2.2 State Risk Assessment

Requirement: 44 CFR §201.4(c)(2)(i): The risk assessment shall include… (i) An overview of the type and location of all natural hazards that can affect the State, including information on previous occurrences of hazard events, as well as the probability of future hazard events, using maps where appropriate;

The spatial distribution of the facilities within hazard zones is not easily viewed on a statewide map. Therefore, maps depicting hazard zones and facilities within those zones have only been created at the regional scale. Those maps can be found in section **2.3**, **Regional Risk Assessments**.

2.2.1 Coastal Hazards

The Pacific Northwest (PNW) coast of Oregon is without doubt one of the most dynamic coastal landscapes in North America, evident by its long sandy beaches, sheer coastal cliffs, dramatic headlands and vistas, and ultimately the power of the Pacific Ocean that serves to erode and change the shape of the coast. It is these qualities along with its various natural resources that have drawn people to live along its narrow shores. However, coastal communities are increasingly under threat from a variety of natural hazards that all come together along the coastal strip. These include wave-induced coastal erosion (both short and long term), wave runup and overtopping (wave-induced flood hazards), inundation of homes by wind-blown sand, coastal landslides, earthquakes, and potentially catastrophic tsunamis generated by the Cascadia Subduction Zone (CSZ). Over time, these hazards are gradually being compounded, in part due to the degree of development that has evolved along the Oregon coast in recent decades. A particular concern is that the local geology and geomorphology of the region have restricted development to low-lying areas, chiefly along dunes, barrier spits, or along coastal bluffs present along the open coast that are subject to varying rates of erosion, and to low-lying areas adjacent to the numerous estuaries that make up the coast. All of these sites are highly susceptible to increased impacts as erosion processes and flood hazards intensify, driven by rising sea level and increased storminess.

Figure 2-29. Erosion at The Capes Condominiums, Oceanside, Oregon

Notes: The Capes, a multi-million dollar condominium complex constructed on an old Holocene dune field adjacent to Oceanside. Due to erosion of the sand at the toe of the bluff during the 1997-98 El Niño winter, the bluff face began to fail threatening several of the homes built nearest the bluff edge.

Source: DOGAMI

Beaches and coastal bluffs are some of the most dynamic landforms, responding to a myriad of variables. Both landforms are constantly changing (at varying time scales) as they respond to changes in the ocean processes (waves, nearshore currents and tides) that affect the beach and toe of the bluff as well as those sub-aerial processes (rainfall, sun, wind) that directly affect coastal bluffs. There are many dangers inherent in living on the coast. While coastal bluffs gradually erode over the long-term, they can also respond very rapidly, at times sliding away (in a matter of minutes to a few hours) so that homes and sections of highways are damaged or destroyed (Figure 2-30A). Beaches are especially dynamic features, as sand is constantly shifted about. This is especially noticeable in major storms, with the shoreline retreating rapidly, periodically destroying homes built too close to the sea. At other times, large quantities of sand migrate back onto beaches, burying homes built atop coastal dunes (Figure 2-30B). There is no location on the Oregon coast that is immune to coastal hazards.

Figure 2-30. A) Emergency Riprap Being Placed in Front of a Home at Gleneden Beach, Following a Recent Bluff Failure (February 2013).
B) Homes Being Inundated with Excess Sand during a Strong Wind Event in November 2001

Source: DOGAMI

Without question, the most important natural variables that influence changes to the shape and width of the beach and ultimately its stability are the beach sand budget (balance of sand entering and leaving the system) and the processes (waves, currents, tides, and wind) that drive the changes.

Human influences associated with jetty construction, dredging practices, coastal engineering, and the introduction of non-native dune grasses have all affected the shape and configuration of the beach, including the volume of sand on a number of Oregon’s beaches, ultimately influencing the stability or instability of these beaches.

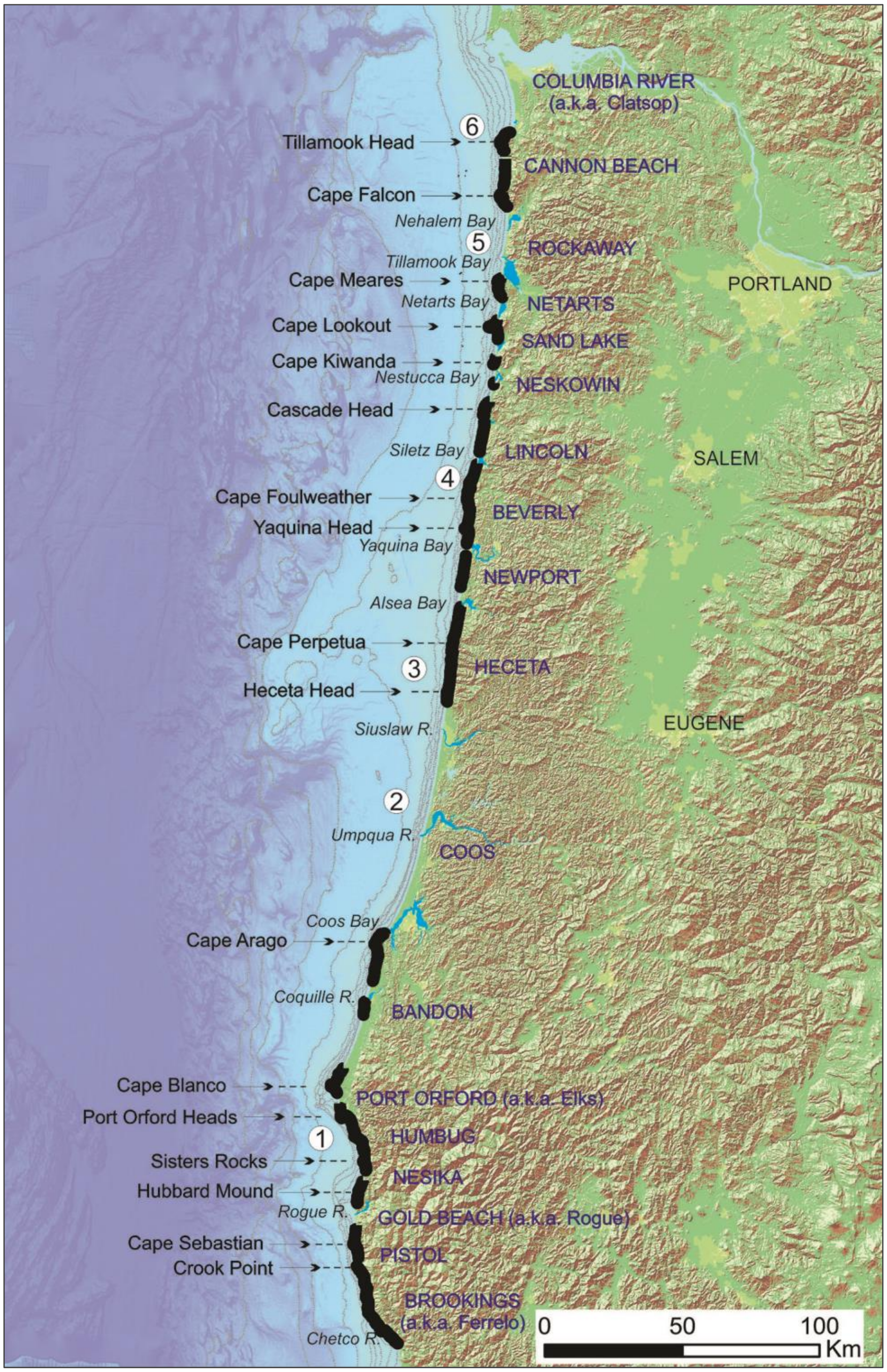
2.2.1.1 Analysis and Characterization

Geology and Geomorphology

The Oregon coast is 366 miles long from the Columbia River to the California border. The present coastline is the result of geologic processes that include a rise in sea level as Ice Age glaciers melted. The coastal geomorphology of this landscape reflects a myriad of geomorphic features (**Figure 2-31**) that range from plunging cliffs (in Regions 1, 4, and 5), rocky shorelines and shore platforms (Regions 1, 3, 5, and 6), wide and narrow sandy beaches backed by both dunes (Regions 2, 5, and 6) and cliffs (Regions 3 and 4), gravel and cobble beaches backed by cliffs (Regions 1, 5, and 6), barrier spits (Regions 2, 4, and 5), and estuaries (Regions 1–6). Cliffed or bluff-backed shorelines make up the bulk of the coast accounting for 58% of the coastline, the remainder being dune-backed. Geomorphically, the coast can be broken up into a series of "pocket beach" littoral cells (**Figure 2-31**)

that reflect resistant headlands (chiefly basalt) interspersed with short to long stretches of beaches backed by both less resistant cliffs and dunes (e.g., Lincoln and Tillamook Counties [Regions 3 and 5 in **Figure 2-31**; also see **Figure 2-32**]). The headlands effectively prevent the exchange of sand between adjacent littoral cells. Some beaches form barrier spits, creating estuaries or bays behind them (e.g., Netarts, Nestucca, and Siletz spits). About 75.6% of the coastline consists of beaches composed of sand or gravel backed by either dunes or bluffs, while the remaining 24.4% of the coast is composed of a mixture of rocky cliffs (including headlands) and shores. Of the 18 littoral cells on the Oregon coast, the largest is the Coos cell, which extends from Cape Arago in the south to Heceta Head in the north, some 62.6 miles long.

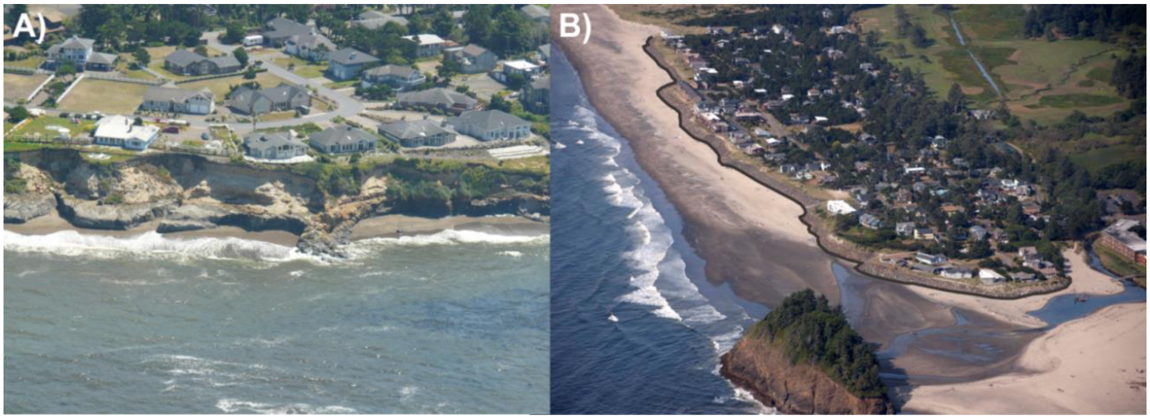
Figure 2-31.Oregon's Coastal Geomorphology and Littoral Cells



Note: Bold black lines denote the locations of cliffs and rocky shores. Faint grey lines denote faulting. Numbers indicate regional coastal geomorphic features: plunging cliffs (1, 4, and 5); rocky shorelines and shore platforms (1, 3, 5, and 6); wide and narrow sandy beaches backed by dunes (2, 5, and 6) and cliffs (3 and 4); gravel and cobble beaches backed by cliffs (1, 5, and 6); barrier spits (2 and 5); and estuaries (1–6).

Source: DOGAMI

Figure 2-32.(A) Houses Line the Cliff at Fogarty Creek in Lincoln County. (B) Extensive Erosion along the Dune-Backed Beaches in Neskowin Have Resulted in the Construction of Massive Riprap



Note the proximity of the eroding cliff edge to homes.

Source: L. Stimely, DOGAMI

Interspersed among the littoral cells are 21 estuaries that range in size from small, such as the Winchuck estuary (0.5 km2) adjacent to the Oregon/California border, to large, such as the Columbia River (380 km2), which separates the states of Oregon and Washington. The estuaries are all ecologically important to many fish and wildlife species and in many cases are the sites of important recreational and commercial enterprise. In general, Oregon estuaries can be divided into two broad groups based on physiographic differences between estuaries located on the north and south coast. On the northern Oregon coast, the prevalence of pocket beach littoral cells and weaker rock formations in the coast range has resulted in more rapid erosion of the region's rock formations. This produces ample material at the coast, and coupled with alongshore sediment transport, has aided the formation of barrier spits across drowned river valleys and hence estuaries. In contrast, sediment loads on the southern Oregon coast are comparatively lower due to there being more resistant rock formations. Furthermore, the region is generally much steeper, which essentially limits the landward extent of the tide in drowned rivers and, hence, ultimately the size of the estuaries.

Unlike much of the U.S. coast, population pressure on the Oregon coast is relatively low and is largely confined to small coastal towns separated by large tracts of coast with little to no development. The bulk of these developments are concentrated on the central to northern Oregon coast in Lincoln, Tillamook, and Clatsop Counties. On the cliffed shores of the central Oregon coast, between Newport and Lincoln City, homes are perched precariously close to the edge of the cliffs (**Figure 2-32A**). In some areas the erosion has become acute, requiring various forms of coastal engineering (commonly riprap) to mitigate the problem **(Figure 2-32B**), and in a few cases the landward removal of the homes. In other areas, critical infrastructure such as US-101 tracks close to the coast, and in a few areas, erosion of the cliffs has resulted in expensive remediation (e.g., adjacent to Nesika Beach in Curry County). Although the processes driving coastal erosion on bluff-backed shores are entirely a function of the delicate balance between the assailing forces (waves, tides, and currents) and properties of the rock (rock type, bedding, strength, etc.), increasing development pressure, weak land-use regulations, a lack of quantitative information, and ignorance of the physical processes have contributed to the need for remediation in many coastal areas.

Elsewhere, significant development is typically located along the most seaward dune (foredune) system (**Figure 2-32B**), as developers seek to capitalize on ocean views and proximity to the beach. However, major storms, especially in the late 1990s have resulted in extensive erosion, with many communities (e.g., Neskowin and Rockaway Beach in Tillamook County) having to resort to major coastal engineering in order to safeguard individual properties. The magnitude and extent of these erosion events have now left entire communities entirely dependent on the integrity of the structures.

Sand Budget

The beach sand budget is the rate at which sand is brought into the coastal system versus the rate at which sand leaves the system. A negative balance means that more sand is leaving than is arriving and results in erosion of that segment of shoreline. A positive balance means that more sand is arriving than is leaving, enabling that segment of shoreline to gain sand and accrete and potentially advance seaward. Along the Oregon coast, potential sources of sand include rivers, bluffs, dunes, and the inner shelf. Potential sand sinks include bays (estuaries), dunes, dredging around the mouths of estuaries, and mining of sand.

Attention is often focused on the effects of beach and dune erosion. Yet, there are segments of Oregon's coast where periodically the concern is excess sand build-up, as has occurred in places like Pacific City, Manzanita, Bayshore Spit, Nedonna, and Cannon Beach.

Classifying Coastal Hazards

Natural hazards that affect coastal regions can be divided into two general classes, *chronic* and *catastrophic*.

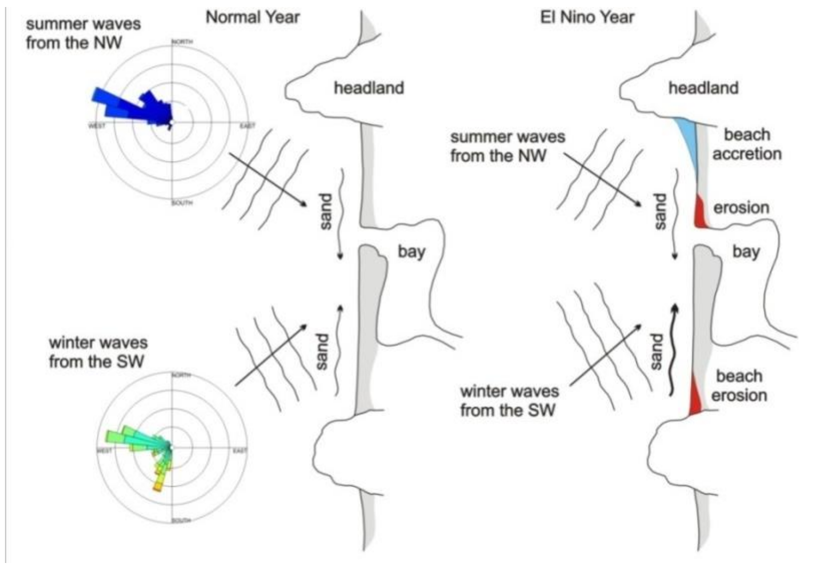
Chronic hazards such as beach, dune, and bluff erosion; landslides; slumps; and flooding of low-lying lands during major storms usually cause gradual and cumulative damage. However, storms that produce large winter waves, heavy rainfall, and/or high winds may result in very rapid erosion or other damage that can affect properties and infrastructure over a matter of hours. The regional, oceanic, and climatic environments that result in intense winter storms determine the severity of chronic hazards along the Oregon coast. Chronic hazards are typically local in nature, and threats to human life and property that arise from them are generally less severe than those associated with catastrophic hazards. However, the wide distribution and frequent occurrence of chronic hazards makes them a more immediate concern.

Catastrophic hazards are regional in scale and scope. Cascadia Subduction Zone earthquakes, and the ground shaking, subsidence, landsliding, liquefaction, and tsunamis that accompany them are catastrophic hazards. Tsunamis generated from distant earthquakes can also cause substantial damage in some coastal areas. The processes associated with earthquakes, tsunamis, floods, and landslides are discussed later in this chapter.

Causes of Coastal Hazards

Chronic coastal hazards include periodic high rates of beach and dune erosion, sand inundation, “hotspot erosion” due to the occurrence of El Niños and from rip current embayments, intermittent coastal flooding as a result of El Niños, storm surges and high ocean waves, and the enduring recession of coastal bluffs due to long-term changes in mean sea level, variations in the magnitude and frequency of storm systems, and climate change. Other important hazards include mass wasting of sea cliffs such as slumping and landslides, which may be due to wave attack and geologic instability.

Figure 2-33.Patterns of Sediment Transport During “Normal” and El Nino Years



Source: Komar (1986)

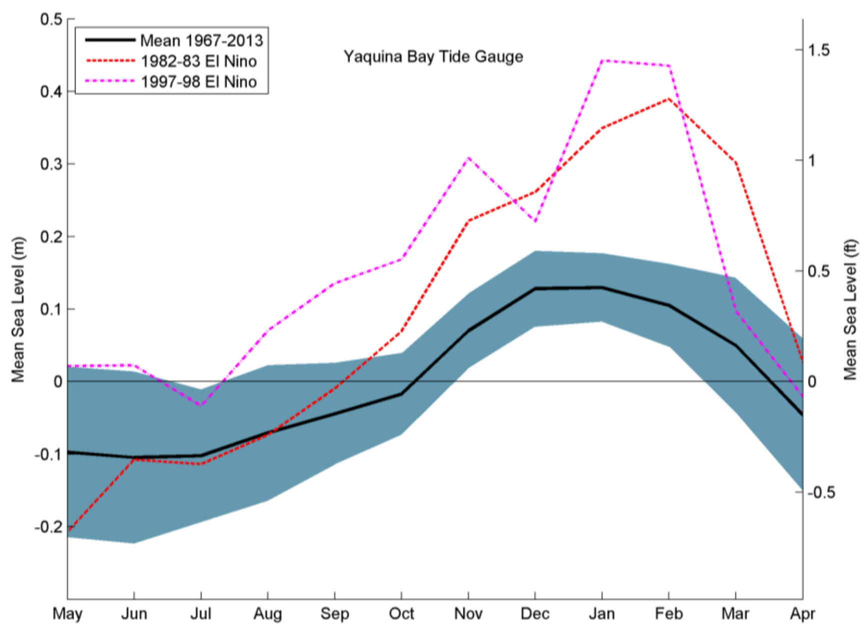
Most of these hazards are the product of the annual barrage of rain, wind, and waves that batter the Oregon coast, causing ever-increasing property damage and losses. A number of these hazards may be further exacerbated by climate cycles such as the El Niño Southern Oscillation, or longer-term climate cycles associated with the Pacific Decadal Oscillation. Other hazards, such as subduction zone earthquakes and resulting tsunamis, can have catastrophic impacts on coastal communities’ residents and infrastructure, and in many areas these impacts will persist for many decades following the event due to adjustments in the coastal morphodynamics following subsidence or uplift of the coast. All of these processes can interact in complex ways, increasing the risk from natural hazards in coastal areas.

Waves

Along dune- and bluff-backed shorelines, waves are the major factor affecting the shape and composition of beaches. Waves transport sand onshore (toward the beach), offshore (seaward to form nearshore bars etc.), and along the beach (longshore transport). Short-term beach and shoreline variability (i.e., storm related changes) is directly dependent on the size of the waves that break along the coast, along with high ocean water levels, and cell circulation patterns associated with rip currents. In contrast, long-term shoreline change is dependent on the balance of the beach sediment budget, changes in sea level over time, and patterns of storminess.

The Oregon coast is exposed to one of the most extreme ocean wave climates in the world, due to its long fetches and the strength of the extratropical storms that develop and track across the North Pacific. These storms exhibit a pronounced seasonal cycle producing the highest waves (mean = 12.8 ft) in the winter, with winter storms commonly generating deep-water wave heights greater than 33 ft, with the largest storms in the region having generated waves in the range of 45 to 50 ft. In contrast, summer months are dominated by considerably smaller waves (mean = 5.3 ft), enabling beaches to rebuild and gain sand eroded by the preceding winter. When large waves are superimposed on high tides, they can reach much higher elevations at the back of the beach, contributing to significantly higher rates of coastal erosion and flood hazards. It is the combined effect of these processes that leads to the erosion of coastal dunes and bluffs, causing them to retreat landward.

Figure 2-34.Average Monthly Tides for the Yaquina Bay Tide Gage Expressed as an Average for the Period 1967–2013, and as Monthly Averages for the 1982-83 and 1997-98 El Niños



Note: Shaded region= ±1 standard deviation providing a measure of normal ranges.
Source: Jonathan Allan, DOGAMI

Winds and waves tend to arrive from the southwest during the winter and from the northwest during the summer. Net sand transport tends to be offshore and to the north in winter and onshore and to the south during the summer (Figure 2-33). El Niño events can exaggerate the characteristic seasonal pattern of erosion and accretion, and may result in an additional 60–80 feet of "hotspot" dune erosion along the southern ends of Oregon's littoral cells, particularly those beaches that are backed by dunes, and on the north side of estuary inlets, rivers and creeks.

Ocean Water Levels

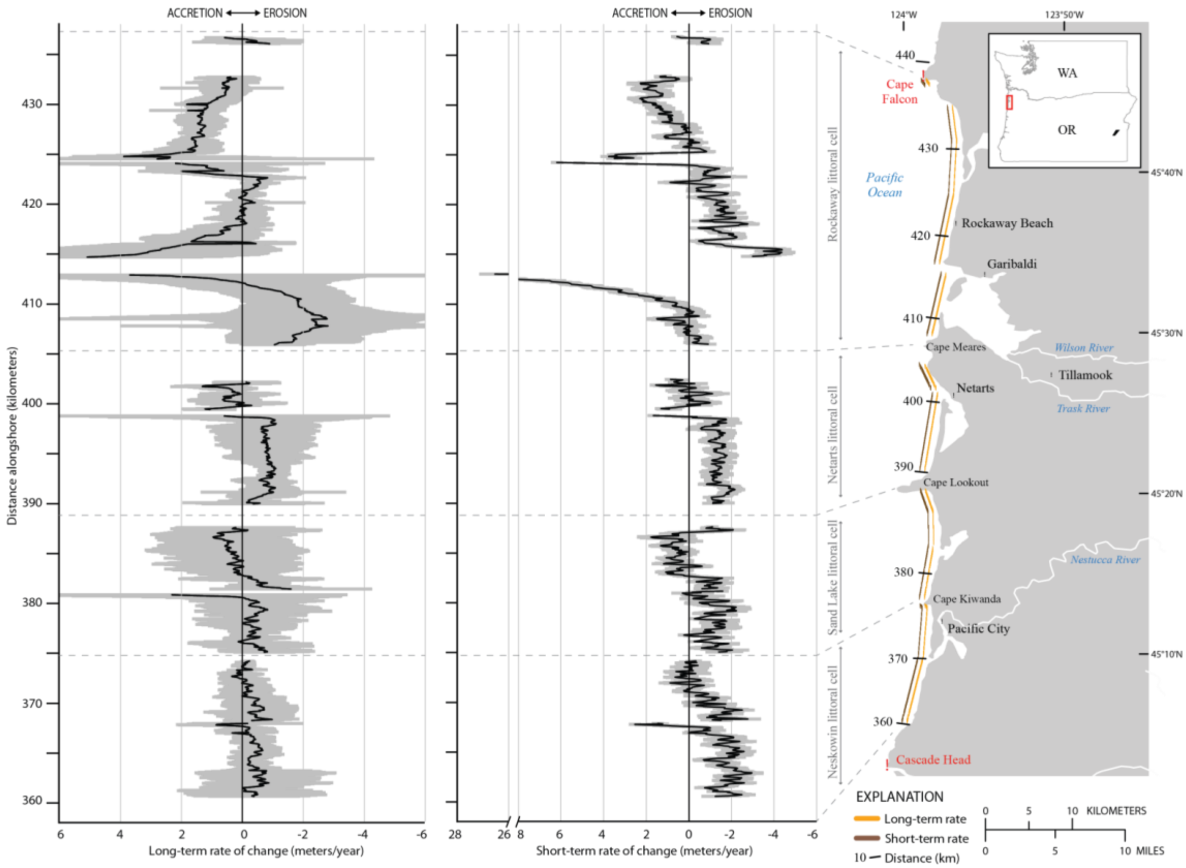
The elevation of the sea is controlled in part by the astronomical tide. High ocean water levels at the shoreline may be the product of combinations of high tides, storm surges, strong onshore-directed winds, El Niños, and wave runup. As can be seen in **Figure 2-34**, the Oregon coast experiences a seasonal cycle in its measured tides, with the tides tending to be highest in the winter and lowest in the summer. This seasonal variation is entirely a function of ocean upwelling during the summer months, which brings cold dense water to the surface; due to the Coriolis effect and ocean currents, this water is directed landward where it piles up along the coast depressing sea level. In the winter this process breaks down resulting in a warming of the ocean, which raises the mean sea level. The typical seasonal variability in water levels is about 0.8 ft, increasing to as much as 2 ft during an El Niño (**Figure 2-34**), essentially raising the mean shoreline elevation, enabling waves to break closer to dunes or along the base of coastal bluffs.

Shoreline Changes

Dune-backed beaches respond very quickly to storm wave erosion, sometimes receding tens of feet during a single storm and hundreds of feet in a single winter season. Beach monitoring studies undertaken by DOGAMI staff (http://nvs.nanoos.org/BeachMapping) have documented storm induced erosion of 30–60 ft from single storm events, while seasonal changes may reach as much as 90–130 ft on the dissipative, flat, sandy beaches of Oregon, and as much as 190 ft on the more reflective, steeper beaches of the south coast (e.g., adjacent to Garrison Lake, Port Orford). Furthermore, during the past 15 years a number of sites on the northern Oregon coast (e.g., Neskowin, Netarts Spit, and Rockaway Beach) have experienced considerable erosion and shoreline retreat. For example, erosion of the beach in Neskowin has resulted in the foredune having receded landward by as much as 150 ft since 1997. South of Twin Rocks near Rockaway, the dune has eroded about 140 ft over the same time period. Continued monitoring of these study sites are now beginning to yield enough data from which trends (erosion or accretion rates) may be extrapolated. These latter datasets are accessible via the web (http://nvs.nanoos.org/BeachMapping).

Recently, studies undertaken by the USGS provide additional insights into the spatial extent of erosion patterns on the Oregon coast. **Figure 2-35** provides analyses of both long-term (about 1900s to 2002) and short-term (about 1960s/80s to 2002) shoreline change patterns along the Tillamook County coast, confirming measured data reported by DOGAMI. As can be seen from the figure, long-term erosion rates (albeit low rates) dominate the bulk of Tillamook County (i.e., Bayocean Spit, Netarts, Sand Lake, and Neskowin littoral cells), while accretion prevailed in the north along Rockaway Beach and on Nehalem Spit. The significant rates of accretion identified adjacent to the mouth of Tillamook Bay are entirely due to construction of the Tillamook jetties, with the north jetty completed in 1917 and the south jetty in 1974. Short-term shoreline change patterns indicate that erosion has continued to dominate the bulk of the shoreline responses observed along the Tillamook County coast. Erosion is especially acute in the Neskowin, Sand Lake and Netarts littoral cells, and especially along Rockaway Beach. In many of these areas, the degree of erosion remains so significant, that were we to experience a major storm(s) in the ensuing winters, the risk of considerable damage to property and infrastructure in these areas would likely be high.

Figure 2-35.Long- and Short-Term Shoreline Change Rates for the Tillamook County Region



Source: http://envision.bioe.orst.edu/StudyAreas/Tillamook/ruggiero_talk_PelicanPub_02102014.pdf

Source: Ruggiero et al. (2013)

The processes of wave attack significantly affect shorelines characterized by indentations, known as inlets. Waves interact with ocean tides and river forces to control patterns of inlet migration. This is especially the case during El Niños. During an El Niño, large storm waves tend to arrive out of the south, which causes the mouth of the estuary to migrate to the north, where it may abut against the shoreline, allowing large winter waves to break much closer to the shore. This can result in significant “hotspot” erosion north of the estuary mouth. Recent examples of the importance of inlet dynamics during an El Niño are Alsea Spit near Waldport (**Figure 2-36**), Netarts Spit near Oceanside, and at Hunter Creek on the southern Oregon coast at Gold Beach.

