ODOT's Climate Change Adaptation Strategy Report

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Oregon Department of Transportation

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2012
ODOT Climate Change Adaptation Strategy Report

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Preface

ODOT is responsible for providing a safe, efficient transportation system, one that balances economic, environmental, and community well-being in a manner that protects the needs of current and future generations. In the face of increased climate variability and change, it becomes even more important to make decisions and take actions that will prepare and protect the transportation system for the future.

Oregon's transportation infrastructure is vulnerable: from increased wave heights and more intense storms causing significant erosion along the coastline to more intense precipitation events resulting in flooding and increasing the incidence of landslides across the state. These are just a few of the impacts of climate change to the transportation sector in Oregon. Climate change will impact the very way ODOT conducts business. For example, design standards may need to be re-evaluated and changed to account for sea level rise; planning cycles might need to expand beyond the short-term and consider climate change over the lifespan of the infrastructure (50 to 100 years); maintenance will likely need to be prepared for more extreme events like landslides and flooding that affect the highway, and even the delivery of projects may be impacted due to changing environmental conditions for permitting.

In order to prepare for these types of impacts ODOT developed this Climate Change Adaptation Strategy Report (Strategy). At this time the Strategy does not attempt to prioritize or rank strategies and actions. However, it does highlight some existing programs or areas where ODOT is currently engaged in adaptation efforts or where adaptation principles might be easily integrated. The Strategy acknowledges that the next step for the agency is to complete a vulnerability and risk assessment of ODOT's assets and systems operations. A vulnerability and risk assessment will not only help ODOT develop a full suite of potential strategies and actions for adaptation, but also help with the prioritization process of these actions in order to efficiently and effectively utilize resources for preparing the transportation system for climate change impacts.

The climate change science in the Strategy is primarily based on data provided by scientists in Oregon, including those that are a part of the Oregon Climate Change Research Institute (OCCRI). The analytical information comes from extensive research into how other transportation agencies, including international agencies, are addressing climate change adaptation. Most importantly, however, experts from various departments within ODOT reviewed and provided input into the Strategy.

The purpose of this Strategy is threefold:

1. Provide a preliminary assessment of the climate change impacts to ODOT's assets and systems operations;
2. Underline the need for a vulnerability and risk assessment; and
3. Identify current areas of adaptive capacity and potential long- and short-term actions to be taken by ODOT.

Climate change affects all aspects of the agency's work, and this Strategy identifies the information, assessments, and next steps for ODOT to take to ensure informed decision-making for agency planning and project development. Adaptation is not the sole responsibility of any one person or one division at ODOT; instead the goal is to integrate adaptation into existing activities and programs, making it a part of how we do business. The ultimate goal is to develop an ODOT Adaptation Plan that will guide the agency's planning, project development, maintenance and operations, and emergency response teams in preparing the transportation system for the impacts of climate change.

1. Introduction

Oregon is experiencing the impacts of climate variability and change in the form of increasing annual air temperature, more frequent and intense flooding events, and severe coastal storms. These, along with other climate impacts, are expected to manifest in various ways as the century progresses due to the accumulation of greenhouse gases in the atmosphere. Potential impacts of climate change in Oregon were recently documented in the [Oregon Climate Assessment Report] (OCAR).[1] The report provides the first comprehensive account of the current state of the climate science and the first account of regionally-specific information about the impacts of climate change in Oregon and the Pacific Northwest. Climate change science continues to evolve, and there are still uncertainties surrounding the exact timing, frequency, and magnitude of some impacts; however there is considerable evidence that climate variability and change are already affecting Oregon in a variety of ways.

> **Climate Change** – Any change in climate over time, whether due to natural variability or as a result of human activity (*IPCC*, 2007).
>
> **Mitigation** – Any action taken to eliminate or reduce the long-term risk and hazards of climate change (*IPCC*, 2007).
>
> **Adaptation** – The adjustment in natural or human systems to a new or changing environment caused by climate change (*IPCC*, 2007).

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concluded that evidence of warming is unequivocal and is caused primarily by human activities.[2] Mitigation strategies, those that limit the amount of greenhouse gas emissions, are only a part of the solution in combating climate change. In fact, "much of the change in climate over the next 30 to 40 years is already determined by the past and present emissions."[3] For this reason it is necessary that all levels of government engage in adaptation planning to deal with the consequences of climate change. Adaptation strategies are "actions by individuals or systems to avoid, withstand, or take advantage of current and projected climate changes and impacts."[4] Climate change will affect a wide array of systems, in a variety of ways; some impacts will occur quickly, while other impacts will occur more gradually over time. Due to this variability, adaptation strategies will vary greatly, from policy changes to technological fixes to adaptive resource management.

The Oregon Department of Transportation (ODOT) is responsible for more than 19,000 lane miles of state highway, 2,700 bridges, thousands of culverts, and other critical infrastructure. All of this infrastructure is potentially vulnerable to the impacts of climate change, such as increased incidence of landslides, flooding, coastal erosion, and wildfires. Additionally, ODOT's maintenance yards, supply sheds, and office buildings may be vulnerable to certain climate change impacts because of their locations. Beyond the impacts to ODOT's structural assets, climate change will impact the way ODOT does business, potentially impacting the way the agency plans and develops projects and responds to emergencies.

Adaptation planning and strategy development will help ODOT reduce the vulnerability and increase the resilience of its infrastructure and operations. This ODOT Climate Change Adaptation Strategy Report (Strategy) includes an assessment of climate change impacts on ODOT's systems. Within each impact

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1 Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds.). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR.. <http://www.occri.net/>

2 "Findings of the IPCC Fourth Assessment Report: Climate Change Mitigation", Union of Concerned Scientists: Citizens and Scientists for Environmental Solutions, 2007. <https://www.ucsusa.org/>

3 "Adapting to the Impacts", *Changing Our Ways: Scotland's Climate Change Programme*, Scottish Executive, 2006. <http://www.gov.scot/Publications/2006/03/30091039/0>

4 "Climate Change 101: Adaptation", PEW Center on Global Climate Change, January 2011. <https://www.c2es.org/document/adaptation-planning-what-u-s-states-and-localities-are-doing/>

assessment some potential adaptation actions are highlighted. The actions show the range of possible adaptation strategies for ODOT, and are by no means complete, but the examples offer a starting point. In many cases the potential actions are just examples of where adaptation and climate change considerations can be integrated into ODOT's existing programs and initiatives, which demonstrates a level of adaptive capacity for the agency. The Strategy also outlines the need and a potential framework for a comprehensive vulnerability and risk assessment of ODOT's assets and system operations. Conducting a vulnerability and risk assessment is key to informing future strategy development, as well as the strategy prioritization and implementation process.

Vulnerability - The potential for a system to be harmed by climate change, considering the impacts of climate change on the system as well as its capacity to adapt (*Pew Center*, 2011).

Resilience - The ability of a system to withstand negative impacts without losing its basic functions (*Pew Center*, 2011).

Adaptive Capacity - A system's inherent ability to adapt or cope with the impacts of climate change (*Pew Center*, 2011).

1.2 Statewide Efforts on Climate Change

The Strategy is focused on climate change adaptation planning; however, it is important to note that the state of Oregon is taking major steps to reduce greenhouse gas emissions, which contribute to climate change. First, the Climate Change Integration Act, passed in 2007, set specific greenhouse gas emissions reduction goals for all sectors of Oregon's economy. Second, the 2010 Oregon Legislature passed a comprehensive bill aimed at reducing greenhouse gas emissions from the transportation sector. The required work from this legislation is referred to collectively as the Oregon Sustainable Transportation Initiative (OSTI). The legislation directed ODOT and the Oregon Department of Land Conservation and Development (DLCD) to coordinate with local governments and metropolitan planning organizations (MPOs) to develop a statewide strategy, a toolkit, scenario planning guidelines and metropolitan area targets to reduce transportation greenhouse emissions.

With respect to adaptation, the state of Oregon also recently took a few important steps. In December of 2010, the Oregon Climate Change Research Institute (OCCRI) published the first of its legislatively-mandated Oregon Climate Assessment Report (OCAR). The biennial report assesses the state of the climate change science and the likely effects of climate change in Oregon. This is the first time regionally-specific climate data about Oregon is available, which will in turn help inform adaptation planning and strategy development for all levels of government in Oregon.

Around the same time that OCCRI was drafting the OCAR, then-Governor Kulongoski convened a committee of state agency directors, led by DLCD, and also included universities and research institutions, to address the issue of adaptation in Oregon. About a year later, the committee released the Oregon Climate Change Adaptation Framework, a broad framework intended to guide Oregon state agencies in assessing the impacts of climate change. The four key purposes of the framework are to:

- Identify likely future climate conditions that pose some risk for Oregonians.
- Assess the capacity of state programs to effectively address climate-related risks to people, communities, infrastructure, and natural resources.
- Identify short-term, low-cost priority actions to prepare for those risks.
- Provide context and initial direction for additional coordination and planning for future climate conditions.

The framework represents a starting point for the state in strategy development and planning for the future effects of climate change. Future work by the state agency directors and workgroup will focus on integrating economic factors into the planning efforts, developing additional adaptation strategies and actions, and incorporating other stakeholders, including local governments, into the planning process.

Adaptation planning is still in the early stages of development in Oregon, but these reports, along with the work of other state and local agencies and organizations, are contributing to a more robust understanding of the impacts of climate change and adaptation.

1.3 Objectives and Scope of an ODOT Adaptation Strategy

Although ODOT's participation in the statewide adaptation process is and will continue to be important, ODOT must develop adaptation strategies that specifically *address the risks and vulnerabilities to the transportation sector and ODOT's management of the transportation system*. Therefore the objectives of this Strategy are to:

1. Provide a preliminary assessment of the climate change impacts and their effects on ODOT assets and systems operations;
2. Underline the need for a vulnerability and risk assessment and present a possible framework; and
3. Identify existing levels of adaptive capacity within the agency and potential long- and short-term actions.

The Oregon transportation sector is very broad and jurisdiction over its infrastructure ranges from federal to local and from public to private. This Strategy focuses on the impacts and potential adaptation strategies for ODOT-owned or controlled assets and systems operations. This includes roadways and the surrounding right-of-way, bridges, and culverts, as well as facilities such as maintenance yards and office buildings. There are some systems where ODOT may have partial control of infrastructure. For example, ODOT's role in planning and influencing the rail system is limited, due to the majority of railroads being privately-owned; however, ODOT does have some responsibility to the system. Thus, the Strategy addresses some of the climate change impacts to railroad infrastructure, but does not go into detail about potential strategies or actions for adaptation.

Likewise the Strategy does not specifically address the potential climate impacts and adaptation strategies for locally-owned facilities and projects funded through ODOT grant programs, like those in ODOT's Transportation Growth Management Program and the Local Government Section. Some of the recommendations may still apply to the development of these projects. This decision is not intended to ignore or de-emphasize the impacts to other transportation infrastructure owned and operated by other jurisdictions; however, at this time it is most feasible and practical to focus solely on ODOT-controlled entities. ODOT recognizes that in order for Oregon's transportation system to truly be prepared for climate change, all infrastructure and systems will need to be assessed in the future.

1.4 Principles of ODOT Adaptation Planning

There are four overarching principles or themes to keep in mind for the ODOT adaptation planning process and these themes recur throughout the Strategy:

1. Interconnectivity –The impacts of climate change and the strategies to adapt to those impacts do not happen in isolation. For example, an increase in sea level rise will not only increase erosion along the coastline, but can also mean more flooding, inundation, and exacerbate incidences of landslides. In a similar vein ODOT must take care that a particular adaptation strategy, which may reduce vulnerability in one area, does not increase risk and vulnerability in another area.
2. Managing uncertainty and flexibility – Climate change science is ever evolving, and as modeling and projection capabilities are refined, the certainty in the projected ranges of climate impacts increase. However, uncertainty is not an excuse for inaction, instead it calls for careful planning and assessment to determine appropriate actions, and regular reassessment. Climate change strategies should be flexible. ODOT must be prepared to deal with various possible futures and adjust over time, rather than wait to react to events.
3. Linking adaptation and mitigation – Neither mitigation nor adaptation alone can fully address the issues of climate change; instead, these approaches must work in tandem in order to reduce the amount of greenhouse gases in the atmosphere. Adaptation requires preparing for impacts of climate change that are already

occurring due to existing levels of emissions. Some mitigation strategies may increase vulnerability to future climate impacts, while some adaptation techniques may result in higher emissions. For example using more air conditioning because of warmer weather contributes to more emissions. By keeping these connections in mind, planners and policymakers can avoid these types of issues in the future.

4. Integrate adaptation into ODOT's business practice and capitalize on existing programs – ODOT views adaptation as a responsible business practice so the goal is to integrate adaptation concepts into existing programs and initiatives. Linking adaptation with existing programs (such as asset management, emergency response, and design standards) allows ODOT to use its resources most effectively, creating better response to potential impacts, while not compromising other needs or programs. Adaptation planning is a multi-disciplinary exercise, where all ODOT sections and departments will need to work together, to prepare for the future.

1.5 Climate Change within the ODOT Sustainability Framework

At ODOT climate change (both mitigation and adaptation) falls under the broader umbrella of sustainability. ODOT is developing a three-volume Sustainability Plan to guide the management of both internal operations and the operation of the broader transportation system. Volumes I and II are complete. Volume I sets the contexts and definitions of sustainability at ODOT, while Volume II guides the sustainable management of ODOT's internal operations including facilities and fleet. Additionally, Volume II outlines strategies such as energy conservation and efficiency, waste reduction, and employee commute options that may help the agency reduce greenhouse gas emissions, and thus mitigate climate change. Some strategies may even potentially help ODOT adapt to the impacts of climate change. The final volume of the ODOT Sustainability Plan, Volume III, will be focused on the sustainable management of the transportation system, which will most likely include programs and strategies for climate change adaptation and mitigation.

ODOT's definition of sustainability, *balancing economic, environmental, and community well-being in a manner that protects the needs of current and future generations*, is an effective way to frame the adaptation planning process at ODOT. Using this sustainability context for adaptation planning; means ODOT staff can focus on implementing strategies that consider the cost (both to ODOT and the public), the environment (impacts of climate change), and the needs of Oregonians and the transportation system as a whole and into the future.

