# Biophysical Climate Risks and Economic Impacts for Washington State

**Prepared by the**

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This report is available for download at:
https://cig.uw.edu/projects/climate-risk-assessment/

The webtool developed for this assessment, *Climate Mapping for a Resilient Washington*, is available at:
https://cig.uw.edu/resources/analysis-tools/climate-mapping-for-a-resilient-washington/

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# Executive Summary

The Washington State 2021-23 Operating Budget ESSB 5092 Sec 606(23)) funded the University of Washington Climate Impacts Group (CIG) to *"provide an updated climate risk assessment designed to inform future updates to the statewide climate resilience strategy."* The UW CIG, with Washington State University IMPACT Center, compiled information on two science-based elements of climate risk:

**Biophysical Impacts:** Projections of the magnitude and timing of changes in the climate and climate-related hazards. Expected climate changes are mapped for Washington State, summarized by county, and presented in an interactive web application for local governments and state agencies, *Climate Mapping for a Resilient Washington*.

**Economic Impacts:** Case studies of the economic consequences of three key biophysical impacts — extreme heat, wildfire, drought —for the economy in Washington.

This assessment of future changes in the climate and climate-related hazards, with associated economic consequences, can inform state and local plans for climate resilience and prioritization of funding for risk-reduction activities.

## Purpose and Need

The current availability of information on changes in the climate and related hazards in Washington State is spotty – varying by hazard, sector, and location. The information on biophysical climate impacts and economic consequences compiled for this proviso fulfills a need for foundational, current scientific information that can be readily accessed, interpreted, and applied to plan and implement actions that enhance state and local climate resilience. Recent reports on how to further climate resilience at the state level all identified the need for technical information to support a coordinated state response to the most pressing climate hazards.

The information and products generated by this proviso aim to support several needs for updating the *2012 Washington State Integrated Climate Response Strategy*. This includes the information on climate impacts necessary to make coordinated and strategic decisions on resilience priorities and the allocation of funds for resilience Resilience actions funded under the Climate Commitment Act are most likely to successfully build resilience if they are informed by *where and when* droughts, high streamflows, sea level rise and wildfires are expected to intensify in a warming climate.

## State Agency Consultation

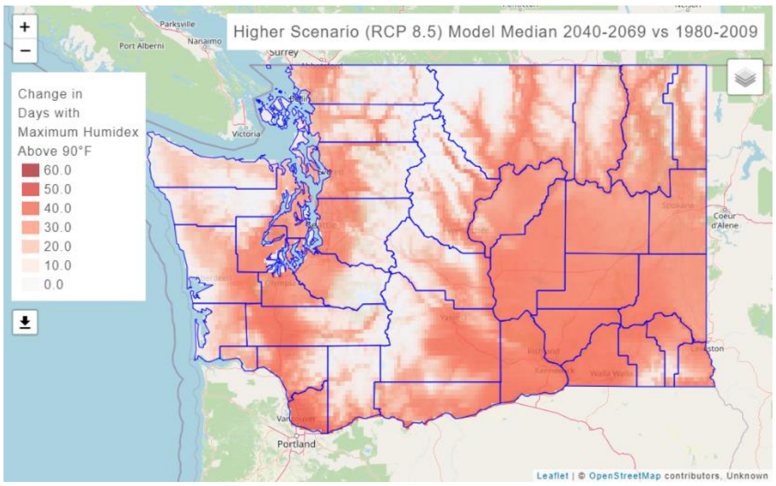
The proviso directed the UW CIG to coordinate with the office of the governor and state agencies to scope the assessment. Given the extensive work on climate resilience by state agencies in the last decade, we consulted with agency staff to determine how an assessment of biophysical climate risks would be most useful. We heard from state agency staff that information on climate impacts for local jurisdictions is an immediate need. This information can enhance local awareness of climate risks and enable local governments to effectively engage in climate resilience planning and grant opportunities at the local, state, and federal level.

# Three Climate Hazard-Sector Combinations

### Extreme Heat & Human Health

*Biophysical Impacts:* By the 2050s (2040-2069), the number of days per year with a humidex above 90°F is expected to increase across the state. A maximum daytime humidex above 90°F corresponds to higher risk of heat-related illness, hospitalization and death, but not all locations and populations will be equally exposed or susceptible. Socioeconomic factors largely determine the inequitable impact of extreme heat.

*Economic Impacts:* One year of heat-related activity losses results in direct losses to industry sales of over $426.1 million-$178.3 million in lost gross state product and losses of over 1,481 full-time equivalent jobs in Washington.

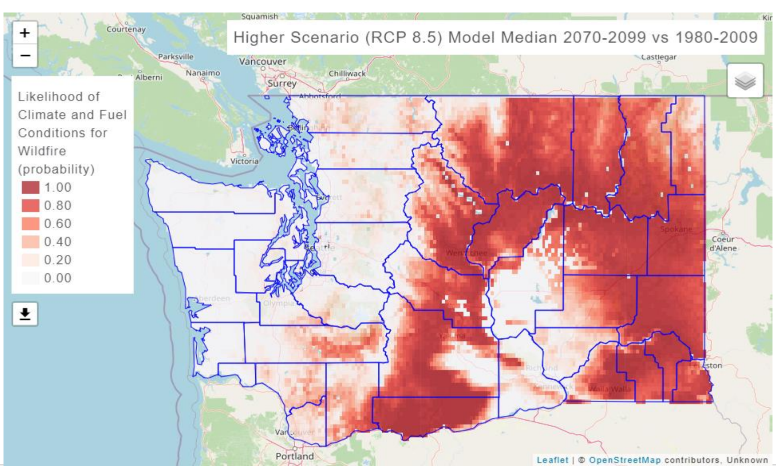



*Expected change in the number of days with Humidex above 90°F across Washington State for the middle of the century (2040-2069) and under a high climate scenario (RCP 8.5). The number of days with a humidex above 90°F indicates potential for heat-related illness and death.*

### Wildfire & Infrastructure

*Biophysical Impacts:* By the end of the century (2070-2099), the likelihood of conditions that support wildfire is expected to increase in central and eastern Washington where wildfire is already most likely, as well as in western Washington, especially southwestern Washington, where current wildfire likelihood is low.

*Economic Impacts:* Based on an analysis of wildfire economic losses in California in 2018, if the economic losses in Washington matched those measured on a per acre basis, Washington's economic losses from direct and indirect wildfire damages would have been $49.8-$53.0 billion in 2021.

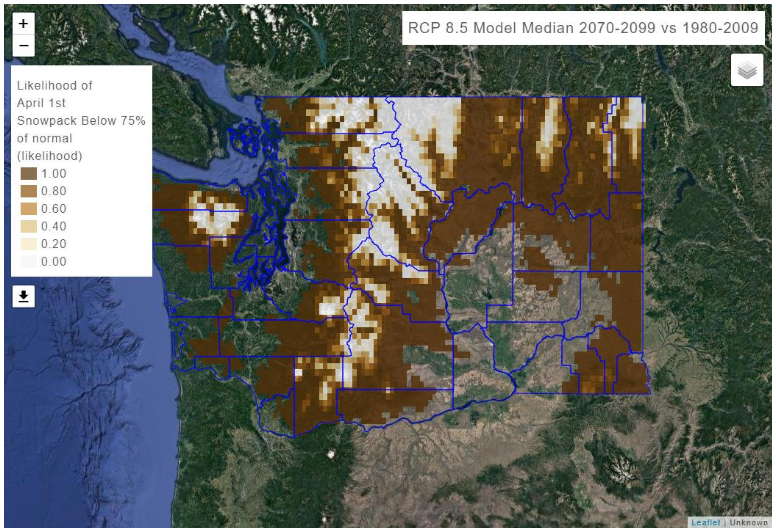



*Expected likelihood of climate and fuel conditions that support wildfire across Washington State for the end of the century (2070-2099) and under a high climate scenario (RCP 8.5). The likelihood of conditions for wildfire indications potential for wildfire damage and disruption.*

## Drought & Agriculture

*Biophysical Impacts:* Climate change is expected to decrease natural water supply in Washington and increase the likelihood of drought. However, the change in likelihood of drought is difficult to model and quantify because drought depends on the complex influence of precipitation, snowpack, and streamflow on overall water supply. Drought can be declared in Washington when and where one or a combination of factors—precipitation, streamflow, snowpack—falls below 75 percent of normal and water users experience hardship. As one example of drought, many low-elevation areas in Washington that currently receive snow are expected to be more likely than not to have snowpack drought (less than 75 percent of normal April 1 snow-water equivalent) by the end of the century (2070-2099).

*Economic Impacts*: An assessment of the 2015 drought by the Washington State Department of Agriculture found that agricultural losses due to the 2015 drought were between $633 million and $773 million. In 2015, irrigated potato acreage in the Odessa subarea fell over 25% primarily because of the dry conditions and lack of water resources that year. A case study of potato production in the Odessa subarea shows that, with supply chain effects included, potato losses from the Odessa Subarea alone accounted for just under $377 million.




*Expected likelihood of snowpack drought (less than 75 percent of normal April 1 snow-water equivalent) across Washington State for the end of the century (2070-2099) and under a high climate scenario (RCP 8.5). Snowpack drought is one indicator of drought for water supplies dependent on spring snowpack.*

## Applications of the Assessment and *Climate Mapping for a Resilient Washington*

**Support state resilience goals and priorities by building local awareness and capacity for resilience.** State agencies enable and support local climate resilience planning and implementation as one way to meet state goals for more resilient communities and natural systems in Washington. Successful implementation hinges, in part, on the capacity and awareness of local governments.

**Support local governments to plan for climate resilience.** The information in this assessment and *Climate Mapping for a Resilient Washington* can support local governments to plan, prepare, and act to build climate resilience. CMRW is integrated into the guidance under development by the Department of Commerce for incorporating climate resilience into local comprehensive plans. When equipped with sufficient knowledge of future climate risks, and given the resources to address them, local governments can act within their authority to build climate resilience.

**Enhance the ability of local governments to secure resilience funding.** Multiple state programs invest funds in local activities that contribute to climate resilience, yet local jurisdictions often lack the information and capacity to ensure that these activities adequately account for risks and incorporate resilience benefits. When local governments are better informed and equipped to understand local climate changes, they will be more likely to successfully secure state and federal funds for risk-reduction activities.

**Assess critical and vulnerable components of the local economy.** Information on current and future biophysical risks can be combined with an economic framework to assess the most critical and vulnerable components of a local economy. This combined information can local governments to assess the economic benefits of climate risk-reduction activities compared to no action.

## Gaps and Next Steps for Statewide Climate Risk Assessment and Resilience Planning

The report, analysis, and web application completed for this proviso can be expanded to (1) include additional analysis of biophysical, economic, and other elements of climate risk assessment, and (2) enhance resilience planning at the state level.

*Climate Risk Assessment*

- Combine information on current and future likelihood of biophysical climate hazards.
- Enable state-level comparison of biophysical climate impacts.
- Assess other elements of climate risk: local exposure, sensitivity, and adaptation.
- Develop a database of assets at risk and estimate their economic value.
- Estimate expected economic impacts with and without adaptive interventions.

*Climate Resilience Planning*

- Identify sector and hazard specific strategies and actions for statewide resilience.
- Identify performance measures and mechanisms for accountability.

## 1. Background and Introduction: Climate Risk Assessment Proviso

The 2021-23 Operating Budget for Washington State funded the Climate Impacts Group (CIG) at the University of Washington to provide updated climate impacts risk assessment in coordination with the office of the Governor.

> ***ESSB 5092 Sec 606(23))*** *$225,000 of the general fund—state appropriation for fiscal year 2022 and $75,000 of the general fund—state appropriation for fiscal year 2023 are provided solely for the climate impacts group in the college of the environment to provide an updated climate impacts risk assessment designed to inform future updates to the statewide climate resilience strategy. The group must coordinate with the office of the governor to refine the scope of assessment. The final report and associated deliverables must be completed and submitted to the governor and appropriate committees of the legislature by December 15, 2022.*

The proviso directed the CIG to refine the scope of the assessment with the office of the Governor and complete a final report for the legislature by December 15, 2022. This report and associated appendix and online materials are the products of that proviso.

**A climate risk assessment that accounts for increases in the likelihood and consequences of climate-related hazards can inform plans for climate resilience and risk reduction.** This assessment is critical to minimize future impacts of climate-related hazards on the state's residents, infrastructure, economy, and natural systems. Approaches to climate risk assessment vary and continue to improve. A comprehensive, state-wide climate risk assessment, comparison and prioritization requires multiple elements to adequately assess risk, which is commonly defined as *likelihood times consequence*. Climate change is a risk multiplier that is widely expected to increase the likelihood and severity, and thus consequences, of most climate-related hazards for which the state already prepares and manages, such as extreme heat, heavy rainfall, riverine and coastal flooding, wildfire, and drought.

**Climate adaptation, or resilience,** is the ongoing process to anticipate, prepare, and adapt to changes in the climate and climate-related hazards to minimize negative impacts on our natural systems, infrastructure and communities and increase their ability to adapt to changing climate conditions.

**Our team, University of Washington Climate Impacts Group and the Washington State University IMPACT Center, compiled information on two key elements of a climate risk assessment: the likelihood of biophysical climate impacts and the potential economic consequences of three key climate-related hazards for Washington.**

1. Biophysical Climate Impacts Assessment: A statewide, sector and location-specific assessment of the biophysical impacts of climate change for which data already exist and that were relatively easy to acquire. The location of climate changes and hazards are mapped across the state. Where data were sufficient, they are presented as the

*change in the likelihood or probability* of climate hazards based on expected changes in the climate through the end of the 21st century.

2. Economic Climate Impacts Assessment: Case studies of the economic consequences of key biophysical impacts for which sufficient data are available. Case studies are focused on three biophysical impacts: extreme heat, wildfire, and drought. Most information on the economic impacts of climate changes and climate-related hazards is based on past events. Although limited in scope, this information can provide insights into potential future economic impacts of climate change when combined with the change in likelihood of climate-related hazards.