Figure 2-36. Alsea Bay Spit Erosion as a Result of the 1982-83 El Niño (left), and State of the Beach in 2009 (right)

Note: Yellow/black line delineates a riprap structure constructed to protect the properties from further erosion. Orange line defines the maximum extent of dune erosion due to wave attack as a result of the 1982-83 event. Note the northward migration of the estuary mouth compared to its position in 2009.

Source: DOGAMI

Floods

Flood Insurance Rate Maps (FIRMs) and Flood Insurance Studies (FISs) are also often used in characterizing and identifying flood-prone areas. FEMA conducted many FISs in the late 1970s and early 1980s. Included were "VE" zones, areas subject to wave action and ocean flooding during a "100-year" event that encompass the area extending from the surf zone to the inland limit of wave runup, and/or wave overtopping and inundation, and/or the location of the primary frontal dune or any other area subject to high-velocity wave action from coastal storms. Areas identified as VE zones are subject to more development standards than other flood zones. Between 2009 and 2014, DOGAMI worked with FEMA to remap FEMA coastal flood zones established for Oregon's coastal communities, utilizing improved topographic information, revised information on extreme storm waves and ocean water levels, and a revised methodology for calculating erosion, wave runup and overtopping.

Landslides

Simple surface sloughing is the dominant process along bluff-backed shorelines. Other shorelines are backed by steep slopes, where deep-seated landslides and slumping are the dominant processes (**Figure 2-37**). The geologic composition of the bluff is a primary control on slope stability.

Headlands, generally composed of basalt, are more resistant to erosion and do not readily give way. In contrast, soft bluff-forming sandstone and mudstone are highly susceptible to slope movement. Prolonged winter rains saturate these porous bluff materials, increasing the likelihood of landslides.

The geometry and structure of bluff materials also affect slope stability by defining lines of weakness and controlling surface and subsurface drainage. As waves remove sediment from the toe of the bluff, the bluffs become increasingly vulnerable to slope failure due to increased exposure to wave attack. The extent to which the beach fronting the bluff acts as a buffer is thus important in this regard. Thus a reduction in the sand beach volume in front of a bluff increases its susceptibility to wave erosion along its toe, which can eventually contribute to the failure of the bluff.

A recent example of such a process occurred at Gleneden Beach in Lincoln County in November 2006 (**Figure 2-37**), when a large rip current embayment (an area of the beach that exhibits more erosion and beach narrowing due to removal of sand by rip currents) formed in front of a portion of the bluff, allowing waves to directly attack the base of the bluff. In a matter of two days, the bluff eroded back by up to 30 ft, undermining the foundations of two homes, and almost resulting in their destruction.

Figure 2-37. Bluff Failure Due to Toe Erosion by Ocean Waves

Note: The top of the bluff eroded landward by about 30 ft over a 48-hour period in November 2006.

Photo source: OPDR

Similar processes occurred nearby during the 1972-73 winter, which led to one home having to be pulled off its foundation. Both examples provide a stark reminder of the danger of building too close to the beach and that these types of changes do occur relatively frequently

Landslide risk is especially high on the southern Oregon coast in Curry County, where multiple slide failures are presently affecting Highway 101. One of the largest recent events occurred on March 3, 2019 at Hooskanaden Creek, affecting travel on Highway 101. Movement in the central part of the landslide near Highway 101 varied from 45 to 130 ft. Significant active landsliding is also evident on the central Oregon coast in the Beverly Beach littoral cell, located immediately north of Yaquina Head. Within this eight mile stretch of highway, there are four active landslide blocks that require frequent remediation of the highway.

Figure 2-38. Landslide Movement Affecting U.S. Highway 101 at Hooskanaden Creek on March 3, 2019. Inset Photo Shows the Overall Scale of the Landslide and Its Proximity to the Coast

Photo source: Michael Olsen, 2020

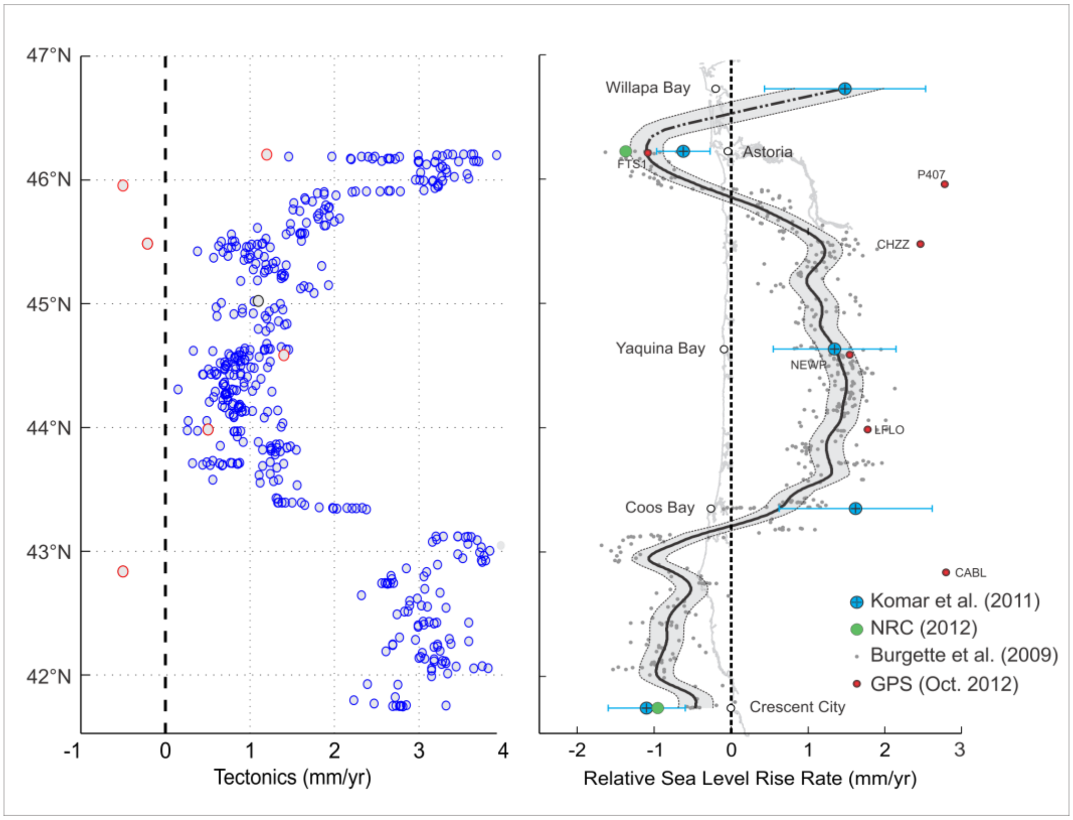
Climate Change and Sea Level Rise

An understanding of the trends and variations in sea level on the Oregon coast provides important insights as to the spatial patterns of erosion and flood hazards. In general, tectonic uplift is occurring at a much faster rate (about 2–4 mm/year) on the south coast (south of about Coos Bay), while the uplift rates on the central to northern Oregon coast are much lower, averaging about 1 mm/year (**Figure 2-39**, left). When combined with regional patterns of sea level change (**Figure 2-39**, right), it is apparent that the southern Oregon coast is essentially an emergent coast, with the coast rising at a much faster rate when compared with sea level. In contrast, the central to northern Oregon coast is a submergent coast due to the fact that sea level is rising faster than the land. Not surprisingly, it is the north coast that exhibits the most pervasive erosion and flood hazards when compared with the south coast.

In 2012, the National Research Council completed a major synthesis of the relative risks of sea level rise on the U.S. West Coast. The consensus from that report is that sea level has risen globally by on average 1.7 mm/year, while rates derived from satellite altimetry indicate an increase in the rate of sea level rise to 3.2 mm/year since 1993 (NRC, 2012). Combining our knowledge of glacial isostatic rebound (the rate at which the earth responds to the removal of ice from the last glaciations), regional tectonics, and future temperature patterns, the committee concluded that sea level on the Oregon coast would increase by approximately 2.1 ft by 2100.

Global measurements of sea level change continue to be quantified through satellite altimetry, with the most recent (February 2020) measurements indicating a net increase of 3.39 mm/year since 1993 (Copernicus Marine and Environment Monitoring Service (CMEMS), Aviso Satellite Altimetry Data website, Mean Sea Level Rise page, https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level.html). Regional projections of future sea level rise scenarios have also been updated for the United States, based on revised global projections of sea level change undertaken using global climate change modeling (Sweet and others, 2017). These revised data reflect the most up-to-date scientific information, including recent observational and modeling literature that examine the potential for rapid ice melt in Greenland and Antarctica. Based on these latest analyses, a physically plausible global sea level rise in the range of 6 ft to 8.9 ft is now more likely. Sweet and others (2017) define six global sea level rise scenarios, termed: Low, Intermediate-low, Intermediate, Intermediate-high, High and Extreme, which correspond to global sea level increases of 1 ft, 1.6 ft, 3.3 ft, 4.9 ft, 6.6 ft, and 8.2 ft respectively. These data have then be used to calculate regional estimates of sea level rise, after accounting for tectonic changes, glacial isostatic rebound, and shifts in ocean circulation patterns. For the Pacific Northwest, Sweet and others (2007) indicate that the regional sea level rise is projected to be less than the global average falling mainly under the Low-to-Intermediate scenarios (e.g., 0.3 -3.3 ft).

Figure 2-39. Coast Variations in Rates of Tectonic Uplift, and Relative Sea Level Trends for the Oregon Coast



Source: Komar and Allan (2010); website: http://www.aviso.oceanobs.com/en/news/ocean-indicators/mean-sea-level/

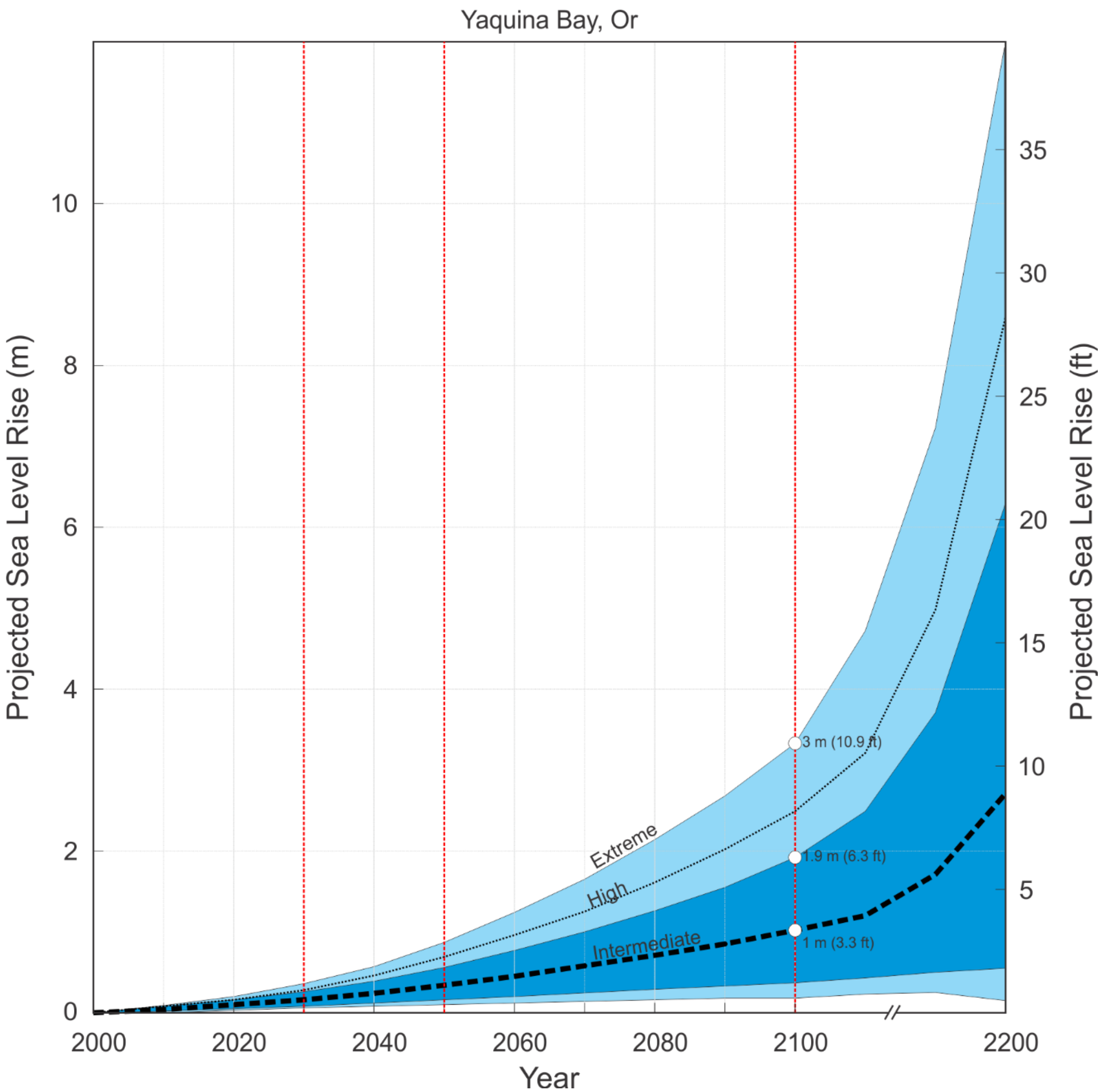
Table 2-21. Projected Sea Level Rise for the Central Oregon Coast

By Year 2030		By Year 2050		By Year 2100	
Projection	Range	Projection	Range	Projection	Range
0.5 ft	0.2–1.2 ft	1.1 ft	0.3–2.9 ft	3.4 ft	0.6–10.9 ft

Table 2-21 presents the revised Sweet and others (2017a) projected sea level rise findings for the Central Oregon coast. The largest increase in regional sea level is estimated to be 10.9 ft by 2100 (Figure 2-40) while the intermediate projection reflects an increase of about 3.4 ft by 2100. As noted previously, the extreme 10.9 ft projection reflects the now plausible scenario of a catastrophic failure of the Greenland and Antarctic ice sheets. Under this latter scenario, projected sea levels in 2200 could well exceed 30 ft along the Oregon coast.

Of importance, these projections assume that sea level is uniform year round. However, as noted previously, sea level on the Oregon coast exhibits a pronounced seasonal cycle of about 0.8 ft between summer and winter, increasing to as much as 2 ft in response to the development of a strong El Niño. Thus, when combined with projected future increases in regional sea level, it becomes apparent that the potential increase in mean sea level could be substantially greater depending on the time of year. For example, by 2100, sea level during an El Niño winter could be as much as 13 ft under the most extreme scenario, raising the mean shoreline position by that amount, which will have shifted upward and landward as beaches respond to the change in mean water levels. Based on these projections, it can be expected that areas presently classified as emergent (e.g., the southern Oregon coast), will become submergent over time as the rate of sea level rise surpasses tectonic uplift. Furthermore, erosion and flood hazards on the northern Oregon coast will almost certainly accelerate, increasing the risk to property.

Figure 2-40. Projected Future Changes in Regional Sea Levels on the Oregon Coast



Source: Created by Jonathan Allan, DOGAMI, with integrated sea level rise projections from Sweet and others (2017).

Human Activities

Human activities affect the stability of all types of shoreline. Large-scale human activities such as jetty construction and maintenance dredging have a long-term effect on large geographic areas. This is particularly true along dune-backed and inlet-affected shorelines such as the Columbia River and Rockaway littoral cells (**Figure 2-31**). The planting of European beach grass (*Ammophila arenaria*) since the early 1900s and, more recently, American beach grass (*Ammophila breviligulata*) has locked up sand in the form of high dunes. Such a process can contribute to a net loss in the beach sand budget and may help drive coastal erosion.

Residential and commercial development can affect shoreline stability over shorter time periods and smaller geographic areas. Activities such as grading and excavation, surface and subsurface drainage alterations, vegetation removal, and vegetative as well as structural shoreline stabilization can all affect shoreline stability.

While site-specific coastal engineering efforts such as the construction of riprap revetments is less likely to cause direct adverse impacts to the beach, the cumulative effect of constructing many of these structures along a particular shore (e.g., as has occurred along the communities of Gleneden Beach, Siletz Spit, Lincoln City, Neskowin, Pacific City, and Rockaway) will almost certainly decrease the volume of sediment being supplied to the beach system, potentially affecting the beach sediment budget and hence the stability of beaches within those littoral cells.

Heavy recreational use in the form of pedestrian and vehicular traffic can affect shoreline stability over shorter time frames and smaller spaces. Because these activities may result in the loss of fragile vegetative cover, they are a particular concern along dune-backed shorelines. Graffiti carving along bluff-backed shorelines is another byproduct of recreational use that can damage fragile shoreline stability.

Historic Coastal Hazard Events

Table 2-22 lists historic coastal erosion and flood hazard events in Oregon.

Table 2-22. Historic Coastal Hazard Events in Oregon

Date	Location	Description
Jan. 1914	Newport	damage (Nicolai Hotel)
1931	Rockaway	coastal damage from December storm
Oct–Dec. 1934	Waldport and Rockaway	flooding (Waldport) coastal damage (Rockaway Beach)
Dec. 1935	Cannon Beach and Rockaway Beach	coastal damage
Jan. 1939	coastwide	severe gale; damage: coastwide severe flooding (Seaside, and Ecola Creek near Cannon Beach): • multiple spit breaches (southern portion of Netarts Spit) • storm damage (along the shore of Lincoln City and at D River) • flooding (Waldport) • extensive damage (Sunset Bay Park) • storm surge overtopped foredune (Garrison Lake plus Elk River lowland)
Dec. 1940	Waldport	flooding
1948	Newport	wave damage (Yaquina Arts Center)
Jan. 1953	Rockaway	70-ft dune retreat; one home removed
Apr. 1958	Sunset Bay State Park Newport	flooding (Sunset Bay); wave damage (Yaquina Arts Center in Newport)
Jan.–Feb. 1960	Sunset Bay State Park	flooding
1964	Cannon Beach	storm damage
Dec. 1967	Netarts Spit Lincoln City Newport Waldport	damage: coastwide State constructed wood bulkhead to protect foredune along 600 ft section (Cape Lookout State Park campground) flooding and logs (Lincoln City) wave damage (Yaquina Arts Center, Newport) flooding (Waldport) Storm damage (Beachside State Park washed up driftwood (Bandon south jetty parking lot)
1971–73	Siletz Spit	high tide line eroded landward by 300 ft Feb. 1973; one home completely destroyed; spit almost breached logs through Sea Gypsy Motel (Nov. 1973)
1982–83	Alsea Spit	northward migration of Alsea Bay mouth; severe erosion
1997–98	Lincoln and Tillamook Counties	El Niño winter (second strongest on record); erosion: considerable
1999	coastwide	five storms between January and March; coastal erosion: extensive, including: • significant erosion (Neskowin, Netarts Spit, Oceanside, Rockaway beach); • overtopping and flooding (Cape Meares) • significant erosion along barrier beach (Garrison Lake); overtopping 27-ft high barrier
Dec. 2007	Tillamook and Clatsop Counties	wind storm
Dec. 7-11 2015	Tillamook and Clatsop Counties	coastal and riverine flooding in response to several days of heavy rain. large storm waves exceeding 30 ft on Dec 11th resulted in coastal erosion issues in several communities.

Date	Location	Description
Feb. 2018	Curry County	major coastal landslide at Hooskanaden, located in southern Curry County
2019-2020	Siletz Spit	significant erosion over the 2019-20 winter resulted in several homes impacted and the need for emergency permits for coastal engineering.

Sources: Allan and Priest (2001); Allan and Komar (2002); Allan et al. (2003, 2006); Allan and Hart (2007, 2008); Allan et al. (2009, 2012); Allan and Stimely (2013); Komar (1986, 1987); Komar and Rea (1976); Komar and McKinney (1977), Komar (1997); Komar and Allan (2010); Peterson et al. (1990); Priest (1999); Revell et al. (2002); Schlicker et al. (1973); Stembridge (1975); and Terich and Komar (1974)

2.2.1.2 Probability

The erosion of the Oregon coast is exceedingly complex, reflecting processes operating over both short and long time scales, and over large spatial scales. However, the most significant erosion effects are largely controlled by high-magnitude (relatively infrequent) events that occur over the winter (the months of October to March), when wave heights and ocean water levels tend to be at their highest. Conversely, problems with sand build-up is a function of a readily available sand supply and its subsequent redistribution by wave (specifically nearshore currents) and wind processes. These latter processes may be periodically enhanced under strong El Niño conditions, resulting in both enhanced beach and dune erosion, and the subsequent redistribution of those eroded sediments to downdrift locations where the sediments accumulate in dunes. The best examples of this process occurring presently on the Oregon coast include the Neskowin littoral cell in Tillamook County; Alsea Spit in central Lincoln County; and at Cannon Beach in Clatsop County.

Waves

Previous analyses of extreme waves for the Oregon coast estimated the “100-year” storm wave to be around 33 feet. In response to a series of large wave events that occurred during the latter half of the 1990s, the wave climate was subsequently re-examined and an updated projection of the 100-year storm wave height was determined, which is now estimated to reach approximately 47–52 feet (**Table 2-23**), depending on which buoy is used. These estimates are of considerable importance to the design of coastal engineering structures and in terms of defining future coastal erosion hazard zones.

Table 2-23. Projection of Extreme Wave Heights for Various Recurrence Intervals

Recurrence Interval (years)	Extreme Wave Heights (feet)	
	NDBC buoy#46002* (Oregon)	NDBC buoy#46005+ (Washington)
10	42.5	41.7
25	46.2	44.0
50	48.8	
75	50.1	45.7
100	51.2	47.1

Note: Each wave height is expected to occur on average once during the recurrence interval. NDBC is National Data Buoy Center

Source: Jonathan Allan, DOGAMI

Sand Inundation

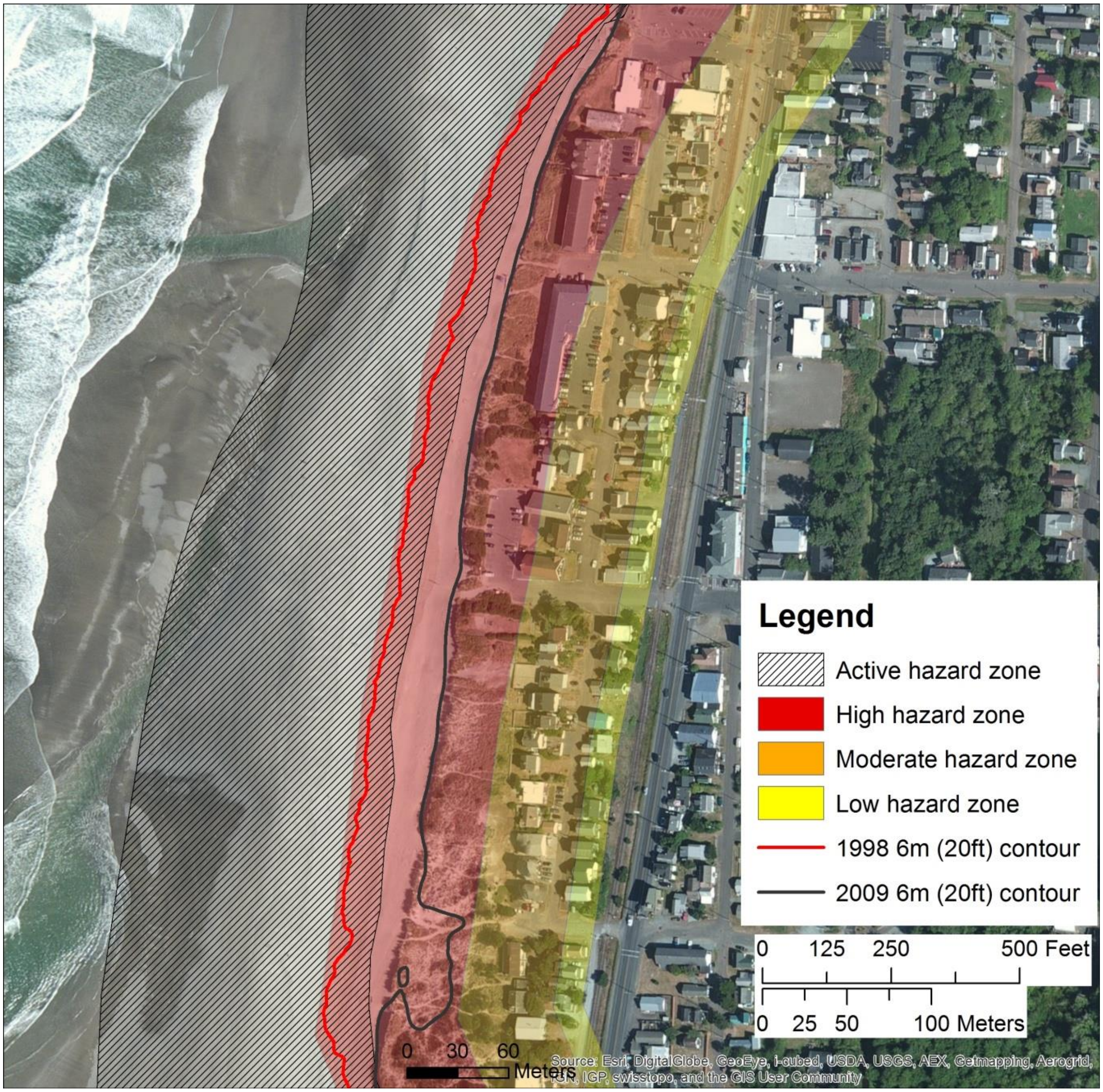
As noted previously, beaches are especially dynamic features, as sand is constantly shifted about. This is especially noticeable in major storms, with the shoreline retreating rapidly, periodically destroying homes built too close to the sea. At other times, large quantities of sand migrate back onto beaches, burying homes built atop coastal dunes (**Figure 2-30B**). The probability of such events taking place has not been adequately studied. However, given existing dune grading activities in several communities, the repeat build-up of sand occurs annually, which may be enhanced during strong El Niño events.

The best examples of sand inundation include the communities of Pacific City located at the north end of the Neskowin littoral cell and along Alsea Spit. In both examples, homes have been built on the seaward foredune, in areas prone to large sand movements. Repeat GPS measurements of the changes taking place in such areas indicate that the annual accumulation of sand among the homes can range from as little as 2 ft to well over 3 ft per year, requiring periodic (in some cases annual) remediation that includes foredune grading to push the sand back out onto the beach. This process will inevitably continue as long as there is a ready supply of sand, a prevailing wave and wind climate that drives sand northward, and the absence of vegetation in the dunes. Thus, while sand grading is used to relocate sand back onto the beach, dune grass planting is a second essential step needed to stabilize the dune. Once grasses have become established, the foredune can be expected to stabilize and begin to slowly advance seaward. The latter process may be aided by careful dune management approaches (e.g. grading) that maintains a well vegetated dune, while encouraging the seaward advance of the dune.

Another notable coastal area presently dealing with sand build-up is a small area north of Ecola Creek in Cannon Beach (Allan and others, 2018). Analyses by Allan and others indicated that about 294,000 yards have accumulated north of Ecola Creek since 1997, necessitating periodic grading of the evolving dune.

Sand aggradation is also significant in the vicinity of Seaside, where it aggrades up against the Seaside promenade, requiring annual grading.

Figure 2-41. Example Map Product Showing Erosion Hazard Zones Developed for Rockaway Beach in Tillamook County



Note: The erosion that has taken place since 1998 (red line) up through 2009 (black line).
Photo source: DOGAMI

Coastal Erosion Hazard Zones

For the purposes of providing erosion hazard information for the Oregon coast, DOGAMI has completed coastal erosion hazard maps for Lincoln, Tillamook, and Clatsop Counties, as well in the Nesika Beach area in Curry County. Maps were completed for these areas mainly because these areas contain the largest concentration of people living along the coastal strip, and in the case of Nesika Beach in response to a specific request by the Department of Land Conservation and Development agency. In all cases, the maps depict erosion hazard zones that fall into four categories (**Figure 2-41**):

- **Active Hazard Zone (AHZ):** For dune-backed shorelines, the AHZ encompasses the active beach to the top of the first vegetated foredune, and includes those areas subject to large morphological changes adjacent to the mouths of the bays due to inlet migration. On bluff-backed shorelines the AHZ includes actively eroding coastal bluff escarpments and active or potentially active coastal landslides.
- **High Hazard Zones (HHZ):** This scenario is based on a large storm wave event (wave heights about 47.6 ft high) occurring over the cycle of an above average high tide, coincident with a 3.3 ft storm surge. The wave heights associated with this scenario have an expected recurrence interval of 50-60 years or a 2% chance in any given year.
- **Moderate Hazard Zones (MHZ):** This scenario is based on an extremely severe storm event (waves about 52.5 ft high) and may or may not encompass a long-term rise in sea level (depends on the coastal region). As with the HHZ, the wave event occurs over the cycle of an above average high tide, coincident with a 5.6 ft storm surge. The wave heights associated with this scenario have an expected recurrence interval of 100 years or a 1% chance in any given year.
- **Low Hazard Zones (LHZ):** This scenario is analogous to the MHZ scenario described previously, with the addition of a 3.3 ft coseismic subsidence of the coast.

In July 2014, DOGAMI completed new updated maps for the dune-backed beaches in Tillamook County using a probabilistic approach to map the erosion hazard zones. The revised modeling used three total water level scenarios (10%, 2%, and 1% events) produced by the combined effect of extreme wave runup (R) plus the tidal elevation (T), and erosion due to sea level rise (low/mean/maximum estimates) at 2030, 2050, and 2100. In total 81 scenarios of coastal erosion were modeled; an additional two scenarios were also modeled that considered the effects of a Cascadia subduction zone earthquake, and the effects of a single (1%) storm, where the storm's duration was taken into account. The completed study ultimately recommended five hazard zones for consideration.

