheat crops do not receive sufficient precipitation, wheat farmers cannot fall back on irrigation to supplement because they do not have access to the state’s irrigated water supplies. The combined effects of precipitation and dryland wheat’s planting cycle also contribute to its low adaptive capacity. If soil moisture levels remain low in early fall, delaying winter wheat planting past September often means that the wheat grows too short in October and November to survive cold winter temperatures.²¹

Another contributing factor to wheat’s vulnerability to drought is that one year of drought in Washington can affect up to three years of wheat yields.²² This is because many wheat farmers in eastern Washington do not plant wheat on their acreages every year. They rotate crops or plant wheat every other year to include time for the ground to lie fallow and improve soil health. The authors of the 2021 Pacific Northwest Water Year Impacts Assessment found that a deficit of seed-zone water and low soil water after an annual fallow inhibits the establishment and growth of wheat.²³ For farmers who plant wheat every other year, one season of drought can impact up to three years of their wheat yields.
Vulnerability

Dryland farmers in Washington state are severely exposed to drought, extremely sensitive to its impacts, and have low capacity to adapt and change their operations, as outlined in the previous sections. In fact, of all the sectors impacted by drought in Washington state, civil engineers Fontaine and Steinemann found that dryland wheat in the south central and east regions of the state are more vulnerable to drought than any other sector. The following section outlines the methods and findings from their study conducted in partnership with state agencies.

Fontaine et. al used the **Vulnerability Assessment Method** to classify the vulnerability of sectors impacted by previous droughts in Washington state that were likely to be impacted by future droughts in their 2009 study.

1. First, they separated the state into six regions: northwest, central west, southwest, north central, southcentral, and east. **Fig. A4 (42)**

   Then the researchers evaluated the vulnerability of five sectors—agriculture, environment, municipal and industrial, recreation, and power—across each of those regions. Each sector contained different sub-sector activities. For example, ski areas are a sub-sector in the recreation category and fisheries are a sub-sector in the environment category.

2. Fontaine, et. al then used an equation to calculate the vulnerability of each sub-sector with a ranking scale from 1 (very low vulnerability) to 5 (extreme vulnerability). They applied this equation across all sub-sectors.

3. The researchers found that across all 34 sub-sectors in the state, dryland agriculture in the south-central region scored the most vulnerable with a score of 4.50, followed by dryland agriculture in the east region with a score of 4.36. Some of the sub-sectors they found were least vulnerable to drought include golf courses, hydropower, and irrigated berries in the northwest region of the state.
Federal and Washington State Drought Classifications

For wheat farmers in Washington, the timing of a federal or state drought emergency declaration determines when farmers can apply to access economic aid through USDA.

Federal Drought Classifications

Dryland wheat farmers can apply for emergency loans through the USDA Farm Service Agency (FSA) after their county experiences eight or more consecutive weeks of drought, which declares that county as a primary federal natural disaster area. Drought.gov is a collaboration at the federal level between USDA, the National Drought Mitigation Center, and the National Oceanic and Atmospheric Association. Experts from the three groups monitor the current drought status of each county in the U.S. using multiple indicators, including temperatures, soil moisture, water levels in streams and lakes, snow cover, meltwater runoff, business interruptions, as well as how recent precipitation totals across the country compare to their long-term averages. They publish and update the map weekly.

The federal drought status is based solely on current conditions, not projections. When a county reaches eight or more consecutive weeks of current drought conditions at the Severe, Extreme, or Exceptional Drought level on drought.gov, that county is automatically declared a primary federal natural disaster area. This makes farm operators in that county, including dryland wheat farmers, eligible to apply for emergency loans through the FSA. Farm operators, including wheat farmers, have eight months from the date of the disaster declaration to apply for the loans. The FSA considers the extent of production losses on each farm that applies and the security and repayment ability of the operator. After experiencing the impacts of eight weeks of Severe, Extreme, or Exceptional Drought, wheat farmers are eligible to apply for the emergency loans. This aid may help dryland wheat farmers eligible for the aid recover some economic losses from drought impacts, but it arrives well after dryland farmers experience drought impacts.
**Washington State Drought Classifications**

Washington state researchers and practitioners who gather annually to explore the water conditions and drought impacts identified a gap in the state-level response to dryland wheat farmers following the impacts of the 2021 drought. There are three main elements to this gap. The first is that the Washington State Department of Agriculture (WSDA) can help connect wheat farmers to federal resources but does not have any independent funding for drought relief for any of the state’s agricultural producers. The following sections outline the other two gaps for wheat farmers at the state level.

**State-Level Drought Advisory**

A Drought Advisory declared by Washington state does not unlock economic resources for the state’s agricultural producers, including dryland wheat farmers. In fact, dryland wheat farmers are not impacted by a Drought Advisory. This is because a state-level Drought Advisory:

- Advises that external stakeholders and water users conserve water
- Indicates to Washington state agencies to prepare for a possible drought emergency declaration
- Triggers more intensive monitoring of the state’s water supply

Dryland wheat farmers do not use irrigation so they cannot heed calls to conserve irrigated water, there are no economic resources for them provided by the state that are mobilized by a Drought Advisory. Their crop growth is not impacted by the state’s snowpack and river levels, which are the main indicators for a State-Level Drought Emergency. In terms of moisture, dryland wheat crop growth is solely impacted by soil moisture from precipitation. A State-Level Drought Advisory does not prepare dryland wheat farmers for a drought emergency because it is a communications and advisory tool centered on mobilizing resources for water users and agricultural producers who rely on irrigation.
State-Level Drought Emergency

Washington state Drought Emergency declarations unlock the federal emergency loan application process managed by the FSA. Whichever drought emergency is declared first – the federal drought natural disaster area or the state drought emergency – opens the door for Washington farmers, including wheat farmers, to apply for the federal loans. However, the State-Level Drought Advisory and Emergency declarations are based on current water supply and projections, not soil moisture levels. Statute RCW 43.83B defines drought as when water supply is intended to by 75% of normal and there is anticipated hardship to water users. In Washington state law, water users indicate those who rely on irrigation, snowpack, or river levels – not those who rely on precipitation. Dryland farmers are not “water users” in the sense indicated under Washington law. Therefore, the decision to declare a state-level emergency drought does not consider the main driver of agricultural drought for dryland farmers, which is current and projected soil moisture levels. Additionally, the state government has discretion in declaring the geographic area included in the emergency, which can range from a specific watershed to the entire state. At both the state and federal levels, there are no economic preparedness or mitigation measures for Washington’s dryland wheat farmers.

Policy Alternatives

Some economic relief measures are less effective or constrained at the state level, including increasing crop insurance coverage and using state funds to provide economic drought relief. Most wheat farmers in Washington state insure some or all their wheat crops to offset the risk of damage from events including drought. Insurance can often cover up to 80% of losses; farmers decide how much of their crop to insure. During times of drought-reduced yields, farmers with crop insurance will receive insurance benefits to cover losses but will not make any profits. Crop insurance is decreasingly beneficial as droughts become more frequent because crop insurance is a short-term recovery tool. Crop insurance also does not provide economic benefit to the communities in which the dryland farmers and grain producers operate.
While Washington state could explore increasing the economic resources for agricultural producers, economic programs to support farmers have historically been provided and managed by the USDA-managed Farm Service Agency, which traces its origins to the Great Depression in the 1930s and the severe drought and dust storms of the Dust Bowl resulting in farm failures. Washington state agencies typically serve as a conduit to the FSA and USDA federal resources. However, two main policy alternatives emerged as viable and feasible state-level policy alternatives to reduce the economic vulnerability of wheat farmers during drought: include soil moisture projections in the state’s indicators for drought emergencies and provide counties more self-discretion to self-determine drought emergencies.

**Alternative: Include Soil Moisture Projections in the State’s Indicators for Drought Emergencies**

Wheat farmers are eligible to apply for federal economic resources once their county is declared a federal natural disaster area through drought.gov. The federal drought includes current soil moisture levels, but not projections of soil moisture. This means that farmers can only apply to access aid when drought impacts are already severe. The other route to accessing federal resources is through a state drought declaration, which includes projections of water supply, but not projections of soil moisture. Because soil moisture projections are missing from both the federal and state drought indicators, both the federal and state government are overlooking a key indicator of drought for dryland wheat farmers. This is an emerging area of study for climate and drought scientists. Researchers at the Central Sierra Snow Laboratory posit that soil moisture is an increasingly important indicator of drought as drought impacts are more likely to continue from one year to the next due to water scarcity induced by climate change.
Alternative: Provide Counties More Discretion to Self-Determine Drought Emergencies

Washington’s Department of Ecology is the lead agency for the state’s drought response. Ecology is responsible for analyzing water supply forecasts from the National Weather Service’s Northwest River Forecast Center and the Natural Resource Conservation Service. Then based on forecasted water supply, Ecology recommends drought advisories and emergencies to the Governor, who officially declares a drought.

But other states use a more decentralized approach to declaring droughts. In Oregon, where ⅔ of the state’s counties produce dryland wheat, counties have formal discretion to request that the Governor declare a drought for their specific county. Stakeholders in Oregon counties evaluate data shared by the Oregon’s Water Supply committee, then can request a drought declaration for their county to the Drought Readiness Council, which recommends action to the Governor of Oregon. The Governor then approves or denies the counties’ requests for a county-specific drought. Fig. A5

![Figure A5: State of Oregon Standard Drought Declaration Process](image-url)
As of May 8, 2022, the Governor of Oregon has declared eleven counties in Oregon to be in a state of drought emergency, meaning they are eligible to apply for the FSA-managed federal aid and emergency loans before the drought impacts become more severe. This gives Oregon wheat farmers more economic security as they begin the process to apply for aid sooner. Giving local officials discretionary power to recommend action for their county is a more decentralized process for declaring droughts than Washington’s current policies. More research is needed to determine if the federal economic aid is first-come first-served, meaning eligible Oregon wheat farmers receive more access to federal economic aid than Washington wheat farmers. If so, this would provide an additional increased benefit from a more decentralized drought declaration process to Washington wheat farmers.

Currently, there is not appropriate representation of the localized impacts of drought in the policy process in the state of Washington. As areas of the state face a higher risk of agricultural drought, particularly eastern Washington, the state government’s powers of broad discretion in selecting which geographic area to use to calculate an average for 75% of normal water supply may become less equitable for those living in the driest areas of the state. Declaring a statewide drought – which Governors of Washington have done in 2001, 2005, 2015, and 2021 – is an overly centralized response to what is often a localized problem. Using counties as a clear geographic area and giving counties representation in the drought declaration process ensures clearer regional boundaries, involves more local stakeholders, and employs a refined approach to determining water supply. Rather than a variable approach to calculate water supply averages currently used.

**Conclusion**

Severe and ongoing droughts induced by climate change have exposed a gap in Washington’s drought response for dryland wheat farmers. This indicates how a local, state, and federal policy context aligns for some stakeholders but do not fully meet for others, leaving dryland wheat farmers increasingly vulnerable to specific climate impacts. Including soil moisture projections in drought declarations or opening pathways for counties to make recommendations to a Washington State Drought Readiness Council provide two options to take steps to close the gap.
Table 2: Dryland Wheat Farming Key Stakeholders

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Role/Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dryland Farmers</td>
<td>Agricultural producers</td>
</tr>
<tr>
<td>Farm Service Agency (FSA)</td>
<td>Administers loans to farm operations and manages agricultural programs</td>
</tr>
<tr>
<td>U.S. Department of Agriculture (USDA)</td>
<td>Federal agency</td>
</tr>
<tr>
<td>Washington State Association of Wheat Growers</td>
<td>Nonprofit trade association 37</td>
</tr>
<tr>
<td>Washington State Department of Agriculture (WSDA)</td>
<td>State agency</td>
</tr>
<tr>
<td>Washington State Department of Ecology</td>
<td>State agency</td>
</tr>
<tr>
<td>Washington State Grain Commission</td>
<td>Self-governing state agency 38</td>
</tr>
<tr>
<td>Wheat Importers in Asia</td>
<td>Purchase Washington wheat</td>
</tr>
</tbody>
</table>
Problem Statement

The Nooksack River Watershed is home to all five species of Pacific Salmon in Washington. This sensitive habitat is being impacted by climate change and human development leading to the rapid decrease of salmon populations. Climate change primarily affects salmon in freshwater streams by increasing stream temperatures. With higher ambient temperatures, snowpack melt begins earlier in the season, shifting peak streamflows in mixed and snow dominant watersheds forward. This shift in timing contributes to declining streamflows during the summer months when several salmon species come to spawn. Higher air temperatures also directly contribute to higher stream temperatures causing significant stress to salmon in the river. Additionally, glacial retreat is resulting in a rapid reduction in ice volume that adds cool water to the Nooksack river watershed. The most important actions to combat climate change on the Nooksack River are restoring riparian zones, floodplain reconnection, wetland restoration, and placement of log jams. Most of these actions are already underway in the Watershed, however, the pace and scale
of implementation needs to be increased. Actions that the state can pursue to address these issues are increased funding to organizations spearheading restoration projects, updating flood management plan requirements, and shifting water management strategies.

**Background**

Salmon are an important part of the Pacific Northwest identity, ecosystem, and economy. Five salmon species can be found in Washington’s coasts and rivers: Chinook, Coho, Chum, Sockeye, and Pink salmon. These fish are keystone species to hundreds of animals and ecosystems that rely on them for nutrients such as orcas, bears, and eagles. As salmon populations decrease, so too does the health of their surrounding environments. Salmon also plays a major role in the Washington economy. The recreational and commercial fishing industry supports an estimated 16,000 jobs in Washington and salmon alone provide over $134 million of economic output to the state every year.

One of the most important habitats for salmon in Washington is the Nooksack River watershed, which is one of three rivers in Washington that is home to all five species of Pacific salmon as well as three species of trout. Fig. B1. These salmon are culturally significant to the Nooksack Indian Tribe and Lummi Nation, particularly the spring Chinook. Impacts of
climate change are threatening survival of the wildlife in this watershed, creating conditions that are affecting seasonal streamflows, increasing stream temperatures, and creating unsafe habitats for salmon migration and spawning. Because the Nooksack Tribe has a place-based heritage, “the Tribe cannot move its geographic base or homeland to where salmon will be located under future climatic conditions.” Current salmon runs in the Nooksack river are estimated to be about 2 to 8% of historical numbers.

**Climate Change, the Nooksack River Watershed, and Salmon**

Salmon and steelhead are anadromous fish, meaning they migrate from the ocean up freshwater rivers and streams to spawn. This migration requires rivers and streams to be capable of sustaining salmon during the most vulnerable parts of their life cycle. To cultivate healthy salmon populations, streams must have low levels of pollution and suitable flow rates to maintain enough habitat for their freshwater life cycle. There are two runs of Chinook salmon in the Nooksack River basin. The spring run salmon enter freshwater as early as March and spawn in August and September before dying. Juvenile salmon can then spend anywhere from a few months all the way up to a year in freshwater streams before migrating to the ocean.

The Nooksack River is dependent on rainfall, snow, and glaciers from the North Cascades for its water, making it a mixed rain and snow dominant
watershed. However, climate change is heavily impacting the hydrologic cycle of the watershed. With higher ambient temperatures, snowpack melt begins earlier in the season, shifting peak streamflows in mixed and snow dominant watersheds forward. Figure B2 (53) shows the shift in historical flows from being highest in May and November to peaking around January by the 2050s. This shift in timing contributes to declining streamflows during the summer months when several salmon species come to spawn. Higher air temperatures also directly contribute to higher stream temperatures causing significant stress to salmon in the river.

Additionally, glacial retreat is resulting in a rapid reduction in ice volume that adds cool water to the Nooksack river watershed. Sediment trapped in glaciers or at the forelands of glaciers will also likely change the sediment dynamics in the watershed as they continue to melt. Increased levels of suspended sediment in the river may clog salmon spawning gravel, damage riparian buffers, or increase heat loading. During these low-flow years, water temperatures can increase to dangerous and even lethal levels for salmon, potentially halting their migration upstream and hindering the spawning season. Low streamflows may also decrease available habitat for spawning, limit food availability, and increase predation.
Water Temperature

Different species of salmon have different thermal tolerances in stream temperature. The Department of Ecology and the US EPA use a 7-day average of the daily maximum (7DADMax) temperature to express temperature thresholds for salmon. Among adult salmon, the 7DADMax is lethal at \( \sim 23^\circ C / 73^\circ F \), migration is inhibited at \( \sim 24^\circ C / 75^\circ F \), and the risk of disease may be elevated at \( \sim 14^\circ C / 60^\circ F \).\textsuperscript{52} \textbf{Figure B3} (54) shows the Chinook life cycle temperature requirements compared with current and forecasted monthly average water temperatures in the South Fork Nooksack River.