**We focused on biophysical climate impacts and their economic consequences because these are two critical science-based elements of a climate risk assessment. These elements will most successfully help to identify and prioritize risk-reduction activities when they are combined with statewide, sector- and location-specific information on other elements of a comprehensive climate risk assessment.**

Four other elements of risk include (1) the *current* likelihood and magnitude of climate-related hazards (underdevelopment by the Emergency Management Department); (2) which populations, natural systems, or assets will be more exposed to climate-related hazards; (3) which populations, natural systems and assets will be more susceptible to climate; (4) the relative level of preparedness, or resilience, of those exposed and sensitive populations, natural systems, and assets. These other elements are not covered in this report; however, we provide some direction on the types of information that can be considered at the local, state and programmatic levels to inform variation in exposure and susceptibility. In Section 7, Gaps and Next Steps, we describe how the information on biophysical and economic climate impacts can be combined with other elements of risk assessment for a holistic assessment of the state's climate risk. We also describe potential next steps towards a climate resilient Washington.

## 2. Purpose and Need: Assessment of Biophysical and Economic Climate Risks

**The current availability of information on changes in the climate and climate-related hazards in Washington State is spotty – varying by hazard, sector, and location.** Decades of climate impacts research and assessment have identified the major climate impact pathways and risks for the state[1]. However, the diversity of local impacts of a changing climate makes it challenging for state and local decision-makers to use this information to effectively plan for resilience and to strategically identify and prioritize risk-reduction activities. At both the local, programmatic level and the larger state or regional level, science-based assessment and mapping of impacts is an important way to plan and prioritize resilience actions. These data are often publicly available but difficult to access and use without substantial training and capacity.

**The information on biophysical climate impacts and economic consequences to Washington compiled for this proviso fulfills a need for foundational, current scientific information that can be readily interpreted and applied to plan and implement efforts that enhance state and local climate resilience.** This includes the information necessary to make coordinated and strategic decisions on resilience priorities and to allocate funds for resilience. This information is relevant and timely given the current and impending funds to support risk-reduction activities that will be generated by state and federal statutes, such as Washington's Climate Commitment Act (CCA) and the federal Inflation Reduction Act and Infrastructure Investment and Jobs Act.

### 2.1 Support Decisions to Allocate Climate Resilience Funding

**Resilience actions funded under the CCA are most likely to successfully build resilience if they are informed by *where and when* droughts, high streamflows, sea level rise and wildfires are expected to intensify in a warming climate.** Funds generated from the auction of greenhouse gas emission allowances under the CCA are to be directed at "the highest risks in the most vulnerable locations." The legislature is responsible for selecting which projects will be funded with auction proceeds, including for the natural solutions account and other programs to increase climate resilience of ecosystems and communities. The natural solutions account is expected to fund projects that protect fish and wildlife habitats, improve aquatic ecosystems and water quality, and protect against floods and wildfires. Actions may include reducing flood risk by restoring floodplains or ensuring sustainable drinking water by increasing water supply.

### 2.2 Support Resilience Planning and Prioritization

**Recent statewide reports and interagency discussions all identified the need for actionable technical information to support a coordinated state response to the most pressing climate hazards facing the state**. The need for scientific and technical information,

[1] Snover, A.K., Mauger, G.S., Whitely Binder, L.C., Krosby, M., Tohver, I. 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers.* State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle

with minimal barriers to access, has been commonly cited in recent reports on potential processes and approaches to build climate resilience in Washington. The state recently explored how to strengthen statewide coordination and prioritization of climate resilience in two reports – *Prioritizing Actions and Investments for Climate Resiliency in Washington*[2], *Climate Governance Report*[3] – and interagency discussions on updating the 2012 *Washington State Integrated Climate Response Strategy*[4].

The 2020 report, *Prioritizing Actions and Investments for Climate Resiliency in Washington*, by the Office of Financial Management (OFM) concluded that, "although Washington invests significantly in projects that contribute to climate resilience, climate resilience is often not the primary focus of such activities." The report highlighted several needs to invest in climate risk reduction to prevent future impacts and better prepare and protect communities from current and future climate-related hazards, while also creating jobs and economic benefits. The report emphasized that, although multiple state agencies plan and invest in climate resilience within their authority, these actions are underfunded and lack a coordinated approach to setting priorities. Two recommendations by OFM were to update the 2012 Integrated Climate Response Strategy and strengthen statutory requirements to incorporate climate resilience into agency projects, programs, and activities.

The 2021 report, *Climate Governance Report* by Cascadia Policy Solutions, similarly advocated for the need to coordinate the state's response and strategies for climate resilience among state agencies and with local jurisdictions. Such strategies are most likely to be successful if they are based on where and by when climate-related hazards are expected to intensify. The 2021 report by recommended (1) coordination of agency risk assessments and response plans, (2) a statewide plan that includes objectives and goals to protect and improve the resilience of ecosystems and communities with strategies to meet those objectives, and (3) coordination between agencies and local municipalities on these strategies. All of these approaches will benefit from the information on biophysical and economic impacts of climate change presented in this report.

### 2.3 Inform Updates to the Washington 2012 Integrated Climate Response Strategy

**The information and products generated by this proviso aim to support several needs for updating the 2012 Integrated Climate Response Strategy.** Any statewide climate resilience plan has a substantial legacy of state agency planning and coordination upon which it can build, while also harnessing new information on climate impacts and economic risks and ensuring that local governments and municipalities also have essential information and capacity. The *Integrated Climate Response Strategy*, led by the Department of Ecology in 2012, aimed to coordinate statewide climate resilience and create a framework to enable state agencies to prepare for and adapt to the impacts of a changing climate. At the time it was drafted, this

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[2] Office of Financial Management.2020. *Prioritizing Actions and Investments for Climate Resiliency in Washington. Report to the Legislature* Ch. 357, Laws of 2020.
[3] Cascadia Policy Solutions 2021.*Climate Governance Report*
[4] Adelsman, H., & Ekrem, J. 2012. *Preparing for a changing climate: Washington State's integrated climate response strategy.* Department of Ecology, Olympia, WA.

strategy was groundbreaking for its depth and breadth of analysis, as well as its long list of contributors, which generated substantial buy-in. The strategy sparked action by agencies to plan for resilience and build the institutional capacity needed to support action. However, progress has since been slow to implement activities aimed at reducing specific climate risks and the vulnerability of Washington State's residents and economic sectors[5].

As the state explores whether and how to update the *2021 Integrated Climate Response Strategy*, critical needs include (1) the scientific basis to identify and prioritize the most pressing climate hazards, (2) a mechanism to ensure that local governments have low-barrier access to this same information so that they can comply with state regulations and requirements for resilience, and (3) an understanding of the potential economic consequences of not acting. This report and associated products compile sector- and location-specific information on the biophysical impacts, make it readily available to local governments across the state, and describe potential economic consequences of not acting to reduce three key climate hazards.

[5] Casola, J., Ziff, D. & Dolšak, N. 2018. *Are Washington State Agencies Preparing for Climate Change?* A report prepared by Climate Impacts Group, University of Washington, Seattle.

## 3. Consultation: Scoping the Climate Risk Assessment

The proviso directed the UW CIG to coordinate with the office of the governor to refine the scope of our assessment. After CIG identified potential elements of a comprehensive climate risk assessment with the governor's office staff, we identified the elements most useful to support prioritization of resilience funds and an update to the 2012 *Integrated Climate Response Strategy*. Staff emphasized the need for information in two areas. The first concerns how biophysical impacts of climate changes and related hazards (e.g., extreme heat, extreme precipitation, drought, wildfire) are expected to vary across the state – which areas will be affected first and worse? The second is the need for information on the economic consequences of climate impacts to compare the financial benefits and costs of risk reduction.

**Given the extensive work on climate resilience by state agencies in the last decade, we consulted with agency staff to determine how an assessment of biophysical climate risks would be most useful to their efforts.** We consulted with the following agencies: Washington Department of Fish and Wildlife, Department of Natural Resources, Emergency Management Department, Department of Ecology, Department of Health, Commerce Department, and the network of agency climate resilience staff through the Interagency Climate Adaptation Network. Through presentations and conversations, we scoped two forms of assessment:

> Option 1: Relative climate exposure across the state to inform statewide resilience policies and funding decisions;
>
> Option 2: Climate risk exposure of local jurisdictions to enhance awareness and capacity to respond to state and federal policies, regulations, and funding opportunities.

**We heard from state agency staff that both options were desired and relevant, and that Option 2 — local government support for climate information — is the greater immediate need.** State agency staff indicated that they have general knowledge of climate impacts and are more able to access existing resources than do local jurisdictions, but they often experience a critical gap in the awareness and capacity of local governments to access and apply climate information. They observed that, in local jurisdictions, planners and officials do not have equitable, inexpensive, low-barrier ways to access relevant climate information to support their efforts to plan, implement local actions, comply with state requirements, and secure state or federal funding for climate resilience. To be successful, local jurisdictions need support. Based on this consultation, we developed Option 2, an assessment of biophysical climate impacts communicated with an interactive web application, *Climate Mapping for a Resilient Washington*, directed at local jurisdictions and designed to support local awareness of climate impacts and build capacity to plan and implement risk-reduction activities.

To ensure that this product would support local governments with state planning requirements and grants related to climate resilience, we conducted a second consultation and review process to solicit feedback on an initial version of the web application. We consulted with state agencies, local governments, private consulting firms engaged in climate resilience, and the Association of Washington Cities. We incorporated their feedback into the final version of the assessment and web application.

## 4. Approach to Climate Risk Assessment: Biophysical and Economic Impacts

The University of Washington Climate Impacts Group and Washington State University IMPACT Center developed two science-based elements of a comprehensive climate risk assessment: biophysical climate impacts and economic impacts of climate-related hazards.

**Biophysical Impacts:** The UW CIG summarized projections of the magnitude and timing of changes in the climate and climate-related hazards in Washington State. In this report, we provide a high-level summary of the approach used to compile and present data on biophysical climate impacts for Washington State. Detailed results are presented in an interactive web application, *Climate Mapping for a Resilient Washington*, available online.

**Economic Impacts:** The WSU IMPACT Center developed a high-level summary of potential impacts to Washington's economy of three key climate-related hazards: extreme heat, wildfire, and drought. We used a case study approach focused on past impacts. In this report, we summarize the approach used for the economic assessment and key results. Additional detail and methods are in Appendix A.

### 4.1 Approach to Assess Biophysical Impacts of Climate Change in Washington

We compiled and curated existing data sources for projected changes in the climate and related hazards in Washington. Climate datasets include projections of precipitation and temperature, sea level rise, snowpack and natural streamflow simulated with hydrologic process models, and wildfire simulated with a fire and vegetation model. Changes are mapped across the state. Where data are sufficient, these are presented in terms of the *change in the likelihood of hazards* based on the projected climate through the end of the 21st century.

Climate data typically include projected changes in the climate for multiple future scenarios based on a set of assumptions about concentrations of greenhouse gases in the atmosphere and different global climate models. Datasets also include multiple values at different timesteps and spatial scales. Of these, we selected a subset of scenarios, time periods, and values for a suite of changes in the climate and related hazards that are common in Washington and useful for assessment and planning across multiple sectors. This subset includes changes in the climate and hazards summarized in the most recent assessments for Washington[6] and the Puget Sound region[7]. We augmented information in these assessments with more recent data and analysis when available. No new climate modeling was conducted for this assessment, but some data were analyzed to calculate seasonal values, key indicators, and changes in the likelihood of hazards in Washington. Additional details and data sources are in Appendix A.

[6] Snover, A.K., Mauger, G.S., Whitely Binder, L.C., Krosby, M., Tohver, I. 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers.* State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle

[7] Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. *State of Knowledge: Climate Change in Puget Sound.* Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle.

***Climate hazards and indicators included in Climate Mapping for a Resilient Washington***

| Climate Hazards | Climate Indicators |
|---|---|
| Extreme Precipitation | Heavy Precipitation Magnitude (percent change)<br>Extreme Precipitation Magnitude (percent change)<br>1 inch Precipitation Days (change in days)<br>2 inch Precipitation Days (change in days)<br>3 inch Precipitation Days (change in days) |
| Extreme Heat | Summer Maximum Temperature (change in °F)<br>Hot Days (change in days)<br>90°F Maximum Humidex Days (change in days)<br>65°F Minimum Humidex Days (change in days)<br>Heating Degree Days (change in degree-days)<br>Cooling Degree Days (change in degree-days)<br>August Stream Temperature (°F) |
| Drought | Total Annual Precipitation (percent change)<br>Late Summer Precipitation (percent change)<br>Precipitation Drought (likelihood)<br>Warm Season Streamflow (percent change)<br>Summer Streamflow (percent change)<br>Duration of Low Streamflow (change in days)<br>Low Streamflow (percent change)<br>Streamflow Timing (ratio)<br>Snowpack Drought (likelihood) |
| Flooding | Peak Streamflow (percent change)<br>Frequency of Peak Streamflow (return interval) |
| Reduced Snowpack | Snowpack (percent change)<br>Streamflow Timing (ratio) |
| Sea Level Rise | Likely Sea Level Rise (ft)<br>High Sea Level Rise (ft) |
| Wildfire | High Fire Danger Days (change in days)<br>Wildfire Likelihood (likelihood) |

***Planning sectors included in Climate Mapping for a Resilient Washington***

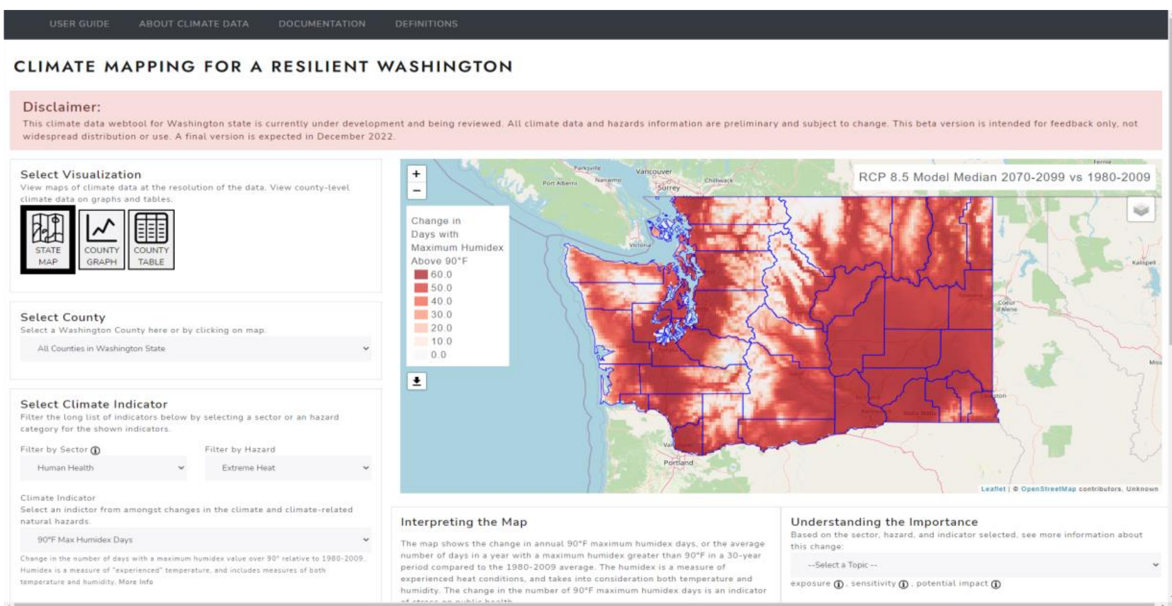
| Sectors | |
|---|---|
| Agriculture<br>Ecosystems<br>Human Health<br>Buildings & Energy<br>Zoning & Development<br>Water Resources | Transportation<br>Economic Development<br>Emergency Management<br>Cultural Resources & Practices<br>Waste Management |

### 4.1.1. Climate Mapping for a Resilient Washington

Rather than list and explain the magnitude and timing of biophysical climate risks in a report, we developed an interactive web application, *Climate Mapping for a Resilient Washington*. This interactive web application compiles all such information in one place and maps climate changes and hazards across the state. Hazards are linked to sector-specific impacts, along with descriptions of the factors that affect exposure and sensitivity locally.