Coastal Flooding

Between 2009 and 2014, DOGAMI completed coastal flood modeling for all seven coastal counties on behalf of the Federal Emergency Management Agency (e.g. Allan and others, 2012, 2015a, 2015b, 2015c, 2015d, 2017). These analyses included assessments of the 1% annual probability, or 100-year, extreme storm wave event and the associated calculated wave setup, runup, and total water level (i.e., the wave runup superimposed on the tidal level) to help guide the determination of Special Flood Hazard Areas (SFHAs). The most significant were regions subject to high coastal flood risk (Zone VE), characterized with base flood elevations (BFEs) that are used to guide building practices. Additional modeling of the 0.2%, or 500-year, event was also undertaken. These analyses represent the best available information to date on the risk of coastal flooding. However, as the effects of climate change begin to accelerate and drive regional and global mean sea level increases, existing areas already prone to flooding (e.g. parts of the northern Oregon coast) will almost certainly become worse, while other areas presently not affected are likely to begin to see an increasing incidence for erosion and propensity for flooding.

Landslides

Landslides are prevalent along the Oregon coast, in areas characterized with steeper slopes, weaker geology, and higher annual precipitation. Of the seven coastal counties, two (Lane and Douglas Counties) have a negligible landslide hazard, while the remaining five counties experience frequent coastal landsliding. Although we do not know exactly where and when landslides will occur, they are more likely to happen in the areas where previous landslides have occurred. Furthermore, they are much more prevalent during heavy rainfall events, and in steep bluff areas subject to wave toe erosion and undercutting. Due to the coastal terrain and proximity to the Cascadia subduction zone, it is certain that the Oregon coast will be severely impacted with many thousands of landslides following a future great earthquake.

Probability of Coastal Hazards in Each Coastal County

To determine the probability of a particular coastal hazard (coastal erosion, flooding, coastal landslide, and - new in 2020 - sand inundation) occurring on the Oregon coast, we first defined the overall exposure level associated with each hazard and for each county. This is needed to appreciate that although certain hazards have a very high probability of occurring everywhere along the Oregon coast, the degree of development varies considerably from county to county (and community to community), which directly impinges on a site’s exposure.

While one can extrapolate a probability for storm events (e.g. 100-year storm), in the context of the NHMP this is not hugely helpful. This is because in some cases smaller, more frequent events (e.g. 10-year storms) may result in cumulative erosion that could well exceed a single 100-year storm. Of importance also is the fact that nowhere has a particular exceedance event been formally defined (e.g. are we concerned about the 10-year, 50-year or 100-year storm?), guided by some planning horizon.

For landslides, we evaluated each county based on whether the local terrain and geology is conducive to landsliding, and whether there were known instances of historical coastal landslides. Thus, counties that had little to no terrain capable of landsliding (e.g. coastal Lane County) were given a low rank, compared with those counties where previous landslides have occurred (e.g. Lincoln County).

Finally, since some hazards have never been defined from a probabilistic standpoint, we decided to focus our attention on a more qualitative classification scheme (Table 2-X). In all cases, the approach used here was guided by local knowledge of the Oregon coast, various technical studies (e.g. FEMA flood modeling, ongoing beach monitoring) and recent research (sea level rise and extreme storms).

Table 2-24. Probability Classification Scheme for Coastal Hazards

Classification	Probability of Outcome	Probability of Outcome with High Uncertainty
Extremely likely	> 99%	> 99%
Very likely	80 - 90%	≥ 80%
Likely	60 - 80%	≥ 60%
About as likely as not	40 - 60%	40 - 60%
Unlikely	15 - 40%	< 40%
Very unlikely	1 - 15%	< 15%
Extremely unlikely	< 1%	< 1%

Source: J. Allan, DOGAMI, 2020

Table 2-25. Probability and Exposure Rankings of Coastal Sand Inundation and Coastal Erosion

		Coastal Sand Inundation		Coastal Erosion	
		Probability	**Exposure**	**Probability**	**Exposure**
Region 1	Clatsop	Likely	Mod High	Extremely likely	High
	Coos	Unlikely	Low	Extremely likely	High
	Curry	Very unlikely	Low	Extremely likely	Moderately Low
	Douglas Coastal	Likely	Low	Extremely likely	Low
	Lane Coastal	Likely	Low	Extremely likely	Moderately Low
	Lincoln	Very unlikely	Low	Extremely likely	Very High
	Tillamook	Extremely likely	High	Extremely likely	Very High

Table 2-26. Probability and Exposure Rankings of Coastal Flooding and Coastal Landslides

		Coastal Flooding		Coastal Landslides	
		Probability	**Exposure**	**Probability**	**Exposure**
Region 1	Clatsop	Likely	Moderately Low	Extremely likely	Moderate
	Coos	Unlikely	Low	Unlikely	Low
	Curry	Unlikely	Low	Extremely likely	Moderate
	Douglas Coastal	Unlikely	Low	Extremely unlikely	Low
	Lane Coastal	Unlikely	Low	Very unlikely	Low
	Lincoln	Unlikely	Low	Extremely likely	High
	Tillamook	Very likely	Moderate	Very likely	Moderate

The final probability ranking, 1 to 5 (1 = low probability/low exposure to 5 = high probability/high exposure), was thus based on the combined probability classification and the degree of exposure of coastal erosion, coastal flooding, coastal landslides, and coastal sand inundation) and ranked accordingly. For example, although the Douglas County coastline is extremely likely to experience erosion in any given year, since there is virtually no development on the open coast, the exposure is considered to be low. Conversely, beaches and dunes in Tillamook County are undergoing active erosion, while the exposure is very high due to the fact there is significant development adjacent to the coast.

Table 2-27. Final Probability Ranking of Coastal Hazards

		Coastal Sand Inundation	Coastal Erosion	Coastal Flooding	Coastal Landslides	Combined Probability
Region 1	Clatsop	3	4	3	4	3.50 = VH
	Coos	1	4	1	1	1.75 = VL
	Curry	1	3	1	4	2.25 = L
	Douglas Coastal	2	2	1	1	1.50 = VL
	Lane Coastal	2	3	1	1	1.75 = VL
	Lincoln	1	5	1	5	3.00 = H
	Tillamook	4	5	4	4	4.25 = VH

Source: J. Allan, DOGAMI, 2020

Climate Change

Recent research indicates that sea levels along Oregon's coast are rising as are wave heights off the Oregon coast. Increasing significant wave heights may be a factor in the observed increase of coastal flooding events in Oregon. During El Niño events, sea levels can rise up to about 1.5 feet (0.5 meters) higher over extended periods (seasons). It is very likely (>90%) that the Oregon coast will experience an increase in coastal erosion and flooding hazards due to climate change induced sea level rise (high confidence) and possible changes to wave dynamics (medium confidence).

2.2.1.3 Vulnerability

Chronic hazards are clearly evident along Oregon's shores, including beach, dune, and bluff erosion, landslides, slumps, gradual weathering of sea cliffs, and flooding of low-lying coastal lands during major storms. The damage caused by chronic hazards is usually gradual and cumulative. The regional, oceanic, and climatic environments that result in intense winter storms determine the severity of chronic hazards along the coast. These hazards threaten property and, in extreme events, human life.

Most Vulnerable Communities

For the 2020 vulnerability assessment, DOGAMI used the hazard mapping from several DOGAMI coastal erosion studies performed between 2001 and 2014. The coastal erosion hazard is mapped as Active, High, Moderate, or Low Hazard Zones which, for the purposes of the 2020 NHMP, were simplified to High (encompassing Active and High), Moderate, and Other (encompassing Low hazards and unmapped areas). The Low hazard zones incorporate hypothetical landslide block failures assumed to fail in the event of a M9 Cascadia earthquake and were placed under "Other" due to their very low probability. However, this data does not cover the entire Oregon coastline: coastal erosion hazard zones have not been created for Lane, Douglas, and Coos Counties, and only partial data coverage exists for Curry County. To address these data gaps, DOGAMI excluded those portions of the coast from the analysis, and instead used a 0.5km buffer of the coastline to delineate an "Other" zone.

State-Owned/Leased Buildings and Critical Facilities and Local Critical Facilities

DOGAMI analyzed the potential dollar loss from coastal hazards to state buildings and critical facilities as well as to local critical facilities statewide. About $11.5M in value of state buildings and state critical facilities are located in coastal erosion hazard areas, and the majority of that value (86%) is located in Lincoln and Tillamook Counties. None is located in Coos, Coastal Douglas, or Coastal Lane Counties. About $285K of value in local critical facilities is located in coastal erosion areas in Clatsop and Tillamook Counties; none in the other coastal counties.

Historic Resources

Of the 3,121 historic resources located in Oregon's coastal counties, none are located in coastal erosion high hazard areas. Only one, in Tillamook County, is located in a moderate coastal erosion hazard area, and 54 are located in low or other coastal erosion hazard areas. Of the 54 in low or other coastal erosion hazard areas, 33 are located in Clatsop county and ten in Tillamook County.

Archaeological Resources

Of the 369 archaeological resources in Oregon's coastal counties, 119 are located in an area of high coastal erosion hazards. Of those, 30 are listed on the National Register of Historic places and 2 are eligible for listing. Eighty-seven have not been evaluated as to their eligibility for listing. The 32 listed and eligible archaeological resources in high coastal erosion hazard areas are located in Clatsop, Lincoln, and Tillamook Counties. Twenty-one other listed and eligible archaeological resources are located in moderate coastal erosion hazard areas in the same three counties. Sixty-seven listed and eligible archaeological resources are located in areas of low or other coastal erosion hazard areas in throughout the coastal counties. The coastal portions of Lane and Douglas Counties were not included in this assessment.

Social Vulnerability

The Centers for Disease Control and Prevention (CDC) has calculated a social vulnerability index to assess community resilience to externalities such as natural hazard events. It employs fifteen social vulnerability factors and uses data from the US Census Bureau's American Community Survey. The index is reported in quintiles (1–5). Social vulnerability scores do not vary by hazard. The counties with the greatest social vulnerability statewide are Marion, Morrow, Umatilla, Wasco, Jefferson, Klamath, and Malheur.

For the 2020 vulnerability assessment, DLCD combined this index with the vulnerability scores for state buildings, state critical facilities, and local critical facilities to calculate an overall vulnerability score for each county. According to this limited assessment, Coos County, the coastal portion of Douglas County, and Lincoln County are more vulnerable than the other coastal counties, but still are only moderately vulnerable.

The Department of Geology and Mineral Industries is the agency with primary oversight of the coastal erosion hazard. Based on agency staff review of the 2020 vulnerability assessment available hazard data, knowledge derived from field experience, discussions with scientists, scientific publications, agency reports, and thesis dissertations, DOGAMI ranks Tillamook, Lincoln, Clatsop, and Curry Counties one through four respectively as the counties most vulnerable to coastal erosion in the state.

Coastal hazards in Coos, Lane, and Douglas Counties are considered to be generally negligible. This is because the bulk of these coastlines have little population base and hence are largely unmodified. In Coos County, coastal hazards can be found in a few discrete communities such as adjacent to the Coquille River south jetty in Bandon and along Lighthouse Beach near Cape Arago. Similarly, coastal hazards in Lane County are confined almost entirely to the Heceta Beach community and adjacent to the Siuslaw River mouth, particularly adjacent to the lower estuary mouth where development lines coastal bluffs that are gradually being eroded by riverine processes.

The most vulnerable counties and communities on the Oregon coast include:

Tillamook County (ranked #1):

- Neskowin (erosion and flooding)
- Pacific City (erosion (1970s); replaced by recent sand inundation),
- Tierra del Mar (erosion and flooding)
- Cape Meares (flooding and landsliding)
- Twin Rocks (erosion and flooding)
- Rockaway Beach (erosion and flooding)
- Nehalem (flooding during extreme high tides)

Lincoln County (ranked #2):

- Yachats to Alsea Spit (erosion)
- Waldport (erosion and flooding)
- Alsea Spit (erosion (1982/83 and 1997/98 El Niños); replaced by recent sand inundation)
- Seal Rock (erosion and landsliding)
- Ona Beach to Southbeach (erosion and landsliding)
- Newport (landsliding)
- Beverly Beach (erosion and landsliding)
- Gleneden Beach to Siletz Spit (erosion, landsliding, and flooding)
- Lincoln City (erosion and landsliding)

Clatsop County (ranked #3):

- Falcon Cove (erosion and landsliding)
- Arch Cape (erosion and flooding)
- Tolovana to Cannon Beach (erosion and flooding)
- Cannon Beach (erosion; sand inundation north of Ecola Creek)
- Ecola State Park (landsliding)
- Seaside (flooding)

Curry County (ranked #4):

- Multiple coastal sections affecting Highway 101 (landsliding and erosion)

- Gold Beach, Hunter Creek (erosion)
- Nesika Beach (erosion and landsliding)
- Port Orford (flooding at Garrison Lake)

Coos County (ranked #5):

- North Coos Spit (erosion)
- Lighthouse Beach (bluff erosion)
- Bandon (erosion and flooding, particularly adjacent to the Coquille River south jetty)

Lane County (ranked #6):

- Heceta Beach (erosion and flooding; erosion especially significant in the north at the mouth of Sutton Creek).

Douglas County (ranked #7)

- Coastal hazards in Douglas County are considered to be negligible.

2.2.1.4 Risk

In the 2020 update DOGAMI and DLCD developed a new risk ranking system that combines the probability of the hazard (based on the new approach described above) with the limited vulnerability assessment to arrive at a composite risk score referred to as the 2020 Risk Score.

According to the 2020 risk assessment, the counties at greatest risk from coastal hazards are Clatsop, Lincoln, and Tillamook Counties. This is consistent with DOGAMI's independent assessment.

2.2.2 Droughts

Despite its rainy reputation, the state of Oregon is often confronted with continuing challenges associated with drought and water scarcity. Precipitation in Oregon follows a distinct spatial and temporal pattern; it tends to fall mostly in the cool season (October–March). The Cascade Mountains block rain-producing weather patterns, creating a very arid and dry environment east of these mountains. Moist air masses originating from the Pacific Ocean cool and condense when they encounter the mountain range, depositing precipitation primarily on the inland valleys and coastal areas.

Oregon's water-related challenges are greater than just the temporal and spatial distribution of precipitation in Oregon. A rapidly growing population in the American West has placed a greater demand on this renewable, yet finite resource. The two terms, drought and water scarcity, are not necessarily synonymous; distinctly, water scarcity implies that demand is exceeding the supply. The combined effects of drought and water scarcity are far-reaching and merit special consideration.

Drought is typically measured in terms of water availability in a defined geographic area. It is common to express drought with a numerical index that ranks severity. Most federal agencies use the Palmer Method which incorporates precipitation, runoff, evaporation, and soil moisture. However, the Palmer Method does not incorporate snowpack as a variable. Therefore, it is does not provide a very accurate indication of drought conditions in Oregon and the Pacific Northwest, although it can be very useful because of its a long-term historical record of wet and dry conditions.

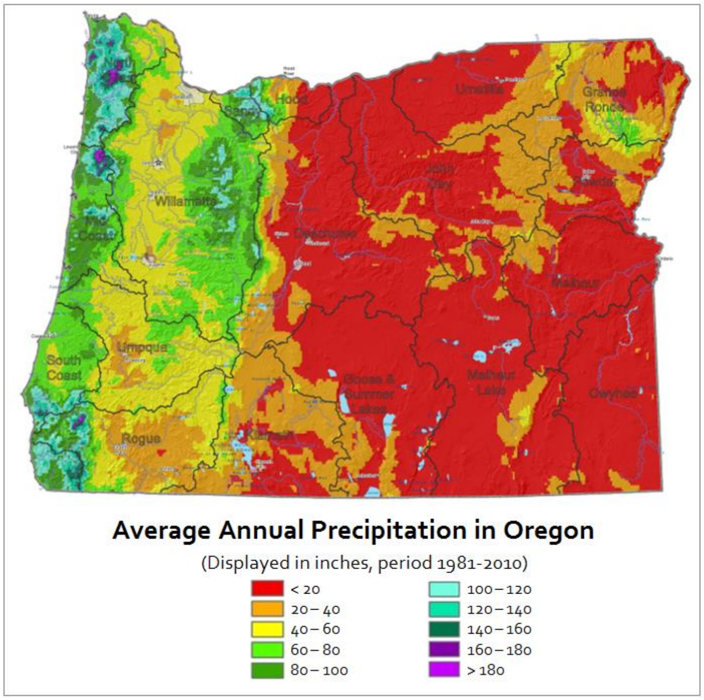
With climate change, snow droughts—the type of drought in which snowpack is low, but precipitation is near normal—are expected to occur more often. The 2015 drought in Oregon was a "snow drought" and serves as a good example of what future climate projections indicate may become commonplace by mid-21st century (Dalton et al., 2017). Going forward, drought indices that can account for a changing climate, such as the Standard Precipitation-Evapotranspiration Index (SPEI), may provide a more accurate estimate of future drought risks.

Oregon's Emergency Operations Plan includes a Drought Annex for the purposes of coordinating state and federal agency response to drought emergencies caused by water shortages and to provide emergency water supplies for human consumption under conditions of inadequate supply. The Annex outlines several steps and lists major responsibilities of various federal, state, and local jurisdictions. It also includes a description of federal drought assistance programs and guidelines for water curtailment planning and program development.

2.2.2.1 Analysis and Characterization

Defining drought can be difficult given the issue of both water supply and demand. Redmond (2002) puts forth a simple definition that encapsulates both supply and demand, "drought is insufficient water to meet needs." Oregon's Legislative Assembly describes drought as a potential state emergency when a lack of water resources threatens the availability of essential services and jeopardizes the peace, health, safety, and welfare of the people of Oregon (Oregon Revised Statute §539.710).

Figure 2-42. Oregon Average Annual Precipitation, 1981–2010



Sources: PRISM Climate Group, Oregon State University (http://www.prism.oregonstate.edu/); map by Oregon Water Resources Department

Droughts can be characterized by the dominant impact caused by increased demand or decreased supply. In the early 1980s, researchers with the National Drought Mitigation Center and the National Center for Atmospheric Research located more than 150 published definitions of drought. There clearly was a need to categorize the hazard by "type of drought." The following definitions are a response to that need. However, drought cannot always be neatly characterized by the following definitions, and sometimes all four definitions can be used to describe a specific instance of drought.

Meteorological or climatological droughts usually are defined in terms of the departure from a normal precipitation pattern and the duration of the event. Drought is a slow-onset phenomenon that usually takes at least three months to develop and may last for several seasons or years.

Agricultural droughts link the various characteristics of meteorological drought to agricultural impacts. The focus is on precipitation shortages and soil-water deficits. Agricultural drought is largely the result of a deficit of soil moisture. A plant's demand for water is dependent on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil.

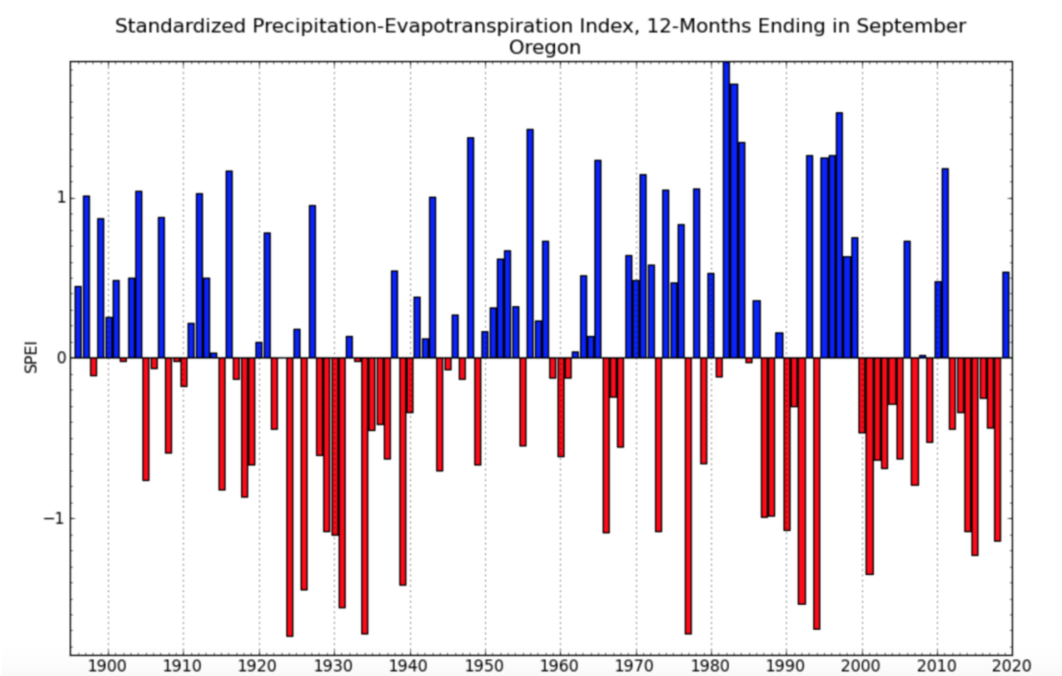
Hydrological droughts refer to deficiencies in surface water and sub-surface water supplies. It is reflected in the level of streamflow, lakes, reservoirs, and groundwater. Hydrological measurements are not the earliest indicators of drought. When precipitation is reduced or deficient over an extended period of time, the shortage will be reflected in declining surface and sub-surface water levels.

Socioeconomic droughts occur when physical water shortage begins to affect people, individually and collectively. Most socioeconomic definitions of drought associate it with supply, demand, and economic good. One could argue that a physical water shortage with no socio-economic impacts is a policy success

History of Droughts in Oregon

Oregon records, dating back to the late 1800s, associate drought with a departure from expected precipitation. Droughts in the Pacific Northwest can persist for a few years, but rarely prolong for a decade. The Dust Bowl era (1930s) had many years with below average precipitation, which caused problems for agriculture, but every year in that decade was not considered to be a drought year. However, three water years in the 1930s fall in the top eight lowest statewide Standard Precipitation-Evapotranspiration Index (SPEI) values on record (1895–2019). While droughts are often referred to as happening in a calendar year, it is more appropriate to define them by water year. The water year begins at the start of the cool, rainy season on October 1 and continues through September 30 of the following year. For example, Water Year 2014 started on October 1, 2013.

Figure 2-43. Water Year Standard Precipitation-Evapotranspiration Index (SPEI) for Oregon



Source: West Wide Drought Tracker, https://wrcc.dri.edu/wwdt/time/, with the following selections: Oregon, SPEI, 1895–2019, September, 12-month

Table 2-28. Water Years with the Lowest SPEI Values, Averaged Statewide, on Record (1895–2019) for the State of Oregon

Rank	Water Year	SPEI Value
1	1924	−1.73
2	1934	−1.72
3	1977	−1.72
4	1994	−1.69
5	1931	−1.56
6	1992	−1.53
7	1926	−1.44
8	1939	−1.41
9	2001	−1.35
10	2015	−1.23
11	2018	−1.14

Source: West Wide Drought Tracker, https://wrcc.dri.edu/wwdt/time/, with the following selections: Oregon, SPEI, 1895–2019, September, 12-month

Low streamflows prevailed in western Oregon during the period from 1976-81, but the worst year, by far, was 1976-77, the single driest year of the century. The Portland Airport received only 7.19 inches of precipitation between October 1976 and February 1977, only 31% of the average 23.16 inches for that period. This drought also impacted California and other parts of the West Coast. It is often acknowledged as one of the most significant droughts in Oregon's history and fittingly shows up as the third lowest SPEI value statewide.

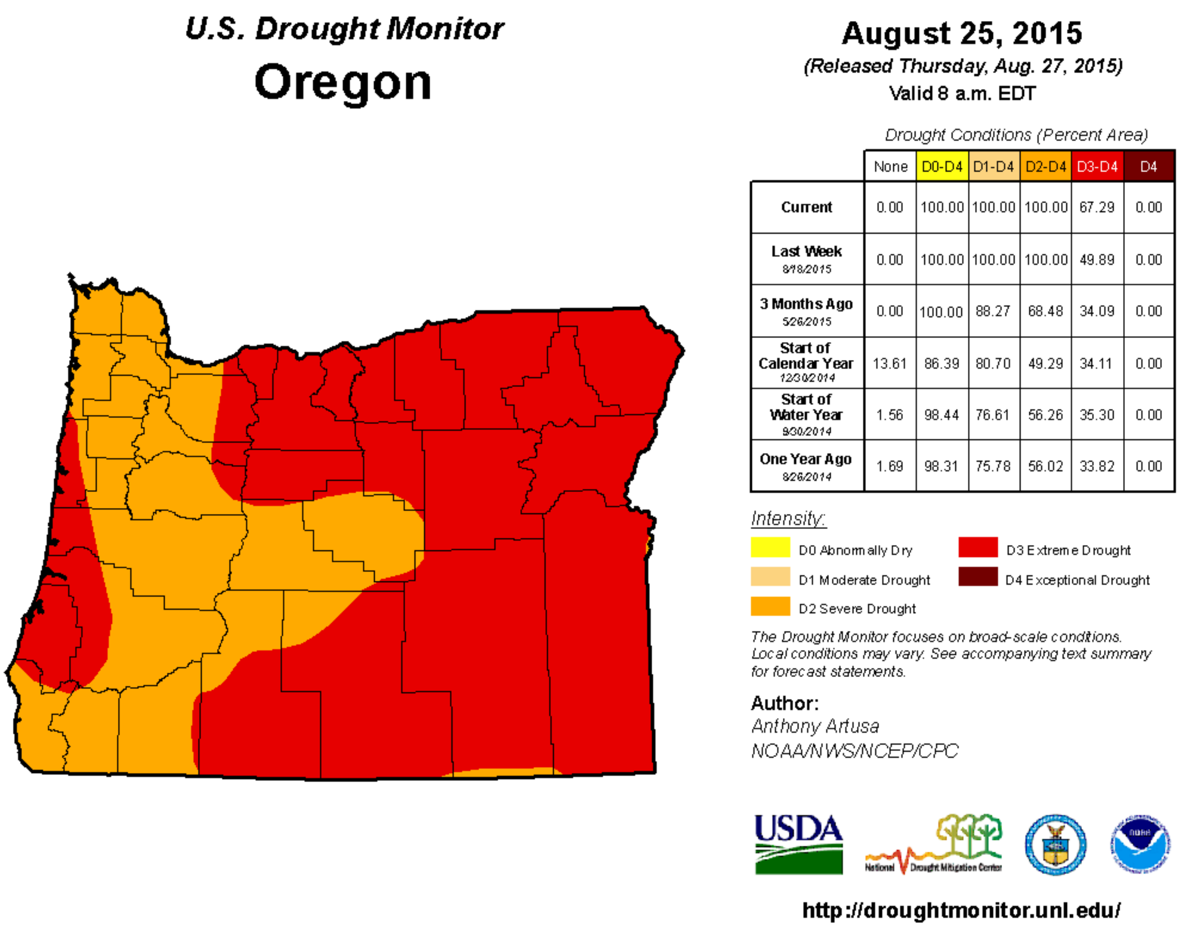
The 1992 drought was not as severe as the 1976-77 drought; however, it did occur toward the end of several years of drier than normal conditions in the late 1980s and early 1990s, making it the peak year for drought conditions. The Governor declared a drought emergency for all Oregon counties (Executive Order 92-21). Forests throughout the state suffered from a lack of moisture. Fires were common and insect pests, which attacked the trees, flourished.

In 2001 and 2002, Oregon experienced drought conditions, affecting six out of eight regions. During the 2005 drought, the Governor issued declarations for 13 counties, all east of the Cascades, and the USDA issued three drought declarations, overlapping two of the Governor's. State declarations were made for Baker, Wallowa, Wheeler, Crook, Deschutes, Klamath, Lake, Hood River, Wasco, Sherman, Gilliam, Morrow, and Umatilla Counties. Federal declarations were made in Coos, Klamath, and Umatilla Counties. Federal drought declarations, similar to declarations by Oregon's governor, provide emergency relief and response actions by various agencies. The U.S. Department of Agriculture, for example, can provide accessibility to emergency loans for crop losses. Since 2001, the Governor has declared a drought in 14 out of 20 years (2001–2020), in at least one Oregon county. Most of these declarations have involved one or more counties in Regions 5-8.

In 2015, Oregon had its warmest year on record. Winter precipitation amounts that year were near normal, but winter temperatures that were 5–6°F above average caused the precipitation that did fall to fall as rain instead of snow, reducing mountain snowpack accumulation. This resulted in record low snowpack across the state, earning official drought declarations for 25 of Oregon's 36 counties (Dalton et al., 2017). At the peak of the drought which began in 2014, all of Oregon was in severe or extreme drought, according to the U.S. Drought Monitor (Figure X).

Recent research has indicated that human-caused climate change exacerbated the 2015 drought in Oregon (Dalton et al., 2017). The 2015 drought in Oregon was a "snow drought" and serves as a good example of what future climate projections indicate may become commonplace by mid-21st century (Dalton et al., 2017).