By the 2040s, a predicted 40 miles of the Nooksack River will have average August temperatures exceeding 64°F as compared to zero miles currently.\textsuperscript{53} This is indicating an increasingly stressful environment for salmon spawning. Currently there are 32 miles of stream listed as threatened under the Clean Water Act in the South Fork Nooksack for stream temperature. Modeling shows that the average stream temperature is projected to rise by 5°F by 2080.\textsuperscript{54} Climate change is projected to increase the frequency and persistence of thermal migration barriers and unhealthy waters for salmon across multiple climate change scenarios.\textsuperscript{55}

![Figure B4: Lynch Glacier in the North Cascades in 1979 and 2005 Source: North Cascades Climate Project](image)

Glacial Retreat

Glacier melt contributes 30% of the streamflow in mid to late summer.\textsuperscript{56} This is a particularly critical time for Spring salmon that spawn during the summer months. Approximately 148 glaciers from Mt. Baker, Mt. Shuksan, and other peaks drain into the watershed annually providing higher streamflows and cooler temperatures for the rivers.\textsuperscript{57} Glaciers in the
North cascades are not only losing mass because of higher air temperatures and extended melting seasons, but also because of decreasing snowpack. Precipitation is falling more frequently as rain, resulting in a predicted 29% loss in snowpack by the 2040s that cannot internally refreeze as effectively and contribute to glacial accumulation.\textsuperscript{58, 59}

\textbf{Figure B4} (55) shows the Lynch Glacier in the North Cascades having retreated 123 meters from 1979 to 2005. This level of glacial retreat is occurring throughout the region. Over half of the glaciated area on Mt. Baker drains to the Nooksack River, but the average retreat of these glaciers is 370 meters from 1979 to 2009.\textsuperscript{60} While air temperature has a higher impact on stream temperatures than glacial runoff, it should be noted that a potential 20% decrease in glacier melt could increase stream temperatures by 0.49°C.\textsuperscript{61}

\textbf{Streamflow Changes}

Low summer streamflow conditions are projected to become more severe in 80% of watersheds across Washington.\textsuperscript{62} The average summer streamflow in the Nooksack has already decreased almost 30% since 1963.\textsuperscript{63} Changes in precipitation patterns and decreases in glacier mass are causing the melting season to start earlier and not last as long. Studies are predicting that at the current rate of melting many of the smaller glaciers will not survive present warming trends, depriving the watershed of critical summer runoff.\textsuperscript{64} The impacts to streamflow will not be uniform across the watershed and as glaciers melt in the short-term, some streams may see an increase in flow.\textsuperscript{65} However, the Nooksack Tribe and research institutions such as Western Washington University are studying what the long-term consequences of climate change are on the hydrologic cycle of the river and are estimating a potential 77%, 65%, and 76% decrease in July streamflow in the North Fork, Middle Fork, and South Fork Nooksack River, respectively.\textsuperscript{66} These rivers will also each experience over a 100% increase in January flows that could threaten channel stability during salmon rearing stages.\textsuperscript{67}
Other Factors Impacting Salmon Habitat

Habitat Degradation

The area surrounding the Nooksack watershed has remained largely rural, however the impacts of forestry and agricultural practices have severely degraded salmon habitat, especially in the upper basin. An estimated 2,269 acres of Nooksack floodplain forest has less than 70% forest cover (the desired target level of the Nooksack Tribe). While there does not appear to be continued permanent removal of forest in the Watershed, the maintained forest clearings within the riparian zones of the Nooksack River present challenging conditions to salmon. Mature trees in riparian zones provide shade to regulate stream temperatures, large woody debris to help form pools and cover, and root structure to help stabilize stream banks. The clearing of logs and other wood from the rivers has depleted the availability of pools and salmon rearing habitat, contributing to channel instability. Channel stability refers to the integrity of the deep, less turbulent areas of a stream. These low streamflow areas are important for spawning and egg survival during the fall and winter. Increased sediment loading from natural (glacial sediment and riverine erosion) and human causes also poses a threat to pool depths for resting salmon and can cause scouring to eggs.

In the lower portion of the watershed, one of the largest threats to salmon recovery is human activity. Whatcom County’s population is estimated to grow nearly 30% by 2036. Research indicates that the toxic effects of pollutants in stormwater runoff are likely the cause of a 60-100% mortality rate of pre-spawn Coho salmon in urban watersheds in Puget Sound. Shoreline armoring that protects infrastructure from damage, prevents erosion that would normally give salmon natural habitat to consume insects and other fish. Approximately, 72% of Whatcom County’s erosional shoreline is either modified or armored.

Fish Passage Barriers

Predicted decreases in summertime low flows will further reduce available habitat by 10% for spring Chinook during the summer holding period according to the watershed management board. With already increasingly limited available habitat, human development has further
reduced this area with barriers to migrating adult salmon. In the Nooksack watershed there are 604 known barriers either partially or fully blocking salmon from reaching their spawning grounds. Many of these barriers are created when roads intersect with streams and the resulting culverts do not account for fish passage. 54% of these barrier culverts are owned by the government.75

**Policy Alternatives**

The most important actions to combat climate change on the Nooksack River according to a qualitative assessment completed by the EPA are restoring riparian zones, floodplain reconnection, wetland restoration, and placement of log jams.76 Most of these actions are already underway in the Watershed, however, the pace and scale of implementation needs to be increased.

**Alternative: Floodplain Reconnection**

A high priority that has been identified for habitat restoration is floodplain reconnection.77 Floodplain reconnection may involve removing levees that keep water in streams from draining into adjacent floodplains or other projects that restore the natural function of river flows. These projects have been implemented by a variety of agencies; however, landowner willingness has constrained the pace and scale of these projects. These projects have been proven to provide an immediate and enduring benefit to salmon recovery efforts.78 Whatcom County and the Whatcom Land Trust have used grants for salmon recovery and flood hazard reduction for floodplain acquisitions and to implement more of these projects in the South Fork of the Nooksack. More money into these funds will help continue the work of protecting floodplains from development and removing infrastructure that is harmful to the Watershed. Updating the requirements for comprehensive flood management plans to mandate floodplain restoration as a part of the risk reduction plan would also help scale up these projects. This would create a state requirement for floodplain restoration in vulnerable areas, providing a variety of benefits to the salmon, environment, and community.
Alternative: Riparian Functions

Reforesting and planting riparian zones are effective ways at providing shade and preventing erosion. The Nooksack Salmon Enhancement Association (NSEA) is non-profit focused on repairing river, creek, and riparian habitat for salmon. This organization also helps remove barriers to migration to improve access to over 50 miles of upstream habitat for spawning adults and juvenile salmon. Planting native plants and trees at a large enough scale can significantly improve habitat for salmon in the Nooksack. Temperature modeling has shown that riparian restoration efforts along the South Fork could lead to temperature reductions as high as 1.4°C. Additional restoration along the tributaries could further reduce the River’s temperature by 0.9°C. Working with state land managers and forest landowners to increase the amount of forest land cover and reduce forest rotation frequency in the Watershed will provide greater protection for the riparian forest.

Alternative: Instream Rehabilitation

In 2020, the Nooksack Tribe completed an extensive restoration project on the North Fork of the Nooksack River by installing 127 engineered logjams. Logjams stabilize the main channel of the river while protecting side channels that salmon like to spawn and rear in. Projects like these in areas that have commonly turbulent waters and high channel turnover rates are a cost-effective way to protect salmon habitat from climate change. Assessing log jam placements for their ability to create temperature refuges for Salmon may help with the future design and placement of these projects.

Alternative: Water Management

The Department of Ecology is responsible for administering state laws that require streams to have enough water to protect and preserve instream resources. To do this, Ecology set specific stream flow levels in administrative rules for the Nooksack River basin in 1985. Once established, these levels served as a water right for the stream and the wildlife that depend on it. However, the instream flow levels in the Nooksack basin are consistently not being met and the Nooksack Tribe states that the water levels remain deficient and over-appropriated. Despite the Lummi Nation and Nooksack Tribe having water rights from time immemorial to support harvestable salmon, lack of legal clarity on tribal water rights has complicated the determination of available water for allocation.
Instream flow requirements only impact water withdrawals from those who have junior water rights (post-1985). Actions from the state, such as adjudication, that impacts the water withdrawals or encourages conservation from senior water rights holders or rural landowners may help increase instream flows to healthy levels for salmon. The Nooksack watershed has been recommended for immediate adjudication\textsuperscript{86}, in which case the state will reassess water rights in the area and determine how much water can be used and what are priorities during shortages.\textsuperscript{87}

**Table 3: Nooksack River Salmon Key Stakeholders**

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPA Region 10</td>
<td>Federal Agency</td>
</tr>
<tr>
<td>NOAA</td>
<td>Federal Agency</td>
</tr>
<tr>
<td>Nooksack Tribe</td>
<td>Sovereign</td>
</tr>
<tr>
<td>Northwest Indian Fisheries Commission</td>
<td>Natural Resource Manager</td>
</tr>
<tr>
<td>Puget Sound Partnership</td>
<td>State Agency</td>
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<tr>
<td>WA Department of Ecology</td>
<td>State Agency</td>
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<tr>
<td>WA Department of Fish and Wildlife</td>
<td>State Agency</td>
</tr>
<tr>
<td>WA Department of Natural Resources</td>
<td>State Agency</td>
</tr>
</tbody>
</table>
Framing Climate Adaptation Opportunities

Case Study: Landslide Hazards in Riverine Areas of the Washington Cascades

Reduce the risk that landslides will disrupt economic activity, road and rail networks transport, and cause property damage.

Problem Statement

Reducing social and economic disruption and improving safety for residents, visitors, and travelers in Washington state by addressing core drivers of landslide risk in a changing climate is critical to the state’s future. In the Pacific Northwest, landslide-triggered erosion, debris and earth flows in a warming climate will likely increase threats to safety, economic well-being, government services and essential intermountain infrastructure and transportation routes connecting eastern and western sides of the state. Services to urban, mountain and rural communities will likely be impacted by increased prevalence and severity of climate-driven landslide hazards.

Precipitation Stress

In western Washington state, extreme precipitation events appear to be increasing. In one study from North Carolina State University, the number of 24-hour periods in which two or more inches of rain fell may be rising when compared to the historical average (black horizontal bar). Fig. C1 In the graph, the green bars represent five-year extreme precipitation events from 1900 to 2020. As green bars extend past the black line, the trends suggest more
extreme precipitation events are occurring in western Washington compared to last century. Aspect Consulting, a geohazard and engineering firm, has examined precipitation coincidence with reported landslides in western Washington transit corridors along I-5 using a tool developed by the USGS. In Figure C2, the plot shows a possible threshold at which landslide risk exists due to impact of heavy precipitation (y-axis) over duration (x-axis). What we may see in western Washington, particularly in the I-5 corridor in the future is the steepness of the curve at the left increases, which would indicate more landslides occurring (yellow area).

**Increased atmospheric river events**

Atmospheric river events are directly responsible for inundating western Washington with heavy rains that eventually trigger landslides. In November 2021, a particularly destructive atmospheric river caused widespread damage in Washington and Canada, stranding 18,000 residents on both sides of the border, closing major transportation routes, and costing at least $1 billion in damages. Research indicates that the El Niño Southern Oscillation (ENSO), which includes both El Niño and La Niña thermocline fluctuations and current changes in the Pacific Ocean, could become more extreme due to human-induced global warming. ENSO is seen as a driving factor to atmospheric river behavior and occurrence, although establishing the extent of these correlations will take more research. The Washington state climatologist anticipates that warmer, wetter conditions (along with increased extreme variability drought years) is likely to occur in Washington in the coming years. Heavy rainfall causes slope instability tipping points. In 2016, researchers looked at how precipitation and GPS-measured soil displacement correlated in the

*Streamflows will peak earlier in wetter winter months when atmospheric river patterns are more common. This could increase flooding by 30 to 40% in western Washington.*
Cascades along the Columbia River outside of Portland, Oregon. They found that landslides typically initiate after 300mm of accumulated precipitation in a 30-day period and one to three months before peak rainfall.\textsuperscript{94} \textbf{Fig. C3}

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{figure_c3.png}
\caption{Researchers in Oregon found that the onset of sliding displacement began (negative slope, black dotted line) one to three months after peak observed rainfall (green line) in the study area. The land had a slight upward “rebound effect” (positive slope, black dotted line) during the lowest precipitation period.}
\end{figure}

\textbf{Long-term changes in precipitation mix}

Climatologists and atmospheric scientists anticipate that across the Cascades more seasonal precipitation will fall as rain instead of snow in a warming climate. This is due in part to the fact that most of the Cascadian snowpack accumulates at approximately the freezing point of 0°C.\textsuperscript{95} Thus small atmospheric temperature changes can have outsized impacts on the seasonal mix. The timing of peak stream flows in Washington state watersheds is expected to change rapidly in this century under likely warming scenarios.\textsuperscript{96} As a result stream flows will peak earlier in the wetter winter months when atmospheric river patterns are more common. This could increase flooding by 30 to 40\% in western Washington.\textsuperscript{97} The reason this is alarming is because rain-snow mix watersheds typically have two periods of peak flows, one in the rainier winter and one when the snowpack melts in the spring. In a warming climate these separate peaks may merge
into one earlier and larger event with more negative impacts due to the larger cumulative effect.\textsuperscript{98}

This will probably have a noticeable impact in rain-snow mixed watersheds that have naturally evolved to handle seasonal flows in two peaks (e.g., Snohomish, Puyallup and Hood Canal watersheds).\textsuperscript{99} In addition, the volume of additional water to be drained is a function of the surface area of the watershed that is likely to convert from snow to rain. This means there is a geometric impact to the volume of water generated by this impending change that will affect flooding, rather than a linear effect.\textsuperscript{9} The Climate Impacts Group estimates that streamflow volume of the one hundred-year (i.e. 1% probability) flood events could increase 18-55\%.\textsuperscript{100}

**Soil & Vegetation Stress**

The geomorphology of Washington state, and the Puget Sound area in particular contributes to a landslide risk.\textsuperscript{101} As a result, even a relatively small area can have multiple soil climate types creating a complex interaction between the land and the water, especially with respect to the infiltration (hydrophilic) or impermeability (hydrophobic) qualities of the soil. A full understanding of how the soil is impacted by climate is beyond the scope of this paper and requires more localized scientific research. However, soil surveys suggest that climate change is one of the key factors determining soil characteristics and will have an impact on the behavior of water in the Cascade range.\textsuperscript{102}

With potential increasing stream flows in Cascade waterways, the question arises if such flows may cause more scouring that destabilizes hillsides by undermining the toe feature of the bottom-most part of a slide that often acts as a plug holding back earth flow. In 2021, Chinese scientists examined scouring erosion on slopes with a focus on small watersheds, which the authors noted had not been studied in as much depth as large-scale basin-wide orographic studies.\textsuperscript{103} They also found that water incision in the studied hillsides typically happened to a greater degree upstream because the water was not yet loaded with sediment at that point. Sediment-loaded flows further downstream had a lessened scouring and incision effect on the hillside, but the effect of scouring was observable.

\* Interview with Guillaume Mauger (Mar. 28, 2022)
Studies show that re-vegetation and replanting forests after fires or timber harvesting is not likely to be effective. In a 2016 study, research scientists compared old-growth hardwood root extent to regenerative pines and found that the latter had substantially shallower root structures than the long-term old-growth flora.\textsuperscript{104}

**Timber Harvesting Practices**

In 2017, Washington State University researchers embarked on a multi-factor study of the potential correlation between timber harvesting and landslide risk under potential global warming scenarios. The study assigned probabilistic values for both soil parameters (internal cohesion and friction of the soil itself) and vegetation parameters (root cohesion and vegetation surcharge).\textsuperscript{105} At the time, the authors noted that this issue was not well-researched.\textsuperscript{106} Barik et al. used the Queets watershed of the Olympic Experimental State Forest (OESF) and applied the Distributed Hydrology Soil Vegetation Model (DHVSM) statistical model. The authors found that under generally accepted potential warming scenarios in Pacific Northwest, timber harvesting may contribute to increased landslide risk in high susceptibility areas of anywhere from 7-12\% in most simulations. They also noted that perhaps 12\% of federal lands may fall within the high-susceptibility category, while 17\% of DNR state managed lands could do so.\textsuperscript{107} One observation of the study authors should be a concern for policymakers, namely that current techniques may be inadequate to the challenge: “[M]ost conservative harvesting techniques aimed at reducing landslide susceptibility are not always effective. Tools are needed to identify where and under what conditions harvesting should be avoided to protect the environment. As climate change is expected to increase the probability of landslide potential in many areas, new tools to identify vulnerable areas should take climate projections into account.”\textsuperscript{108}

**Wildfires and Extreme Heat Waves**

Researchers at the USGS are developing GIS tools to map localized debris flow risks following significant fires. Wildfires create a substantial risk of landslides, including rockslides, earth flows, and debris flows. Wildfires instantaneously burn the root structures that hold soil in place.\textsuperscript{109} The fires also create hydrophobicity\textsuperscript{110} (water-repellence) due to ash and residual oils left over from combustion. This condition may trigger surface runoff by sealing the soil after a fire.\textsuperscript{111} When typical rainstorms occur,
dangerous flash-flooding and sediment flows are possible.\textsuperscript{112} However, even this effect may be influenced by the first rains after a fire. If they are gentle, it is possible the hydrophobic layer may be dissipated. If the immediate rains are heavy, however, catastrophic debris flows can result.\textsuperscript{113} That said, surface-run off is a main cause of post-fire debris flows.\textsuperscript{w} These debris flows can be five times as destructive as flood waters and move at 35 mph.\textsuperscript{x} These dynamic topology risks can remain for five years after a fire.\textsuperscript{114} With respect to heat waves, the 2021 extraordinary heat dome over the Pacific Northwest offered a window into a future in which acute heat events cause substantial damage to forest flora in ways that are both visible from plant wilting and desiccation, as well as invisible causes from vascular root damage.\textsuperscript{115}

Residential and Commercial Development Stress

The USGS Landslide Handbook states that “Populations expanding onto new land and creating neighborhoods, town and cities is the primary means by which humans contribute to the occurrence of landslides. Disturbing or changing drainage patterns, destabilizing slopes and removing vegetation are common human-induced factors that may initiate landslides.”\textsuperscript{116} Overall, Washington state has seen a marked increase in net migration and natural increase of residents in the time between the 2010 and 2020 decennial U.S. census surveys, with 14.6\% (980,741) gain.\textsuperscript{117} Mountain communities have seen some of the largest percentage increases in their population.\textsuperscript{118} The follow-on effect from such population increases appears in other trends as well. According to the Washington State Office of Financial Management (OFM) transportation statistics, roadway usage of all types has been rising in every year from 2010-2018.\textsuperscript{119}

The disruption to transportation-centric economic activity and connection is one of the most significant concerns related to landslides.\textsuperscript{120} Even seemingly moderate landslide events can cause months of disruption and repair work to roadways.\textsuperscript{121} In 2013, WSDOT’s rail division convened a Landslide Mitigation Working Group, funded by Connect Washington,

\textsuperscript{w} Interview with Jaime Kostelnick, USGS (Apr. 1, 2022)