***Although national climate resilience web applications provide similar functionality, Climate Mapping for a Resilient Washington is designed to meet the specific needs of Washingtonians by including expected changes in streamflow, snowpack, drought, and wildfire.***

CMRW includes climate hazards that are critical to understand in order to manage the state's natural resources and protect residents and communities but are not commonly included in national-scale applications. National applications typically include only the indicators that are consistently available for the whole country, such as temperature and precipitation.

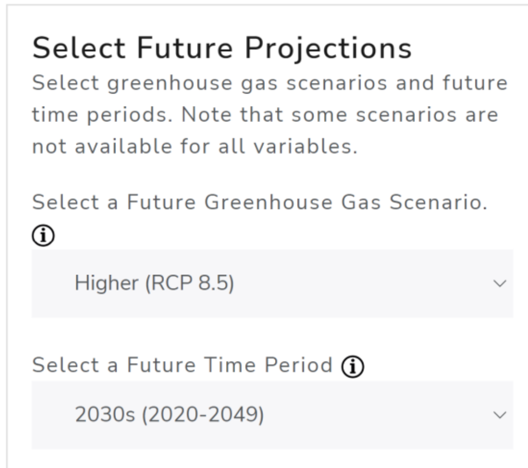



Users can filter data and customize information for their specific planning, assessment, funding and outreach applications. For each hazard-sector combination, a subset of indicators is shown that is most relevant for that sector. For example, users interested in extreme heat and human health can select from three indicators of heat effects on human health: summer maximum temperature, days above 90°F maximum humidex, and days above 65°F minimum humidex days. Users interested instead in extreme heat and impacts to the transportation sector-, will see a different indicator relevant to that sector, the number of hot days above 100°F. A description of the indicator alongside the map, explains its relevance to the sector. The sectors shown are those commonly used in local and regional planning, such as comprehensive planning.

**Future Time Periods and Climate Change Scenarios**

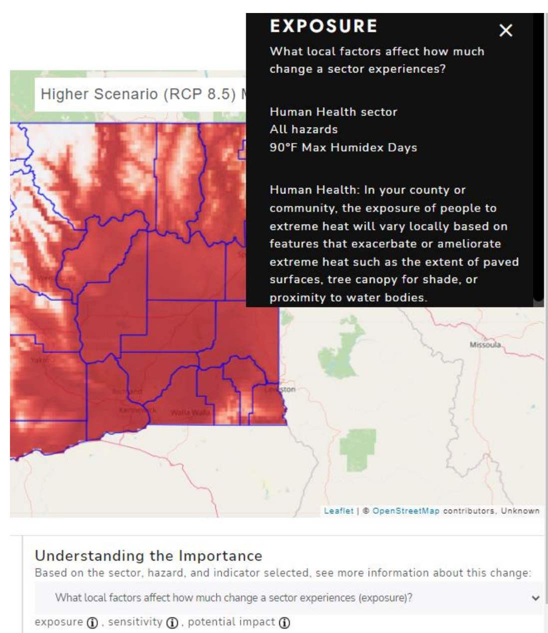
Users can filter data for the time periods that align with their planning horizon. Changes in the climate will progress over time, in most cases intensifying with more warming. Users can view changes for multiple future time periods through 2100, as consistent with their planning needs. As is standard practice in climate science, changes in the climate are summarized as the average over 30-year periods to illustrate long-term climate trends rather than short-term climatic variability. The decade labels are the center decade for each 30-year time period, for the example the 2030s refers to the 30-year period of 2020-2049.

Users can filter data for one or more climate scenarios; options vary by indicator climate indicators. Projected changes in the climate are a function of scenarios of future concentrations of greenhouse gases in the atmosphere (labeled Representative Concentration Pathways, RCPs), which are used by the international climate science community in computer models to simulate changes in the climate. Greenhouse gas scenarios are based on a standard set of assumptions about technology, humanity and policy decisions. The scenarios describe different climate futures; all are possible depending on near-term emissions.



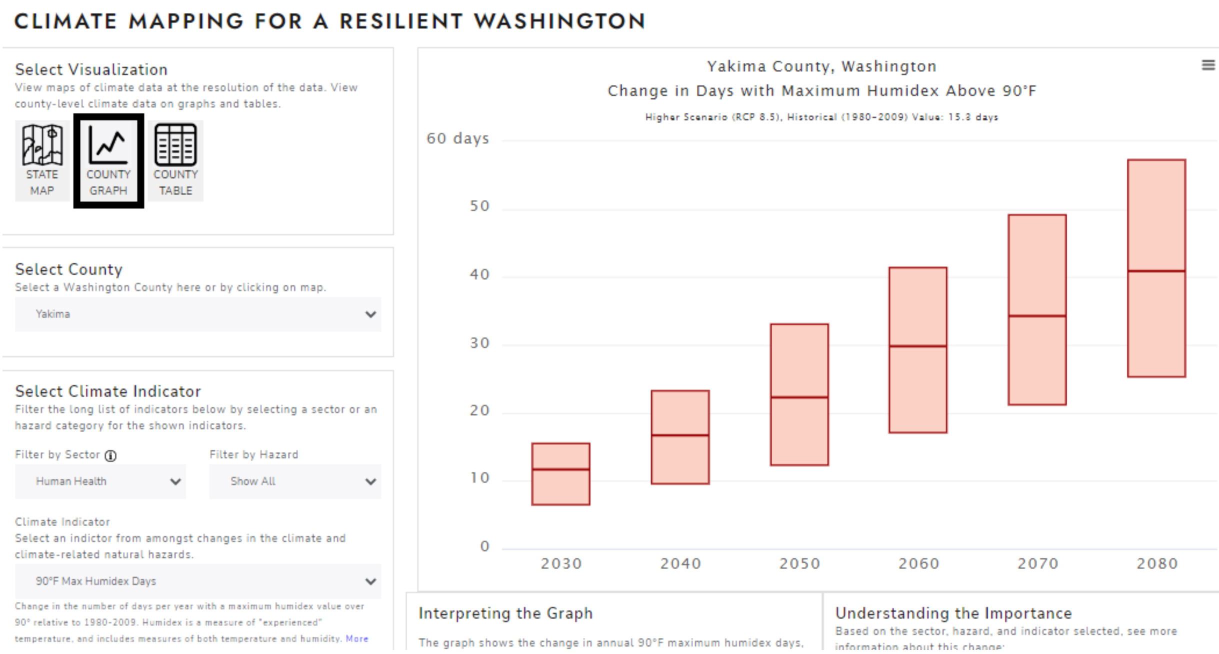

**Local Variation in Exposure, Sensitivity, and Impacts**

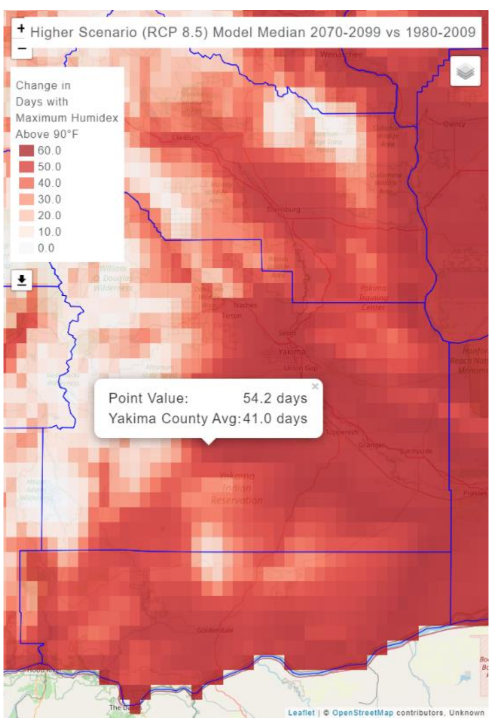
Information on biophysical climate impacts alone does not capture local variation in populations, assets, and ecosystems that will determine their vulnerability to climate hazards. At the local level, sub-populations, assets, and ecosystems will be more *exposed* to changes because of their location within a county or community. Biophysical impacts also do not capture local variation in sub-populations, assets, or ecosystems that will be more *sensitive*, or susceptible, to these changes because of factors that predispose them to climate impacts, such as pre-existing conditions and non-climatic stressors. Local information on exposure and sensitivity is a product of a climate vulnerability assessment best derived from local data, knowledge, and expertise, and it is also critical for a comprehensive risk assessment. *Climate Mapping for a Resilient Washington* guides users in the type of data and information to consider in assessing local variation in vulnerability as the first step towards a local climate vulnerability assessment.



**County-level Summaries**

*Climate Mapping for a Resilient Washington* allows users to select a county and provides a summary of changes in the climate specific to that county. Whether in Stevens, Clallam, or Yakima counties, local planners, policy-makers, and residents can all access information specific to their location. Graphs and tables with county-specific values can be downloaded and integrated into reports, plans, or presentations.




**YAKIMA COUNTY**
**CHANGE IN DAYS WITH MAXIMUM HUMIDEX ABOVE 90°F**

| | MODEL MEDIAN | MODEL RANGE (10TH TO 90TH PERCENTILE) |
|---|---|---|
| 1980-2009 | | |
| Historical Baseline | 15 days | 14 to 17 days |
| 2020-2049 | | |
| Higher Scenario (RCP 8.5) | 11.7 days | 6.4 to 15.4 days |
| Lower Scenario (RCP 4.5) | 9.6 days | 4.3 to 14.4 days |
| 2030-2059 | | |
| Higher Scenario (RCP 8.5) | 16.8 days | 9.5 to 23.2 days |
| Lower Scenario (RCP 4.5) | 13.0 days | 5.2 to 17.9 days |
| 2040-2069 | | |
| Higher Scenario (RCP 8.5) | 22.4 days | 12.3 to 33.0 days |
| Lower Scenario (RCP 4.5) | 14.4 days | 7.3 to 23.8 days |
| 2050-2079 | | |
| Higher Scenario (RCP 8.5) | 29.9 days | 17.0 to 41.4 days |
| Lower Scenario (RCP 4.5) | 16.9 days | 9.6 to 28.0 days |
| 2060-2089 | | |
| Higher Scenario (RCP 8.5) | 34.3 days | 21.2 to 49.1 days |
| Lower Scenario (RCP 4.5) | 19.1 days | 11.2 to 31.0 days |
| 2070-2099 | | |
| Higher Scenario (RCP 8.5) | 41.0 days | 25.3 to 57.2 days |
| Lower Scenario (RCP 4.5) | 21.4 days | 13.0 to 31.6 days |

### 4.2 Approach to Assess Economic Impacts of Climate Change in Washington

As challenging as it is to determine the likelihood of biophysical impacts associated with climate change, the associated economic risks add even more complexity. When biophysical impacts occur, this leads to economic changes in quantities supplied and demanded in specific markets. In addition to immediate economic damages, climate impacts often affect transportation and supply chain networks, resulting in mid- and long-term market disruptions.

The economic framework for estimating economic disruptions due to climate hazards has largely utilized multi-disaster footprint models (MDFM), which build from the standard input-output (I-O) models similar to that developed and curated by OFM over the past several decades. Additional data and research are needed to determine the sensitivity of industrial and household activity to these changes in the climate to connect changes in the climate with the economic output variables embedded in I-O models.

We assessed the potential economic damages associated with three climate-related hazards — extreme heat, wildfire, and drought — and how they spread through an economy. We draw lessons from where risks have been realized and economic consequences have been measured. Where possible, we focus on the economic consequences of hazards in Washington. Where the economic consequences in Washington have not been measured, we use research from other regions and discuss the implications for Washington. The case studies focus on market activities and asset values to provide insight into the potential economic consequences Washington has experienced and is more likely to experience in the future. Here we introduce three case studies of three climate-related hazard and their economic consequences (Sections 4.2.1, 4.2.2, and 4.2.3). We discuss the results in Section 5.