Figure 2-44. August 25, 2015 U.S. Drought Monitor Report for Oregon



	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.00	100.00	100.00	100.00	67.29	0.00
Last Week 8/18/2015	0.00	100.00	100.00	100.00	49.89	0.00
3 Months Ago 5/26/2015	0.00	100.00	88.27	68.48	34.09	0.00
Start of Calendar Year 12/30/2014	13.61	86.39	80.70	49.29	34.11	0.00
Start of Water Year 9/30/2014	1.56	98.44	76.61	56.26	35.30	0.00
One Year Ago 8/26/2014	1.69	98.31	75.78	56.02	33.82	0.00

Source: U.S. Drought Monitor (http://droughtmonitor.unl.edu/)

Impacts

Droughts are not just a summer-time phenomenon; winter droughts can have a profound impact on the state's agricultural sector, particularly east of the Cascade Mountains. Below-average snowfall in Oregon's higher elevations has a far-reaching effect on the entire state, especially in terms of hydroelectric power generation, irrigation, recreation, and industrial uses. In March of 2014, Mount Ashland Ski Resort in southern Oregon announced that it would be unable to open due to the lack of snow. The following year the Ski Resort had to make snow in order to open. The lack of snow has affected other regions of the state as well. In the Klamath Basin, the Natural Resources Conservation Service reports that the mountains are generally snow-free below 5,000 feet. The Taylor Butte SNOTEL site at elevation 5,030 feet was snow-free on March 1, 2014, a first for the site since it was installed in 1979. Five long-term snow measurement sites in the Klamath basin set new record lows for March 1 snowpack. In fact, 81% of measurement sites west of 115°W (near the eastern border of Nevada) set record low April 1 snowpack in 2015, a quarter of which recorded no snow for the first time (Mote et al., 2016).

There also are environmental consequences. A prolonged drought in Oregon's forests promotes an increase of insect pests, which in turn, damage trees already weakened by a lack of water. In the Willamette Valley, for example, there has been an unusual pattern of tree mortality involving Douglas fir, grand fir, and western red cedar. Water stress brought on by drought and other factors is the central cause in these mortality events (Oregon Department of Forestry, 2008).

A moisture-deficient forest constitutes a significant fire hazard (see the **Wildfire** section of this Plan). The 2015 wildfire season was one of the most severe in the Pacific Northwest. In addition, drought and water scarcity add another dimension of stress to imperiled species. The following information addresses the impact of a severe or prolonged drought on the population, infrastructure, facilities, economy, and environment of Oregon:

Population: Droughts can affect all segments of Oregon's population, particularly those employed in water-dependent activities (e.g., agriculture, hydroelectric generation, recreation, etc.). For example, in 2015 farmers in eastern Oregon's Treasure Valley received a third of their normal irrigation water (Dalton et al., 2017). Also, domestic water-users may be subject to stringent conservation measures (e.g., rationing) during times of drought and could see increases in electricity consumption and associated costs.

Infrastructure: Infrastructure such as highways, bridges, energy and water conveyance systems, etc., is typically unaffected by drought. However drought can cause structural damage. An example would include be areas of severe soil shrinkage. In these uncommon situations, soil shrinkage would affect the foundation upon which the infrastructure was built. In addition, water-borne transportation systems (e.g., ferries, barges, etc.) could be impacted by periods of low water.

Critical/essential facilities: Facilities affected by drought conditions include communications facilities, hospitals, and correctional facilities that are subject to power failures. Storage systems for potable water, sewage treatment facilities, water storage for firefighting, and hydroelectric generating plants also are vulnerable. Low water also means reduced hydroelectric production especially as the habitat benefits of water compete with other beneficial uses.

State-owned or -operated facilities: A variety of state-owned or -operated facilities could be affected by a prolonged drought. The most obvious include schools, universities, office buildings, health-care facilities, etc. Power outages are always a concern. Maintenance activities (e.g., grounds, parks, etc.) may be curtailed during periods of drought. The Oregon Parks and Recreation Department operates several campground and day-use facilities that could be impacted by a drought. For example, in 2015 visitation at Detroit Lake decreased 26% due to low water levels and unusable boat ramps (Dalton et al., 2017).

Economy: Drought has an impact on a variety of economic sectors. These include water-dependent activities and economic activities requiring significant amounts of hydroelectric power. The agricultural sector is especially vulnerable as are some recreation-based economies (e.g., boating, fishing, water or snow skiing). Whole communities can be affected. This was particularly evident during the 2001 water year when many Oregon counties sought relief through state and federal drought assistance programs.

Water Year 2001 was the third driest water year in Oregon's climate history; the drought was one of the most economically significant in the state's history. The community of Detroit, in Marion County, suffered economic hardships when lake levels became too low to support recreational summer activities. The drought directly affected over 200,000 irrigated acres in the Klamath River Basin. Farmers were among the first to be affected, followed by local agricultural support industries (e.g., pesticides, fertilizer, farm equipment, etc.), as well as Native American Tribes which depend on local fisheries.

The 2015 drought during the state's warmest year on record also saw major economic impacts, straining summer recreational activities such as skiing, boating, fishing, and hunting, as well as the local economies that depend on visitors. Detroit Lake, for example, saw a 26 percent decline in visitors due to low water levels and inaccessible boat ramps. Winter recreational activities also felt the impact of a record-low snowpack. Mt. Ashland ski resort wasn't able to open during the 2014-15 ski season.

Limited water supply and high temperatures damaged crops and reduced yields, and ranchers in multiple counties struggled with dry pastures and limited water for livestock. Heat-stressed cattle were fed supplemental rations to help provide necessary nutrients. Some ranchers shipped cattle to feedlots earlier than normal or weaned calves early, due to a lack of feed and water.

The 2015 fire season for the Pacific Northwest was notable for its severity and cost. The Oregon Department of Forestry estimates that large-fire costs for state agencies amounted to $94.4 million, more than $70 million in additional expenses compared to the 10-year average of $22.3 million.

Documenting drought conditions, especially its impacts on people and the environment, is an important component of understanding and preparing for future droughts. Using drought emergency relief funds, the state of Washington completed an economic assessment that quantifies the impacts of the 2015 drought on the state's farmers and ranchers, an effort that had not previously been done at the statewide level.

Oregon does not have the resources to conduct a thorough analysis of drought's impact to various sectors. Today, most impact-related data are collected anecdotally. The state should invest in ways to track and quantify the effects of drought and assist the most vulnerable communities.

Environment: Oregon has several fish species listed as threatened or endangered under the Endangered Species Act (ESA). Some of these species have habitat requirements that are jeopardized by the needs or desires of humans. For example, in times of scarcity, the amount of water needed to maintain habitat for fish species may conflict with the needs of consumptive uses of water. The state of Oregon is committed to implementation of the ESA and the viability of a productive economic base. There are no easy solutions, only continuous work to resolve difficult drought situations.

There were several significant fish die-offs in 2015. Most noteworthy in the Willamette, Clackamas, John Day, and Deschutes Rivers and some hatcheries, where high water temperatures amplified the effects of naturally occurring parasites. Half of Oregon's hatcheries were affected by drought conditions in 2015. The Department of Fish and Wildlife implemented a daily fishing curtailment regulation in nearly every stream in Oregon in 2015. This was the first time that a statewide curtailment was implemented.

Historic Drought Events

Table 2-29. Historic Droughts and Dry Periods in Oregon

Date	Location	Description
1928-41	statewide	prolonged drier than normal conditions that caused major problems for agriculture; the three Tillamook burns, in the normally wet coastal range, the first in 1933, were the most significant impacts of this very dry period
1976-77	western Oregon	the 1977 drought was one of the most significant on record in western Oregon
1985–94	statewide	generally dry period, capped by statewide droughts in 1992 and 1994; 10 consecutive years of dry conditions caused problems throughout the state, such as fires and insect outbreaks
2001-02	affected all regions except Regions 2, 3	the second most intense drought in Oregon's history; 18 counties with state drought declaration (2001); 23 counties state-declared drought (2002); some of the 2001 and 2002 drought declarations were in effect through June or December 2003
2003	Regions 5–8	Governor-declared drought issued in seven counties: Sherman, Wheeler, Crook, Baker, Wallowa, Malheur, and Harney
2004	Regions 5–8	Governor-declared drought issued in four counties: Morrow, Klamath, Baker, and Malheur
2005	Regions 5–7	affected area: 13 of Oregon's 36 counties
2007	Regions 6–8	Governor-declared drought emergency in Lake, Grant, Baker, Union, Malheur, and Harney Counties
2008	Region 5	Governor-declared drought emergency in Sherman and Gilliam Counties
2010	Region 6	Governor-declared drought emergency for Klamath County and contiguous counties
2012	Region 6	Governor-declared drought emergency for the Lost River Basin, located in Klamath County and Lake County
2013	Regions 5–8	Governor-declared drought in Gilliam, Morrow, Klamath, Baker, and Malheur Counties
2014	Regions 4, 6–8	Governor-declared drought in 10 counties: Klamath, Lake, Malheur, Harney, Jackson, Josephine, Crook, Wheeler, Grant, and Baker; Oregon experienced its third driest Nov.–Jan. period since 1895
2015	statewide	Governor-declared drought in 25 counties, with federal declarations in all counties. Oregon experienced its warmest year on record (1895–2019) resulting in record low snowpack across the state. All of Oregon was in severe or extreme drought at the peak of the drought in August, according to the U.S. Drought Monitor.
2018	Regions 4-8, 1	Governor-declared drought in 11 counties
2020	Region 1, 6	Governor-declared drought in Klamath and Curry Counties as of April 28, 2020.

Sources: Taylor and Hatton (1999); Governor-declared drought declarations obtained from the Oregon State Archives division

2.2.2.2 Probability

Drought is a normal, recurrent feature of climate, although many erroneously consider it a rare and random event. It is a temporary condition and differs from aridity because the latter is restricted to low rainfall regions and is a permanent feature of climate. It is rare for drought not to occur somewhere in North America each year. Despite impressive achievements in the science of climatology, estimating drought probability and frequency continues to be difficult. This is because of the many variables that contribute to weather behavior, climate change, and the absence of historic information.

Climate Variability

The variability of Oregon's climate often can be attributed to long-term oscillations in the equatorial Pacific Ocean: El Niño and La Niña. Simply stated, these systems involve the movement of abnormally warm or cool water into the eastern Pacific, dramatically affecting the weather in the Pacific Northwest. El Niño tends to bring warm and dry winters; the inverse is true with La Niña. However, there have been wet years during an El Niño event, dry years in a La Niña, and both types of water years in neutral conditions. In other words, El Niño and La Niña do not explain all of the variability in every given winter. Also, climate change is reducing the robustness of the low-elevation snowpack, which will likely influence the frequency of drought conditions and associated impacts on Oregon communities.

Drought – The Nebulous Natural Hazard

- Drought is often associated with water scarcity, which usually is perceived as a "human-caused" hazard, rather than a "natural" hazard.
- Drought is frequently an "incremental" hazard, the onset and end are often difficult to determine. Also, its effects may accumulate slowly over a considerable period of time and may linger for years after the termination of the event.
- Quantifying impacts and provisions for disaster relief is a less clear task than it is for other natural hazards.
- The lack of a precise and universally accepted definition adds to the confusion about whether or not a drought actually exists.
- Droughts are often defined by growing seasons, the water year, and livestock impacts.

An El Niño system moves heat, both in terms of water temperature and in atmospheric convection. The heat is transported toward North America, increasing the likelihood of mild temperatures and dry conditions in Oregon. Its effects are most pronounced from December through March.

La Niña conditions are more or less opposite of those created by El Niño. It involves the movement of abnormally cool water into the eastern Pacific. This event increases the likelihood of cooler than normal temperatures in Oregon and increased precipitation. It also is most pronounced from December to March

Predicting Droughts in Oregon

Predicting weather patterns is difficult at best; however, the 1997-98 El Niño event marked the first time in history that climate scientists were able to predict abnormal flooding and drought months in advance for various locations around the United States (http://www.nationalgeographic.com/elnino/mainpage2.html). The methodology consists of monitoring water temperatures, air temperatures, and relative humidity plus measuring sea-surface elevations. Once an El Niño or La Niña pattern is established, climatologists can project regional climatic behavior. Although the scientific community is optimistic about its recent forecasting achievements, not all droughts are associated with El Niño or La Niña events.

Climate Change

Climate models project warmer, drier summers for Oregon, with mean projected increases in summer temperatures of 4.5 to 6.3 °F and a decline in mean summer precipitation amounts of 6.3 to 8.7% by mid-21st century relative to late 20th century depending on emissions scenario (Table 2-3, Table 2-4). These summer conditions will be coupled with projected decreases in mountain snowpack due to warmer winter temperatures. Models project a mean increase in winter temperatures of 3.3 to 4.5 °F by mid-21st century relative to late-20th century depending on emissions scenario (Table 2-3). This combination of factors increases the likelihood that Oregon will experience increased frequency of one or more types of drought drought under future climate change. In addition, Oregon is projected to experience an increase in the frequency of summer drought conditions as summarized by the standard precipitation-evaporation index (SPEI) due largely to projected decreases in summer precipitation and increases in potential evapotranspiration (Dalton et al., 2017).

It is *very likely* (>90%) that drought frequency due to low spring snowpack—"snow droughts"—will increase in the future because of the direct link between temperature and snow accumulation and melt. The 2015 snow drought provides a glimpse into the future. It is also *very likely* (>90%) that drought frequency due to high spring and summer evaporative demand will increase in the future. It is likely (>66%) that drought frequency due to low summer runoff will increase. It is *more likely than not* (>50%) that drought frequency due to low summer precipitation and due to low summer soil moisture in the upper soil layer will increase. Snow drought is very likely to increase in mid-to-low elevation mountainous regions of the Cascades (Regions 2-4, 6) and eastern Oregon (Region 7). Droughts due to lower summer precipitation, soil moisture, and runoff are more likely to increase in western Oregon (Regions 1-4) than in eastern Oregon (particularly Regions 6 and 8) due to projected spatial patterns in precipitation change.

2.2.2.3 Vulnerability

There is a tendency to associate drought conditions with the arid sections of the state, principally east of the Cascade Mountains. However, this perception is not entirely accurate. During the winter of 2002-03, during 2015 and as recent as 2020, Coos and Curry Counties on the southwestern coast experienced drought conditions.

When a drought occurs, it may affect all regions of the state. However, most of Oregon's urban areas usually fare much better during a drought than rural, less populated regions of the state.

By encouraging or invoking water conservation measures during a drought, a public municipal water system can reduce residential and industrial demand for water.

Rural areas are much more dependent on water for irrigation for agricultural production. Landowners in rural or less-populated areas are often reliant on individual, privately owned wells as a drinking water source. Generally speaking, counties east of the Cascades and in the southern portions of the state are more prone to drought-related impacts.

Most Vulnerable Communities

The Oregon Water Resources Department (OWRD) is the state agency with primary oversight of drought conditions and mitigation activities. Based on the frequency of drought declarations issued by the Governor issued since 1992, Klamath and Baker Counties are the most vulnerable to drought. Klamath County has been under a Governor-declared drought on 14 occasions since 1992, while Baker County has received 11 declarations during this same time period. Lake, Malheur, Sherman, Gilliam, and Morrow Counties are vulnerable as well.

These communities were identified as most vulnerable based on only one indicator: the frequency of drought declarations. A broader, more detailed assessment that considers other factors, such as past economic or environmental drought-related impacts for each community, would help the state better prioritize its mitigation and response-related activities.

Social Vulnerability

The Centers for Disease Control and Prevention (CDC) has calculated a social vulnerability index to assess community resilience to externalities such as natural hazard events. It employs fifteen social vulnerability factors and uses data from the US Census Bureau's American Community Survey. The index is reported in quintiles (1-5). Social vulnerability scores do not vary by hazard. The counties with the greatest social vulnerability statewide are Marion, Morrow, Umatilla, Wasco, Jefferson, Klamath, and Malheur. The high social vulnerability of Klamath, Malheur, and Morrow Counties compounds their high vulnerability to drought.

2.2.2.4 Risk

With respect to natural hazards, risk can be expressed as the probability of a hazard occurring combined with the potential for property damage and loss of life. The probability of drought is difficult to predict because of the multitude of variables that contribute to it and the lack of historic data. Projected increases in temperature coupled with decreases in precipitation make it likely that Oregon will experience more frequent droughts, especially "snow droughts." Droughts occur throughout the state, winter and summer, and create a wide variety of impacts, particularly in rural areas. While the communities most vulnerable to drought are all located east of the Cascades, drought occurs and its impacts are felt statewide. We do not have the data to make a quantitative assessment of risk from drought; however, there has been a drought event in fourteen of the last twenty years. Qualitatively, the risk of drought in Oregon is at least moderate to high, and likely to become very high in future years.

2.2.3 Earthquakes

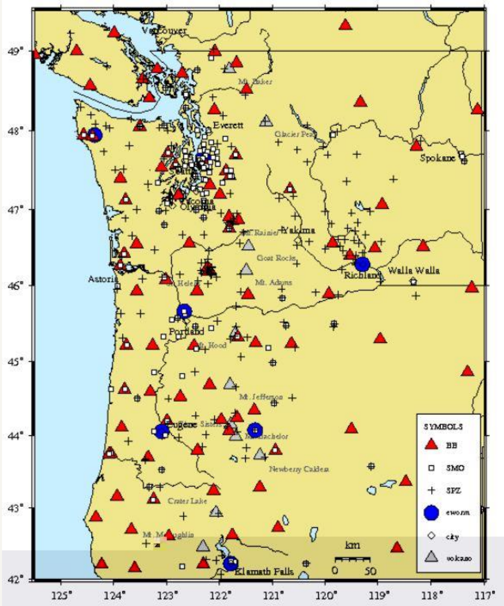
Oregon has experienced few damaging earthquakes during its recorded history, leading to complacency and lack of attention to earthquake-resistant design and construction. Since the mid-1980s, an increasing body of geologic and seismologic research has changed the scientific understanding of earthquake hazards in Oregon, and in recent years several large and destructive earthquakes around the world have heightened public awareness. Recognized hazards range from moderate sized crustal earthquakes in eastern Oregon to massive subduction zone megathrust events off the Oregon coast. All have the potential for significant damage as long as most of Oregon's buildings and infrastructure have inadequate seismic resistance. The scale of structural retrofit and replacement needed to make Oregon earthquake safe is huge, and beyond our capacity to implement in anything less than decades. To manage the human and economic impact of the next damaging earthquake will require thoughtful and comprehensive emergency response planning, based on realistic loss estimates driven by accurate and detailed geologic and seismologic, structural and cultural information. To minimize the human and economic impact of the next damaging earthquake will require a sustained program of public education, forward-thinking research, and structural replacement and retrofit, based on cost-effective earthquake resistant design and a combination of public funding and private sector incentives

2.2.3.1 Analysis and Characterization

Earthquake Sources

Earthquakes are a highly variable natural phenomenon. The vast majority occur when two masses of rock in the earth's crust abruptly move past each other along a large crack or fracture called a fault. The energy released as the two parts slide along the fault produces waves of shaking that we perceive as an earthquake. Faults typically build up stress over decades to millennia in response to large-scale movement of the earth's tectonic plates. Even the most active faults only produce damaging earthquakes at intervals of a century or more, and for many the intervals are much longer. As a result, it is very difficult to forecast the likelihood of an earthquake on a particular fault because we rarely have a long enough record to determine a statistically meaningful return period (average time between earthquakes).

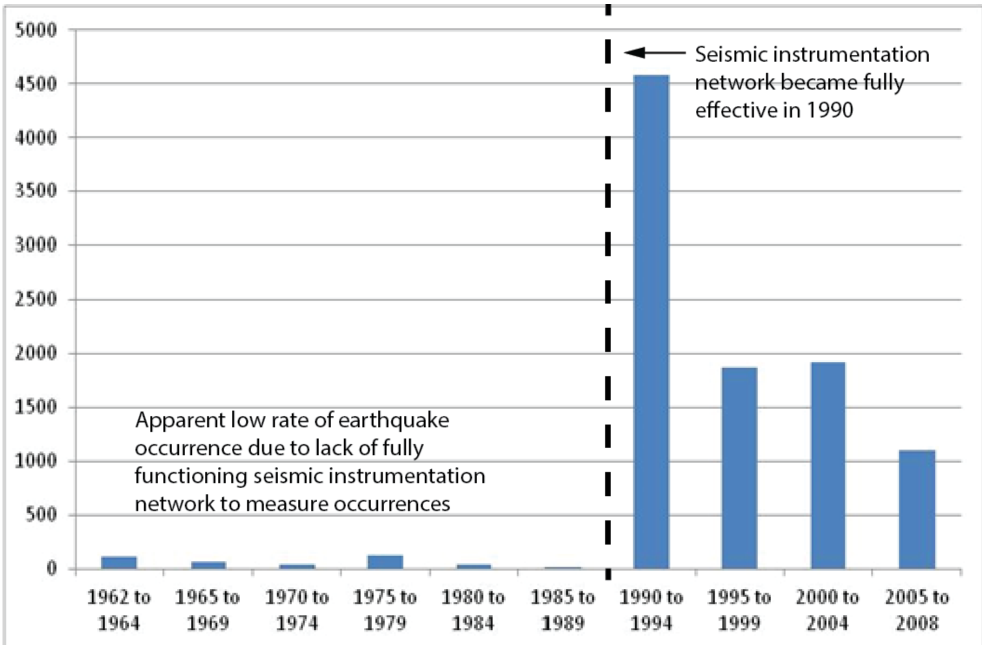
Figure 2-45. Earthquake Monitoring Stations in the Pacific Northwest



Note: The earthquake monitoring network system is operated out of the University of Washington by the Pacific Northwest Seismic Network.

Source: Pacific Northwest Seismic Network (http://www.pnsn.org/)

Figure 2-46. Annual Rate of Earthquake Occurrence in Oregon, in 5-Year Increments



Note: Seismic instruments began operation in 1970, but the network only became fully effective in 1990. Spike in earthquake numbers in the early 1990s is due to aftershocks from the 1993 Scotts Mills and Klamath Falls earthquakes.

Source: Unknown

The history of earthquakes in a region comes from three types of information. Instrumental data comes from networks of seismic recording instruments (seismographs) that are widely deployed in the Pacific Northwest.

Seismic networks can detect very small earthquakes, locate them to within a few miles, and determine their magnitude accurately. Seismographs have only existed for about a century, and in Oregon, the instrumental record is really only complete and modern from about 1990 on. Historical felt location data comes from verbal and written reports of earthquake effects. The felt record extends back to the mid-1800s for Oregon, but only locates moderate to large earthquakes, and those only with an accuracy of tens or even hundreds of miles.

Paleoseismic data use geologic records of earthquake effects to determine the approximate size and timing of earthquakes that happened in prehistoric times. The paleoseismic record can extend back for thousands or tens of thousands of years, but provides only approximate information about the size, time and place of past large earthquakes.

Figure 2-47. Deep Sea Sediment Cores that Record Past Megathrust Earthquakes off the Oregon Coast

Note: Red T's mark the top of each layer

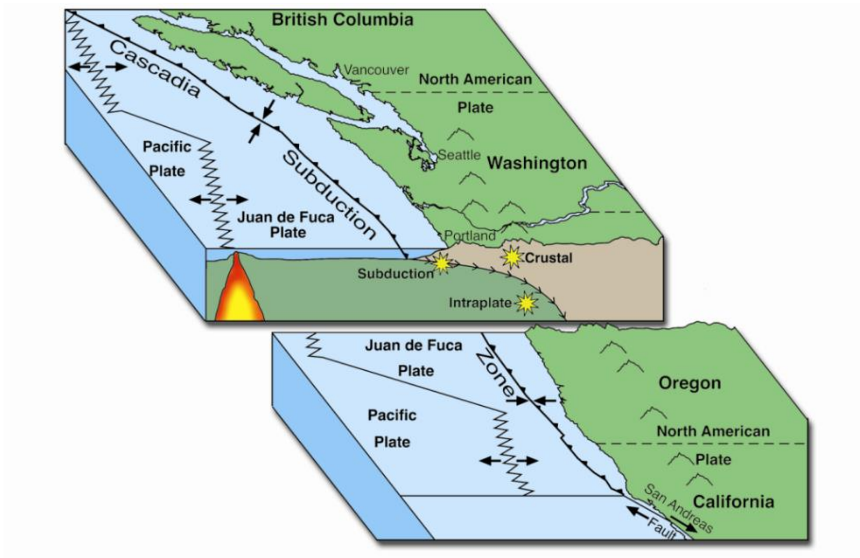
Source: Goldfinger et al. (2011)

In Oregon, the combined earthquake history derived from these three sources clearly outlines two major types of earthquake hazard and two less significant sources. By far the greatest is the hazard posed by infrequent **megathrust earthquakes** on the Cascadia Subduction Zone. The second major hazard comes from smaller **crustal earthquakes** on faults in or near populated areas, which includes all of Oregon's damaging historic earthquakes. Intraplate earthquakes, which have been historically damaging in the Puget Sound area, are possible in Oregon but no damaging prehistoric or historic events are known. Finally, earthquakes associated with Oregon's many young volcanoes may produce damaging shaking in communities close to the volcano.

The Cascadia Subduction Zone is the boundary between two of the earth's crustal plates. These continent-sized plates are in constant slow motion, and the boundaries between plates are the site of most earthquake activity around the globe. At the Cascadia Subduction Zone, the Juan De Fuca plate, located offshore of Oregon and Washington, slides to the northeast and under the North American plate, which extends from the Oregon coast clear to the middle of the Atlantic Ocean. The Juan de Fuca plate slides beneath the continent (subducts) at about 1.5 inches per year, a speed which has been directly measured using high-accuracy GPS. The fault that separates the plates extends from Cape Mendocino in Northern California to Vancouver Island in British Columbia, and slopes down to the east from the sea floor. The fault is usually locked, so that rather than sliding slowly and continuously, the 1.5 inches per year of subduction motion builds tremendous stress along the fault. This stress is periodically released in a megathrust earthquake, which can have a magnitude anywhere from 8.3 to 9.3.

Figure 2-48 is a schematic three-dimensional diagram with the generalized locations of the three types of earthquake sources found in Oregon: subduction zone, crustal, and intraplate.

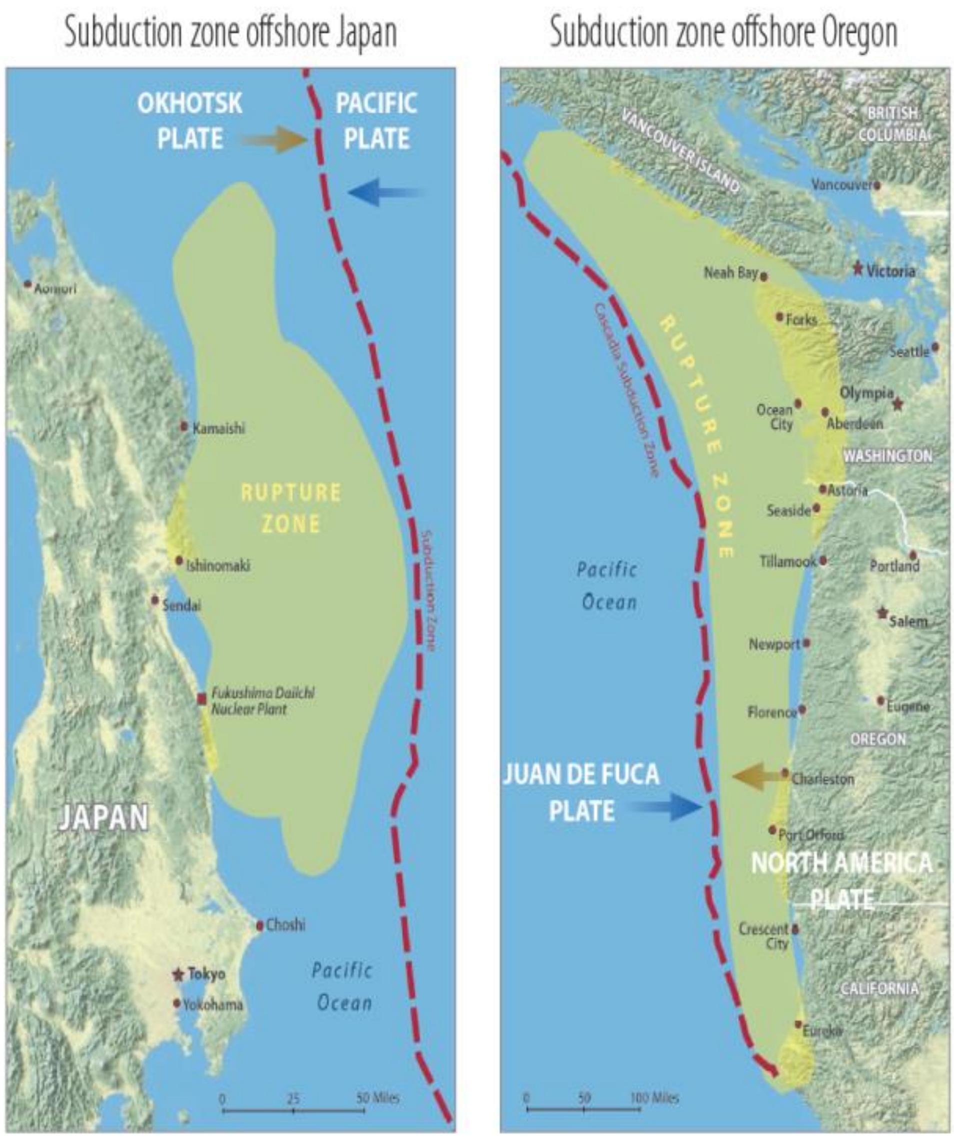
Figure 2-48. General Source Areas for Subduction Zone, Crustal Earthquakes, and Intraplate Earthquakes



Source: DOGAMI

The Cascadia Subduction Zone closely mirrors the subduction zone in northern Japan that produced the 2011 Tohoku earthquake (**Figure 2-49**). This magnitude 9 megathrust event and its associated tsunami captured the world's attention with unforgettable images of destruction on a massive scale. Oregon should regard this as a window into our future, as this is the very type of earthquake that our best science tells us is likely on the Cascadia Subduction Zone. Particular attention must be paid to the incredibly destructive tsunami that accompanied the Tohoku earthquake, and we must plan for a similar tsunami in Oregon. (See the **Tsunami** section of this Plan for more information about tsunamis in Oregon.)

