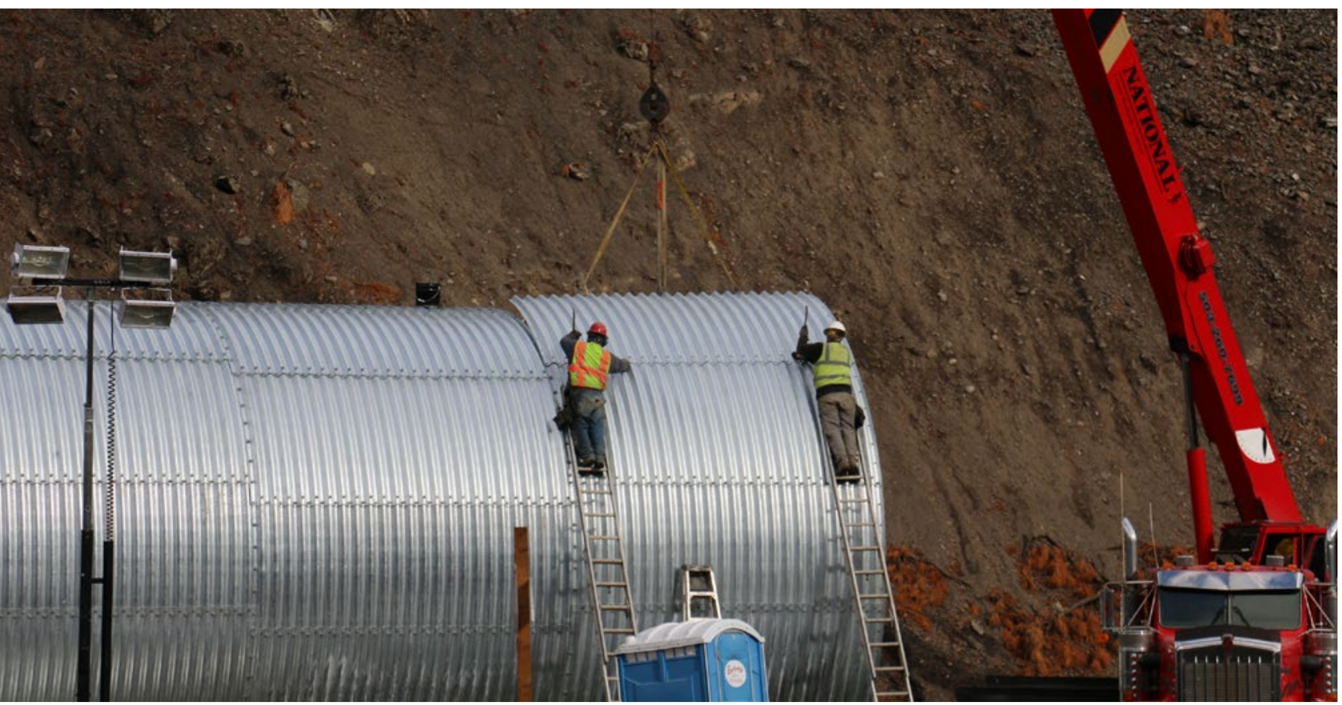
Oregon Department of Transportation

Climate Adaptation & Resilience Roadmap

DECEMBER 2022

ABSTRACT

This document provides a practical guide to operationalizing climate adaptation and resilience. It outlines strategies and implementation actions that will help ODOT institutionalize climate resilience in the ways the agency plans for, invests in, builds, manages, maintains, and supports the multi-modal transportation system.



A resilient transportation system has design-level robustness so that it can withstand severe blows; it is adaptable so that it can respond appropriately to threats and it can mitigate the consequences of threats through response and recovery operations.

The transportation system ***includes physical, technical, social, and institutional elements*** that are all critical to resilience.

– US Department of Transportation

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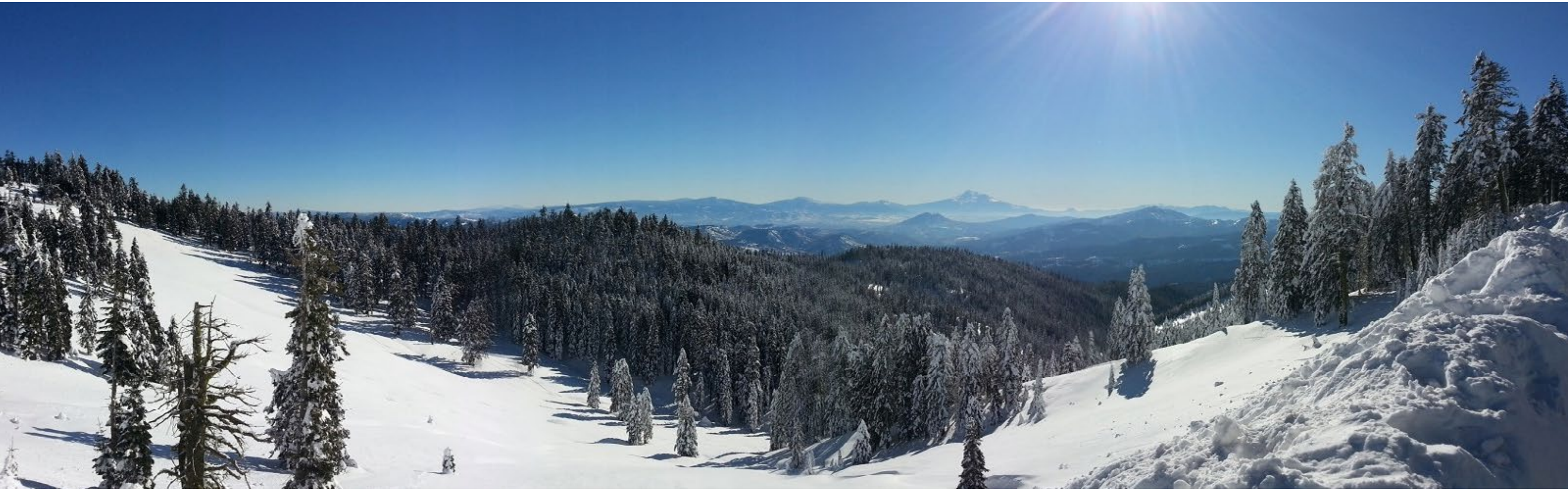


GLOSSARY

The following is a glossary of terms relevant to or commonly used throughout the document.

ACTIONS – The "hows" for carrying out a specific strategy. In this document, actions are linked to strategies and objectives. Objectives are the "whats" or the individual steps that carry out a strategy.

ADAPTATION – Adjustment in natural or human systems in anticipation of or response to a changing environment in a way that effectively uses beneficial opportunities or reduces negative effects.

AREA COMMISSIONS ON TRANSPORTATION (ACTS) – Area Commissions on Transportation are advisory groups chartered by the Oregon Transportation Commission. They address all aspects of transportation with a primary focus on the state transportation system and regional and local transportation issues that affect the state system. ACTs play a key advisory role in the development of the Statewide Transportation Improvement Program and establish a public process for area STIP project selection priorities.

CLIMATE DATA – Quantitative and qualitative information that spans both historical and projected changes and hazards resulting from climate change.

CLIMATE EQUITY – Ensuring that the people and communities who are least culpable in the warming of the planet, and most vulnerable to the impacts of climate change, do not suffer disproportionately as a result of historical injustice and disinvestment. (Climate Equity Blueprint)

CLIMATE HAZARD – A climate- or weather-related event or condition that can damage ODOT infrastructure or disrupt the ODOT system. For this project, we are considering the following hazards (see definition of "extreme"):

- Extreme heat (AKA "very hot days")
- Extreme precipitation
- Floods and high-water events
- Freeze/thaw
- Extreme snowfall
- Wildfire
- Landslides
- Coastal erosion
- Coastal flooding

CLIMATE RESILIENCE – The capacity of a system to prevent, withstand, respond to, and recover from a climate change-related disruption. In the case of ODOT, a resilient system, when faced with an extreme climate event, would be able to minimize disruptions to the highway system, minimize risk to workers and users of the system, maximize the ability to quickly recover from any disruptions that do occur, and minimize repair and maintenance time and costs over the long term.

CLIMATE RISK – The potential for climate change-related consequences where something of value (e.g., infrastructure, health and safety) is at stake and where the outcome is uncertain. Risks are often evaluated in terms of how likely they are to occur (likelihood) and the damages that would result if they did happen (consequences).

CONSEQUENCES – A subsequent result that follows from damage to or loss of an asset.

CORRIDOR – State highway segments of up to 50 miles (maximum).

DATA-DRIVEN DECISION MAKING – Using facts, metrics, and data to inform decision making and improve the safety and efficiency of ODOT's multimodal transportation system.

ELDERLY POPULATIONS – Elderly people, or individuals aged 65 or older, face disproportionate climate impacts. Elderly people are more likely to have chronic health conditions, require medications for treatment, and have higher rates of physical and cognitive impairments. Because of these conditions, elderly people are generally more sensitive to climate impacts, such as extreme heat, poor air quality, extreme events, and vector-borne diseases.

EQUITY – Not all people, or all communities, are starting from the same place due to historic and current systems of oppression. Equity is the effort to provide different levels of support based on an individual's or group's needs in order to achieve fairness in outcomes. Equity actionably empowers communities most affected by systemic oppression and requires the redistribution of resources, power, and opportunity to those communities. (State of Oregon, Office of the Governor)

EXPOSURE – The presence of assets, people, and ecosystems in places where they could be adversely affected by hazards.

EXTREME EVENTS – Extreme events are occurrences of unusually severe weather or climate conditions that can cause devastating impacts on the transportation system, communities and natural resources. We measure "extreme" depending on the event, as defined within the document. For example, common practice is to measure extreme precipitation as events that meet or exceed the 95th percentile at a particular location. In this way, an "extreme" is event is relative and place-based.

FRONTLINE COMMUNITIES – Also known as "Climate Vulnerable Communities." Those that experience "first and worst" the consequences of climate change. These are often communities of color, immigrants, rural communities, low-income communities, Tribal and indigenous people who have long been excluded from the policy and funding decisions and processes used to address climate change. (Climate Equity Blueprint)

FUTURE CLIMATE CONDITIONS – The projected or expected state of the climate, including temperature, precipitation, and other climate factors. This information is used to help identify climate impacts and hazards, and opportunities for adaptation and resilience. While the science cannot predict exactly what will occur, climate projections can help identify which climate hazards may increase in severity and frequency in a given geographical location. They also indicate that reliance on historical events and practices is no longer sufficient or appropriate for planning and investment.

LEADERSHIP – ODOT is responsible for the development, management, and execution of this Roadmap in accordance with Executive Order 20-04 and the agency's formally proposed actions to reduce greenhouse gas emissions and adapt to the impacts of climate change. Leadership of a "One ODOT" approach to carrying out the Roadmap comes from the Climate Office, in coordination with ODOT executive leadership, divisions and sections.

LOW-INCOME RURAL COMMUNITIES – Any geographic area that is ten miles or more from the centroid of a population center of 40,000 people or more is rural (Oregon Office of Rural Health). Low-income rural communities comprise of low-income households in areas or counties that do not have at least one Census Bureau-defined Urban Cluster. In addition to similar environmental injustices that low-income urban communities face, low-income rural communities may experience transportation burden to access resources and amenities. Low-income households also typically live in older housing units, which increase exposure to environmental hazards. They also have less access to resources that would bolster their resilience to economic, environmental, and social changes, such as health care, insurance coverage, and healthy foods. Twenty five of Oregon's 36 counties are rural.

LOW-INCOME URBAN COMMUNITIES – Low-income urban communities comprise of low-income households—or households that earn less than or equal to 80% of the area median income—in urban areas or counties with at least one Census Bureau-defined Urban Cluster of 50,000 or more. Urban counties include Columbia, Multnomah, Washington, Clackamas, Yamhill, Marion, Polk, Benton, Lane, Deschutes, and Jackson County. Due to previous environmental injustices, these low-income communities are more likely to be geographically close to sources of pollution, such as from highway vehicle traffic and industrial sources. Low-income households also typically live in older housing units, which increase exposure to environmental hazards. They also have less access to resources that would bolster their resilience to economic, environmental, and social changes, such as health care, insurance coverage, and healthy foods.

MITIGATION – Climate change mitigation measures reduce greenhouse gas emissions, slow down global warming, and avoid the worst potential impacts of climate change.

OBJECTIVE – Objectives are the "whats" or the individual steps to carry out a strategy. In this document, objectives are linked to strategies and actions, which are the "hows" to carry out a strategy.

PUBLIC ENGAGEMENT – Public engagement is a way of bringing citizens, community non-profit organizations, businesses, and government together to solve problems that affect people's lives. Adaptation and resilience require coordination across multiple sectors, geographical scales, and units of government. Public engagement is a very inclusive problem-solving approach to deal with complex public problems.

REPRESENTATIVE CONCENTRATION PATHWAY (RCP) 8.5 – RCP 8.5 refers to the **concentration of carbon that delivers global warming at an average of 8.5 watts per square meter** across the planet. The RCP 8.5 pathway delivers a temperature increase of about 4.3˚C by 2100, relative to pre-industrial temperatures. It is a greenhouse gas concentration (not emissions) trajectory adopted by the Intergovernmental Panel on Climate Change and widely used across climate change scenario literature.

RESILIENCE – The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.

STRATEGY – A strategy is a plan of action or policy designed to achieve a major or overall aim, in this case climate resilience.

SUSTAINABLE FUNDING – Continual and sufficient financial support.

TRIBAL NATIONS – Tribal Nations in Oregon are inclusive of nine federally recognized Tribes. These Tribal Nations have existed as sovereign governments before European colonization and settlement and continue to rely on the environment and environmental resources for spiritual, economic, health, and cultural purposes. Because of their historical and current relationship to the environment, Tribes across the Pacific Northwest experience a greater burden of climate change and environmental hazards, leading to disproportionate and disparate health, economic, social, and cultural outcomes.

CHAPTER 1:
INTRODUCTION & BACKGROUND

The Oregon Department of Transportation manages Oregon's state highway system. The agency's mission is to maintain a safe and reliable multimodal transportation system that connects people and helps Oregon's communities and economy thrive. Extreme weather and climate change pose serious and increasing risks to transportation systems. Adapting how ODOT plans, designs, operates and maintains these systems will reduce travel delays and disruptions and lower costs from repairs and reconstruction.

Oregon's best available climate change projections indicate that average annual temperatures will increase 5°F by the 2050s and 8.2°F by the 2080s. The frequency, duration, and intensity of extreme heat events is also expected to increase over time.[1] Drier and hotter conditions will exacerbate wildfire risk; fires will be more frequent, large and destructive. Floods will be more frequent and severe, and their "footprint" will expand in and beyond areas currently affected. The winter weather conditions and atmospheric river events that cause safety concerns and contribute to transportation delays and closures (i.e., "winter events") are expected to become more intense, increasingly variable, and harder to predict.[2] These changes directly expose infrastructure, employees and the public to more frequent and intense hazard events.

In Oregon, primary climate stressors and their transportation impacts include:

- *Increased Frequency / Magnitude of Inland Flooding*
  Transportation impacts include: damage and road closures resulting from concentrated runoff and scour, flooding, landslides and rock-fall.
- *Higher Sea Levels/Coastal Storms*
  Transportation impacts include: damage and road closures from increased wave heights, flooding, storm surge, and coastal erosion.
- *Extreme Heat*
  Transportation impacts include: damage and road closures due to heat and wildfires. Health and safety concerns for personnel.

1 Dalton, M., and E. Fleishman, editors. 2021. Fifth Oregon Climate Assessment. Oregon Climate Change Research Institute, Oregon State University, Corvallis, Oregon. https://blogs.oregonstate.edu/occri/oregon-climate-assessments/.

2 Mote, P.W., J. Abatzoglou, K.D. Dello, K. Hegewisch, and D.E. Rupp, 2019: Fourth Oregon Climate Assessment Report. Oregon Climate Change Research Institute. occri.net/ocar4

PURPOSE OF THIS DOCUMENT

The purpose of the Climate Adaptation and Resilience Roadmap is to set the agency's strategic vision and framework for building resilience to climate change. The roadmap presents a statewide climate risk assessment and outlines the adaptation strategies and actions the agency will take to increase transportation system resilience.

Oregon is already experiencing extreme weather events and consequences that are projected to become more widespread and severe in the coming decades. To reduce risk and address changes as they evolve, ODOT needs to account for climate change in design, operations, maintenance and project planning. Climate adaptation and resilience planning is not just about abstract or uncertain future events. It is also about preparing for and adapting to impacts that are already occurring today, while considering how the events might change or increase in magnitude and frequency going forward. These events impact ODOT's ability to maintain a safe, reliable and fiscally sustainable transportation system and workforce.

An Ounce of Prevention is Worth a Pound of Cure

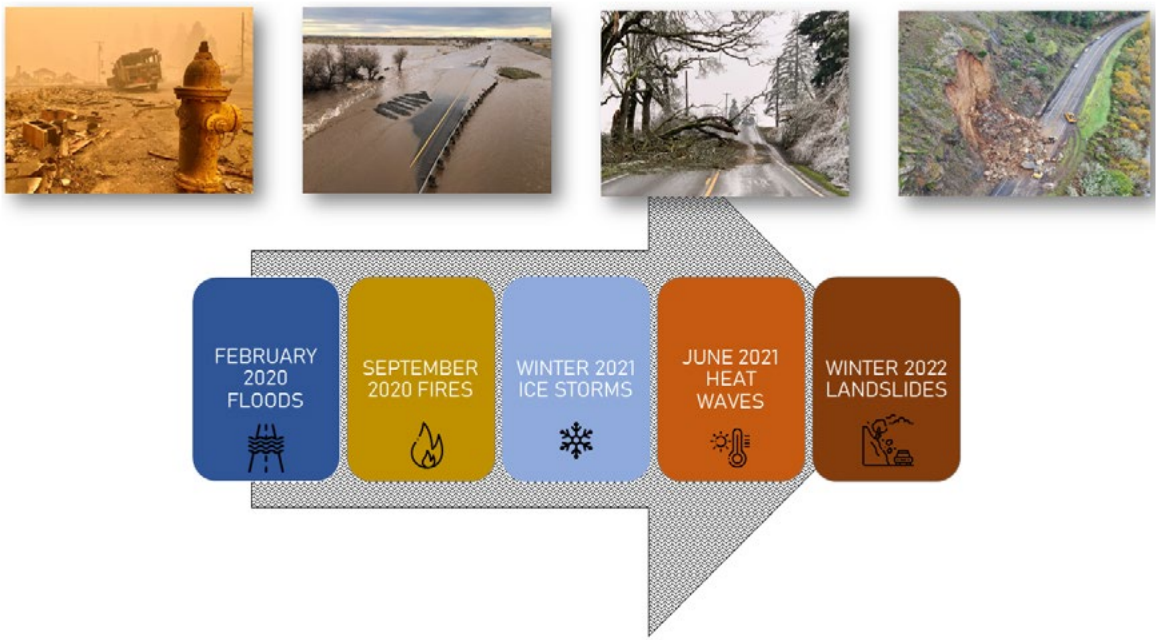
Investing in upgrades that reduce or avoid damage saves lives, protects infrastructure, helps economies recover faster and lowers recovery costs. When ODOT acts proactively, the agency can expect a substantial return that is four to six time the initial investment, according to the 2019 federal Multi-Hazard Mitigation Council report on the cost and benefits of preventing infrastructure damage from climate hazard events (Climate Equity Blueprint, 2021; Natural Hazard Mitigation Saves, 2019).[3]

The Business Case for Proactive Adaptation

Frequent delays and closures impact the movement of freight, and influence where people choose to live or work. These challenges also impact the economy as a whole, but can be difficult to quantify.

ODOT's Statewide Integrated Model helps the agency estimate economic losses from transportation interruptions due to hazard events. The agency is already using the model as part of strategies for maximizing resilience funding (see strategy 3.3). The model is currently being applied to several high-risk locations across the state highway system. The results will help the agency gain a better understanding of potential outcomes of intentional investment and disinvestment. The model results will also be used to inform development of potential funding scenarios and resilience investment business cases.

3 Council, M. H. M. (2019). Natural Hazard Mitigation Saves: 2019 Report. Accessed 12/04/22 at https://www.nibs.org/projects/natural-hazard-mitigation-saves-2019-report



Extreme events with severe transportation system safety and reliability consequences since 2020.

Failure to adapt through inaction will increase risks of damage to transportation systems, with negative impacts on people, the economy and more. ODOT can strategically build system resilience by assessing risks and responding with targeted and agency-relevant decisions that support prevention, preparedness, response and recovery.

WHOLE-OF-GOVERNMENT PRIORITY

ODOT must serve the public interest and be responsive to state and federal requirements. This includes recent state executive orders, which directed ODOT to consider climate change resilience and adaptation, with a focus on protecting vulnerable populations and safeguarding state and federal investments. In 2020, ODOT and other state agencies adopted climate change and social equity policy priorities. These priorities have since been codified in the ODOT Strategic Action Plan, which directs near-term agency action. The plan prioritizes equity, modernizing the transportation system, and sufficient and reliable funding.

At the federal level, climate resilience is a critical, whole-of-government priority. To translate this ambitious vision to action, Congress passed the $1.2 trillion Infrastructure Investment and Jobs Act which provides federal funding for departments of transportation across the nation. The funding is aimed at reducing greenhouse gas emissions, addressing climate hazard impacts, and bolstering climate resilience and equity outcomes. The roadmap strategies and actions are designed to best position ODOT to take full advantage of new dedicated and competitive funding opportunities to support delivering on our mission into the future. The adoption of this plan is just the beginning however; an “all hands on deck” approach is required to facilitate agency change at all levels.