#### 4.2.1 Case Study: Extreme Heat and Health

There are a variety of channels by which productivity losses are generated during periods of, and around, extreme heat days. Individual productivity may decline while on the job, but absenteeism occurs as well, and is more frequent among employees receiving paid leave[8]. A simulation model was developed based on literature regarding extreme heat and economic output as measured by GDP. Industries most susceptible to extreme heat (e.g., agriculture, manufacturing, construction) are likely to see reductions in economic output of roughly 2% for each day of extreme heat[9]. Reductions in productivity account for both absenteeism and lower productivity output for employees that continue to work.[10] This results in reduced business-to-business activity in those periods. Total productivity losses do not account for the loss in human life and the non-market values of premature mortality or other non-monetary damages caused by extreme heat. Once direct industry losses are calculated they may be run through an I-O or

[8] Zivin and Neidell 2014. Temperature and the Allocation of Time: Implications for Climate Change. *Journal of Labor Economics* 32 (1): 1-26.
[9] Somanathan, E. et al. 2021. The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing. *Journal of Political Economy* 129 (6):1797-1827.
[10] Care must be taken to ensure that overlap (co-morbidity) between the extreme heat and drought impacts are not double counted and overstate the economic impacts. In this case we are not summing the drought and extreme heat impacts, so we do not address such double counting.

MDFM, as described in the Appendix B. This modeling framework will show the reductions in variable expenses that ultimately reduce the money flowing through the supply networks in the state. All such lost economic activity may be directly tied to the extreme heat event, without which more economic activity and productivity would have happened.

### 4.2.2 Case Study: Wildfire

Estimates of the economic losses associated with Washington's 2021 wildfire season are derived from data collected on California's 2018 wildfire season. In 2018 approximately 2,320,567 acres of land burned in California[11]. A comprehensive economic analysis of the 2018 fire season in California is available, but no such analysis has been done for recent wildfire seasons in Washington.[12] Because of this we draw from the California research to discuss potential damages in Washington.[13] In California, 2018 was one of the worst fire seasons on record. Nearly 2% of the state was burned by over 8,500 fires. The economic analysis of the 2018 wildfires estimated capital losses (replacement costs for assets; morbidity, mortality, and health costs including lost working time and medical expenses); transportation and adaptive behaviors (e.g., traffic disturbances, lost working time from active avoidance); and all associated forward linked economic multiplier effects.

Based on measures of capital asset losses (not including the lost timber), healthcare costs, and indirect costs, total damages to California in 2018 amounted to $148.5 billion. Only 27% of this amount came from direct capital losses, with healthcare and indirect costs contributing 31.5% and 41.5%, respectively. Capital costs did not account for natural resources losses, which would have been substantial and contributed to forward linked losses for the agricultural and timber processing industries. Thus, the $148.5 billion likely understates the true impacts of the 2018 wildfires. The total damage estimate of $148.5 billion combined with a total area burned of 1.9 million acres leads to a damage estimate of roughly $78,158 per acre. Although there are differences between California and Washington, the per acre damages can be used to estimate wildfire damages in Washington in 2021 based on the total area burned.

### 4.2.3 Case Study: Water Shortage and Potato Production

We conducted a case study of the water shortage and drought conditions of 2015 specifically on the potato production and processing sectors of the Odessa Subarea in Washington. We used an Input-Output model, similar to that developed and housed at OFM,[14] to determine the total regional economic losses from the reductions in value produced. Potatoes are one of nature's water balloons, so without available moisture and excessively dry conditions, yields and quality are greatly reduced. Losses in potato production and processing in 2015 are calculated as the difference between the decade average yields and the 2015 yields. We attribute most of that difference to the absence of quality irrigation water and the absence of the moisture in the soil

[11] Wildland Fire Emissions Inventory System https://wfeis.mtri.org/stats
[12] Wang, D et al. 2021. Economic footprint of California Wildfires in 2018. Nature Sustainability. 4:252-260.
[13] Similarities between home value distributions and the state forests are unlikely, i.e., harvest rates, forest density, timber mix, etc. Forest fires have disparate impacts compared with grassland or shrubland fires.
[14] The Washington Input-Output Model available from Office of Financial Management at https://ofm.wa.gov/washington-data-research/economy-and-labor-force/washington-input-output-model

and atmosphere. Yield losses reduced spending throughout the potato value chain. The analysis captured the total lost activity throughout those value chains, including the lost income to households. Industries such as chemical and fertilizer manufacturers, retail trade, and transportation were all damaged by the reductions in farm income. Households within the supply chain had less income and prices for processed potatoes rose. Extreme heat was not considered as a factor leading to yield loss and there is some overlap between the drought and the extreme heat experienced that year. Appropriate measures are needed in future analysis to ensure that comorbidity issues do not result in double counting of economic impacts and modeling can isolate the portion of yield loss due to drought vs. extreme heat.

## 5. Results Three Climate Hazard-Sector Combinations: Extreme Heat and Human Health, Wildfire and Infrastructure, and Drought and Agriculture

### 5.1 Extreme Heat and Human Health in Washington

Three separate sources of information about extreme heat risk to human health and response options can be combined for a holistic approach to risk assessment and resilience planning. These sources are expected changes in extreme heat (discussed in Section 5.1.1), economic impacts (5.1.2), and a problem-oriented evaluation of variation in exposure, sensitivity, and capacity to adapt (5.1.3)[15].

#### 5.1.1 Expected Changes in Extreme Heat

Both average temperatures and extreme high temperatures are expected to increase across the state, with potential consequences for human health and well-being. Not all locations and populations will be equally exposed or susceptible to this hazard. Without sufficient efforts to adapt, extreme heat is expected to increase the risk of heat-related illness and other severe health complications that can lead to hospitalization and death. For example, in King County when daily maximum or minimum temperatures reach or exceed the historical 99th percentile[16], risk of death increases 10 percent, hospitalizations rise 2 percent, and calls for emergency services increase up to 14 percent.

Extreme heat can be characterized in several ways. One of the most effective predictors of extreme heat risk for people is humidex, an index that measures the combined effects of temperature and humidity. A maximum daytime humidex above 90°F and a maximum nighttime humidex above 65°F corresponds to higher risk of heat-related illness, hospitalization and death. Nighttime high events are currently increasing more than daytime high events in the Pacific Northwest[17] and this can be especially harmful to human health in regions with limited experience with warm nights and few households with indoor air conditioning.

More extreme heat due to climate change is only one factor that affects the exposure of local populations to heat. Local conditions within a county or community will further intensify or ease the exposure of certain areas and populations to extreme heat. Examples include the amplifying effects of paved surfaces and urban heat islands[18] or the cooling effects of water bodies and tree canopy cover. The sensitivity, or susceptibility, of populations within a community or county will also depend on physiological tolerances and aggravating circumstances.

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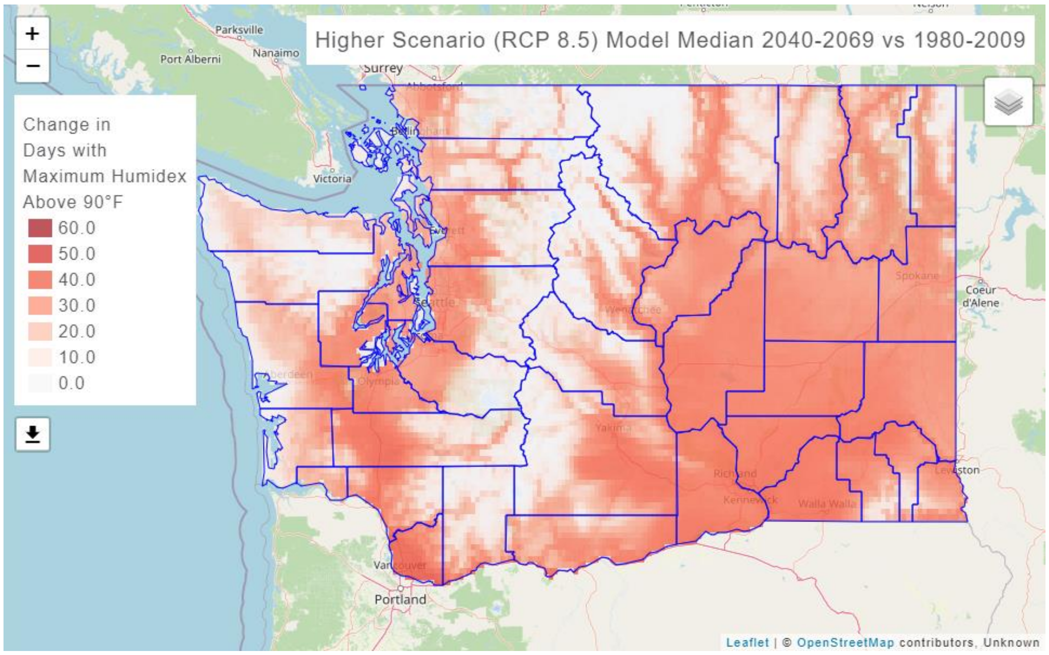
[15] Additional information on this available at https://cig.uw.edu/projects/a-problem-oriented-approach-to-washington-states-climate-response-strategy/

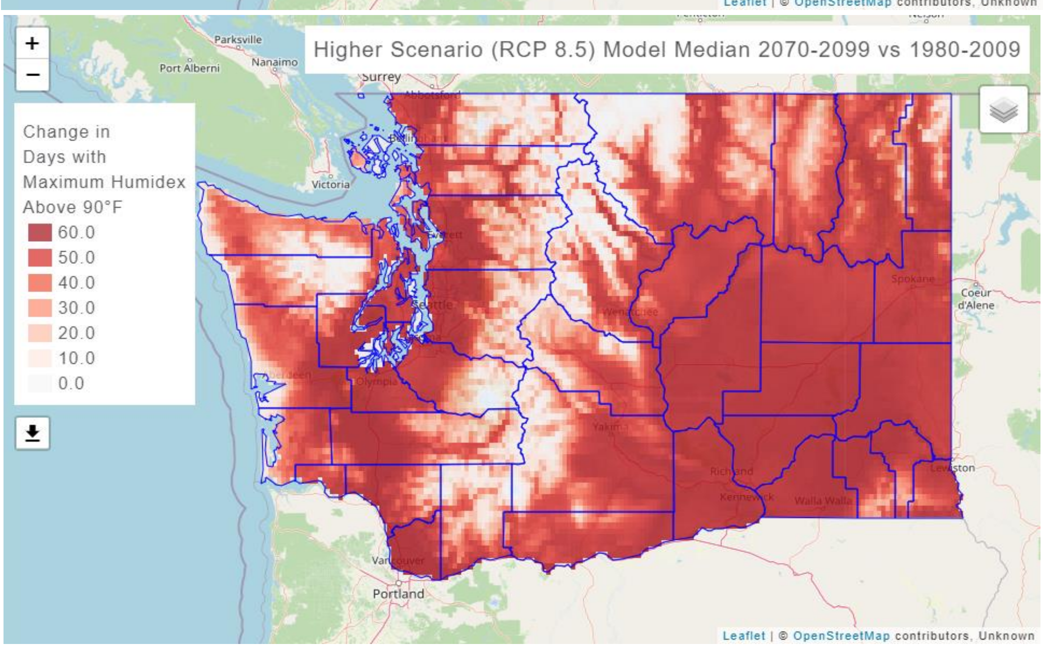
[16] A 99th percentile heat day in King County, based on observations between 1980 and 2010, is a day when the humidex exceeds 97°F (36.1°C). A humidex of 36.1°C is roughly equivalent to 81°F and roughly 70% relative humidity–the average humidity in Seattle in August–or 97°F with 30% relative humidity–the relative humidity recorded throughout western Washington during the 2021 heat wave.

[17] Bumbaco, K.A.et al.2013. History of Pacific Northwest Heat Waves: Synoptic Pattern and Trends. *Journal of Applied Meteorology and Climatology*. 52 (7) 1618-1631.

[18] Areas that lack vegetation and have a concentration of development are considered urban heat islands because they become relatively hotter than outlying areas. The urban heat island effect can increase temperatures 1-7°F during the day and 2-5°F at night relative to adjacent rural areas.

**By the 2050s (2040-2069), the number of days per year with a humidex above 90°F is expected to increase across the state and in some regions more than others**[19]. Lower elevations in the Puget Sound region and eastern Washington are expected to be more exposed to extreme heat than on the outer coast and higher elevation areas. By the 2080s (2070-2099 average compared to 1980-2009), extreme heat will intensify and the differences between a higher (RCP 8.5) and lower (RCP 4.5, not shown) scenario are expected to be more apparent.



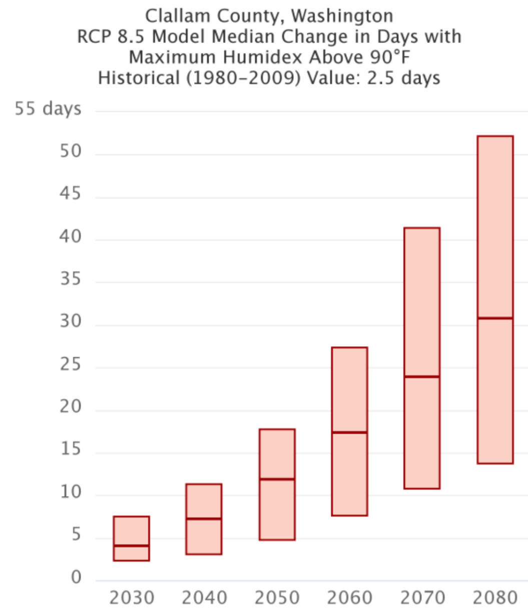




[19] Abatzoglou J.T. and Brown T.J. 2012. A comparison of statistical downscaling methods suited for wildfire applications. *International Journal of Climatology*. 32: 772-780.