Figure 2-49. Comparison of the Northern Japan Subduction Zone in and the Cascadia Subduction Zone



Note: Yellow patches are the measured earthquake rupture zone in Japan, modeled earthquake rupture zone in Oregon.

Source: DOGAMI

Crustal earthquakes occur for the most part on shore on much smaller faults located in the North American plate. These are the more familiar "California-style" earthquakes with magnitudes in the 5 to 7 range. Although much smaller than the megathrust earthquakes, crustal earthquakes may occur much closer to population centers, and are capable of producing severe shaking and damage in localized areas. For many parts of eastern Oregon, crustal faults dominate the hazard, and they may also have a significant impact in the Portland region and Willamette Valley.

2011 Tohoku Earthquake Numbers

- about 16,000 dead
- 92% of deaths due to tsunami (drowning)
- Fatality rate within the tsunami inundation zone about 16%
- about 4,000 missing (as of 10/12/2011)
- about 6,000 injuries
- Population within 40 km of coastline about 3,000,000
- about 300,000 homes destroyed
- about 600,000 homes damaged

Intraplate earthquakes are a third type that is common in the Puget Sound, where they represent most of the historical record of damaging events. In Oregon, these earthquakes occur at much lower rates, and none have ever been close to a damaging magnitude. They contribute little to the aggregate hazard in most of Oregon.

Earthquake Effects

Earthquake damage is largely controlled by the strength of shaking at a given site. The strength of shaking at any point is a complex function of many factors, but magnitude of the earthquake (which defines the amount of energy released) and distance from the epicenter or fault rupture, are the most important. The ripples in a pond that form around a dropped pebble spread out and get smaller as they move away from the source. Earthquake shaking behaves in the same way: you can experience the same strength of shaking 10 miles from a magnitude 6 earthquake as you would feel 100 miles from a magnitude 9 earthquake.

Two measurement scales are used to describe the magnitude and intensity of earthquakes. To measure the magnitude, the "moment magnitude" (M_w, or M) scale uses the Arabic numbering scale. It provides clues to the physical size of an earthquake (NOAA-OAR-CPO-2014-2003692) and is more accurate than the previously used Richter scale for larger earthquakes. The second scale, the "modified Mercalli," measures the shaking intensity and is based on felt observations and is therefore more subjective than the mathematically derived moment magnitude. It uses Roman numerals to indicate the severity of shaking. It is important to understand the relationship between the intensity of shaking the amount of damage expected from a given earthquake scenario.

Table 2-30 gives an abbreviated description of the 12 levels of Modified Mercalli intensity.

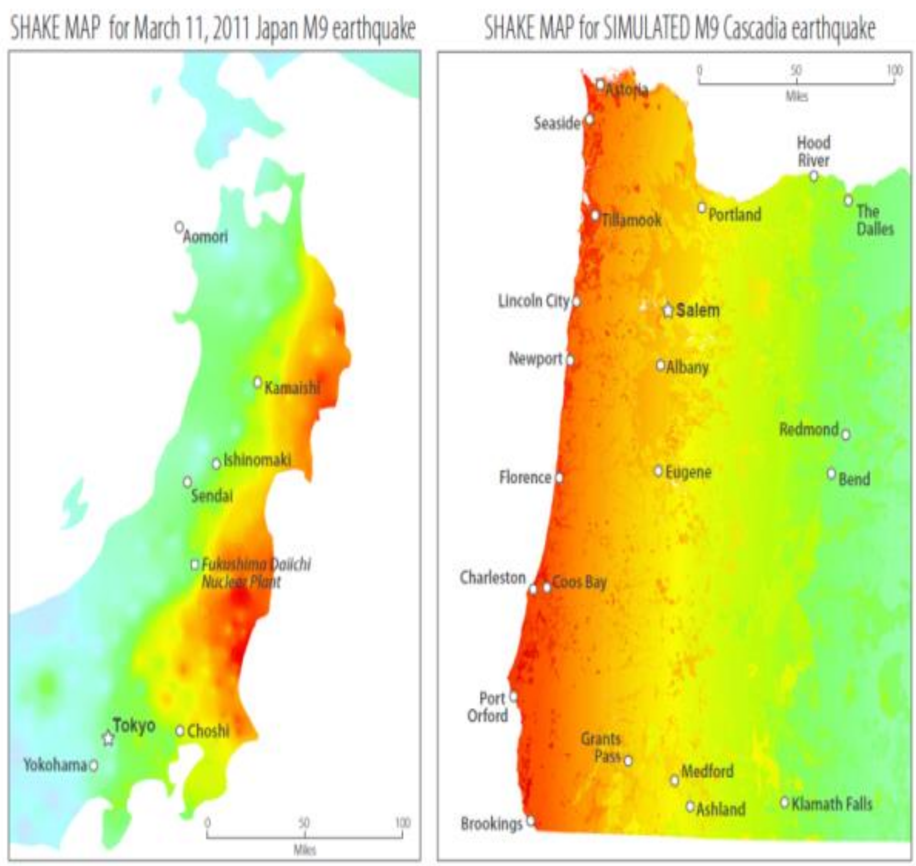
Table 2-30. Levels of Modified Mercalli Intensity

Level	Intensity
I	not felt except by a very few under especially favorable conditions
II	felt only by a few persons at rest, especially on upper floors of buildings
III	felt quite noticeably by persons indoors, especially on upper floors of buildings; many people do not recognize it as an earthquake; standing motor cars may rock slightly; vibrations similar to the passing of a truck; duration estimated
IV	felt indoors by many, outdoors by few during the day; at night, some awakened; dishes, windows, doors disturbed; walls make cracking sound; sensation like heavy truck striking building; standing motor cars rocked noticeably
V	felt by nearly everyone; many awakened; some dishes, windows broken; unstable objects overturned; pendulum clocks may stop
VI	felt by all, many frightened; some heavy furniture moved; a few instances of fallen plaster; damage slight
VII	damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken
VIII	damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse; damage great in poorly built structures; fall of chimneys, factory stacks, columns, monuments, walls; heavy furniture overturned
IX	damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; damage great in substantial buildings, with partial collapse; buildings shifted off foundations
X	some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; rails bent
XI	few, if any (masonry) structures remain standing; bridges destroyed; rails bent greatly
XII	damage total; lines of sight and level are distorted; objects thrown into the air

Sources: http://earthquake.usgs.gov/learn/topics/mercalli.php, abridged from *The Severity of an Earthquake* (http://pubs.usgs.gov/gip/earthq4/severitygip.html); U.S. Geological Survey General Interest Publication 1989-288-913

Future megathrust earthquakes on the Cascadia Subduction Zone (CSZ) will occur off the coast, and the strength of shaking will decrease inland. Oregon coastal communities will experience severe shaking, but the Portland area and Willamette Valley communities are far enough inland that they will feel much less shaking. Because of the size of the megathrust fault, the shaking will impact all of Oregon west of the Cascades, and will still be felt to the east of the Cascades, and will extend to northern California and British Columbia. The other unique characteristic of megathrust earthquakes is that the strong shaking will last for several minutes, in contrast to a large crustal earthquake, which might shake for only 30 seconds. The long duration of shaking contributes greatly to damage, as structures go through repeated cycles of shaking. **Figure 2-50** shows a side-by-side comparison of ShakeMaps for (a) the 2011 M9 earthquake in Japan, and (b) a simulated M9 CSZ event in Oregon.

Figure 2-50. Comparison of Measured Shaking from Tohoku Earthquake and Simulated Shaking from M9 Cascadia Megathrust Earthquake

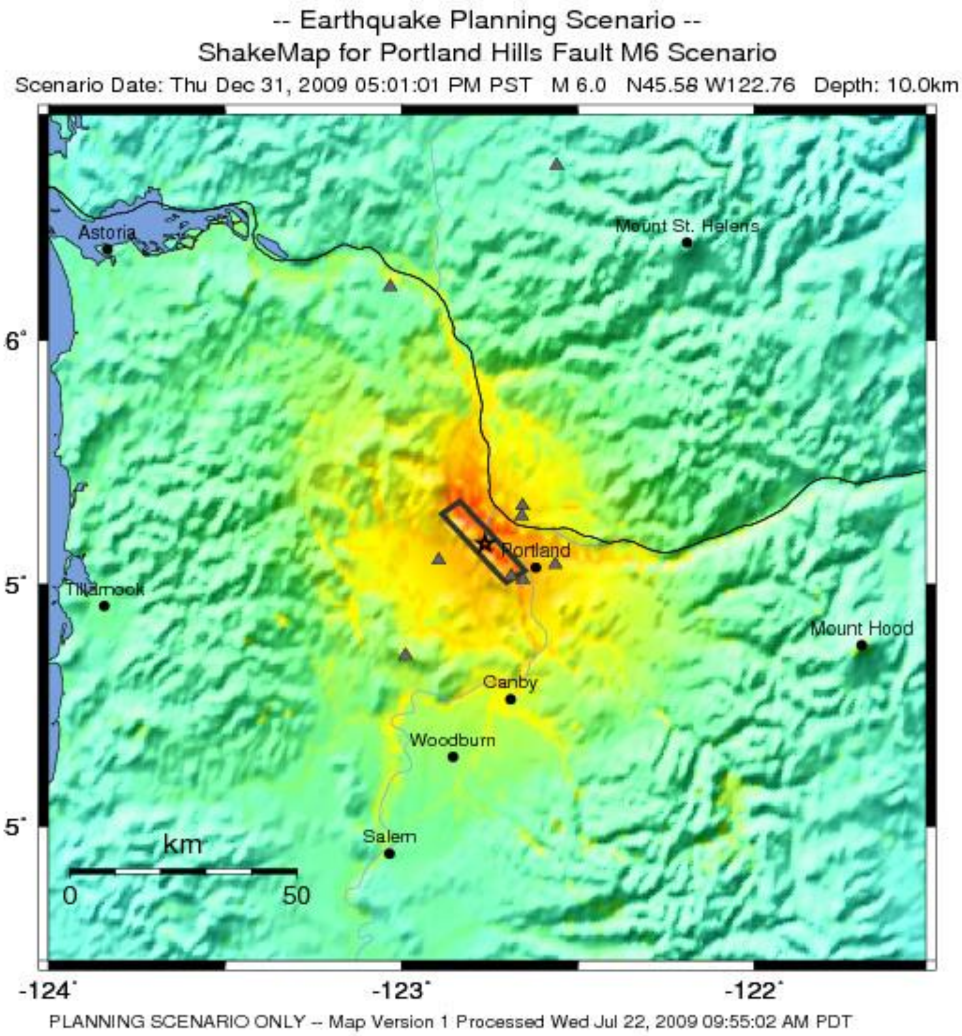


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Source: DOGAMI, *Cascadia* Winter 2012(http://www.oregongeology.org/pubs/cascadia/CascadiaWinter2012.pdf)

Future crustal earthquakes will occur along one of many Oregon fault lines, and the shaking will be strongest near the epicenter, and will decrease fairly quickly as you move away. So a magnitude 6 earthquake in Klamath Falls may cause significant damage near the epicenter, but will be only weakly felt in Medford or Eugene. **Figure 2-51** shows a M6 crustal fault ShakeMap scenario along the Portland Hills fault.

Figure 2-51. Simulated Shaking from M6.0 Crustal Earthquake on the Portland Hills Fault

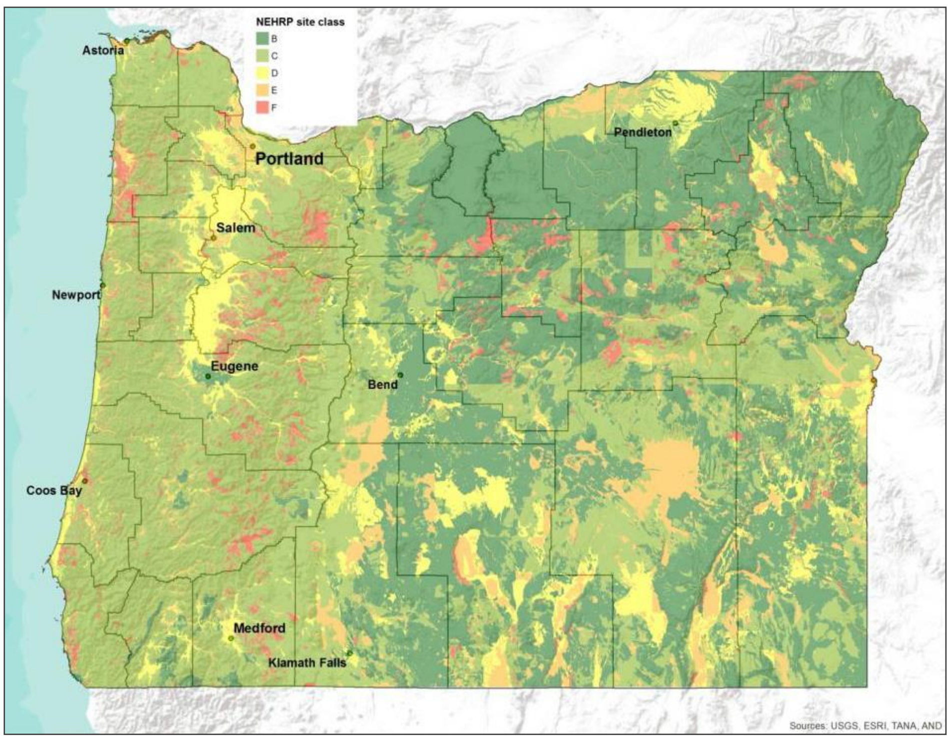


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Source: U.S. Geological Survey

The other important factor in controlling earthquake damage is the contribution of local geology. Soft soils can strongly amplify shaking (**Figure 2-52**), loose saturated sand or silt can liquefy, causing dramatic damage, and new landslides can occur on steep slopes while existing landslide deposits may start to move again. These effects can occur regardless of earthquake source, and the geologic factors that cause them can be identified in advance by geologic and geotechnical studies. Liquefaction- and earthquake-induced landslides are both more likely to occur during the several minutes of shaking produced by a megathrust earthquake, and these effects are expected to be widespread during the next event (**Figure 2-53**, **Figure 2-54**, and **Figure 2-55**). In 2013, DOGAMI published a suite of statewide earthquake hazard maps with GIS files in Open-File Report O-13-06, *Ground motion, ground deformation, tsunami inundation, coseismic subsidence, and damage potential maps for the 2012 Oregon Resilience Plan for Cascadia Subduction Zone earthquakes* (Madin and Burns, 2013; http://www.oregongeology.org/pubs/ofr/p-O-13-06.htm). DOGAMI is currently updating those maps with more detailed geologic information using funds from Oregon DAS-GEO. The updates will be published in 2021

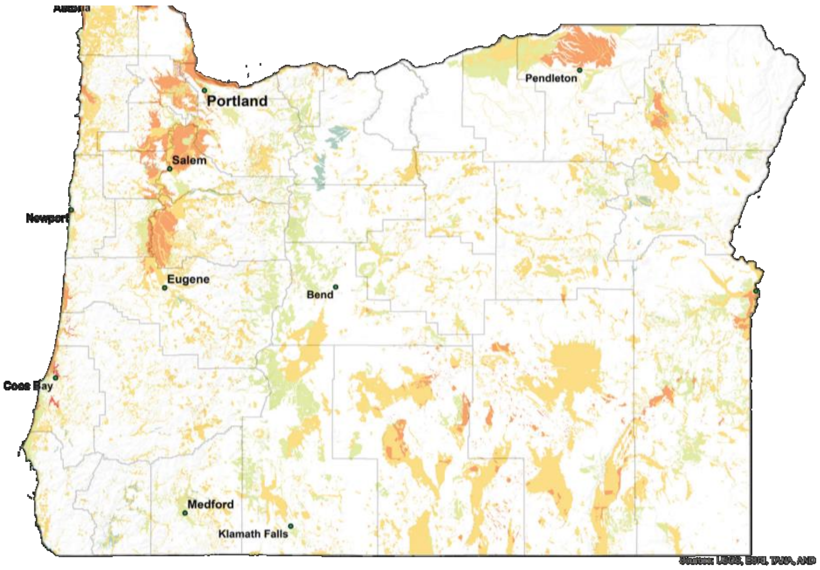
Figure 2-52. Soils Map Showing Where Soils Can Amplify Earthquake Ground Shaking



Note: This NEHRP soils map shows areas where soils can amplify the earthquake ground shaking. NEHRP site class F soils (dark orange on map) are prone to produce the greatest amplification.

Source: Madin and Burns (2013)

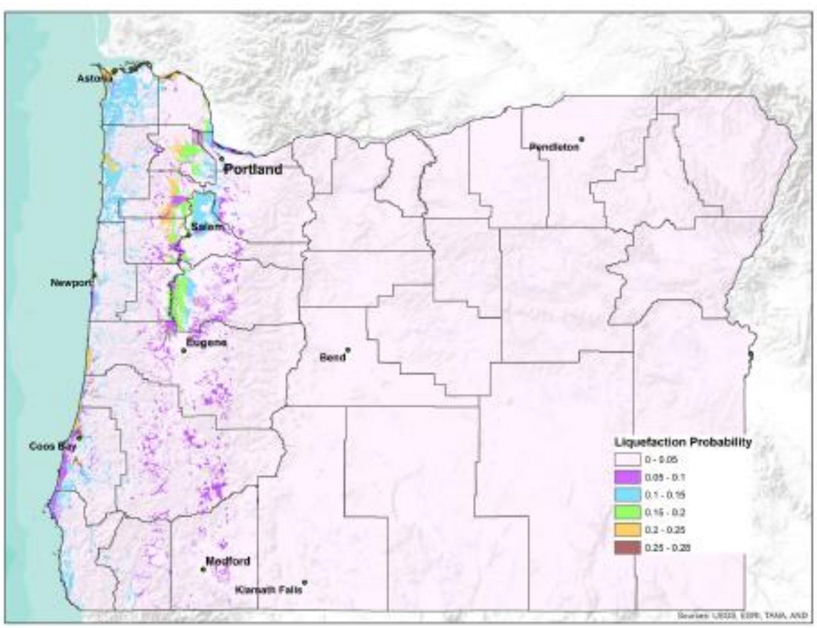
Figure 2-53. Liquefaction Susceptibility Map



Note: This liquefaction susceptibility map shows areas where soils can liquefy due to the earthquake ground shaking. Areas in red are most prone to liquefy.

Source: Madin and Burns (2013)

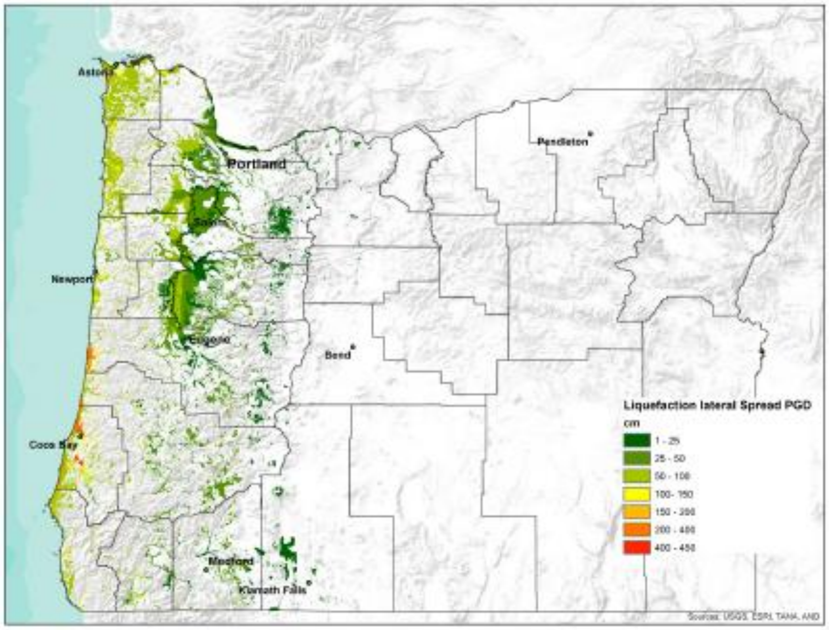
Figure 2-54. Liquefaction Probability Map



Note: This liquefaction probability map shows the probability of soil liquefaction due to a magnitude 9 Cascadia earthquake. Areas in dark red have the highest probability.

Source: Madin and Burns (2013)

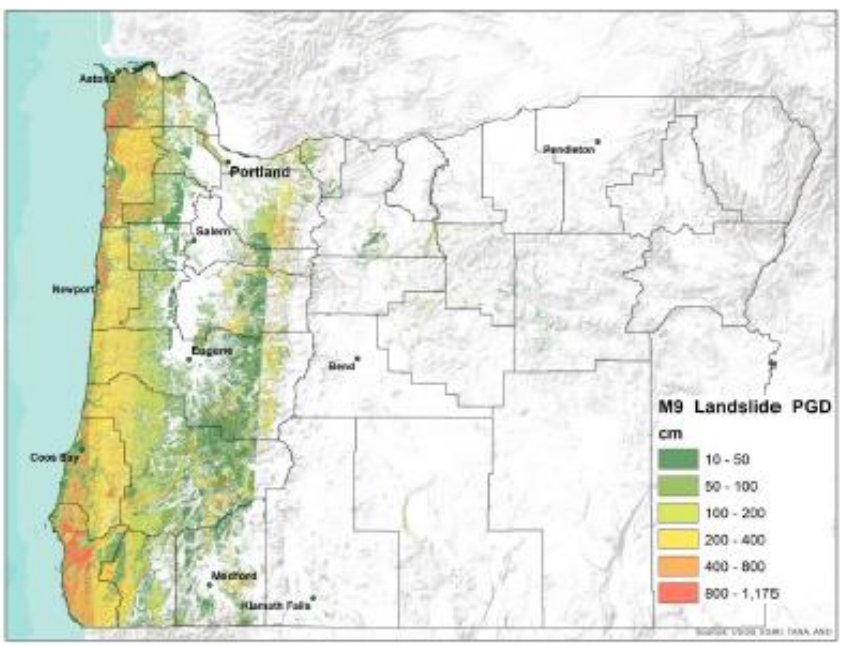
Figure 2-55. Lateral Spreading Map



Note: This lateral spreading map shows areas of lateral spreading hazard due to a magnitude 9 Cascadia earthquake. Areas in red have the highest displacement.

Source: Madin and Burns (2013)

Figure 2-56. Expected Displacement Map



Note: This landslide hazard map shows areas and amount of expected displacement due to a magnitude 9 Cascadia earthquake. Areas in red have the highest displacement.

Source: Madin and Burns (2013)

Historic Earthquake Events

Table 2-31 lists historic earthquakes in Oregon from both CSZ events and combined crustal events.

Table 2-31. Historic Earthquakes in Oregon

Date	Location	Description
1873[1]	Del Norte County, Calif.	felt in Portland; localized chimney damage as far north as Port Orford, Oregon
1877[1]	Portland, Oregon	intensity VII; chimney damage
1892[1]	Portland, Oregon	intensity VI; affected area: 26,000 square kilometers; buildings swayed, people terrified and rushed into the street; felt in Astoria and Salem
1893[1]	Umatilla, Oregon	intensity VI-VII; damage to buildings in Umatilla
1896[1]	McMinnville, Oregon	intensity VI; three shocks in succession in McMinnville; main shock felt at Portland and Salem
1906[1]	Paisley, Oregon	intensity V; three additional shocks followed within 1.5 hours
1913[1]	Seven Devil's Mountains of western Idaho	intensity V; broke windows and dishes
1915[1]	Portland, Oregon	intensity V; three shocks reported; rattled dishes, rocked chairs, and caused fright at Portland
1923[1]	southern Oregon	intensity V; plaster fell at Alturas, California; tremor felt at Lakeview, Oregon
Apr. 8, 1927[1]	eastern Baker County,	maximum intensity V (Halfway and Richland); center: eastern Baker County; felt widely over eastern Oregon
July 15 – Nov. 1936[1]	Milton-Freewater, Oregon	intensity VII; magnitude 5.75; center: near the State line between Milton-Freewater, Oregon, and Walla Walla, Washington; affected area: 272,000 sq km in the two states and Idaho; ground cracking observed 6.5 km west of Freewater; marked changes in flow of well water chimneys damaged, plaster broken and walls cracked in Freewater and Umapine; total damage: $100,000; numerous aftershocks up to Nov. 17 (more than 20 moderate shocks during the night and stronger ones (V) on July 18 and Aug. 4 and 27)
Dec. 29, 1941[1]	Portland, Oregon	intensity VI; affected area: 13,000 sq km (Portland); felt at Hillsboro, Sherwood, Yamhill, and into Washington (Vancouver and Woodland); windows broken
Apr. 13, 1941[1]	Olympia, Wash.	magnitude 7.0; at Olympia, Washington, and a broad area around the capital city; fatalities: 8; damage: $25 million; affected area: 388,000 sq km; damage: widespread (Oregon); injuries: several (Astoria and Portland); maximum intensity: VIII (Clatskanie and Rainier); chimneys twisted and fell; damage to brick and masonry
Dec. 15, 1953[1]	Portland, Oregon	intensity: VI; minor damage (Portland area); affected area: 7,700 sq km; one cracked chimney and slight damage to fireplace tile; plaster cracking (Portland and Roy, Oregon, and Vancouver, Washington)
Nov. 16, 1957[1]	Salem, Oregon	intensity VI; affected area: 11,600 sq km (northwestern Oregon); frightened all in the city and cracked plaster (West Salem)
Aug. 18, 1961[1]	Albany/Lebanon, Oregon	intensity VI; magnitude 4.5; affected area: 18,000 sq km; felt region extended into Cowlitz County, Wash; damage: minor (Albany and Lebanon, south of the 1957 center); felt in both cities; two house chimneys toppled, and plaster cracked
Nov. 6, 1961[1]	Portland, Oregon	intensity VI; affected area: 23,000 sq km (northwestern Oregon and southwestern Washington); principle damage: plaster cracking; part of a chimney fell, and windows and lights broke

Date	Location	Description
May 26 – June 11, 1968[1]	Oregon/Calif. border	intensity: VI; magnitude: 4.7; affected area: 18,000 sq km (in the two states); series of earthquakes near the Oregon-California border; chimneys fell or cracked, and part of an old rock cellar wall fell; ground fissures in Bidwell Creek Canyon, near Fort Bidwell, California
1993[2]	Scott's Mills, Oregon	5.7 M_w; largest earthquake since 1981; felt from Puget Sound to Roseburg, Oregon[4]
1993[3]	Klamath Falls, Oregon	5.9 M_w and 6.0 M_w[3]; affected area: 130,000 sq km (southwestern Oregon and northern California); losses: concentrated in downtown area; intensity VII in downtown Klamath Falls and immediate vicinity and to the Oregon Institute of Technology, but surrounding experienced intensity VI[5]; fatalities: 2
2001[2]	Nisqually, Wash.	felt as far south as central Oregon
Jan. 4, 2015	NW Nevada	M4.1, 1.5 km deep
Jan. 22, 2015	NW Nevada	M4.5, 1.5 km deep
May 8, 2015	Pacific Ocean, west of Coos Bay, Oregon	M4.4, 10 km deep
Jul. 4, 2015	east of Springfield, Oregon	M4.0, 8 km deep
Jul. – Dec. 2015	NW Nevada	M4.0-4.7, 1.3-1.5 km deep; cluster of earthquakes
Nov. 29, 2019	Port Orford, Oregon	M4.5, 16.7 km deep
Feb. 8, 2020	Pacific Ocean west of Coos Bay, Oregon	M4.7, 10 km deep

Sources:

(1) USGS. Oregon Earthquake History. Retrieved October 28, 2013, http://earthquake.usgs.gov/earthquakes/states/oregon/history.php

(2) USGS. Earthquake Archive. Retrieved October 28, 2013, http://earthquake.usgs.gov/earthquakes/search/

(3) Sherrod, D. R. (1993)

(4) Thomas et al. (1996)

(5) Dewey (1993

(6) Bott and Wong (1993)

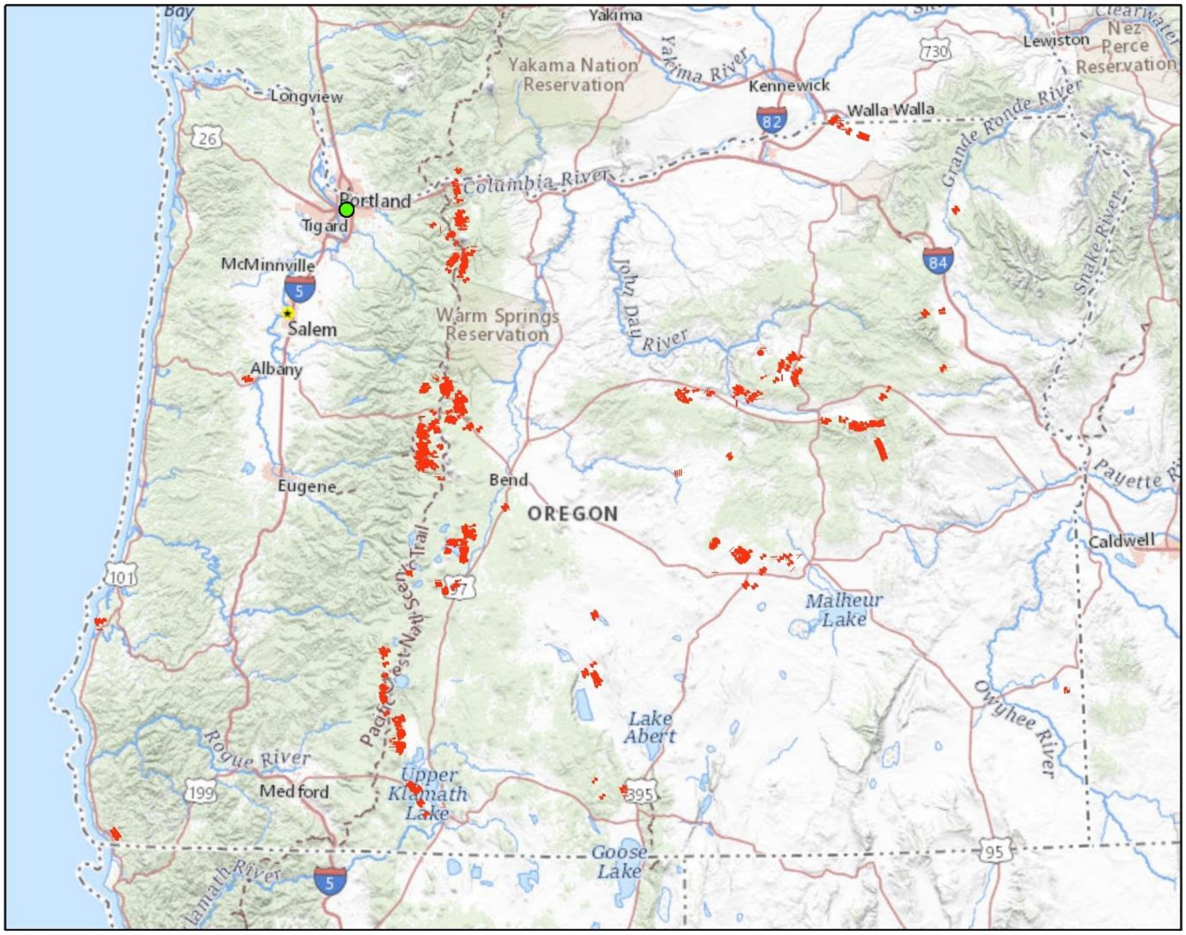
(7) Pacific Northwest Seismic Network, Retrieved May 22, 2020, https://pnsn.org/events?custom_search=true

2.2.3.2 Probability

The probability of damaging earthquakes varies widely across the state. In coastal and western Oregon, the hazard is dominated by Cascadia subduction earthquakes originating from a single fault with a well-understood recurrence history. For eastern Oregon, the hazard is dominated by numerous crustal faults and background seismicity, with poorly understood probability that varies from region to region.