\textsuperscript{x} Ibid.
“composed of 17 different agencies including BNSF Railway, Sound Transit, Amtrak, and several state agencies and municipalities.”\textsuperscript{122} WSDOT explained in a public release announcing funding for further landslide mitigation study that from 2010-2015, five hundred Amtrak Cascade trains were cancelled or disrupted due to landslides.\textsuperscript{123}

**Construction in High-Risk Zones**

In February 2020, winter rainstorms triggered landslides across the Puget Sound region, impacting numerous roadways.\textsuperscript{124} Similarly in 2021, landslides caused significant disruptions in the Puget Sound.\textsuperscript{125} These situations provide an example of how widespread and challenging landslide risk is to the built environment. These hazards impede roadways with debris and mudflows and causing roadways themselves to collapse. Key state roads like SR410, which serves the Crystal Mountain area are experiencing multiple slide events in a single season.\textsuperscript{126} In 2013, WSDOT issued a report in which it developed a methodology for examining land development near transit corridors. In their research, the lack of coordinated data on land development along roadways is a key challenge that the researchers identified.\textsuperscript{127} The authors used a case-study method to suggest potential options for analysis in Washington state, as well as reviewed peer programs at other state departments of transportation. One of the key concerns is that failure to plan ahead results in substantial and costly retrofits once risks are assessed.\textsuperscript{128} Likewise, Mirus et al. focused on a need for more collaborations to obtain data that transcends state and national boundaries as well to assist better broad-based planning.\textsuperscript{129} In addition, the international context may well provide examples of infrastructure decision-analytical frameworks that can improve landslide risk assessments for roadways.\textsuperscript{130}

**Inadequate Land-Use Policies**

Washington state metropolitan areas have a bias toward zoning for single-family housing in fast-growing urban and suburban areas. In King County, upwards of 75\% of buildable land is zoned for single family homes.\textsuperscript{131} This has created an acute housing shortage\textsuperscript{132} that has pushed residents into smaller communities in riskier environments in search of affordable places to live. City planners and developers can build housing in safe and stable in these locations through cooperative policies and innovative ownership structures. For example, in the wake of the Carlton Complex Fire in the Methow Valley, local government community leaders and residents created
the Methow Valley Land Trust, a community land trust model, to develop a comprehensive well-planned affordable housing to replace 350 destroyed housing units.133

Policy Alternatives

Alternatives for Precipitation-related Slope Stress

- **Continue enhancing landslide inventories**: Use the King County process for methodological review of landslide risk as a pilot for scoring and indexing the inventoried landslides with governmental, academic and private-sector experts.134

- **Examine the DNR’s LiDAR deployment program** to see if it has considered climate change risks in selecting modeling strategy. In 2015, DNR requested funding to meet the state’s mandate to conduct LiDAR landslide surveys (RCW 43.92.025) following the Oso landslide.135

- **Prepare for earlier and more frequent landslides in a warmer and wetter future Cascade climate**, which may require reassessment of risk mapping and risk modeling if based on historical rainfall and peak stream flow timing from the 20th century. Assumptions of risk must be recalibrated to a different precipitation context than has existed before in the state.136

- **Use the Blue Mountain Adaptation Partnership as a model for science-management collaboration** for the development of vulnerability assessments and sensitivity maps that bring together cross-domain experts like hydrologists, biologists, forest service staff, and engineers to assess where the increased stream flows will create landslide risks in a changing climate.137

Alternatives for Timber and Forest Management Stress

- **Improve Landslide Susceptibility Mapping and Comparative Analysis**: There are multiple ways of approaching landslide susceptibility mapping. Landslide mapping can be distributed, qualitative, deterministic or hybrid techniques.138 Additional mapping techniques could involve
using novel statistical models to map the potential hydrological changes that would occur if timber were cut from a particular stand.\textsuperscript{139}

- **Re-evaluate forest management and timber harvesting techniques** in light of the potential amplifying effect of climate change on landslide risk in state and federal managed forests.\textsuperscript{y} A partnership between the City of Darrington, Washington, Forterra and the Darrington Wood Innovation Center could provide a model for creating forest products for modern wood construction techniques, applying new forest management principles.\textsuperscript{140}

- **Revisit Techniques for Emergency Logging of Wildfire Areas** Soil is often placed under duress due to certain timber-extraction techniques.\textsuperscript{141} These practices include use of heavy machinery, log-dragging and other rapid harvesting practices. The use of these techniques often arises when post-fire forests are logged on an emergency basis to remove burned and dead trees quickly for timber salvage.\textsuperscript{142} There is an understandable effort to recover as much useful timber as possible. However, the soil is often vulnerable to failures due to the fire-related stress when these techniques are applied. Revising these techniques, when possible, protects sensitive soil from unintended damage associated with these removals.

**Alternatives for Wildfire and Vegetative Loss Stress**

- **Prioritize Protecting the Tree Canopy & Removing Ladder Fuels** While this paper is not focused on wildfire risk reduction per se, reducing landslide risk will involve similar objectives to reducing wildfire risks. In this sense, removing “ladder fuels” which are small trees that allow a fire to reach the tree canopy is a means for reducing wildfire risk that could lessen the chance for intense wildfires and allows the soil to be anchored to stronger trees that survive the fire.\textsuperscript{z}

\textsuperscript{y} Interview with Dr. Muhammad Barik (Apr. 8, 2022)

\textsuperscript{z} Interview with Dr. M. Safeeq. Khan (Apr. 4, 2022)
• **Reconsider Landscape Restoration Programs:** There is scant support that merely planting trees is an effective reforestation strategy. A four-part strategy built on resistance, realignment, resiliency and response could provide a more thoughtful approach to mitigating wildfire damage. Note that this will be challenging as reducing wildfire risk could involve removal of fire-prone tree species that provide soil-anchoring value.

• **Continue to Deepen Localized Post-Fire Risk Assessment with BAER teams and NWS, Emergency Alert Services, and Local News Emergency Condition Alerts** The USGS designed a post-fire debris flow dashboard to map risk of potential flows. The 6-person team maps debris flow hazards during and after fires with assistance of on-the-ground Burn Area Emergency Response (BAER) teams.

• **Develop trustworthy local community sources for sharing these risk assessments** will improve the public’s openness to considering this information, rather than having it come solely from a federal agency. Look to enhance landslide risk alert services involves not “over-warning” the public with “false alarms”.

**Alternatives for Land-use and Development Stress**

• **Use city up-zoning and a community land trust model** to help near mountain cities and rural communities build well designed, affordable multi-unit housing that keep residents from dispersing toward the WUI in an unplanned way. This may also help rural mountain towns build using scalable engineering best practices unavailable to individuals.

• **More Comprehensive Land-Development Coordination:** Build upon the recommendations by University of Washington researchers in their WSDOT study “Land Development Risks Along State Transportation Corridors.” Coordinate inter-agency information sharing to obtain accurate data on land-use implications of development near roadways.

• **Examine the effectiveness and challenges of the online portal for King County, Washington’s permitting division.**
For example, it is worth examining if King County’s iMAP GIS landslide layer tool incorporates climate change impact possibilities.\textsuperscript{151} King County uses several portals that relate to landslide risk that should be integrated together.\textsuperscript{152}

- **Consider whether local ordinances in key metropolitan counties should be reexamined** in light of climate change modeling on landslide impacts. For example, King County Ordinance KCC 21A.24.310 specifies development standards and alterations. Furthermore, county-level analyses of hazard risks should ensure that climate change modeling a factor that is considered.\textsuperscript{153}

- **Ensure legally mandated landslide analyses account for potential climate change impacts.** One challenge of proposing landslide alternatives is that this issue involves complex legal regimes required by state law. For example, the Growth Management Act specifies that defined geological hazards, including landslides, be considered when developing land.\textsuperscript{154} These mandates must include climate change as a component of the required analysis and planning.

### Alternatives for Infrastructure Build and Maintenance Stress

- **Deploy Iterative Risk Analysis Frameworks:** The international context may offer valuable analytical frameworks given the ubiquity of landslides and transportation infrastructure throughout the world.\textsuperscript{155}

- **Carefully assess new residential developments** because transit infrastructure follows growth and becomes difficult to halt once people need and demand it.\textsuperscript{aa}

- **Examine semipermeable pavements and porous asphalts as a means to prevent surface runoff** and allow for the infiltration of water thereby decreasing sediment loading in streambeds.\textsuperscript{156} However, use in high mountain passes and steep sloped areas in the Cascades may present technical challenges.\textsuperscript{157}

\textsuperscript{aa} Interview with Dr. Anne V. Moudon (Apr. 30, 2022)
Conclusion

Landslide risk in the transit corridors and residential areas of the Cascades has always been framed as a facet of our weather, geology and location. The tendency has been to view landslide risk as an immutable fact of life. Now, we can see how the various stresses contribute to increased risk. Figure C4 shows how landslide risks involve both climate factors and human-driven behaviors. This diagram sets aside geological risks such as earthquakes and volcanoes, as well as deep-seated landslides that are set off by landscape features that may have been developing over centuries. The diagram demonstrates that when considering landslide risks, policymakers should focus on centering climate change for key conditioning factors. By doing this, the public can reframe its relationship to landslides in a way that appreciates the escalating or changing nature of the risk. This in turn can open new policy windows for considering different potential solutions or alternative social policies that could help Washington state adapt to this evolving risk.
Table 4: Cascade Landslide Key Stakeholders

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Role</th>
<th>Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amtrak</td>
<td>Interstate Rail Transport</td>
<td>Transport</td>
</tr>
<tr>
<td>BNSF</td>
<td>Private/Commercial Rail</td>
<td>Transport</td>
</tr>
<tr>
<td>City/Municipality</td>
<td>Public Works, Roads, Permitting, EMS, Continuity of Service</td>
<td>State (Sub)</td>
</tr>
<tr>
<td>County Government (e.g. King County)</td>
<td>Public Works, Roads, Permitting, EMS, Hazard Mapping</td>
<td>State (Sub)</td>
</tr>
<tr>
<td>Federal Emergency Management Agency (FEMA)</td>
<td>Response &amp; Recovery</td>
<td>Federal</td>
</tr>
<tr>
<td>Federal Highway Administration (FHA)</td>
<td>Infrastructure Construction &amp; Management</td>
<td>Federal</td>
</tr>
<tr>
<td>U.S. Department of Transportation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The INGAA Foundation (Landslide Hazard Manual for Pipelines)</td>
<td>Infrastructure Risk Management</td>
<td>Industry Trade Group</td>
</tr>
<tr>
<td>Insurance Industry (Property, Economic Loss/Disruption, Life)</td>
<td>Risk Management &amp; Mitigation</td>
<td>Private/Public</td>
</tr>
<tr>
<td>Sound Transit</td>
<td>Regional Rail/Bus Rapid Transit</td>
<td>Transport</td>
</tr>
<tr>
<td>Sovereign Tribes located within Washington State</td>
<td>Tribal Sovereign</td>
<td>National Relations</td>
</tr>
<tr>
<td>State Commissions (e.g. Oso SR530 Landslide)</td>
<td>After-Action</td>
<td>State</td>
</tr>
<tr>
<td>U.S. Forest Service (USFS) United States Dept. of Agriculture</td>
<td>Forest and Timber Management/Regulatory</td>
<td>Federal</td>
</tr>
<tr>
<td>U.S. Park Service (Dept. of Interior)</td>
<td>Management/Regulatory</td>
<td>Federal</td>
</tr>
<tr>
<td>United States Geologic Survey (USGS)</td>
<td>Research/Regulatory/Risk Assessment/Mapping/Emergency Communication</td>
<td>Federal</td>
</tr>
<tr>
<td>Washington Department of Ecology (Ecology)</td>
<td>Ecosystem and Habitat Protection, Resiliency, Recovery, Coastal Erosion</td>
<td>State</td>
</tr>
<tr>
<td>Washington Department of Natural Resources (DNR)</td>
<td>Fire/Flood Risk Mitigation Emergency Management Public Communication Forest Products Sustainable Forest Management Resource Management</td>
<td>State</td>
</tr>
<tr>
<td>Washington Department of Transportation (WSDOT) Landslide Hazard Working Group</td>
<td>Transportation &amp; Infrastructure</td>
<td>State</td>
</tr>
<tr>
<td>Washington Military Division – Emergency Management Department (WSD-EMD)</td>
<td>WA National Guard</td>
<td>State</td>
</tr>
</tbody>
</table>
### Table 5: Cascade Landslide Collaboration Models
In examining landslide risk, several collaboration models can serve as inspiration. Some examples are provided below in a non-exhaustive list of collaboration programs to bring together diverse stakeholders.

<table>
<thead>
<tr>
<th>Name</th>
<th>Focus Area</th>
<th>Model</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Mountain Adaptation Partnership</td>
<td>Habitat Protection and Risk</td>
<td>Public-Private-Academic</td>
<td>1. Synthesize published information and data to assess the exposure, sensitivity, and adaptive capacity of key resource areas – hydrology and access, fisheries, and vegetation and disturbance; 2. Develop science-based adaptation strategies that will help to mitigate the negative effects of climate change and assist the transition of biological systems and management to a warmer climate; 3. Ensure the adaptation strategies are incorporated into relevant planning documents; and 4. Foster an enduring partnership to facilitate ongoing dialogue and activities related to climate change in the Blue Mountains region. [158]</td>
</tr>
<tr>
<td>WSDOT Landslide Area Working Group (Connect Washington funded)</td>
<td>Infrastructure Protection and Recovery</td>
<td>Public-Private</td>
<td>WSDOT, Amtrak, BNSF Railway, Sound Transit and 13 other state and community partners formed the Landslide Mitigation Work Group in 2013. The group has researched historical slide locations and causes along coastal bluffs and used that data to identify the six project sites. The group also meets with local governments and citizens about ways landowners can help prevent slides on their property. [159]</td>
</tr>
<tr>
<td>Darrington Wood Innovation Center (DWIC)</td>
<td>Forest Products and Sustainable Forest Management</td>
<td>Public-Private-Non-Profit</td>
<td>The Darrington Wood Innovation Center (DWIC) is a collaboration between the Town of Darrington, Snohomish County and Forterra. The 94-acre campus will house the next generation of high-tech wood product companies and to reinvigorate the wood products industry in the town, county and the Pacific Northwest. Through responsible harvest of narrow-diameter trees often as part of thinning projects, the feeder fiber for CLT keeps old and second growth trees intact and forests healthy. [160]</td>
</tr>
<tr>
<td>King County-Shannon &amp; Watkins, Inc.</td>
<td>Modern landslide risk mapping</td>
<td>Private Contract</td>
<td>King County retained Shannon &amp; Wilson, Inc. to map deep-seated landslides within the study limits using the procedure in the Oregon State Department of Geology and Mineral Industries (OR DOGAMI) Special Paper 42 (Burns and Madin 2009).</td>
</tr>
<tr>
<td>Puerto Rico Post-Maria Collaboration Analysis</td>
<td>Resiliency and Equity</td>
<td>Public-Academic-Community</td>
<td>The approach described in this article involved the formation of a core team of government and university partners that expanded in membership to conduct collaborative work with an informal network of hazards professionals from diverse sectors in Puerto Rico. The following principles guided this process: cultural competence, ethical engagement, listening, inclusive decision making, empathy, convergence research, nested mentoring, adaptability, and reciprocity. [161]</td>
</tr>
<tr>
<td>Snohomish County SR530 Landslide Commission</td>
<td>Recovery/After-Disaster</td>
<td>Government Commission &amp; Report</td>
<td>The 530 Landslide Commission following the Oso Landslide convened and made several recommendations including a landslide risk mapping program. This is an example of alternatives that involve government and legislative action. Unfortunately, the policy making window and funding for actions on the recommendations of such collaborations are often closely associated with disasters that capture politician and public attention.</td>
</tr>
</tbody>
</table>
Problem Statement

Communities in western Washington located within floodplains are increasingly vulnerable to flooding events. The health and economic stability of these communities depends on state policy because they are highly reliant on the infrastructure, development, and resources adjacent to rivers for daily life. Vulnerability to flooding stems from increased precipitation rates and strengthening high streamflow events, which are caused by atmospheric rivers, an issue not directly solvable through the efforts laid out in this report. Flooding will continue impacting these communities due to ineffective flood control infrastructure, increased river sedimentation rates, and incentivized development in flood prone areas. Recent climate projections show increases in high intensity storm events along the Pacific. Without significant adjustments around the rivers and related floodplains of western Washington, extreme flood events are likely to continue occurring in the coming years.

Several policy solutions can reduce the burden experienced by these communities. These solutions include physical approaches, such as river management through the development of wetland habitats upstream from communities. Also, investments in alternative levees designs and expansion of floodplains may prove useful. For example, development-based approaches such as adjusting community infrastructure to handle flooding
events. Finally, policy-based approaches such as rewriting state or national policies to limit development in floodplains or provide financial incentives for residents to relocate out of floodplains is a key solution. Each policy solution recommended maintains the goal of reducing an aspect of the impacts of flooding on these western Washington communities. The implementation of these alternatives will not stop the underlying climatic trend of increased high streamflow rain events, nor do the recommended alternatives prevent all negative impacts associated with flooding in the affected communities.

**Background**

Riverine flooding in western Washington is an increasing concern. High streamflow events caused by atmospheric rivers\textsuperscript{bb} are leading to significant impacts to the economic well-being of the communities located along the rivers in the Puget Sound watershed. While the rate and intensity of

**Figure D1: Location of the largest flood events between 1980-2010 in Washington**

\textsuperscript{bb} Atmospheric rivers are relatively narrow regions of heavy moisture in the atmosphere that are responsible for most of the transport of water vapor from the Hawaiian tropics to the western coast of the U.S. Atmospheric rivers may be different sizes, like hurricanes, but those that contain the largest amount of water vapor and strongest winds are responsible for extreme rainfall events and floods in western Washington.
atmospheric river events involves climate variability and cannot be controlled, aspects such as the direction and rate of river flow, location of development, or age and capacity of flood control infrastructure each plays a role in the effects of flooding experienced by communities.