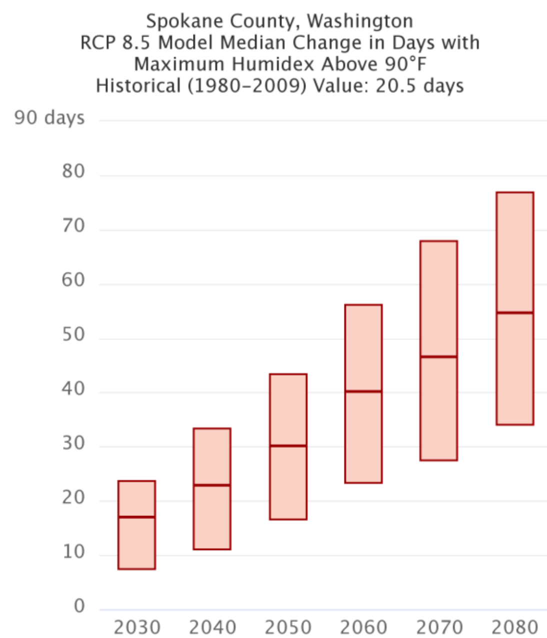
**County-Level Variation in Extreme Heat Exposure**

Exposure to extreme heat varies across the state. County-level summaries from *Climate Mapping for a Resilience Washington* show local changes that can help planners and decision makers understand vulnerability and prioritize climate hazards. Counties along the outer coast, for example, will have more moderate increases in extreme heat.

Counties in western Washington currently have few days per year with a maximum humidex over 90°F. They are expected to have large increases in the number of days above this threshold as the climate warms, especially for a higher climate scenario (RCP 8.5). For example, on average, Clallam County historically (1980-2009), has had only 2.5 days per year above a humidex of 90°F, but the county is expected to increase to 30.8 (range 13.7-52.1) such days by the end of the century (2070-2099) for a high scenario (RCP 8.5). Although this number of high humidex days will remain well below the number of high humidex days for counties in central and eastern Washington, residents in western Washington are less adapted to heat and are therefore at greater risk of impacts to human health.




Counties in eastern Washington currently have many more days per year with a maximum humidex above 90°F compared to counties in western Washington. This number of days is expected to increase to almost the full length of the summer season. For example, by the end of the century (2070-2099), Spokane County's days above a 90°F humidex are expected to increase from 20.5 days per year (historical average, 1980-2009) to 54.7 (range 33.9-76.8) days for a high climate scenario (RCP 8.5). Values are shown for the median and the range ($10^{th}$-$90^{th}$ percentile) of multiple climate models although there is a range in the magnitude of changes that models project, all models show the same direction of change, an increase.



### 5.1.2 Economic Impacts of Extreme Heat for Human Health

Washington State currently supports over 4.4 million jobs and over $609 billion in gross state product annually. Based on model simulation results, one year of heat-related activity losses results in direct losses to industry sales of over $426.1 million-$178.3 million in lost gross state product and losses of over 1,481 full-time equivalent jobs. These losses are only the direct effects of extreme heat on human productivity; other direct losses (e.g., in agricultural yields and premature mortality) are not captured in these figures. Thus, these results represent a lower-bound estimate of the potential GDP impacts of excess heat.

The economic impacts of extreme heat on human activity do not stop with direct effects. Reduced output and gross state product result in lower business and employee income. Lower business income, in turn, reduces business-to-business transactions, which reduces demand throughout the state's supply networks, slows port and transportation activity, and reduces the income to all vendors of the directly affected industries. Total reduced sales from these losses are over $175.8 million: $111.4 million in GSP reduction and 941 fewer FTE jobs. Total expected losses from this source of economic damage are outlined below. Of the results reported, total losses to the state from reduced business activity represents $15.3 million. This does not include reduced household tax receipts, social insurance taxes, or corporate and excise taxes.

***Summary of simulated economic losses from heat induced productivity losses in Washington***

| | Sales | GSP | Income | Jobs |
|---|---|---|---|---|
| Direct | -$426,195,401 | -$178,300,903 | -$115,017,720 | -1,487 |
| Indirect | -$158,470,052 | -$86,824,700 | -$53,853,030 | -676 |
| Induced | -$175,884,255 | -$111,469,037 | -$60,595,758 | -941 |
| **Total** | **-$760,549,708** | **-$376,594,641** | **-$229,466,509** | **-3,104** |

### 5.1.3 Strategies and Actions: Extreme Heat and Human Health

Certain populations are more vulnerable to extreme heat than others, a fact that is masked by population-wide health statistics. Vulnerability to extreme heat is a function of a person's physiological sensitivity to extreme heat, the duration and intensity of their exposure, and their capacity to adapt to or avoid heat stress. Some populations are more sensitive to heat-related hospitalization and death. These include older adults and infants, people with pre-existing medical conditions (e.g., cardiovascular disease, kidney disease, respiratory disease), people who are unable to care for themselves, are socially isolated or bedridden, or those living or working in an urban heat island. Households without access to air conditioning (AC) or public cooling facilities, such as cooling centers, splash pads, or parks will also be more sensitive to exposure to extreme heat.

Socioeconomic factors largely determine the inequitable impact of extreme heat. Pollution contributing to heat-sensitive medical conditions, and urban heat islands that amplify heat exposure, are not evenly distributed across a metropolitan area. These inequities are closely linked to the state's legacy of racially discriminatory housing policies and decades of disinvestment. Neighborhoods that were formerly redlined generally have more air pollution, fewer trees, and an abundance of heat-absorbing artificial surfaces, causing urban heat islands that contribute to physiological maladies linked to a higher risk of death during heat waves.

The responses of state and local agencies to health risks from extreme heat have been largely opportunistic and limited in scope. As examples: the Washington State Department of Labor & Industries has expanded heat safety standards for outdoor workers, requiring more rest during hot days; the Department of Social and Health Services has issued guidance to its providers to closely monitor residents for signs of heat-related illness during heat waves; and King County has prioritized the protection and expansion of urban tree canopy and greenspace in the areas of greatest need. These measures illustrate the diverse actors and strategies for reducing heat-related illness and death. However, the death toll directly caused by the heat wave in 2021, 95 heat-related deaths in one week, illustrates the significance of heat-related illness and death. Without further adaptation, health impacts, especially for certain sensitive populations, will continue and worsen from climate change.

Multiple factors drive heat-related hospitalizations and death: sensitivity, exposure, and inadequate capacity to adapt. Framing the problem of managing effects of extreme heat on health to include these factors enables a thorough identification of strategies and actions that reduce these drivers of vulnerability. We present a subset of adaptation actions for human health and extreme heat to illustrate potential adaptive strategies across the four phases of emergency management: mitigation, preparedness, response, and recovery. A portfolio of policies—not a single, uniform solution—will most effectively reduce the risk of vulnerable populations to heat-related illness and death. A portfolio approach also provides critical redundancy in support systems, which can save a life during a heat emergency.

***Heat-related adaptation actions at different phases of emergency management in response to factors contributing to vulnerability to extreme heat***

| | Mitigation | Preparedness | Response | Recovery |
|---|---|---|---|---|
| Sensitivity | Address external factors driving preexisting conditions such as cardiovascular, kidney, and respiratory disease (e.g., air pollution, lead poisoning)<br><br>Discourage unhealthy behaviors around diet and nutrition (e.g., foods high in sodium, fat, and sugar) | Expand informed consent to include heat sensitivity among individuals taking medications that affect the body's ability to maintain homeostasis<br><br>Use community- based networks to monitor vulnerable individuals and households<br><br>Train social workers and direct care workers on how to spot and treat HRI | Increase EMS staffing during heat events to respond to increased calls for help<br><br>Increase the number of ventilators and other life-saving interventions available for healthcare workers | Increase access to healthcare to identify/address illnesses and heat-contributing causes of death (e.g., medical screening and physiological monitoring) |
| Exposure | Increase shade and vegetation in urban heat islands through building codes, land use planning, or urban forestry initiatives<br><br>Increase use of cool surfaces in urban heat islands to increase albedo effect of pavement and rooftops | Improve outreach and culturally specific communication to neighborhoods within urban heat island<br><br>Mandate cooling periods for workers; encourage beneficial behavioral strategies, such as hydration and rest | Deploy infrastructure, such as splash pads or misters for localized cooling<br><br>Improve use of cooling centers by addressing issues with access, misinformation, and stigma | Use surveillance data to improve/refine heat response plans (e.g., health sensitivity-vulnerability maps, EMS call data)<br><br>Apply for FEMA funding, such as Public Assistance or Hazard Mitigation Grant Program to reimburse emergency protective measures and/or finance future heat mitigation projects |
| Adaptive Capacity | Leverage flexible funding assistance programs to improve access/utilization of residential AC, e.g., LIHEAP, Community Development Block Grant Program, 1115 Medicaid waivers.<br><br>Encourage diversification and growth of summer season electric generation to improve reliability of grid | Partner with property holders that have large, indoor spaces with working AC (e.g., malls, churches)<br><br>Increase touch points in communicating how to diagnose onset of HRI and ways of reducing heat stress, such as increasing hydration, reducing physical exertion, avoiding sun exposure, and cooling the neck<br>Integrate acclimatization into occupational heat safety rules | Open cooling centers; extend hours of existing public facilities with AC, such as libraries<br><br>Improve access and safety at beaches and swimming pools<br>Deploy mobile teams to distribute water and cooling accessories or provide transportation to cooling centers | Bolster energy-assistance programs to help vulnerable populations pay higher utility bills resulting from running AC during instances of extreme heat |

## 5.2 Wildfire Likelihood and Infrastructure in Washington

### 5.2.1 Expected Increases in the Likelihood of Wildfire

Climate change is expected to increase both the length of the fire season[20], and the frequency and area burned by wildfires in Washington[21]. Higher temperatures and drier conditions in summer reduce the moisture in live and dead vegetation (e.g., fuel), creating conditions that enable fires to burn more easily and spread more quickly over larger areas. Fires may also burn with greater intensity and more severely in ecosystems where these climate conditions are combined with management practices that have increased the amount of vegetation, such as exclusion of small, low-severity fires or the introduction of flammable invasive plant species.

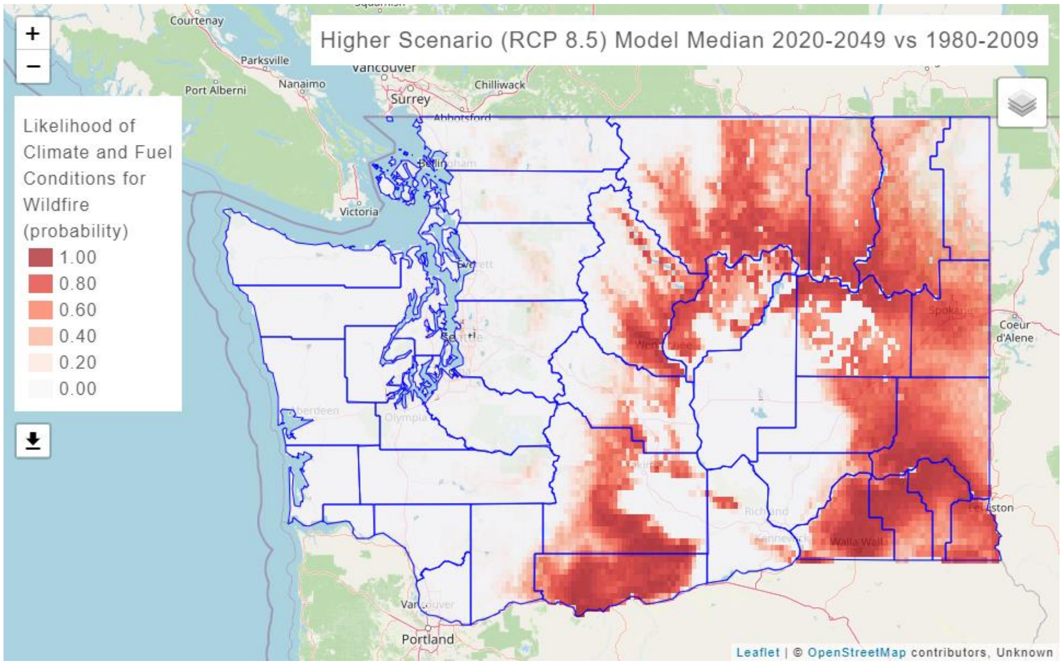
Wildfire is a critical component of most ecosystems in Washington. Characteristic fires provide ecological benefits (e.g., reduce fuels, create wildlife habitat, and enable regeneration of certain plant species), but large and uncharacteristically intense wildfires that burn into communities in the wildland-urban interface (WUI)[22] can cause significant economic losses at the state and local level, ecological consequences, and be harmful, even fatal, for humans. Wildfires of the last decade have also highlighted that nowhere in Washington is immune to poor air quality from wildfire smoke.

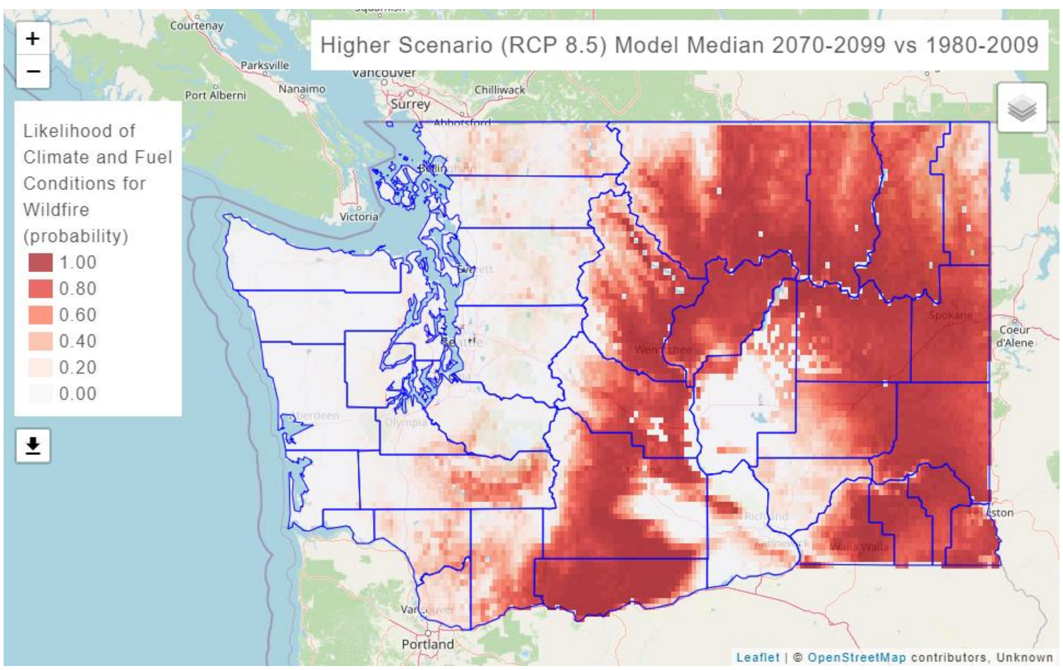
Similar to extreme heat, not all locations and sub-populations in the state will be equally exposed to a higher likelihood of wildfire in a warming climate. Infrastructure and people located in the WUI are a greatest risk. An often-overlooked contributor to increasing wildfire risk in Washington is the expansion of the WUI. From 2000 to 2010, Washington saw a 14 percent increase in the total WUI area. Many people building and moving into the WUI may be unaware of current or future wildfire risk.