Mitigation vs. Adaptation

Climate change mitigation measures reduce greenhouse gas emissions, slow down global warming, and avoid the worst potential impacts of climate change.

Climate change adaptation measures reduce or avoid impacts from climate change related hazards.

Mitigating climate change is critical. As more work is done worldwide to mitigate emissions and slow climate change, Oregonians may experience more stabilization of climate conditions and less negative climate impacts affecting the transportation system. However, until that shift happens, intentional prioritization of adaptation is still necessary to avoid or reduce harm, and increase resilience.

CHAPTER 2:

STATEWIDE CLIMATE HAZARD RISK ASSESSMENT

The Statewide Climate Hazard Risk Assessment helps ODOT better understand system-wide risks and vulnerabilities. The assessment is a future-focused analysis of the state highway system that combines risks from hazards, travel demand, social disparity and economic impact at the corridor level. An online map with a suite of data layers depicting study results is available here.

Risk assessments are a critical tool for informing climate change adaptation and resilience strategies and actions. The study results and map products allow the agency to:

- Better understand costs related to hazard impacts.
- Summarize most and least dominant risks state-wide and regionally.
- Locate specific high-risk corridors for priority consideration.
- Identify data needs to support ongoing risk assessment into the future.

Together, these assessment elements inform Oregon-specific strategies and actions to support climate change resilience.

Hazards

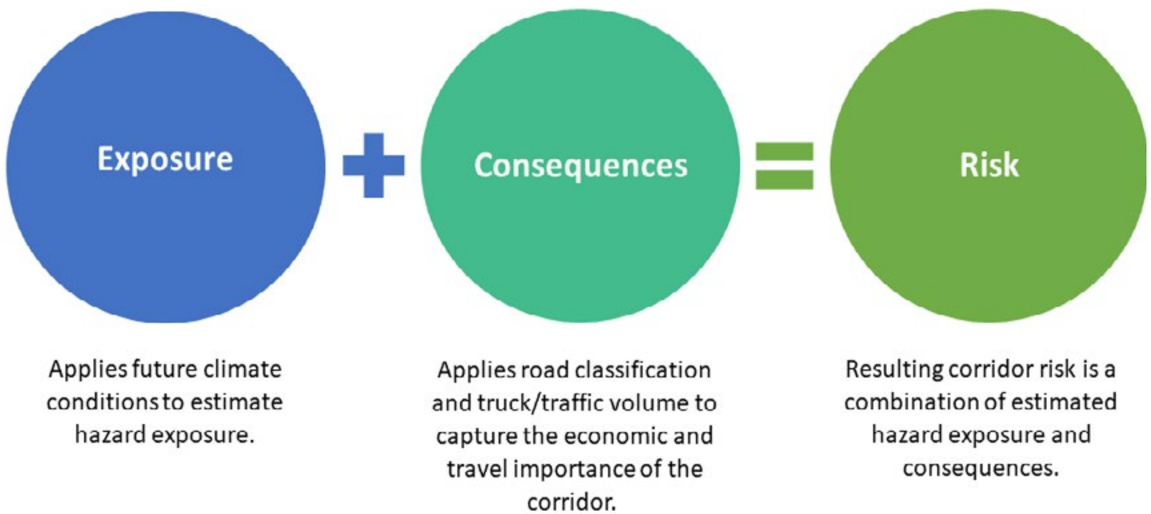
Reducing risk and adapting to hazards is a critical part of building resilience along state highway corridors. The study includes nine hazards affecting transportation along state highways. These hazards are expected to get worse and happen more often into the future.

Study Hazards

- **Landslides**
- **Wildfires**
- **Very Hot Days**
- **Daily Freeze/Thaw**
- **Very Heavy Precipitation**
- **Snow Days**
- **Inland Flooding**
- **Coastal Flooding**
- **Coastal Erosion**

OVERVIEW OF APPROACH & METHODOLOGY

The risk assessment provides a unique, statewide, multi-hazard risk perspective with future risk estimations for nine hazards that impact Oregon's state highway system. The result is corridor-level risk estimates for each hazard, along with a multi-hazard analysis that reveals corridors susceptible to multiple, overlapping hazards. Mid- and late-century risk projections are provided and assume a "business as usual" greenhouse gas concentration scenario (representative concentration pathway 8.5)[4]. Risk estimations come from combining corridor-level exposure with climate change and consequences (think economic consequences of a road closure). Easy to interpret, qualitative risk rankings are provided for each corridor and include low, medium, high and very high risk.



Risk is a function of climate change and hazard exposure with transportation consequences. A better understanding of risk can help ODOT target limited resources in key areas of concern.

4 Corridors are state highway segments with a maximum length of 50 miles.

Though not included in the corridor level risk scores, about a decade of emergency response data was examined to take stock of current locations and patterns of hazard-related disruption. While the data are limited, they do provide the opportunity to overlay historical and future information, which can be useful for anticipating critical areas of high adaptation needs. This can also be combined with social equity data, asset condition and other relevant infrastructure-related details to inform corridor-level resilience efforts that tell a more complete story about areas of high potential need. This approach can be best for highlighting the projects that have a range of co-benefits and are poised for resilience funding opportunities.

The ODOT Climate Office is working with the agency's GIS unit to develop dynamic, web-based Climate Hazard Risk Maps that will continue to evolve. The maps currently provide detailed and summary data layers that now expand beyond the original risk assessment. An example is the Resilience Corridor layer that facilitates prioritizing "high need" resilience areas based on three primary factors:

- Climate vulnerability: corridor segments projected to be at high risk to the greatest number of climate hazards, historical incidents and condition of infrastructure;
- Economic significance: corridor segments primarily on ODOT Priority Corridors[5]; and
- Social equity: corridor segments located in areas of high social disparity.

The maps can be referenced alongside this report to help illustrate risk assessment findings.

5 Oregon Transportation Commission. 2020. Investment Strategy Update. Viewed 12/8/22 at https://www.oregon.gov/odot/Get-Involved/OTCSupportMaterials/Agenda_D_Draft_2020_Investment_Strategy.pdf

What do the Climate Hazard Risk Maps tell us?

Wildfires in western Oregon, particularly in ODOT Regions 1 and 2, are projected to increase the most.

- This growing wildfire footprint overlaps with Oregon's most densely populated areas with significant transportation networks, infrastructure and assets.
- Due to the large amount of fuel (large trees and dense brush), the potential for large, destructive fires is high.
- Smoke and other secondary impacts of wildfire in highly populated areas will further complicate transportation safety and require thoughtful collaboration across agencies.

Landslides are another widespread hazard with risks magnified by wildfire and heavy precipitation.

- Wildfire burns off vegetation that holds soil in place and reduces water absorption in soil. Heavy rains that follow can cause more soil erosion, destabilization and flooding.
- Landslides and sinkholes have been the most expensive to repair, totaling about $62 million over 13 years (2009-2021).
- This financial burden can be lessened by proactive, large-scale fixes (where warranted).

Coastal corridors are on the front line of climate change.

- Sea levels are rising and the coastline is eroding more quickly.
- Climate change is responsible for more frequent and worsening extreme weather events, like heavy rain and flooding, high temperatures, and wildfires.
- Multiple, overlapping hazards threaten road and stormwater infrastructure, culverts, and bridge assets. Infrastructure in poor or critical condition is especially vulnerable.

SHIFTING PRIORITIES IN A FISCALLY CONSTRAINED ENVIRONMENT

Financial risk is also relevant to resilience. ODOT routinely faces costs related to weather events but has not yet tried to associate costs with specific climate driven hazards. To better understand the financial impacts of hazards, this study includes an inventory of internal data from across programs and provides information on historical hazard-specific costs (See Appendix A2).

The data, gathered from interviews with ODOT maintenance leadership and their financial records, indicates that climate change is worsening hazard-related challenges. Hazard impacts are shifting from a predictable, seasonal cadence to a near-constant barrage of varied challenges. Maintenance is struggling to keep up.

The Maintenance Division does not have sustainable staffing or funding, and will likely face further funding reductions in the future. These cuts are expected despite ongoing climate impacts on a transportation system that was not designed or built to endure them. Understanding and addressing financial risk is critical to improving resilience.

The data we present here helps the agency better understand current cost burdens and potential future needs. Evaluating cost data alongside corridor risk projections will help the agency to deduce potential future financial risk, quantify and communicate about resilience investment needs, and take full advantage of funding opportunities.

SUMMARY RESULTS:
SYSTEM-WIDE HAZARDS

The hazards detailed here focus on the highest levels of risk exposure (on a scale from low, medium, high and very high) to help target resilience needs and inform the roadmap strategies and actions. A better understanding of high risk is helpful for a number of reasons, including a better sense of the breadth of the challenges ahead, and more confidence in proactive investments to lessen negative impacts.

Inland flooding

Inland flooding can damage road infrastructure, culverts, bridges, and maintenance facilities and equipment. Flooding impacts the public via delays, detours, closures and safety issues that can be both long and short-term. Longer term disruptions can have negative economic impacts for communities and businesses. These impacts are more significant for poor and marginalized communities, relative to others, since these communities often lack the capacity and resources to prepare for and recover from extreme events.

Statewide, 78% of total highway road miles will be exposed to inland flooding by 2050 and 72% are rated as high risk. Flood risk is expected to get worse across most of the system with the largest increases concentrated along coastal corridors and in the wetter, western half of the state. These areas are already the most flood prone, as indicated by historical floodplain maps and historical high water and flood event data. While it's important to focus efforts in high risk areas, flooding will likely get worse in places where flooding is currently less frequent. Being prepared ahead of time will help ODOT maintain the ability to recover quickly.

We know that flooding in Oregon is nothing new, but the frequency and cost of extreme events in recent years has been significant and is expected to continue.

What are other DOTs doing to improve flood resilience?

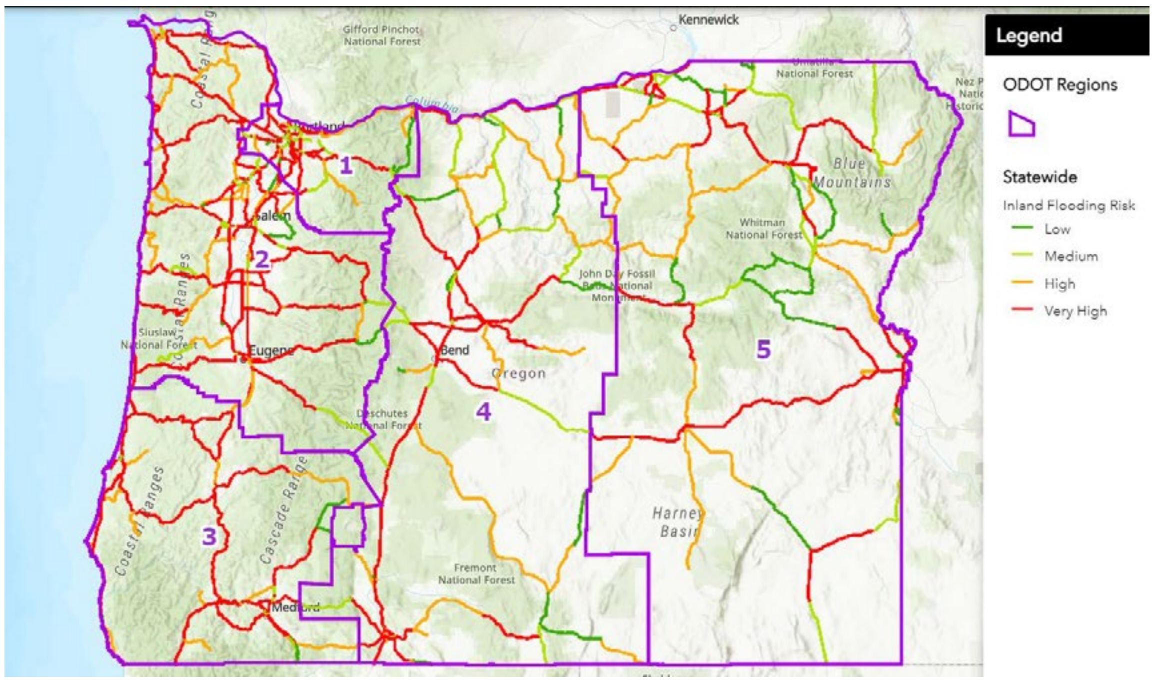
Washington developed the Creating a Resilient Transportation Network in Skagit County: Using Flood Studies to Inform Transportation Asset Management and Climate Change and Innovative Stormwater Control resources.

California details the Caltrans Activities to Address Climate Change (Table 12, P.75)

Idaho developed Enhancing the Resilience of Idaho's Transportation System to Natural Hazards and Climate Change.

British Columbia integrates climate change data into their flood mitigation planning.

For example, in February 2020 rain and snow melt, driven by an atmospheric river, led to [disaster-level flooding](#) that caused evacuations, rescues and deaths near Pendleton, Oregon. Interstate 84, one of the state's key travel and freight corridors, was closed to at least one lane of traffic for six days. Four nearby state highways were also impacted by closures (Highways 204, 207, 237 and 245). Cost estimates for road and bridge damage, and debris removal are upwards of $12 million, with an additional $17 million requested from ODOT to FHWA for damages to major transportation networks.[6]



Map of ODOT managed roads with estimated risk for inland flood risk by 2050.

Inland Flooding by the Numbers

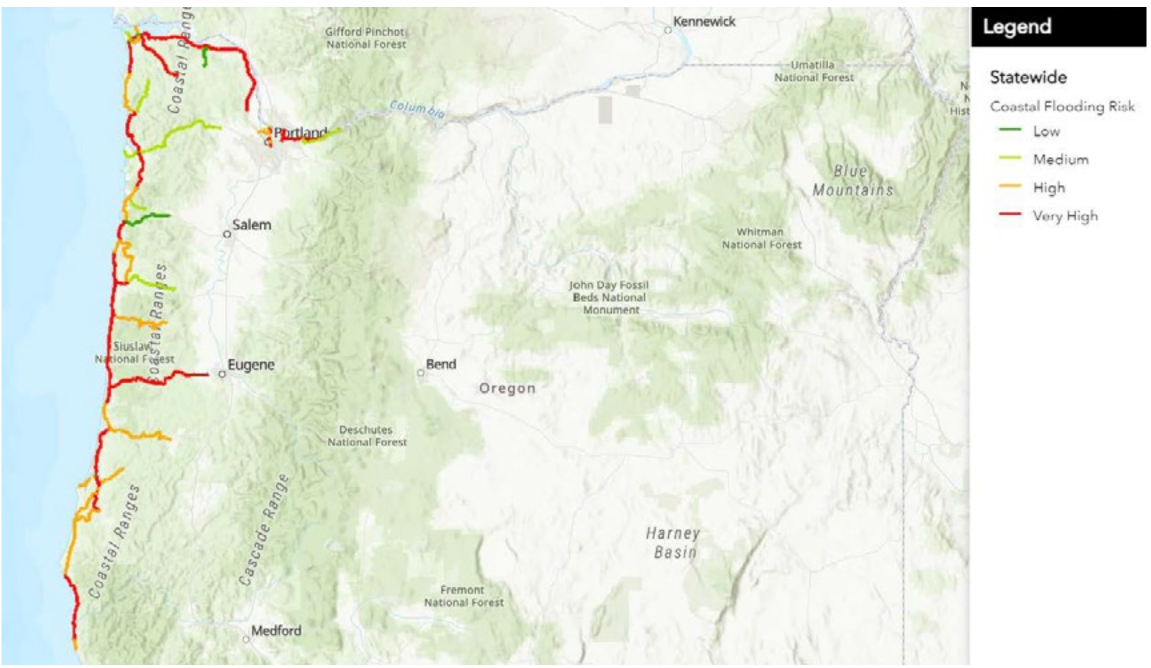
- **72% of state highway road miles** are at high risk of inland flooding.
- There are **3,125 culverts** rated in critical condition. The majority are concentrated on the west side of Oregon where projected flood risk is greatest.
- There are **527 bridges rated in poor condition.** The majority are concentrated on the west side of Oregon where projected flood risk is greatest.
- **1,015 hours of transportation delays** (19% of total delayed hours) were caused by flooding and high water events between 2013 and 2021.
- Nine years (2013-2021) of flood related emergency maintenance costs totaled **$23.4 million**.

6 OEM https://storymaps.arcgis.com/stories/cb570e3df4e14e03a096b0b920534db9

Coastal Flooding & Erosion

Coastal flooding can be caused and worsened by multiple factors that happen at the same time. The largest flooding events come from heavy rain storms and atmospheric river events, coupled with king tides (highest high tide), high winds and even small amounts of rain-driven snowmelt.[7]

While coastal corridors make up only 11% of total state highway road miles, 72% of these corridors are at high risk of flooding. High risk areas are those in the coastal floodplain where seal level rise is projected to have the greatest impact and historically-based flood probabilities are highest.



Map of ODOT managed roads with estimated risk for coastal flooding by 2055..

What are other DOTs doing to improve flood resilience?

- Check out Alaska's Coastal Resilience Assessment to see how other coastal states consider community needs, fish, transportation and other factors to isolate risks and evaluate resilience opportunities.
- Learn about the CalTrans approach to modeling cliff retreat and considering adaptation options (p.19).

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7 https://climate.nasa.gov/news/2740/climate-change-may-lead-to-bigger-atmospheric-rivers/

Many of the same causes of coastal flooding also influence erosion, including cliff retreat (see Appendix A1 for coastal erosion map). Just 3% of total state highway miles are exposed to coastal erosion, but of these corridors 69% are high risk. Rising sea levels also play a key role in worsening erosion, flood, high tide and storm surge (wind) events.

Drivers of erosion and flooding come from both ocean and the land. As a result, coastal corridors are at an increased risk of severe and destabilizing effects on road infrastructure, culverts, bridges, buildings and equipment.

Adaptation options to reduce or avoid damage can be limited in the coastal environment for several reasons:

» There is limited land area available to re-route roads and move infrastructure out of harm's way.
» The topography of the Oregon Coast Range includes east-west oriented river drainages that flow from steep and often unstable terrain before crossing state highways.
» Detour routes are constrained along Oregon's coast, so flood or erosion related delays and closures can result in significant travel times.

Flooding and erosion are tied to many of the same weather events, which exacerbates risk of simultaneous events with related safety issues and consequences to travel reliability. These hazard challenges can have significant impacts on the movement of goods and services, with large negative effects on natural resource and tourism-dependent economies.

Future Coastal Flooding and Erosion by the Numbers

- 922 miles of coastal road are expected to be susceptible to coastal flooding by 2050, affecting regions 1, 2 and 3.
- 820 miles of coastal road are expected to be susceptible to coastal erosion by 2050, affecting regions 2 and 3.
- 72% of coastal state highways are projected to be at high risk of flooding by 2050.
- 69% of corridors exposed to coastal erosion are projected to be high risk by 2050.

Very Hot Days

The frequency, duration, and intensity of very hot days is expected to increase over time. In this case, we measure very hot days as the hottest 5% of days. This represents the hottest days experienced at a given location for a place-based perspective, since we know that the hottest days in Medford are different from the hottest days in Astoria, for example. Statewide, 71% of the state highway system (5,872 road miles) is projected to have more frequent very hot days by 2050. Increases are projected to be more mild west of the Cascades, with increases of 2° (coastal areas) to 8° Fahrenheit (inland areas). More extreme increases are expected east of the Cascades, with increases ranging from 8° to 10° F.

Typical summer heat can add wear and tear to roadways by contributing to cracking, raveling, tracking and oxidation. These effects are likely to be more pronounced under future summer conditions, and especially in high traffic areas. Pavement is designed to withstand high heat, however more frequent and intense heat events will increase stresses and thus maintenance demand.

ODOT can aid adaptations to heat extremes by improving shade in highly exposed areas (e.g., transit stops); using lighter colored paving materials or pavement alternatives at ODOT buildings and facilities; planting heat-tolerant vegetation in the right of way; and improving partnerships with emergency services help with warnings and education, evacuations, public access to cooling resources, and more.