1.6 Structure of the Strategy

This Strategy is divided into four main sections. In addition to this introduction, the Strategy includes: the potential impacts of climate change in Oregon; the economic impacts of adaptation; assessment of climate change impacts to ODOT operations; and next steps for adaptation planning at ODOT. The information for the Strategy comes from extensive research into how other transportation agencies, including international agencies, are addressing climate change and adaptation. Most importantly, however, experts from many of ODOT's divisions reviewed and provided input. Each section is briefly described below:

> *Potential Impacts of Climate Change in Oregon*
> This section outlines the current climate change science and expected future impacts in Oregon and the Pacific Northwest. The section only highlights the impacts specific to the transportation sector, and consequently is not intended to provide a comprehensive forecast of all potential climate change effects in Oregon.
>
> *Economic Impacts*
> There are economic costs associated with climate change and the failure to adapt (inaction), be it in damage to infrastructure, or the financial impacts of disrupted freight routes. Adaptation strategies may

require additional funding. This section will begin the discussion of comparing costs of inaction with the costs of adaptation strategies and will outline how ODOT will assess these types of costs during adaptation planning and strategy development.

Assessment of Climate Change Impacts to ODOT
This section, the foundation of the Strategy, describes some of the vulnerabilities of Oregon's transportation system; outlines the overarching need for further vulnerability and risk assessments; summarizes some current actions of Oregon state agencies in terms of climate change adaptation; and provides a few examples of potential adaptation actions to reduce vulnerability and increase resilience for each potential impact of climate change.

Next Steps and Conclusion
Although ODOT is able to identify key adaptation actions and strategies, ODOT will need to continue to develop a plan to guide long-term decision-making and investments. Climate change science and adaptation information continues to evolve and ODOT adaptation planning will be an iterative process.

2. Potential Impacts of Climate Change in Oregon

Climate change is a global issue that is expected to impact regions around the world; however impacts will not be spread uniformly across each region. Some regions may get drier, while others will experience an increase in precipitation and thus a wetter climate. Below is a brief compilation of some of the research on climate change in Oregon and the Pacific Northwest. Later sections of this Strategy will address how these effects impact the transportation system and ODOT's assets and operations. Much of the information below is from the OCAR, published by OCCRI.

None of these impacts are unique to climate change; in fact Oregon is experiencing these types of events on a regular basis, but what happens if these impacts or events were to increase in magnitude and frequency? The fact is ODOT crews are having trouble dealing with the frequency and magnitude of these impacts now. Therefore adaptation planning is not just about abstract or uncertain future events, it is about preparing and adapting to impacts that are already occurring today, while considering how the events might change in the future.

2.1 Coastal

Oregon's coast has always been susceptible to extreme weather events and variability; still, it is projected that coastal regions will be impacted even more by events such as storm surges, increases in wave heights, and sea level rise, causing severe flooding and erosion along the coast.

Due to the tectonic forces off the Oregon coast, there are some areas of the shoreline where the rate of vertical land movement is seemingly keeping up with the current rate of sea level rise. However, by the mid-21st century increases in sea level rise are expected to exceed the rates of uplift along the entire Oregon coast. This sea level rise will result in increased erosion, even where there were little or no erosion impacts in the past.[5]

Historically the estimated regional rate of sea level rise has been approximately 2.3 millimeters per year in the

5 Peter Ruggiero, et al. "Impacts of climate change on Oregon's coasts and estuaries", Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, 218. <http://www.occri.net/>

Pacific Northwest.[6] The most recent estimates call for an increase of 55 centimeters (about 1.8 feet) of sea level rise by 2050 and 128 centimeters (a little over 4 feet) rise by 2100 in the Pacific Northwest. These numbers represent a low-probability, high-impact estimate of local sea level rise for areas along the Oregon coast experiencing little vertical land movement. The sea level rise estimate also combines the IPCC high emissions scenario with 1) higher estimates of ice loss from Greenland and Antarctica; 2) seasonal changes in atmospheric circulation in the Pacific; and 3) vertical land deformation. [7]

While the direct impacts of sea level rise may not be felt along the entire Oregon coast until 2100, the severity of winter storms and the wave heights these storms generate are already increasing. Simple coastal models over the last 30 years indicate that wave height increases play a more significant role than sea level rise on coastal flooding and erosion along the Oregon coast.[8] The most extreme storm in recent years in terms of wave heights measured occurred in March 1999, when the wave heights reached an average of 14 to 15 meters during the event and the highest waves reached 25 meters, the height of a ten-story building. According to Peter Ruggiero, an assistant professor at Oregon State University, “Data covering a period of more than 30 years now indicate that a 100-year (1 percent annual probability of occurrence) wave could reach 46 feet (14 meters) or even higher.”[9]

2.2 Changes in Air Temperature

Over the 20th century every station in the United States Historical Climatology Network in Oregon showed an increase in annual mean temperature with an average observed increase of 1.5 ºF for the century.[10,11] The OCCRI indicates average annual air temperature will increase around 0.2-1ºF per decade in Oregon; nevertheless the actual amount of warming will depend partly on the rate of global greenhouse gas emissions. Temperature projections are never absolute; the science indicates that Oregon can likely expect additional warming through the end of the century.[12]

2.2.1 Changes in Vegetation and Wildlife Species

Vegetation and wildlife species are very sensitive to their surrounding climates, and climate change in Oregon is likely to affect the types and distribution of species throughout Oregon. Vegetation models show that due to temperature increases at higher elevations, areas of subalpine forest and tundra are projected to decrease. Areas of shrubland in the eastern part of the state will likely decrease, being replaced in part with forest and woodlands, which are projected to increase. On the coast, areas of mixed evergreen and subtropical mixed forest are likely to expand, marking a major transition from temperate to subtropical species.

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6 R.J., Burgette, et al., “Interseismic uplift rates for western Oregon and along-strike variation in locking on the Cascadia subduction zones”, Journal of Geophysical Research Letters, 114, B01408 in Peter Ruggiero, et al. “Impacts of climate change on Oregon’s coasts and estuaries”, Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, 216. <http://www.occri.net/>

7 Peter Ruggiero, et al. “Impacts of climate change on Oregon’s coasts and estuaries”, Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, 218. <http://www.occri.net/>

8 Ibid, 227.

9 “The Wave of the Future: Higher Waves Increase Erosion and Flooding Along the Oregon Coast”, National Oceanic and Atmospheric Administration (NOAA), <http://www.noaa.gov/news-features>

10 Executive Summary, Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR. <http://www.occri.net/>

11 Philip W. Mote, et al. “Climate Change in Oregon’s Land and Marine Environments”, Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds), College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR. <http://www.occri.net/>

12 Executive Summary, Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR. <http://www.occri.net/>

Furthermore, pests and diseases are projected to expand northward as air temperature in Oregon continues to increase. For example, the presence of mountain pine beetle increased over the last eight years and population numbers will likely continue to grow as the climate warms in Oregon. In general, insects and disease will expand northward in latitude, toward the coast and upward in elevation in a warming climate.[13]

Some patterns and trends in shifting wildlife and vegetation species are already evident; the following are listed in the OCAR[14]:

- Insects from south of Oregon, including pests, are moving into the state, and the timing of development of native species is advancing as spring conditions arrive sooner.
- Frogs are reproducing earlier in the year compared to past decades and emergent infectious diseases affecting frogs and their relatives are increasing in severity.
- Land birds are shifting their distributions northward and migrating earlier.
- Small mammals in eastern Oregon are contracting their habitat area or ranges on mountaintops.
- In fresh waters, climate-related habitat loss has increased in severity for salmon and other cool-water fish.

2.2.2 Wildfire

The OCAR states that incidences of wildfire are likely to increase around Oregon. In fact, the regional forest area burned is estimated to increase between 180 and 300 percent by the end of the century.[15] Fire activity is expected to increase for all the major forest types in Oregon. In western Oregon, the projected warmer and drier summers will lead to the potential of more wildfires. Likewise, wildfires are expected to increase in eastern Oregon due to the potential for increased vegetation growth in the milder winters, which provides more fuel for probable wildfires.[16]

2.3 Storm Intensity

Storm intensity is an ambiguous term. For the purpose of this report, storm intensity represents two specific impacts. First, storm intensity refers to the *incidence of extreme events* such as those classified by the Federal Emergency Management Agency (FEMA) as major disasters and other extreme winter, wind storm events, and extreme precipitation or rainfall events. Second, this refers to the impacts of *hazard trees* along highways that fall onto the roadway or disrupt power lines and other infrastructure on ODOT right-of-way during storms. The focus on hazard trees may seem narrow; however it is a considerable issue on Oregon's highways, causing significant delays and safety risks to the public. It is important to note that other extreme events like landslides and flooding are addressed in more detail in subsequent sections of the Strategy.

2.3.1 Extreme Storm Events

In the three years from 2006 to 2009, there were five FEMA Major Disaster Declarations in Oregon due to storms, flooding, landslides, and mudslides. In the 10 years prior, only seven declarations were made (three of which occurred in the same year, 1996).[17] This does not prove that climate change is causing these

13 Sarah L. Shafer, et al. "The Potential Effects of Climate Change on Oregon's Vegetation", Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR. <http://www.occri.net/>

14 Mark A. Hixon, et al. "Oregon's Fish and Wildlife in a Changing Climate", Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, 268. <http://www.occri.net/>

15 Executive Summary, Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR. <http://www.occri.net/>

16 Ibid.

17 "Oregon Disaster History: Major Disaster Declarations" Federal Emergency Management Agency, <https://www.fema.gov/news-releases>

severe storm events, still it may illustrate that the number of large storm, flooding, and landslide events is increasing. Extreme storms also include the incidence of extreme daily precipitation events, which in turn usually result in increased flooding, landslides, and other events, and winter storms.

2.3.2 Hazard Trees

Storm events, including wind storms, will potentially become more intense and frequent in Oregon. As a result of these more intense storms, tree corridor management practices such as hazard tree assessments and removal, and proactively removing potentially hazardous trees prior to storm events are becoming more common around the ODOT Districts. Tree corridor management is vital because during winter storms, especially wind and ice storms, trees fall across highways blocking traffic and pulling down power lines. Winter damage, diseases, and pests make trees along ODOT-owned highways vulnerable to falling across highways which threatens public safety, the mobility of traffic, and the infrastructure.

2.4 Changes in Precipitation

There are trends in the current regional models in terms of *seasonal precipitation*. Summer precipitation is projected to decrease somewhere along the order of 5-15 percent, while winter precipitation will most likely increase by about 15-30 percent.[18] Despite, the trends in *seasonal precipitation*, there is an amount of uncertainty when it comes to projecting changes and variability in *annual precipitation* caused by climate change. In addition to changes in average seasonal precipitation, the fourth assessment report by the IPCC indicates that extreme hydrologic events such as floods and droughts are anticipated to increase.[19]

2.4.1 Flooding

There is some evidence in global and regional climate models that extreme daily precipitation in the Pacific Northwest will increase in the 21st century, although there is still a need for more research in this area. Such extreme daily precipitation events will be a driver in flood events across Oregon. Another possible driver of flooding is the warmer winter weather which may lead to more winter precipitation falling as rain and more rapid melting of winter snow.[20]

2.4.2 Changes in Seasonal Flow Rates

Due to increasing air temperature, potentially leading to less precipitation falling as snow, the snowpack in the region is predicted to continue to decline, especially at low and middle elevations. For example, the average decline of April 1 snowpack in the Cascade Mountains was about 25 percent over the past 40 to 70 years.[21] Snowpack is projected to continue to decline by as much as 40 percent in the Cascades by the 2040's.[22] Changes in temperature impact the timing of runoff and streamflow. In particular, warmer winter temperatures mean less snowpack, but it also may lead to earlier spring snowmelt which will shift the timing

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18 Philip Mote and Salathé E., Future climate in the Pacific Northwest, Chapter 1 in the Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate (Seattle, Washington: University of Washington Climate Impacts Group, 2009). <http://cses.washington.edu/>

19 Heejun Chang, et al. "Climate Changes and Freshwater Resources in Oregon", Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, 94. <http://www.occri.net/>

20 "Increased frequency of extreme precipitation events and incidence and magnitude of damaging floods", The Oregon Statewide Adaptation Framework (2010), 70.

21 Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr, and P. Whetton, 2007: Regional climate projections. In: *Climate Change 2007: The Physical Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, 847-940.

22 Payne, J.T., A.W. Wood, A.F. Hamlet, R.N. Palmer, and D.P. Lettenmaier, 2004: Mitigating the effects of climate change on the water resources of the Columbia River Basin. *Climate Change,* 233-256.

of peak flows. Some streams may peak earlier in the year,[23] which will have significant impacts on water availability and navigation.

2.4.3 Landslides and Rockfalls

Landslides are one of Oregon's most costly natural hazards, with damages exceeding $100 million statewide some years.[24] Already a significant hazard in Oregon, landslides could become even more common with an increase in intense precipitation events around the state. Groundwater levels impact the risk of landslides in Oregon: the more water in the ground, the higher the likelihood of a landslide. With an already elevated groundwater surface in the winter months, smaller rainfall events will trigger more landslide movement. Landslides and erosion will impact areas around the state (not just the coastal regions). Specifically, there are areas around Portland that are highly susceptible to slide events and will be even more vulnerable during intense precipitation events.[25] According to the U.S. Geological Survey (USGS) altered slope areas such as those formed by roadcuts or other human infrastructure are more susceptible to debris flows and landslides. In fact, "debris flows and other landslides onto roadways are common during rainstorms, and often occur during milder rainfall conditions than needed for debris flows on natural slopes."[26]

2.5 Social Impacts

The impacts in this section can be more aptly described as indirect climate change impacts. In other words, due to climate change effects like increased air temperature, changes in precipitation, and increased sea level rise there will be a significant impact to Oregon's society. Oregon may see an increase in population, due to an influx of "climate refugees" or more generally people moving to a more desirable climate. Changes in Oregon's population will impact ODOT's work; however more research needs to occur in order to better inform strategy development and long-range planning policies.