Over the last decade, DOGAMI has been acquiring and analyzing large swaths of high-resolution lidar topographic data throughout Oregon. In Eastern Oregon and the Cascades, this has led to the identification of dozens of previously unknown, active young fault segments. **Figure 2-57** shows these newly discovered faults; very few have been investigated, none in detail.

Figure 2-57. Surface Faulting Identified with Lidar Data



Note: Red lines show surface rupturing faults that have been identified by inspection of lidar topographic data collected by the Oregon Lidar Consortium. Most of these faults should be considered active, though few have been studied in the field and none in detail.

Source: Ian Madin, DOGAMI, Esri basemap

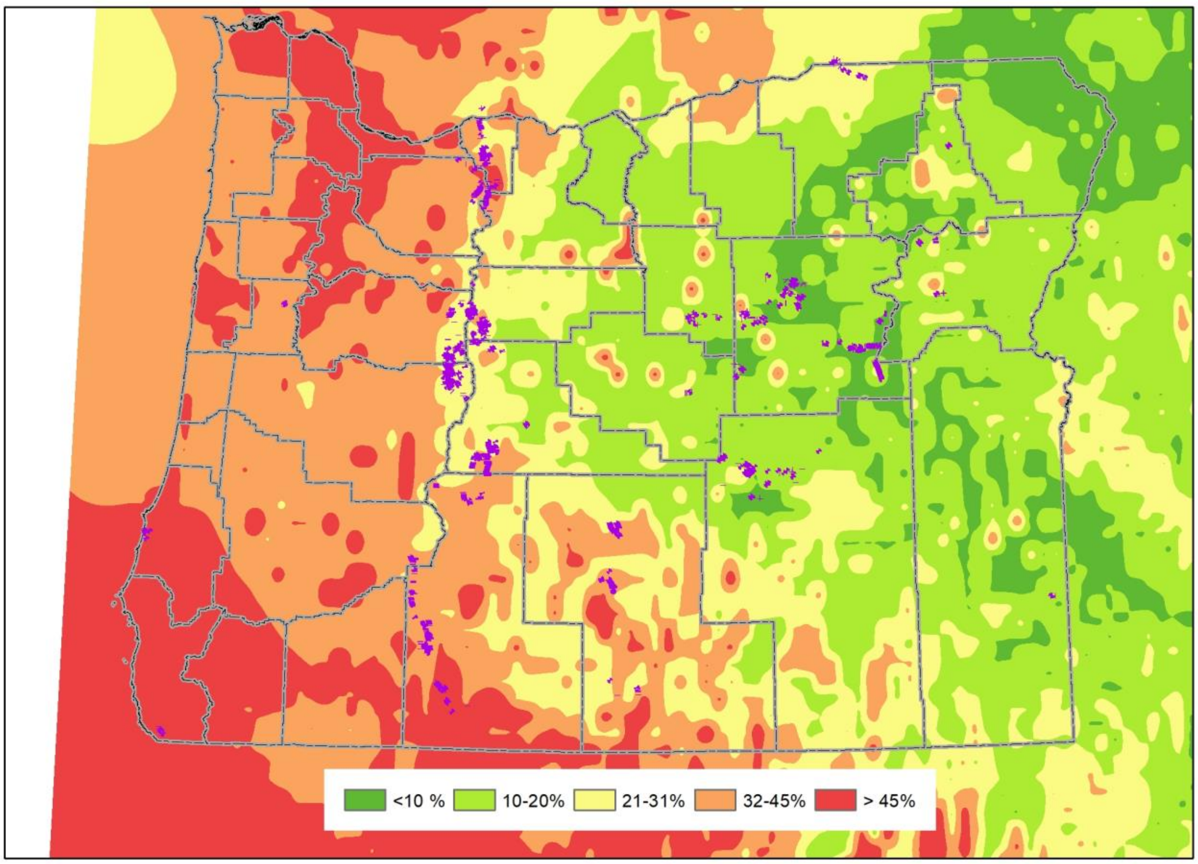
In this update (2020), new information was available to provide a more quantitative assessment of the counties in Oregon with the greatest earthquake hazard probability. USGS has published a 2018 update of its National Seismic Hazard Maps. They now include a map of the probability of experiencing damaging shaking, based on all known earthquake sources, history, and local soil conditions. The results of this map for Oregon are shown in **Figure 2-58**. The newly identified active young fault segments shown in Figure 2-30 are also shown in **Figure 2-58**.

Figure 2-58 shows the probabilistic hazard for the entire state. This map shows the likelihood of shaking strong enough to cause damage in the next 100 years. The threshold for damage is set at Modified Mercalli Intensity VI, the level at which structural damage begins to occur, and the map uses the most recent (2018) USGS National Seismic Hazard Map probabilistic bedrock shaking combined with a topography-based model of amplification due to soft soils. This map incorporates all that is known about the probabilities of earthquake on the Cascadia Subduction

Zone, and all Oregon faults for which published slip rate information is available. It does not include the recently discovered faults shown in Figure 2-30.

For Oregon west of the crest of the Cascades, the Cascadia subduction zone is responsible for most of the hazard, as shown in **Figure 2-58**. The paleoseismic record includes 18 magnitude 8.8–9.1 megathrust earthquakes in the last 10,000 years that affected the entire subduction zone. The return period for the largest earthquakes is 530 years, and the probability of the next such event occurring in the next 50 years ranges from 7 to 12%. An additional 10–20 smaller, magnitude 8.3–8.5, earthquakes affected only the southern half of Oregon and northern California. The average return period for these is about 240 years, and the probability of a small or large subduction earthquake occurring in the next 50 years is 37–43%.

Figure 2-58. Probability of experiencing shaking of Modified Mercalli Intensity VI or greater during the next 100 years

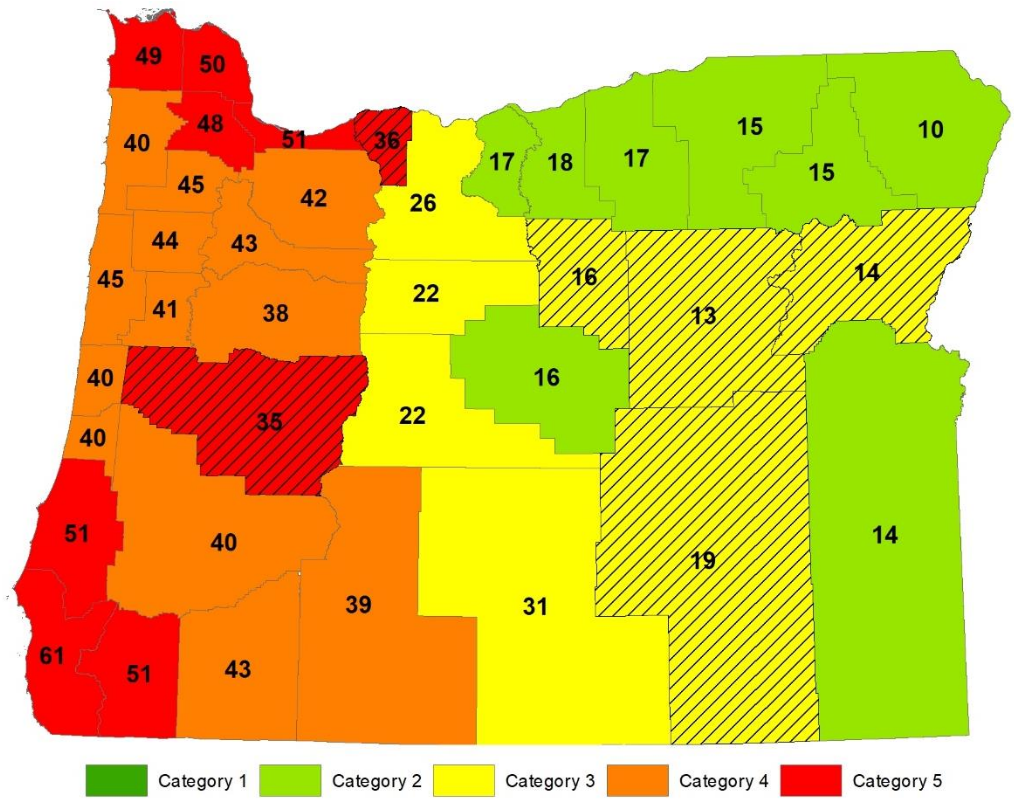


Note: Purple lines are faults that have been recently discovered with lidar data that are not included in the USGS hazard map models.

Source: USGS

Using these two new sources of information, DOGAMI has developed a new probability ranking for Oregon counties that is based on the average probability of experiencing damaging shaking during the next 100 years, modified in some cases by the presence of newly discovered lidar faults. If a county had newly discovered faults that were within 10-12 miles of a community, the category defined by the average probability of damaging shaking was increased one step. The results of this ranking are shown in **Figure 2-59**.

Figure 2-59. 2020 Oregon Earthquake Probability Ranking Based on Mean County Value of the Probability of Damaging Shaking and Presence of Newly Discovered Faults (Figures 2-30 and 2-31)



Note: Counties with hatching had their probability category increased one step due to newly discovered faults.
Source: DOGAMI

To rank the earthquake probability for each of the counties using the 2020 risk assessment methodology, DOGAMI used the data for the map in Figure 2-31 and interpolated a raster for the State of Oregon using 30 meter cells. DOGAMI then calculated the mean value of that probability for each of the counties in Oregon and used those values to rank them from 1 (least probability) to 5 (greatest probability).

- Category 1 100-year probability < 10%
- Category 2 100 year probability 10-20%
- Category 3 100 year probability 21-31%
- Category 4 100 year probability 32-45%
- Category 5 100 year probability > 45%

Where one of the newly-discovered faults mapped in **Figure 2-57** is within 10-20 miles of a community, the probability level was increased by one category. The probability levels for Baker, Grant, Harney, Hood River, and Wheeler Counties, and the non-coastal portion of Lane County were all increased in this way.

Table 2-32. Probability of Earthquake by County using the 2020 Risk Assessment Methodology

Region	County	Probability	Category # 1 - 5
Region 1	Clatsop	49	5
	Coos	51	5
	Curry	61	5
	Douglas Coastal	40	4
	Lane Coastal	40	4
	Lincoln	45	4
	Tillamook	40	4
Region 2	Clackamas	42	4
	Columbia	50	5
	Multnomah	51	5
	Washington	48	5
Region 3	Benton	41	4
	Lane	35	5
	Linn	38	4
	Marion	43	4
	Polk	44	4
	Yamhill	45	4
Region 4	Douglas	40	4
	Jackson	43	4
	Josephine	51	5
Region 5	Gilliam	18	2
	Hood River	36	5
	Morrow	17	2
	Sherman	17	2
	Umatilla	15	2
	Wasco	26	3
Region 6	Crook	16	2
	Deschutes	22	3
	Jefferson	22	3
	Klamath	39	4
	Lake	31	3
	Wheeler	16	3
Region 7	Baker	14	3
	Grant	13	3
	Union	15	2
	Wallowa	10	2
Region 8	Harney	19	3
	Malheur	14	2

2.2.3.3 Vulnerability

Oregon has a long history of earthquakes (and tsunamis, which often accompany major off-shore seismic events) because of the state's proximity to the Cascadia Subduction Zone (CSZ) just off the Pacific Coast, and also from crustal faults that run under or near populated areas. Oregon is vulnerable to damage because of its topography and geology; many of its local soil profiles are prone to liquefaction during the shaking that would occur during a Cascadia event. Depending on the size of the fault rupture, areas receiving major damage from a magnitude 8.0–9.0 earthquake would include most of the counties in western Oregon; the heavily populated metropolitan areas of Portland, Salem, and Eugene would certainly experience major damage.

A major Cascadia earthquake (>M_W 8.5) or a local crustal earthquake (>M_W 5.0) would be devastating to the Portland Metro area. The Northern Willamette Valley/Portland Metro Region is the most densely populated region with a total population of almost 1.5 million people. A major earthquake would likely do extensive damage to many of the region's 1382 bridges and overpasses as few bridges have been retrofitted to withstand this type of event. In addition, many structures are located on soils likely to experience liquefaction from the shaking that would occur. Most of the state's major critical infrastructure such as energy sector lifelines, transportation hubs, and medical facilities is particularly vulnerable to damage from liquefaction and long periods of shaking. The Northern Willamette Valley/Portland Metro Region also has 49 dams that could be affected by a major earthquake.

Depending on the size of the fault rupture, this magnitude of earthquake would likely cause extensive damage to structures and infrastructure in the Mid/Southern Willamette Valley Region as well. The city of Salem, Oregon's state capital, is only 46 miles south of Portland. To gain a perspective of the potential damage from a major earthquake, 169 of the state's facilities are located in or near Salem. To replace these state facilities would cost over $850 million dollars. Marion County, where Salem is located, has over 20 dams and 400 bridges that could also be affected.

The long-term effects from a major earthquake would be felt for years. Major damage would likely occur to most of western Oregon's public and private buildings, its vast road network, to its rail lines and power transmission lines, and to the state's most important employment centers.

A major earthquake that occurs in the southern, central, or eastern areas of Oregon would be catastrophic to that region. It may also be catastrophic to the state economically if key facilities and infrastructure (i.e., highways, bridges, rail lines, power transmission lines, and dams) are damaged to the degree that links with the Portland Metro region and the rest of the state could not quickly be repaired. However, the length of time for the state to recover from such a disaster occurring in an area away from the Portland Metro area should be much shorter than if the same event occurred near Portland.

In the late 1990s, DOGAMI developed two earthquake loss models for Oregon: (a) a magnitude 8.5 Cascadia Subduction Zone (CSZ), and (b) a 500-yr probabilistic ground motion model, which combines CSZ, intraplate and crustal events. Both models are based on Hazus, a computer program developed by the Federal Emergency Management Agency (FEMA) as a means of determining potential losses from earthquakes. The CSZ event is based on a potential 8.5 earthquake generated off the Oregon coast. The 500-yr model incorporates earthquake ground motions with 10% chance of exceedance in the next 50 years, which was used by the building code. It does not look at a single earthquake (as in the CSZ model) but encompasses many faults.

Neither model takes into account damage and losses from unreinforced masonry buildings or tsunamis. Due to the limitations of Hazus with respect to modeling damage from unreinforced masonry buildings and tsunamis at that time, DOGAMI estimated fatalities outside of the Hazus model. DOGAMI developed lower bound estimates on the order of 5,000 fatalities.

DOGAMI investigators caution that the models contain a high degree of uncertainty and should be used only for general planning and policy purposes. Despite the model limitations, valuable estimates of damage, functionality and relationships between county estimates are made available for each region within Oregon. Results for each State of Oregon Natural Hazard Region are found in the **Regional Risk Assessments** section.

In 2000, DOGAMI co-organized an important conference convening scientists to discuss the Cascadia fault. At this Geological Society of America Penrose conference, which was held in Seaside, Oregon, there was scientific consensus that the most recent Cascadia earthquake occurred in 1700, that it was a magnitude 9 earthquake, and the Cascadia fault would produce future magnitude 9 earthquakes and damaging tsunamis (DOGAMI Special Paper 33, https://www.oregongeology.org/pubs/sp/SP-33.pdf)

Also in 2000, the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) developed a report called "Oregon at Risk" which addressed the many cross-cutting effects that earthquakes have on our communities, including the basic services provided by infrastructure. Five objectives were outlined: (a) earthquake awareness and education, (b) earthquake risk information, (c) earthquake safety of buildings and lifelines, (d) geoscience and technical information, and (e) emergency pre-disaster planning, response, and recovery. The report is available on the following the Oregon Office of Emergency Management webpage: https://www.oregon.gov/oem/Documents/Oregon_at_Risk_2000.pdf

In 2007, DOGAMI (Lewis, 2007) completed a rapid visual screening (RVS) of educational and emergency facilities in communities across Oregon, as directed by the Oregon Legislature in Senate Bill 2 (2005). RVS is a technique developed by the Federal Emergency Management Agency (FEMA), known as FEMA 154, to identify, inventory, and rank buildings that are potentially vulnerable to seismic events. DOGAMI surveyed a total of 3,349 buildings, giving each a “low,” “moderate,” “high,” or “very high” potential of collapse in the event of an earthquake. It is important to note that these rankings represent a probability of collapse based on limited observed and analytical data and are therefore *approximate* rankings (Lewis, 2007). The RVS study can help prioritize which buildings require additional studies and which do not. To fully assess a building’s potential of collapse, a more detailed engineering study completed by a qualified professional is required. Details of this study for each State of Oregon Natural Hazard Region can be found in the **Regional Risk Assessments** section.

In 2012 the USGS published Professional Paper 1661-F, *Turbidite Event History — Methods and Implications for Holocene Paleoseismicity of the Cascadia Subduction Zone* (Goldfinger et al., 2012), which provides the most comprehensive catalog of prehistoric Cascadia Subduction earthquakes to date, including a 10,000 year chronology (**Table 2-33**) of as many as 40 subduction earthquakes ranging from about M8.1 to about M9.3. This study forms the basis for efforts to evaluate the consequences and likelihood of future Cascadia earthquakes, and has been particularly useful in DOGAMI's program to map tsunami inundation zones along the Oregon coast.

Table 2-33. Turbidite Event History Methods and Implications for Holocene Paleoseismicity of the Cascadia Subduction Zone

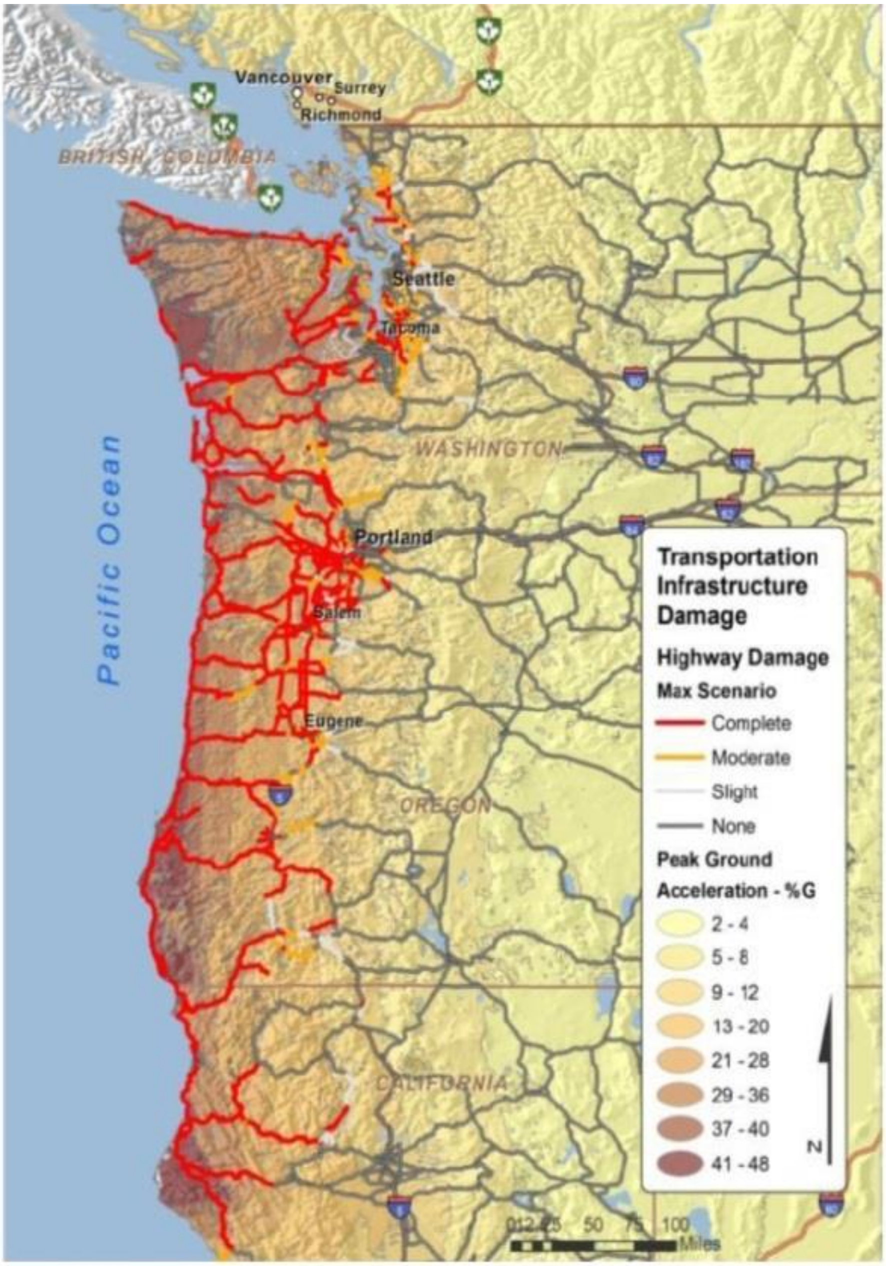
Turbidite number	Mean age	Northern margin following interval, in years	Northern margin slip from following time, in meters	Southern margin interval, in years	Southern margin slip from time, in meters	Average northern and southern slip, in meters	Segment name	Rupture length, in kilometers	Rupture width, in kilometers	Mw	Seismic moment
1	250					16.0	A	1,000	83	9.00	398.4E+27
2	482	232	8.9	232	8.3	8.4	A	1,000	55	8.70	138.3E+27
2a	550			57	2.1	2.1	D	222	40	8.19	23.8E+27
3	798	305	11.2	248	8.9	10.0	A	1,000	83	8.87	250.2E+27
3a	1,077			279	10.0	10.0	C	444	50	8.34	40.1E+27
4	1,243	446	16.3	167	6.0	11.2	A	1,000	83	8.90	277.9E+27
4a	1,429			186	6.7	6.7	C	444	50	8.25	29.9E+27
5	1,554	311	11.4	125	4.5	7.9	A	1,000	83	8.80	197.4E+27
5a	1,820			266	9.6	9.6	C	444	50	8.41	51.9E+27
5b	2,036			216	7.8	7.8	B	660	60	8.66	122.5E+27
5c	2,323			286	10.3	10.3	C	444	50	8.41	51.1E+27
6	2,536	982	35.9	213	7.7	21.8	A	1,000	83	9.09	542.7E+27
6a	2,730			194	7.0	7.0	D	222	40	8.24	28.7E+27
7	3,028	492	18.0	298	10.7	14.4	A	1,000	83	8.97	358.2E+27
7a	3,157			129	4.6	4.6	D	222	40	8.23	27.5E+27
8	3,443	415	15.2	286	10.3	12.7	A	1,000	83	8.94	317.2E+27
8a	3,599			442	5.6	0.0	B	660	60	8.67	124.4E+27
8b	3,890			447	10.5	10.5	D	222	40	8.15	21.0E+27
9	4,108	665	24.4	218	7.9	16.1	A	1,000	83	9.01	401.1E+27
9a	4,438			548	11.9	0.0	B	660	60	8.35	41.4E+27
9b	4,535			426	3.5	3.5	D	222	40	8.17	22.5E+27
10	4,770	661	24.2	235	8.5	16.3	A	1,000	83	9.01	406.6E+27
10a	5,062			292	10.5	10.5	C	444	50	8.39	47.6E+27
10b	5,260			198	7.1	7.1	B	660	60	8.43	55.7E+27
10c	5,390			130	4.7	4.7	C	444	50	8.55	82.7E+27
10d	5,735			344	12.4	12.4	C	444	50	7.90	9.0E+27
10f	5,772			37	1.3	1.3	C	444	50	8.37	44.8E+27
11	5,959	1189	43.5	187	6.7	25.1	A	1,000	83	9.13	625.5E+27
12	6,466	508	18.6	508	18.3	18.4	A	1,000	55	8.93	304.0E+27
12a	6,903			437	15.7	15.7	D	222	40	8.22	26.7E+27
13	7,182	715	26.2	278	10.0	18.1	A	1,000	83	9.04	450.7E+27
14*	7,625	443	16.2	443	16.0	16.1	A	1,000	83	9.01	400.7E+27
14a	7,943			318	11.4	11.4	D	222	40	8.17	22.1E+27
15	8,173	548	20.1	230	8.3	14.2	A	1,000	83	8.97	353.0E+27
15a	8,459			286	10.3	10.3	D	222	40	8.36	42.9E+27
16	8,906	733	26.8	447	16.1	21.4	A	1,000	83	9.09	534.1E+27
16a	9,074			169	6.1	6.1	D	222	40	7.54	2.6E+27
17	9,101	195	7.2	27	1.0	4.1	A	1,000	55	8.49	67.0E+27
17a	9,218	117	4.3	117	4.2	4.2	A	1,000	55	8.50	70.1E+27
18	9,795	577	21.1	577	20.8	20.9	A	1,000	83	9.08	521.2E+27

Source: Goldfinger et al. (2012)

In 2013, DOGAMI published Open-File Report O-13-09, *Earthquake Risk Study for Oregon's Critical Energy Infrastructure Hub* (Wang et al., 2013). This report highlights the concentration of critical energy facilities in the Portland Harbor area of the lower Willamette River, and the seismic risk posed by a combination of liquefiable soils and the age and poor condition of many facilities in the area. The report also points out how dependent Oregon is on this concentration of facilities for virtually all petroleum products used in the State, and the potential impacts on post-earthquake recovery if these facilities are damaged.

Also in 2013, the Cascadia Region Earthquake Workgroup (CREW) issued a Cascadia magnitude 9 scenario, which provided a narrative on the expected effects throughout the region including northern California, Oregon, Washington, and British Columbia (www.crew.org). Some of the CREW scenario was obtained from the 2011 Federal Emergency Management Agency (FEMA) regional planning scenario for the Pacific Northwest (Draft Analytical Baseline Study for the Cascadia Earthquake and Tsunami, September 12, 2011) based on a magnitude 9 megathrust earthquake. Using the most current version of Hazus, FEMA's disaster loss modeling software, they have prepared the most comprehensive and realistic Cascadia scenario to date). In addition to Hazus analysis, FEMA evaluated likely tsunami effects for several Oregon coastal communities. Data like this provides a critical tool for planning emergency response and for designing a resiliency plan, as it highlights areas of infrastructure damage that affect the entire system. State and local government agencies have been working with FEMA to provide local knowledge to inform the scenario, and the final document and associated databases should be adopted as the basis for planning. In general the scenario results predict severe damage in coastal areas, particularly in tsunami inundation zones with widespread but moderate damage along the I-5 corridor (**Figure 2-60**). For more information about tsunamis in Oregon, see the **Tsunami** section. For more information about seismic lifeline vulnerability see Section **2.1.6**, **Seismic Transportation Lifeline Vulnerabilities** section.

Figure 2-60. Draft Hazus Results from the 2011 FEMA Analytical Baseline Study for the Cascadia Earthquake and Tsunami



Source: FEMA

The Oregon Seismic Safety Policy Advisory Commission (OSSPAC) developed a report in 2013 entitled "The Oregon Resilience Plan: Reducing Risk and Improving Recovery for the Next Cascadia Earthquake and Tsunami." The report (**Appendix** 9.2.2), which was commissioned by a legislative resolution, estimated the impacts of an M9.0 Cascadia subduction earthquake on the State's population, buildings, and infrastructure with a focus on seven sectors:

- Businesses,
- Coastal communities,
- Energy,
- Transportation,
- Communication,
- Critical buildings, and
- Water and wastewater.

For each of these sectors the Plan sets a desired level of performance (time to recover a given level of service) and estimates performance under current conditions in each of four earthquake impact zones:

- **Tsunami**, where damage will be complete and saving lives through evacuation is the main focus;
- **Coastal**, where damage will be severe and the focus will be on managing a displaced population with little functioning infrastructure;
- **Valley**, where moderate damage will be widespread, and the focus will be on restoring services quickly to re-start the economy; and
- **Eastern**, where damage will be light and the focus will be on staging recovery efforts for the rest of the state.