In November 2021, areas of Washington state experienced historic flooding stemming from high streamflow events along the Nooksack River. The flood was estimated to cause upwards of $50 million in damage to rural farming communities, including significant flooding to upwards of 75% of homes.\textsuperscript{163} 164 Regionally, Washington’s Pierce County, located in the Puyallup River Watershed, experienced an estimated $725 million in damage following the occurrence of a 100-year flood.\textsuperscript{165} As communities continue to develop in floodplains, it is paramount to understand the risks associated with this type of development in order to increase the resiliency of these communities.

Rates of flooding have increased over the past forty years\textsuperscript{dd} and are projected to increase due to high intensity events such as atmospheric rivers.\textsuperscript{166} Communities along rivers in western Washington will experience most of these impacts.\textsuperscript{167} Compounded with developmental shortcomings such as outdated flood control infrastructure (FCI),\textsuperscript{ee} location of community assets\textsuperscript{ff} and private land development, this trend will lead to an increased risk of health and economic consequences from flooding impacts. The key goal is to protect downstream communities and infrastructure from the physical and economic impacts of flooding following high flow events. This goal and the analysis presented were developed through the problem orientation framework. This framework

\begin{itemize}
\item \textsuperscript{cc} Jones explains that a 100-year flood as the public understands it is increasingly false, with hundred-year floods now likely to take place multiple times a decade.
\item \textsuperscript{dd} See Figure D1 (76), The largest floods in Washington in a 30-year window are all isolated to the latter five years of the study.
\item \textsuperscript{ee} Flood control infrastructure is infrastructure that is developed to control flooding, through flood prevention barriers such as levees, or through water retention infrastructure, such as dams.
\item \textsuperscript{ff} A community asset is a piece of infrastructure relied upon by residents and community groups.
\end{itemize}
utilizes the identification of physical projections,\textsuperscript{gg} trend data,\textsuperscript{hh} and conditioning factors\textsuperscript{ii} to formulate successful policy recommendations.

**Failure of Flood Control Infrastructure (FCI)**

A major concern identified through this process is the increasing rates of 100-year flood events taking place in areas “protected” by FCI.\textsuperscript{168} When the U.S. Army Corps of Engineers developed many of the state’s active levees to protect riverside communities, the intensity of flooding events and levels of high streamflow peaked at lesser levels, requiring lower standards for accreditation.\textsuperscript{169} The State of Washington and the Army Corps of Engineers maintains 352 levees covering 644 total miles of river edge with an average levee age of 60 years.\textsuperscript{170} This type of unequipped infrastructure\textsuperscript{jj} is no longer able to handle the increasing intensity of weather events. As motivated by recent flooding events along the Nooksack and Sumas Rivers most recently or significantly flooding events along the Carbon and White Rivers in 2009,\textsuperscript{171} infrastructure initially designed to protect communities is now leading to increased costs and damages\textsuperscript{172} during these massive flood events. Multiple factors beyond the previously identified atmospheric rivers themselves contribute to high flooding rates around areas of infrastructure.

A first major factor that impacts the ability of flood control infrastructure from preventing flooding events is varied rates of sediment buildup. The geography of Western Washington is highly varied, leading to a diversity in sources of the rivers in the region. Rivers that are mainly glacial-fed tend to carry more sediment.\textsuperscript{kk}\ Figure D2 (79) shows the annual sediment load of each of the major rivers draining into the Puget Sound,

\begin{itemize}
\item Such as increased flood events.
\item Such as rates of sediment buildup or number of floods experienced.
\item Such as poorly placed developments or inadequate infrastructure.
\item Unequipped infrastructure is flood control infrastructure that is no longer able to handle high streamflow events, leading to increased rates of 100-year floods.
\item Washington is the second most glaciated state behind Alaska, according to Hekkers and Thornycroft.
\end{itemize}
Framing Climate Adaptation Opportunities

totaling an estimated 6.5 million tons of sediment annually\textsuperscript{174} with an average discharge of water of 41,000 cubic feet per second.\textsuperscript{175} During periods of high flows, such as atmospheric rivers, sediment transport increases significantly, impacting downstream river channels and sediment discharge potential. These concentrated storms can carry upwards of 50% of a river's annual sediment discharge.\textsuperscript{176} As the rate of sediment deposition increases during continued high streamflow precipitation events, bodies of water are unable to convey the additional water through their channels, causing overtopping of levees, both natural and manmade.\textsuperscript{177} This may stem from continued sediment accumulation through these successive high streamflow events. The compounded buildup significantly reduces a river's capacity to carry water.\textsuperscript{178} Conversely, for so-called “fixed-bed” rivers, where sediment deposition is less common, water flow remains consistent, even during similar high streamflow precipitation events.

The location of flood control infrastructure (e.g., levees) in relation to the communities it protects and the rivers it contains is a significant factor leading to performance failure (i.e. “levee overtopping”). Flooding occurs in pinch points of rivers in which the natural flow and river morphology is altered by this FCI.\textsuperscript{179} Cities dependent on floodplain control have the ability to reduce low-level flooding (which can maintain ecological benefits) but are less prepared to mitigate extreme flood events.\textsuperscript{180} Decades of river control

\textsuperscript{174} According to Kammerer, by comparison, the much larger Columbia River maintains an annual sediment discharge of over 10 million tons, with an average discharge of 265,000 cubic feet per second.

\textsuperscript{177} Examples include the Carbon and White Rivers, and the 2009 flooding events that led to the alternative development of both the floodplain and the infrastructure protecting the area from high streamflow events. Czuba, Czuba and Magirl.
techniques prevent rivers from maintaining their natural flow paths, leading to excessive flooding once FCI fails and floodwaters return to their natural floodplains. This type of approach to river control and river management allows for an increasingly false sense of security around the safety of communities to flooding.

Policy Alternatives for Inadequate Flood Infrastructure

Several alternatives around reducing flooding or breaching of flood control infrastructure are available and implementable within Washington. These approaches include upstream river redesigns, sediment management, or larger scale town development. The main alternatives to reduce flooding and the failure of FCI are proposed based on their feasibility due to funding, collaboration, and demonstrated effectiveness.

Alternative: Create of Wetland Habitat and Floodable Habitat Upstream

This alternative will reduce the impacts of sedimentation on flood control infrastructure, and decrease the overall rate of high flows, potentially preventing the number of 100-year floods. New riparian habitats will be able to capture portions of sediment, absorb significant amounts of water, and slow the speed of the water during high streamflow events. This approach will take the form of nature-based solutions in flood management, which when effective can reduce the reliance on hard infrastructure such as dikes, dams, and levees. When implemented effectively, the creation of new wetland habitat will incorporate a wide array of partners. Partnerships must include all affiliated

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A natural floodplain is an area which remains at risk to significant flooding at the 100- or 500-year level, prior to the implementation of flood control infrastructure. An area remains a natural floodplain following the addition of FCI, and on the chance that infrastructure fails, will remain susceptible to flooding.

Dams, dikes, and levees are structures meant to control the flow of water, mainly in the form of preventing water from overtopping physical infrastructures.
landowners within the watershed and floodplain. This is required because the impact of an upstream development will significantly alter the downstream water quality. Stakeholders to be included in this alternative are local landowners, river adjacent municipalities, Washington State Department of Fish and Wildlife, US Fish and Wildlife, National Park Service, or the National Forest Service, depending on the locations, and tribal representatives, such as Nooksack, Muckleshoot, Puyallup, Skagit.\textsuperscript{pp}

**Alternative: Install Setback Levee to Mitigate Active Flooding**

A mitigation approach includes the design and implementation of setback levees during the point of flooding. These approaches will require localized expertise to advise on where to locate setback levees to absorb floodwaters. When implemented correctly, these setback levees can absorb floodwaters from high-speed rivers, reducing cumulative speeds of water flow, and providing specified and repeatable areas for floodwaters to go.\textsuperscript{183} Setback levees will provide areas to absorb high amounts of sediment, preventing further buildup downstream. The setback levees will only be necessary during periods of high streamflow events and will not be relied upon year-round.\textsuperscript{184}

- Setback levees require significant logistical hurdles and numerous steps prior to effective implementation. Within Washington, Pierce County has several proposed setback levees. These projects include input from local tribes, State and Federal Agencies, and regional developers.\textsuperscript{185}

- An example of a setback levee in the city of Sequim, Washington is shown in **Figure D3** (80). Within the proposed floodplain, a setback levee is placed a significant distance away from the nominal location of the river, allowing for a natural pattern of movement for the water and sediment during high flow events.

\textsuperscript{pp} According to Governor’s Office of Indian Affairs Input from Tribal Representation may supersede land rights and ownership. Most tribal entities within Washington maintain “the right to fish at usual and accustomed grounds.”
Alternative: Employ Climate-Adapted Development Practices

Climate-adapted development is a mitigation and preparedness approach to dealing with flooding. By increasing the resilience of communities through an expectation of flooding in urban design, cities will be able to lessen the effects of floodwaters. These adaptations may take several different forms in terms of flood risk management. Examples include the allocation of space in urban areas, planning for more stormwater to drain quickly. Future urban designs should feature increased greenspaces or “green” rivers adjacent to high valued infrastructure. The redesign of the Seoul Riverfront located in downtown South Korea provides a vivid example of this philosophy in action. The riverfront has a path for expected floodwater during the rainy season, while it becomes useable parkland for the public during the drier months. Smaller scale and localized examples of this program include the removable floodwall in the city of Sedro-Woolley. Slight redesigns of downtown areas to manage stormwater events may allow most local infrastructure to stay safe without requiring an entire redesign of an urban or commercial area. Some key issues to keep in mind:

- Local municipalities, urban design firms, local business owners, town councils, and construction or development companies are key set of diverse stakeholders needed to apply this adaptation technique. These collaborations can take time to work well.
- Climate-adapted development will impose increased financial burdens on participating communities. Smaller communities with limited budgets should approach this development with caution because some of these newer urban planning techniques may involve innovative designs that may not be cost effective.
- The public should not understand climate-adapted development to be a panacea to climate change, requiring no other changes. There is a danger that people will assume that we can simply “innovate our way out” of climate-related problems without making other changes.

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99 This mitigation approach will not prevent flooding from taking place, but it will limit the impact a flood event on residents.
Additional alternatives exist which are likely to produce reductions in failures of flood prevention infrastructure. These alternatives were not introduced due to potential impacts they have around critical habitats, significant costs for implementation, or substantial amounts current planning and investment already taking place.

**Location of Development**

A second major concern found through the application of the problem orientation to flooding risks in western Washington focuses on the location of development in high flood risk areas. Population growth within the Puget Sound region is leading to more development in flood prone areas, reducing the absorption capacity around rivers. A combination of population growth, developmental pressures, and ineffective policies have allowed towns to continue developing in areas of high flood risk. Development in these areas remains legal, due to permitting approvals allowing cities to be developed in natural but not regulatory floodplains. Beyond this, communities impacted by flooding are provided significant financial resources to limit losses caused by flood events leading to the support of development in natural floodplains across Washington state.

A major factor around development is the continued approval for towns to develop in potential floodplains. Towns such as Elbe, Everson, Hamilton, Sultan, and Sumner have been identified as experiencing “extreme risk” for flooding of road, commercial, and residential developments. As shown in Figure D4 (84), Everson, Washington, has significant infrastructure development in flood prone areas, typical of towns along western Washington rivers. The residential and commercial development shaded in blue-green marks 100-

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190 These five towns were chosen due to their proximity on each of the major rivers within Washington.

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A regulatory floodplain is the area which remains at risk for significant flooding at the 100-year floodplain level following the addition of flood control infrastructure. Regulatory floodplains are often a reorientation of a natural floodplain.
The financial impacts of floods on these small towns are significant, leading to increasing payouts from the National Flood Insurance Program (NFIP). In 2020, FEMA repaid $4 million to Hamilton, a town of 300 residents, along with alternative buyout approaches to residents in flood-exposed homes.

An additional factor motivating continued development in flood prone areas comes from the federal subsidization of development in flood prone areas. Current FEMA funding primarily provides retroactive aid. The agency estimates that it spent around $18 billion annually in NFIP payments between 2010 and 2018. In comparison to the recently approved federal Flood Mitigation Assistance of $1.16 billion and Hazard Mitigation Grant Program of $3.46 billion, the annual aid for flood prevention from the federal government is only one third of the aid for flood disaster insurance.

Locally, this pattern repeats itself. The Washington Hazard Mitigation Program provides $8 million in public work grant assistance against $2 million in Hazard Mitigation. By providing reactionary financial support, both federal and state programs are providing assurances that continued development in floodplains is feasible into the future.

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100-Year floodplains are areas with a 1% annual chance of flooding.

500-year floodplains are areas with a 0.2% annual chance of flooding.
Federal, state, and local funding opportunities or incentives can significantly influence the behavior of individual property owners. By providing assurances that homeowners and private landowners will receive funding following historic flooding events, these residents are unlikely to move their property out of floodplains or stop developing in these areas.

**Policy Alternatives for Location Development**

Numerous alternatives are available to motivate the development of private property outside of floodplains. These alternatives are highly regulatory, ensuring their effectiveness upon implementation, while potentially meeting local resistance when introduced publicly. A set of alternatives include the following strategies.

**Alternative: Adjust the Development Standards from 100-Year Floodplains to 500-Year Floodplains**

This alternative is preventative. Common development planning focuses on limiting the development of cities and areas in 100-year floodplains. A report from the USGS shows that previous flooding events labeled as 100-year floods are now taking place more than once per decade. This proposal would increase the developmental standards for state and municipal infrastructure to develop in areas that are at a 500-year flood standard. This transition will limit the development along low-lying areas adjacent to rivers. A process transitioning a town to a 500-year floodplain can reduce the likelihood of infrastructure flooding by 50 times in a given year.

- This proposal is policy-based, requiring support from the Office for Regulatory Innovation and Assistance, Local Governments, Municipal Research and Services Center of Washington, FEMA, local flood insurance providers, and landowners.

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\[ vV \] Currently, the state of Washington requires significant preparation from property owners and developers to submit and construct properties within 100-year flood zones through the Floodplain Development Permitting, according to the Governor’s Office for Regulatory Innovation and Assistance.
• Changes in the layouts of various areas will happen slowly, as individual developments will transition beyond the 100-year floodplain, rather than the entirety of a flood prone area being moved at once.

Alternative: Increase Incentives for Developments Outside of Floodplains

This aid-based preventative alternative is presented with the aim of ensuring residents move outside of floodplains. Both FEMA and the Washington State Department of Revenue should provide public financial support or tax breaks or credits to housing development taking place outside of floodplains. Currently, limited funding opportunities are available through local partnerships within the Floodplains by Design program. In order to increase the cumulative impact, more funding needs to be provided through this program or similar programs. A 2019 National Institute of Building Sciences report found that a $900 million investment in new home development would lead to $4.2 billion in benefits or cost savings from alleviated flood damages. A total tax benefit of $9,000 per household built outside of a floodplain should be provided to new home builders, in line with the rates found in the 2019 Report. A transition to funding preventative projects in the medium and long-term will be difficult to balance, given the continued need for FEMA rapid response funds, as disasters continue to take place in the short-term.

Additional alternatives exist that could effectively transition communities away from flood vulnerable areas. These alternatives were not introduced due to the variance in stakeholder support required for effective implementation. Additional funding from private foundations, reductions in insurance support to landowners in flood vulnerable areas, or municipal land policy changes require widespread collaboration across varying parties which requires significant planning and investment to be successful.
Conclusion

Preventable extreme riverine flooding in Washington communities will continue barring significant policy changes to adapt to climate change. Through focusing on specific features and how they increase or decrease the impacts of flooding, this study highlights aspects of flooding to Washington communities and potential approaches for reduction. Flood control infrastructure throughout the region was installed to control the path of rivers. Significant weather events continue to show that this type of infrastructure is not effective at protecting communities. Beyond failing infrastructure, community development is exacerbating the impacts caused by flooding. Without a significant motivation to relocate communities and private property, residents will continue to need financial support to mitigate the impact of flooding. Policies that either lessen the intensity of streamflow events or relocate development out of flood prone areas will be the most effective at reducing the losses, both physically and financially, of communities during periods following high streamflow events.
Table 6: Riverine Flooding Key Stakeholders

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Role</th>
<th>Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonneville Power Administration</td>
<td>Energy Supply and Production,</td>
<td>Regional</td>
</tr>
<tr>
<td></td>
<td>Infrastructure</td>
<td></td>
</tr>
<tr>
<td>Bureau of Reclamation</td>
<td>Infrastructure and Water Quality</td>
<td>Federal</td>
</tr>
<tr>
<td>Climate Impacts Group</td>
<td>Planning and Research</td>
<td>Institutional</td>
</tr>
<tr>
<td>Federal Emergency Management FEMA</td>
<td>Emergency Response and Funding</td>
<td>Federal</td>
</tr>
<tr>
<td>Land Trusts</td>
<td>Conservation and Prevention</td>
<td>Local, State, Federal</td>
</tr>
<tr>
<td>Local Businesses</td>
<td>Economic</td>
<td>Local</td>
</tr>
<tr>
<td>Local Municipalities</td>
<td>Government</td>
<td>County</td>
</tr>
<tr>
<td>Local Tribes</td>
<td>Habitat, Riparian Management</td>
<td>Tribal</td>
</tr>
<tr>
<td>National Marine Fisheries Service</td>
<td>Habitat and Ecological Management</td>
<td>Federal</td>
</tr>
<tr>
<td>Public Utility Providers</td>
<td>Infrastructure, Utility</td>
<td>Local</td>
</tr>
<tr>
<td>U.S. Army Corps of Engineers</td>
<td>Infrastructure</td>
<td>Federal</td>
</tr>
<tr>
<td>U.S. Fish and Wildlife Services</td>
<td>Habitat and Environmental Management</td>
<td>State</td>
</tr>
<tr>
<td>U.S. Forest Service</td>
<td>Management</td>
<td>Federal</td>
</tr>
<tr>
<td>U.S. Park Service</td>
<td>Management</td>
<td>Federal</td>
</tr>
<tr>
<td>Urban Design Firms</td>
<td>Planning</td>
<td>Local</td>
</tr>
<tr>
<td>Washington Department of Ecology</td>
<td>Habitat and Environmental Management</td>
<td>State</td>
</tr>
<tr>
<td>Washington Department of Revenue</td>
<td>Financial</td>
<td>State</td>
</tr>
<tr>
<td>Washington Department of Transportation</td>
<td>Infrastructure</td>
<td>State</td>
</tr>
<tr>
<td>Washington State Department of Fish and Wildlife</td>
<td>Habitat and Environmental Management</td>
<td>State</td>
</tr>
</tbody>
</table>
### Table 7: Flood Risk Examples in Western Washington

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>River</th>
<th>Properties in 100-year floodplain</th>
<th>Recent Flooding Impacts or potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centralia</td>
<td>Lewis County</td>
<td>Chehalis River</td>
<td>43%</td>
<td>Dozens of rescues needed during flood events in 2022.</td>
</tr>
<tr>
<td>Everson</td>
<td>Whatcom County</td>
<td>Nooksack River</td>
<td>61%</td>
<td>Everson impacted in November 2021 flooding, part of a larger $50 million in damages.</td>
</tr>
<tr>
<td>Hamilton</td>
<td>Skagit Co</td>
<td>Skagit River</td>
<td>87%</td>
<td>$4 million in flood insurance claims, 2020 flood.</td>
</tr>
<tr>
<td>Sultan</td>
<td>Snohomish Co</td>
<td>Skykomish River</td>
<td>30%</td>
<td>$1 million infrastructure project to prevent continued flooding in Sultan.</td>
</tr>
</tbody>
</table>

Sources: Zucco, Associated Press, Pulkkinen, Watanabe
4.2 Key Insights, Opportunities & Challenges of Each Case Study

Dryland Wheat Farming & Drought

Using the problem orientation to identify impacts of drought in Washington state and a corresponding goal statement was an iterative process. We began by identifying stakeholders particularly affected during times of drought. Many stakeholders affected by drought were connected to Washington’s agricultural sector. Damages from drought were typically measured through economic losses.