2.5.1 Population Movement

The impacts of climate change are already causing the migration of people around the world. Stressors such as sea level rise, increased flooding, hazard events, breakdown of agricultural systems and livelihoods, etc. all contribute to human migration and are all expected to increase. Current projections vary widely from 25 to 50 million migrants in 2010 to almost 700 million by 2050.[27] This great uncertainty means much more research is needed to determine the number of potential migrants and where they will relocate.

Oregon's population is projected to increase by 13 percent by 2020 and about 63 percent of that will be due to net migration into the state.[28] According to the OCAR, "Climate conditions, even though changed from historic patterns, may be relatively attractive [in Oregon] compared to other parts of the country and therefore may attract "climate-refugees" seeking more optimum climate conditions."[29] More research

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23 Executive Summary, Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR. <http://www.occri.net/>
24 Vicki S. McConnell, "New maps reveal landslides using laser based imaging: New technology is helping state geologists create some of the most accurate landslide inventory maps in the world", Oregon Department of Geology and Mineral Industries, News Release: April 20, 2009. <https://www.oregongeology.org/ >
25 "Landslide Hazards Fact Sheet", U.S. Geological Survey, 2000. <https://pubs.usgs.gov/fs/fs-0071-00/fs-0071-00.pdf>
26 Ibid
27 Myers, N. 2001. Environmental refugees: A growing phenomenon of the 21st century. Philosophical Transactions of the Royal Society B 357:609- 613. doi 10.1098/rstb.2001.0953
28 Executive Summary, Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR. <http://www.occri.net/>
29 Peter Ruggiero, et al. "Impacts of climate change on Oregon's coasts and estuaries", Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, 254. <http://www.occri.net/>

is needed on this topic, however there is evidence that Oregon's population will increase due to people migrating because of climate change impacts.

3. Economic Impacts Discussion

Climate change will have serious impacts on every sector of the economy in every country around the world. Although these impacts may be unevenly distributed across regions and economies, research demonstrates that the actual economic effects of climate change will be experienced across the world economy.[30]

There are three types of costs associated with climate change adaptation: 1) the cost of inaction, 2) the cost of adapting to climate change, and 3) the costs averted or revenue saved from adapting. These costs and benefits of adapting to climate change will impact both ODOT and the public. Climate change is a global issue; however, the sections below focus on these three potential economic impacts to ODOT and Oregon communities.

3.1 Cost of Inaction

Carbon dioxide and other greenhouse gases remain in the earth's atmosphere for multiple centuries after they are produced, thus influencing future climate.[31] Even if greenhouse gas emissions were stopped today, the world will still experience climate change caused by past and current emissions. For this reason, local communities and states will need to adapt to this level of climate change.

For this Strategy the cost of inaction represents the costs of not preparing or adapting the transportation system for the potential impacts of climate change. There are additional costs associated with not mitigating or reducing greenhouse gas emissions; but those are not discussed in this report.[32]

For ODOT the cost of inaction is associated with the cost of continually repairing stretches of highway that are impacted by floods, erosion, landslides, and other weather-related events. One example of how these costs will be borne by ODOT is through the increased incidence of landslides. During a five-year period from 1995-2000 approximately $22.3 million was spent on landslide repairs along U.S. Highway 101, much of which was performed under emergency conditions.[33] Incidences of landslides are projected to increase due to climate change, further increasing costs for maintenance. In most cases the "maintenance expenditures for landslides and rockfalls usually have a modest return to the highway system in terms of actually mitigating problems."[34] This means that the money is not going to the permanent stabilization of slopes and preventing future slides, consequently the costs will keep rising over time as slopes continue to fail. Similar conclusions can be drawn for the other types of programs at ODOT. ODOT spends its resources on reacting to emergency situations while those same funds could go towards preventing or better preparing for future events. Permanent repairs can be expensive; however habitual repairs may be more expensive in the long run.

30 *US Economic Impacts of Climate Change and the Costs of Inaction* (2007), A Review and Assessment by the Center for Integrative Environmental Research (CIER) at the University of Maryland.
31 *Climate Change 101: Overview,* Pew Center for Global Climate Change, <https://www.c2es.org/category/climate-basics/>
32 The Stern Review, a report that assess the evidence and builds understanding of the economics of climate change, determined that unabated climate change could cost the world at least 5% of gross domestic product (GDP) each year and if more dramatic climate and emissions predictions come true, the cost could be more than 20% of GDP. Source: *Stern Review: The Economics of Climate Change* (2006), Sir Nicholas Stern.
33 "Landslide and Rockfall Program: 2012-2015 State Transportation Improvement Program Report", Oregon Department of Transportation, ODOT.
34 Ibid.

There will be direct costs to Oregonians for not adapting the transportation system to climate change. Road closures, traffic delays, and traffic detours caused by events such as flooding and landslides will result in economic losses to Oregonians. It is estimated that the 24 hour delay of a single truck costs over $500. Given the volume of traffic on many of Oregon State highways, the cumulative costs might be huge, especially considering that some events can close a highway for weeks.[35] Communities used as detour routes experience increased safety and noise impacts. In fact, as the 2003 Bridge Options Report outlines, in some instances ODOT must repair or replace bridges on the detour routes as a result of damage caused by the large trucks and traffic volumes caused by a detour. This places an increased financial burden on the agency, not to mention jeopardizing the safety and livelihoods of small communities.[36] Beyond the costs of diminished freight mobility, many of Oregon's highways serve as lifeline routes and closures and delays on these integral highways impact the movement of medical supplies and care, food distribution, and other essential services to impacted communities.

3.2 Cost of Adaptation

The second category of costs to ODOT is associated with implementing preparation and adaptation strategies, from the cost of building higher and stronger bridges to stabilizing erosion along highways. The Stern Review states that for many sectors adaptation options and actions will provide benefits in excess of cost, "but at higher temperatures, the *cost of adaptation will rise sharply* and the residual damages remain large. The additional costs of making new infrastructure and buildings resilient to climate change in OECD [Organization for Economic Co-operation and Development] countries could be $15-150 billion each year (0.05-0.5% of Gross Domestic Product (GDP))."[37] If you apply these percentages to the 2009 Oregon GDP, $165 billion, the additional costs of making new infrastructure resilient to climate change could be between $82.5 - 825 million each year, depending on impacts. The costs for adaptation strategies will vary depending on the strategy; however the reality is that protecting, preparing, and adapting infrastructure and systems operations will have a cost.

3.3 Benefits or Costs Averted

The third type of cost to consider is not truly a cost but rather a potential benefit. ODOT and Oregon communities will avert costs by taking proactive steps to adapt, before the Oregon transportation sector is negatively impacted by climate change. In other words, ODOT and Oregon will benefit from acting early. The cost averted must be compared to the cost associated with implementing adaptation strategies as well as the cost of inaction. In fact, "well-targeted, early investment to improve climate resilience – whether in infrastructure development, technology advances, capacity improvement, shifts in systems and behaviors, or risk transfer measures – is likely to be cheaper and more effective for the world community than complex disaster relief efforts after the event."[38] Some adaptation strategies will be more expensive, as building a new highway or structure on new alignments is costly. However, for many strategies while the initial cost of building resiliency might be higher, it is important to consider the cost benefits and lifetime costs of these measures, as these measures probably have smaller life cycle costs. These are not simple costs to determine, but all of these cost considerations are important for developing adaptation strategies.

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35 "Landslide and Rockfall Program: 2012-2015 State Transportation Improvement Program Report", Oregon Department of Transportation, ODOT.

36 Oregon Department of Transportation, *Economic and Bridge Options Report,* prepared by the Economic & Bridge Options Team, January 15,2003; <https://www.oregon.gov/ODOT/>

37 *Stern Review: The Economics of Climate Change* (2006), Sir Nicholas Stern.

38 Martin Parry, et. al. *Shaping Climate-Resilient Development: A Framework for Decision-Making* (2009), a report of the Economics of Climate Adaptation Working Group in Environment Magazine.

3.4 The Process for Measuring Costs

ODOT has not determined the exact process for quantifying the costs associated with inaction and adaptation strategies, however as the previous sections have discussed, ODOT identified some of the essential costs to consider. In order to determine the costs of inaction or a business as usual scenario (not adapting to climate change), the following costs should be taken into consideration:

- **Annual maintenance costs** – For example, trends from the Landslide and Rockfall Program show an increase in annual maintenance costs over the years, which is likely to keep increasing due to climate change. It is important to acknowledge that materials and labor costs do tend to trend upward from year-to-year, due in part to inflation; however climate change may very well add to these increases in cost.
- **Annual emergency repair costs** – In many cases the annual maintenance cost figures do not include emergency repair costs. Although emergencies cannot be predicted and will vary from year to year, it is projected that climate change will cause more of these emergency events in the future, placing a greater economic burden on ODOT and Oregon.
- **Closure costs both for freight mobility and impacts to local economies** – The economic impact of traffic delay, closures, and detours is severe, both for freight movement and for local economies cut off during these closures.

Next, the costs of adaptation strategies and measures may be a bit more difficult to quantify given the wide range of possible strategies and actions that have yet to be determined. However, it should be possible to estimate the costs of actions including designing for higher bridges, stabilizing slopes, installing more monitoring, and other possible adaptation strategies.

There are still many unknowns about the economic impacts of climate change and more information is needed, but this is a starting point. What we do know is that ODOT must consider all three – the economic impacts of inaction, the cost of implementing, and the cost of aversion – when implementing adaptation strategies. Understanding both in terms of direct costs to the agency and the costs to the public will help ODOT determine the most effective and efficient strategies for adapting Oregon's transportation sector. ODOT will work internally and with its partners to continue assessing and forecasting the costs associated with adaptation.

4. Assessment of Climate Change Impacts to ODOT

Climate change will impact the Oregon transportation system in a number of ways. This section provides more detail as to how specific climate impacts will affect ODOT's transportation infrastructure and operations. The following sub-sections address ODOT's known vulnerabilities to a particular climate impact; outline some key assessment questions to help inform a future vulnerability and risk assessment; and provide brief summaries of some actions other Oregon State Agencies are taking for adaptation. Additionally, many of the sub-sections include information on potential actions for adaptation and examples of ODOT's current adaptive capacity, or ability to cope with the consequences of climate change.

> **Vulnerability Assessment:** Identifies existing stressors facing transportation systems and projects how climate change will impact and/or introduce new stressors in the future. The findings of the assessment can then be ranked to assess, prioritize, and address vulnerabilities (*FHWA,* 2010).
>
> **Risk Assessment:** Evaluates the likelihood and consequence of climate-related impacts on transportation and can be rooted in engineering applications. Many times this assessment will quantify the product of the probabilities of exposure and vulnerability (*FHWA,* 2010).
>
> **Adaptation Assessment:** Identifies, plans, prioritizes, implements, and measures transportation management options available for effectively adapting to climate change impacts (*FHWA,* 2010).

Prior to developing a full list of adaptation strategies, ODOT will conduct a vulnerability and risk assessment. This assessment will help the agency identify where its infrastructure and operations are most vulnerable and at risk in order to more strategically prepare the system for the future. There are a number of vulnerability and risk assessment models or frameworks available to ODOT and a staff work group will determine the most practical and proper framework for ODOT.

Washington's Approach

The Washington State Department of Transportation (WSDOT) piloted FHWA's *Conceptual Model for Assessing Vulnerability and Risk of Climate Change Effects on Transportation Infrastructure*[39] (See Figure 1). As part of this conceptual model both asset information and climate information are needed to determine the vulnerability of the transportation system. In Washington, state law established that the climate change science is to be provided by the Department of Ecology and the University of Washington Climate Impacts Group. Therefore, WSDOT is not involved in determining the science or ranges of impacts, instead the agency is responsible for developing an inventory of its assets, assessing the criticality (how important the assets or roadway segments are within the Washington transportation system), and then determining if the segment is vulnerable to the climate impacts provided by the Climate Impacts Group. WSDOT released its *Climate Impacts Vulnerability Assessment Report* in November 2011.

ODOT's Asset Management Approach

In order to perform a vulnerability and risk assessment, ODOT needs both climate science and asset information. The ODOT Asset Management Section is responsible for *strategically managing ODOT's assets by utilizing integrated and systematic data collection, storage, analysis and reporting standards on a broad range of transportation system assets, optimizing funding and life-cycle decisions for operations, maintenance, and construction business functions*.[40] Identifying ODOT's assets and the location and condition of those assets

39 *Assessing Vulnerability and Risk of Climate Change Effects on Transportation Infrastructure: Pilot of the Conceptual Model,* Federal Highway Administration, <https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/index.cfm>