Heat (especially extreme heat) contributes to wildfire conditions, which is also a threat to human health and safety. The catastrophic Labor Day Fires in 2020 burned over a million total

Heat Islands

Pavement absorbs heat and slowly releases it. This can contribute to "heat islanding" and make hot days feel even hotter, particularly in urban environments. Poor and disadvantaged communities are disproportionately exposed and harmed by heat islands.[1] Extreme heat can be lethal; more than 100 people died across Oregon during a "heat dome" event in June 2021. Temperatures soared to over 110° and lingered for three consecutive days in Oregon's most populous cities and surrounding areas.[2] In the Portland area, power cables melted, which disabled transit systems and caused residential outages. Businesses and schools closed due to lack of air conditioning, and roads in Washington closed due to asphalt buckling.[3] Additional heatwaves struck weeks later in late July and mid-August.[4]

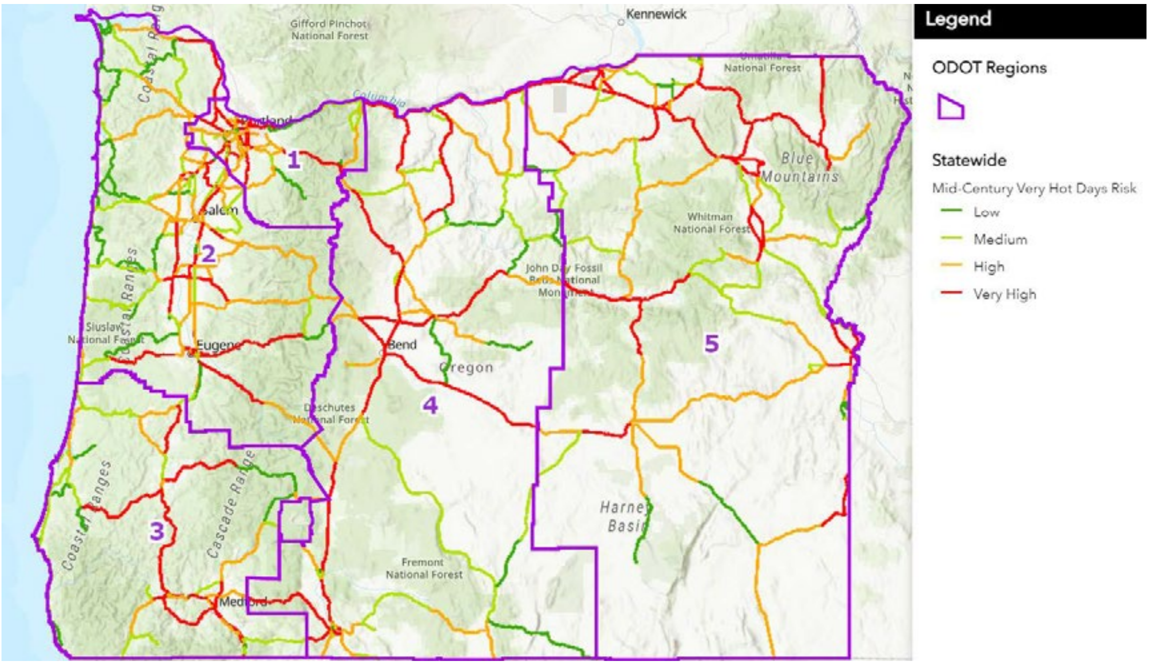
1 Hsu, A., Sheriff, G., Chakraborty, T., & Manya, D. (2021). Disproportionate exposure to urban heat island intensity across major US cities. Nature communications, 12(1), 1-11.

2 Oregon Public Broadcasting (2021). *Oregon wasn't prepared for the heat wave. Experts say the state can do better.* 10 July 2021. Accessed at: https://www.opb.org/article/2021/07/10/oregon-heat-wave-deaths-lessons-preparedness/

3 National Public Radio. (2021). PHOTOS: *The Record-Breaking Heat Wave That's Scorching The Pacific Northwest.* 29 June, 2021. Accessed at: https://www.npr.org/2021/06/29/1011269025/photos-the-pacific-northwest-heatwave-is-melting-power-cables-and-buckling-roads

4 Oregon Public Broadcasting (2021). P*ortland-area communities to open cooling centers during heat wave.* 29, July 2021. Accessed at: https://www.opb.org/article/2021/07/29/portland-metro-area-cooling-centers-heat-wave/

acres, put a half a million Oregonians under an evacuation notice and led to 40,000 people fleeing their homes for safety. The event was a grim reminder of the devastation wildfire can have on communities, the environment, and transportation infrastructure.



Map of ODOT managed roads with estimated risk for very hot days by 2055.

Very Hot Days by the Numbers

- 5,872 road miles are projected to be exposed by 2050.
- 71% of the state highway system is projected to be at high risk of exposure by 2050.
- Extreme heat events in 2021 were lethal and damaged transportation infrastructure.
- Extreme heat contributed to the 2020 Labor Day fires that burned over 1,000,000 acres and displaced 40,000 people in Oregon.
- Nine years (2013-2021) of wildfire related emergency maintenance costs totaled $58.6 million. Extreme heat and dryness contribute to wildfire conditions.

SUMMARY RESULTS:
REGIONAL

This summary of hazards facing ODOT regions spotlights how essential improved data and increased capacity is for addressing the challenges ahead. Whole transportation system resilience is greater than the sum of its regional parts and requires an all hands on deck, “One ODOT” approach.

See the Overview of Approach & Methodology section for a helpful graphic and refresher on definitions of exposure, consequences and risk. Risk rankings are low, medium, high and very high.

Region 1

Region 1, located in the urban north, has historically experienced some of the highest precipitation rates in the state and is projected to see increases in the .01-.1 inch range by 2050 to 2100. Increased precipitation rates can contribute to landslides, especially after wildfire.

By 2050, 72% of Region 1 roadways are expected to be at high risk of inland flooding, and 47% of corridors affected by ocean tides will be at high risk of flooding.

While increased flooding represents a shift in a current norm, adapting to expected changes in wildfire and extreme heat are less familiar challenges. Region 1 shows the second highest projected exposure to wildfire (percent area burned) and extreme heat increases (2-8° F) by 2050.

The return on investment for proactive risk reduction in Region 1 is high, due to the interaction between high risk hazards (e.g., fire, flooding and landslides), and their tendency to intensify one another.

Region 1 future high risk road exposure to climate hazards

- Very hot days: 74% of road miles are at high risk (ranked 2nd)
- Inland flooding: 72% of road miles exposed are at high risk
- Coastal flooding: 47% of road miles exposed are at high risk
- Landslides: 35% of road miles exposed are at high risk
- Wildfire: 33% of road miles exposed are at high risk

Region 2 

Region 2 includes much of west side of the state and has historically been prone to floods and landslides. Between 2013 and 2021, the region experienced 1,099 flood and high water emergency events that impacted the transportation system. Costs from sinks and landslides between 2009 and 2021 totaled $12.2 million.

Region 2 ranks first for future, expected exposure to high risk of very heavy precipitation and wildfire increases. It ranks second for highest future landslide and flood risks. Coastal erosion rates are already high and risk is expected to increase. Changes to heat and fire risk are less familiar to the region and together they will worsen existing challenges like erosion and landslides. Therefore, proactive adaptations that reduce interacting risk factors during recovery and seasonal preparation — post-fire erosion control, for example — will help to improve overall resilience.

Region 3 

Region 3 covers a large area in the southwest where flood and high water events dominated emergency responses from 2013-2021 (56% of total responses.) Landslide-related costs outpaced all other regions; $38 million from 2009-2021.

Region 3 has the greatest exposure to high flood, landslide, and coastal flooding risk by 2050. The region had the highest number of emergency responses related to fire west of the Cascades (265 events from 2013-2021), but has the lowest projected exposure to high wildfire risk and extreme heat increases among regions (10% and 63% of roadways, respectively).

Region 2 future high risk road exposure to climate hazards

- Coastal erosion: 83% of road miles exposed are at high risk (ranked 1st)
- Inland flooding: 82% of road miles exposed are at high risk (ranked 2nd)
- Coastal flooding: 68% of coastal road miles exposed are at high risk (ranked 2nd)
- Landslides: 45% of road miles exposed are at high risk (ranked 2nd)

Region 3 future high risk road exposure to climate hazards

- Coastal flooding: 92% of coastal road miles exposed are high risk (ranked 1st)
- Inland flooding: 89% of road miles exposed are at high risk (ranked 1st)
- Coastal erosion: 54% of coastal road miles exposed are at high risk (ranked 2nd)
- Landslides: 47% of road miles exposed are at high risk (ranked 1st)

Region 4

Historically, Region 4 has experienced the highest number of emergency "winter events" and wildfires (1,258 and 398, respectively between 2013 and 2020). In terms of future risk, the region is expected to see significant high risk exposure to extreme heat and daily freeze/thaw cycles. Snow covered area is expected to decrease over time, as is the likelihood of "snow days" (6 inches or more of snowfall in 24 hours, as defined by ODOT).

The changes in extreme heat may contribute to more wildfires throughout the region.

Locations where flooding and landslides already occur are likely to experience more of these challenges into the future, particularly if impacted by wildfire. Region 4 had the lowest costs associated with hazards, totaling $3.6 million (2% of total costs). Lower costs could be linked to fewer large-scale events during the time period studied. The region had the highest number of "unspecified" events that were difficult to link to costs. Hazard-cost tracking improvements at the region level could benefit preparedness and prioritization of strategic prevention efforts.

Region 5

Hazards associated with extreme winter and summer conditions are likely to see the most change over time. Region 5 has historically (2013-2020) experienced the second highest number of "winter event" emergency responses. System-wide, winter events contributed to 64% of total delay hours. Projections suggest that high risk of freeze/thaw cycles and their impacts could affect 79% of exposed roadways in the region. Region level data collection is critical for understanding where shifts to winter conditions are occurring and their significance (for better or for worse) to transportation safety and reliability.

Region 5 has also seen the second highest number of wildfire related emergency responses historically. Increases in extreme heat are likely to increase wildfire risk, and exacerbate the health and transportation challenges related to smoke. Region 5 has comparatively low risk of flooding and landslides, however increases in wildfire frequency and intensity may change risk dynamics.

Region 4 future high risk road exposure to climate hazards

- Very hot days: 70% of road miles exposed are at high risk of heat increases (ranked 2nd)
- Freeze/thaw effects: 70% of road miles exposed are at high risk (ranked 2nd)
- Inland flooding: 58% of road miles exposed are at high risk (lowest among regions)
- Landslides: 28% of road miles exposed are at high risk (second lowest)

Region 5 high risk road exposure to climate hazards

- Very hot days: 80% of road miles exposed are at high risk of increases in extreme heat (ranked 1st)
- Freeze/thaw effects: 79% of road miles exposed are at high risk (ranked 1st)

HAZARD MAINTENANCE COSTS

ODOT's maintenance expenditure data from emergency events provides some insight into the financial impact of the recent hazardous event trends. Current cost data show a snapshot of significant spikes related to natural hazard response over the last decade (2009-2021), with a total price tag of $168.3 million. Climate hazards caused a cumulative 5,832 hours (243 days) of delay[8] from 2013-2021. The data adds to the story of how climate change is currently impacting the system, which event types tend to coincide with higher expenses, and what these trends look like from a system-wide and regional perspective.

It's difficult to identify long-term trends from one decade of data, but the data can highlight shorter-term patterns, cost increases and outlier years where very large cost increases are associated with major events. A primary goal of the cost analysis exercise is to inform planning by identifying how cost tracking, budgeting, or other processes could be adjusted to improve information about climate-related costs. As climate conditions change, cost spikes are expected to continue. This trend will create a financial burden for the agency, and can strain the availability of resources needed to maintain and improve the transportation system. Further, the strain of hazardous events on infrastructure and response personnel, combined with the cost burden, may significantly undermine transportation resilience into the future.

8 Delay data related to climate hazards come from ODOT's TOCs dataset, which specifies hazard-related delay time by total minutes for flood/high water events, winter events, and fires. Flood and high water data include events in 2021, while fire and winter event data extend through 2020 only.

Hazard Maintenance Cost Analysis

Hazard	R1	R2	R3	R4	R5	Grand Total
Fires	$37,343,895	$10,411,505	$6,923,646	$1,178,491	2,744,205	$58,601,742
Flooding	$126,305	$6,090,602	$744,906	$396,165	18,675,489	$23,033,467
Hazard Trees	$431,980	$3,274,597	$5,911,282			$9,617,859
Ice Hazards	$3,930,240	$421,528				$4,351,768
Slides & Sinks	$9,670,428	$12,239,689	$38,065,273	$1,236,869	783,567	$61,995,826
Unspecified Hazard	$231,864	$1,750,036	$4,688,512	$797,819	264,279	$7,732,510
Grand Total	**$51,734,712**	**$34,187,957**	**$56,333,619**	**$3,609,344**	**$22,467,540**	**$168,333,172**

Source: ODOT Delivery and Operations Budget Office Maintenance Emergency Event Expenditure History dataset (2009-2021)

The cost analysis revealed needed improvements in cost tracking of hazard events; however the information in hand helps to lay the foundation for developing a baseline understanding of hazard related costs. ODOT is already working to improve tracking and reporting in order to better evaluate trends over time. It is expected that the methods applied in this report will not necessarily need to change as data improves. Hazard cost tracking is a new approach to using existing information and will continue to be an important component of building agency resilience to climate change.

IMPLICATIONS FOR REGIONS

The data reflect the variations in climate across that state. Emergency events that impact each region commonly correlate with climatic differences.

For instance, wildfire and winter events are much more common on the east side of the Cascade Range, where conditions are comparatively dry. In contrast, flooding and landslides are dominant west of the Cascades, where rainfall is comparatively high and sometimes extreme. The information provides insight into where proactive, hazard-specific adaptation measures could be targeted to reduce vulnerabilities.

Costs summarized

- Hazards are expensive. Current cost data show a snapshot of significant spikes related to natural hazard response over the last decade (2009-2021), with a total price tag of $168,333,172.
- Region 3 experienced the highest hazard-related costs during the time period studied, dominated by extreme events, including landslides.
- Slides and sinks were the costliest hazard across all regions at about $62 million.
- Data improvements linking hazards with costs is critical to building on the information we have, informing resource needs and planning for ODOT's financial future.

CHAPTER 3:

TRANSLATING RISK TO ACTION

Increasing event impacts across the system and an uncertain future signals a need for a closer look at risk factors and a strategic approach to improving resilience. In addition to the hazard risk assessment and internal data analysis (e.g., costs and historical hazard events), interviews were conducted by the Climate Office with regions and across disciplines to better understand agency resilience. Finally, best practices already in place across DOTs helped to inform the details of the roadmap. Each of these aspects of developing the roadmap played a key role in guiding an agency-specific set of climate change adaptation and resilience strategies and actions.

AN EAR TO THE GROUND: ENGAGEMENT

Building an agency roadmap that facilitates resilience and adaptation requires knowing where we are starting from, and knowing what our strengths and weaknesses are. To this end, internal conversations were centered on two central questions:

1. What is ODOT already doing to be resilient (what's going well)?
2. What barriers need to be overcome in order to expand or improve these efforts at ODOT?

These critical questions were explored with agency and region leadership, program, policy, and technical management, and field staff. This approach ensured a clear understanding of how challenges and opportunities are perceived at all levels.

Interviews with ODOT Staff

Interviews with ODOT leadership, region subject matter experts, and strategic communications staff were an essential step toward understanding adaptation and resilience needs at a practical scale. Three primary interviews focused on cost information with headquarters leadership, capturing regional resilience needs and barriers from the perspective of regional leadership, and a follow up interview with roundtable participants from the Communications Division to further discuss the role of Communications in facilitating resilience building changes at ODOT. Each of these interviews helped to refine data used in this report's analysis or informed the development of the adaptation strategies and actions.

The discussions with regional staff were noteworthy; staff emphasized resilience needs and barriers, as well as the variety of climate change resilience building activities that are already embedded in ODOT's daily work of maintaining system safety and reliability. These range from rapid responses to emergencies, post- event discussions to learn from experience, proactive signage and public communication efforts, equipment sharing, shifting personnel capacity, and much more. The insights regarding strengths, needs and barriers to improvement directly informed the final strategies and actions outlined in Chapter 4 of this document.

Roundtable Discussions by Discipline

Four roundtable discussions organized around discipline areas within ODOT were held in fall 2021 to bring together representatives from ODOT maintenance and operations, project delivery, design and engineering, funding programs, policy analysis, and communications groups. Like the regional interviews, the goal was to gather qualitative feedback regarding the draft climate change adaptation strategies and actions. Participants discussed draft climate resilience strategies and actions, articulated potential obstacles to resilience improvement efforts, and expanded on existing efforts to advance established practices around seeking out and applying lessons learned.

Key Needs and Barriers to Overcome

There are needs and barriers that must be addressed to make meaningful and efficient progress toward resilience including:

Needs:
- Increased personnel and funding is needed. See strategies [1.3, 3.1, 3.2, 3.3, 4.4]
- Consultation with Tribes and Indigenous groups about adaptation needs and solutions is needed. See strategy [1.3]
- Centralized data, educational materials, and training to learn more about climate data, resilience needs, and adaptation best practices are needed and critical to success. See strategies [2.3, 2.4]

Barriers:
- Lack of agency-wide adoption of policies that incentivize resilience work, and a lack of tools to support that work. See strategy [1.1, 2.2, 3.3]
- Lack of standardized hazard cost tracking impacts ability to understand patterns of change and resource needs over time. See strategies [2.3, 2.4]
- Inconsistent and fragmented methods of capturing and sharing hazard impact data across the agency. See strategies [1.2, 2.3]

External Engagement | Area Commissions on Transportation (ACTs)

Communicating about local transportation network needs and challenges is a critical component of resilience planning. It also opens up opportunity for expanding co-benefits of planned work and leveraging funding opportunities to enable expansion of resilience efforts and increased efficiency of funds. External engagement with several Area Commissions on Transportation (ACTs) added local transportation system context. Local systems are an essential consideration given the interconnected nature of state-wide transportation systems.

Outreach with ACTs was used to present preliminary findings and gather insights to augment ODOT's resilience strategies and actions. Key themes from this initial engagement include:

» Ensuring Tribes were included and consulted about adaptation needs and solutions.
» Opportunities for collaboration exist; communicating with counties and other jurisdictions about their formal adaptation planning processes is an important early step in coordinating efforts.
» Ongoing engagement with ACTs will aid communication and coordination efforts.

The climate office and other ODOT leadership will continue to engage with ACT members throughout the state. The goal will be to keep lines of communication open and active, particularly as ODOT operationalizes resilience strategies.

RESILIENCE ACTIVITIES AND ODOT'S DAILY WORK

ODOT is already engaging in adaptation actions that improve preparation, reaction and recovery from climate extremes. These approaches are strongly maintenance and communications focused, which means there's opportunity to weave climate change considerations into ODOT programs more broadly. The desired outcome is to harness opportunities at the earliest stages of project planning, to have updated and climate-responsive design guidance, and to work with existing maintenance protocols to target high risk locations. Notably, ODOT already engages in both proactive and reactive practices that can improve climate change resilience, though these are not acknowledged as such.

Internal discussions held across ODOT divisions (communications, maintenance and operations, delivery, design & engineering, policy and programs) provided insight into the resilience efforts that the agency already has underway. The adaptation and resilience building strategies and actions detailed below reflect ODOT's existing work. They also include recommendations for future direction, identify barriers to success, and incorporate "best practices" from the Federal Highway Administration and other state DOTs.

Current Proactive Resilience Tools

- Seasonal/weather event planning meetings
- Social media
- Electronic (VMS) signage
- Road cameras
- Snow fencing (limited)
- Rock fencing
- Landslide monitoring
- Multi-lingual communications
- Cross-state emergency preparation
- Case studies
- Asset condition ratings

Current Reactive Resilience Tools

- Fixing and replacing, rather than upgrading
- Emergency response
- Post-event debriefings
- Social media
- Equipment sharing
- Personnel role flexibility
- Detours/closures
- Multi-lingual communications
- Cross-state emergency response

Communications

- A key strength of ODOT's resilience approach (present and future) are the multiple approaches to communication.
- Existing internal communication approaches are considered to be very good. They also provide a foundation for more education and training efforts related to climate change adaptation and resilience building.
- Existing strengths around external communication include information sharing between county, city and state; social media and TripCheck as public information hubs; and cross-agency networking efforts. Communications around emergency response are tested and drilled, and leaders in the discipline are thinking ahead about how to better understand gaps (e.g., who among the public is missing a message vs ignoring it).

Maintenance & Operations

- ODOT has strong, established emergency agreements in place for equipment sharing internally and externally to support event response.
- The agency uses existing roadside variable message signs to keep travelers up to date on system conditions and delays.
- Computerized radio systems are communication systems built to withstand large events and are used across agencies. ODOT has adopted this but it's expensive and needs continued support.
- Data tracking systems exist to detail the types of events impacting the system by location, including delay time.
- Response to emergency maintenance events is considered to be very good, but increasingly causes burn out in personnel.
- Risk-based decision making and practical solutions have served well so far and will continue to be important going forward.
- ODOT holds pre-winter operations meetings each year with local, state, and interstate partner agencies. The meetings cover predicted winter conditions but also serve to update contacts and refresh event and closure plans.

Delivery, Design & Engineering

- TransGIS is an existing tool used for planning that is set up well for adding additional climate risk information.
- New social equity mapping efforts at ODOT will better serve historically marginalized communities.
- There's an existing process for innovative project pilots and many existing pilots have a corridor-scale focus.
- Engineers can design things very well if they know materials and goals.
- Manuals and guidance documents exist that influence infrastructure- these are responsive to change and can be updated over time as new, local climate information develops.
- Internal coordination with maintenance is considered to be to be important and there's support for shifting the timing and purpose of current communications to acknowledge maintenance's long-term responsibility or "inheritance" of all that is designed and built at ODOT.

Policy and Programs

- There is consensus among the group regarding the need to institutionalize or codify resilience within existing agency policy.
- Shared focus on a need for easy-to-implement resilience strategies.
- Funding and staffing needs are well understood.
- ODOT has a history of working with partner agencies to find middle ground; more of this kind of cooperation will likely be necessary.
- ODOT has models in place to help inform future conditions and planning. These could be updated to consider future climate change.
- ODOT is a data-rich environment and can do more to share data across the agency, beyond the agency, and make data-driven decisions.

CHAPTER 4:
THE ROAD TO CLIMATE RESILIENCE

Chapter 4 includes the strategies and implementation actions that represent the culmination of the two-year roadmap development effort. The strategies and implementation actions reflect the work ODOT must do over the next five years in order to advance the agency's resilience goals. The strategies outlined in this chapter will be applied in the context of ODOT's broad transportation goals and objectives.