Within the agricultural sector in Washington state, we identified two major stakeholder groups, farmers who use irrigation (water rights holders) and those who do not (dryland producers). We dove into researching the impacts on both stakeholder groups. Among water rights holders, junior water rights holders were particularly vulnerable to drought because senior water rights holders had more priority in water usage during drought emergencies. We began exploring the trends, conditioning factors, and alternatives related to a goal statement of reducing the economic vulnerability of junior water rights holders. The Washington State Department of Ecology manages the state’s water resources and has identified potential policy alternatives to reduce the vulnerability of junior water rights users during times of drought. The problem orientation model seemed to have less impact on discovering new policy alternatives in this space, so we returned to the dryland farmers stakeholder group.

Washington dryland farmers – and wheat farmers in particular – were heavily impacted by the 2015 and 2021 severe and exceptional droughts. Researchers, journalists, and scientists agreed that there was a gap in the state’s response to dryland farmers, but no specific paths forward. We decided to focus our goal statement on reducing the economic vulnerability of dryland farmers during times of drought. Then we gathered trends. How bad was the problem? At what rate was it getting better or worse? This led us into conditioning factors. Were there different factors that accelerated the problem of economic vulnerability for dryland farmers during times of drought? We reached out to a subject matter expert in agricultural and
economic sciences at Washington State University who confirmed our findings and direction.

We returned to researching state level policies related to drought emergencies. We found that at the state level, the current drought emergency policy was a conditioning factor because it focused its declaration on “water users,” which excluded dryland farmers, yet a state level drought emergency was a key path to receiving federal aid for Washington wheat farmers.

Given that the 2021 severe and exceptional ongoing drought also reduced agricultural productivity in Oregon and Idaho, we explored both states’ drought emergency declaration processes. While researching Oregon’s policies, we found that Oregon had expanded their definition of stakeholders during times of drought beyond water users and had a county-based gradual process to declare drought emergencies. Oregon’s state government has less discretion in defining the geographic areas of drought and more powers of drought declaration rested with county commissioners than in Washington.

For future studies, we recommend conducting a policy analysis of a gradual drought emergency declaration process in Washington state to explore which stakeholders would benefit and which would not from authorizing counties to use more discretion in the drought declaration process.

Mitigating Impacts of Climate Change on Salmon in the Nooksack Watershed

When choosing topics to test out the problem orientation framework, we wanted to choose subjects that we were personally interested in and that would be of high value to the state of Washington. This brought around long discussions over the values that should be prioritized in this project and how choosing goals and problems to address is truly an expression of values that are important to the decision-maker.

Varied by state agencies, Washington publicly promotes many values such as public health, a strong economy, equity, and a healthy environment.
These values do not always coincide with each other, which is why policy making is always an indicator of the priorities that matter to each stakeholder.

When choosing the subject of salmon survival in the Nooksack River watershed, several values came up in the research. Healthy salmon are a large part of the Washington economy. Salmon are of major cultural significance to indigenous tribes in the region and the salmon life cycle is a vital part of healthy riparian ecosystems. Deciding on what it is the state values most about salmon survival is what drives policy alternatives and implementation. Hatcheries could potentially be one policy alternative that allows the state to meet tribal treaty requirements and maintain the fishing economy in Washington; however, hatchery fish can negatively impact wild salmon populations. If the values of the Nooksack Tribe are prioritized, the alternatives would primarily focus on habitat restoration throughout the watershed that protects salmon from increasingly harmful impacts from climate change and human development. Weighing the costs and benefits of many alternatives required knowledge from many stakeholders and an understanding of their priorities.

Using the problem orientation framework to discuss salmon survival required iterative goal setting. There is a wide variety of salmon species that each have unique life cycles, not even to mention the equally vulnerable trout populations. However, the problem orientation framework is meant to result in specific implementation strategies for the defined problem, meaning that it is not practical to try and save every salmon in all of Washington with a ten-page case study. When research started, the initial goal was to ensure sufficient streamflows for salmon migration and spawning habitat. After realizing that we had mistakenly fallen into a goal displacement predicament by referencing a potential solution in the problem statement, we decided to narrow the scope in a different direction. Instead of looking for alternatives that would only
address streamflow, we chose to address salmon in one watershed. This helped by only having to address the specific issues at play in one crucial watershed instead of understanding the challenges salmon are facing across Washington. This led to much more targeted and implementable alternatives that could be useful to the state.

Reducing the Landslide Risk to Cascade Communities

In examining landslides using the problem orientation approach, many aspects of the framework were helpful. First, in talking with academic researchers and state and federal agency staff, we were able to identify the key trends influencing landslide risk and frame them in a cohesive way using the organizational concepts embodied by the problem orientation analysis. It also helped illuminate some of the attenuated connections such as development in the wildland-urban interface (WUI) and emergency timber clearances as a potential risk factor for mountain landslides which otherwise would not have been readily apparent. In talking with staff at the Washington Department of Natural Resources (DNR), the USGS, and academic scientists, they shared a belief that climate change will alter the nature of landslide risk in the state.

In particular, the interlocking risk of wildfires, another climate change impact in our state, will enhance landslide risk in mountainous areas of the state. A powerful insight is that landslide risks may actually be an under-appreciated climate change indicator and is worthy of additional research and focus through a climate-change lens rather than a traditional weather hazard framework. Additionally, the problem orientation illuminated a diverse group of stakeholders related to the landslide risk, including but not limited to tribal communities, timber industry, transit and logistics firms and agencies, insurers, city planners, homeowners, and recreational enthusiasts. All of these groups have a stake in working together to enhance resilience and adaptation to landslide risk in the state. The problem orientation offers a chance to find alternatives that are built on problem solving rather than purely competitive priorities that are at odds with one another. For example, timber companies have as vested an interest in preventing landslides caused by their operations due to the business disruption from blocked roadways and danger to their own employees and
the communities in which they operate. The problem orientation identified key areas that can be focused on such as enhanced mapping, potential resilient infrastructure materials, and reconsiderations of planning policies.

The challenges of the problem orientation emerged in the complexity of the landslide problem. Landslide risk is enhanced by a number of complex factors ranging from non-climate related aspects like immutable Cascadian geology and soil composition to entirely human caused actions, such as local-level development and land use planning policies. The path dependency of certain rail and road networks that exist on steep slopes (e.g. U.S.2 and I-90) also causes problems that are difficult to resolve even when the risks are apparent. Addressing all of these issues in a comprehensive problem orientation approach is challenging and resulted in a large, highly technical paper that was not easy to explain to the public or to a policymaker pressed for time. It is possible that because so many agencies are involved, the audience may retreat back into their silos viewing landslides as a topic that does not benefit from a comprehensive strategy. It may be worthwhile to develop more specific goals related to landslides and pursue the problem orientation approach in a more targeted manner to encourage cooperative partnerships that are pragmatic and feasible.

**Protecting Downstream Communities from the Impacts of Riverine Flooding**

Through the application of the problem orientation framework to the goal of protecting downstream communities and infrastructure from the economic impacts of flooding we learned a number of lessons. The problem orientation framework was an effective approach to defining and prioritizing the impacts of a broad issue. By understanding each aspect of the problem orientation, we were able to identify the best available research into specific sections of the framework through reorienting how to approach a

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*Vogel, Cherney and Lowham*
complicated problem with a focus on each individual aspect. We were also able to see how the aspects influence the larger scope of impact and how different proposed solutions are able to be implemented in areas of localized issues. Through the different trends and conditioning factors identified in the research around flooding impacts, the problem orientation framework highlighted that there is no singular solution to ensure the success of the goal introduced.

However, within the implementation of the problem orientation, a set of subtle changes and additions to the framework was highly beneficial in the final product. These two additions allowed for increased project clarity and added depth to the individual aspects of research. The two adjustments which provided the largest amount of benefit in this paper were:

- The restructuring of the paper’s format to create a more direct path, combining trends and alternative research while introducing the potential policy alternatives to mitigate them.
- A renewed emphasis on major and minor stakeholders, found through a highly iterative stakeholder mapping process.

Restructuring the problem orientation evolved the design of the final case study and refined the connections between aspects of the framework more broadly. When introduced, a set of the trends identified appeared to have their own unique and direct conditioning factors. Each of the conditioning factors presented issues solvable by one or multiple policy options or alternatives. Following this structure helped re-organize the findings gained using the problem orientation. Rather than the research following a linear path outlined in Chapter 2.5 (22), using a flexible approach was more effective.

The restructuring removed the linearity from the problem orientation process, and instead created a semblance of a multi-track approach. This approach ends with the same, or similar policy alternatives. It is effective in using the problem orientation framework as a way to tell a compelling story. In the problem orientation reorganization, this approach identified individual tracks, each based around the effects of trend data paired with the conditioning factors which exacerbated the trends. From there, the potential alternatives are able to be connected directly to the trends that they relate to. By aligning each of the related aspects of the problem orientation, this allowed for both a streamlined research process and a straightforward connection to the array of stakeholders.
An additional adjustment around increased stakeholder mapping was successful in expanding the depth of the problem orientation. Throughout the evaluation of the problem orientation process, there was a potential to identify and connect a broad list of stakeholders. Between identifying stakeholders impacted by the trends, projections, and conditioning factors of the introduced problem, the problem orientation provided a variation in the affected stakeholders. Following this, the policy alternatives which could be proposed are connected to a different set of stakeholders and may provide benefits to the initially affected stakeholders while not retaining the same level of benefit to each involved party. In regard to the flooding issue, the issues around sediment build-up can lead to flooding to individual communities, damage infrastructure, or prevent the use of certain public property. However, potential solutions to riverine flooding might require actions or behaviors from landowners, currently unimpeded by flooding. By examining the impacted stakeholders during each step of the problem orientation, an effective acknowledgement of each perspective around the issue helps strengthen the ultimate result.

4.3 Shared Insights & Opportunities Across All Four Case Studies

We found three major shared insights and opportunities across our four case studies.

1. The problem orientation can be used as a tool to channel inquiry into bounded climate impact policy problems.

After we identified a specific set of conditioning factors for a climate impact, we were able to explore how other states, watersheds, counties, or locales were coping with similar climate impacts. While the context inevitably differed across communities, exploring how one region adapted to riverine flooding impacts gave us insight into a possible path forward for another locale. In this way, we found that the problem orientation can be used to identify how to live with climate change as communities continue to respond to climate impacts.
through maintaining the status quo or attempting to make meaningful short or long-term policy changes.

2 **Knowing what we valued and learning the values of the community for our case studies was crucial to making research decisions and justifying our direction at each step of the process.**

Whether the value was about protecting public health, the economy, or ecosystems, we learned that having a clear understanding of what is valued by whom illuminates the boundaries and purpose of the original goal statement. Returning to the guiding value or values after completing the problem orientation also served as a way for us to ensure that we were on track with our original goal.

3 **The problem orientation confirmed that there is a bridgeable gap between scientists and policymakers.**

The problem orientation helped us surface two under-utilized climate indicators when used in the context of climate adaptation planning. We found that soil moisture is an underutilized indicator of agricultural, meteorological, and hydrologic drought. We also found that landslide risk is an underutilized climate indicator. These insights were gained through careful, bounded research and confirmed through interviews with subject matter experts. The problem orientation helped us see a bridge across the gap between scientists and policymakers by exploring how to best incorporate the most accurate and relevant scientific data and findings into climate change adaptation planning within a specific problem area.

4.4 **Shared Challenges Encountered in All Four Case Studies**

Our team ran into similar challenges when setting our goals. In addition to the four case studies that are presented in this report, we identified and considered several other areas for analysis:

- **Reduce nutrient loss** on farms from soil erosion during excessive precipitation events.
• Limit financial loss to agricultural producers during periods of excessive flooding.
• Minimize the ecological impacts of flooding on watersheds and estuaries.
• Prepare urban critical infrastructure such as schools, facilities, and public buildings, for significant flooding events.
• Reduce the economic vulnerability of junior water rights holders during periods of water scarcity.
• Maintain consistent supply of hydropower through decreasing water availability.

We did not ultimately pursue these goals because they were either too wide in scope, there was not enough research available, or our timeline was too constrained. Ultimately, we encountered three key challenges in using the problem orientation to guide climate adaptation goal-setting and identify policy alternatives.

1 Explaining the problem orientation framework as novel

A challenge of the problem orientation is explaining its application to someone who may believe that the framework is not novel. The problem orientation requires a nuanced understanding of the connections between the problem, goal, trends, conditioning factors, and alternatives. Agency officials and staff may contend that they already use a problem orientation approach when examining issues and that this approach does not represent a new means of analysis. Thus, the analyst using this framework must make a deliberate effort to explain why this approach is different from existing practices and how to apply the problem orientation to identify hidden issues. This is a challenge in the climate space where problems and goals are highly technical, deeply researched, and in some cases fairly well-described.

2 Avoiding goal substitution due to stakeholder/agency constraints

Goal substitution occurs when the analyst substitutes a potential alternative to a problem or trend as the entire goal. This reduces the power of the problem orientation approach because it constrains the analysis of the problem and shaping of the goal to one that the analyst believes is achievable. Goal substitution is particularly likely to occur in the climate
space because agencies are highly constrained by their mandates, legal limits, and political constraints from acting beyond their specified area of focus. For that reason, staff at one agency may not accept the framing of a problem which inherently involves authority vested in another agency. We found that in fashioning our alternatives, it was worthwhile to attempt to include options that would appeal to multiple agencies rather than focus on goals that only applied to a single entity.

3 Selecting appropriate conditioning factors

Throughout our analysis, we often found that our issues were interlocked with one another in complex ways beyond the scope of our analysis. For example, landslide risk causes sedimentation that can impact salmon habitats. Wildfire risk can destabilize slopes, cause localized riverine flooding and impact salmon runs and habitats. Diverting snowpack waters to prevent flooding and soil erosion can change streamflow temperatures important to salmon. In shaping our problems, we narrowed and set aside some of these factors to focus the analysis on our goals.

Using the problem orientation for climate resilience adaptation requires the analyst to impose constraints on the conditioning factors, otherwise the potential universe of conditioning and influencing factors can become unwieldy. Without constraints, we found that the analysis may lose explanatory power because there are too many influences or too few. Thus, the strength of the analysis is connected to the perceived value of the selected conditioning factors. It is likely that selecting these factors will be more contentious than the analyst may expect. In addition to research, interviews, fact-finding, and community forums may be strategies to enhance the process of selecting conditioning factors. This is important because excluding a factor means conditions affecting a relevant stakeholder group may be overlooked (ex: homeowners, the unhoused, BIPOC communities, and tribal groups, etc.).
4.5 Policy Analysis Limitations

In addition to challenges, we also experienced limitations in research, data collection and access, audience limitations, and limitations of the problem orientation in action.

Research Limitations

There was sometimes a lack of available information regarding detailed trend data at the local level. Given the breadth of research led by the International Panel on Climate Change (IPCC) there is significant information on major climate trends globally and nationally. As the geographic scope of an impact narrows, the same depth of information is more difficult to come by locally. Individual climate impacts within the state of Washington require highly specific research investments, likely at the county or municipal levels. While areas of high population and high funding are able to invest in such resources, not every county is able to provide similar levels of data regarding each problem identified. This led to a significant variance in the amount of data available for each aspect of the problems identified.

The problem orientation tends to identify subgoals and additional problems. One of the challenges and limits of its use is that for high-level problems and goals it can become difficult to “bound” the research. One can be led further and further into complicated studies that require domain-specific scientific understanding to correctly interpret and apply. The problem orientation requires iteration to be effective, but that is not built into the orientation itself. It is a model for organizing information, not a process. Gathering data on the trends, conditioning factors, and policy alternatives requires focused work on each area, then comparing preliminary findings across all three areas to see where the data is aligning.

Each step of the process requires focused research. Aligning the trends, conditioning factors, and policy alternatives requires dismissing many other possible lines of inquiry. The problem orientation does not include a framework for identifying the most impactful climate problems. We uncovered many more possible case studies than the four case studies

xx Earth Economics; Mosbrucker, Major and Spicer
we focused on. It is up to the researcher to decide which climate problems are most important to devote time and energy researching.