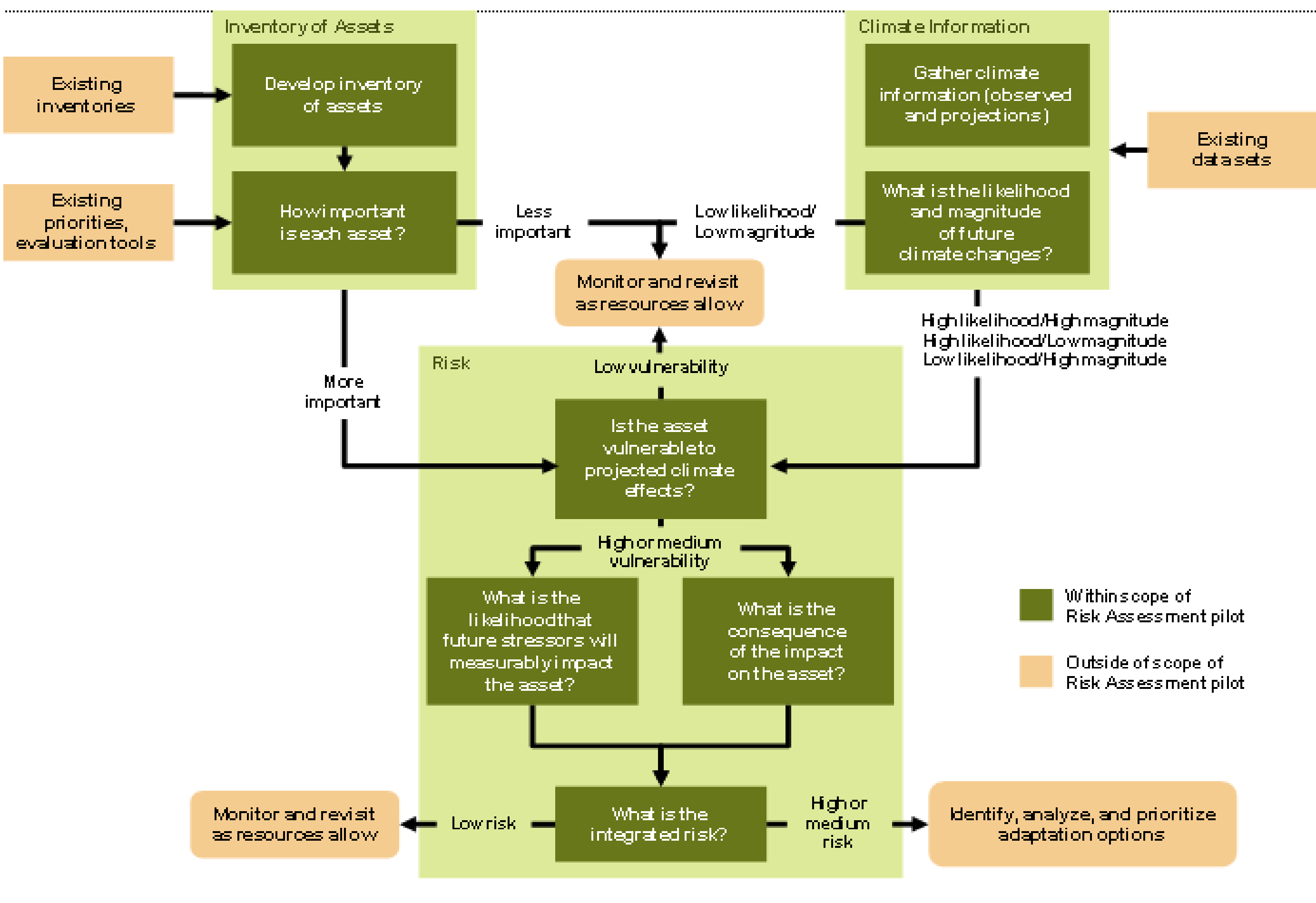
40 ODOT Asset Management Section, <https://www.oregon.gov/ODOT/>

is an important piece for a climate change vulnerability and risk assessment. Therefore, a key next step is to work with the existing Asset Management Section to better integrate climate change impacts and adaptation considerations into existing initiatives in the section.

By conducting a vulnerability and risk assessment for ODOT's assets and the system as a whole, the agency will be able to prioritize the most at risk and vulnerable areas of the transportation system. ODOT already understands some of the vulnerabilities facing the transportation system, just from the institutional knowledge and experience of ODOT crews, however a more comprehensive assessment will provide the agency with more information for future strategic planning of the system.

Finally, it is important to note that the *Potential Actions for Adaptation* that are outlined in the following sub-sections are just some initial ideas and do not represent all the possible strategies for adaptation; nor are these strategies necessarily representative of what ODOT is committed to do for adaptation. On the other hand, the *Examples of ODOT's Adaptive Capacity* represents some current programs or initiatives where ODOT already has some level or ability to cope with the consequences of climate change. While some adaptation strategies may be new, many are simply extensions or modifications of existing programs or efforts, like those addressed in the following sub-sections.

Figure 1: FHWA Conceptual Model for Assessing Vulnerability and Risk of Climate Change Effects on Transportation Infrastructure



4.1 Coastal Impacts

Known vulnerabilities:

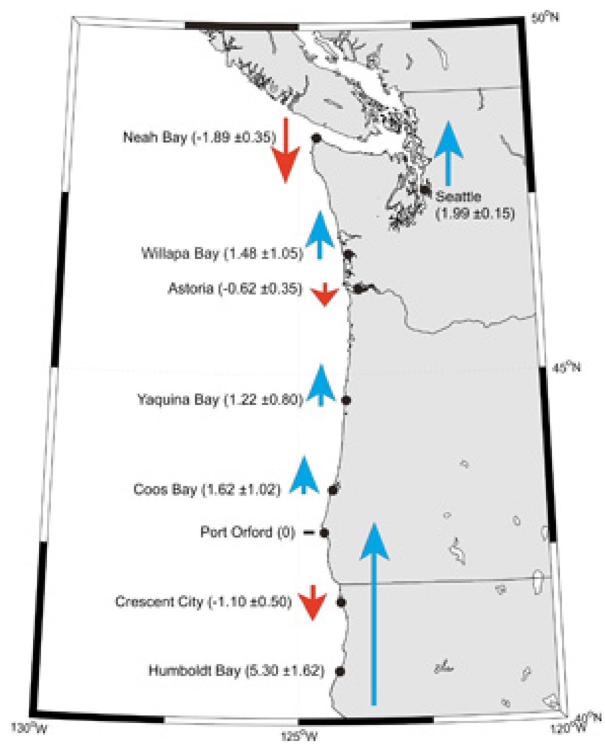
Oregon's coastal areas have always been susceptible to extreme weather events, however the OCCRI projects that impacts to coastal regions will be greater in the future, including increased wave activity, storm surges, sea level rise, flooding, erosion, and landslides. Oregon's coastal roadways already experience the effects of climate change. U.S. Highway 101 near the City of Seaside, Oregon experiences habitual flooding problems causing road closures and delays multiple times every year. Seaside is by far not the only town where this type of flooding occurs, in fact the OCCRI estimates that the frequency and magnitude of coastal flooding events may continue to increase over the next century.[41]

* 2-4 feet of sea level rise by 2100.
* Increases in wave heights.
* Increase in inundation and erosion along entire coastline.

As potential sea levels rise, wave heights increase, and more intense storm surges occur, erosion along the entire coastline will threaten infrastructure and potentially close stretches of highway. While it is common for coastal bluffs, beaches, and cliffs to gradually erode over time, increases in wave heights and storm intensity can increase the rate and magnitude of this erosion, sometimes causing rapid sliding of bluffs that damage or destroy built infrastructure.

Increased erosion along the coast will also impact landslide prone areas. Erosion at the toe of a landslide results in an overall reduction of the resisting forces that prevent or reduce slide movement. There are many of these types of slides on the coast that creep along year after year and are waiting for a reason – such as reduced toe resistance (erosion) – to accelerate their movement. Presently, there are an unknown number of ancient landslides that are not currently active, but will activate with toe erosion, sea level rise, and increased precipitation. ODOT is using Light Detection and Ranging (LiDAR) data as it becomes available to locate and delineate these ancient, inactive landslides that underlie the Oregon highway system to be better prepared for possible events.

Figure 2:



Colored arrows represent the rates of change in relative sea levels (mm/yr), generated using summer data only. Blue means relative sea level rise, while red means a the relative sea level dropped. (After Komar et al., in press).

Coastal storm water management and other drainage facilities are particularly vulnerable and may be insufficient to manage storm water or even fail because of the increase in magnitude and frequency of rainfall events, and especially in combination with an increase in tidal elevations. "Systems at or near capacity today may be unable to handle future storm loads, which could have a significant effect on location and future development."[42]

Impacts on the coast reach beyond the highway-related infrastructure. The North Bend and Astoria airport

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41 Legislative Summary, Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR. <http://www.occri.net/>

42 Peter Ruggiero, et al. "Impacts of climate change on Oregon's coasts and estuaries", Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, 255. <http://www.occri.net/>

runways are located on filled estuarine wetlands, which may put them at risk to sea level rise and inundation from increased storm surges and corresponding wave height increases.[43] Furthermore, harbors and port facilities are vulnerable to the impacts of higher tides and storm surges. While ODOT does not necessarily have control over these types of infrastructure, these impacts are important to note for the broader statewide adaptation context. If these forms of transportation were inhibited because of climate change impacts, people will turn to the roadway system for their needs, adding an impact on the system that ODOT operates.

Example of ODOT's Adaptive Capacity

- *Spencer Creek Bridge* - The original roadway approaches were along an eroding shoreline, in an area subject to landslide hazards, and there was a concern that these approaches would not hold up for the intended design life of the bridge. After consulting experts, including the Army Corps of Engineers, it was decided to shift the highway alignment 50 feet to the east in high beach erosion areas, thus hoping to avoid sea cliff erosion impacts for a least 50 years. This is a clear example of how a project considered future impacts in the design.
- *Erosion Mosaics of U.S. Highway 101* - These photo mosaics pinpoint roadway segments that are near the beach and may be vulnerable to surf erosion and sea level rise.

Finally, climate change may impact Oregon Emergency Management (OEM) and ODOT's emergency response teams. Both the northern and southern coasts in Oregon experienced events over the last five years that completely isolated coastal cities for days due to roadway closures caused by flooding, landslides, erosion, and fallen trees. In December 2007, all roads to the northern coast were closed because of weather related hazards, isolating cities from Tillamook to Astoria. A similar event occurred in 2005 on the southern coast, cutting off cities for days because of weather induced damage and closures of transportation corridors. These events illustrate the reality that weather events can cripple the transportation system in Oregon and that adaptation strategies are important mechanisms for ensuring that these corridors stay open as much as possible. These types of storms, while not solely caused by climate change, are projected to increase with stronger storm surges and more flooding events. ODOT, along with other agencies, may need to adapt its emergency response practices and procedures to ensure that cities and towns are not closed off from necessary goods and services for extended periods of time.

Vulnerability and Risk Assessment:

Although there are known vulnerabilities and risks along the Oregon coastline to ODOT's infrastructure and systems, the first step in adaptation planning is to conduct a more comprehensive vulnerability and risk assessment of these aspects. Such assessments will help determine how and to what level the agency's assets or systems will be impacted by climate change to better inform strategy development and implementation prioritization.

Given the size and scope of adapting Oregon's transportation system to climate change, prioritizing areas and specific infrastructure will ensure resources are focused in the most efficient manner. There are a few key assessments or actions that ODOT, in consultation with other key partners, can conduct for coastal infrastructure to help pinpoint vulnerable and high risk areas:

- Identify and map where U.S. Highway 101 is most vulnerable to storm surges, wave height increases, and sea level rise.

43 Peter Ruggiero, et al. "Impacts of climate change on Oregon's coasts and estuaries", Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, 255. <http://www.occri.net/>

- Coordinate needs and mapping capabilities with Oregon Department of Geology and Mineral Industries (DOGAMI) and other agencies.
- Inventory coastal assets including roads, bridges, drainage facilities, etc.; including condition of the asset and frequency of repair of the asset.
- Assess how sea level rise will impact river levels in Oregon, and the vulnerability of infrastructure along those rivers.
- Identify critical freight and lifeline routes:
    - How will these routes be impacted by climate change?
    - Prioritize infrastructure along these routes.
    - Identify primary detour routes.

Current State Agency Actions:

- ODOT is preparing scour analyses of 69 coastal bridges to determine the stability of the bridge base.
- Chapter 10, Section 10.8.7 (Sea Level Change) in the *ODOT Hydraulics Manual*, acknowledges that sea level change should be considered in coastal structure design and offers summaries of the mean sea level trends along the Oregon Coast.
- Oregon Beach and Shoreline Mapping and Analysis Program (OBSMAP) – DOGAMI, the Coastal Management Program (OCMP) of DLCD, the Oregon Parks and Recreation Department (OPRD), the Washington Department of Ecology, and Oregon State University are coordinating on the OBSMAP to provide high-quality scientific information of the changing faces of the Oregon coast.[44] There are two broad goals of the OBSMAP effort: 1) to provide up-to-date information on the state of beaches and shorelines along the Pacific Northwest coast, and 2) to develop an improved understanding of the seasonal-interannual-decadal changes in Oregon beaches. The OBSMAP monitoring network currently consists of 119 active beach monitoring sites funded through the Northwest Association of Networked Observing Systems (NANOOS).[45]
- DLCD is developing an inventory of the location, condition, and legal status of dikes, levees, and other reclamation infrastructure around Oregon's outer coast estuaries.
- The Oregon Watershed Enhancement Board (OWEB) provided funding for a west coast sea level rise study by the National Academy of Sciences under the West Coast Governor's Agreement. This research will evaluate the major contributing factors to global sea level rise, provide values or ranges of values of global sea level rise for the years 2030, 2050, and 2100, and where possible provide specific values for the regional and local contributors to sea level rise along the west-coast. The report is expected to be released by the end of 2012.

Potential Actions for Adaptation

* *Mitigate shoreline erosion* - Develop best management practices (BMPs) and guidelines to mitigate shoreline erosion and stabilize transportation infrastructure at risk of coastal erosion.
* *Create coastal hazard maps* - Develop standardized, detailed coastal hazard maps for priority areas along the Oregon coast.
* *Develop design and engineering standards* - Develop specifications for bridges, roadways, culverts, and other infrastructure that takes into account increases in climate change impacts.

44 Find more information about OBSMAP at: <https://www.oregongeology.org/>

45 Peter Ruggiero, et al. "Impacts of climate change on Oregon's coasts and estuaries", Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, 227. <http://www.occri.net/>

4.2 Changes in Air Temperature

Known Vulnerabilities:

Oregon is known for its relatively mild climate, still the average mean air temperature is projected to rise about 0.2 - 1ºF per decade. This increase in air temperature may potentially impact the pavement structures in roadways and bridges across Oregon. An increase in air temperature can cause some pavement materials (particularly asphalt binders) to degrade at a quicker rate, leading to rutting, cracking, and potholing. This presents both a safety risk to motorists and a financial burden for ODOT Maintenance and Operations crews that must repair the roads. However, the current life cycle of ODOT's pavement is 15 to 20 years, so unless there is an immediate and drastic increase in air temperature, the pavement that is already on the road will not be impacted; instead, the development and consideration of future pavement technology and design standards is more important.

- ✳ The average annual air temperature is projected to increase 2.0 - 1 ºF per decade.
- ✳ The actual amount of warming will depend on the rate of change in global greenhouse gas emissions.
- ✳ Models project warmer and drier summers in the region.

An increase in air temperature may impact ODOT's Maintenance and Operations crews, as well as others that work outside on the highway infrastructure. Increases in air temperature may limit the time these crews are able to work due to potential hazardous heat conditions and other weather related health and safety concerns.