Not all subpopulations or infrastructure in the WUI and exposed to a high likelihood of wildfire will be equally susceptible to the impacts of wildfire. For example, non-English speaking populations may have less access to resources and information related to wildfire preparedness or evacuation. Low-income populations and those with substandard housing may have fewer resources or less access to resources to help recover after a wildfire. Outdoor workers in the agriculture, construction, and recreation sectors may be more susceptible to wildfire smoke. Similarly, inherent characteristics of infrastructure, such as the materials that make up buildings and energy infrastructure, can make it more or less susceptible to fire.

[20] Jolly, M. W. et al., 2015. Climate-induced variations in global wildfire danger from 1979 to 2013. Natural Communications. 6: 7537.
[21] Sheehan, T., D. Bachelet, K. Ferschweiler. 2015. Projected major fire and vegetation changes in the Pacific Northwest of the conterminous United States under selected CMIP5 climate futures. Ecological Modeling. 317:16-29
[22] The wildland-urban interface (WUI) are areas where wildlands and structures meet or intermingle. It refers to proximity of structures and natural ecosystems (e.g., forests) and does not indicate risk.

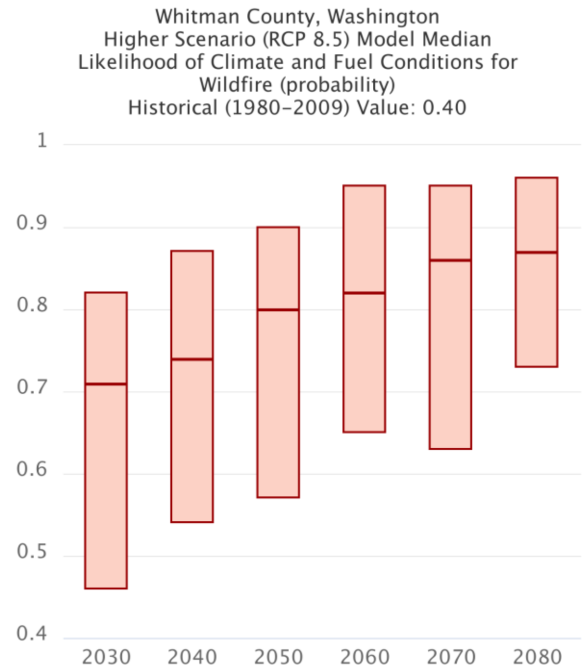
**By the 2050s (2040-2069), the likelihood of climate and fuel conditions that can support wildfire in any year are expected to increase throughout much of the state.** The likelihood of wildfire conditions is expected to initially increase in central and eastern Washington, consistent with where wildfire is already most likely. By the end of the century (2070-2099 average compared to 1980-2009 average), the likelihood of conditions that support wildfire is expected to increase more in those areas, as well as in western Washington, especially southwestern Washington where current wildfire likelihood is low.



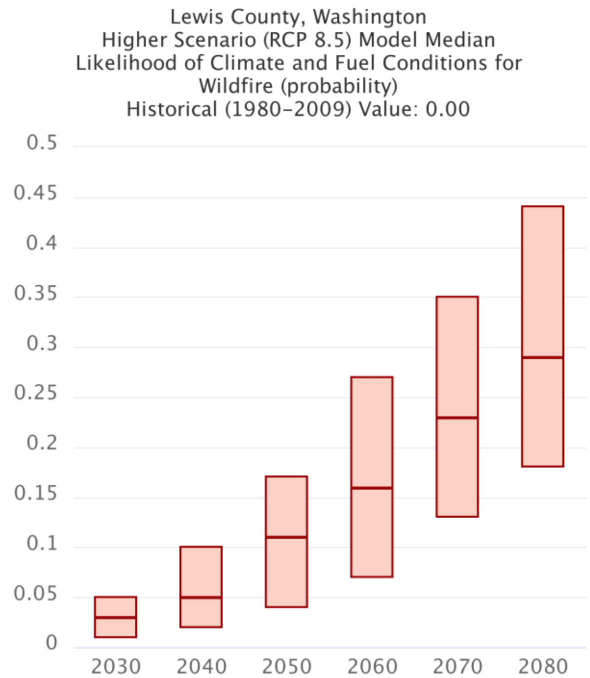



**County-Level Variation in the Expected Change in Wildfire Likelihood**

Many counties in eastern Washington already have a high likelihood of climate and vegetation conditions that can support wildfire in any one year. That likelihood is expected to further increase with drier conditions. For example, on average, Whitman County has 0.40 probability historically (1980-2009) that conditions in a year will enable wildfire. The probability of wildfire conditions there is expected to increase to 0.87 (range 0.73-0.96) for a high (RCP 8.5) scenario by the end of the century (2070-2099). The expected change in wildfire probability is similar for a lower scenario (RCP 4.5) not shown.




In contrast, counties in western Washington generally have a much lower likelihood of climate and fuel conditions that can support wildfire in any given year. For example, on average, Lewis County historically (1980-2009) has had a less than 0.01 probability that conditions in any one year will be sufficient for wildfire. The probability of wildfire conditions there is expected to increase to 0.29 (range 0.18-0.44) for a high (RCP 8.5) scenario by the end of the century (2070-2099). The expected change in wildfire probability is generally lower and has a larger range for a lower climate scenario (RCP 4.5) not shown but is still expected to increase.



### 5.2.2. Economic Impacts of Wildfire

Wildfires pose multiple economic risks including lost timber value, home destruction and reduced property values, transportation disruptions, and increased carbon emissions. In 2021 634,567 acres burned in Washington. Based on the analysis of wildfire economic losses in California, if the economic losses in Washington matched those measured in California on a per acre basis, Washington's economic losses from direct and indirect damages would have been $49.8-$53.0 billion in 2021.

These damages do not account for the lost timber assets (i.e., the stock of trees in our forests). The fire damage on the asset value of the forests creates no new activity or asset value in other segments of the economy, thus representing an almost entirely negative economic change. The forests represent a "savings account" that timber companies can draw from in the future, but wildfire acts as a withdrawal since timber can no longer be harvested except in the immediate case of salvage logging in some areas. At an estimated $0.55 per cubic foot of timber or $467 in lost asset value per acre, Washington lost $226 million to $314.9 million in timber values during the 2021 growing season. In addition to direct losses, a more thorough accounting would also measure the losses in forestry and agricultural output. Lost hours worked, increased transportation disruptions, and mortality and morbidity should all be quantified as part of the economic costs associated with wildfires. The true results of fire damage in Washington require comprehensive knowledge of what land types and forest resources, as well as health risks and capital assets, were affected. The severity of economic damages will be directly linked to the frequency and severity of wildfires.

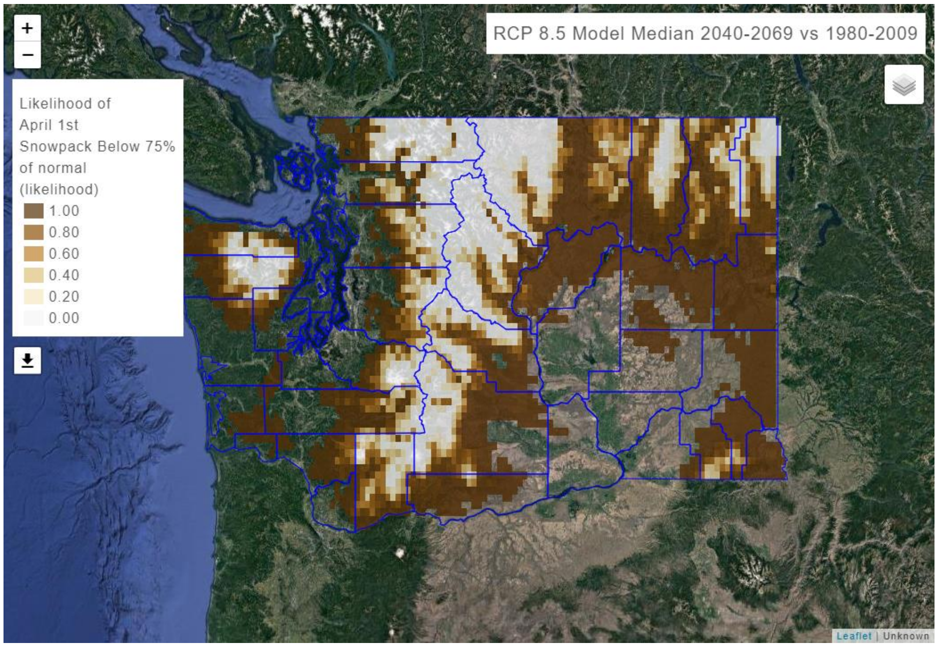
## 5.3. Drought and Agriculture in Washington

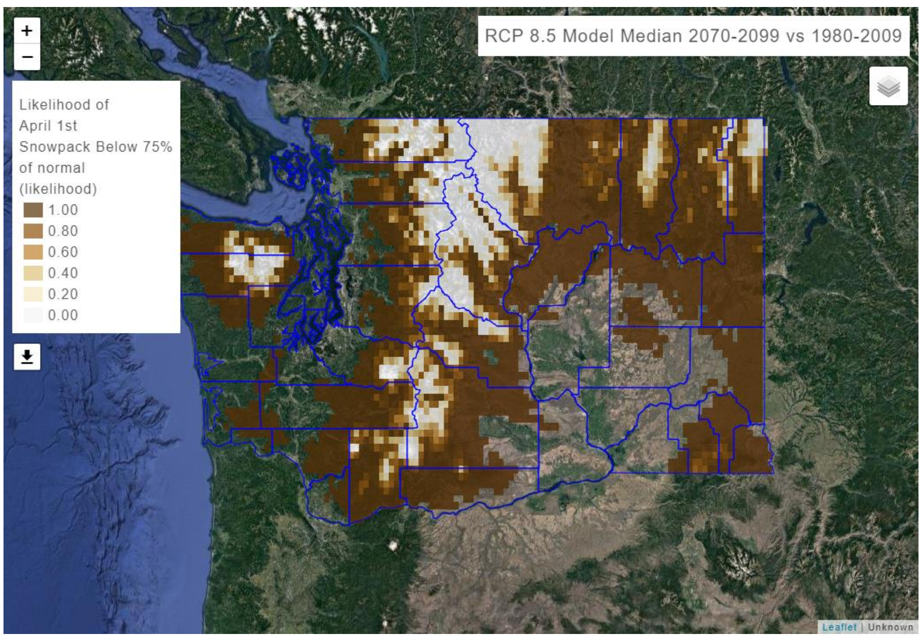
### 5.3.1 Expected Increases in the Likelihood of Drought

Climate change is expected to increase drought in Washington. However, the change in likelihood of drought is difficult to model and quantify because drought depends on the complex influence of precipitation, snowpack, and streamflow on overall water supply. Natural water supply in Washington is expected to decrease with warming. Rising temperatures, leading to declining snowpack, and combined with less precipitation in summer, are expected to reduce natural water supply. The likelihood of drought in any one year is expected to increase, especially as it relates to the amount of snowpack available to contribute to water supply. However, drought not only means drier conditions; it also requires that someone or something is negatively affected by a lack of water (i.e. hardship). In Washington, the legal definition of drought is based on water availability, which captures these criteria. A drought is declared when water supply is expected to fall below 75 percent of normal *and* water users in an area will probably incur hardship because of the lack of water.

Drought can be declared when one or a combination of factors—precipitation, streamflow, snowpack—falls below 75 percent of normal and hardship occurs. *Climate Mapping for a Resilient Washington* presents multiple indicators of drought, because different indicators are relevant for water supply in different areas. For example, snowpack is critical for water supply in areas dependent on surface water coming from mid to high elevations, but it is less relevant in areas that depend on groundwater. Consistent with Washington's legal definition of drought, drought indicators (e.g. snowpack and precipitation) are presented as the likelihood of being below 75 percent of normal.

**By mid-century (2040-2069), many low-elevation areas in Washington that currently receive snow are more likely to have snowpack drought** (less than 75 percent of the 1980-2009 average April 1 snow-water equivalent)[23]. By the end of the century (2070-2099), the area with high likelihood of snowpack drought is expected to expand upward in elevation. Only the highest elevations of the Cascade and Olympic Mountains will continue to have a low likelihood of snowpack drought, especially for a high (RCP 8.5) scenario.