**Data Limitations**

Given the specificity of the problem orientation and its implementation as related to Washington-centric climate issues, occurrences of lack of available data took place. These presented themselves in the form of:

- Known research priorities lacking available funding or staffing.\(^{yzz}\)
- Issues identified by the research team which do not have Washington or domestic research available.
- Issues identified by the research team which represent climatic trends on a national or global scale\(^{aaa}\) but have not been downscaled to cover regional impacts.

**Communication Limitations**

The use of the problem orientation depends to some extent upon the intended audience. All aspects of these complicated climate impact problems cannot be examined without potentially losing insight to cascading complexity. A limitation of our report is that the target audience for the findings of the case studies shifted while we were writing the report. We began by writing to hypothetical policymakers and state agency staff ultimately wrote our case studies to new researchers joining the Climate Impacts Group. The shifting target audience made decisions on shaping the analysis, the level of detail to include, and structuring the report challenging. The shifting audience also resulted in variable strategies.

\(^{y}\)Mauger

\(^{z}\)Czuba, Magirl and Czuba

\(^{aaa}\)IPCC 6; Pörtner, Roberts and Poloczanska
Real-World Context Limitations

In several interviews, the scientists were understandably cautious about exceeding the scope of their research. This is an example of how it can be difficult for policymakers in the climate space to see the big picture. Many interviewees cautioned on limited domain expertise and limited purposes or uses of their studies. They were circumspect about drawing climate causal relationships to trends and conditioning factors without further specific studies. This caution occurred even while noting the trends and conditioning factors discussed with the team were highly likely to be influential on the problem. In some cases, research scientists on key studies had “moved on” to other research areas, positions, universities or the private sector, leaving potentially intriguing lines of inquiry without forward progress. These promising studies therefore had a \textit{sui generis} quality that resisted more broad application.

When using the problem orientation there is an inherent tension in the scope of a goal statement. Climate-focused policymakers are looking at a big picture that can motivate the state to act. They may want to choose ambitious goals which resonate with the public. Trying to explain a very broad issue with the problem orientation may run into scientists who are distrustful of expansive explanatory attempts. One research professor quipped to a team member: “You’ve asked me a really good question that could fill twenty Ph.D. theses.” Scientists are steeped in their expertise which can be narrow, but deep, and are trained to see goals around specific knowledge-domains. For example, another interviewee explained the critical difference between “hydrology and hydrodynamics” when analyzing an issue. Yet if one is too narrow in setting a goal, it may cause goal substitution which is not actually analyzing the problem with enough breadth to identify root causes of a larger issue, and instead using a specific alternative or limited domain-focus as the entire goal. This can inhibit intergovernmental cooperation and collaboration and may result in a solution that doesn’t actually solve the wider unexamined problem.

\textit{In several interviews, the scientists were understandably cautious about exceeding the scope of their research. This is an example of how it can be difficult for policymakers in the climate space to see the big picture.}
This challenge may impact alternatives. Some interviewees explained that trust in government is a critical barrier for data collection on certain solutions or dissemination of best practices to the public. This exchange of information can be challenging with residents who are skeptical of the government’s motives and are reluctant to receive advice from government officials or engage in feedback with government agencies. One interviewee noted that a potentially useful reporting tool was deactivated because no one in the public used it. Another interviewee noted that gathering input from the public to shape their understanding of an agency communication portal was difficult because only the most motivated people called them, usually with complaints, skewing the type of feedback they obtained.

Finally, the need to provide a digestible explanation requires simplification in the climate space. This can be highly controversial to the public, who may perceive such necessary boundaries as intentional efforts to exclude them from the discussion. Such concerns carry heavy equity and fairness challenges for policymakers committed to a values-based approach. This difficulty may be particularly acute if trends, projections or conditioning factors these excluded “out-groups” perceive as influential on a problem are rejected by the analyst as insufficiently explanatory or causally connected to the problem in the manner in which the analyst frames it when shaping the goal.

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ccc Interview with Dr. Kate Mickelson (Apr. 14, 2022)

ddd Interview with Dr. Susan Schnur (Apr. 14, 2022)
Recommendations
Chapter 5: Recommendations

Based on our experience using the problem orientation, we identified the following key recommendations which we expand upon in this chapter:

- Identify and center values
- Include environmental justice
- Focused goal setting
- Map stakeholders
- Adapt the structure
- After the problem orientation

5.1 Center Values

Based on insights from using the problem orientation framework for our case studies, we determined that it is pivotal for the analyst to explicitly identify the core values motivating their goal justification. This act is critical to the fair and equitable determination and implementation of the alternatives.

State adaptation plans are typically written by a variety of representatives from state agencies and other organizations. This requires knowing what each stakeholder group is aiming to achieve to meet the priorities of everyone involved. Identifying the overarching mission, vision, and values of future climate adaptation plans will have major implications on which problems and alternatives the writers of future climate adaptation plans choose to highlight. Washington state agencies publicly promote many values, including public health, a strong economy, equity, and a healthy environment. The prioritization of these values guide goals and alternatives during the planning process.

When climate adaptation planners know the guiding set of values driving research and decision-making, they gain a clear understanding of the cumulative risk. Climate risk is a dynamic, complex, and vitally important concept to address. Socio-economic development, physical and social
vulnerability, and societal responses all shape and impact climate risk. When assessing Washington’s climate risks, it is important to address what risks are unacceptable and must be mitigated. A set of hazards exist that we will be unable to adapt to. Some coastal communities will experience significant sea-level rise while others will be impacted by drought or the continued loss of glaciers. Economic risks to implement adaptation strategies may be unsuccessful. Indigenous tribes will have sacred cultural sites or symbols at risk which state agencies failed to prioritize previously. Values such as these should impact what a society deems as important and unacceptable to lose. Designing policy analyses for climate adaptation strategies should consider the predetermined values. These values will assist in how the risks associated with potential adaptation scenarios will be evaluated.

5.2 Include Environmental Justice

While the problem orientation framework is meant to be ethically agnostic and amoral, users of the framework will inevitably approach an analysis with their own perspectives and biases. This context can inform which details they present using the framework and potentially cause the implementation of solutions that are ineffective or inequitable.

We recommend including environmental justice as an additional key value guiding future climate adaptation planning. Environmental justice must be at the core of any climate adaptation plan to protect those most vulnerable to climate change. The Washington State Legislature passed the Health Equity for All (HEAL) Act during the 2021 legislative session. The Act helps to institutionalize environmental justice into state programs and policies. The HEAL Act defines environmental justice as:

[T]he fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, rules, and policies. Environmental justice includes addressing disproportionate environmental health impacts in all laws, rules, and policies with environmental impacts by prioritizing vulnerable

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*We understand risk to mean the compounding effects of hazards, vulnerability, exposure, and response as explained by Pörtner, Roberts and Poloczanska.*
populations and overburdened communities, the equitable distribution of resources and benefits, and eliminating harm.

The HEAL Act includes a set of specific agency requirements. The third requires agencies to “incorporate environmental justice in implementation plans of agency strategic plans.” We highly recommend that environmental justice is included as a potential value and as a guiding orientation for implementing strategic plans around climate adaptation.

Including environmental justice as a value in climate adaptation planning and incorporating environmental justice in agencies’ implementation plans is one additional step to ensure that policymakers consider the impact of potential policy alternatives on historically marginalized communities most vulnerable to climate change.

5.3 Focus Goal Setting

The problem orientation framework provides specific implementation strategies for a defined problem. To do this effectively, the goal must be narrow enough to identify specific conditioning factors and alternatives that address the root causes of the issue. Fig. 5-1 (107) Through the application of the problem orientation to specific problems, we found it challenging to define narrow goals when discussing climate change. This is because climate change is a set of numerous problems occurring at varying levels and within many different policy contexts. If the problem orientation method were used for climate adaptation planning, policy analysts must reach a balance between how narrow the goals are and how many goals must be reached. Figure D5 (87) We found that scoping the goals as narrow as possible helped us identify the strongest policy alternatives for consideration. However, if the goals are as narrow and specific as they were for the four case studies in this report, dozens if not hundreds of goals would have to be created to cover all the impacts in need of climate adaptation planning in Washington state.

HEAL Act, Washington State Senate Bill 5141.
Within the umbrella category of changing patterns of precipitation, we could have identified and pursued many additional goals. To use the problem orientation effectively within statewide climate adaptation planning, we recommend identifying as many goals as possible, then prioritizing them using criteria such as potential impact to public health and urgency for consideration.

5.4 Identify Stakeholder Connections

Once the mission, vision, and values are constructed, our next recommendation is to apply stakeholder mapping. Given the complexity of any individual climate or environmental issue, every decision made impacts a wide array of stakeholders. The execution of stakeholder mapping should be an iterative process, observed and evaluated within each step of the problem orientation framework following the clarification of goals. Effective use of this process allows for a holistic understanding of the impacts and
benefits incurred to all parties involved, starting with the projected climatic changes to the final benefits and requirements laid out within the proposed alternatives.

*We make the following considerations for stakeholder mapping through each step of the problem orientation:*

**Trends**

The problems identified maintain numerous different trends, which when combined identify the problem as a consistent issue. Each trend has the potential to involve one or multiple stakeholders. Trends include recurring environmental impacts and engaging stakeholders concerned with land impacts. Trends also include financial losses, or the requirements of longer-term renovations connected to larger municipalities or community groups. Trends involving future impacts require the consideration of multigenerational stakeholders. Through the problem orientation process, each trend should be examined around which current and future stakeholders should be included.

**Conditioning Factors**

Each conditioning factor contains similar scopes to the identified trends. These factors aim to highlight the aspects that exacerbate trends. Factors such as local policies and current state legislation have widespread impacts on the decision-making of residents. Additional factors such as developments and location of residents have additional impacts on trends. As found when examining climate adaptation more specifically, environmental factors themselves present a much larger subsection of stakeholders seldom effectively represented policy valuations. Each conditioning factor impacts numerous stakeholder groups. By adequately identifying which stakeholders are impacted by each factor, policy alternatives will be significantly more inclusive and attainable.

**Policy Alternatives**

The proposed alternatives require significant research around stakeholders. The complexity of each problem presented requires engagement by numerous parties to define an effective solution. A policy alternative that excludes sufficient stakeholder perspectives is an ineffective
policy solution. Some climate adaptation failures are due to expertise being siloed rather than shared collaboratively. Effective stakeholder mapping around policy alternatives includes identifying the stakeholders’ expertise and resources to implement a solution and connecting it to the stakeholders benefiting from a recommended solution. The complexities of issues laid out by the problem orientation framework often highlight the inability for individual policy alternatives to provide benefits to all stakeholders involved. Stakeholder mapping around alternatives allows policymakers to implement effective benefit-cost analyses, weighing the benefits received by certain parties against the cost of implementation or lack of benefits for other groups. In weighing alternatives, it is important to prioritize underrepresented stakeholders in the decision-making process to ensure environmentally just outcomes are available.

Through the implementation of the problem orientation framework through climate adaptation planning, our team found that iterative stakeholder assessment helped develop a robust understanding of each step of the process. By assessing potential affected stakeholders throughout each stage of the problem orientation, the proposed policy recommendations are able to provide benefit to more of the impacted stakeholders. Additionally, stakeholder mapping is successful at presenting the perspectives of neglected stakeholder groups.

While no policy will be able to represent and mitigate the concerns expressed by each stakeholder, understanding which stakeholders are excluded by each proposed policy, or which stakeholders are required to contribute to effective policies, stakeholder mapping will better inform the policies developed through the problem orientation framework. The benefits experienced through the application of stakeholder mapping within each of the case studies supports our recommendation for the inclusion of an iterative stakeholder mapping process to the problem orientation framework.

5.5 Adapt the Analytical Process

As initially described in the work of Dr. Vogel and his colleagues, the problem orientation provides a linear structure. During the initial process of researching and conceptualizing the framework, this linear structure was

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Vogel, Cherney and Lowham.
effective for organizing copious research on each issue. Our team developed our case studies by identifying the related trends, conditioning factors, and policy alternatives, as well as the path between the problem definition, goal-orientation, and the potential resilience alternatives. During this process, the flexibility of the problem orientation framework offered us opportunities to consider different organizational structures to enhance the explanatory value of the analysis. The figure below compares a linear approach in which the researcher examines each part of the problem orientation before proceeding to the next step to an iterative approach in which different aspects of the problem are taken through the entire analysis in parallel.

Implementations of the problem orientation framework stem from a common introduction of problem statement to goal identification to trend definition. This linear approach aligns closely with the concepts introduced in The Policy Sciences as a Transdisciplinary approach for Policy Studies and the initial problem orientation framework as introduced to our team. Within this framework, a set of conditioning factors align independently, each impacting aspects of the trends identified. Following this, the suite of policy alternatives is introduced. Figure 5-2 (111) shows an example of the linear style approach of application of the problem orientation. The hierarchical approach of the problem orientation framework closely intertwines the identified the latter steps of the problem orientation framework. This connection aligns individuals' trends to conditioning factors and their reflecting policy alternatives. In Figure 5-3 (112) we see an iterative approach in which reconsiderations are made at many levels to refine and reassess the process. This is a useful approach for engagement with communities and a wide stakeholder group, or for problems that evolve quickly, but it is time-consuming and slower. Iterative approaches may stall or lose momentum.

Our recommendation around structure variation is to promote flexibility around the structure of the problem orientation. The goal of the problem orientation framework is to ensure policy alternatives are introduced that cover all aspects of the identified problem and goal. By reducing the rigidity of the research process around the problem orientation, different specific problems will receive different avenues of analysis. Within the application of the framework to our four case studies, each research process and evaluation took a different shape, while still being based on the...
same problem orientation. Given the complexities experienced by the research team in the four identified climate adaptation problems and the greater complexities of issues the problem orientation may be used for in the future, ensuring that the application of the framework remains adaptive will contribute to the success of the goals and an effective implementation of the framework.

**Figure 5-2 Linear Process for Problem Orientation Use:** In linear problem orientation use, the policy analyst attempts to establish each step with a degree of confidence before proceeding to the next part of the analysis. This is an effective approach where time to iterate is not available or a collaboration group does not have the capacity to meet several times. This can also be an effective approach where the problems are well described in general.
Iterative Process for Problem Orientation: In iterative problem orientation use, the policy analyst engages in an ongoing cycle of reconsideration and enhancement. In this context, revisiting the problem may be necessary and goals can be narrowed, refined or even wholly reconsidered. This is a good option where the climate science and technology evolve rapidly. This is also a desirable application when the problem is not well understood. Finally community involvement will often require an iterative approach to reconsider blind spots and missed opportunities as necessary consultations on core values, equity and community-centric priorities often take multiple attempts to succeed.
5.6 Debrief the Experience

After using the problem orientation to determine goals and identify policy alternatives directly linked to specific climate adaptation challenges, we recommend that policymakers and analysts specifically meet to consider which additional stakeholders may be affected by the policy alternatives. Recognizing the potential to cause unintended harm or benefits to additional stakeholders not originally identified through the problem orientation process is key. For example, changing the process of how drought is declared in Washington state to reduce dryland wheat farmers’ economic vulnerability to drought may have unintended impacts on other agricultural producers. We recommend that if climate adaptation planners use the problem orientation framework, they expand their analysis to more broadly consider possible unintended impacts of the potential policy alternatives that they may identify.
Capstone Conclusion

The use of the problem orientation as an approach to frame climate adaptation opportunities was enlightening and valuable. Following our research, we found that implementation of the problem orientation framework provided both benefits and challenges when applied within the broader realm of climate adaptation. By introducing a new approach to problem identification, the framework allowed our research team to dissect complex issues, centering the impact of climate change on diverse communities across Washington state. We identified actionable, pragmatic alternatives state policymakers may use to help Washingtonians adapt to climate threats.

It is easy to be overwhelmed by the interlocking nature of climate change adaptation policy problems. The problem orientation required us to pause and carefully consider the connections between trends, projections, conditioning factors, and alternatives for our specific goals. In so doing, we could see potential gaps in current policymaking with more clarity. Through our research and analysis, we recommend using the problem orientation framework as a tool and including additional steps of identifying values, including environmental justice, focusing goals, mapping stakeholders, and tailoring the process of using the framework as needed.

Applying the framework was limited in some cases by the scope of available research. We also found that using the problem orientation is challenging in the climate space, because reducing conditioning factors for one impact may unintentionally exacerbate another. The problem orientation and climate adaptation planning are heavily dependent on framing goals, which means analyzing even a single climate impact can proceed along justifiably different paths. Still, the framework was effective in demystifying daunting climate problems, which allowed our research team to identify realistic adaptation opportunities. This provided us with the hope that, as aspiring policymakers and analysts, we have a new set of tools to chart equitable pathways forward to address climate change in our communities.
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Appendices
Appendix A: Interviews of Subject Matter Experts

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Appendix B: Glossary

**100-Year Flood Plain:** Areas with a 1% annual chance of flooding that will be protected by a Federal flood control system where construction has reached specified legal requirements. (FEMA)

**500-year floodplain:** Area with a 0.2% (or 1 in 500 chance) annual chance of flooding. This zone is also used to designate base floodplain of lesser hazards, such as areas protected by levees from 100-year flood, or shallow flooding areas with average depths of less than one foot or drainage areas less than 1 square mile. (FEMA)

**A1B/B1:** These refer to two emissions scenarios from the Special Report on Emissions Scenarios (SRES). These emission scenarios are relevant to climate models in the Pacific Northwest and Washington State in particular and are frequently used to analyze climate impact projections relevant to precipitation in the 21st century.