For the first three zones, times for restoration of services (**Table 2-34**) are typically several months, and in some cases several years, a clearly unacceptable level of performance, and far short of the general performance goal of two weeks to restore most services to functional, if not original conditions. These results are particularly sobering in the face of the report's finding that where services are not restored within 2 to 4 weeks, businesses will either fail or leave.

The report includes extensive recommendations for actions that if implemented over the next 50 years, should greatly improve the performance of Oregon's buildings and infrastructure in the next great earthquake. These include:

- Undertaking comprehensive assessments of key structures and systems,
- Launching a sustained program of investment in retrofit of Oregon's public buildings,
- Creating a package of incentives to help Oregon's private sector improve its resilience, and
- Updating public policies to streamline recovery and to increase public preparedness

Upon consideration of the Plan, the 2013 Oregon Legislature passed Senate Bill 33 establishing an Oregon Resilience Task Force to facilitate a comprehensive and robust plan to implement the Oregon Resilience Plan. The Task Force will report to the Oregon Legislature during the 2015 session.

The report and an executive summary are available at:

- https://www.oregon.gov/oem/Documents/2014_ORTF_cover_letter.pdf and
- https://www.oregon.gov/oem/Documents/2014_ORTF_report.pdf.

Table 2-34. Estimated Times for Restoration Services Post CSZ and Tsunami Event

Critical Service	Zone	Estimated Time to Restore Service
Electricity	Valley	1 to 3 months
Electricity	Coast	3 to 6 months
Police and fire stations	Valley	2 to 4 months
Drinking water and sewer	Valley	1 month to 1 year
Drinking water and sewer	Coast	1 to 3 years
Top-priority highways (partial restoration)	Valley	6 to 12 months
Healthcare facilities	Valley	18 months
Healthcare facilities	Coast	3 years

Source: Oregon Resilience Plan, OSSPAC (2013)

Most Vulnerable Communities

Although it is relatively straightforward to rank counties based on earthquake hazards, it is much more complicated to rank them based on vulnerability. The severity of the expected hazard varies widely among Oregon counties, as does the amount of exposed population, buildings and infrastructure, and the fragility of those structures. Damage and loss estimates made using FEMA's Hazus software take all of these factors into account, and as a result can provide consistent information to compare community vulnerability. Although DOGAMI has developed Hazus loss estimates in recent years for many Oregon communities, the only statewide Hazus data that allows comparison of county vulnerability are from a study published in 1999. That study looked at two earthquake scenarios: (a) a magnitude 8.5 earthquake on the Cascadia Subduction Zone (CSZ), and (b) a probabilistic shaking based on the shaking expected to have a 10% chance of occurring in the next 50 years (500-year model).

The CSZ event is based on a potential magnitude 8.5 earthquake generated off the Oregon coast. The model does not take into account a tsunami, which probably would develop from the event. The 500-Year crustal model does not look at a single earthquake (as in the CSZ model); it encompasses many faults, each with a 10% chance of producing an earthquake in the next 50 years. The model assumes that each fault will produce a single "average" earthquake during this time. Neither model takes unreinforced masonry buildings into consideration.

DOGAMI investigators caution that the models contain a high degree of uncertainty and should be used only for general planning purposes. Despite their limitations, the models do provide some approximate estimates of damage.

Table 2-35 lists all counties in the state in the order of projected losses and damages (highest to lowest) based on the two models mentioned above. See DOGAMI Special Paper 29 (Wang and

Clark, 1999; http://www.oregongeology.org/pubs/sp/SP-29.pdf) for more information on these earthquake loss models.

Table 2-35. Projected Loss and Damage Rankings by County from Two Earthquake Loss Models

Counties listed from highest to lowest based on projected losses and damages due to a *Cascadia Subduction Zone (CSZ) earthquake*		Counties listed from highest to lowest based on projected losses and damages due to *combined crustal events using a 500-year model*	
1. Multnomah	19. Klamath	1. Multnomah	19. Columbia
2. Lane	20. Deschutes	3. Lane	21. Umatilla
3. Coos	21. Hood River	3. Lane	21. Umatilla
4. Washington	22. Jefferson	4. Marion	22. Hood River
5. Marion	23. Grant	5. Clackamas	23. Malheur
6. Benton	24. Gilliam	6. Coos	24. Lake
7. Lincoln	25. Harney	7. Jackson	25. Wasco
8. Josephine	26. Lake	8. Benton	26. Jefferson
9. Clatsop	27. Umatilla	9. Linn	27. Baker
10. Jackson	28. Baker	10. Klamath	28. Morrow
11. Linn	29. Crook	11. Josephine	29. Union
12. Curry	30. Malheur	12. Lincoln	30. Wallowa
13. Clackamas	31. Morrow	13. Clatsop	31. Crook
14. Douglas	32. Sherman	14. Yamhill	32. Grant
15. Yamhill	33. Union	15. Douglas	33. Harney
16. Polk	34. Wallowa	16. Polk	34. Sherman
17. Tillamook	35. Wasco	17. Curry	35. Wheeler
18. Columbia	36. Wheeler	18. Tillamook	36. Gilliam

Source: Wang and Clark (1999)

It should be emphasized that the original 1999 DOGAMI study did not include tsunami-related losses. In the future, an updated Hazus study should include the current population and infrastructure as well as losses from a tsunami. If tsunami losses are included, rankings might shift.

It is also important to note that total losses will generally be a function of the population of the county. It may be a better approach to look at the loss ratio, or the cost of damage expressed as a percentage of total value. A county with a small population and a large loss ratio might still have smaller total losses than a populous county with a very low loss ratio.

State-Owned/Leased Buildings and Critical Facilities and Local Critical Facilities

For the 2020 vulnerability assessment, DOGAMI used Hazus-MH to estimate potential loss from a Magnitude 9 Cascadia Subduction Zone (CSZ) event and a 2500-year probabilistic scenario. The damage estimates from the CSZ were very low east of the Cascade Mountains, so the loss estimates reported from this event are limited to the western regions (#1-4) (Madin and Burns, 2013). DOGAMI assessed the four eastern regions (#5-8) with the USGS 2500-year probabilistic scenario (Petersen and others, 2014). The analysis incorporated information about the earthquake scenario (such as coseismic liquefaction and landslide potential), as well as building characteristics (including the seismic building code and building material). The results of the analyses are provided as a loss estimation (the building damage in dollars) and as a loss ratio (the loss estimation divided by the total value of the building) reported as a percentage at the county level.

DOGAMI used the loss ratio to formulate a separate relative vulnerability score for the state buildings, state critical facilities, and local critical facilities data sets. The percentage of loss for each county was statistically distributed into 5 categories (Very Low, Low, Moderate, High, or Very High). The vulnerability scores derived were used along with each county's social vulnerability score to calculate an overall vulnerability score for each county in Oregon.

Of 5,350 state facilities evaluated, 838 building were flagged as extensively or completely damaged following a CSZ event (Regions 1-4) or a 2,500-year probabilistic scenario (Regions 5-8) totaling over $1.3 billion in potential damage to property. Among the 1,647 critical state facilities, 360 were flagged as extensively or completely damaged.

Of 8,757 local critical facilities evaluated, 1,880 buildings were flagged as completely or extensively damaged following a CSZ event (Regions 1-4) or a 2500-year probabilistic scenario (Regions 5-8) totaling over $4.3 billion in potential damage to property.

Historic Resources

Of the 58,872 historic resources statewide, 31,928 are in an area of high or very high exposure to ground shaking amplification, over 30% of them in Multnomah County. Many fewer, 2,594 are in an area of high or very high liquefaction potential, almost 58% of them in Linn County.

Archaeological Resources

Of the 43,659 archaeological resources located in earthquake hazard areas statewide, 964 are in areas of high earthquake hazards. Of those, 28 are listed on the National Register of Historic Places and 41 are eligible for listing. Fifty have been determined not eligible, and 845 have not been evaluated. By far, the majority of archaeological resources in earthquake hazard areas (33,643) are located in areas of low earthquake hazards.

Social Vulnerability

The Centers for Disease Control and Prevention (CDC) has calculated a social vulnerability index to assess community resilience to externalities such as natural hazard events. It employs fifteen social vulnerability factors and uses data from the US Census Bureau's American Community Survey. The index is reported in quintiles (1-5). Social vulnerability scores do not vary by hazard. The counties with the greatest social vulnerability statewide are Marion, Morrow, Umatilla, Wasco, Jefferson, Klamath, and Malheur.

For the 2020 vulnerability assessment, DLCD combined this index with the vulnerability scores for state buildings, state critical facilities, and local critical facilities to calculate an overall vulnerability score for each county. According to this limited assessment, Coos, Lincoln, the coastal portions of Douglas and Lane, Linn, Marion, Yamhill, Hood River, Morrow, Umatilla, Klamath and Lake Counties are the most vulnerable to impacts from earthquake hazards.

Seismic Lifelines

Please refer to Section **2.1.6**, **Seismic Transportation Lifeline Vulnerabilities** for a discussion of potential seismic impacts to the state transportation system, its vulnerabilities and potential loss estimates.

2.2.3.4 Risk

In the 2020 update DOGAMI and DLCD developed a new risk ranking system that combines the probability of the hazard (based on the new approach described above) with the limited vulnerability assessment to arrive at a composite risk score referred to as the 2020 Risk Score. Those results are presented in **Table 2-36**, and clearly differ from the 1999 loss-based ranking in **Table 2-35**. For a variety of reasons, the 1999 loss-based rankings and the 2020 loss-based rankings are not comparable.

According to the 2020 risk assessment, the counties at greatest risk from earthquake hazards are Clatsop, Coos, Curry, the coastal portions of Douglas and Lane, Lincoln, Multnomah, Linn, Marion, Yamhill, Douglas, Jackson, Josephine, Hood River, Klamath, and Lake Counties.

Table 2-36. 2020 Risk Assessment Methodology County Earthquake Risk Scores

Region	County	Earthquake Risk
Region 1	Clatsop	VH
	Coos	VH
	Curry	VH
	Douglas Coastal	VH
	Lane Coastal	VH
	Lincoln	VH
	Tillamook	H
Region 2	Clackamas	L
	Columbia	M
	Multnomah	VH
	Washington	M
Region 3	Benton	M
	Lane	M
	Linn	VH
	Marion	VH
	Polk	H
	Yamhill	VH
Region 4	Douglas	VH
	Jackson	VH
	Josephine	VH

Region	County	Earthquake Risk
Region 5	Gilliam	VL
	Hood River	VH
	Morrow	H
	Sherman	VL
	Umatilla	H
	Wasco	H
Region 6	Crook	M
	Deschutes	VL
	Jefferson	H
	Klamath	VH
	Lake	VH
	Wheeler	VL
Region 7	Baker	M
	Grant	VL
	Union	L
	Wallowa	M
Region 8	Harney	M
	Malheur	M

Source: DOGAMI, DLCD (2020)

2.2.4 Extreme Heat

Extreme heat is associated with more fatalities than any other severe weather event in the United States. For the first time, extreme heat is included as a hazard in the 2020 Oregon NHMP. This is due to the recognition that as the climate continues to warm, extreme heat events will be an emerging hazard with implications for public health as well as infrastructure. Extreme heat events are expected to increase in frequency, duration, and intensity in Oregon due to continued warming temperatures. In fact, the hottest days in summer are projected to warm more than the change in mean temperature over the Pacific Northwest (Dalton et al., 2017). Extreme heat events occur from time to time as a result of natural variability, but human-caused climate change is already contributing to the severity of such events (Vose et al., 2017).

2.2.4.1 Analysis and Characterization

Extreme heat events occur from time to time as a result of natural variability. Synoptic conditions that drive extreme heat events in the Pacific Northwest include, upper-level ridges—or large areas of high atmospheric pressure—and strong offshore flow. There are several ways to measure extreme heat. One common way is to count the number of days with temperatures above a certain threshold, such as days with temperatures above 90°F. Areas that climatologically see the greatest number of very hot temperature days include inland areas at lower elevations in eastern Oregon, as well as parts of southern Oregon, particularly the Rogue River Valley. Human-caused climate change is already contributing to the severity of such events (Vose et al., 2017).

Recent extremely hot summers (2015, 2017, and 2018) in highly populated parts of western Oregon have been unprecedented and have brought increased interest in the effect of global warming on local summer temperatures. In Oregon's biggest city, Portland, summer extreme heat in terms of annual total days over 90°F has steadily increased in frequency and severity despite large year-to-year variability. The record number of days over 90°F in Portland was set in 2018. Today, Portland sees about nine more days above 90°F than in 1940. This trend will continue, though the rate of change may increase, along with continued year-to-year variability. The hot summers of 2015, 2017, and 2018 serve as wake-up calls for what is to come, as they are good examples of what is projected to be relatively common by the mid-21st century.

The National Weather Service issues heat warnings when the heat index exceeds given local thresholds. The heat index is a measure of how hot it feels combining both temperature and relative humidity. As relative humidity increases, a given temperature can feel even hotter. **Figure 2-61** displays NOAA's National Weather Service rubric for temperature and relative humidity according to the danger of heat-related illnesses.

Figure 2-61. NOAA National Weather Service Heat Index

NOAA's National Weather Service

Heat Index

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

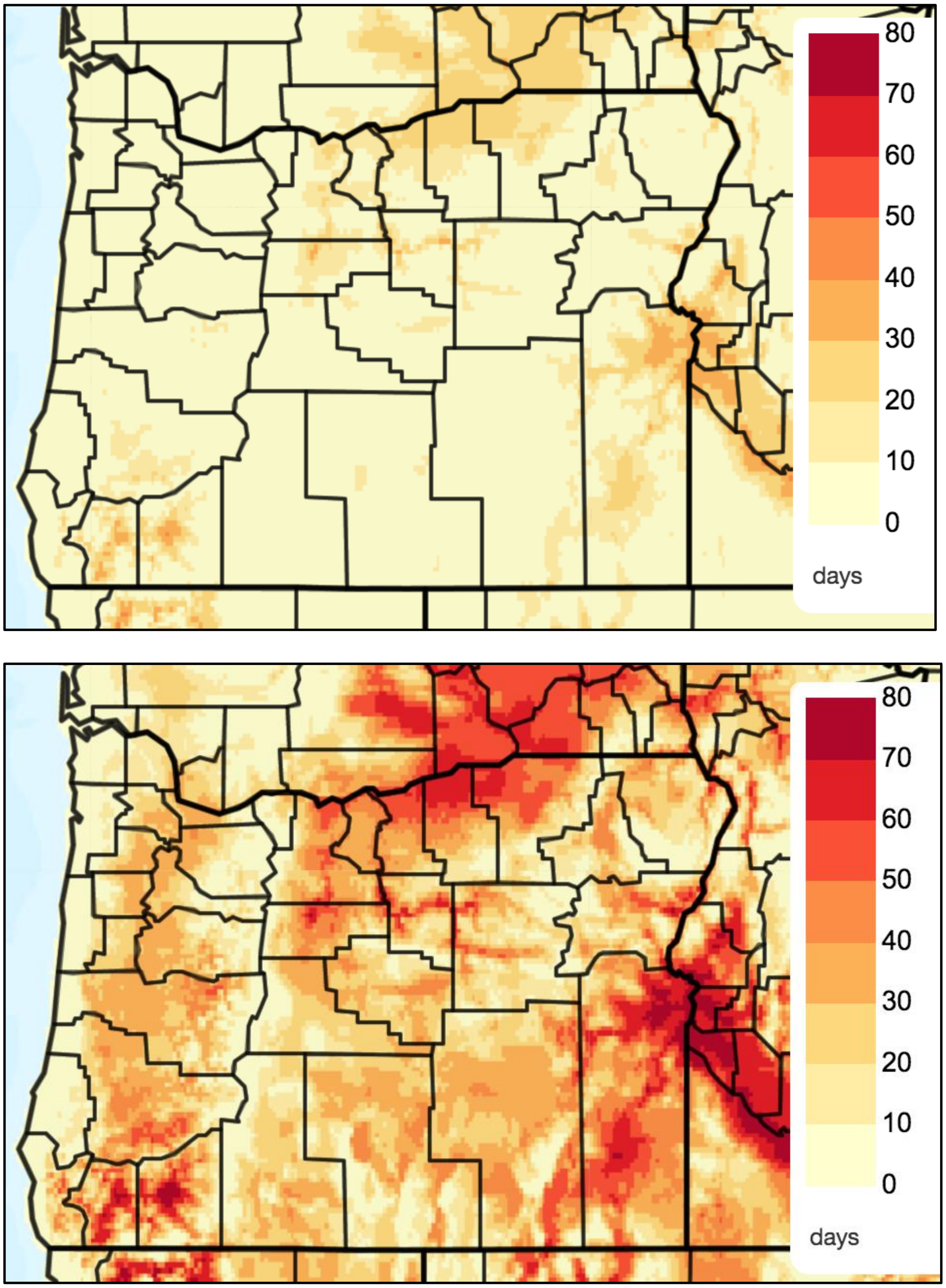
Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution | Extreme Caution | Danger | Extreme Danger

Source: https://www.weather.gov/phi/heat

There have historically been few places in Oregon that experience substantial number of days with heat index greater than 90°F. Under future climate change, however, nearly the entire state could see substantial increases in such extreme heat days (**Figure 2-62**).

Figure 2-62. Frequency of Days April–October with Heat Index ≥ 90°F in Historic (1971–2000, top) and Future (2040–2069, bottom) Periods under RCP 8.5



Note: Displayed is the multi-model mean derived from 18 downscaled CMIP5 climate models.

Source: Northwest Climate Toolbox, https://climatetoolbox.org/tool/climate-mapper

Historic Extreme Heat Events

Table 2-37. Historic Heat and Excessive Heat Events in Oregon

Date	Location	Notes
July 26–28, 1998	Region 2	A three-day heat wave brought record high temperatures to western Oregon. The high temperature of 99 degrees at Portland International Airport on the 26th eclipsed the previous record for that date of 98 set in 1988, and the high of 101 on the 28th broke the previous daily record of 99 set in 1973. In Eugene, the high of 102 on the 26th broke the previous daily record of 101 set in 1988, and the 105 degrees on the 27th tied the record high for the month of July. There was one reported death from heat-related illness.
July 10–14, 2002	Region 5–7	A record breaking heat wave shattered many daily record high temperatures across the state, with a few locations breaking all-time records.
June 24–26, 2006	Region 1–3, 5	A broad upper ridge of unusually high height coupled with a thermally-induced surface trough of low pressure lingered over the Pacific Northwest for several days. This pattern resulted in persistent offshore flow, and therefore many days of record-smashing high temperatures. Many cities in Oregon saw record-breaking daily high temperatures for multiple days in a row.
July 20-24, 2006	Region 1–3, 5, 7	An unusually strong ridge of high pressure brought several days of record breaking hot and humid weather to NW Oregon. Many cities in Oregon saw record-breaking daily high temperatures for multiple days in a row. Many daily maximums were between 10 and 20 degrees above normal. A few sites reported record high minimum temperatures during this very humid event; a couple broke all-time record high minimums as well. 4500 homes lost power during this event. In north central and eastern Oregon, daily maximum temperatures between 100 and 113 degrees were observed at lower elevations, with temperatures 90 to 100 degrees at elevations up to 4000 feet. Several people were treated for heat related illness.
June 28–30, 2008	Region 2, 3, 5, 7	An upper level ridge and thermal trough across the Pacific Northwest produced temperatures above 100 degrees for two consecutive days breaking records in many locations. Two people died of heat-related illness.
August 15–17, 2008	Region 5–7	Excessive Heat Event: An upper level ridge and dry air brought excessive heat into eastern Oregon. Many locations experienced multiple days of at least 100 degree temperatures.
July 25–26, 2010	Region 5, 7	Excessive Heat Event: Temperatures topped 100 degrees for two successive days in Hermiston, Pendleton, 5 miles northeast of Pendleton, Ione, Echo, Arlington, and Umatilla.
August 1, 2011	Region 5	A dry weak westerly flow aloft under a broad upper level high pressure system combined with a surface thermal trough to bring several days of temperatures in the 90s.
July 1, 2014	Region 3	An upper level ridge combined with a surface thermal trough and low level offshore winds resulted in a hot day across Northwest Oregon where inland temperatures peaked in the upper 90s inland and the upper 80s along the coast.
June 7–9, 2015	Region 2	An unseasonably strong upper level ridge of high pressure resulted in hot temperatures early in June where high temperatures were in the low to mid 90s, which were around 20 degrees higher than the seasonal normals. The low temperatures were also unseasonably warm. The hospital visits for heat related illness for Northwest Oregon increased by 50 during this period.

Date	Location	Notes
June 26–28, 2015	Region 2, 3	Excessive Heat Event: A strong upper level ridge of high pressure resulted in hot temperatures across Northwest Oregon. Afternoon temperatures peaked in the low 90s to the low 100s, which are around 20 degrees warmer than the seasonal normals. Monsoonal moisture and onshore winds resulted in fairly high humidities (40 to 50% in the afternoons) making the temperatures feel 2 to 5 degrees warmer than they were. The mid-level moisture also added to an increase of thunderstorms around the region. Clouds from these thunderstorms limited overnight radiation cooling. Nighttime temperatures were in the mid 60s to low 70s, which are 10 to 15 degrees warmer than the seasonal normals. There were several new daily records set for the warmest low temperatures. The Multnomah County had 10 emergency room visits for heat related illnesses. There were two reported drownings, including one at nighttime.
July 1–5, 2015	Region 2, 3	A strong upper ridge over the region resulted in hot weather for the Willamette Valley where temperatures peaked 10 to 15 degrees Fahrenheit above the seasonal normal. High Temperatures were in the mid 90s to low 100s. The low temperatures were also unseasonably warm.
July 28–30, 2015	Region 2, 3	Excessive Heat Event: A strong upper level ridge resulted in excessively warm temperatures where the high temperatures were 15 to 20 degrees Fahrenheit above the seasonal normal. High temperatures were in the upper 90s to around 105 for the Willamette Valley. The daily maximum temperature of 105 degrees at Eugene broke the previous record of 99 last set in 2003. Emergency Preparedness officials opened cooling shelters. Several people were treated for heat related illnesses at medical centers. Local newspapers reported 3 separate incidents where children were left in hot cars in the Eugene area.
August 18–19, 2015	Region 2	Excessive Heat Event: Strong high pressure at the surface and aloft over the area resulted in excessively hot temperatures across northwest Oregon. Warming aloft combined with offshore winds and a thermal trough west of the Cascades contributed to the heat. Temperatures peaked in the mid to upper 90s which is 10 to 15 degrees above the seasonal normal in most areas. Daily high temperatures broke several records at area airports.
June 2–5, 2016	Region 3	Excessive Heat Event: Unseasonably strong ridge of high pressure resulted in a period of early-season hot temperatures across Northwest Oregon. Temperatures of 95 to 100 in early June lead to people seeking relief at local rivers. Three drownings were reported.
August 11–14, 2016	Region 2	Ridge of high pressure lead to hot temperatures across Northwest Oregon. Temperatures in the upper 80s to mid 90s lead to people seeking relief at local rivers. Two river drownings were reported in the Greater Portland Metro area during this heat event.
August 25-26, 2016	Region 1, 2	Ridge of high pressure and offshore winds brought temperatures along the North Oregon Coast up into the mid 80s to mid 90s on August 25. Inland, temperatures on August 25-26 reached the upper 90s. Temperatures in the mid 80s to mid 90s lead to people seeking relief at local rivers, lakes, and beaches. One swimmer drowned. News reported 8 runners were taken to the hospital with heat-related injuries during the Hood-to-Coast relay through Portland.
May 22-23, 2017	Region 2	Ridge of high pressure brought a couple days of warm weather. Temperatures climbed up into the upper 80s to low 90s in many locations across the area. Early season heat led people to seek relief in local rivers and lakes. While air temperatures were warm, river and lake temperatures were still cold, leading to two drownings across the area.

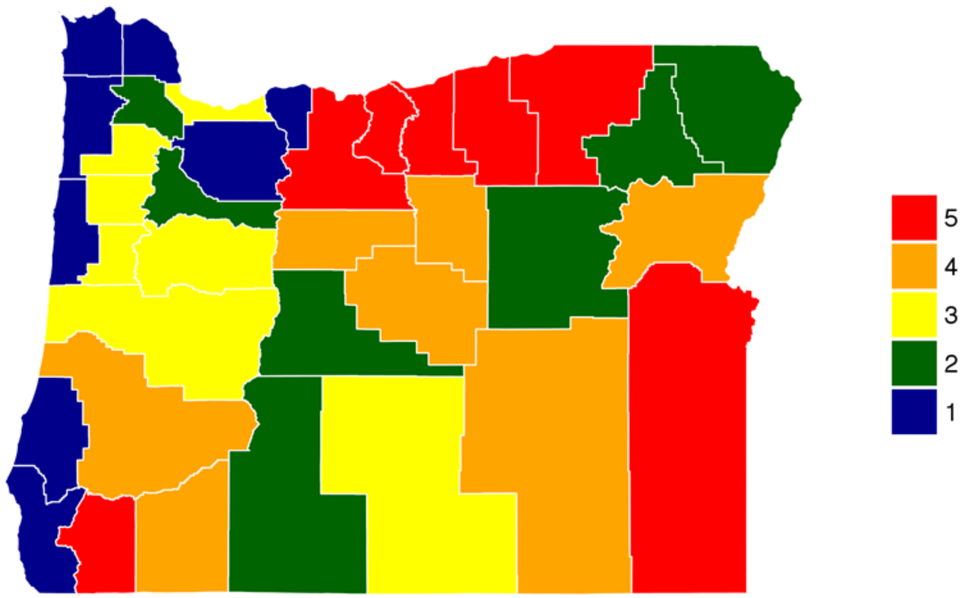
Date	Location	Notes
August 1–4, 2017	Region 2–4, 6	Excessive Heat Event: Strong high pressure brought record breaking heat to many parts of southwest, south central, and northwest Oregon. Region 2–3: The record-breaking heat led people to seek relief at local rivers. Two people drowned while swimming. Region 4: Reported high temperatures during this interval ranged from 98 to 112 degrees (Jackson), 95 to 110 degrees (Douglas), 87 to 109 degrees (Josephine, eastern Curry). Region 6: Reported high temperatures during this interval ranged from 82 to 102 degrees.
July 12–17, 2018	Region 2, 3, 4	Region 2–3: High pressure over the region led to a stretch of hot day July 12 through July 17th. Hot temperatures led people to cool off in local rivers. There were two drownings recorded on July 16 and July 18. Temperatures on July 16th near the Sandy River in Troutdale got up to 98 degrees Region 4: Strong high pressure coupled with very dry air brought very hot temperatures to the area during this interval. High temperatures ranged from 89 to 105 degrees (Jackson) and from 91 to 104 degrees (Josephine, eastern Curry).
June 11–12, 2019	Region 4 and eastern Curry County	Strong high pressure and a very dry air mass made for hot conditions over southwest Oregon during this interval. Reported high temperatures ranged from 95 to 101 degrees (Jackson), 89 to 101 degrees (Douglas), 88 to 105 degrees (Josephine, eastern Curry).
August 27-28, 2019	Region 4 and eastern Curry County	Excessive Heat Event: High pressure aloft forced a thermal trough near the coast to move inland, bringing hot and dry conditions to the inland west side valleys in southwest Oregon. Reported high temperatures in this zone ranged from 99 to 106 degrees on 08/27 and from 92 to 95 degrees on 08/28. Low temperatures on the morning of 08/28 ranged from 50 to 67 degrees.

Source: https://www.ncdc.noaa.gov/stormevents

2.2.4.2 Probability

The relative probability of experiencing extreme heat events was determined by dividing the counties into quintiles based on historic and projected future frequency of days with heat index above 90°F (as shown in **Figure 2-62**). Counties in the bottom quintile had the lowest frequency of days with heat index above 90°F relative to the rest of the state and were given a score of 1 meaning "very low." The probability of extreme heat events is highest in southern Oregon (Region 4), Columbia Plateau (Region 5), parts of central Oregon (Region 6), and Snake River Plain in eastern Oregon (Region 8). It is lowest on the coast (Region 1) and high elevations in Regions 2, 3, 7. **Figure 2-63** shows the relative probability rankings of each county in Oregon.

Figure 2-63. Relative Probability of Extreme Heat



Note: 5 = "Very High"; 4 = "High"; 3 = "Moderate"; 2 = "Low"; 1 = "Very Low"

Source: Oregon Climate Change Research Institute

Climate Change

In the future, extreme heat events are expected to increase in frequency, duration, and intensity due to warming temperatures in all eight regions in the 2020 Oregon NHMP. It is extremely likely (>95%) that the frequency and severity of extreme heat events will increase over the next several decades across Oregon (very high confidence). Increases in extreme heat events are likely to be greater for eastern Oregon (Region 5–8) than for western Oregon (Region 1–4) (Dalton et al., 2017). Inland areas at lower elevations, which climatologically see the greatest number of very hot temperature days, will see an even greater number of very hot days in the coming decades. Most locations in Oregon except the mountains and the coast will experience at least an additional 30 hot days per year, in many places doubling the frequency of such days (Mote et al., 2019). Very hot days, measured in an absolute sense, will continue to be rare in coastal and high elevation regions.

2.2.4.3 Vulnerability

Extreme heat is associated with more fatalities than any other severe weather event in the United States. Extreme heat events occur from time to time as a result of natural climatic variability, but are expected to increase in frequency, duration, and intensity in Oregon due to continued warming temperatures.

This section covers impacts of extreme heat and which groups of people are most vulnerable as well as a simple vulnerability assessment to identify the relative vulnerability across the state in terms of sensitivity and adaptive capacity.