Example of ODOT's Adaptive Capacity

Given the variable climatic regions that already exist in Oregon, ODOT may already be producing the proper types of pavement to withstand an increase in air temperature. The issue then becomes the necessity of monitoring, prioritizing, and implementing the correct pavement types, at the correct time.

Railroad infrastructure, including heavy freight, passenger rail, and light rail, is also vulnerable to increases in air temperature, potentially causing track deformities which lead to equipment failure or derailments. Again, while ODOT does not have direct control over much of the rail systems in Oregon, it is important to recognize the impacts to these other modes. Since many rail systems run parallel to or nearby the highway system, equipment failures and derailments caused by track deformities may also impact the highway causing closures or potential dangerous situations for those travelling on the highway.

Vulnerability and Risk Assessment:

There are a few key assessments or actions that ODOT, in consultation with other key partners, can conduct to help pinpoint vulnerable and high risk areas:

- Assess the common types of pavement that ODOT uses and test performance under warmer temperatures.
- Assess and track failures in pavement systems due to temperature changes.
- Work with railroads to determine how rail assets may be impacted by an increase in air temperature.
- Assess freight and lifeline routes –
    - What are the conditions of the pavements along these routes?
    - How often are these routes repaved?
    - What are the particular pavement designs or technologies that can be used on these routes?

4.2.1 Changes in Vegetation and Wildlife Species

Known Vulnerabilities:

ODOT is responsible for the management of the right-of-way (ROW) that surrounds highways, bridges, and other infrastructure. In many areas of the state, the ROW includes various types of vegetation that is managed and maintained by ODOT to ensure traveler safety, mobility, and protection of infrastructure. If vegetation species shift, ODOT maintenance and vegetation management crews will likely have to change or adapt their current methods of management.

- Plant and animal species are projected to migrate upward or northward.
- Pests, diseases, and invasive species may become more abundant and resilient.

The presence of invasive species is projected to increase with warmer temperatures. ODOT already spends considerable time and resources on invasive species management and an increase in this type of vegetation or species will place an even greater burden on ODOT operations and budget. Highways and other transportation corridors can act as pathways for the spread of invasive and non-native species. While ODOT cannot make sure that every vehicle that passes along its highways does not become a conduit for the spread of invasive species, the agency can take steps to ensure its equipment (mowers, boom trucks, etc.) do not contribute to the spread of invasive species around Oregon.

There is the possibility that more species will become classified as threatened or endangered because of shifting habitats and other issues. As part of ODOT's mission, the agency is committed to the protection and preservation of Oregon's environment while meeting applicable environmental laws and regulations, including the Endangered Species Act (ESA). ODOT must continually ensure its projects comply with the ESA since a majority of the agency's projects have a federal connection, whether in funding, permits, or because they occur on federal property. An increase in listed species or a shift in the habitat of listed species will impact the way ODOT does business into the future and it may increase the cost and time needed for project permitting and approval.

Examples of ODOT's Adaptive Capacity

ODOT is taking adaptive measures to accommodate the migrating and habitat patterns of wildlife species, while still protecting the integrity of its structures and the safety of the travelling public. A few examples of such adaptive measures are:

- *Bat Boxes* – Bridge designers worked with biologists and regulatory agencies to develop guidance for providing proper bat habitat for new and rehabilitated bridges.
- *Fish Passage Regulation* – The current fish passage regulations require larger culverts and bridges to allow for unrestricted movement of fish; this may serve a dual purpose for climate change adaptation and accommodating greater water flows.

Collisions with wildlife present a major safety risk on Oregon highways. As vegetation and wildlife species shift, so too might the migration patterns of animal species. In response to these changing patterns the current rate of animal and vehicle collisions may change. Shifting species and habitats will be a public safety issue for those using the transportation system. Shifting species are also a concern for ODOT project development, as the agency works to maintain habitat connectivity throughout Oregon during construction and after project completion.

ODOT's storm water systems include both built, engineered treatment facilities, and non-engineered systems. Non-engineered systems include vegetation systems along roadways that treat runoff. As Oregon's climate changes, vegetation options that are currently used in these storm water systems may no longer be an option because the plants can no longer grow in the climate. Conversely, in places like eastern Oregon vegetated storm water systems may be used more often due to certain changes in climate. ODOT is in a good position to adapt to these types of shifts because the agency already uses different storm water strategies in the various climatic regions represented in Oregon. The biggest issue is to recognize when the shifts in vegetation species will occur and properly plan and manage the storm water and other drainage systems according to these shifts.

Finally, the pattern, location, and size of wetlands will likely change; for example wetlands that depend on snowmelt are projected to diminish or disappear due to an increase in average air temperature.[46] ODOT owns and manages many wetlands and wetland mitigation banks. Wetland mitigation is required both by the Oregon Department of State Lands (DSL) and the U.S. Army Corps of Engineers. Currently the permitting process for these mitigation sites does not acknowledge climate change impacts or that wetland sites will probably change in the future because of climate change. Future highway projects may face very different environmental mitigation requirements than they do today.[47]

Potential Actions for Adaptation

- *Address climate change impacts in ODOT Vegetation Management Plans* – Document and research trends in how vegetation species may shift and incorporate this knowledge into the Vegetation Management Plans.
- *Develop wetland mitigation bank site permitting guidance on acknowledging climate change impacts* – Partner with the responsible regulatory agencies to determine how climate change will impact the wetland mitigation banks across the state, and the course of action for future mitigation bank permitting guidance.

Vulnerability and Risk Assessment:

There are a few key assessments or actions that ODOT, in consultation with other key partners, can conduct to help pinpoint vulnerable and high risk areas:

- Inventory of vegetated storm water systems and wetland mitigation sites.
- Condition assessment of wetland mitigation sites.
- Assessment of existing wildlife corridors and migration patterns.

Current State Agency Actions:

- The Oregon Department of Forestry (ODF) is developing an inventory of current forest tree and other plant species distributions. This will provide a baseline for monitoring potential changes in species geography.
- The Oregon Invasive Species Council (OISC) conducts an effort to keep invasive species out of Oregon and to eliminate, reduce, or mitigate the impacts of invasive species already established in Oregon. The council helps address gaps in authority to deal with certain invasive species.[48]
- OWEB provides grant funding for priority weed, invasive species and pest treatment programs.

Elk near I-84, picture courtesy of ODOT

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46 Mark A. Hixon, et al. "Oregon's Fish and Wildlife in a Changing Climate", Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, 280. <http://www.occri.net/>

47 Michael D. Meyer; Adjo Amekudzi; and John Patrick O'Har, Transportation Asset Management Systems and Climate Change: An Adaptive Systems Management Approach (2009), Submitted to the Transportation Research Board (TRB), 4.

48 Find out more information about the Oregon Invasive Species Council at: <https://www.oregoninvasivespeciescouncil.org/>

4.2.2 Wildfires

Known Vulnerabilities:

Considering the ODOT Districts with a history of wildfires, all have reported that wildfires have become more frequent and more intense in the last few years. The regional forest area burned is estimated to increase between 180 and 300 percent by the end of the century.[49] The biggest consequence of wildfires for the transportation sector is road closures and thus the disruption in mobility of people, goods, and services, either because the road is directly in the path of the fire, or because fire crews are using the roadway for a staging and dispatch area.

* Expected increase in wildfire activity in all major forest types.
* Regional forest area burned is estimated to increase between 180 and 300% by the end of the century.

Wildfires lead to erosion problems near ODOT's infrastructure, specifically when all of the trees and other vegetation, that stabilize the surrounding soil, are burned. These burned areas are also more susceptible to debris flows and landslides because there is no longer live vegetation to hold the slope in place. Damaged trees left standing pose a threat to traffic mobility and safety because they are likely to fall across the roadway at unexpected times after a wildfire. Trees weakened by fire have a higher vulnerability to insect attacks and disease, which further weakens the trees and increases the risk of them falling across the highway. Smoke from wildfires can reduce visibility and cause safety issues for drivers. In some cases, this may lead to secondary incidences like crashes or slower driving that impact the flow of the system and pose a safety risk for drivers. Finally, the heat from more intense and frequent fires may impact the integrity of pavement and other structures, although more research is needed to determine the impact of extreme heat on structures.

ODOT does not have a large role in actively fighting wildfires; however the transportation sector is significantly impacted during such events. Improvements in communication and coordination with other local, state, and federal agencies will help minimize impacts to transportation corridors. Additionally, developing partnerships on tree and vegetation management practices to reduce wildfire vulnerability and risk along highways may decrease impacts into the future.

Potential Actions for Adaptation

* *Research heat impacts on infrastructure* – Investigate how the heat from more frequent and intense wildfires impacts transportation structures.
* *Develop mitigation and stabilization plans for slopes and road bases* – Identify areas that are both vulnerable to slide activity and are located in the wildfire prone or vulnerable areas. Plan and develop guidelines for conducting assessments of slopes immediately following a wildfire event.
* *Implement more aggressive forest and vegetation management* – More aggressive forest management is needed to reduce fuel next to the highway or other critical transportation routes.

Vulnerability and Risk Assessment:

There are a few key assessments or actions that ODOT, in consultation with other key partners, can conduct to help pinpoint vulnerable and high risk areas:

- Assess capacity of mapping of wildfire hazards and vulnerable areas.
- Inventory infrastructure that is located in vulnerable wildfire areas.
- Inventory transportation infrastructure impacted by past wildfires.
- Assess critical freight and lifeline routes –
    - How have these critical routes been impacted by past wildfires?
    - Are more of these routes projected to be impacted by an increase in incidence of wildfires?

49 Executive Summary, Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR. <http://www.occri.net/>

Current State and Federal Agency Actions:

- Wildfire Risk Explorer, a web-based resource housed by the Natural Resources Digital Library at Oregon State University, is a site which provides state agencies and the public with an array of maps and information about wildfires in Oregon.[50]
- ODF maintains fire detection and suppression capabilities and a forest health monitoring and mapping program; administers the Oregon Smoke Management Program to manage prescribed burning on forestland; and manages forest thinning on state and private forestlands for fuels management and ecosystem health.
- ODF is incorporating adaptation to climate change in the new Forestry Program for Oregon.
- The US Forest Service's Burned Area Emergency Rehabilitation (BAER) program sends a survey team to do an initial assessment of burn severity and to estimate the likely future downstream impacts due to flooding, landslides, and soil erosion. The BAER objectives are:
    - Determine if emergency resource or human health and safety conditions exist.
    - Alleviate emergency conditions to help stabilize soil, control water, sediment and debris movement; prevent impairment of ecosystems; mitigate significant threats to health, safety, life, property and downstream values at risk.
    - Monitor the implementation and effectiveness of emergency treatments.[51]

Example of Wildfire Impacts on ODOT

On August 29, 2011 wildfires caused the closure of segments of U.S. Highway 26, 197, and 97, all at the same time. While ODOT staff did a great job in communicating to the public about alternative routes, assisting travelers on the highways and keeping traffic moving, if these types of events were to increase or occur for longer durations, a significant burden would be placed on ODOT operations. These types of disruptions affect Oregon's economy by impacting freight, the movement of other goods and services, and basic travel around the state.

Shadow Lake Fire , picture courtesy of ODOT

50 Find more information on the Wildfire Risk Explorer at: <http://oregonexplorer.info/topics/wildfire-risk?ptopic=62>

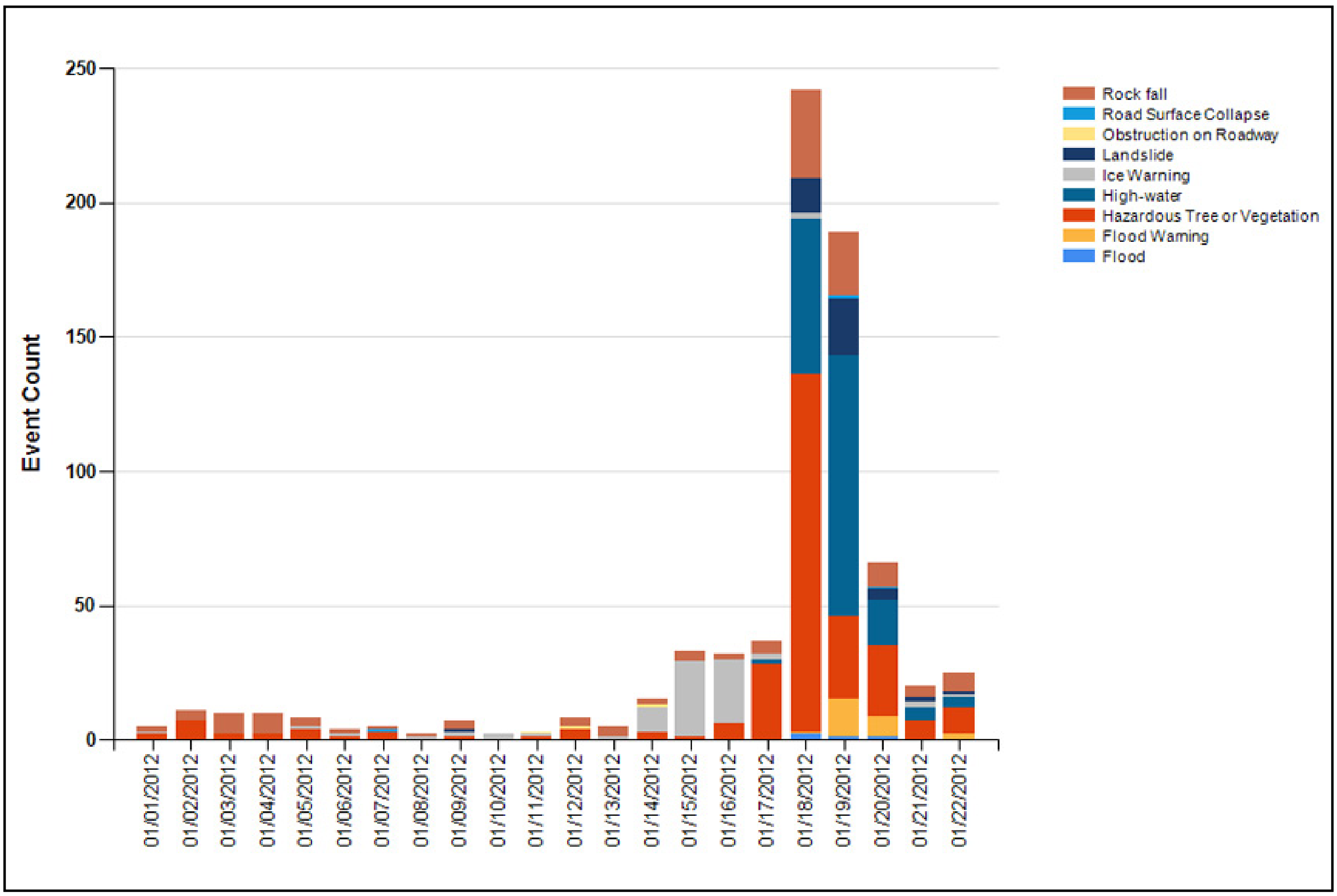
51 Find more information on the US Forest Service BAER Program at: <https://www.fs.usda.gov/r1>

4.3 Storm Intensity

Storm intensity is an ambiguous term, but for the purposes of this Strategy and relating directly to ODOT operations and experience, storm intensity refers to two specific types of impacts. First, storm intensity refers to the potential increase in incidence of extreme events like windstorms, ice storms, extreme daily precipitation events, or FEMA disaster declarations. For example, in January 2012, a series of strong storms hit Oregon. During this storm, Cape Foulweather, near Depoe Bay, experienced 110-mile-per-hour winds; Yachats received nine inches of rain in less than 24 hours; while Mt. Bachelor saw more than 35 inches of snow in that same period. Additionally, rivers, creeks, and streams across western Oregon rose above flood stage and many parts of the highways in eastern Oregon were covered in ice. While this does not prove that climate change is causing these severe storm events, it may illustrate that the number of large storm, flooding, and snow events are increasing.