**Adaptation:** Adaptation means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimize the damage they can cause or taking advantage of opportunities that may arise. Examples of adaptation measures include large-scale infrastructure changes, such as building defenses to protect against sea-level rise, as well behavioral shifts, such as individuals reducing their food waste. In essence, adaptation can be understood as the process of adjusting to the current and future effects of climate change. (European Environment Agency)

**Adaptive Capacity:** The combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities. (IPCC)

**Adjudication (Water Rights):** A judicial proceeding by which vested or existing water rights, federal reserved water rights, and water rights awarded by the state under a permit system are integrated, and priority dates for all water rights are determined for an entire watershed or ground water basin. The process is referred to as general stream adjudication. (University of Montana)

**Adhesion (Soil):** The ability to stick (Cambridge)

**Alternative (problem orientation):** As applied in the problem orientation framework by Vogel et. al., a potential solution which directly reduces the negative impact of a referenced conditioning factor. Alternatives ideally should not be disconnected from the conditioning factor that relates to trend(s).

**Anadromous (Salmon):** The term that describes fish born in freshwater who spend most of their lives in saltwater and return to freshwater to spawn, such as salmon and some species of sturgeon. (NOAA Fisheries)
Anthropogenic: Resulting from or produced by human beings. In the climate space anthropogenic refers to climate changes that can be attributed to human-driven activities. (IPCC)

Appropriated (Water Right): A water right acquired through the prior appropriation doctrine, as provided by state law, as either a vested, existing, or permitted water right. Often referred to as a “state-law water right." (University of Montana)

Army Corp of Engineers (U.S.): Federal agency charged with overseeing, maintaining and controlling certain water engineering infrastructure in U.S. watersheds and waterways among numerous other engineering mandates.

Atmospheric Rivers: Atmospheric rivers are relatively narrow regions in the atmosphere that are responsible for most of the transport of water vapor from the tropics. Atmospheric rivers come in all shapes and sizes but those that contain the largest amounts of water vapor and strongest winds are responsible for extreme rainfall events and floods. (National Weather Service)

BAER: Burn Area Emergency Response teams are interdisciplinary teams composed of resource specialists who determine the need for, prescribe, and sometimes implement emergency treatments to minimize threats to life or property or to stabilize and prevent further unacceptable degradation to natural and cultural resources resulting from the effects of wildfire. (Bureau of Indian Affairs)

Beneficial Use (Water): The use of water for a purpose identified by the state as a beneficial use. Each state defines in law what uses are beneficial. They typically include consumptive uses such as agriculture, domestic, industrial, mining, recreation, etc. They may also include non-consumptive uses such as fisheries, riparian, aesthetic, recreation, etc. (University of Montana)

Bureau of Reclamation: Federal agency that manages critical dam infrastructure in Washington State and can make determinations about water release that can impact flooding, irrigable water availability, reservoir levels, salmon habitats, and other large-scale water usage scenarios.

Climate: Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. (IPCC)

Community Asset: A community asset is a piece of infrastructure relied upon by local residents and community groups.

Community Land Trusts: Community land trusts are nonprofit, community-based organizations designed to ensure community stewardship of land. Community land
trusts can be used for many types of development (including commercial and retail) but are primarily used to ensure long-term housing affordability. To do so, the trust acquires land and maintains ownership of it permanently.

**Conditioning Factor (problem orientation):** As applied in the problem orientation framework by Vogel et. al., a factor that enhances the occurrence of a trend. A conditioning factor may be commonly understood to be an influence.

**Debris Flow:** Debris flows are fast-moving landslides that are particularly dangerous to life and property because they move quickly, destroy objects in their paths, and often strike without warning. (USGS)

**Deep-Seated Landslide:** Those in which the bulk of the slide plane lies below the roots of forest trees. This depth can range from ten feet to several hundreds of feet. These slides tend to be a result of change in the geologic and hydrologic processes in the area of the landslide, such as seismic shaking or increased levels of groundwater. Once formed, deep-seated landslides can persist for a few years, even centuries. (Washington Forest Protection Association)

**Distributed Hydrology Soil Vegetation Model (DHSMV):** Developed at the University of Washington, a statistical method of modeling slope vulnerability using a set of inputs. DHSMV may provide a more accurate model for landslide risks in mountainous areas in the Pacific Northwest.

**DOGAMI:** Oregon Department of Geology and Mineral Industries

**Downscaling:** Downscaling is a method that derives local- to regional-scale (up to 100 km) information from larger-scale models or data analyses. (IPCC) The need to downscale global or hemispheric climate models to the Pacific Northwest is a challenge for predicting climate impacts.

**Drought:** A period of abnormally dry weather long enough to cause a serious hydrological imbalance. Drought is a relative term, therefore any discussion in terms of precipitation deficit must refer to the particular precipitation-related activity that is under discussion. (IPCC) Definitions of drought have been variable, as recently as the 1980s officials cataloged more than 150 published definitions. (NIDIS) See Drought Types.

**Drought Advisory:** One of two designations used by the State of Washington to classify drought conditions based on water supply. The lower of the two classifications.

**Drought Emergency:** One of two designations used by the State of Washington to classify drought conditions based on water supply. The higher of the two classifications.

**Drought Types:** Meteorological Drought: When dry weather patterns dominate an area. Hydrological Drought: When low water supply becomes evident in the water system. Agricultural Drought: When crops become affected by drought. Socioeconomic Drought: When the supply and demand of various commodities is affected by drought. Ecological
Drought: When natural ecosystems are affected by drought. (National Integrated Drought Information System, NIDIS)

**Dryland Crops:** Winter wheat, spring wheat, barley, canola (oil seed), triticale, legumes, and hay in Washington State (DNR)

**Dryland Farming:** Dryland farming is often described as crop production without irrigation during a dry season, usually in a region that receives at least 20 inches (50 cm) of annual rainfall, and utilizes the moisture stored in the soil from the rainy season. A broader definition of dry farming is a low-input, place-based approach to producing crops within the constraints of your climate. As we define it, a dry-farmed crop is irrigated once or not at all. Farmers globally are exploring adopting dry farming methods as a climate resilience strategy to cope with less water available for irrigation. (Oregon State University/Dry Farming Institute)

**Endangered Species Act (ESA):** 16 U.S.C. 1531-1544. The Endangered Species Act prohibits the import, export, or taking of fish and wildlife and plants that are listed as threatened or endangered species; provides for adding species to and removing them from the list of threatened and endangered species, and for preparing and implementing plans for their recovery; provides for interagency cooperation to avoid take of listed species and for issuing permits for otherwise prohibited activities; provides for cooperation with States, including authorization of financial assistance; and implements the provisions of the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES). (USFWS)

**El Niño and Southern Oscillation (ENSO):** El Niño and the Southern Oscillation, also known as ENSO, is a natural periodic fluctuation in sea surface temperature (El Niño/La Niña) and the air pressure of the overlying atmosphere (Southern Oscillation) across the equatorial Pacific Ocean. (NOAA). The cycle impacts global climate across the vast Pacific Ocean area, including precipitation and seasonal temperature impacts in the Pacific Northwest and continental US. It is possible that anthropogenic climate forcings are impacting the severity of this natural climate process.

**Ecology (Agency):** Washington Department of Ecology

**Flood Control Infrastructure FCI:** Flooding Control Infrastructure defined as infrastructure that is developed to control flooding, through flood prevention barriers such as levees, or through water retention infrastructure, such as dams.

**First-in-time/First-in-right:** A principle of the prior appropriation doctrine. Every water right is recognized with a priority date. The earliest date is the most senior right, with the later dates a junior right to those preceding them. The most senior right is entitled to water first, followed by the next most senior right, and so on. When water supply is limited, the most junior rights may not be fulfilled. (University of Montana)

**Fish Passage:** State highways cross streams and rivers in thousands of places in Washington State, which can impede fish migration. We have worked for nearly three decades to improve fish passage and reconnect streams to help keep our waterways...
healthy. This primarily involves culvert redesign or removal. (WSDOT) Fish passage can also refer to man-made devices to assist salmon with migration over dams in a separate agency process (WDFW)

**Flood:** The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods.

**Flood Mapping Process:** FEMA provides the technology and relies on community leaders to share local knowledge and plans to make the maps as accurate as possible. FEMA and the floodplain administrator work with local engineers and surveyors to collect the data to inform the maps. Community members are also invited to provide information to help local officials better understand how water drains in the area. FEMA works with local experts before combining the data into a computer model that is used to create the updated flood map. (FEMA)

**GHG:** Greenhouse Gasses. These are molecules, and/or elements that create a heat-trapping effect when they accumulate in the upper atmosphere. Scientists are in near unanimous consensus that these gasses are causing global warming and changes to the Earth’s climatic system.

**GIS:** Geographic Information System mapping (ESRI)

**Goal:** As applied in the problem orientation framework by Vogel et. al., this is a succinct statement of the intentional desired outcome of the analysis.

**Growing Regions (Wheat):** Production in Washington has three main growing regions based on precipitation: low, intermediate and high. Whitman County, which is situated within the rolling hills of the Palouse, produces the most wheat of any county in the U.S. and receives more than 20 inches of precipitation annually. Walla Walla County, near the Oregon border also receives nearly as much precipitation and is very productive. The vast majority of wheat acreage in Eastern Washington, however, is in the low and intermediate precipitation zones, receiving annually from 8 to 15 inches of moisture in the form of snow and rain. Much of this land is summer fallowed, that is, the land is only cropped every other year to allow the ground to rest a year between crops to accumulate moisture. (Washington Grain Commission)

**Hazard:** The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources. (IPCC)

**HEAL Act:** Healthy Environment for All. A Washington State law passed in 2021 The passage of the Healthy Environment for All (HEAL) Act in 2021 is a historic step toward eliminating environmental and health disparities among communities of color and low income households. It is the first statewide law in Washington to create a coordinated state agency approach to environmental justice. (Washington State Department of
Health). The law covers seven state agencies: the Washington State Department of Health (DOH); the state departments of Agriculture, Commerce, Ecology, Natural Resources, and Transportation; and Puget Sound Partnership. It allows other agencies to opt in. The HEAL Act builds on and implements some of the key recommendations from the Environmental Justice Task Force.

Heat (Thermal) Loading: Influences that raise the temperature. In the context of streams or rivers, inputs that increase the amount of heat. (US DOI) This can influence the viability of salmon.

Heuristic: A technique or strategy for enabling someone to discover or learn something for themselves

High Risk (Flooding): Flood maps show how likely it is for an area to flood. Any place with a 1% chance or higher chance of experiencing a flood each year is considered to have a high risk. Those areas have at least a one-in-four chance of flooding during a 30-year mortgage. (FEMA) See Flood Map Process, above.

Hydrodynamics: The scientific study of the motion of fluids, especially non-compressible liquids, under the influence of internal and external forces. For this work we specific it as the flow of water through a watershed is hydrodynamics. This is complicated because significant amounts of water flow unseen through aquifers.

Hydrology: The study of water particularly as a science in response to the need to understand the complex water systems of the Earth and help solve water problems. The hydrology of a watershed relates to the overall “water budget” and is relatively easy to calculate based on precipitation and water outflows.

Hydrophilic: Surfaces that attract water. In the context of soil science, hydrophilic soils absorb water.

Hydrophobic: Surfaces that repel water. In a post-wildfire scenario hydrophobic soil leads to surface run-off that can cause slope failures.

Instream Flow: State law requires that enough water is kept in streams and rivers to protect and preserve instream resources and values such as fish, wildlife, recreation, aesthetics, water quality, and navigation. One of the most effective tools for protecting streamflows is to set instream flows, which are flow levels adopted into rule. Instream flows cover nearly half of the state’s watersheds and the Columbia River. (Washington Department of Ecology)

IPCC: United Nations Intergovernmental Panel on Climate Change. The IPCC is completing its sixth reporting cycle and has published reports for policymakers in February 2022.

Junior Water Rights: Under the prior appropriation doctrine, water rights that fulfilled after older rights (senior) have been fulfilled, but will not be fulfilled when the source is insufficient to support more senior rights (University of Montana)
**Ladder Fuels**: Fuels which provide vertical continuity between strata, thereby allowing fire to carry from surface fuels into the crowns of trees or shrubs with relative ease. They help initiate and assure the continuation of crowning. (National Wildlife Coordinating Group)

**Land use and land use change**: Land use refers to the total of arrangements, activities, and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction, and conservation)

**Landslides**: The movement of a mass of rock, debris, or earth down a slope. Landslides are a type of "mass wasting," which denotes any down-slope movement of soil and rock under the direct influence of gravity. The term "landslide" encompasses five modes of slope movement: falls, topples, slides, spreads, and flows. (USGS)

**LiDAR**: Light Detection And Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. (American Geosciences Institute)

**Mitigation (Climate)**: Mitigation means making the impacts of climate change less severe by preventing or reducing the emission of greenhouse gasses (GHG) into the atmosphere. Mitigation is achieved either by reducing the sources of these gasses — e.g. by increasing the share of renewable energies or establishing a cleaner mobility system — or by enhancing the storage of these gasses — e.g. by increasing the size of forests. In short, mitigation is a human intervention that reduces the sources of GHG emissions and/or enhances the sinks. (European Environment Agency)

**Orographic Effect**: Mountainous areas tend to have greater amounts of precipitation than surrounding lowlands due to the orographic effect, in which rising air currents cool and release their moisture as precipitation (USDA: Fundamentals of Watershed Hydrology). This is a common feature of the Washington Cascades and has an impact on precipitation distribution in the state.

**Natural Floodplain**: A natural floodplain is an area which remains at risk to significant flooding at the 100- or 500-year level, prior to the implementation of flood control infrastructure. An area remains a natural floodplain following the addition of FCI, and on the chance that infrastructure fails, will remain susceptible to flooding.

**Nooksack Tribe**: “We are a tribe of approximately 2,000 members, located in our ancestral homeland in the northwest corner of Washington State. Our name comes from a place name in our language and translates to “always bracken fern roots,” which illustrates our close ties to our land and the resources that continue to give strength to our people. Our tribe is located in Deming, Washington, just 15 miles east of Bellingham, 12 miles south of the Canadian border, nestled amongst majestic mountains, lush forest, and the meandering and dynamic Nooksack River. Here in this scenic locale, we maintain a Tribal Council and Tribal Government. Both our Council and Government
work to create a better future for every Nooksack and ensure our tribe’s sovereignty.”
(Tribal website)

**Nooksack River:** The Nooksack River is a river in western Whatcom County of the northwestern U.S. state of Washington, draining extensive valley systems within the North Cascades around Mount Shuksan, Mount Baker and the Twin Sisters, and a portion of Fraser Lowland south of the Canada–United States border. The river *proper* begins with the merging of three main tributaries, namely the North Fork, Middle Fork and South Fork, near Deming. All three forks originate in the Mount Baker Wilderness, and the North Fork, the longest of the three, is sometimes considered the main river. The Nooksack is approximately 75 miles (121 km) in total length measuring from the North Fork headwaters. The lower Nooksack flows as a northerly loop through the fertile southern Fraser Lowland agricultural area before emptying into Bellingham Bay and, via the Strait of Juan de Fuca and the Strait of Georgia, communicating with the Pacific Ocean. (Wikipedia)

**Permitted Water Right:** Water rights issued as a permit under state water statutes, which specifies location, amount, use, timing, and priority date for the water. (University of Montana)

**Priority Date:** The date used to determine senior and junior water rights. For a new permit applicant, it is the date the application is correctly filed. For vested water rights, the date of first beneficial use as determined by a court declaration. For federal reserved water rights, the date Congress or the President established the federal reservation. (University of Montana)

**Prior Appropriation Doctrine:** A method of allocating water rights whereby the first person to appropriate a quantity of water from a water source for a beneficial use has the right to continue to use the appropriate quantity of water for that beneficial use. Subsequent persons can appropriate the remaining water for their own beneficial purposes, provided they do not interfere with the rights of prior appropriators. (University of Montana)

**Problem Orientation Heuristic & Framework:** A model of analysis proposed in a paper by Dr. Jason Vogel and co-authors for examining and analyzing problems and developing solutions

**Rain-Dominant Watersheds:** Rain dominant watersheds are typically lower in elevation and mostly on the west side of the Cascades. They receive little snowfall. Streamflow in these watersheds peaks in the cool season, roughly in phase with peak precipitation (usually November through January). (CIG)

**Regulatory Floodplain:** A regulatory floodplain is the area which remains at risk for significant flooding at the 100-year floodplain level following the addition of flood control infrastructure. Regulatory Floodplains are often a reorientation of a natural floodplain.

**Resilience (Climate):** The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and
efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions. (IPCC)

**Riparian Buffer:** An area adjacent to a stream, lake, or wetland that contains a combination of trees, shrubs, and/or other perennial plants and is managed differently from the surrounding landscape, primarily to provide conservation benefits. (USDA)

**Riverine (Ecosystem):** Also called a *lotic* ecosystem, any spring, stream, or river viewed as an ecosystem. (Britannica)

**Root Density:** The property that helps soil bind and stay in place. Timber harvesting, drought and wildfire tree loss can reduce vegetation with deep root structures and reduce root density. This can cause soil stability to decline.

**Rotational Landslide:** A landslide on which the surface of rupture is curved upward (spoon-shaped), and the slide movement is more or less rotational about an axis that is parallel to the contour of the slope. (USGS)

**Scour:** Occurs when water erodes the sediments that surround the base or support structures for bridges, roads, and other man-made buildings. Scour is often caused by fast-moving water, so scour often occurs during floods. (USGS)

**Sedimentation:** The depositing or formation of sediment carried through the flow of liquid.

**Semi-Arid Ecosystems:** In semi-arid ecosystems, the soil water content is often too dry for rapid germination of seeds. Some agricultural systems depend on planting into marginal soil water as a way of outcompeting weeds or for establishing annual winter grasses in the fall. Winter wheat producers in low precipitation areas of the Pacific Northwest, United States, use a 13- to 14-mo period of fallow to control weeds and store water before planting. Maximum yields are produced from late August to mid-September plantings. If seed-zone water is marginal or inadequate for germination, then germination is delayed until the onset of fall rains in October or later. (USDA)

**Senior Water Rights:** Under the prior appropriation doctrine, water rights that are fulfilled before more recent (junior) rights are fulfilled. (University of Montana)

**Shallow-Rapid Landslide:** Shallow-rapid landslides are debris-flow slides that occur within the forest rooting zone, generally less than 10 feet deep. They are typically initiated by intense rainfall and/or rapid snowmelt. Sudden saturation of the ground loosens the soil and triggers the slide. Shallow slides usually follow a long saturation period that is punctuated by an intense burst of precipitation over several hours or a few days. At some point, gravity overtakes the hillside and the muddy soil mass breaks loose. (Washington Forest Protection Association)

**Snowmelt-Dominant Watershed:** In snowmelt dominant watersheds, much of the winter precipitation is stored in the snowpack, which melts in the spring and early
summer resulting in low streamflow in the cool season and peak streamflow in late spring or early summer (May-July). (CIG)

**Snowpack:** In mountainous areas that experience a winter season, precipitation can fall in the form of snow. Snow that has fallen on the ground and does not melt for months due to below-freezing temperatures is called snowpack. (National Geographic Society) In Washington State, the accumulated Cascadian snowpack is often referred to as the “Sixth Reservoir” because it effectively naturally stores water for release in spring and summer.