Operational planning efforts directly following the approval of this plan will identify the specific agency activities and milestones that will allow ODOT and the climate office to meaningfully track and report progress. The implementation plans, tailored to each action, will link new and ongoing work efforts to desired outcomes and resilience plan goals.

The 2023-2027 Climate Adaptation and Resilience Roadmap was developed based on the results of the statewide climate hazards risk assessment's best available climate data, staff input, and best practice research. With access to new and improved data, emerging research and technological advancements, enhanced guidance, education and training ODOT will be positioned to take advantage of funding opportunities. The agency will also be able to better manage existing conditions and challenges while preparing to tackle those on the horizon. The lessons learned while implementing new work efforts — and monitoring ongoing ones —will be used to adjust subsequent work plans and future iterations.

GUIDING PRINCIPLES

Three core principles cut across all adaptation strategies and actions and represent what the agency can continue to strive for in support of climate resilience. These include climate equity; community engagement, communication and coordination; and economic impact.

CLIMATE EQUITY

Climate change is fundamentally tied to social equity and justice. The negative consequences of a changing climate are not endured the same way across the Oregon public. Low income and disadvantaged communities[9] are not on equal or fair footing when it comes to preparing for or coping with the negative effects of climate change. For example, socio-economic differences directly influence how impacts like health, safety, and emergency event response are experienced, and influence access to resources and information for recovery or avoiding harm in the first place. It is unjust that low income and disadvantaged communities contribute the least to the causes of climate change, but are disproportionately harmed.

9 Disadvantaged communities are communities that experience disproportionately high and adverse health, environmental, climate related, economic, and other cumulative impacts. Factors contributing to disadvantage include systemic discrimination and related factors such as race or ethnicity, underemployment, incarceration, education access, disability, age, English language proficiency and much more.

Guiding Principles

- **Climate Equity**
  ODOT prioritizes protection and resilience within marginalized, low-income, indigenous and Tribal communities, who are most at-risk of harm from climate hazards.
- **Community Engagement, Communication & Coordination**
  Meaningful engagement processes aim to better understand community needs, learn from their experience and create a channel for outreach and education. Communicating strategically and coordinating with internal and external partners, stakeholders and the public will lead to increased alignment, leveraged resources, and increased adaptive capacity.
- **Economic Sustainability**
  Adaptation measures and investment strategies focus on prioritized transportation system vulnerabilities that account for the impact of climate-related system disruptions on Oregon's economy. Tools help simplify and accelerate access to data that illustrate the value of increased transportation resilience.

Equity acknowledges that not all people, or all communities, are starting from the same place due to historic and current systems of oppression. Equity is the effort to provide different levels of support based on an individual's or group's needs in order to achieve fairness in outcomes. Equity actionably empowers communities most impacted by systemic oppression and requires the redistribution of resources, power, and opportunity to those communities (see glossary terms and definitions).

When we think about enhancing climate change resilience, there is potential to harm communities with interventions if they are not appropriately designed. Equity is relevant to the origins and impacts of climate change, and critical to the processes and decisions made to adapt and build resilience. Restoring justice to the process of building lasting resilience requires addressing Oregon's history, learning from past harms and charting a better path forward.

COMMUNITY ENGAGEMENT

Community engagement plays a critical role in Oregon’s resilience future. Transportation decisions made today will have long-term legacies. Communities impacted by resilience building efforts need to be engaged to help ensure long-lasting and broad benefits. Public engagement, particularly with historically marginalized, low income and disadvantaged communities, is considered essential to getting adaptation right.

Public engagement, particularly with low income and disadvantaged communities, is considered essential to getting adaptation right. The better engaged the public is — particularly those directly impacted by ODOT work — the better the potential outcomes. With social equity as a guiding principal, ODOT can help set the standard for state agencies committed to a transportation system that serves all needs, especially in the face of climate change challenges.

When it comes to adapting and building resilience to negative climate change impacts, how well the agency serves the most vulnerable will be a vital measure of success. The roadmap includes specific strategies and actions that infuse equity improvements across the fabric of resilience building efforts.

Tribal and Community-Level Engagement Strategies

- Consult with Tribes and Indigenous groups to locate climate change vulnerability and solutions from their perspective, then integrate this information into decision making.
- Acknowledge gaps in ODOT’s historical knowledge of hazard impacts to the system and invite knowledge sharing about climate change and its impacts to honor Tribal and Indigenous stewardship since time immemorial. A deep knowledge of the land and its history is foundational to understanding threats and best approaches to address them.

Reciprocity in who benefits from information sharing is fundamental to building long-term relationship with Tribes and other Indigenous partners.

COMMUNICATION AND COORDINATION

Strong partnerships across the transportation sector are essential to acknowledge resilience vulnerabilities and leverage opportunities from ties between transportation networks. Even under uncertain climate conditions, ODOT can move forward with greater confidence in long-lasting investments that benefit generations when partnerships and partner commitments are forged.

Example communication and coordination actions

ODOT will advance climate equity across agency resilience efforts with:

- Solutions and interagency agreements that reflect strong partnerships and collaboration among state, federal, and local agencies responding to climate impacts.

  Example action: Develop collaborative strategies/ shared goals with inter-agency stakeholders (MPOs, cities, counties, multimodal agencies (e.g. transit service providers))

- Coordination with local partner agencies improves ODOT's ability to effectively prepare for and respond to major events.

  Example action: Link to local systems to ensure adequate system redundancies in high-risk corridors – particularly where state systems are lacking (consider adding redundancies where practicable).

ECONOMIC SUSTAINABILITY

Oregon's transportation systems were not built with current climate impacts in mind. Therefore, to build a climate resilient transportation system, adaptation science must inform future planning, maintenance, design and construction moving forward. These steps support maintaining and optimizing system functionality going forward and reduce the impact of climate variability and change on economic viability and sustainability. The ODOT resilience corridors (see Appendix A1), identified as part of this work, represent the priority corridors (those of economic importance that are currently prioritized for upkeep and investment) that are at the highest risk of disruption from climate impacts. In addition to these corridors, a broad cost analysis of recent, historical hazard events highlights the financial strain already incurred by the agency and provides insight into future fiscal burden as trends continue and worsen.

The roadmap outlines strategies and actions ODOT must take in order to minimize climate change impacts and maximize resilience investments. For example, ODOT must develop and implement better tracking on the fiscal impacts of climate hazards and economic analyses (i.e. cost-benefit analyses) to help inform and strengthen the business case for making climate resilience investments. Cost-benefit analyses, coupled with the resilience corridor considerations, will help screen resilience projects and adaptation approaches to identify the best projects to prioritize for funding.

The Infrastructure Investment and Jobs Act (IIJA) (2021) established the Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation (PROTECT) program, providing $92 million over five years to Oregon and will be offering $250 million in competitive grants opportunities in Federal Fiscal Year (FFY) 2022 aimed at increasing the resilience of transportation systems nation-wide. This includes funding for evacuation routes, coastal resilience, making existing infrastructure more resilient, or efforts to move infrastructure to nearby locations that are less impacted by extreme weather and natural disasters. The Bipartisan Infrastructure Law incorporates resilience considerations into existing transportation programs. This includes improvements to the National Highway Performance Program, Surface Transportation Block Grant Program, and FHWA’s Emergency Relief Program. DOTs across the country are faced with funding constraints and hard trade-offs when making investment decisions. In this regard, ODOT is no different.

Oregon Department of Transportation and Oregon’s transportation system face significant long-term funding challenges. A number of trends will drive changes in the way the state invests in the transportation system, while other trends will create significant challenges for the revenue needed to invest in the system. ODOT will need to position itself to take full advantage of new and emerging funding opportunities to manage the converging challenges the agency is facing. To this end, ODOT will undertake the work of integrating the best available climate science and data into investment strategies and decision-making processes. To complement these efforts, ODOT’s Transportation Policy and Analysis Unit (TPAU) is using modeling to capture the economic impacts of disruption at some of the highest risk locations throughout the state. This analysis will to help provide a more comprehensive understanding of the extent of financial exposure ODOT faces if nothing is done to strengthen and enhance system resilience. It will also highlight the potential return on up-front investments in climate adaptation.

RESILIENCE GOALS, ADAPTATION STRATEGIES AND IMPLEMENTATION ACTIONS

Information is constantly changing and improving, yet timely infrastructure decisions require accurate data about the extent, timing, and distribution of potential risks and impacts. An increasingly unpredictable environment poses a challenge and compounded by major transportation infrastructure and urban centers built in climate vulnerable locations. The risk perceptions among the public and decision-makers also vary widely. These challenges are at the heart of the goals, strategies, and actions outlined below as they were designed to be flexible enough to account for the regional climate variability and other localized context and conditions on the ground.

To develop this list of strategies, we engaged in a series of internal interviews, facilitated four discipline focused Resilience Roundtable discussions and consulted resilience plans of other state departments of transportation. Through these efforts, we identified strategies that would help ODOT achieve several goals across four key outcome areas:

- Institutionalize Resilience Priority
- Advance Research & Data-Driven Practices
- Maximize Resilience Investments
- Build Climate Resilient Infrastructure

RESILIENCE GOALS

Institutionalize Resilience Priority	Advance Research & Data-Driven Practices	Maximize Resilience Investments	Build Climate Resilient Infrastructure
» ODOT has an integrated policy and decision-making framework that prioritizes climate resilience, emergency preparedness and response. » Employees understand how their work supporting adaptation and resilience outcomes ties into the broader agency policy agenda. » ODOT has strong internal and external coordination and partnerships.	» ODOT is able to proactively monitor and document climate related impacts to the transportation system. » ODOT staff have increased access and ability to interpret climate change information using relevant data and maps » Tracking change and monitoring progress guides decision making as climate change effects evolve over time.	» ODOT understands and is positioned to take full advantage of the variety of existing and emerging funding opportunities that can be used for resilience investments. » Funded projects are selected, scoped, and designed to effectively address known risks and shifting needs.	» Infrastructure investments enhance protection and resilience of infrastructure to climate hazards. » Resilience-building efforts prioritize vulnerable communities, especially those marginalized by structural targeting and historical divestment. » The potential impacts of not proactively investing in adaptation are well understood when deciding how to make the best use of limited resources. » Investments advance ODOT's ability to meet its mission into the future.

* ***Resilience*** *is the ability to anticipate, prepare for or adapt to conditions; or withstand, respond to or recover rapidly from system disruptions.*
* ***Climate change*** *adaptation strives to reduce or avoid impacts from climate change related hazards.*

RESILIENCE STRATEGIES

Institutionalize Resilience Priority	Advance Research & Data-Driven Decision-Making	Maximize Resilience Investments	Build & Maintain Climate-Resilient Infrastructure
1.1 Codify climate considerations in policy plans and decision-making processes	2.1 Develop resilience research plan	3.1 Develop resilience investment strategy	4.1 Connect system-level risk assessment to project-level planning and decision-making
1.2 Adopt holistic all-hazards approach to address system vulnerabilities	2.2 Establish resilience performance measures, monitor and report on agency performance/ progress	3.2 Build a business case for resilience investments.	4.2 Pilot context-sensitive solutions, promote green infrastructure options wherever practicable
1.3 Facilitate collaborative, multi-partner approaches to climate risk and disaster planning efforts	2.3 Deploy comprehensive incident and hazard event, cost and other data-tracking systems necessary to enable climate informed decisions.	3.3 Prepare odot for funding opportunities to ensure the agency is competitive	4.3 Adopt climate informed design standards, guidance, and tools
	2.4 Provide guidance, education and training regarding new data systems, tools and emerging technology		4.4 Update maintenance practices to increase proactive maintenance on resilience corridors.

OUTCOME AREA: Institutionalize Resilience Priority » ODOT has an integrated policy and decision-making framework that prioritizes climate resilience, emergency preparedness and response. » Employees understand how their work supporting adaptation and resilience outcomes ties into the broader agency policy agenda. » ODOT has strong internal and external coordination and partnerships.			
	Strategies	Anticipated Start Year	Implementation Actions
1.1	Codify climate adaptation considerations in policies, programs and decision-making processes	2022	Update agency policy plans to integrate climate risk considerations and prioritize resilience outcomes.
		2022	Establish consistent agency resilience goals, talking points, and language used to describe ODOT's climate adaptation and resilience work-efforts.
		2023	Integrate climate risk data into decision-making processes, starting with high-impact decisions.
		2024	Incorporate climate resilience into Agency contracting requirements.
1.2	Adopt holistic all-hazards approach to address system vulnerabilities	2024	Promote an all-hazards resilience approach.
		2024	Establish agency-wide funding and repair policies that promote proactive maintenance and adaptive upgrades
		2023-24	Include consideration of future stressors (e.g., flooding or accelerated sea level rise) when making decisions about siting transportation infrastructure, maintenance equipment and other facilities.
		2023-24	Consider climate risk in asset inventories, planning and environmental review decisions.
1.3	Facilitate (lead) collaborative, multi-partner approaches to climate risk management and disaster planning efforts	2023	Prepare a communications plan for engaging internal partners, agencies and the public.
		2023-24	Use data to improve coordination among emergency management partners; establish new agreements/ partnerships with local emergency management to plan for evacuation of vulnerable populations during wildfires and other climate hazard events; (e.g., establish emergency evacuation routes on public lands).
		2024-25	Leverage existing resources to cover increased costs and personnel demands.
		2024-25	Establish reciprocal staffing relationships with other state agencies to share seasonal/ temporary hires and streamline hiring processes.

OUTCOME AREA: Advance Research And Data-Driven Decision-Making

- ODOT is able to proactively monitor and document climate related impacts to the transportation system.
- ODOT staff have increased access and ability to interpret climate change information using relevant data and maps
- Tracking change and monitoring progress guides decision making as climate change effects evolve over time.

	Strategies	Anticipated Start Year	Implementation Actions
2.1	Develop resilience research plan	2022-Ongoing	Expand participation in and advancement of state and national research activities.
		2023-24	Establish long-term data coordination strategy with relevant state agencies and research institutions; pair the best available climate science with engineering practitioners and increase efforts to fund research pilot opportunities and partnerships.
2.2	Establish resilience performance measures and monitor agency progress	2023	Link resilience outcomes to existing agency performance measures and requirements.
		2023	Identify and continue to expand on metrics related to resilience and climate equity outcomes.
		2024	Adopt metrics for tracking impacts of climate stressors to specific asset-types over time.
		Ongoing	Review and update indicators, metrics and performance measures periodically, informed by updated best practices and available data
2.3	Deploy comprehensive incident and hazard event, cost and other data-tracking systems necessary to enable climate informed decisions.	2024	Enhance monitoring for vulnerable assets before, during, and after hazard event
		2023-24	Track climate impacts on repair costs, maintenance and operations budgets and staffing to inform response protocols.
		2024-25	Track both the immediate infrastructure costs and economic impacts as well as the long-term downstream costs and impacts.
2.4	Provide guidance, education and training regarding new data systems, tools and emerging technology	2023	Publish a centralized hub for all ODOT relevant climate data, education resources, and tools.
		2023-24	Create a forum for outreach and education on resilience risks and avoidance.
		2023-Ongoing	Provide professional development and skill enhancing training programs based on emerging best practices and available information.

OUTCOME AREA: Maximize Resilience Investments

- ODOT understands and is positioned to take full advantage of the variety of existing and emerging funding opportunities that can be used for resilience investments.
- Funded projects are selected, scoped, and designed to effectively address known risks and shifting needs.

	Strategies	Anticipated Start Year	Implementation Actions
3.1	Develop resilience investment strategy	2022	Conduct a resilience needs analysis; gather local knowledge and information about local systems to inform this assessment.
	Build a business-case for resilience investments.	2022	Identify federal, state, and local funding sources that can be used for resilience investments and examine how funding levels for existing investment programs, maintenance and operations are causally related to resilience outcomes.
	Develop resilience investment strategy	2023	Develop tracking tools – tied to agency resilience performance metrics – to determine effectiveness of resilience investments.
3.2	Build a business-case for resilience investments.	2024	Use in-house modeling capabilities to evaluate impacts of potential disruption at high-risk locations throughout the state to inform cost benefit analysis and funding needs.
	Develop resilience investment strategy	2024	Develop investment scenarios with detailed cost-estimates related to proactive versus reactive adaptation measures.
	Build a business-case for resilience investments.	2023-24	Apply adaptation index during STIP development process to inform program funding allocation decisions and project scoping and selection processes.
3.3	Prepare odot for funding opportunities to ensure the agency is competitive	2023	Match unfunded infrastructure resilience needs to funding opportunities.
		2023-24	Identify existing STIP projects across programs with complimentary goals and seek leveraging opportunities whenever practicable.
		2024-25	Apply adaptation index to proposed projects to identify and cultivate competitive resilience projects to advance for potential funding opportunities.

OUTCOME AREA: Build and Maintain Climate-Resilient Infrastructure

- Infrastructure investments enhance protection and resilience of infrastructure to climate hazards.
- Resilience-building efforts prioritize vulnerable communities, especially those marginalized by structural targeting and historical divestment.
- The potential impacts of not proactively investing in adaptation are well understood when deciding how to make the best use of limited resources.
- Investments advance ODOT's ability to meet its mission into the future.

	Strategies	Anticipated Start Year	Implementation Actions
4.1	Connect System-Level Risk Assessment to Project-Level Planning and Decision-making	2022	Adopt Climate Hazard Risk Maps as agency tool to identify and prioritize resilience corridors for strategic investment (see Special Note on PROTECT, below).
		2022	Integrate consideration of climate risks in existing infrastructure funding programs project selection criteria.

Special Note Re: Federal Funding Opportunities: Promoting Resilient Operations for Transformative, Efficient, and Cost Saving Transportation (PROTECT) Program and mapped Resilience Corridors

The PROTECT program, established under IIJA (2021), consists of both dedicated formula and grant funding to help states improve the resiliency of transportation infrastructure. The program funds project enhancements to ensure investments enable ODOT to better anticipate, prepare for, and adapt to changing conditions and disruptions in response to extreme weather events and natural disasters.

Funding: Oregon will receive a formula allocation of $93.8 million over five years. 2% of these funds ($1.8 million) are set aside for resilience planning activities. Additionally, $1.4 billion in competitive grant funds will be available nationwide for planning, resilience, community resilience and evacuation routes, and at-risk coastal infrastructure.

Program Approach: For the 2024-27 STIP, ODOT will use the climate hazard risk maps and guidance. In future STIP cycles, projects located on tiered resilience corridors (see attached Resilience Corridor maps) will be prioritized for formula funding and advanced for grant funding opportunities as applicable. The resilience corridor maps combine a number of factors, including asset condition data, past incidents and system disruptions, as well as social disparity and future climate projections. Using these combined factors to identify resilience investments will help to position the agency to strategically pursue PROTECT grants while addressing high priority resilience needs.

Planning Funds: *ODOT is targeting the PROTECT planning funds first to develop specific corridor level strategies for addressing risks and enhancing resilience.*

OUTCOME AREA: Build and Maintain Climate-Resilient Infrastructure » Infrastructure investments enhance protection and resilience of infrastructure to climate hazards. » Resilience-building efforts prioritize vulnerable communities, especially those marginalized by structural targeting and historical divestment. » The potential impacts of not proactively investing in adaptation are well understood when deciding how to make the best use of limited resources. » Investments advance ODOT's ability to meet its mission into the future.			
4.2	Pilot context-sensitive solutions, promote green infrastructure options wherever practicable	2023 - Ongoing	Pilot use and application of resilience data, design innovations and best practices for high-risk, hazard-prone infrastructure (start with culverts and bridges; phase expansion to additional assets/programs).
		Ongoing	Promote use of green infrastructure and nature-based solutions wherever practicable that align with both resiliency and greenhouse gas reduction goals (e.g. carbon sequestration).
4.3	Adopt climate informed design standards, guidance, and tools	2024	Adopt project engineering design guidance and standards that integrate climate data to account for identified risks.
		2024	Periodically update design guidance and manuals to reflect the best available data, emerging trends, and technological advances (start with most relevant manuals and guidance, phase expansion to additional reference documents at time of scheduled update).
4.4	Prepare ODOT for funding opportunities to ensure the agency is competitive	2023	Evaluate routine, maintenance schedules to ensure high higher priority higher risk areas are prioritized.
		2023 - 24	Establish protocols for responsive short and long-term staffing after an event/ in preparation for an event season (e.g. fire and flood).

NEXT STEPS

Over the next several months, ODOT's Climate Office Adaptation Team will work with a cross-functional implementation team, made up of subject matter experts across ODOT divisions to operationalize resilience strategies, develop a centralized governance and reporting structure. Effective implementation will require cross-functional coordination internally and also with federal, state and local agency partners, Tribes and Indigenous groups, community members to find collaborative approaches and solutions, connect with impacted stakeholders, and learn best practices.

Some of the Actions ODOT will take during Year One Implementation:

» Update agency policy plans to integrate climate risk considerations.
» Establish consistent agency resilience goals, talking points, and language.
» Integrate climate risk data into decision-making processes, starting with high-impact decisions.
» Develop agency-wide metrics for tracking impacts of climate stressors.
» Expand participation in and advancement of research activities.
» Publish a centralized hub for all ODOT relevant climate data, education resources, and tools.
» Identify federal, state, and local funding sources that can be used for resilience investments.
» Use in-house modeling and economic analysis to inform cost benefit analysis and funding needs.
» Use adaptation index to cultivate competitive resilience projects for potential funding opportunities.
» Adopt Climate Hazard Risk Maps as agency tool to identify and prioritize investments on resilience corridors.
» Pilot use and application of climate data and resilience best practices for hazard-prone infrastructure on resilience corridors.
» Evaluate routine, maintenance schedules to ensure resilience corridors areas are prioritized.