Second, storm intensity refers to the impacts from hazard trees in the ROW falling on roadways and pulling down power lines during some of these extreme storm events or other hazardous conditions that affect the highways. Severe storms are not a new phenomenon in Oregon, but climate change will likely lead to an increase in incidence of these extreme storms, thus it is important that ODOT develop strategies to be prepared for that increase. More details about storm impacts like flooding and landslides will be covered in subsequent sections of the Strategy.

Figure 3: Statewide Summary by Type of Event (January 1st - 22nd, 2012)



4.3.1 Extreme Storm Events

Known Vulnerabilities:

Extreme storm events occur in all regions of Oregon and have a tremendous impact on the transportation sector. Storms such as ice, wind, snow, and rain impact both the mobility of traffic and freight across the state, but also can severely damage infrastructure. These types of storms also increase the risk of landslides and rockfalls, flooding, and erosion. While storms are not necessarily caused by climate change, Oregon may experience more frequent and intense weather events due to a variable and changing climate. These types of events cause road closures, as seen in December 2007, when all roads to the northern coast were closed because of weather-related hazards, isolating cities from Tillamook to Astoria. Also view the graph which illustrates the number of events ODOT responded to in the first three weeks of January 2012 (Figure 3). On one day alone, ODOT responded to 250 weather-related events across the state, this number does not include the more common traffic incidence responses.

✴ Incidence of extreme events may increase due to climate change.

It is ODOT's mission to provide a safe and efficient transportation system, but storm events put extra stress on ODOT's resources and personnel. Severe storms and weather can disrupt and close transportation corridors around the state. While ODOT is extremely proficient at responding to storm events and keeping transportation corridors open, responding to extreme, emergency events diverts resources from the routine maintenance needs across the state and climate change may just add to the need for these resources. Storm events will continue to impact Oregon, but adaptation strategies are important mechanisms to ensure transportation corridors stay open and safe for the travelling public.

In addition to a potential increase in storm events, preparing for other extreme events such as earthquakes and tsunamis is important for ODOT. While current research does not explicitly link climate change with more frequent earthquakes and tsunamis, these are hazards in Oregon, and adaptation planning and hazard mitigation preparation are mutually beneficial planning exercises.

Potential Actions for Adaptation

✴ *Continue to implement a strong Emergency Response Program* – A strong emergency response program will assist the agency in better dealing with the impacts of climate change. Technical guidance and training for making rapid permanent repairs will allow crews to get back to maintaining the whole highway system.

✴ *Coordinate with Oregon Emergency Management (OEM) and Hazard Mitigation* – Work with OEM, the State Interagency Hazard Mitigation Team (IHMT), and the Oregon Partnership for Disaster Resilience with state and local hazard mitigation and preparedness plans, including planning for tsunamis and earthquakes.

Vulnerability and Risk Assessment:

There are a few key assessments or actions that ODOT, in consultation with other key partners, can conduct to help pinpoint vulnerable and high risk areas:

- Assess how and to what extent certain infrastructure is impacted by extreme storms.
- Assess the capacity of emergency response teams on a regional basis; are there regions or districts that need more help and/or resources for their emergency response teams?
- Assess critical freight and lifeline routes that are impacted by extreme storm events:
    - How often do these routes get closed? How long are they typically closed during these events?
    - What are the yearly maintenance expenses for repairing these routes after major storms?

4.3.2 Hazard Trees

Known Vulnerabilities:

As a result of these more intense storms, particularly from the Willamette Valley to the coast, trees are blown down, fall over roadways and often pull down power lines. Another contributing factor to these hazard trees is saturated soils, meaning increased rainstorms in combination with high winds will increase the likelihood of trees falling in the ROW and on roads. Fallen trees block traffic on major highways, cutting off the delivery of resources and in many cases electricity to towns for days. These falling trees pose a significant safety risk to ODOT maintenance crews and the public. ODOT, in consultation with other state and local agencies, including the Oregon Public Utility Commission (OPUC), must coordinate emergency response activities to open the highways for traffic and power line repair.

- ✴ Storm events including wind storms and winter storms that knock trees across roadways will potentially become more intense and frequent in Oregon.

Tree corridor management practices such as wind hardening and hazard tree assessment and removal programs are becoming more common around the ODOT Districts. Tree corridor management is important because trees lining Oregon's roadways are vulnerable during storm events. In addition to identifying and removing these hazard trees, crews have begun to plant Western Red Cedars because they are more wind resistant and less susceptible to disease, which makes them less vulnerable than the Douglas Firs, which are currently lining the roadways.

Potential Actions for Adaptation

- ✴ *Continue to implement the Highway Division Maintenance Leadership Team Operational Notice for Prioritization of Hazard Tree Removal/ Tree Corridor Plans and Vegetation Management Plans* – Create corridor tree plans to prioritize stretches of highway with tree issues and minimize risk of hazard trees through tree risk assessments, hazard tree evaluation, planning, inventory, and management plans.

Examples of ODOT's Adaptive Capacity

ODOT is working with the Parks and Recreation Department to allow a contractor to remove fallen trees and those trees deemed a threat to traffic on the highway in the Van Duzer State Scenic Corridor, between Grand Ronde and the coast. The trees will be donated or sold by the Parks Department to improve aquatic habitats elsewhere in the state.

Storm events put significant stress on trees. Many trees may bend over the road under the stress of wind or ice, but not actually break. This causes significant damage to the trees that is not easily detected by the untrained eye. Then come mid-summer or on a calm day these trees may fall onto roads and cars.

Vulnerability and Risk Assessment:

There are a few key assessments or actions that ODOT, in consultation with other key partners, can conduct to help pinpoint vulnerable and high risk areas:

- Identify the most vulnerable corridors in terms of hazard trees that impact roadways.
- Assess and prioritize vulnerable hazard tree corridors which intersect with the identified critical freight and lifeline routes.

Example of Increased Pests in Oregon

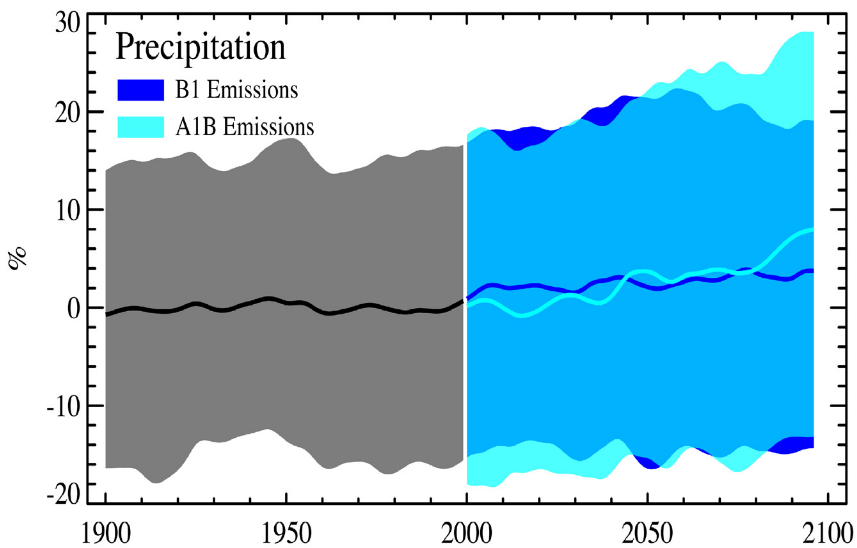
An increase in air temperature will contribute to more pests, specifically the Mountain Pine Beetle. This beetle is already causing damage in Oregon's forests. Rot, diseases, and invasive insects weaken and kill trees, making the trees even more vulnerable to wildfire or falling across roadways causing damage and mobility impacts.

4.4 Changes in Precipitation

Changes in *annual* precipitation are extremely uncertain; nevertheless there is some degree of certainty around the potential *seasonal* changes in precipitation, as well as some indication that extreme daily precipitation events will increase in the 21st century.[52] An increase in intense precipitation events will have profound impacts on the transportation infrastructure and system in Oregon. Flooding events close major roadways and can cause significant damage to pavement and bridge structures. Variations in soil moisture levels can affect the structural integrity of roads, bridges, tunnels, and other infrastructure. Additionally, standing water on the roadway is hazardous to drivers and to the pavement structures. These are just a few of the impacts that changes in precipitation patterns will have on the transportation sector in Oregon. The following sections will give further detail into the impacts of increases in flood events, seasonal flow rate changes, and incidences of landslides.

- Seasonal precipitation is expected to change in Oregon.
- Summer precipitation is projected to decrease, while winter precipitation is likely to increase.
- No clear trends in annual precipitation in Oregon.

Figure 4:



This figure shows the trends in precipitation based on the two emissions scenarios in the IPCC. As shown, trends in annual precipitation are not very clear, although the simulations show a slight increase in average annual precipitation in the Pacific Northwest. There are much clearer trends in seasonal precipitation, with summer precipitation projected to decrease and winter precipitation to increase. From Mote and Salathé (2010).

4.4.1 Flooding

Known Vulnerabilities:

Floods are common throughout many regions of Oregon and many areas have an extensive history of flooding. Flood events cause traffic delays and disruptions and in some cases, cause the complete closure of a highway. River flooding can cause bridge foundation instability due to scour. ODOT's maintenance personnel monitor these scour critical bridges, especially in times of heavy precipitation events.

- Extreme daily precipitation events may increase in intensity and frequency which will lead to more flooding.
- Warmer winters will lead to more precipitation falling as rain and more rapid snow melt, leading to flooding.

ODOT developed, and is now testing, a bridge alerts database. The database will monitor flooding conditions and send automatic notifications of potentially hazardous conditions to maintenance personnel. An action plan is being developed for each scour critical bridge that will specify detailed actions for ODOT to carry out once an alert is sent.

52 Legislative Summary, Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR. <http://www.occri.net/>

More intense precipitation events will have an impact on ODOT's drainage facilities including culverts and storm water systems. There are thousands of culverts across the state, many of which are nearing the end of their lifespan or are not sufficient for water flow even under current conditions. There are areas where maintenance crews have to unclog the culverts on a regular basis. An increase in intense precipitation events will likely lead to more impacts to these culverts and causing road washouts, flooding, and even more damage to the culvert.

Example of ODOT's Adaptive Capacity

- The existing near real time rain and flood monitoring stations are presently being used by the bridge alerts database to automatically notify maintenance personnel of pre-determined conditions that can cause bridge instability. The system is being tested in Regions 3 and 5 and will be expanded to the rest of the state as experience is gained on how best to monitor each bridge and what actions are needed when flooding events occur.
- Inventorying culvert assets, including condition, size, and location is extremely important. In addition to this asset inventory, Regions are asked to prioritize culverts in need of rehabilitation or replacement. Region 2 has developed culvert prioritization criteria which includes aspects such as risk of catastrophic failure, culvert condition, maintenance frequency, maintenance difficulty, traffic volume, and risk to public safety, among other things. Funding and resources are always an issue for repair and replacement of culverts; however, a prioritization process and full inventory of assets help focus resources when available.

Additionally, the increase in extreme precipitation events has the potential to inundate Oregon's storm water infrastructure, which will cause damage to the infrastructure and potentially cause serious water quality issues. If the current capacity of the storm water system cannot accommodate an increase in water then facilities will be overrun and will not be able to treat all of the water. This means that toxins will remain in the water as it returns to fresh bodies of water such as rivers and streams and as it soaks into the soil. Moreover, if facilities are overwhelmed with water the facilities might suffer damage, which again will impact the environment. This will place a financial burden on ODOT, because maintenance crews now must spend time and money to fix these damaged facilities. ODOT is responsible to treat all runoff from its roadways; therefore more flooding will create more runoff that ODOT must treat.

According to a case study of Portland, Oregon, nuisance flooding is likely to become more common at road cross-sections that have a history of chronic flooding because climate change will likely bring more frequent storm events with a return period of less than 25 years.[53]

ODOT has some adaptive capacity in certain areas regarding fish passage. For example, ODOT builds larger culverts or replaces culverts with bridges to allow for unrestricted movement of fish in Oregon. Due to this program, the re-sizing of the culverts may serve a dual purpose of being able to handle increases in flows during extreme precipitation events.