**Soil Moisture:** Water stored in or at the land surface and available for evapotranspiration. (IPCC)

**Spring Wheat:** In Washington state, spring wheat is planted in the early spring months of March and April. (Washington Grain Commission)

**State-Specific Drought Impacts:** Compiled by the National Drought Mitigation Center involves five classes of drought for a state, listed from lowest to highest. In 2021, the percentage of Washington having this designation: abnormally dry (100%), moderate drought (73%), severe drought (55%), extreme drought (47%), and exceptional drought (29%).

**Streamflow:** Water flow within a river channel, for example, expressed in m3 s-1. A synonym for river discharge. (IPCC)

**SWE:** Snow Water Equivalent. A measure of meltwater related to snowpack levels in the Cascade.

**Transient (Mixed Rain-Snow) Watersheds:** Transient watersheds are characterized as mixed rain- snow due to their mid-range elevation. These watersheds receive some snowfall, some of which melts in the cool season and some of which is stored over winter and melts as seasonal temperatures increase. Rivers draining these watersheds typically experience two streamflow peaks: one in winter coinciding with seasonal maximum precipitation, and another in late spring or early summer when water stored in snowpack melts. (CIG). These watersheds are highly sensitive to warming climate change due to existing close to the freeze point of water.

**Translational Landslide:** The mass in a translational landslide moves out, or down and outward, along a relatively planar surface with little rotational movement or backward tilting. (USGS)

**Trend (problem orientation):** As applied in the problem orientation framework by Vogel et. al., data that explains the change in the nature of an occurrence in one direction or another.

**Water Budget:** How much water enters into a particular area in a given period of time. This represents an overall assessment of water into the system which can then be traced as it moves through a watershed. This budget is dynamic in some regions as it
depends on precipitation or can be relatively stable if its sources are reliable and predictable.

**Water Right:** A system of rights to allocate the use of water that travels or collects in streams, rivers, lakes, ponds, or underground, including the allocation of the water to storage. Water rights are property rights, but water right holders do not own the water itself, they possess the right to use it. Depending on the type of water law doctrine they may be attached to ownership of the land, or they may exist as a separate property right.

**Watershed:** A land area that channels rainfall and snowmelt to creeks, streams, and rivers, and eventually to outflow points such as reservoirs, bays, and the ocean. (NOAA)

**Winter Wheat:** In Washington state, winter wheat harvest begins in July with spring wheat harvest starting a month later. Harvest continues through September depending on where the wheat is grown. In 2021, Washington wheat growers harvested 2.33 million acres of wheat for total wheat production of 87.1 million bushels. (Washington Grain Commission)

**WALERT:** The state emergency warning system and staff administered by the Washington DNR relevant to landslides, flooding, and fire risks.

**Yómech:** Nooksack term for spring salmon (Chinook and King) courtesy Jeremiah Johnny from the Nooksack Tribe Culture Department
Endnotes

DRYLAND WHEAT FARMING


4 Ibid.


10 “College of Agricultural, Human, and Natural Resources Sciences.” IMPACT Center at Washington State University, http://ses.wsu.edu/impact-center/.


25 Ibid.


30 Ibid.


**NOOKSACK RIVER SALMON**


Ibid.

While Steelhead are a type of trout and not salmon, they have similar vulnerabilities to climate change and human development. As they are also listed as an endangered species, many salmon recovery organizations do not discriminate between the fish.

Nooksack Salmon Enhancement Association. “Chinook Salmon.” 2022, https://www.n-sea.org/chinook-salmon#:~:text=In%20Whatcom%20County%3A%20There%20are,until%20mid%2DAugust%20through%20September

Ibid.


Ibid.


Ibid.

Environmental Protection Agency (2016)


Nooksack Indian Tribe (2016)


CASCADE LANDSLIDES


Tall, Jonathan, “Climate change is making temperatures warmer, and Washington will only keep getting wetter”, The Front, Dec. 12, 2021. https://www.westernfrontonline.com/article/2021/12/la-nina (“The rains are going to be that much heavier, because a warmer atmosphere has a significantly higher moisture content.’ [State Climatologist Nick] Bond said these weather events are becoming more frequent as climate change makes the temperature warmer. While that doesn’t mean every single fall and winter is going to be like this, during years that do have frequent rain, the outcome is more likely because of proximal weather events, like the drought conditions Washington experienced. ‘This isn’t the new normal,’ he said. ‘But it is an example of what’s expected to happen with more frequency.’”)

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Hu, Xie, Teng Wang, Thomas C Pierson, Zhong Lu, Jinwoo Kim, and Thomas H Cecere. “Detecting Seasonal Landslide Movement within the Cascade Landslide Complex (Washington) Using Time-series SAR Imagery.” Remote Sensing of Environment 187 (2016): 49-61. (“Our data show that the sliding motion tends to initiate shortly after the autumn rains begin in October or November (roughly when the 30-day accumulated precipitation total exceeds 300 mm), normally one to three months ahead of the arrival of the precipitation peak (red arrows). The gaps between the precipitation peak and the midpoint of sliding acceleration are typically within two months (blue arrows). Slope movement is triggered when shear stress exceeds shear strength.”)

Khan, Mohammad Safeeq; Shukla, Shraddhanand; Arismendi, Ivan; Grant, Gordon E; Lewis, Sarah L; Nolin, Anne. Influence of winter season climate variability on snow–precipitation ratio in the western United States. International journal of climatology, 2016-07, Vol.36 (9), p.3175-3190. Chichester, UK: John Wiley & Sons, Ltd. (“In the western United States, climate warming poses a unique threat to water and snow hydrology because much of the snowpack accumulates at temperatures near 0 °C. As the climate continues to warm, much of the region’s precipitation is expected to switch from snow to rain, causing flashier hydrographs, earlier inflow to reservoirs, and reduced spring and summer snowpack.”)


Author Interview with Guillaume Mauger, Research Scientist, University of Washington, Climate Impacts Group (Mar. 28, 2022) available at https://cig.uw.edu/about/people/guillaume-mauger/

Barik et al. (2017)

Barik et al. (2017) (“Averages over all of the climate scenarios show 7.6% and 12.1% increases in high landslide susceptibility areas in the OESF and the WDNR domains, respectively. All four climate scenarios are consistent in projecting increased landslide susceptibility in the DNR-managed active logging areas (north-western part of the Queets basin). While up to 12.2% of the federal lands (the Olympic National Park) are projected to fall in the high susceptibility category, this number is even higher (17.1%) for the state-managed lands (WDNR lands”)

Barik, et al. (2017)


Pierre-Louis (2022) (“When the fires burn super, super hot, oils and other chemicals in your vegetation leave almost a kind of plastic-wrap layer on the soil,” Cara Farr, the national coordinator for the U.S. Forest Service Burned Area Emergency Response program, told me. This phenomenon, called hydrophobicity, keeps the soil from absorbing rain not just at the surface, but deeper.”)


Pierre-Louis (2022) (“[Hydrophobicity] doesn’t typically pose a problem if the first rainfalls after a wildfire are light: Those drops break up that plastic-like layer, allowing the rain to penetrate the earth. But “if you get a heavy rainstorm after a fire, that’ll drive an increased flooding,” Farr said—and an increased risk of the type of landslide loosed in Montecito. Heavy rains can essentially separate the upper layers of the soil from the hydrophobic layer below.”)

National Weather Service (Oxnard, CA), Post Wildfire Flash Flood and Debris Flow Guide. (August 2015) available at https://www.wrh.noaa.gov/lox/hydrology/files/DebrisFlowSurvivalGuide.pdf (“Flood risk remains significantly higher until vegetation is restored—up to 5 years after a wildfire. Flooding after fire is often more severe, as debris and ash left from the fire can form mudflows. As rainwater moves across charred and denuded ground, it can also pick up soil and sediment and carry it in a stream of floodwaters. These mudflows can cause significant damage.”)

Rosen, Julia. “How heat waves warp ecosystems” High County News (Nov. 22, 2021)

USGS Landslide Handbook, p. 33.

State of Washington, Office of Financial Management, Forecasting & Research Division, 2021 Population Trends (March 2022), Table 2. Population and components of population change by county: April 2010 to April 2020. Washington State has been adding residents at a fast clip in the time between the 2010 and 2020 census surveys. Counties with significant portions of the Cascades that have seen growth including Chelan (6,688, 9.2%), Skagit (12,622, 10.8%), Snohomish (114,622 16.1%), King (338,426, 17.5), Kittitas (5,553 13.6%).
The top ten municipalities for percentage growth in the state were Ridgefield (18.3%), Black Diamond (15.1%), Winlock (8.9%), Edgewood (7.7%), Leavenworth (7.5%), Tenino (7.3%), La Center (6.9%), West Richland (6.4%), Chelan (6.2%) and Sumas (5.7%). Many of these are located in the Cascade Range. Municipalities necessarily have fewer resources and budgets to implement costly solutions where landslide risk may be present. Focusing on these communities is not a hypothetical concern. Sumas, situated near the Canadian border, was devastated by the extraordinary flooding of the Nooksack River in 2021.

Vehicle miles traveled in the state have increased on all roadways including the interstate system, state highways, country roads and city streets. Washington State Data Book, Transportation available at https://ofm.wa.gov/sites/default/files/public/datarsearch/databook/pdf/transportation.pdf

USGS Landslide Handbook, p. 34 (“One of the greatest potential consequences from landslides is to the transportation industry[.] Cut and fill failures along roadways and railways, as well as collapse of roads from underlying weak and slide-prone soils and fill are common problems...All types of landslides can lead to temporary or long-term closing of crucial routes for commerce, tourism, and emergency activities due to road or rail blockage by dirt, debris and (or) rocks. Even slow creep can affect linear infrastructure, creating maintenance problems.”)


Book, 2015. While not explicitly in mountain networks, this project provided an example of WSDOT’s coordination with respect to rail-related issues and landslides. (“The most landslide prone areas along the Amtrak Cascades corridor are found north of Seattle along the coastal bluffs in Snohomish County. Every year, more than 200,000 Amtrak Cascades passengers travel this area between Seattle and Vancouver, British Columbia. During the rainy season, landslides sometimes impact the rail service when unstable slopes slide onto the tracks. More than 500 Amtrak Cascades trains were cancelled or disrupted over the last five years due to landslides. After each landslide, passenger trains are halted for 48 hours while nearby slopes are evaluated, and tracks are cleared and verified for safe passenger train travel. The result is poor on-time performance and many unhappy passengers. Limiting the number of landslides along the rail corridor is critical to Amtrak Cascades goals to increase the reliability of passenger rail service in the Pacific Northwest.”)

Godwin (2020)

Mapes (2022)

Godwin (2020)


Moudon et al., 2013 (“If these risks are realized, political pressure may mount to fund expensive retrofits or capacity improvements that impose both short-term and long-term social, environmental, and financial costs.”)

Mirus et al. (2020)
Framing Climate Adaptation Opportunities


“In 2010, Seattle had 462,000 jobs and 308,000 homes. This was a ratio of 1.50 jobs to homes, a ratio that should have been maintained during this last decade of job growth...By 2020, [job growth] reached 620,000 but homes only grew 368,000. While 60,000 new homes sounds great, Seattle remains 45,000 homes short of matching its 2010 jobs to homes ratio.” DiRaimo (2021)

133 Scruggs, Gregory, Mountain towns across the West are facing a housing crisis. Can the Methow break the mold?, The Seattle Times (Feb. 12, 2022) (“In the wake of the wildfire, a group of civic leaders calling themselves Methow Valley Long Term Recovery began plotting the valley’s future. A consultant hired by the group recommended establishing a community land trust as a low-hanging fruit.”)


See October 2017 presentation discussing DNR’s LiDAR program in context of SR530 Landslide Commission, Final Report of Dec. 15, 2014. https://wsg.washington.edu/wacoast/meetings/2017-10-Oct/Jacobacci%20EO%20October%205th2.pdf It is worth examining if this program mandate employs climate change modeling in scoping the nature of the landslide risks that need to be modeled using LiDAR.

136 Israel & Snoever (2016)


138 “Landslide susceptibility mapping methods can be classified according to whether they are distributed, qualitative, statistical, deterministic, or hybrid techniques (Mantovani et al., 1996, Saha et al., 2005, Ayalew et al., 2005). All of these techniques are based on the relationships of different landslide controlling factors with landslides observations (Guzzetti et al., 1999, Lee and Min, 2001).” Barik et al, (2017)

139 Lugg, Jaquelyn. University of California, Merced (ANR). “New research clarifies impacts of timber harvest on sediment in watersheds” (Aug. 11, 2020) interviewing Prof. M.S. Khan. available at https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=43344 (“To isolate the relative contributions of streamflow changes and increased sediment supply on sediment transport, Khan and colleagues developed a statistical reconstruction technique to account for the hydrologic changes following harvest.”)


141 Lugg (2020) interviewing Prof. M.S. Khan. (“[S]trategies that limit ground disruption – like suspending logs while transporting instead of dragging them, avoiding heavy machinery when and where possible, and mastication and mulching – are likely to be highly effective in reducing sediment yields.”)

142 Professor Mohammad Safeeq Khan, University of California Merced, Interview (Apr. 4, 2022) https://ucanr.edu/?facultyid=43890
Framing Climate Adaptation Opportunities


144 Hessburg, et al. (2021)


147 Ibid.

148 Ibid.


151 “King County, Washington IMap Tool.” ArcGIS Web Application, King County, Washington, https://gismaps.kingcounty.gov/iMap/.

152 For example, in 2016, King County had a disparate set of areas for learning about landslide risk on its own website. Department of Natural Resources and Park – Water and Land Resources Division, River and Floodplain Management Section. “Mapping of Potential Landslide Hazards in King County” (Nov. 1, 2016) https://kingcounty.gov/~i-media/services/environment/water-and-land/landslides/documents/2016-11-Green-River-Workshop.ashx?la=en

153 See e.g., Snohomish County Geologic Hazards, Landslide Hazard Areas Index Map (Aug. 10, 2016) available at https://www.snooco.org/w1/services/Docs/SCD/PDF/PDS_CAR/Landslide%20Hazard%20Areas_CW_10_2_INDEX.pdf accessed Mar. 25, 2022. These county-level hazard analyses should consider climate change modeling of the likely increasing risks of landslides in a warming climate.

154 See WAC 365-190-120(1), et. seq. for definitions of geologically hazardous areas. Ensuring these state codes require climate change modeling considerations could improve the legal regime for development planning for landslide risk. https://app.leg.wa.gov/wac/default.aspx?cite=365-190-120

155 “Snohomish County’s emergency management director, John Pennington, has said the Oso community understood the risks, yet he also described Saturday’s slide as unforeseen. Miller, who wrote the 1999 report, said the truth may lie somewhere in the middle. ‘It depends what timeframe you are looking at. If you are a geologist who thinks in terms of thousands of years, it is inevitable,’ he said. ‘If you are a county planner who’s thinking in terms of less than a human lifespan, it’s very improbable.’” Kaminsky (2014)

156 Antunes, Lucas Niehuns, Calum Sydney, Enedir Ghisi, et al., Reduction of Environmental Impacts Due to Using Permeable Pavements to Harvest Stormwater, Water 2020, 12, 2849; doi:10.3390/w12102840 (October 2020), available at https://www.mdpi.com/2073-4441/12/10/2840/pdf (“An effective solution to improve drainage efficiency in urban centres is the large-scale use of sustainable urban drainage systems (SUDS). SUDS are a source of stormwater runoff by using infiltration and storage in situ to reduce runoff discharge.”)
Some of the advantages of porous asphalt include surfaces that can melt snow and ice faster, reducing water run-off and sediment loading in waterways, recharging groundwater by infiltration, improved wet-weather visibility for drivers and reduction in stormwater runoff. However, key disadvantages are requirements for specialized maintenance to prevent clogging, limited use for heavy loading areas where sharp turns are probable (e.g. snowplows), sloped pavements require extra design considerations, and higher initial costs (which may be offset by the improved drainage causing less stress on infrastructure).


RIVERINE FLOODING

Neiman, Schick and Ralph
Campbell and King
Associated Press
Earth Economics; Mosbrucker, Major and Spicer
NOAA National Centers for Environmental Information
Neiman, Schick and Ralph
Jones
Huxley College for the Environment
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Czuba, Czuba and Magirl
Liao
Czuba, Magirl and Czuba
Ibid.
Lincoln
Mosbrucker, Major and Spicer
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Ibid.
Mauger

Hartmann, Slavikova and McCarthy

Baker

Pierce County Public Works

Ibid.

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Architecture Boston

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Pierce County Public Works

Dunagan

Puget Sound Regional Council

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Ibid.

Ibid.

Whatcom County, Washington

Federal Emergency Management Agency

Ibid.

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Federal Emergency Management Agency

Governor’s Office for Regulatory Innovation and Assistance

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Washington State Department of Revenue

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Floodplains By Design

Multi-Hazard Mitigation Council

Ibid.