Interested in what other DOTs in the West are doing to improve climate change resilience?

- WSDOT
- Idaho Transportation Department
- Montana's Climate Solutions Plan
- CalTrans Climate Change Vulnerability Assessment
- Colorado Resilience Program
- British Columbia, Canada

Other Resources

- Incorporating the Costs and Benefits of Adaptation Measures in Preparation for Extreme Weather Events and Climate Change—Guidebook (NCHRP)
- Climate Change and Resilience: Improving the Long-term Sustainability of the U.S. Transportation System (US DOT)
- Climate Action Plan: Revitalizing Efforts to Bolster Adaptation & Increase Resilience (US DOT)

Adopting this roadmap marks the beginning of documenting and expanding on ODOT's portfolio of climate adaptation and resilience efforts, including internal efforts to more fully capture impacts of climate change on agency budgets, resources and operations. As the agency undertakes operational planning and implementation of these strategies we are committed to remaining nimble and responsive to the fiscal landscape and constrained resources of the agency. Reducing the burden climate hazards and impacts place on ODOT budgets, staff, and other limited resources is at the heart of adaptation and resilience work.

APPENDICES

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A-1 | Risk Assessment Methodology

Detailed description of Consultant desktop study and climate adaptation risk assessment of ODOT priority corridors. ODOT data and hazard response used to inform the development of summary data layers, including the Resilience Corridor layer that will facilitate prioritizing "high need" resilience areas most at-risk of repeated impacts and disruption.

- Risk Assessment Methodology Details
- Data Details
- Historical Hazard Response Patterns by ODOT Region
- Resilience Corridors

Risk Assessment Methodology Details

The desktop multi-hazard risk assessment was carried out through a consultant firm (ICF) in summer 2021.

Decision-Making Context

The goals of the project are to 1) understand climate change risks to transportation assets statewide and 2) develop an agency-wide operational adaptation strategy. The risk assessment provides an understanding of priority system-wide risks, rather than focusing on individual assets, to inform operational action on adaptation across the department's agencies and Regions.

Scope of Assets

The study evaluates climate change risks to highways at a corridor scale.
Corridors are defined by highway segments. A corridor length cap of 50 miles is applied in situations where segments are particularly long in between highway intersections.

This corridor approach is similar to the ODOT Seismic Lifelines Evaluation; and the Vulnerability Synthesis and Identification Study (2012). In order to present results per ODOT Region, the corridors are segmented by Region.

Overview of Risk Assessment Methodology

The risk assessment focuses on the key question: Where are the highest risks to ODOT under a changing climate? **High risk areas of greatest concern include**: corridors that will continue to experience greater increases in risk ('hotspots') as well as corridors that may be overlooked.

- Priority corridor hotspots: Where corridors are already getting attention (e.g., investment priorities, dispatches to respond to weather-related incidents), how is the climate changing? Is the climate changing in a way that may increase incidents?
- Non-priority corridor hotspots: Where corridors with projected increases in climate hazards, but currently are not getting attention (e.g., not investment priorities)? These non-priority corridors may be overlooked under changing climate conditions.

The risk assessment methodology is comprised of two sequential analytical components to address the above questions:

- **Desktop analysis** of risk to screen for high-risk corridors

i. An indicator-based approach to screen for high exposure and consequences
ii. A desktop screen for risk hotspots under future climate conditions

Risk is analyzed as a function of exposure and consequences (Figure 1).[1] The desktop analysis systematically screens for exposure and consequences using an indicator-based approach, which identifies characteristics or attributes of corridors that serve as indicators of their exposure and consequences. The desktop analysis scores the exposure and consequences indicators (i.e., on a scale of 1 to 5), and then combines the scores to calculate a risk score for each corridor. Risk scores are expressed on both a per-hazard basis, and on a combined multi-hazard basis.

Figure 1. This assessment will evaluate exposure and consequences as components of risk, and ultimately high risk areas of concern

This screening helps to identify high risk corridors that may experience a) greater severity of exposure and b) greater potential consequences. The analysis zooms out to identify corridors of high risk that may be hotspots for ODOT using data on investment priorities, condition, and past operations dispatches.

Analyzing Exposure

Exposure Methodology

Exposure of corridors is based on the following climate hazards:

- Extreme temperature
- Freeze/thaw
- Extreme precipitation
- Snowfall
- Inland flooding
- Landslides
- Wildfire
- Sea level rise and storm surge
- Coastal erosion

The exposure assessment summarizes trends in projected changes to each climate hazard. Each corridor receives an exposure ranking using ICF's in-house calculations. The geospatial data about each hazard is described in the sections below.

[1] Exposure: "The presence of assets, people, and ecosystems in places where they could be adversely affected by hazards." Consequences: "A subsequent result that follows from damage to or loss of an asset." Definitions were established at the outset of this project.

Exposure Indicators

Table 1 below outlines the selected exposure indicators included in the risk assessment. All hazards are evaluated spatially.

Table 1. Summary of climate indicators

Hazard	Indicator	Justification
Very hot days	Change in what is considered a "very hot day," categorized by the 95th percentile temperature	The 95th percentile temperature is a standard measure of extreme heat used in risk assessments. Percentile thresholds best communicate local extremes and how they differ across the state, such as between mountain and low-lying regions.
Freeze/thaw	Number of days that experience a daily freeze/thaw cycle	Freeze/thaw cycles can expand and damage pavements. Indicator represents days when maximum temperature is above freezing and the minimum temperature is below freezing. Indicator value is in absolute value (rather than change) because winter events are very disruptive in some places, and looking at only the change could understate the future threat, particularly since extreme winter weather could increase in some areas even if there is a downward trend overall.
Very heavy precipitation	Change in what is considered "very heavy precipitation," categorized by the 95th percentile precipitation	The 95th percentile precipitation is a standard measure of extreme precipitation used in risk assessments. Percentile thresholds best communicate local extremes and how they differ across the state. Additionally, very heavy precipitation is one factor that contributes to landslides, as well as impacts to stormwater systems and small hydraulic systems such as culverts.
Snow days	Number of days per year with 6" of snow or more	ODOT has experienced operational impacts in the past from 24 hour snowfall of 6 inches or more. Indicator represents the number of days with daily mean temperatures at or below 32°F and precipitation at or above 6.0", assuming a snow to liquid ratio[2] of 10. Indicator value is in absolute value

[2] Since downscaled climate models do not simulate snowfall, we project liquid precipitation to snowfall using a snow to liquid ratio. We used 6.0" of liquid precipitation as a proxy for 6" of snowfall, assuming a ratio of 10. The recommended conversion factor is supported by a range of information and datasets.

- NOAA generally defines a snow to liquid ratio of 10 for temperatures between 34 and 28 F, https://www.ncdc.noaa.gov/sites/default/files/attachments/Estimating_the_Water_Equivalent_of_Snow.pdf.
- NOAA uses ratios ranging from 6 to 13 in Oregon for snowfall analyses, which skews between 9 and 13 in areas most frequently experiencing snowfall (with lower values in the western and low elevation portions of the state, e.g., https://www.nohrsc.noaa.gov/snowfall/data/resources/SLR_climatology/. A ratio of 10 lies within and slightly on the lower end of this range, meaning that it likely well represents 6" snowfall at lower

		(rather than change) because winter events are very disruptive in some places, and looking at only the change could understate the future threat, particularly since extreme winter weather could increase in some areas even if there is a downward trend overall.
Inland flooding	100-year and 500-year floodplain	Although FEMA flood maps represent present day risks, the 100-year and 500-year flood zones indicate which areas are most likely to flood first, or more frequently, as the climate changes. However, digitized FEMA maps are available for only part of Oregon. Therefore, ICF combined the FEMA flood maps with the less granular Aqueduct dataset, which evaluates both current and projected riverine flooding.
Landslides	Historical landslide susceptibility events	Climate *projections* are not available for landslide hazards, so historical information is used. Areas already experience slide activity may be more susceptible to landslides in the future. In the exposure scoring, landslide-prone areas that may experience notable increases in future precipitation and future wildfire will receive higher scores.
Wildfire	Change in percent area burned by wildfire per year	Wildfire presents a primary risk to transportation assets and operations.
Coastal flooding	Coastal floodplain extent from sea level rise and sea level rise plus a 1% annual chance coastal flood and 50% annual chance coastal flood	Coastal flooding in Oregon results from both sea level rise and storms.
Coastal erosion	Coastal erosion hazard zone	Climate projections are not available for coastal erosion hazards. Although coastal erosion maps represent present day risks, these areas may be more susceptible to landslides in the future.

Exposure Datasets and Assumptions

Climate hazard information is used to underpin the climate change risk assessment based on best available science that builds on the Oregon Climate Change Research Institute's (OCCRI) Fourth Oregon Climate Assessment Report (2019) and Fifth Oregon Climate Assessment

elevations, and maybe more conservative at higher elevations where snowfall thresholds are likely also higher.

- NOAA uses this article as a basis for snow to liquid ratios. On average, the article reports ratios of 12.4 in Pendleton, 11.7 in Medford, and 9.1 in Portland.

Report (2021). [3] The sections below detail the datasets, methodology, and assumptions used to develop relevant climate hazard information.

For temperature and precipitation – including **very hot days, very heavy precipitation, freeze thaw**, and **snow days** – ICF produced customized projections for Oregon based on the following datasets and assumptions:

- **Datasets**
  ICF used Localized Constructed Analogs (LOCA) statistically downscaled global climate model projections, which present future climate hazard information at a 3.7-mile resolution compatible with regional and local planning. Using high resolution LOCA projections provides a range of benefits, including better estimates of extreme weather and more spatially coherent projections compared to alternative datasets.
- **Historical baseline**
  The baseline time period uses the average of the 30-year period of 1971 – 2000, which is mostly aligned with the Oregon Fifth Assessment Report, which uses a time period that starts and ends just one year earlier (1970-1999).
- **Projection time horizons**
  Mid- and late-century projection horizons centered on 2055 and 2085, respectively, are used in order to match the timeframes used in the Fifth Oregon Climate Assessment Report. Mid-century uses the average of the 30-year period of 2040 – 2069 and late-century will use 2070 – 2099.
- **Global Climate Models (GCMs)**
  Climate hazard projections use the model ensemble mean of 10 of the best performing LOCA downscaled GCMs relative to simulating historical climate in the Pacific Northwest,[4] as identified by Rupp et al. 2013.[5] Using an ensemble of GCMs better accounts for natural climate variability, model uncertainty, and a range of plausible climate outcomes.
- **Representative Concentration Pathway (RCP)**
  The exposure analysis is bounded by two greenhouse gas concentration pathways, both of which were used in the Fifth Oregon Climate Change Assessment. RCP 4.5 assumes

[3] Our proposed assumptions for some hazards differ somewhat from the OCCRI report. We propose using LOCA downscaled projections whereas the OCCRI report used MACA downscaled. LOCA is considered a preferable dataset for handling extremes, and we therefore recommend it over MACA. Also, the OCCRI report used different global climate models (GCMs) than we recommend using; our recommendations are based on which GCMs are considered the best fit for the Pacific Northwest; the OCCRI report did not record why other GCMs were used for that study.
[4] The 10 GCMs include CNRM-CM5, CESM1-CAM5, CanESM2, HadGEM2-ES, EC-EARTH, CESM1-BGC, HadGEM2-CC, CCSM4, HadGEM2-AO, CMCC-CM.
[5] Rupp et al. (2013), "Evaluation of CMIP5 20th century climate simulations for the Pacific Northwest USA," *Journal of Geophysical Research: Atmospheres*, 2.

significant reductions in greenhouse gases prior to mid-century and RCP 8.5 assumes plausible, largely unabated global greenhouse gas concentrations through the 21st century. RCPs 4.5 and 8.5 are commonly used in climate change studies and help evaluate risks associated with mitigated climate change versus more aggressive climate change, respectively. For the risk assessment, the focus is on RCP 8.5 only to prepare for the more pessimistic risks.

- **Methodology**
  Temperature and precipitation projections use the standard "delta method," which refers to the practice of adding modeled change between the historical baseline and future time horizons to observed values derived over the baseline time period. This improves projections and helps "ground-truth" to local planning areas. To accomplish this, ICF used a best available reanalysis dataset matched to the 3.7-mile resolution LOCA downscaled climate projection dataset.[6]

Geospatial hazard data is used to inform exposure for the other hazards, as described below:

- **Wildfire**
  Future wildfire risk is characterized using projections of wildfire burn areas made available through the Climate Toolbox. The Climate Toolbox was developed by leading researchers including from OCCRI to include authoritative wildfire projections at a fine spatial resolution based on 20 GCMs. Projections focus on mid-century (2040 – 2069) and late century (2070 – 2099) under RCP 4.5 and 8.5 and relative to a 1971-2000 historical baseline in order to match the approach for temperature and precipitation projections detailed above. The Climate Toolbox is recommended over the Oregon Wildfire Risk Explorer because the Climate Toolbox accounts for future projections whereas the Oregon Explorer dataset represents present-day risk.
- **Landslides**
  Data from ODOT's Unstable Slopes Program is used, which maps landslide and rock fall locations and sites. The ODOT Unstable Slopes Program has inventoried the areas with the highest landslide risk. For corridors where ODOT data are unavailable, ICF supplemented the gaps with the Oregon Department of Geology and Mineral Industries (DOGAMI) Statewide Landslide Information Database for Oregon (SLIDO) data. Given that drivers of landslides are heavy rainfall events and post-wildfire events, ICF assessed future landslide exposure in relation to future heavy precipitation and wildfire projections.

[6] "Reanalysis" is a term-of-art referring to the use of a model to interpolate observations in order to create spatially and temporally continuous information about past weather and climate conditions. Details regarding the dataset are provided in Livneh et a. (2015), "A spatially comprehensive, hydrometeorological data set for Mexico, the U.S., and Southern Canada 1950 – 2013," *Scientific Data*, 2(150042).

- **Inland flooding**
The World Resources Institute's Aqueduct tool, combined with the Federal Emergency Management Agency (FEMA) Flood Rate Insurance Maps (FIRM) are used to evaluate inland flood exposure. FEMA flood maps represent *present* day flood zones, rather than future the flood zones. However, these flood zones indicate areas that are most likely to flood first, or more frequently, as the climate changes. Note, however, that digitized FEMA flood maps are available only for part of the state (Figure 2). Therefore, ICF combined the FEMA flood maps with the less granular Aqueduct dataset, which evaluates both historical and projected riverine flooding. Aqueduct evaluates historical and projected flooding using global flood models. This dataset is less granular than the FEMA maps, but provides a reasonable approximation for areas where FEMA maps aren't digitized, and also where new flood areas may emerge in the future. Aqueduct provides data on historical and projected flood depth; however, ICF identified outliers in the depth data and therefore used the flood footprint only. Under the Aqueduct dataset, projection parameters are matched to the approach for temperature and precipitation projections detailed above: RCPs 4.5 and 8.5 for mid-century (2030–2069 centered around 2050) and late century (2060–2099 centered around 2080) using the GCM most suitable for the Pacific Northwest.[7] The combined dataset maps the extent of inland flooding from both the FEMA and Aqueduct datasets. A limitation of our study is that these two datasets were built using different methodology; however, for purposes of this study, the combination of the datasets provide a reasonable look into future change in inland flooding across the state.

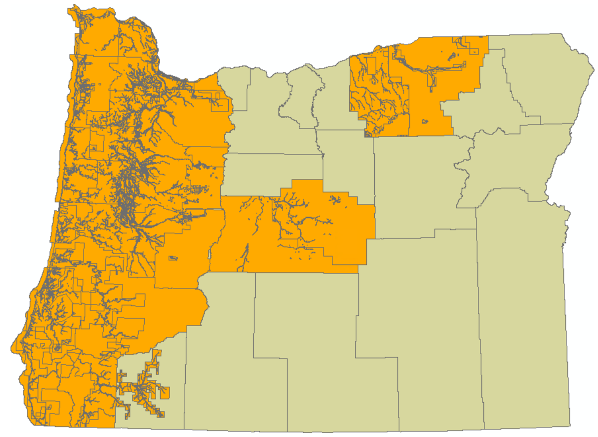

Figure 2. Extent of digitized FEMA flood maps available.

- **Sea level rise and storm surge (coastal flooding)**
Sea level rise and storm surge mapping of ODOT assets from Oregon Department of Land Conservation and Development's (DLCD) Estuarine Sea Level Rise Exposure Inventory: State Highways (2017) are used as primary sources of data. The estuary study uses mid-century (2050) and late-century (2100) projections of 1.5 feet and 4.6

[7] HadGEM2-ES. The four other options for GCMs within Aqueduct are not within the 10 best performing models for the Pacific Northwest.

feet of sea level rise, respectively,[8] plus coastal flood events in the study were evaluated for a 1% annual chance coastal flood and 50% annual chance coastal flood. The geographic scope of the study included 21 major estuaries and the surrounding low-lying shorelands (less than 25 feet in elevation), excluding the Columbia River. Because this dataset does not cover the Columbia River nor the coastal areas in between estuaries, ICF filled in these data gaps with the sea level rise mapping from the NOAA Sea Level Rise Viewer.[9] The estuary flooding dataset, where available, supersedes the data from the NOAA SLR viewer since it is more detailed. A limitation is that the two datasets were built using different methodology; however, the combination of the datasets will provide a reasonable look into future sea levels across the state.

- **Coastal Erosion**
  The analysis uses the Coastal Erosion data layer from DOGAMI. Where DOGAMI data are unavailable, ICF supplemented gaps along the coast with ODOT's Unstable Slopes Program data.

Exposure Scoring

For each exposure indicator, ICF defined scoring bins based on the climate data and input from ODOT on scoring thresholds (see

[8] Although the sea level rise projections source is slightly out of date (National Research Council of the National Academies, 2012), the projections do not vary substantially from updated projections; the Fourth Oregon Climate Assessment Report indicates projections for sea level rise to 2050 have not changed substantially in recent years, although intermediate estimates for 2100 are somewhat higher than some previous assessments.

[9] In order to combine the estuary and NOAA datasets, the team used comparable flood depths for each flooding scenario. Since the NOAA Viewer has data in increments of whole feet, and the estuary study rounded to hundredths of feet, ICF needed a way to pair the NOAA sea level rise increments with the flooding scenarios in the estuary study. To do so, ICF rounded the estuary data to the nearest whole integer for each flooding scenario (i.e. 50% chance flood in 2050; 50% chance flood in 2100) or, in cases where the range did not coalesce around a single integer, rounded up (i.e. for 1% chance flood in 2050; 1% chance flood in 2100). The flood depth values for each flooding scenarios are:

Coastal flooding scenario	Range of flood depths in estuary study	Flood depth increment from NOAA dataset
50% chance flood in 2050	3.90 to 4.23 feet	4 feet
1% chance flood in 2050	5.12 to 5.61 feet	6 feet
50% chance flood in 2100	6.98 to 7.32 feet	7 feet
1% chance flood in 2100	8.21 to 8.69 feet	9 feet

Table 2). The exposure scoring bins are summarized in the following table. For all hazards, exposure scoring of a corridor takes the highest exposure value of an indicator along the corridor segment, and considers the entire segment to have that score, rather than averaging scores along a segment.

Table 2. Exposure scoring bins for each indicator

Hazard	Indicator	Indicator value	Exposure score	Justification
Very hot days	Increase in temperature threshold for "very hot" days (°F)	<=2	1	Assets and operations may be adversely affected by exposure to changes in extreme heat.
		<=4	2	
		<=6	3	
		<=8	4	
		>8	5	
Very heavy precipitation	Increase in precipitation threshold for "Very Heavy Precipitation" days (inches)	<=0	1	Stormwater and small culverts assets may be sensitive to a 0.3 inch increase in heavy precipitation. Increases in heavy precipitation, in combination with other factors, have the potential to increase landslides.[10]
		<=0.1	2	
		<=0.2	3	
		<=0.3	4	
		>0.3	5	
Wildfire	Change in Percent Area Burned	<=0	1	Assets and operations may be adversely affected by exposure to increases, rather than decreases, in wildfire.
		<=4	2	
		<=8	3	
		<=12	4	
		>12	5	
Snow days	Cumulative number of weeks with 6" or more of daily snowfall	<=1	1	Projections indicate all decreases across the state. Binning by absolute number of days reflects areas of relatively high exposure to this winter condition in the future, and the analysis will be supplemented with discussion of areas with large decreases in exposure.
		<=2	2	
		<=3	3	
		<=4	4	
		>4	5	
Daily freeze thaw	Cumulative number of weeks experiencing daily freeze thaw cycles	<=3	1	Projections indicate all decreases across the state. Binning by absolute number of days reflects areas of relatively high exposure to this winter condition in the future, and the analysis will be supplemented with discussion of areas with large decreases in exposure.
		<=6	2	
		<=9	3	
		<=12	4	
		>12	5	

[10] Source: Discussion with Lu Saechao and Curran Mohney on 3/1/2021.