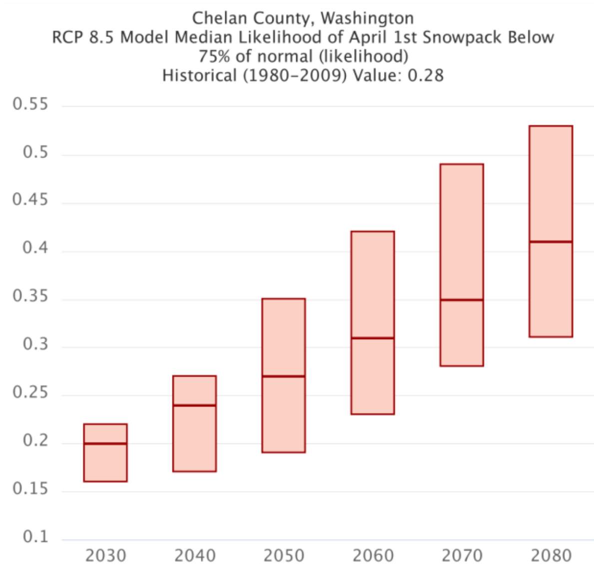


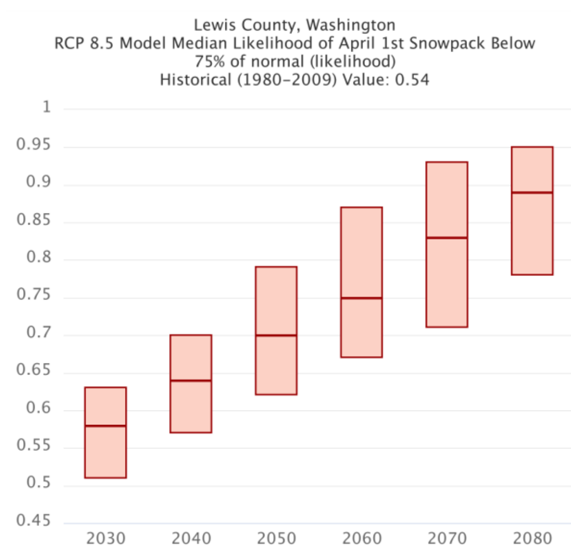

[23] Chegwidden, O. S., B. Nijssen, D. E. Rupp, P. W. Mote, 2017: Hydrologic Response of the Columbia River System to Climate Change [Data set].

## County Level Variation in the Expected Likelihood of Snowpack Drought

The likelihood of snowpack drought will also increase in counties with substantial area at higher elevations, such as Chelan County, but this likelihood is not expected to increase as much as in lower elevation counties to the west. In Chelan County the likelihood of snowpack drought is expected to increase from 0.28 historically (1980-2009), to 0.41 (range 0.31-0.53) for a high (RCP 8.5) scenario by the end of the century (2070-2099).

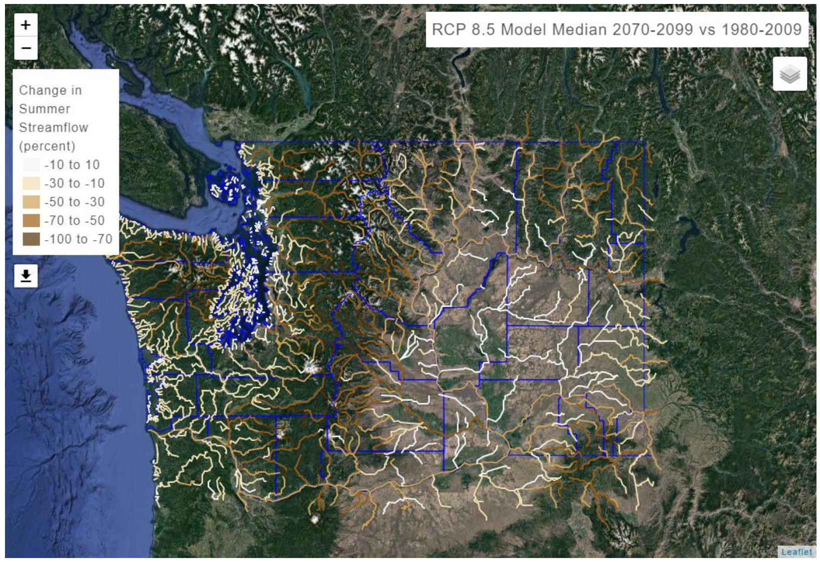



Counties with a higher likelihood of snowpack drought in the future are those on the west slope of the Cascade and Olympic Mountains with substantial areas of low-elevation foothills, such as Lewis County. By the end of the century (2070-2099), the likelihood of snowpack drought In Lewis County will increase from 0.54 historically (1980-2009) to 0.89 (range 0.78-0.95) for a high (RCP 8.5) scenario.

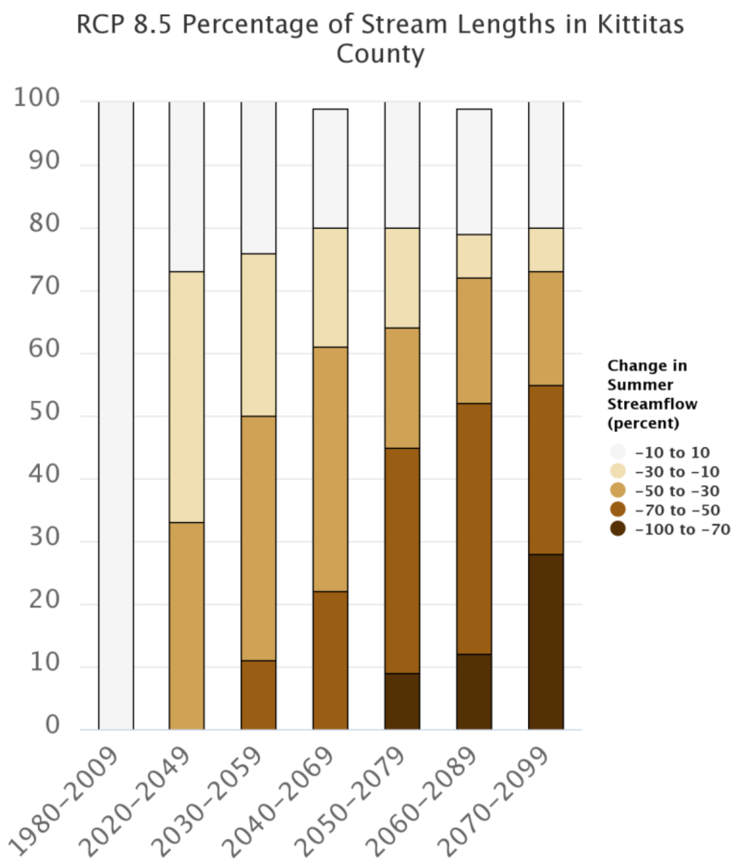


## County Level Variation in the Expected Changes in Natural Summer Streamflow

By mid-century (2040-2069), natural summer streamflow is expected to decrease for most streams in Washington, especially streams that flow from higher elevations in western and northeastern Washington[24]. By the end of the century, summer streamflow is expected to further decrease across the state, with decreases in natural summer streamflows of over 70 percent in many areas.




In counties with many streams supplied by melting snowpack from the Olympic and southern Cascade mountains, natural summer streamflow will decline through the end of the century. For example, for over half the streams in Kittitas County, natural summer streamflow is expected to decrease by 50 percent or more by the end of the century (2040-2069) relative to historical (1980-2009 average) flows for a high scenario (RCP 8.5). Similar changes are expected for a lower scenario (not shown).




[24] Chegwidden, O. S., B. Nijssen, D. E. Rupp, P. W. Mote. 2017. Hydrologic Response of the Columbia River System to Climate Change [Data set]. Zenodo.

### 5.3.2. Economic Impacts of Water Shortage on Potato Production in Odessa Subarea

**Washington State Department of Agriculture 2015 Drought Assessment**

2015 was one of the driest years in Washington's history, which prompted the Department of Ecology to request a full study of the drought by Washington State Department of Agriculture's (WSDA) Natural Resources Assessment Section (NRAS). The stated objective was "to assess the gross value of lost production, as well as some additional expenses growers incurred due to the drought." Net and indirect impacts of drought were not part of the department's stated objective, nor was distinguishing between the drought and the extreme heat events that occurred that year.

The WSDA evaluated different hydrological regions in the state and broke down their analysis by primary commodity, capturing over 77% of agricultural acreage in Washington. They found that agricultural losses due to the 2015 drought were between $633 million and $773 million. However, because agriculture is part of a broader food supply chain, the economic consequences of these direct effects were not fully monetized.

**Potato Case Study**

This case study shows that, with supply chain effects, potato losses from the Odessa Subarea alone accounted for just under $377 million. The Odessa Subarea underlies Adams, Franklin, Grant, and Lincoln counties in east-central Washington. This area of Washington is extremely dry and relies on subsurface water. This area boasts the highest potato yields in the United States, but it is dependent on irrigation. In 2005, the Odessa Subarea had 35,600 acres in potato production. In 2015, irrigated potato acreage in the subarea fell more than 25% to 26,519 acres, primarily because of the dry conditions and lack of water resources in that year.
Even with poor water supply and reduced acreage, growers in the subarea produced over 943,000 tons of potatoes. The Odessa Subarea is 132.4 times more concentrated in potato production than the average region in the United States. The region has a strong comparative advantage in potato production, but only insofar as it has access to water.

***Concentration of potato production value in the Odessa Subarea***

| Region | Potato Production (Sales in thousands) | Total Regional (Sales in thousands) | Concentration |
|---|---|---|---|
| Four-county region (Adams, Franklin, Grant, Lincoln) | $201,293 | $6,023,766 | 132.4 |
| Washington State | $771,210 | $362,656,959 | 8.4 |
| United States | $3,750,246 | $14,863,510,830 | 1.0 |

Source: USDA NASS Quick Stats, Emsi, and author's calculations

The costs of losing potato production in the Odessa Subarea would exceed $37 million, and about 1,100 jobs would no longer be supported. The long-term impacts may extend even further if potato processing plants reduced their output. Under this scenario, total reductions in regional output would exceed $138 million, with a loss of nearly 3,000 jobs. These losses may seem minor relative to the entire economy, but they reflect only the losses from potato outputs. The real costs of losing water in the Odessa Subarea would also affect forage producers, specialty crop producers (e.g., mint, pepper, onion, carrot), and wine grape growers. Even the few wheat producers who do irrigate their crops would be under pressure.

***Range of economic losses to the four-county region from losing potato production***

| | Sales | Value added | Income | Jobs |
|---|---|---|---|---|
| Direct effect | ($111,384) | ($27,240) | ($27,853) | (933) |
| Multiplier effects | ($22,489) | ($10,121) | ($7,899) | (229) |
| Total effects | ($133,873) | ($37,361) | ($35,752) | (1,162) |

Source: Emsi 2017.1 and author's calculations

***Range of economic losses to the four-county region from losing potato production and processing***

| | Sales | Value added | Income | Jobs |
|---|---|---|---|---|
| Direct effect | ($387,024) | ($76,828) | ($61,070) | (1,229) |
| Multiplier effects | ($219,573) | ($61,371) | ($53,036) | (1,576) |
| Total impacts | ($606,596) | ($138,200) | ($114,106) | (2,805) |

Source: Emsi 2017.1 and author's calculations

## 6. Applications of the Assessment and Mapping of Climate Hazards

Although climate change is a global phenomenon, building climate resilience is best accomplished at the state and local level. State government is critical to increasing climate resilience. It provides guidance, regulations, funding, a technical assistance and approves local plans, while enabling coordination and consistency with state goals and priorities. However, action by local governments and communities will be essential to implement state resilience goals. Local communities have substantial and specific knowledge about the particular susceptibility of populations, assets, and infrastructure. When equipped with sufficient knowledge of future climate risks, and given the resources to address them, local governments can act within their authority to build resilience in response to local conditions.

At the CIG, local governments and consultants frequently contact us to assist with access, interpretation, and application of scientific and technical information on expected changes in the climate and related hazards. Although we strive to meet demand one-on-one, our capacity is limited. A single web application can never meet the needs of all users – training and technical support will continue to be necessary – but *Climate Mapping for a Resilient Washington* fills a critical gap in the demand for local information to support climate resilience plans.

***Climate Mapping for a Resilient Washington enhances statewide capacity to build climate resilience by enabling all jurisdictions to equitably access a common set of climate hazard data with minimal barriers***

### 6.1 Support State Resilience Goals and Priorities through Local Capacity Building

Several state agencies are exploring pathways to support local climate resilience planning and implementation to meet state goals for more resilient communities and natural systems. Many mechanisms to build resilience (e.g., permitting, land use planning, building codes, zoning, emergency response) are decided at the local level. Collectively, these local actions can contribute substantially to statewide resilience goals. Successful implementation hinges, in part, on the capacity and awareness of local governments. *Climate Mapping for a Resilient Washington* will add knowledge at a local scale and build capacity for local planners and government officials to plan for climate resilience. Local-scale information also enhances motivation to develop and ownership of the responses.

**Data and information in *Climate Mapping for a Resilient Washington* offers multiple ways to support local governments to plan, prepare, and act to build climate resilience.** Customized maps, graphs, and tables that depict changes in the climate and related hazards can be used by local governments to:

- Facilitate external and internal education, training, outreach, and communications.
- Support the development of local climate resilience, adaptation, or action plans.
- Enable more effective collaboration with state agencies on climate resilience goals.

- Enhance knowledge and capacity to consider climate resilience in state and federally required plans and programs, such as the comprehensive plan, water system plans, hazard mitigation plans, watershed plans and the shoreline master program.

### 6.2 Support Local Governments to Plan for Climate Resilience in Comprehensive Plans

**A near-term application of this assessment and Climate Mapping for a Resilient Washington is climate resilience elements of comprehensive guidance for which is currently under development by the Washington State Department of Commerce.** Commerce is developing guidance and a model element to assist cities and counties to incorporate climate resilience into comprehensive plans. While developing *CMRW*, we worked directly with Commerce to connect the web application, and the data it includes, with their draft guidance for the climate resilience element and menu of example goals and policies. By either using guidance developed by Commerce or developing their own process, cities and counties can voluntarily integrate resilience goals and policies into comprehensive plans. The CMRW webtool is integrated into the draft planning guidance by Commerce and includes sectors and hazards that are relevant for comprehensive planning. The pilot program led by Commerce will test the web application for its effectiveness in supporting the comprehensive planning process.

### 6.3 Enhance the Ability of Local Governments to Secure Resilience Funding

**Multiple state programs invest funds in local activities that contribute to climate resilience and risk reduction, yet local jurisdictions often lack the information and capacity to ensure that these activities adequately account for risks and incorporate resilience benefits.** When local governments are better informed and equipped to understand local climate changes and their potential impacts, they will be more likely to successfully consider climate resilience in projects and secure state and federal resilience funding. For example, the Recreation and Conservation Office (RCO) invests public funds through local projects to support objectives for public benefit, such as salmon and orca recovery, wildlife conservation, and outdoor recreation opportunities. The RCO recognizes not only the risk that climate change poses to many of their investments, but also the opportunities that these investments present to increase the climate resilience of Washington’s communities and natural systems. Through such programs, RCO and other state grant administrators encourage project sponsors to consider both the potential impacts of climate hazards on projects and the benefits of projects for risk reduction. This is most likely to succeed if project sponsors have locally relevant information that can inform grant proposals and project designs. Similarly federal grants are opportunities for local jurisdictions to secure funds for climate resilience projects.