Potential Actions for Adaptation

- *Armor of critical areas and infrastructure* – Designate critical roadways (areas) and infrastructure for armoring. Not all roadways or infrastructure near waterways need heavy armoring; however there are critical corridors around the state that are habitually being damaged and closed. Develop the criteria and guidelines for determining these critical areas.
- *Continue ODOT's Drainage Facilities Management System database (DFMS) and culvert management* – ODOT embarked on a comprehensive program to inventory and assess the condition of culverts located along the state's highways. The goal of this effort is to set a consistent statewide standard for inventorying and rating culverts, as well as uploading this information into ODOT's DFMS database.

53 Heejun Chang, et al. "Climate Changes and Freshwater Resources in Oregon", Oregon Climate Change Research Institute (2010), Oregon Climate Assessment Report, K.D. Dello and P.W. Mote (eds). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, 95. <http://www.occri.net/>

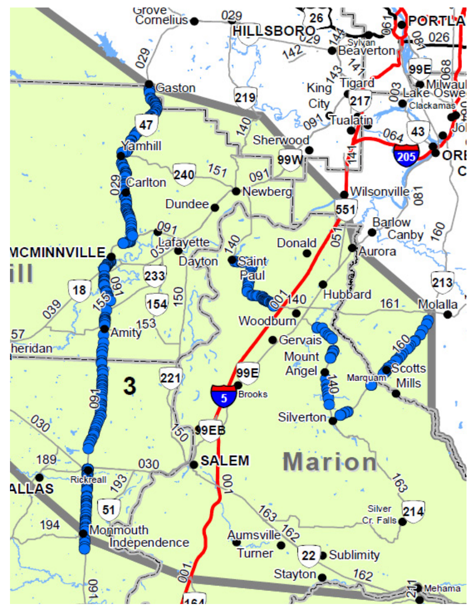
New bridges are typically both longer and wider than the bridges they replaced. While the increased length can increase the hydraulic opening and thus allow the bridge to perform better during an extreme precipitation event or snow melt, this can be offset by limitations to protecting the bridge foundations due to meeting environmental performance standards. Modern bridges typically have more extensive foundations due to changes in both hydraulic and seismic design standards. The combination of increased bridge size and modern design standards greatly increases the cost of bridge construction. The result is that many of the bridges that are currently vulnerable to floods will remain in service for many years to come. On the other hand, bridges that are being built now and within the last few years are most likely built to a standard where increases in water levels due to flooding will not severely impact the structure.

Vulnerability and Risk Assessment:

There are a few key assessments or actions that ODOT, in consultation with other key partners, can conduct to help pinpoint vulnerable and high risk areas:

- Continue to identify and inventory the location and assess capacity of culverts and storm water systems (both engineered and non-engineered systems) across the state.
    - These assessments will include overall condition and serviceability of systems and areas around the system: condition of soil, embankments, vegetation, stream, and channel associated with the drainage system; as well as information surrounding issues such as fish passage, hydraulic adequacy, route importance, and other construction and maintenance activities planned for the highway.
- Assess capacity and accuracy of Oregon flood maps.
- Inventory infrastructure that is habitually impacted by flooding.
- Track maintenance and repairs on infrastructure when damage was caused by flooding.
- Assess the capacity of bridges; how will flooding impact the bridge structure and how much water can flow under the bridge?
- Assess likely future flood conditions and relative risk in areas where development and infrastructure improvements are likely to occur.
- Assess how flooding events have impacted critical freight and lifeline routes, and how a potential increase in flooding events might impact these routes in the future.

Figure 5:



Snapshot of completed culvert inventory along 99W.

Current State Agency Actions:

- ODOT has automatic flood warning systems at Seaside and Cushman to warn the public of flooding hazards and has developed and is testing a database to automatically notify maintenance personnel of potential hazardous conditions occurring at bridges throughout the state.
- DLCD provides technical and financial assistance to implement FEMA's National Flood Insurance Program (NFIP), and provides technical and financial assistance to local communities as requested to conduct planning for areas subject to natural hazards, including hazards related to climate. DLCD is also completing FEMA's map modernization program for Oregon communities participating in the NFIP, and is developing a five-year scope of work and plan to implement FEMA's new RiskMap program.
- DOGAMI is re-delineating flood hazards for FEMA in selected counties using high-resolution LiDAR elevation data, and developing protocols for modeling varying flood discharges using USGS StreamStats data and ArcGeoRas software.
- DSL issues permits for stream bank stabilization and erosion control to protect property from damaging floods.

4.4.2 Changes in Seasonal Flow Rates

Known Vulnerabilities:

Warmer winter temperatures mean that more precipitation will likely fall as rain instead of snow and existing snowpack will probably melt earlier. This along with other impacts of climate change will result in greater volatility in streamflows that will impact inland waterway travel and barge movement. Transportation on rivers is impacted by high water and low water, so barge flow may be disrupted both in the winter when streamflows are predicted to be full with more winter rain and snow melt and in the summer when streamflows will be lower due to decreased precipitation and the earlier snow melt. Periodic channel closings or restrictions may occur during flooding events and low water events. Higher water levels also restrict boat movement because of limited clearance under bridges. Changes in silt deposition may lead to reduced depth of channels in some inland waterways, thus impacting the possible long-term viability of some inland navigation routes.

- ✴ Snow cover may melt earlier in the year, leading to higher spring flows and lower late summer flows.
- ✴ Climate change may result in greater volatility in streamflows.

Stream or river morphology describes the shape of a river channel and how the channel changes over time. The morphology of a river channel is a function of a number of processes and environmental conditions, including the flow rates, composition and the amount of erosion of the riverbed and riverbanks, vegetation and the rate of plant growth along the river, the availability of sediment, the size and composition of the sediment moving through the channel, and other environmental conditions. While change in river morphology is not exclusively related to climate change, it is a critical issue for ODOT. Meandering rivers and streams have the potential to significantly impact roadways, bridges, and other transportation infrastructure that lie in the river's changing path.

Vulnerability and Risk Assessment:

There are a few key assessments or actions that ODOT, in consultation with other key partners, can conduct to help pinpoint vulnerable and high risk areas:

- Track and inventory road and infrastructure washout spots.
- Assess how washout events have impacted freight and lifeline routs.

Current State Agency Actions:

- Integrated Water Resources Strategy (IWRS) – The Oregon Water Resources Department (OWRD), in consultation with other state agencies, is tasked with developing the IWRS. The IWRS is a roadmap for the state to follow as it prepares to meet Oregon's water needs now and in the future, for both in-stream and out-of-stream uses from surface water and groundwater.[54]

Potential Actions for Adaptation

- ✴ *Establish a network of monitoring stations* – Partner with other agencies to increase the number of monitoring stations and stream gauges. The faster ODOT crews know what is happening, the better they can protect the public and infrastructure by shifting the appropriate resources.

54 Find more information about IWRS at: <https://www.oregon.gov/owrd/pages/law/integrated_water_supply_strategy.aspx>

4.4.3 Landslides and Rockfalls

Known Vulnerabilities:

Landslides are one of Oregon's most costly natural hazards, with damages exceeding $100 million statewide some years.[55] Slopes, embankments, and drainage systems are deteriorating on many of the Oregon State highways and will result in an increase in landslides and rockfalls. Currently landslides and rockfalls affect approximately 497 centerline miles of Oregon State Highway.[56]

- More intense precipitation events have the potential to cause more landslides.
- Altered slopes like those formed by transportation infrastructure are more susceptible to landslides.

Landslides vary in size and are typically a function of geology, slope, soil and rock strength, and surface or groundwater, in addition to a triggering mechanism. Landslides and rockfalls are caused by many different triggering mechanisms, including extreme weather and precipitation events, sea level rise, erosion, higher groundwater levels, and earthquakes.

One of the biggest drivers of landslides is groundwater; the more water in the ground, the higher the likelihood of a landslide. Where climate models show an increase in annual rainfall, it can be expected that these areas will also have a higher groundwater surface level. With an already elevated groundwater level in the winter months, as is the case in many areas in western Oregon, it will take smaller rainfall events to trigger more landslide movement. Increased rainfall means that the normal slides ODOT deals with will get worse (increase in size, rate, and movement magnitude), but there will also be an increase in incidence of new slides around the state.[57]

Rockfalls are another type of landslide, which primarily occur in the eastern side of the state. Rockfalls are a significant risk on the highway system, causing 21 fatalities since 1993 (non-rockfall landslides have only caused three fatalities in that same time). It typically only takes a small volume of water to trigger a rockfall; consequently any increase in precipitation will correspond to an increase in rockfalls. There are areas around the state where every rain event is accompanied by rockfall; therefore an increase in precipitation events will increase the number and magnitude of rockfalls.[58]

In Oregon, slopes that are steeper than 70 percent have a risk of rapidly moving landslide activity regardless of geologic unit.[59] According to the USGS, altered slope areas such as those formed by roadcuts or other human infrastructure needs are more susceptible to debris flows and landslides. In fact, "road construction and grading for building sites and roads can cause landslides in locations which

Potential Actions for Adaptation

- *Continue ODOT's Unstable Slopes Program* – The purpose of the Unstable Slopes Program is to inventory and rate all landslides, rockfalls, and other types of unstable slopes affecting the State's highway infrastructure. Consider climate change as a factor in rating and prioritizing landslide areas.
- *Develop design and engineering standards and guidance* – Develop further standards for slopes near new and repaired infrastructure, in order to mitigate vulnerability to future landslides.

55 Vicki S. McConnell, "New maps reveal landslides using laser based imaging: New technology is helping state geologists create some of the most accurate landslide inventory maps in the world", Oregon Department of Geology and Mineral Industries, News Release: April 20, 2009. <https://www.oregongeology.org/ >

56 "Landslide and Rockfall Program: 2012-2015 State Transportation Improvement Program Report", Oregon Department of Transportation, ODOT.

57 Information provided by Curran E. Mohney, ODOT Engineering Geology Program Leader

58 Ibid.

59 "Landslide and Debris Flow Chapter", State of Oregon Natural Hazards Mitigation Plan (2009), prepared by the State Interagency Hazard Mitigation Team, LS-2. <https://opdr.uoregon.edu/>

otherwise would not have experienced landslides."[60] Roadways, blocked culverts, and poorly managed storm water facilities all lead to altering surface and/or groundwater flows, which increases the potential of landslides.

According to the ODOT Landslide and Rockfall Program, the cost to repair the existing high priority sites is estimated at $592 million, while the estimated cost to repair the Immediate Need sites is approximately $185 million. Currently, the Landslide and Rockfall Program is falling behind its goals, meaning significant hazards and roadway damage remain unmitigated due to insufficient funding to repair the problems. Historic averages indicate that ODOT can expect an approximate four percent increase in the number of slide and rockfall problems each year while it typically only repairs two percent of the high priority sites.[61]

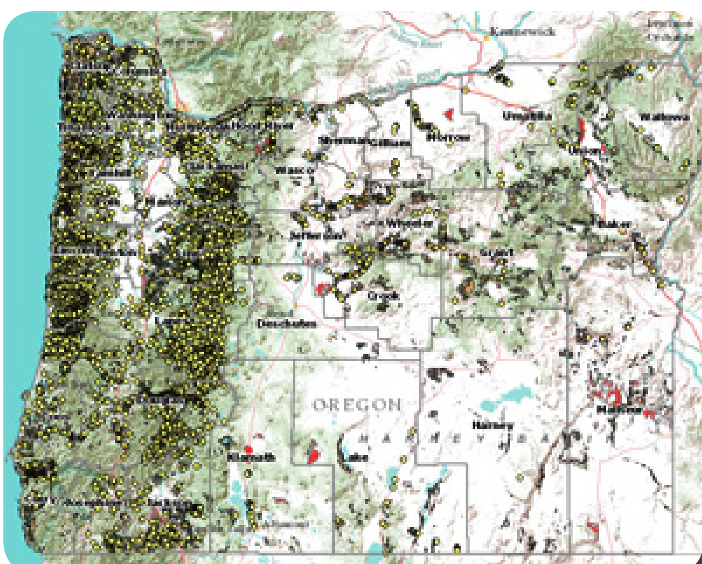
Picture Courtesy of ODOT

Landslides often close highways or restrict lane use for many weeks or months, which has a significant impact on freight mobility. These delays in freight movement impact overall state commerce and the economic livelihoods of local communities, who are sometimes completely cut off due to landslide road closures.

Vulnerability and Risk Assessment:
There are a few key assessments or actions that ODOT, in consultation with other key partners, can conduct to help pinpoint vulnerable and high risk areas:
- Inventory infrastructure and corridors that have been damaged by past landslides.
- Continue assessment of landslide hazards along critical freight and lifeline routes.

Current State Agency Actions:
- DOGAMI is conducting a landslide inventory for USGS and self-selected counties and cities using high-resolution LiDAR elevation data, and is developing a protocol for modeling landslide susceptibility.
- ODF is using LiDAR technology to map landslides in state forests.

Figure 6:



Statewide Landslide Information Database for Oregon (SLIDO- 2) is a compilation of landslides in Oregon that have been identified on published maps.
See more information on SLIDO

60 "Landslide and Debris Flow Chapter", State of Oregon Natural Hazards Mitigation Plan (2009), prepared by the State Interagency Hazard Mitigation Team, LS-4. < https://opdr.uoregon.edu/>
61 "Landslide and Rockfall Program: 2012-2015 State Transportation Improvement Program Report", Oregon Department of Transportation, ODOT.

4.5 Social Impacts

The social impacts addressed in this section can be more aptly described as secondary or indirect climate change impacts. Climate change effects like increased air temperature, changes in precipitation, and sea level rise have indirect impacts to Oregon's society. These impacts include a possible increase in population and changing demands on transportation modes and systems. Much more research and information is needed to identify all the possible indirect impacts to ODOT's management and operation of the transportation system; however the following sub-section addresses the impact of population movement, which is of great concern to transportation planners and others at ODOT.

4.5.1 Population Movement

Known Vulnerabilities:

Populations across the world are projected to shift and move due to the impacts of climate change. Some regions may become uninhabitable due to increasing temperatures, sea level rise, or even shifting agricultural productivity.

* Oregon's population is projected to increase 25%, in part due to net migration into the state.
* Social behavior like human migration is difficult to forecast.
* Increases in population will put more demand on transportation systems of all modes.