Hazard	Indicator	Indicator value	Exposure score	Justification
Inland flooding	Location relative to FEMA and Aqueduct Flood Zones	Not exposed; outside of both FEMA and Aqueduct Flood Zones	1	Assets located in a flood zone are more exposed than assets outside of the flood zone. Assets located in present-day flood zones are more likely to be adversely affected sooner.
		In late-century 500-year flood zone	2	
		In late-century 100-year flood zone	2.5	
		In mid-century 500-year flood zone	3	
		In mid-century 100-year zone	3.5	
		In historical 500-year flood zone	4	
		In historical 100-year flood zone	5	
Coastal flooding	Location relative to projected coastal flooding zones	Not exposed; outside of coastal flooding zones	1	Locations inundated under lower storm scenarios are more likely to be adversely affected by projected changes in climate more frequently.
		In late-century 1% annual chance flood zone	2	
		In late-century 50% annual chance flood zone	3	
		In mid-century 1% annual chance flood zone	4	
		In mid-century 50% annual chance flood zone	5	

Hazard	Indicator	A) Unstable Slopes Failure Hazard Score	B) DOGAMI SLIDO	Exposure score	Exposure score adjustment for projected climate	Justification
Landslides	A) Unstable Slopes Failure Hazard Score B) Along corridors where Unstable Slopes Program has not inventoried, apply DOGAMI SLIDO data For both, overlay projected heavy precipitation and wildfire	Not exposed; no Unstable Slopes data along inventoried corridors	Not exposed; no SLIDO records of incidents	1	No adjustment to areas not currently exposed.	Projected increases in heavy precipitation and wildfire have the potential to increase landslides. The Unstable Slopes Failure Hazard Score represents the pace of slides in the past (High represents rapid slides that have created road hazards; Not scored, Low, and Medium represent slower slides or very small failures that did not affect the roadway). The Unstable Slopes Program has prioritized inventory of the landslide areas with highest risk to ODOT. Therefore, along corridors where Unstable Slopes Program has not yet inventoried, the SLIDO data should be considered 'low' exposure.[11]
		Failure Hazard Score of: Not scored; Low; or Medium	Presence of SLIDO records of incidents Within 80 feet of SLIDO records, in either direct from centerline of highway	2	No adjustment to landslides score if the average of the heavy precipitation score and wildfire score is 1. Increase score by 1 if the average of the heavy precipitation score and wildfire score is 2-3. Increase score by 2 if the average of the heavy precipitation score and wildfire score is 4-5.	
		Failure Hazard Score of: High	-	3		
		-	-	4		
		-	-	5		

[11] Source: Discussion with Curran Mohney on 3/1/2021.

Hazard	Indicator	A) DOGAMI Coastal erosion zone	B) Unstable Slopes Failure Hazard Score	Exposure score	Exposure score adjustment for projected climate	Justification
Coastal erosion	A) Location relative to DOGAMI coastal erosion zones B) Where DOGAMI data are unavailable, apply Failure Hazard Score from Unstable Slopes For both, overlay projected coastal flooding zones	Not exposed; outside of coastal erosion zones	Not exposed; no Unstable Slopes data	1	No adjustment to areas not currently exposed.	Projected increases in coastal flooding have the potential to exacerbate coastal erosion. DOGAMI coastal erosion zones (Low, Moderate, High, Very High) are considered within a single bin with a buffer added because coastal erosion adjacent to a highway has the potential to undermine the foundation.
		-	Failure Hazard Score of: Not scored; Low; or Medium	2	Increase score by 1 if exposed to 1% annual chance coastal flooding event. Increase score by 2 if exposed to 50% annual chance coastal flooding event.	
		Within 80 feet of the DOGAMI coastal erosion zones, in either direct from centerline of highway	Failure Hazard Score of: High	3		
		-	-	4		
		-	-	5		

Analyzing Consequences

Like exposure, consequences are evaluated using an indicator approach. Consequence indicators provide insight into the potential impacts on the system, and broader community, if disruptions along a highway segment were to occur.

Indicators

- **Functional classification**
  Disruption to higher functional classes of highways could cause greater consequences on the economy or local communities.
- **Traffic flow (in terms of average annual daily traffic [AADT])**
  Disruption to high-traffic routes could impose greater consequences than less-traveled routes.
- **Truck flow (in terms of AADT)**
  Disruption to high truck traffic routes could impose greater consequences to the economy.

The consequences indicators are scored based on indicator values shown in Table 3. AADT for traffic and truck flow is scored based on percentile *by region* in order to capture relative consequences within a region, especially regions with more rural areas. The findings are presented by region, and the statewide summary of findings will note the differences in the percentile values.

Table 3. Scoring for consequences indicators.

Indicator	Indicator Value	Score
Roadway Functional Class **Layer from TransGIS: "Federal Functional Class - State"**	Urban Interstate; Other Urban Fwys & Expressways; Rural Interstate	5
	Other Urban Principal Arterial; Other Rural Principal Arterial	4
	Urban Minor Arterial; Rural Minor Arterial	3
	Urban Minor Collector; Urban Collector; Rural Minor Collector; Rural Major Collector	2
	Urban Local; Rural Local	1
Traffic flow (AADT)	80-100 percentile of ODOT region	5
	60-80 percentile of ODOT region	4
	40-60 percentile of ODOT region	3
	20-40 percentile of ODOT region	2
	0-20 percentile of ODOT region	1
Truck flow (AADT)	80-100 percentile of ODOT region	5
	60-80 percentile of ODOT region	4
	40-60 percentile of ODOT region	3

	20-40 percentile of ODOT region	2
	0-20 percentile of ODOT region	1

For each highway segment, the scores of the Roadway Functional Class and the AADT indicators are averaged (with equal weights) to determine the final consequences score.

Assessing Risk

A final risk score is calculated using the average exposure and consequences scores (on the scale of 1 to 5) for each corridor to each hazard, as shown in Table 4. For coastal flooding and coastal erosion, if there is no exposure (exposure score of 1), risk is null.

Table 4. Quantitative risk matrix.

		Consequences 1	2	3	4	5
Exposure	**1**	1.0	1.5	2.0	2.5	3.0
	2	1.5	2.0	2.5	3.0	3.5
	3	2.0	2.5	3.0	3.5	4.0
	4	2.5	3.0	3.5	4.0	4.5
	5	3.0	3.5	4.0	4.5	5.0

Identifying Risk

Corridor-scale risk is represented in a [climate hazard risk map](). A final risk score is represented for all state highway road segments using Jenks natural breaks classification. Qualitative risk ratings are assigned with a range of “low” “medium” “high” and “very high” so that relative risk is binned to represent lowest to highest risk scores. Note that the lowest and highest risk scores vary across hazards and time scales.

Identifying High Risk Areas of Concern- Resilience Corridors

Resilience Corridors are preferential corridors for transportation resilience building efforts and are divided into a three-tiered priority system based on three factors: climate change, social disparity, and travel disruption potential. Tiering criteria considers future climate, historical hazard events, social disparity status and asset (bridge and culvert) conditions. Future climate conditions reflect mid-century warming projections, which assume a “business as usual” emissions trajectory. Higher risk is determined as a higher number of projected hazard types (flood, wildfire, landslide, etc.) along a corridor, combined with a high number of historical hazard events. Tiers 1 and 2 include ODOT priority corridors, which have higher truck and traffic flows and are given preference for maintenance and other investments. Tier 3 includes lower truck and traffic flow corridors that have historically not received preference for maintenance or other investments.

Methods applied: These analyses were carried out using ESRI ArcMap 10.1. All TOCs and landslide data were combined and functioned as point values to provide a count of historical events or “incidents” along each corridor (highway segment). A count of climate vulnerable assets in fragile condition (“poor” bridges and “critical” culverts) was derived for each corridor. Corridors with a higher number of combined vulnerable assets are included. Social equity data was overlaid so that only corridors that intersect high social disparity block groups are included (Tiers 1 & 3). Total mileage was calculated for each segment, with all segments over 0.5 miles included. These values were combined with the projected number of climate hazards expected (multi-hazard data) to impact each corridor by mid-century. All criteria are considered equally with no weighting assigned, so that corridors with the highest number of projected climate hazards, the highest number of historical events, and the highest number of vulnerable assets are prioritized. Tier 1 corridors overlap with high social disparity block groups, Tier 2 corridors overlap with lower social disparity block groups, and Tier 3 applies these criteria to non-priority corridors. The result is a “sorting” exercise that highlights ODOT’s most climate change vulnerable corridors with approach that provides wide coverage across the state.

Table 5. ODOT data available to identify high risk hotspots.

ODOT data	Risk assessment hazards	Notes
Fix It Priority Routes	All	Represents ODOT investment priorities to fix or preserve the system.
TOCS winter	Snowfall, freeze/thaw	4000 records
TOCS wildfire	Wildfire	1100 records
TOCS high water	Heavy precipitation	4,700 records. Generally, a high water incident is considered water on the roadway which is passible by vehicles. *This layer was combined with TOCS flood data for mapping purposes.
TOCS flood	Inland flooding	32 records. An incident coded as a flood is generally used when a roadway is not passible or if the conditions are off the highway but merit ODOT’s attention. *This layer was combined

ODOT data	Risk assessment hazards	Notes
		with TOCS high water data for mapping purposes.
Unstable Slopes	Landslides	13,048 records
Asset condition	Infrastructure vulnerability	All culverts rated as in "critical" condition and all bridges rated as in "poor" condition.
Multi-hazard risk	Nine climate hazards (see table 2)	Ranges from exposure to 0-9 overlapping hazards by mid-century.
Social Equity	All	High and medium-high social disparity block groups based on ODOTs statewide equity layer.

Data Details

Exposure

Determining exposure involves peering into the future and linking future hazards with specific locations and corridors. The process of matching corridors with climate projections and related risks uses gridded climate change projections to locate each hazard at a six kilometer spatial scale. Customized projections were developed for extreme temperature, extreme precipitation, freeze thaw, and snowfall using the standard "delta method." This entails adding the modeled change between the historical baseline (1970-2000) and future time horizons (mid-century 2040 – 2069 and late century 2070 – 2099) to the observed values derived over the baseline period. Projections assume a "business as usual" future with limited reductions in carbon emissions (representative concentration pathway 8.5). Exposure values related to the remaining four hazards were individually customized based on available data. Details are provided in Appendix A-1. The exposure analysis was combined with consequences (see below) to derive final climate change risk scores. It is helpful to keep in mind that risk values correspond with larger predicted changes, in part because more change is considered to be more disruptive and more difficult to adapt to.

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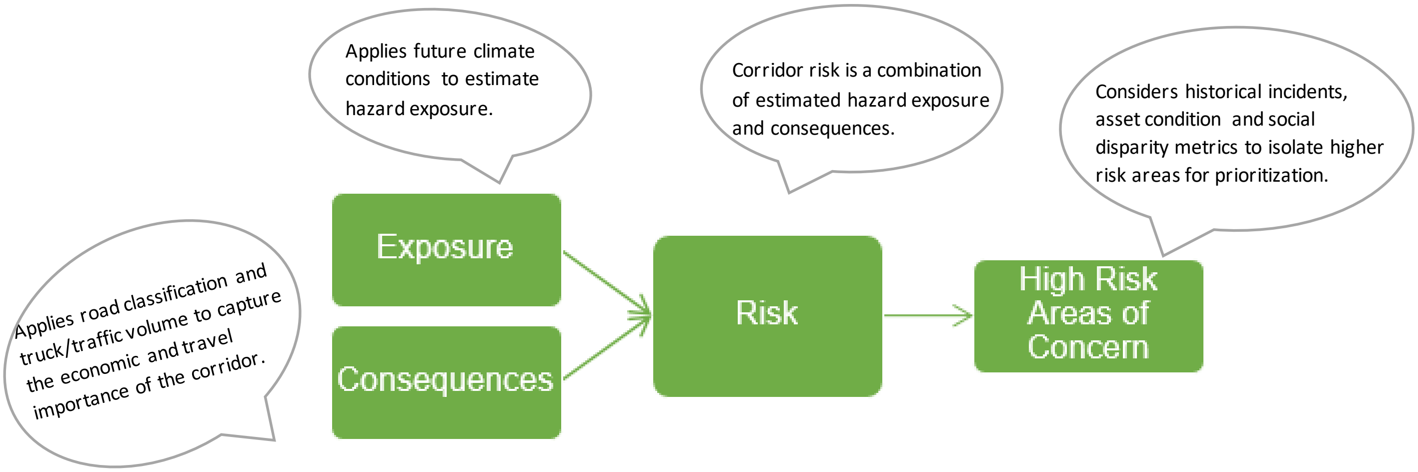


Figure 1. Risk Methodology. Risk is a function of climate change and hazard exposure with transportation consequences. A better understanding of risk can help ODOT target limited resources in key areas of concern.

Projected Climate Data

ODOT worked with a consultant to develop robust future climate projections for nine hazards that mirror datasets and analytic approaches used by Oregon's Climate Change Research Institute in the biennial state Climate Assessments (table 1). The mid- and late century projection horizons[1] referred to in the assessment are 2055 and 2085, respectively, in order to match the timeframes used in the Fifth Oregon Climate Assessment Report.

Table 1. Projected Climate Data.

Hazard	Indicator	Data Source	Justification
Extreme heat 	Change in what is considered a "very hot day," categorized by the 95th percentile temperature	LOCA/GCM	The 95th percentile temperature is a standard measure of extreme heat used in risk assessments. Percentile thresholds best communicate local extremes and how they differ across the state, such as between mountain and low-lying regions.
Freeze/thaw 	Number of days that experience a daily freeze/thaw cycle	LOCA/GCM	Freeze/thaw cycles can expand and damage pavements. This indicator represents days when maximum temperature is above freezing and the minimum temperature is below freezing. The indicator value is represented as an absolute value (rather than change) because winter events are very disruptive in some places and looking at only the change could understate the future threat, particularly since extreme winter weather could increase in some areas even if there is a downward trend overall.

[1] Mid-century projections use the average of the 30-year period of 2040 – 2069 and late-century projections use the average of the 30-year period from 2070 – 2099. The analysis is bounded by a greenhouse gas representative concentration pathway (RCP). RCP 8.5 assumes plausible, largely unabated global greenhouse gas concentrations through the 21st century (table x).

Extreme precipitation 	Change in what is considered “very heavy precipitation,” categorized by the 95th percentile precipitation	LOCA/GCM	The 95th percentile precipitation is a standard measure of extreme precipitation used in risk assessments. Percentile thresholds best communicate local extremes and how they differ across the state.
Snowfall 	Number of days with 24-hour snowfall of 6” or more	LOCA/GCM	ODOT has experienced operational impacts in the past from 24-hour snowfall of 6 inches or more. Indicator represents the number of days with daily mean temperatures at or below 32°F and precipitation at or above 6.0”, assuming a snow to liquid ratio[2] of 10. Indicator value is in absolute value.
Inland flooding 	100-year and 500-year floodplain	FEMA, Aqueduct	Although FEMA flood maps represent present day risks, the 100-year and 500-year flood zones indicate which areas are most likely to flood first, or more frequently, as the climate changes. FEMA flood maps were combined with the projected Aqueduct dataset.
Landslides 	Historical landslide susceptibility events	DOGAMI SLIDO & ODOT Unstable Slopes Program	Climate *projections* are not available for landslide hazards, so historical information is used. Areas already experience slide activity may be more susceptible to landslides in the future. In the exposure scoring, landslide-prone areas that may experience notable increases in future precipitation and future wildfire will receive higher scores.
Wildfire 	Change in percent area burned by wildfire per year	Climate Toolbox Climate Mapper	Wildfire presents a primary risk to transportation assets and operations.
Coastal flooding 	Coastal floodplain extent from sea level rise and sea level rise plus a 1% annual chance coastal flood and 50% annual chance coastal flood	DLCD, NOAA	Coastal flooding in Oregon results from both sea level rise and storms.
Coastal erosion 	Coastal erosion hazard zone	DOGAMI SLIDO & ODOT Unstable Slopes Program	Climate projections are not available for coastal erosion hazards. Although coastal erosion maps represent present day risks, these areas may be more susceptible to landslides in the future.

Historical Climate Data

The historical climate data baseline time period uses the average of the 30-year period of 1971 – 2000 (table 2). These are included in the climate hazard risk map and include coastal erosion data, inland flooding, wildfire, observed very hot days, observed very heavy precipitation, observed snow days, and observed daily freeze/thaw values.

Table 2. Hazard Variables. Details regarding each of the historical climate variables considered in the study, along with a definition.

Hazard	Indicator
Extreme heat	Observed "very hot days," categorized by the 95th percentile average temperature from 1971 – 2000.
Freeze/thaw	Average number of days that experience a daily freeze/thaw cycle from 1971 – 2000.
Extreme precipitation	Observed "very heavy precipitation," categorized by the average 95th percentile precipitation from 1971 – 2000.
Snowfall	Observed average number of days per year with 6" of snow or more from 1971 – 2000.
Inland flooding	100-year and 500-year floodplain
Landslides	Historical landslide susceptibility events
Wildfire	Historical simulation of mean change in percent area burned by wildfire per year from 1971 – 2000.
Coastal flooding	Coastal floodplain extent from sea level rise and sea level rise plus a 1% annual chance coastal flood and 50% annual chance coastal flood
Coastal erosion	Coastal erosion hazard zone

Historical Hazards: Internal ODOT Data

Climate change will continue to bring more frequent and intense weather events that can trigger hazards. Corridors with greater numbers of historical hazard impacts will likely continue to be "problem areas" where impacts and transportation disruptions are likely to be most frequent. Internal emergency response (TOCs) data from events between 2013 and 2020[3] are used to capture actual impacts to the system, like the number and types of events and the extent of delay.

[3] The high water/flooding event data extends through 2021.

Because of the current limited data available but potential for improved future data availability, the project team developed a methodology that will be adaptable and remain consistent as data improvements evolve over time. For example, current detail about "winter events" is limited and likely envelopes multiple and overlapping storm impacts. The methodology used here can accommodate improvements to data detail as they are developed.

Consequences

The gravity of consequences related to travel disruption is determined by ranking corridors based on road classification, truck flow and traffic flow (table 3). Higher functional classification is associated with higher potential for negative consequences on the economy and local communities. Higher truck and traffic flows are also associated with higher consequences. The study consultant, ICF, used an in-house approach to calculate and normalize exposure, consequences and final risk scores. The final risk scores are applied to the hazard-specific corridor scale risk analyses (see the web map). Note that social equity is applied to the resilience corridor maps for a holistic look at system resilience, but is not included in the climate change risk analysis (see below).

Table 3. Consequence Measures. Measures used to calculate corridor-scale hazard risk potential.

Consequence Measures
Functional classification: Disruption to higher functional classes of highways could cause greater consequences on the economy or local communities.
Traffic flow (in terms of Annual average daily traffic [AADT]): disruption to high-traffic routes could impose greater consequences than less-traveled routes.
Truck flow (in terms of AADT): Disruption to high truck traffic routes could impose greater consequences to the economy.

Risk

Each corridor is assigned a risk score (low, medium, high, very high) based on proximity to projected exposure to each of the nine study climate hazards (table 1a), combined with the potential consequences (see online map). A corridor approach to calculating risk helps the agency better prepare. It provides a specific risk level that helps us better understand which of the current hazard challenges already present along each corridor are most likely to get worse. By mapping this information, we can get a better sense of where the specific risk types are located, where they might overlap and interact (e.g., wildfire and landslides), and we can see side-wide and regional patterns that can guide decisions about where to be proactive first.

We know that risk is more than just the threat of physical damage to the transportation system from hazards. There's are also human and financial elements to risk. From a human perspective, poor and marginalized communities are at higher risk of negative impacts. For example, neighborhoods that experience less marginalization (low social disparity) have more monetary, educational and political resources and have more means to recover after a disruptive event. These neighborhoods are also less likely to be located in hazard-prone areas or be located near older infrastructure that's less likely withstand hazard impacts. As a result, corridor scale climate change risk is amplified in neighborhoods with higher social disparity. Communities nearest to high risk corridors are more likely than any others to depend on those corridors, they are therefore most likely to be harmed by disruptions, detours and safety challenges. To help locate human risk and resilience building needs, we integrate ODOT's Social Equity Disparity Index into a corridor-scale priority system (see Resilience Corridors, below).

Table 4. Summary of Data Uses & Applications.

Data	How is it used?	Where is it applied?
Future/historical climate data	Calculate corridor-scale exposure	Corridor risk analysis, climate hazard web map
Historical hazard incidents	Locate highest risk corridors	Web map, resilience corridors
Truck/traffic flow, Roadway class	Calculate corridor-scale consequences	Corridor risk analysis, climate hazard web map
Asset condition	Locate highest risk corridors	Web map, resilience corridors
Priority/low-traffic state highway corridor designation	Locate highest risk corridors	Corridor risk analysis, web map, resilience corridors
Historical hazard impacts costs	Assess costs by hazard state-wide and by ODOT Region	See Appendix A-2

Resilience Corridors

Overlapping types of risk are combined into resilience corridors. The three-tier approach is mapped for a helpful visual and provides a clearer path for decision makers when prioritizing resilience work. The sources informing the resilience corridors include: multiple projected hazards (mid-century), historical hazard impacts (TOCs data), social disparity and asset condition. When viewed together, these variables can improve knowledge about vulnerabilities and guide decision making about locating resilience efforts (table 4). The resilience corridors show where overlapping resilience challenges coexist to help the agency target resources where they are needed most. Along with adding transparency regarding current and potential future problem areas, this information can be used to continue guiding the Statewide Transportation Improvements Program investments and prioritize candidates for federal grant opportunities. [see strategies 3.3, 4.1]

Resilience Corridors

Resilience Corridors are preferential corridors for transportation resilience building efforts and are divided into a three-tiered priority system based on three factors: climate change, social disparity, and travel disruption potential. This approach helps the agency address a suite of helpful questions, such as: where are corridors at highest risk of climate change impacts? Who will be affected, and what resources do they have to respond and recover? And how big is the likely economic and human impact from transportation disruptions if these roadways fail?