### 6.4 Assess Critical and Vulnerable Components of the Local Economy

**Information on current and future biophysical risks can be combined with an economic framework to assess the most critical and vulnerable components of a local economy.** This combined information can enable decision-makers to assess the economic benefits of climate risk-reduction activities. Particular assets may have more critical economic value to one community, but other assets are more critical to others. Information on which assets are more important to the economy of the state will allow prioritization of those assets at various levels of government and ultimately allow those communities to recover from climate events quicker and with less economic disruption. The framework and data from such economic analyses are designed to help make the economy more resilient to biophysical impacts when they happen.

## 7. Gaps and Next Steps: Statewide Climate Risk Assessment and Resilience

The report, analysis, and web application completed for this proviso can be expanded to include additional analysis and curation of information to support state and local climate resilience planning and risk reduction. Gaps and next steps are described below related to three areas of additional work: (1) analysis of biophysical and economic climate risks, (2) other elements of climate risk assessment, and (3) enhanced resilience planning at the state level.

### 7.1 Combine Information on Current and Future Likelihood of Climate Hazards

**A comprehensive climate risk assessment could be developed that combines information on the *future* likelihood with the *current* likelihood of climate hazards.** The assessment of biophysical climate risks completed for this proviso focuses on the *future change* in the likelihood and magnitude of climate hazards. It may be important to prioritize risk reduction in areas where hazards now are unlikely, but may substantially increase in the future, because these areas may be less adapted to and prepared for the hazard. Conversely, risk reduction may be a priority in areas where hazard likelihood is *already high*, despite little change in future if these areas are not now sufficiently prepared. A constructive approach to risk assessment is to combine future changes in the likelihood of hazards with current likelihood of hazards as described in hazard profiles for the State Hazard Mitigation Plan[25]. To support this, some changes in future hazards not currently quantified as change in likelihood could be quantified this way with additional analysis. For example, sea level rise information can be converted to the change in the likelihood of coastal storms. Likelihood is useful for informing risk assessment and prioritization for climate resilience, similar to how it is commonly used in hazard mitigation plans.

### 7.2 Enable State-level Comparison of Biophysical Climate Impacts

***Climate Mapping for a Resilient Washington* targets information for local jurisdictions, but with little effort, it could be tailored to also include more functionality for statewide comparison of climate hazards and indicators.** Through the scoping and feedback phase, we heard from multiple potential users that the following additional functionality would be useful:

- Present county-level information in a format that enables easier comparison and ranking among counties.
- Develop regional (e.g., eastern and western Washington) summaries of hazards to inform resilience plans at these levels.

[25] 2018 State Enhanced Hazard Mitigation Core Plan https://mil.wa.gov/enhanced-hazard-mitigation-plan

- Add climate indicators and hazard summaries for regulatory planning areas and watersheds to support state agency resilience efforts.

### 7.3 Assess Other Elements of Climate Risk: Local Exposure, Sensitivity, and Adaptation

**Local exposure:** A comprehensive risk assessment would include statewide, sector- and location-specific information about the populations, natural systems and assets exposed to hazards. *Climate Mapping for a Resilient Washington* guides local governments and planners on the type of information to consider in order to determine where people and resources will be most exposed to hazards, such as current flood zones or designated wildland-urban interface, but that information is not integrated into the web tool. Similar to climate exposure, data on current local hazard exposure could be compiled and curated. These data are also inconsistent and vary by hazard, sector, and location. It is this local exposure that creates sufficient granularity to inform where risk reduction should be prioritized at the local scale. Local variation in climate change alone is insufficient to inform priorities at this scale.

**Sensitivity:** CMRW also does not include information on the factors that predispose certain populations, assets, or natural systems to be more susceptible, or sensitive, to the hazards. Factors that affect sensitivity differ among sectors and hazards, and could be compiled to highlight communities or systems more at risk because of their particular sensitivities, as in the example of subpopulation sensitivity to extreme heat. The *Washington Environmental Health Disparities Map*[26] or the *Climate Health and Risk Tool* (CHaRT) under development by the UW Center for Health and the Global Environment (UW CHanGE)[27] are potential sources of information on sensitive subpopulations. CHaRT allows users to visualize the health risk associated with climate hazards, such as extreme heat, across communities in Washington State. CHaRT provides information about risk levels at a neighborhood level and information related to the underlying drivers of that risk, including information about the population at risk and factors that affect population vulnerability in a given location.

**Capacity to Adapt:** Even where communities or assets are particularly exposed and sensitive, they still may not warrant the highest priority for risk reduction if substantial resources are already allocated to the need. Statewide, sector- and location-specific information about the relative level of preparedness and resilience locally is another element of a comprehensive climate risk assessment which can help ensure that resources reach the places with the greatest need, rather than those that already have substantial resources and capacity. Capacity to adapt will greatly influence who is affected and where resilience can be implemented. For example, an area with high likelihood of current and future flooding, but also significant resources dedicated to flood protection infrastructure and response through existing programs, is unlikely to be a high priority candidate for future resilience funding.

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[26] Washington Tracking Network, Washington Environmental Health Disparities Map. Department of Health https://doh.wa.gov/data-and-statistical-reports/washington-tracking-network-wtn/washington-environmental-health-disparities-map
[27] CHaRT is in the final stages of development, will be released in early 2023, and will be available on the website of the UW Center for Health and the Global Environment (UW CHanGE) https://deohs.washington.edu/change/.

### 7.4 Develop a Database of Assets at Risk

**Develop a database of all county level human, physical, and natural resource assets (market and non-market values) at risk from climate change.** The database could include

- Public land and natural resource assets (e.g., forestry data from the US Forest Services Forest Inventory and Analysis program
- Agricultural production values by commodity (USDA NASS, USDA ERS)
- Private assets (e.g., housing and commercial property assets and industry production)
- Labor and human capital assets (as discussed in section 5.1.2)
- Non-market values (e.g., salmonid habitats, wilderness assets, statistical value of life)

Where data do not exist, survey and statistical assessments may be needed. In the 2015 assessment of drought effects on agriculture, the Washington State Department of Agriculture and the Washington State Academy of Science made a similar recommendation "…In addition, now is the time to develop a robust plan for continued data collection. Required data and strategies for collection and ongoing analysis need to be identified in order to give Washington State the ability to assist growers and plan for a future that will include increased incidence of severe weather events such as the 2015 drought."[28]

### 7.5 Estimate the Value of Assets at Risk

**Once assets at risk are comprehensively identified and accounted for, models could be constructed and designed to assess the value of those assets.** Prices of assets are dynamic and thus the value of our regional economy is in constant flux. Calculating and maintaining estimates of the value of assets goes beyond multiplying consumer prices by asset volumes. For example, greater distance to market often leads to an asset becoming less valuable. Human capital assets generate different values in different locations. The structure for valuing the assets needs to rest on a framework that can be easily updated (e.g., via a dashboard) as value determinants adjust to market conditions. This process should be based on research and model designs that have been developed and deployed in the scientific literature. This process will be difficult and time-intensive because precedents need to be carefully identified and reviewed before implementation. Doing this for the first time will result in "bugs" in the system that will require refinement over time. As processes change data are not comparable year-over-year. A set of base metrics that are comparable will be needed so that economic variables can be scaled for time series comparisons. The results of this process will be new datasets for the state and county economies. This datasets alone will be a helpful resource for local leaders as they develop climate resiliency strategies.

### 7.6 Estimate Expected Economic Impacts With and Without Adaptive Interventions

**Adapt the Washington-Idaho Computable General Equilibrium (WAID-CGE) model to assess economic impacts with and without adaptive interventions and implementation of climate resilience strategies.** This model is based on Washington Social Accounting Matrices and allows assessment of the household welfare effects of specific adaptive interventions. It has

[28] Washington Dept. of Agriculture. 2017. 2015 Drought and Agriculture. https://drought.unl.edu/archive/assessments/WashingtonState-2015.pdf

been used to assess the economic effects of revenue neutral carbon taxes,[29] biofuel policies,[30] etc. This model compares adaptive interventions on an economic basis, a step that is necessary to ensure that the intervention is not more costly than the climate impact itself.

### 7.7 Identify Sector and Hazard Specific Strategies and Actions for Statewide Resilience

**Updates to the 2012 Integrated Climate Response Strategy could benefit from an assessment of potential strategies and actions that focus on specific sector-hazard combinations and highlight coordination across agencies and among levels of government.** The problem-oriented analysis described for extreme heat and human health (Section 5.1.3) is one way to identify resilience gaps and a suite of strategies and actions. This approach makes it possible to address the highest risks, for the most vulnerable populations, in the most exposed locations. Commonly cited barriers to climate resilience are often institutional, such as inadequate institutional support, overlapping or confusing mandates and authorities, and limited financial or human capacity. To address these institutional barriers requires both problem-oriented assessment of current barriers and opportunities for resilience strategies and actions. The problem-oriented analysis relies on a combination of stakeholder interviews and a literature review, and it uses methodologies from policy sciences to synthesize contextual scientific, economic and demographic information about a specific hazard into a condensed description of the problem.

### 7.7 Identify Performance Measures and Mechanisms for Accountability

**Performance metrics could be developed to track the effectiveness of resilience actions for multiple aspects of vulnerability.** The 2012 Integrated Climate Response Strategy did not include performance measures for building resilience or mechanisms for accountability —that is, who is expected to do what by when. Going forward, a problem-oriented analysis of specific hazard-sector combinations could highlight multiple aspects of vulnerability, including the exposure to climate hazards, inherent factors that lead to greater susceptibility, and factors that limit the potential for populations, species, or natural systems to adapt. For example, in the case of extreme heat and public health, certain subpopulations are more sensitive as a result of particular chronic medical conditions. Services like cooling centers or energy assistance programs could evaluate their effectiveness by surveying their end users on issues pertaining to accessibility, communication strategies, and accommodations for populations at greater risk.

[29] Galinato et al., 2015. How Does Washington State Initiative 732 Impact the Agriculture and Forestry Sectors? *Western Economic Forum* 14: 2
[30] McCullough et al., 2011. Economic and Environmental Impacts of Washington State Biofuel Policy Alternatives. *Journal of Agricultural and Resource* Economics. 36: 3

## Appendix A: Data Types and Sources in Climate Mapping for a Resilient Washington

| Climate Change or Natural Hazard | Data Source | Native Resolution | Citation |
|---|---|---|---|
| Total Annual Precipitation<br>Late Summer Precipitation<br>Precipitation Drought<br>Heavy Precipitation Magnitude<br>Extreme Precipitation Magnitude<br>1 inch Precipitation Days<br>2 inch Precipitation Days<br>3 inch Precipitation Days | Dynamically Downscaled Hydroclimate Projections: WRF model | 12km x 12km | Salathé, E.P., Leung, L.R., Qian, Y., Zhang, Y. 2010. *Regional climate model projections for the State of Washington*. Climatic Change 102(1-2): 51-75. https://doi.org/10.1007/s10584-010-9849-y |
| Warm Season Streamflow<br>Summer Streamflow<br>Duration of of Low Streamflow<br>Low Streamflow<br>Streamflow Timing<br>Peak Streamflow<br>Frequency of Peak Streamflow<br>Snowpack<br>Snowpack Drought | Re-routed RMJOCII – public data source pending. | 0.0625° x 00.625° for SWE data, 11723 segments for streamflow data | Chegwidden, O. S., B. Nijssen, D. E. Rupp, P. W. Mote. 2017. *Hydrologic Response of the Columbia River System to Climate Change* [Data set]. Zenodo. doi:10.5281/zenodo.854763. |
| Likely Sea Level Rise<br>High Sea Level Rise | PROJECTED SEA LEVEL RISE FOR WASHINGTON STATE – A 2018 ASSESSMENT | 171 coastal segments | Miller, I.M., Morgan, H., Mauger, G., Newton, T., Weldon, R., Schmidt, D., Welch, M., Grossman, E. 2018. *Projected Sea Level Rise for Washington State – A 2018 Assessment*. A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, University of Oregon, University of Washington, and US Geological Survey. Prepared for the Washington Coastal Resilience Project. updated 07/2019. |
| Summer Maximum Temperature<br>Hot Days<br>90°F Maximum Humidex Days<br>65° Minimum Humidex Days<br>Heating Degree Days<br>Cooling Degree Days<br>High Fire Danger Days | MACAv2-METDATA | 4km x 4km | Abatzoglou J.T. and Brown T.J. *A comparison of statistical downscaling methods suited for wildfire applications.* 2012. Int. J. Climatol., 32: 772-780. https://doi.org/10.1002/joc.2312 |
| August Stream Temperature | NorWeST Summer Stream | N/A | Isaak, D., S. Wenger, E. Peterson, J. Ver Hoef, D. Nagel, C. Luce, S. Hostetler, J. Dunham, B. Roper, S. Wollrab, |

| | | | |
|---|---|---|---|
| | Temperature Model | | G. Chandler, D. Horan, S. Parkes-Payne. 2017. *The NorWeST summer stream temperature model and scenarios for the western U.S.: A crowd-sourced database and new geospatial tools foster a user community and predict broad climate warming of rivers and streams.* Water Resources Research, 53: 9181-9205. https://doi.org/10.1002/2017WR020969. |
| Wildfire Likelihood | Projected major fire and vegetation changes in the Pacific Northwest of the conterminous United States under selected CMIP5 climate futures | 0.0417° x 0.0417° | Sheehan, T., D. Bachelet, K. Ferschweiler. 2015. *Projected major fire and vegetation changes in the Pacific Northwest of the conterminous United States under selected CMIP5 climate futures.* Ecological Modelling. 317. 16-29. 10.1016/j.ecolmodel.2015.08.023. |
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