Oregon's population is expected to increase over 25 percent between 2010 and 2030, presenting new and continuing challenges for the transportation system.[62] Climate change impacts in the Pacific Northwest are projected to be relatively less severe than other areas of the country, and therefore the region will be more attractive to moving populations. Both rural and urban areas in the Pacific Northwest are likely to see an increase in population due in part to displacement because of climate change-related events. This type of trend is likely to accelerate the demand for all modes of transportation, including rail and public transit, as well as increase congestion and deterioration of road systems. ODOT's facilities are not currently equipped to meet the alternative transportation demands of a growing population. There is still much to learn and research about the possible impacts and projections of human population movement. ODOT will continue to research and monitor this issue to determine the impacts on the transportation system.

Photo courtesy of Jennifer R.

Assessments and Potential Strategies and Actions:

At this time there are no ODOT specific strategies for adapting to the potential of population increases and movement due to climate change beyond the identification of need for further research. Further research, monitoring, and discussion are the next steps in developing strategies in this area.

Photo courtesy of The Columbian

62 ODOT State of the System, Report 2010, Oregon Department of Transportation, Transportation Development Division. <https://www.oregon.gov/ODOT>

5. Next Steps

Although ODOT is able to identify a number of key vulnerabilities and risks, along with some potential adaptation actions or strategies, there is more work to be done. Specifically, a comprehensive vulnerability and risk assessment is needed to more clearly demonstrate and pinpoint the areas of higher climate impact risks. While ODOT does have a level of existing adaptive capacity and some existing programs where the consideration of climate change impacts can be easily integrated, this Strategy has identified some next steps in adaptation planning. These next steps include: performing further research; coordinating and collaborating with other agencies and local jurisdictions; and continuing to develop and implement adaptation strategies.

There is still a level of uncertainty about the specific impacts of climate, especially at the local level; however that does not mean that ODOT cannot or should not move ahead with adaptation. As more information and data are presented, ODOT will continue to use the most up-to-date science for its adaptation efforts and strategy implementation.

Form an ODOT Climate Change Adaptation Work Group:

Adaptation planning cannot occur in just one section of the agency. Due to the magnitude of potential issues caused by climate change, adaptation planning will require staff from across the agency to work together. The goal is to form a work group with ODOT staff with various expertises to work on issues such as conducting a vulnerability and risk assessment; developing prioritization criteria for strategies and actions; coordinating with regulatory partners; developing an outreach and communication plan; and identifying further research needs. This group will provide a forum for working out issues and direction as ODOT continues adaptation planning. The first and primary task of this work group will be to develop the framework for the climate change vulnerability and risk assessment and conduct this assessment for ODOT's assets and systems.

Conduct Vulnerability and Risk Assessments:

As discussed throughout the Strategy conducting a vulnerability and risk assessment of the ODOT controlled sections of the transportation system is the first step for adaptation planning. There are a number of ways these assessments may be performed, however, FHWA created a conceptual Risk Assessment Model[63] to help transportation decision makers identify which assets are most exposed or vulnerable to the threats from climate change.

An integrated risk assessment will jointly consider the likelihood that an asset will experience a particular climate impact, and the consequence of that impact on the surrounding region and community. This can include health and safety, economic, environmental, and cultural impacts. Understanding where the transportation system is vulnerable and at the highest risk to climate change will help ODOT prioritize the appropriate adaptation strategies and actions.

One of the main tasks of the ODOT Climate Change Adaptation Work Group will be to coordinate and conduct this vulnerability and risk assessment, which is projected to be completed during 2012. The vulnerability and risk assessment will be the foundation for much of the adaptation work at ODOT, and will allow the agency to take a strategic look at the transportation system and the risks the system, infrastructure, and operations face due to climate change.

As the agency works to improve efficiencies and maximize the use of limited resources, this assessment will allow ODOT to develop an adaptation plan that will help prioritize and implement strategies.

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63 *Assessing Vulnerability and Risk of Climate Change Effects on Transportation Infrastructure: Pilot of the Conceptual Model,* Federal Highway Administration, Figure 1, <https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/index.cfm>

Identify further research needs and data gaps:
Continued research is important for ODOT as it works to develop and implement the most effective and appropriate adaptation strategies. It will be important to engage the ODOT Research Unit and utilize other research initiatives in Oregon, like the Oregon Transportation Research and Education Consortium (OTREC), to conduct further research on the impacts of climate change and adaptation planning strategies. Other ongoing research from various research boards and organizations will provide ODOT with important information on climate science and transportation adaptation planning.

Monitoring:
Climate change and its impacts to the transportation sector will change over time. Implementing actual adaptation measures is just one part of the process. Data collection and monitoring are necessary to ensure that measures are still being effective and conditions have not changed. For example, if ODOT identifies and maps the erosion hot spots along the coast, conditions are likely to change over time, hence continual monitoring is an important step. Monitoring projects will allow for ODOT to gain important data and information.

Coordination and Collaboration with other agencies:
Climate change adaptation planning and implementation cannot be effective in a vacuum; instead all levels of government and all types of organizations and agencies need to coordinate and collaborate on adaptation responses. One important area for collaboration is with ODOT's regulatory partners and other jurisdictional partners. Since many of ODOT's projects are subject to various regulations, adaptation decisions cannot just be made by ODOT. ODOT and its regulatory partners will need to work together to develop and implement adaptation. An example of this is wetland mitigation banks. As discussed earlier, the pattern, location, and size of wetlands will likely change. Currently the permits on these banks do not account for these changes, meaning ODOT may fall out of compliance, due to circumstances beyond the agency's control. By working with the appropriate agencies, these sorts of conflicts can be resolved and effective, sustainable solutions can be found.

For ODOT, there are some climate impacts that can be addressed through collaboration with other state and local entities, rather than having to create new ODOT specific policies or programs. A great example of this is the work DOGAMI is doing on coastal hazard mapping; ODOT geologists, engineers, and planners can use the information DOGAMI is collecting, instead of developing a separate coastal inspection, or data collection program. Working with other agencies and organizations limits the duplication of adaptation research and work, thus allowing ODOT to focus its time and resources in the most effective manner and on the adaptation measures that are needed.

Additionally, collaboration with other state departments of transportation (DOTs) will provide ODOT with an important source of information. For example, ODOT, WSDOT, and California DOT (Caltrans) are working together to share information, experiences, and best management practices in the areas of climate change mitigation and adaptation. These types of partnerships will continue to be important as ODOT works on climate change and other issues.

Finally, collaboration and coordination with local governments and jurisdictions is an important aspect of adaptation planning. While this Strategy and the vulnerability and risk assessments primarily address ODOT assets and operations, the agency is keenly aware that local agencies and governments are facing many of the same impacts and might be impacted by how ODOT implements certain strategies. It is for those reasons that ODOT will continue to work with and coordinate as much as possible with local jurisdictions. Full adaptation of Oregon's transportation system will require partnerships and collaborations at all levels of government.

Communication and outreach:
In addition to developing strategies for adapting Oregon's transportation sector, one of ODOT's main responsibilities is to provide information to ODOT staff and the public about climate change, its impacts, and how to prepare for those impacts. Because the implementation of adaptation strategies will reach across ODOT divisions, internal communication is essential. Since Oregon is already experiencing the impacts of climate change, educating the public on how the transportation sector is preparing and adapting for the continued climate impacts is important. As it is ODOT's mission to provide a safe and efficient transportation system, public outreach will help demonstrate how various adaptation actions are achieving that mission and keeping people and goods moving along Oregon's highways.

6. Conclusion
Oregon's transportation system is vulnerable to the impacts of climate change. Given the observed and anticipated impacts to infrastructure and operations, prudent measures to adapt and prepare must be taken now by ODOT. This document outlines some of the basic strategies for adapting the transportation system and infrastructure to some of the potential impacts of climate change. More importantly, however, the Strategy highlights the need for ODOT to conduct a vulnerability and risk assessment prior to full scale strategy development and implementation. Adaptation actions do not need to wait for the completion of the assessment, but the assessment will inform a more strategic and efficient adaptation plan, which is essential for the agency. Climate change means that the future is not going to look like the past, and ODOT must develop policies, strategies, designs, and programs that will help the transportation decision-making process take into account this changing future.

ODOT is already taking some important next steps like convening an Adaptation Work Group to work on the climate change vulnerability and risk assessment, but there are other actions that ODOT employees can take that will help in the adaptation process. In fact many of the *Potential Actions for Adaptation* that are outlined in the salmon colored text boxes in this Strategy are actions that are already being undertaken by various divisions in ODOT. The actions simply need to be implemented in a more programmatic or uniform manner to better prepare the entire system. ODOT can make tremendous strides by refining existing programs to consider climate change impacts to more fully prepare the transportation system, while still using existing resources in an efficient and responsible manner to fulfill the mission of the agency.

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Appendix 1 - List of Acronyms

Caltrans – California Department of Transportation

DLCD – Department of Land Conservation and Development

DOGAMI – Oregon Department of Geology and Mineral Industries

DSL – Oregon Department of State Lands

FEMA – Federal Emergency Management Agency

GDP – Gross Domestic Product

IHMT – Oregon Interagency Hazard Mitigation Team

IPCC – Intergovernmental Panel on Climate Change

IWRS – Integrated Water Resource Strategy

LiDAR – Light Detection and Ranging

MPO – Metropolitan Planning Organization

NFIP – National Flood Insurance Program

OBSMAP – Oregon Beach and Shoreline Mapping and Analysis Program

OCAR – Oregon Climate Assessment Report

OCCRI – Oregon Climate Change Research Institute

OCMP – Oregon Coastal Management Program

ODF – Oregon Department of Forestry

ODOT – Oregon Department of Transportation

OECD – Organization for Economic Co-operation and Development

OEM – Oregon Emergency Management

OISC – Oregon Invasive Species Council

OPRD – Oregon Parks and Recreation Department

OPUC – Oregon Public Utilities Commission

OSTI – Oregon Sustainable Transportation Initiative

OTREC – Oregon Transportation Research and Education Consortium

OWEB – Oregon Watershed Enhancement Board

OWRD – Oregon Water Resources Department

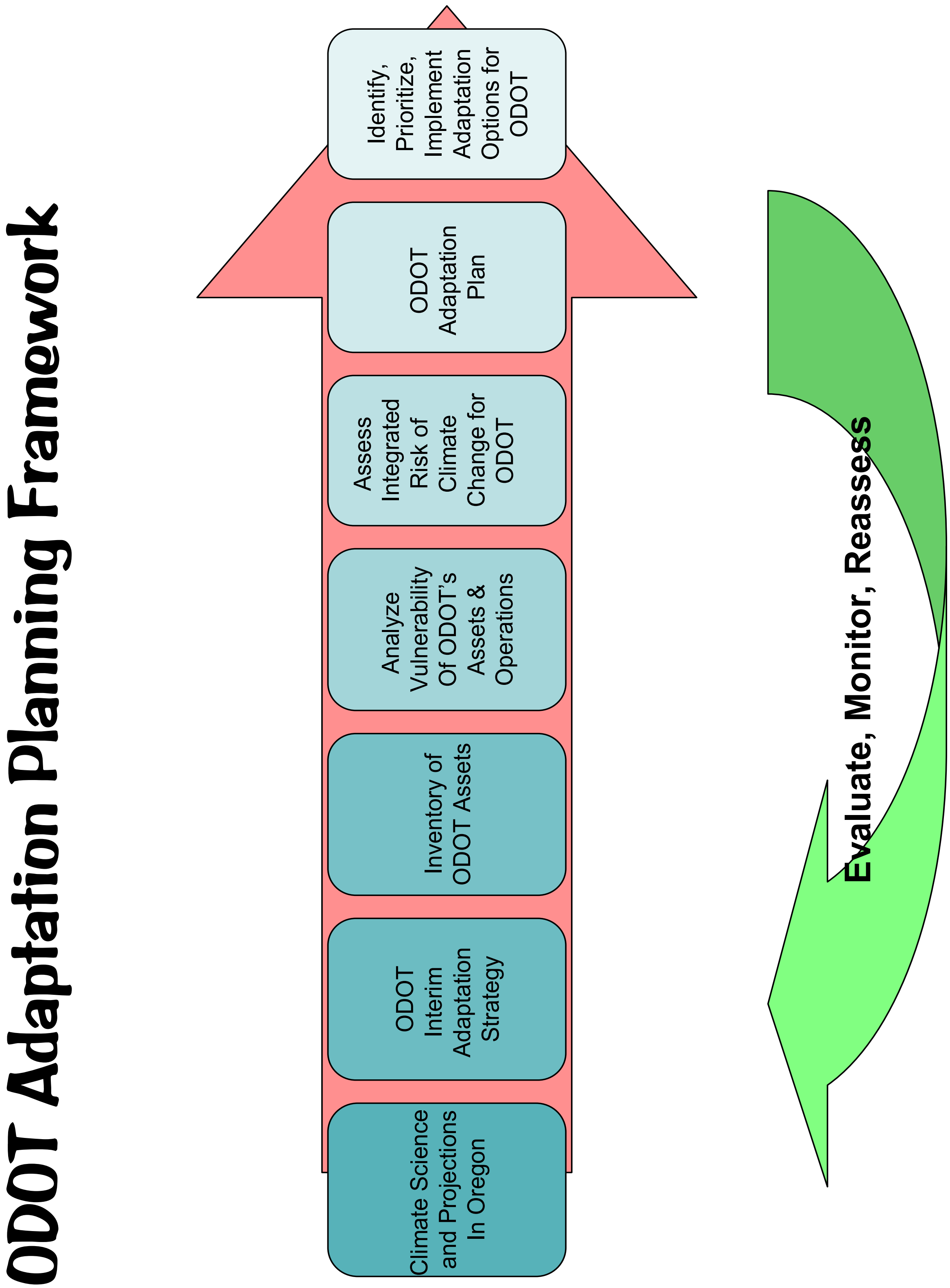
RHRS – Rockfall Hazard Rating System

ROW – Right-of-way

USGS – U.S. Geological Survey

WSDOT – Washington Department of Transportation

Appendix 2 - ODOT Adaptation Planning Framework



ODOT SUSTAINABILITY