Tiering criteria considers future climate, historical hazard events, social disparity status and asset (bridge and culvert) conditions. Future climate conditions reflect mid-century warming projections, which assume a “business as usual” emissions trajectory. Higher risk is determined as a higher number of projected hazard types (flood, wildfire, landslide, etc.) along a corridor, combined with a high number of historical hazard events. It is important to note that not all hazard events are caused by climate change, but that climate change is increasing the strength and frequency of extreme weather events that trigger hazards.

Tiers 1 and 2 include ODOT priority corridors, which have higher truck and traffic flows and are given preference for maintenance and other investments. Tier 3 includes lower truck and traffic flow corridors that have historically not received preference for maintenance or other investments.

Tier 1 🔴	ODOT priority corridors, highest climate risk, highest social disparity, total historical events, assets in poor or critical condition. **558 road miles, 593 vulnerable assets**
Tier 2 🟡	ODOT priority corridors, highest climate risk, medium/low social disparity, total historical events, assets in poor or critical condition. **665 road miles, 557 vulnerable assets**
Tier 3 🔵	Low volume corridors, highest climate risk, highest social disparity, total historical events, assets in poor or critical condition. **481 road miles, 881 vulnerable assets**

Tier 1 corridors are first-choice for resilience building investment. These corridors experience the highest truck and traffic flows (i.e., "priority" corridors) and have the highest risk for future climate hazard impacts. Additionally, these corridors are located in areas with the highest levels of social disparity, where interruptions to travel reliability and safety are most disruptive to wellbeing and most difficult to cope with. Tier 1 corridors are ranked in order of the highest number of assets in "poor" or "critical" condition and the highest number of historical hazard events, including floods and high water events, landslides, fires and winter events.

Highway Name	Region	District	Miles	Culvert	Bridge	Total Vulnerable Assets	Total Hazard Events
Oregon Coast (Hwy 101)	2,3	1,4,5,7	61	90	21	111	605
Pacific (I-5)	2,3	2B,3,7,8	89	97	13	110	951
Columbia River (I-84)	1,4	2B, 2C, 9	67	89	9	98	667
Old Oregon Trail (I-84)	5	12,13,14	93	68	6	74	610
Lower Columbia River (US 30)	1,2	1, 2B	30	39	12	51	456
Willamette (Hwy 58)	2	5	43	39	1	40	64
The Dalles-California (US 97)	4	10,11	42	32	1	33	870
Umpqua	3	7	30	28	0	28	256
Central Oregon (Hwy 20)	4,5	14	69	24	1	25	203
Salmon River	2	4,3	34	21	2	23	69

Tier 1 by the numbers

- 558 total miles
- bridges in poor condition = 66
- culverts in critical condition = 527
- historical floods/high water events = 968
- historical fires= 1,963
- historical winter events = 697
- historical landslides = 1,123
- 4,751 historical hazard events

Key Take-Aways

- Wildfire was the dominant T1 hazard over the last decade, followed by landslides. These hazards were associated with the highest emergency response related (whole system) costs over the same time period ($58,601,742 & $61,995,826 respectively).

- T1 corridors have the largest number of critical culverts and total number of vulnerable assets on Priority routes.
- 21 bridge assets on the Oregon Coast Highway (101) are in poor condition in T1 and when combined with T3 totals 41 bridges. The Oregon coast is highly vulnerable to flooding, erosion, landslides, storm surges and sea level rise, and their combined effects may accelerate infrastructure degradation into the future.

Tier 2 corridors are second choice for resilience building investment. These corridors experience the highest truck and traffic flows (i.e., "priority" corridors) and are at highest risk for future climate hazard impacts. These corridors are located in areas with lower levels of social disparity, where coping with and adapting to climate hazard impacts are less burdensome. Tier 2 corridors are ranked in order of the highest number of assets in "poor" or "critical" condition and the highest number of historical hazard events.

Highway Name	Region	District	Mile	Culvert	Bridges	Total Vulnerable Assets	Total Hazard Events
Pacific (I-5)	1,2,3	2B,3,4,5,7	109	121	20	141	2226
Old Oregon Trail (I-84)	5	12,13	98	76	4	80	633
Lower Columbia River (US 30)	1,2	1,2B	59	75	3	78	414
The Dalles-California (US 97)	4	10,11	124	75		75	1350
Central Oregon (Hwy 20)	5,4	10	99	58	2	60	245
Oregon Coast (Hwy 101)	2,3	1,4,5,7	49	54	4	58	316
Columbia River (I-84)	5,4,1	2B,2C,9	69	28	3	31	1136
Sherman	4	9	33	20	0	20	93
Mt. Hood	1	2C	25	11	3	14	127

<u>Tier 2 by the numbers</u>

- 665 total miles
- bridges in poor condition = 39
- culverts in critical condition = 518
- historical floods/high water events = 1,515
- historical fires= 3,130
- historical winter events = 1,130
- historical landslides = 897
- 6,672 historical hazard events

Key Take-Aways

- Wildfire was the dominant T2 hazard over the last decade, followed by flooding. Whole-system costs related to flooding amounted to $23,033,467 over the same time period, representing the third highest cost hazard impacting the system.
- T2 corridors experienced the highest number of total hazard events (6,540) across all tiers, making up 45% of total (14,475).

Tier 3 corridors are third choice for resilience building investment. These corridors experience lower truck and traffic flows but represent state highway corridors with the highest risk for future climate hazard impacts. They also have historically not been prioritized for repair and upkeep. These corridors are located in areas with the high levels of social disparity, where interruptions to travel reliability and safety are most disruptive to wellbeing and most difficult to cope with. Tier 3 corridors are ranked in order of the highest number of assets in "poor" or "critical" condition and the highest number of historical hazard events.

Highway Name	Region	District	Miles	Culverts	Bridges	Total Vulnerable Assets	Total Hazard Events
Oregon Coast (Hwy 101)	2,3	1,4,5,7	135	277	20	297	1202
Weston-Elgin	5	12,13	33	86	1	87	171
Ochoco	4	10	60	84	0	84	261
Jacksonville	3	8	20	55	0	55	235
Historic Columbia River	4,1	2C,9	17	51	4	55	119
Wallowa Lake	5	13	42	49	1	50	186
Hood River	1	2C	14	35	6	41	176
Coos Bay-Roseburg	3	7	25	32	3	35	79
O Neil	4	10	16	28	0	28	57
Elkton-Sutherlin	3	7	12	27	0	27	32
Florence-Eugene	2	5	14	23	0	23	107
Fremont	4	11	31	19	0	19	34
Coos River	3	7	3	17	0	17	3
North Umpqua Highway East	3	7,8	19	15	0	15	59
Nehalem	2	1	4	15	0	15	38
Culver	4	10	11	12	0	12	58
Mckenzie-Bend	4	10	7	11	0	11	288
Clackamas	1	2C	18	9	1	10	79

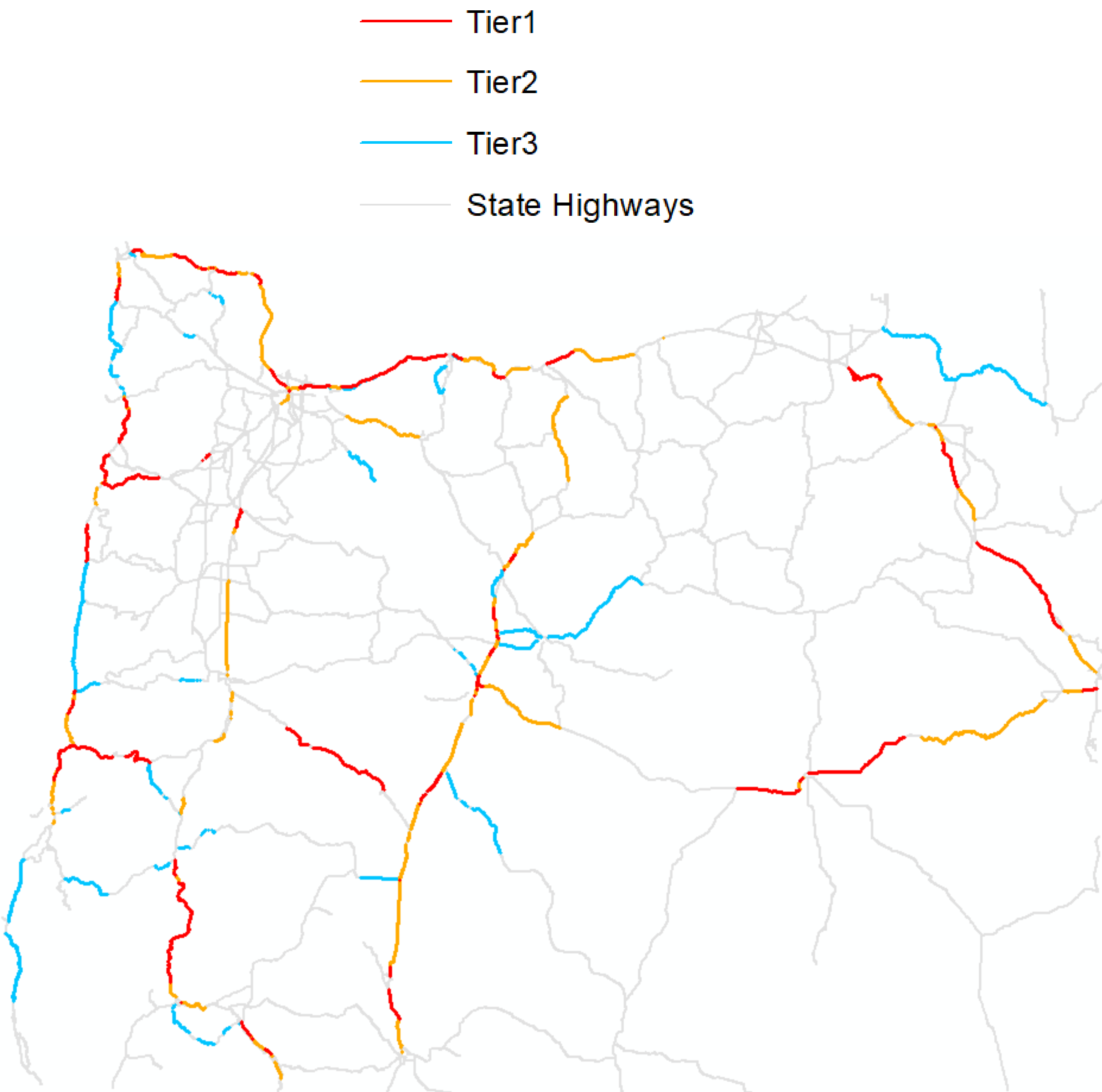
Tier 3 by the numbers

- 481 total miles
- bridges in poor condition = 36
- culverts in critical condition = 845
- historical fires= 1,164
- historical winter events = 326
- historical landslides = 1,121
- historical floods/high water events = 573
- 3,184 historical hazard events

Key Take-Aways

- Wildfires were the dominant hazard impacting T3 corridors over the last decade, followed closely by landslides.
- T3 has the highest density of vulnerable assets per mile, which could potentially yield a greater ROI from a corridor-scale resilience improvement approach.

Resilience Corridors



A-2 | Cost Analysis

Underlying data and information regarding ODOT's cost tracking of hazard events. Consultant analysis using ODOT data and information helps to lay the foundation for developing a baseline understanding of hazard related costs. While this data may change overtime, as tracking methods improve, the analysis methods in this report will not necessarily need to change. Hazard cost tracking is a new approach to using existing information and will continue to be an important component of building agency resilience to climate change.

- Climate Hazard Cost-tracking
- System-wide Event Costs
- Regional Costs

Climate Hazard Cost Tracking[1]

Sources of Cost Data

ICF used maintenance expenditure data from emergency events:

- Data received from Delivery and Operations Budget Office (April 2021).
- Data from 2009-2021.
- Spreadsheet lists of emergency relief (ER) events, including Region impacted and maintenance cost expenditures.
  - Several ER events listed are directly relevant to hazards covered as part of the ODOT risk assessment: flooding, fires, slides
  - Other ER events listed may be relevant, but require making assumptions about the definitions of the events and causes: e.g., hazard trees, scour, sinks, erosion, washout, and ice hazards.

ICF developed charts, graphs and statistics to identify basic themes about past costs and associated hazards. Where no clear trends are identified, ICF qualitatively discusses key takeaways in a narrative.

When calculating cost totals, ICF makes simplifying assumptions. For example, assumptions are made about event definitions and event types in order to tie them to the hazards (e.g., the event type 'erosion' may be tied to coastal erosion, coastal flooding, and inland flooding).

ICF supplemented the analysis with information from an interview with Headquarters leadership focused on costs.

Summary of datasets

ICF initially set out to identify three broad categories of costs relevant to DOTs.

- Cost of maintenance
- Costs of damages associated with disasters
- User delay costs

Costs of maintenance are applied. The limitations of the other two types of costs are summarized in Table 1.

Table 1. Summary of types of cost and impacts data we reviewed, and identified limitations.

Type	ODOT dataset	Potential application	Dataset limitation
Emergency events	Maintenance Emergency Event Expenditure History	**Cost of maintenance**	Cleanest dataset for application to this subtask

[1] This memo was altered from its original version (written by ICF) to include only methodology details (amended by ODOT).

Disaster declarations data	i) FHWA Emergency Relief/Disaster Declaration Event History (2005-2017)	**Cost of damages associated with disasters**	Unable to track down FHWA ER event codes to determine the root disaster events
	ii) Data from select recent disaster declaration events from case studies	**Cost of damages associated with disasters**	Case study approach is limited in illustrating trends over time
Incident data	Transportation Operation Center Systems (TOCS) data (2012-2021)	**User delay costs**	Deprioritized in order to focus on direct costs to ODOT

Disaster declarations data

Disaster Declaration Events

ICF reviewed FHWA Emergency Relief/Disaster Declaration Event History. In addition to the spreadsheet, ICF received a summary table of recurring events along ODOT highways reported out in the TAMP.

- Data received from Transportation Program (11/2020).
- Dataset from 2005-2017 includes:
    - 11 unique FHWA event codes for the time period, with scores of records per disaster event
    - For each record: estimated costs, federal reimbursement, type of damage (e.g., slide, storm damage, sink, etc.)
- Gaps in data:
    - ODOT was unable to track down disaster events associated with the 11 FHWA event codes. Dataset cannot be applied without information on the root events.
    - Metadata tab is limited and data are not well organized, which would require many assumptions about the data.

Case studies: Select Disaster Declaration Events

As part of research for the original set of case studies, ICF identified and summarized impact and cost data from select events:

- Pendleton 2020 floods case study:

    As a result of the floods, the US Department of Transportation made available to ODOT $1 million in “quick-release” emergency funds for federal highways to assist with repairs. ODOT also requested upwards of $17 million from the Federal Highway Administration to assist with repairs to major transportation networks in affected areas. ODOT closed I-84 for multiple miles in several areas from February 6 to 11, 2020 in order to make repairs. ODOT also made repairs along Highway 204. Specific repair projects, the cost of which are expected to be reimbursed by the Federal Highway Administration, include the following:

  - I-84: Pendleton Bridge debris and drift removal ($188K)
  - I-84: Umatilla River levee repair ($1.9M)
  - I-84: Stanfield Freeway repair including guardrail repairs and replacements, culvert clearing, reinforcement of interstate due to structural integrity loss ($6.7M)
  - OR204: Shoulder repair, washed out embankment repair, and vertical wall repair and replacement ($7.2M)
  - OR244: Guardrail post repair and replacement, shoulder repair and replacement ($100K)

On April 3, 2020 President Trump made a major disaster declaration for the state of Oregon and ordered Federal assistance to aid ongoing recovery efforts from the February floods. This federal funding is available for hazard mitigation measures statewide, temporary housing and home repairs, and loans to recover property losses, among other programs.

- Wildfire case study:
    - 2015 Canyon Complex Fire
        - ODOT incurred approximately $5 million in expenses for the fire; much of these expenses were reimbursed by FHWA or at a 90% federal cost-share.
    - 2017 Eagle Creek Fire
        - As of August 2018, costs associated with the 2017 Eagle Creek fire, High Cascade, North Umpqua fire, and damage from associated slides had surpassed $20 Million.
    - 2020 fires
        - At the time of this report, transportation damages and debris removal costs have reached approximately $657 million, though total disaster costs are expected to exceed $1 billion. These costs include:
            - Approximately $21.5– $35 million in costs for road repairs and operational needs; ODOT received $5 million for quick-release Emergency Relief and applied for an additional $30 million in aid to cover continued costs for clearing, repairing, and reopening roads.
            - ~$622 million for debris clean-up and management (not including household hazardous waste removal) conducted by the Debris Management Task Force, jointly led by OEM, ODOT and DEQ. Notably, this cost is an initial estimate, and only includes efforts eligible for FEMA reimbursement; that is, other infrastructure rebuilding necessary for long-term recovery is not included. Additionally, the federal cost-share is assumed to be the 75% minimum, though FEMA can adjust it to up to 100% (Congressman DeFazio is pushing for FEMA to fund 15% above the minimum).

- 2019 Hooskanaden Landslide case study:
    - Daily time and operating costs; cost to stabilize slope.
- In addition to disaster declarations cost data (summarized above), the original case studies identified sparse maintenance and operation cost data associated with non-disaster events.
    - Coastal erosion: Beverly Beach case study: annual average maintenance costs without a major erosion event; costs of adaptation.

TOCS incident data

ICF reviewed the Transportation Operation Center Systems (TOCS) data. This dataset does not contain cost data, though it contains data on incidents that could be used to estimate user-delay costs through a back-of-the-envelope calculation. This approach was deprioritized in order to focus on direct costs to ODOT.

- Data from System Operations & ITS (12/2020 and 2/21) containing data on flood, high water, wildfire, and winter events.
- Data set ranges from 2012-2021 and includes ~10,000 total incidents tagged under the following hazards:
    - High-water (4700 records)
    - Flood (32 records)
    - Wildfire (1100 records)
    - Winter (4000 records)

Limitations of the Assessment

ICF was unable to identify information on costs for three of the hazards in the vulnerability assessment: extreme temperature, freeze/thaw, extreme precipitation (though cost information on flooding are captured).

It is not possible to quantify the relationship between climate exposure and costs for the following reasons:

- Limited duration of incident and cost data. The dataset duration insufficient to make many conclusions about changes in climate or identify definitive trends.
- It is also not accurate to do a 1-to-1 comparison of costs vs. weather patterns.
- Non-emergency maintenance or repairs may occur based on when funds are available and the activity can be scheduled, rather than when damage immediately occurs.
- Costs may go up for reasons other than increases in frequency or severity of damage.

System-Wide Historical Hazard Events and Maintenance Costs

System-wide Hazards and Event Impacts

The following are derived from Technical Operations Center (TOCs) data and provide insight into the last decade of hazard-related emergency event impacts to state highway corridors in terms of frequency and duration of interruption (figure 1). TOCs event data are labeled as “high water” and “flood” events (combined here), “winter events” and “wildfire.” Winter events can include multiple hazard types related to a single event (e.g. a rain and wind storm leads to flooding and landslide response). Of total, current, state-wide system disruptions recorded (n=9,627 from 2013-2020); floods/high water events make up 4,622 events (48%), winter weather related events make up 3,722 (39%) and wildfires account for 1,093 (11%) events. In terms of system impacts from delays and closures, the majority of events (about 74%) lasted 5 or fewer hours.

The analysis suggests that ODOT responded to thousands of events related to multiple different hazard types over the last decade. This also means that state assets and infrastructure were exposed to this high number of events. As event frequency and intensity increases, demands on maintenance district and incident response personnel and budgets are likely to increase too, which has widespread implications on other maintenance needs (i.e. adding to the overwhelming backlog of deferred maintenance statewide). Event occurrences are changing from seasonal patterns that allowed for planning and budgeting, to unpredictable, year-round demand. This stretches personnel capacity and the agency’s ability to respond; thus, delay times are likely to increase as are cost burdens from time and equipment demands.

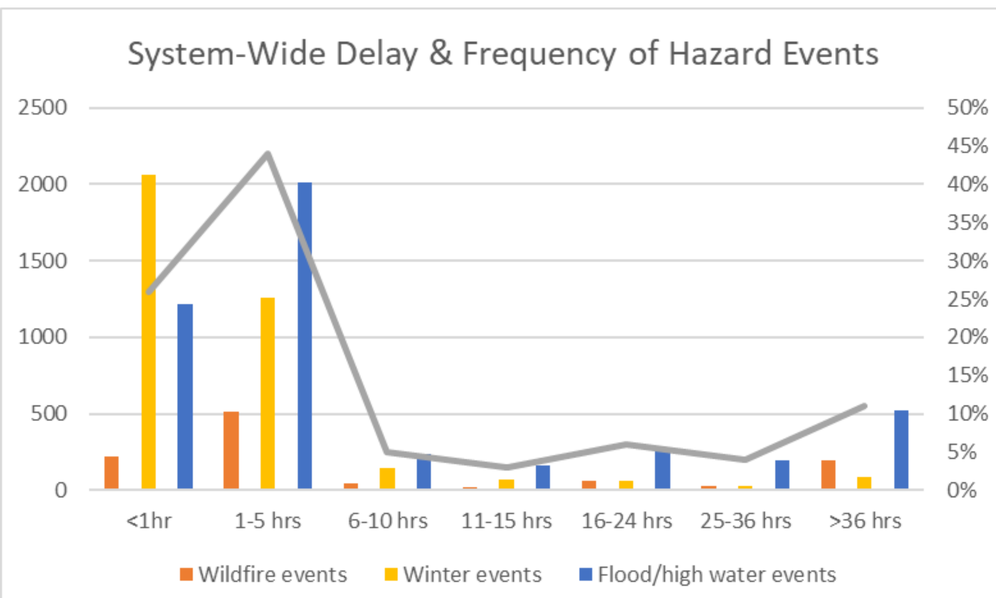


Figure 1. System-wide Delay and Event Frequency. System impacts from hazard events are shown by hours of delay, frequency of event (left y-axis), and percentage of overall event types (right y-axis). Note that delays from landslides are not specified but may be included as “winter events.” Source: ODOT TOCs dataset.*all event dates extend from 2013-2020, with the exception of flood/high water events (through 2021).

Wildfire

Wildfire is a natural occurring process in Oregon, but the state and the rest of the western US have seen an increase in the number and extent of wildfires since the 1970s (Mote et al 2014). ODOT data shows that wildfire-related interruptions to state highway corridors over the last decade mostly occurred during late summer and early fall months. The majority of wildfire events (67%) lasted five or fewer hours. Wildfire was the least frequent TOCs event type but uniquely associated with a few delay periods that lasted several weeks and months. These longer-term closures relate to the extreme 2020 fire season and represent the potential for high-level destruction and longer-term safety loss. Increased dryness and extreme heat days is lengthening Oregon's wildfire season and contributing to larger, more frequent and more intense wildfires that occur earlier in summer and later into fall (Dalton & Fleishman 2021). Wildfire is also associated with latent hazardous effects such as rock fall, debris flows and landslides. The expected increases in wildfire breadth, intensity and frequency in Oregon may lead to more of these interrelated safety challenges and interruptions.

Winter Events

Winter events require the highest number of emergency responses from ODOT (39% of total events) but related delay time periods tend to be short. More than half (55%) of winter event related delays lasted less than an hour. As Oregon's average winter temperatures climb, winter driving conditions across the state are becoming more variable and harder to predict. The resulting changes to winter driving conditions are specific to place and are unlikely to look like the past. Warmer conditions could improve winter driving conditions in some areas and worsen or make planning ahead more difficult in others, due to increasing variability and more frequent and intense extreme events (Dalton et al 2013). ODOT will benefit from continued applications of cameras and signage that improve safety communication and any new efforts that inform travelers to changes to road conditions as they develop.

High Water/Flood Events

Overall, 4,622 flood and high-water events caused disruptions to the system and ranged from a few minutes to 26 days.[5] Flood and high-water events are common through winter and spring but require emergency response nearly year-round. Oregon's coastline is flood prone and this trend is expected to increase during winter and spring months into the future due to the combine effects of high intensity precipitation, higher high tide events and sea level rise (May et al 2018, Dalton & Fleishman 2021). Almost one quarter of high water/flood events (1,017 events) took place in or near the Coast Range in western Oregon, and one third of related disruptions lasted 5 or more hours. Box A. System delays from high water and flood events.

System delays from high water and flood events are shown below. The longer the delay, the larger the size and darker the color of the circle. The map shows an overall trend of west-side-dominant flooding, clusters of events across the state, and corridor sections that are most and least often effected.

High Water & Flood Related Delays (2013-2021)

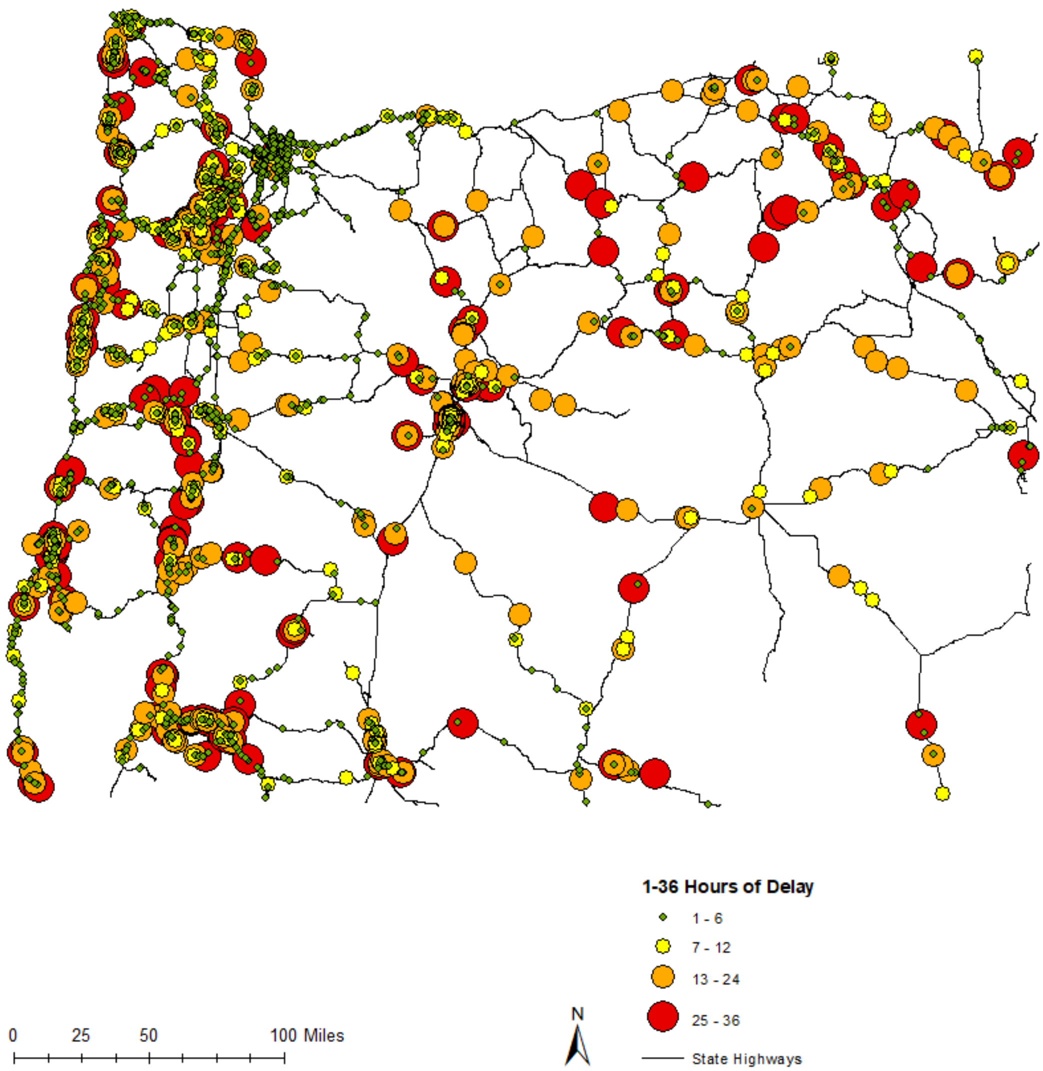


Figure 2. System delays from high water and flood events.

Hazard Maintenance Costs

ODOT's maintenance expenditure data from emergency events provides insight into the financial impact of the recent hazardous event trends discussed above (figure 3a). Cost data add to the story of how climate change is currently impacting the system, which event types tend to coincide with higher expenses, and what these trends look like from a system-wide and regional perspective. This data lays the foundation for developing a baseline understanding hazard related costs. ODOT is already working to improve tracking and reporting in order to evaluate trends over time.

Current cost data show a snapshot of significant spikes related to natural hazard response over the last decade (2009-2021), with a total price tag of $168,333,172 (see table 1 & figures 3a/3b).

Table 1. Costs by Hazard and Region (SFYs 2009-2021).

Hazard	R1	R2	R3	R4	R5	Grand Total
Fires	$37,343,895	$10,411,505	$6,923,646	$1,178,491	2,744,205	**$58,601,742**
Flooding	$126,305	$6,090,602	$744,906	$396,165	18,675,489	**$23,033,467**
Hazard Trees	$431,980	$3,274,597	$5,911,282			**$9,617,859**
Ice Hazards	$3,930,240	$421,528				**$4,351,768**
Slides & Sinks	$9,670,428	$12,239,689	$38,065,273	$1,236,869	783,567	**$61,995,826**
Unspecified Hazard	$231,864	$1,750,036	$4,688,512	$797,819	264,279	**$7,732,510**
Grand Total	**$51,734,712**	**$34,187,957**	**$56,333,619**	**$3,609,344**	**$22,467,540**	**$168,333,172**

Source: ODOT Delivery and Operations Budget Office Maintenance Emergency Event Expenditure History dataset (2009-2021).

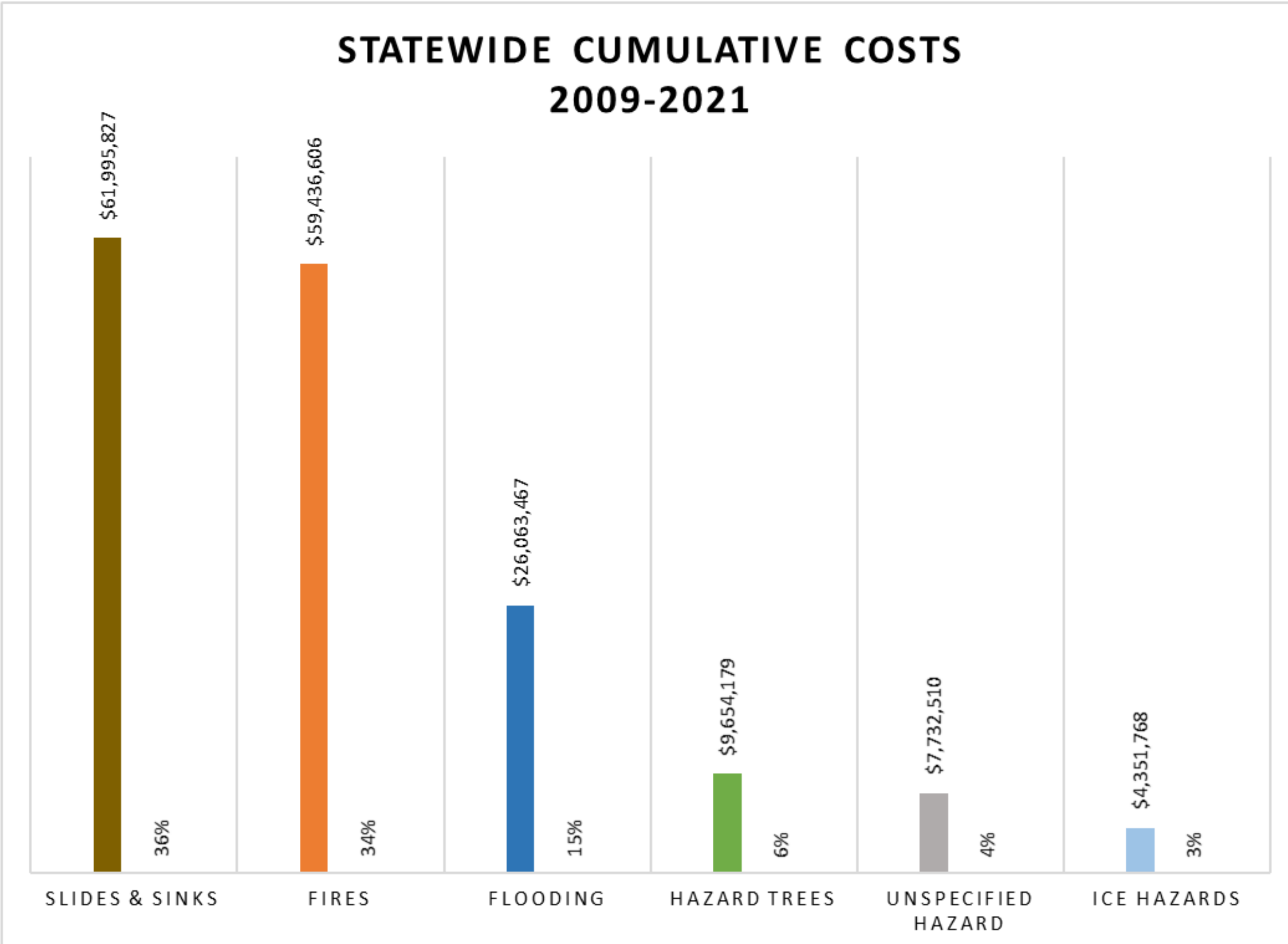


Figure 3a. Cumulative Costs by Hazard Type (FYs 2009-2021). Source: ODOT Emergency Response datasets for fiscal years 2009-2021. Source: ODOT Delivery and Operations Budget Office Maintenance Emergency Event Expenditure History (2010-2021).

Between fiscal years (FY) 2009–10 and 2014–15, related costs were at or below $5 million per year, with the exception of FY 2011–12 reaching over $10.5 million due to large landslide-related costs. FY 2015–16 punctuated the decade with a significant cost spike trend that rose to $25 million in both FY 2018–19 and 2019–20, and peaked in FY 2021 to nearly $44 million due, in large part, to the devastating wildfires that occurred in 2020.

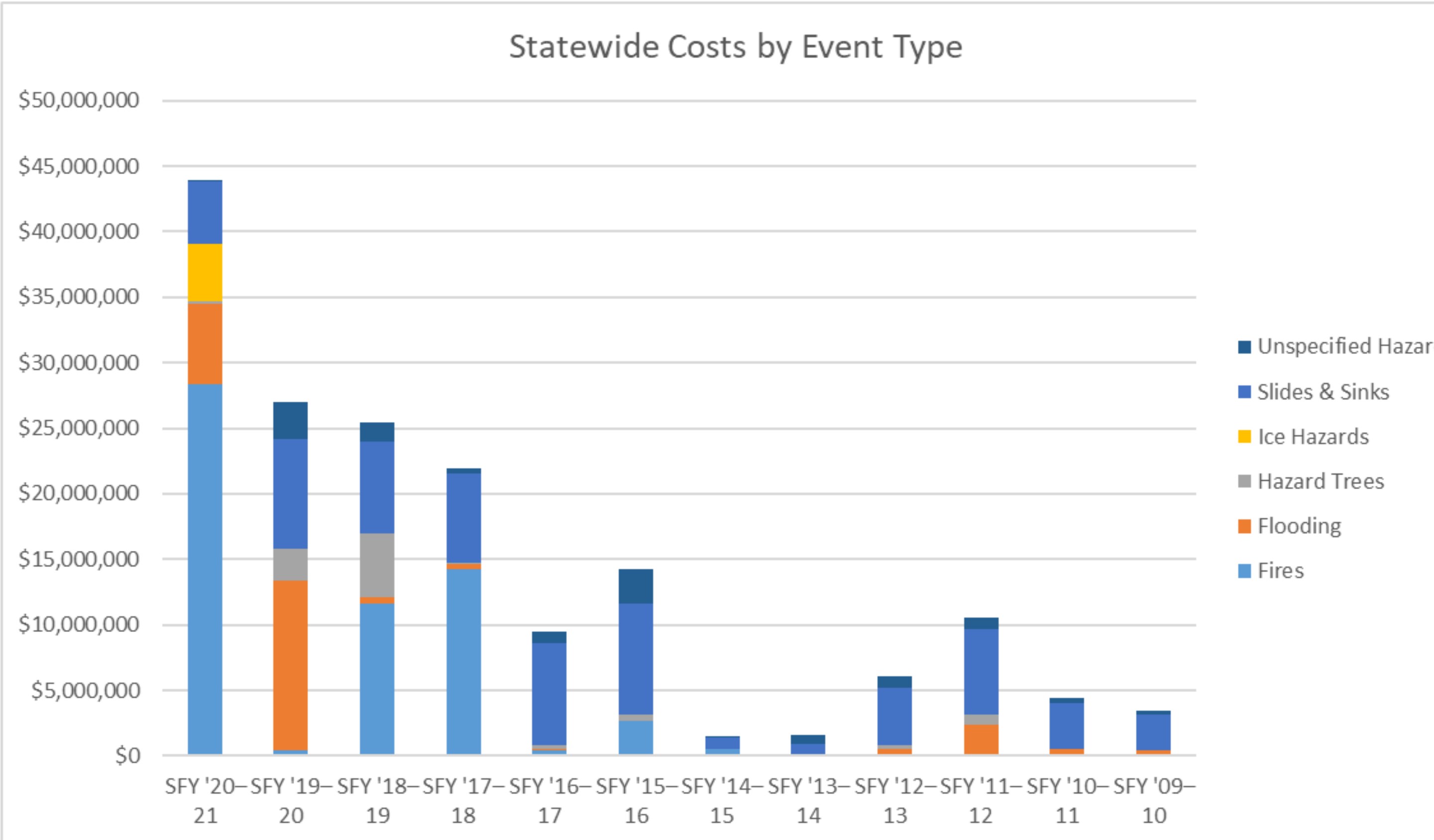


Figure 3b. Statewide Costs by Event Type (FYs 2009–2021). The graph shows cost spikes and an upward trajectory since FY 2015-2016. Note that costs related to hazard types are reflected but expenditures can continue beyond the year of event occurrence.

As climate conditions change, cost spikes are expected to continue and create financial burden. This trend can strain the availability of resources needed to maintain and improve the transportation system. Further, the strain of hazardous events on infrastructure and response personnel, combined with the cost burden, have the potential to significantly undermine transportation resilience into the future.

Hazard Event Costs by ODOT Region

ODOT expenditures related to hazards (2009-2021) were not spread uniformly across regions and show a distinct east-west dichotomy in hazard types and associated costs. Total expenditures were $168,333,172 over ten years studied (table 9). The highest combined costs are associated with slides and sinks ($61,995,826 or 37%), followed by fire ($58,601,742 or 35%). Major events are clear drivers of these costs; however, these are not unique (every region was impacted) and best available science indicates the frequency and intensity of extreme events will increase into the future (May et al 2018, Dalton & Fleishman 2021).

An important consideration is that data is limited to 12 years of emergency event cost information. This data was the most complete and best available source of information about hazard-specific expenditures. While this timeframe is insufficient to establish a trend, it does provide baseline information for ODOT to consider moving forward and it provides some helpful details about recent expense patterns that show consistency across regions. Aligning current hazards with costs at the region level provides insight into future potential cost burden types and ranges. In order for ODOT to identify trends and track changes in costs related to hazards over time, an updated approach to data collection that provides clear associations between hazard types and costs is essential. Beyond budgeting, this information could inform cost benefit analyses and other methods that support decision making around adaptation and mitigation investment choices.

Table 9. Costs by Hazard and Region (FYs 2009-2021).

Hazard	R1	R2	R3	R4	R5	Grand Total
Fires	$37,343,895	$10,411,505	$6,923,646	$1,178,491	2,744,205	$58,601,742
Flooding	$126,305	$6,090,602	$744,906	$396,165	18,675,489	$23,033,467
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Grand Total	$51,734,712	$34,187,957	$56,333,619	$3,609,344	$22,467,540	$168,333,172

Source: ODOT Delivery and Operations Budget Office Maintenance Emergency Event Expenditure History dataset (2010-2021).

Region 1

Total costs incurred by Region 1 were $51,734,712 (31% of total). Fires, slides/sinks and ice hazards were the costliest hazard types effecting Region 1 from 2009-2021 ($50,944,563). Fire related costs alone reached $37 million cumulatively from FYs '09–10 to '20–21 (table 11). A major slide event incurred over $2 million in costs in FY '09–10 as well. Region 1 had the highest hazard related costs over the time period studied, indicating great potential for high return on investment from targeted adaptation and resilience-building efforts.

Region 2

Region 2 total costs amounted to $34,187,957 (20% of total). The region experienced especially high costs related to slides and sinks ($12,239,689) and fires ($10,411,505). The unspecified hazard costs of $1,750,036 indicate an opportunity to improve data and cost tracking.

Region 3

Grand total costs from hazards in Region 3 were $56,333,619, the highest among regions (33% of total). Slides and sinks ($38,065,273) made up 66% of total costs, far outweighing other hazards during this time period. Region 3 had the highest amount of unspecified hazard costs (61% of total), signaling an opportunity to improve data and cost tracking.

Region 4

Region 4 costs associated with hazards were lowest, at $3,609,344 (2% of total). Costs were significantly lower for Region 4 compared to other regions during the time period studied, with fires and slides/sinks showing comparable significance. Lower costs are at least somewhat associated with the dearth of hazard tree or ice related hazards recorded as emergency response events. Other reasons could include fewer large-scale events that other regions faced, such as the 2020 flood and fire seasons. For the purposes to resilience building, improving data transparency around unspecified events could benefit preparedness and prioritization of strategic prevention efforts.

Region 5

Total costs related to hazards in Region 4 were $22,467,540 (13% of total). A majority of those costs were associated with an extreme flooding event, which is illustrative of major unforeseen expenditures in resources, time and personnel. Costs related to fires were another major expense in Region 5, relative to others. While fire is slightly more common in Region 5 than others, related costs are lower. This is potentially related to more frequent but less severe fire.