Vulnerable Populations and Impacts

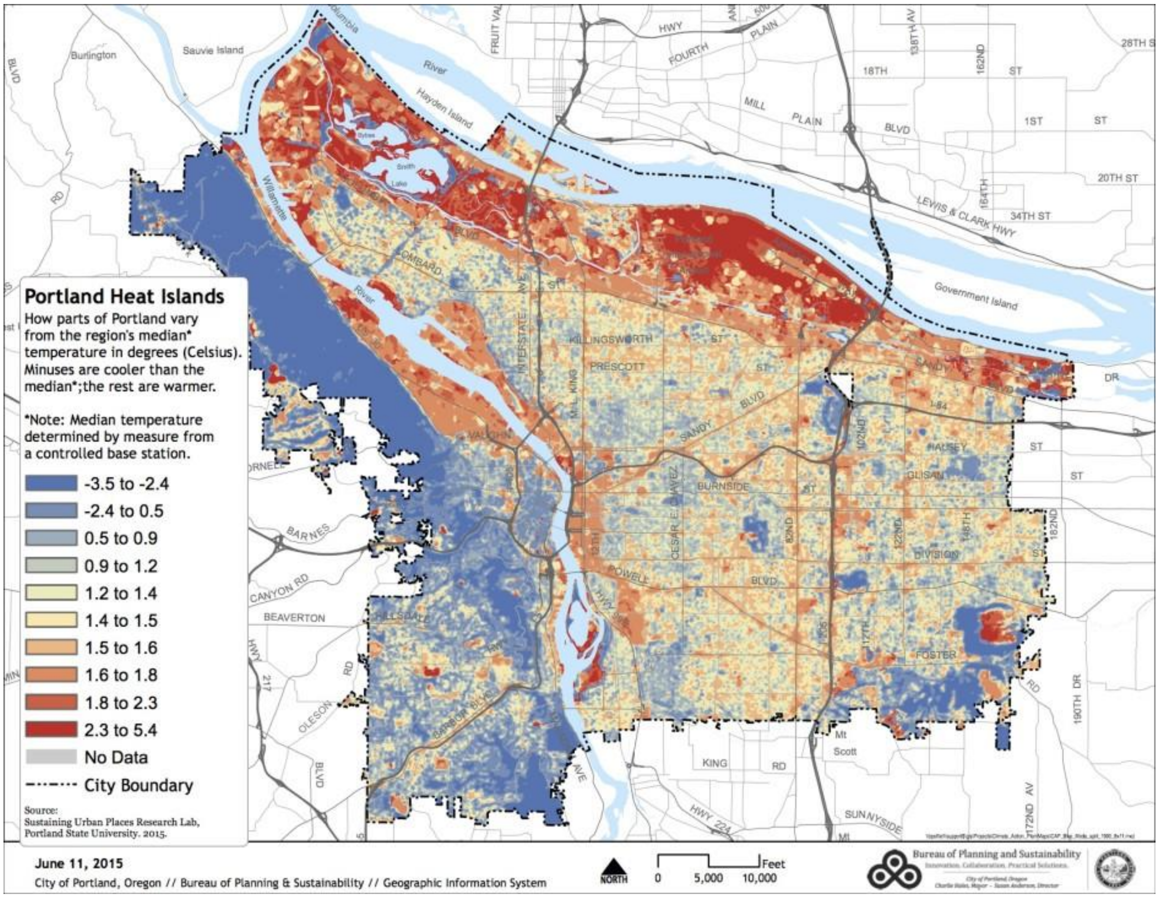
Extreme heat events can bring a wide array of impacts from increased morbidity and mortality from heat-related illness to disrupted transportation and infrastructure damaged by extreme heat.

Heat exposure can lead to heat rashes, heat cramps, heat exhaustion, and heat stroke. The adverse effects are not limited to the direct physiological consequences. Indirect impacts include the exacerbation of existing renal, cardiovascular, and respiratory conditions. Mental health can also be affected by extreme heat (https://www.ncbi.nlm.nih.gov/pubmed/30007545). There is evidence that extreme heat is associated with higher levels of aggression, violence, and suicidal behavior. Heat-related impacts on health may be immediate or delayed. Even small increases in average summer temperatures can lead to increases in heat-related deaths, especially among those with underlying medical conditions. A three-fold increase in heat-related illness has been documented in Oregon with each 10 °F rise in daily maximum temperature (Dalton et al., 2013).

Heat waves will result in increased deaths and illness among vulnerable human populations. Older adults, children, infants, people with existing medical conditions or disabilities, low-income communities, and outdoor workers are among the groups most threatened by heat waves (Ebi et al., 2018). People who work outside (including construction workers, farmworkers, foresters and fishers), as well as outdoor athletes face higher exposures to extreme heat. People who live in social isolation, including linguistic isolation or those living alone with few social relationships are also at higher risk. Social determinants, including race and ethnicity, income and educational attainment are correlated to numerous health outcomes, including heat-related illness.

Extreme heat in urban areas poses risk to human health and safety, especially for those living and working in urban heat islands. People living outdoors or in the upper floors of multi-family housing units may be particularly vulnerable. In cities, non-white populations are more likely to live in urban heat islands neighborhoods with impervious surfaces and low tree coverage, and areas with limited access to green space. Urban areas also may face increased energy and water demand and increased risk of disruption to civic and economic activity. A study of Portland, OR residents found that sociodemographic factors such as income, race, age, and English-speaking ability are associated with higher risk of adverse heat effects (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5923682/). **Figure 2-64** shows Portland's urban heat islands, locations that see hotter temperatures during heat events.

Figure 2-64. Portland, Oregon's Urban Heat Islands, the Parts of the City That See Hotter Temperatures in Heat Waves



Source: Shandas, V. and J. Voelkel, Sustaining Urban Places Research (SURP) Lab, Portland State University, 2016.

People working and living in less urban areas are also at risk. For example, farmworkers must often work outdoors (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4199019/) and are therefore more exposed to heat for greater periods of time. Approximately 30% of those interviewed in Oregon reported two or more heat related illness symptoms during their work. These symptoms, and associated hospitalizations, will naturally increase with higher temperatures if adequate protections are not provided. People living in areas like the Oregon coast or mountains might not be acclimated to extreme heat events and may lack critical infrastructure or protective equipment, for example air conditioning.

In addition to human health impacts, extreme heat events can disrupt transportation by delaying rail and air transportation when safe operating guidelines are exceeded, damaging rail tracks that may bend or roadway joints that may buckle under extreme heat (Jacobs et al., 2018). Heat waves can increase the demands on electric power for cooling, increasing the risk of cascading failures within the electric power network (Clarke et al., 2018). In addition, prolonged warm temperatures and severe heat are associated with tree mortality and forest conditions favorable to wildfire and wild fire spread making it more difficult to fight ongoing wildfires.

Oregon Health Authority Extreme Heat Planning and Response

Heat-related deaths and illness are preventable, yet many Oregonians are not familiar with the risks or what they can do to protect themselves. The Oregon Health Authority and some local health departments have produced risk communication materials to educate the public on symptoms, warning signs and recommended actions by vulnerable group, including fact sheets in multiple languages. Depending on a person's housing, access to transportation, and other factors these behavioral changes may be more difficult.

The Oregon Health Authority (OHA) has the capacity to track heat related illnesses in the state with a 24-hour lag. When heat waves occur, the agency, through its Electronic Surveillance System for the Early Notification System of Community-Based Epidemics (ESSENCE), generally observes an increase in heat-related emergency department visits (https://www.oregon.gov/oha/PH/DISEASESCONDITIONS/COMMUNICABLEDISEASE/PREPAREDNESSSURVEILLANCEEPIDEMIOLOGY/ESSENCE/Documents/HazardReports/ESSENCE_Hazards.pdf). While ESSENCE provides valuable data to inform scope and outreach, it could be improved by increasing reporting by health care clinics and increasing public health capacity to monitor and analyze the received data. Hospitalization data are also available, albeit with a much longer lag than ESSENCE. During 2013-2017, there were 219 hospitalizations for heat-related illness in Oregon, mostly in those 35 years and older (https://ephtracking.cdc.gov/DataExplorer/#/).

Oregon has some capacity for shelter from heat, but these cooling centers are limited in number and geographical distribution. Improvements in the built environment, including the expansion of tree canopies, shaded parks, fountains, and wading pools can provide public access to cooling. There is a need to engage more healthcare providers and coordinated care organizations (CCOs) who may be able to help prevent heat-related illness and death among vulnerable groups through targeted education and delivery of health-related services to Oregon Health Plan members (http://www.oregon.gov/oha/HPA/HP/docs/OHA%208440%20CCOHousing-Survey-Report.pdf).

A Crisis and Emergency Risk Communications (CERC) toolkit has been developed by OHA, translated into multiple languages, and promoted for use by local public health authorities. This toolkit provides critical information about the signs of heat illness, frequently asked questions, evidence-based social media messages, talking points and press releases. OHA's Public Health Duty Officer is routinely notified by National Weather Service (NWS) staff of impending extreme weather, including heat waves, and participates in NWS weather briefings.

OHA has identified the need for a more detailed vulnerability assessment. There also may be opportunity to strengthen early warning systems using meteorological and health data to issue targeted warnings to people in Oregon. OHA and local public health authorities can often provide community partners with technical assistance to develop heat response plans. These can include developing thresholds for certain actions and a tiered approach, such as when sporting events should take extra protective measures and when the events should be canceled. Creating clear plans for responding to extreme heat can help community partners make the right call at the right time. Based on data analysis that showed a high number of heat-related hospitalizations related to outdoor athletic events, the Multnomah County Health Department piloted a project with the City of Portland to include extreme heat guidelines for large outdoor event organizers within the City's permitting process.

In 2020, Governor Kate Brown issued Executive Order 20-04 that included several directives to State Agencies to address climate change impacts, including a specific directive to Oregon Health Authority to work with the Oregon Occupational Safety and Health (OSHA) to propose new standards for protecting outdoor workers from extreme heat.

Vulnerability Assessment

Vulnerability is defined as the combination of sensitivity to extreme heat and level of adaptive capacity in response to extreme heat. For the purposes of this plan, one measure of sensitivity and one measure of adaptive capacity were selected and combined to assess vulnerability by county in Oregon.

Sensitivity

Sensitivity is the degree to which people or communities are negatively affected by extreme heat exposures. Certain populations are more sensitive than others. Older adults, infants and children, pregnant women, people with preexisting diseases and those who take certain medications that affect thermoregulation or block nerve impulses are some of the populations with higher sensitivity.

For this assessment, sensitivity to extreme heat events was defined using the Center for Disease Control and Prevention (CDC) 2016 Social Vulnerability Index, https://svi.cdc.gov/data-and-tools-download.html. The CDC used 15 metrics of social vulnerability including metrics related to socioeconomic status, household composition and disability, minority status and language, and housing and transportation. The CDC's overall vulnerability scores are normalized from 0 to 1, such that a score of 1 is the greatest vulnerability. Overall vulnerability scores were obtained for each county in Oregon and sorted by quintiles and given rankings shown in **Table 2-38**. A ranking of 1 means "very low" sensitivity and a ranking of 5 means "very high" sensitivity. For example, Josephine County's overall vulnerability score from the CDC Social Vulnerability Index is 0.669, which falls in the 0.6–0.8 range and was given a sensitivity rank of 4 meaning "high" sensitivity. Sensitivity rankings for all counties are shown in column 1 of **Table 2-38**.

Table 2-38. Sensitivity Rankings

Quantile Range	Sensitivity	Rank	Vulnerability
0.0 – 0.2	Very Low	1	Very Low
0.2 – 0.4	Low	2	Low
0.4 – 0.6	Moderate	3	Moderate
0.6 – 0.8	High	4	High
0.8 – 1.0	Very High	5	Very High

Adaptive Capacity

Adaptive capacity is the ability of communities, institutions, or people to adjust to potential hazards, to take advantage of opportunities, or to respond to consequences in ways that reduce harmful exposures (i.e., the ability to prepare for, respond to, and cope with heat events). Health outcomes are strongly influenced by adaptive capacity factors, including those related to the natural and built environments, government regulations and response. Examples of factors that influence a person's adaptive capacity to extreme heat include access to air conditioning and the ability to afford to run it, housing quality, access to information in one's first language, access to cooling centers or other built environment features like parks or natural areas, access to transportation, access to health care, and strong social networks.

Adaptive capacity to extreme heat is defined here as percent of homes with air conditioning, however the authors note that this measure has its flaws. First, it assumes that people who have access to cooling systems are able to afford to use them. Second, the data only includes single-family homes, which omits populations living in multi-family housing or who are house-less.

The Northwest Energy Efficiency Alliance (NEEA) assessed the penetration of cooling systems in Oregon in 2016–2017 (https://neea.org/img/uploads/Residential-Building-Stock-Assessment-II-Single-Family-Homes-Report-2016-2017.pdf). According the NEEA's analysis, about 68% of single-family homes and manufactured homes in Oregon have cooling systems, and about one quarter of multifamily residences have cooling systems. **Table 2-39** breaks down air-conditioning penetration of single-family and manufactured homes by cooling zones.

Table 2-39. Percentage of Homes with Cooling Equipment

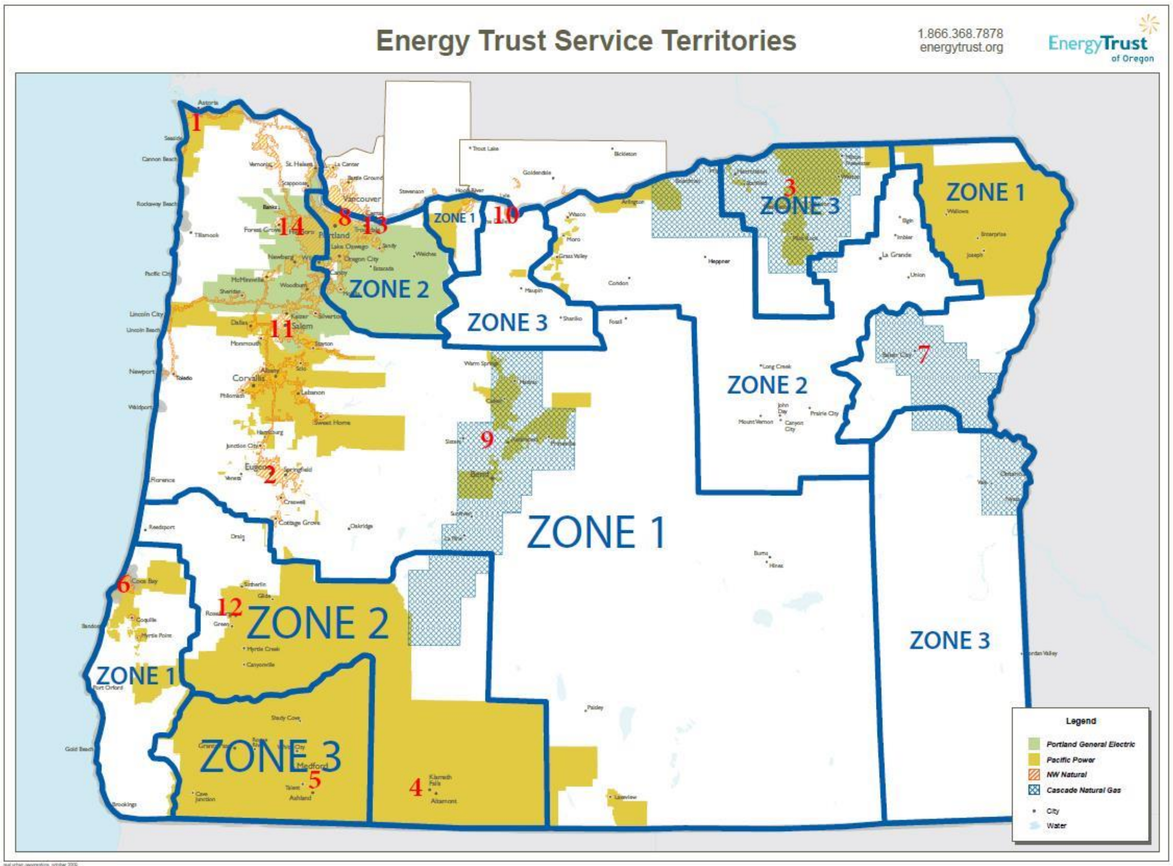
	Single Family Homes	Manufactured Homes
Cooling Zone 1 (All of Regions 1 and 3 plus Columbia, Washington, Hood River, Jefferson, Wheeler, Crook, Deschutes, Lake, Wallowa, Baker, Harney Counties)	57.7%	59.5%
Cooling Zone 2 (Multnomah, Clackamas, Douglas, Sherman, Gilliam, Morrow, Klamath, Union, Grant Counties)	55.4%	66.8%
Cooling Zone 3 (Josephine, Jackson, Malheur, Wasco, and Umatilla Counties)	90.7%	76.9%
All Cooling Zones (Oregon)	67.9%	67.7%

Source: https://neea.org/img/uploads/Residential-Building-Stock-Assessment-II-Single-Family-Homes-Report-2016-2017.pdf, page 41

The Northwest Power and Conservation Council (www.nwcouncil.org.) defines cooling zones in terms of annual cooling degree-days, derived by subtracting 65 degrees from the daily average temperature. Days with average temperatures at or below 65 degrees are not cooling-degree days. Cooling Zone 1 is defined as having fewer than 300 cooling degree-days annually; Cooling Zone 2 is defined as having 300 to 600 cooling degree-days annually; and Cooling Zone 3 is defined as having more than 600 cooling degree-days annually. **Figure 2-65** and **Table 2-39** display Cooling Zones for each Oregon county according to Energy Trust of Oregon (https://www.energytrust.org/wp-content/uploads/2018/06/AC-Research_PhaseII_9MAR2018_Final.pdf).

Air-conditioning penetration is highest (91%) in Cooling Zone 3, which includes Josephine, Jackson, Malheur, Wasco, and Umatilla counties—the places accustomed to extreme heat. Just more than half of single-family homes in Cooling Zones 1 (58%) and 2 (55%) have air-conditioning. Even though Cooling Zone 3 counties have high probabilities of extreme heat events occurring, those locations are also more accustomed and prepared for extreme heat. Other areas of Oregon can experience extreme heat, and can expect to experience extreme heat with greater frequency under climate change, yet about half of homes in Cooling Zones 1 and 2 don't have cooling systems in place making those counties more vulnerable in terms of adaptive capacity to extreme heat events than counties in Cooling Zone 3.

Figure 2-65. Cooling Zones



Note: Red numerals indicate weather station numbers.

Source: Energy Trust of Oregon, https://www.energytrust.org/wp-content/uploads/2018/06/AC-Research_PhaseII_9MAR2018_Final.pdf

Rankings for this adaptive capacity measure were determined by quintiles of percent of single-family homes with cooling systems. For example, cooling zones with 0 to 20% of single-family homes with air-conditioning were assigned a score of 5 meaning that adaptive capacity is very low (meaning higher vulnerability). Cooling zones 1 and 2 had between 40% and 60% of single-family homes with air-conditioning and counties in those zones ranked at a 3 for "moderate" adaptive capacity. Cooling zone 3 had between 80% and 100% of single-family homes with air-conditioning and counties in that zone ranked at a 1 for "very high" adaptive capacity (meaning lower vulnerability). Adaptive capacity rankings for each county are shown in column 2 in **Table 2-40**.

Table 2-40. Adaptive Capacity Rankings

Quantile Range	Adaptive Capacity	Rank	Vulnerability
0.0 – 0.2	Very Low	5	Very High
0.2 – 0.4	Low	4	High
0.4 – 0.6	Moderate	3	Moderate
0.6 – 0.8	High	2	Low
0.8 – 1.0	Very High	1	Very Low

Methodology and Results

The relative vulnerability of Oregon counties to extreme heat was determined by adding the rankings for sensitivity (social vulnerability) and adaptive capacity (air conditioning). The sum of the two components ranged from 1 to 10. Rankings were determined as follows: total vulnerability scores of 1–2 earned a ranking of 1 (very low); scores of 3–4 earned a ranking of 2 (low); scores of 5–6 earned a ranking of 3 (moderate); scores of 7–8 earned a ranking of 4 (high); and scores of 9–10 earned a ranking of 5 (very high). Rankings for NHMP regions are averages of the counties within a region rounded to the nearest whole number **Table 2-41** displays the vulnerability rankings as well as rankings for sensitivity and adaptive capacity for each county and NHMP region.

Relative vulnerability is low in Region 2, high in Region 3, and moderate throughout the rest of the state. It is notable that while the vulnerability scores are moderate for Regions 5, 6 and 8 and high for Region 3, they are the only regions that have counties with very high sensitivity: Marion County (Region 3); Morrow, Umatilla, and Wasco Counties (Region 5); Jefferson and Klamath Counties (Region 6); and Malheur County (Region 8). Adaptive capacity is ranked 1 (very low vulnerability) in five counties and moderate in the rest; no counties rank 4 or 5 (very high vulnerability) for adaptive capacity. The high and very high sensitivity scores are tempered by very low and moderate adaptive capacity scores, resulting in primarily moderate vulnerability scores.

Most Vulnerable Communities

According to this method of assessing vulnerability, Region 3 is the most vulnerable overall to extreme heat, and Coos, Linn, Marion, Yamhill, Douglas, Morrow, Jefferson, Klamath, and Lake Counties are the counties most vulnerable to extreme heat statewide.

Table 2-41. Relative Vulnerability Rankings for Oregon Counties and Regions

County	Sensitivity	Adaptive Capacity	Vulnerability
Region 1	**3**	**3**	**3**
Clatsop	2	3	3
Coos	4	3	4
Curry	2	3	3
Lincoln	3	3	3
Tillamook	2	3	3
Region 2	**2**	**3**	**2**
Clackamas	1	3	2
Columbia	1	3	2
Multnomah	3	3	3
Washington	1	3	2
Region 3	**4**	**3**	**4**
Benton	2	3	3
Lane	3	3	3
Linn	4	3	4
Marion	5	3	4
Polk	3	3	3
Yamhill	4	3	4
Region 4	**4**	**2**	**3**
Douglas	4	3	4
Jackson	4	1	3
Josephine	4	1	3
Region 5	**3**	**2**	**3**
Gilliam	1	3	2
Hood River	3	3	3
Morrow	5	3	4
Sherman	1	3	2
Umatilla	5	1	3
Wasco	5	1	3
Region 6	**3**	**3**	**3**
Crook	3	3	3
Deschutes	1	3	2
Jefferson	5	3	4
Klamath	5	3	4
Lake	4	3	4
Wheeler	1	3	2
Region 7	**2**	**3**	**3**
Baker	2	3	3
Grant	1	3	2
Union	2	3	3
Wallowa	2	3	3
Region 8	**4**	**2**	**3**
Harney	3	3	3
Malheur	5	1	3

Source: Oregon Climate Change Research Institute

2.2.4.4 Risk

With respect to extreme heat, risk is defined as the combination of the likelihood of occurrence of extreme heat events (probability) and vulnerability to extreme heat (which includes sensitivity and adaptive capacity).

The relative risk of Oregon counties to extreme heat was determined by adding the rankings for probability (**Figure 2-63** and **Table 2-42**, column 2) and vulnerability (**Table 2-42**, column 3). The sum of the two components ranged from 1 to 10. Rankings were determined as follows: total vulnerability scores of 1–2 earned a ranking of 1; scores of 3–4 earned a ranking of 2; scores of 5–6 earned a ranking of 3; scores of 7–8 earned a ranking of 4; and scores of 9–10 earned a ranking of 5. Rankings for NHMP regions are averages of the counties within a region rounded to the nearest whole number.**Table 2-42** displays the relative risk rankings as well as the rankings for relative probability and relative vulnerability for each county and NHMP region.

Region 4, Region 5, and Region 8 face the greatest risk from extreme heat. Morrow County alone (Region 5) is at very high risk. The counties at high risk are: Linn, Yamhill, Douglas, Jackson, Josephine, Gilliam, Sherman, Umatilla, Wasco, Crook, Jefferson, Lake, Baker, Harney, and Malheur.

Table 2-42. Risk Rankings for Oregon Counties and Regions

County	Probability	Vulnerability	Risk
Region 1	**1**	**3**	**2**
Clatsop	1	3	2
Coos	1	4	3
Curry	1	3	2
Lincoln	1	3	2
Tillamook	1	3	2
Region 2	**2**	**2**	**2**
Clackamas	1	2	2
Columbia	1	2	2
Multnomah	3	3	3
Washington	2	2	2
Region 3	**3**	**4**	**3**
Benton	3	3	3
Lane	3	3	3
Linn	3	4	4
Marion	2	4	3
Polk	3	3	3
Yamhill	3	4	4
Region 4	**4**	**3**	**4**
Douglas	4	4	4
Jackson	4	3	4
Josephine	5	3	4
Region 5	**4**	**3**	**4**
Gilliam	5	2	4
Hood River	1	3	2
Morrow	5	4	5
Sherman	5	2	4
Umatilla	5	3	4
Wasco	5	3	4
Region 6	**3**	**3**	**3**
Crook	4	3	4
Deschutes	2	2	2
Jefferson	4	4	4
Klamath	2	4	3
Lake	3	4	4
Wheeler	4	2	3
Region 7	**3**	**3**	**3**
Baker	4	3	4
Grant	2	2	2
Union	2	3	3
Wallowa	2	3	3
Region 8	**5**	**3**	**4**
Harney	4	3	4
Malheur	5	3	4

Source: Oregon Climate Change Research Institute

2.2.5 Floods

Floods are a common and widespread natural hazard in Oregon; the state has an extensive history of flooding. Flooding typically results from large-scale weather systems that generate prolonged rainfall or rain-on-snow events that result in large amounts of runoff. Other sources of flooding include flash floods associated with locally intense thunderstorms, channel migration, ice or debris jams, and, much less frequently, dam failures.

The National Flood Insurance Program (NFIP) identifies 252 communities in Oregon as flood-prone including locations in all 36 counties, 213 cities, and three Tribal Nations. Every county and all but one of these flood-prone cities participates in the NFIP, allowing residents to purchase NFIP flood insurance. Nine additional cities for which FEMA has not mapped Special Flood Hazard Areas also belong to the NFIP, indicating that they believe a flood hazard exists within their jurisdiction and that their residents should have access to NFIP flood insurance.

2.2.5.1 Analysis and Characterization

History of Flooding in Oregon

Oregon has an extensive history of flooding. **Table 2-43** summarizes major floods within the state. Oregon's deadliest recorded flood occurred in Heppner in 1903 when a June 14th storm dropped 1.5 inches of rain within a twenty-minute period. The storm was centered in the headwaters area of Willow Creek above Heppner in Northeastern Oregon. Within minutes, a five-foot wall of water and debris poured through Heppner with enough velocity to rip homes off foundations. These floodwaters claimed 247 lives.

Another late spring flood in 1948 is best remembered for destroying the entire city of Vanport (now Delta Park). Record flow levels on the Columbia River caused the structural failure of a dike. Much of Vanport was destroyed in minutes and was never rebuilt. Nineteen thousand people lost their homes and eighteen people lost their lives.

Many of Oregon's floods of records occurred in December 1964 and January 1965 during the "Christmas Flood." Damage from these floods totaled over $157 million dollars and twenty Oregonians lost their lives. From December 20 through 24, 1964, the most severe rainstorm to occur in Central Oregon and one of the most severe west of the Cascades left many areas with two thirds their normal annual rainfall in five days. The ensuing floods destroyed hundreds of homes and businesses, forced the evacuation of thousands of people, destroyed at least 30 bridges, and washed out hundreds of miles of roads and highways.

A similar flood event occurred in February 1996. Following an extended period of unseasonably cold weather and heavy snowfall in the Pacific Northwest, warming temperatures and rain began thawing the snowpack and frozen rivers throughout Oregon. On February 6, a strong subtropical jet stream or "Pineapple Express" reached Oregon. This warm, humid air mass brought record rainfall amounts, quickly melting the snowpack. At least twenty-five rivers reached flood stage. Many reached flood levels comparable to those reached in the 1964 flood. Twenty-seven of Oregon's 36 counties were eventually covered by a Presidential major disaster declaration due to this event. Statewide, damages totaled over $280 million.

A series of powerful wind and rain storms caused extensive flooding in northwestern in December of 2007. Three people were killed as a result of these storms. The City of Vernonia was hard hit with over 200 buildings substantially damaged and subsequently elevated or bought-out by FEMA.

Types of Flooding

Riverine: Riverine flooding is the most common flood hazard in Oregon. It is caused by the passage of a larger quantity of water than can be contained within the normal stream channel. The increased stream flow is usually caused by heavy rainfall over a period of several days. Examples of riverine events are the flooding in December 2007, February 1996, and December 1964 to January 1965. The most severe flooding conditions occur, however, when heavy rainfall is augmented by rapid snowmelt. These rain-on-snow events occur on mountain slopes within the low elevation snow zones of the Pacific Northwest. These events make more water available for runoff than does precipitation alone by melting the snowpack and by adding a small amount of condensate to the snowpack (van Heeswijk et al., 1996). If the ground is frozen, stream flow can be increased even more by the inability of the soil to absorb additional runoff. Rain falling on snow also is a major cause of mid-winter avalanches, which tend to coincide with flood events. Significant rain-on-snow events occur in years that are colder and wetter than normal because snow accumulates at lower elevations, and then is melted off during subsequent rain events (Ferguson, 2000). Rain-on-snow events, including those that occurred in 1894, 1948, 1964, 1977, and 1996 (**Table 2-44**), are associated with some of the State's most damaging floods.

Flash floods: Flash flooding is caused by extremely intense rainfall over a short period of time, commonly within a single drainage. Flash floods usually occur in the summer during the thunderstorm season. The two key contributors to flash flooding are rainfall intensity and duration. Topography, soil conditions, and ground cover also impact flooding. Flash floods, because of their intensity, often pick up large loads of sediment and other solid materials. In these situations, a flash flood may arrive as a fast moving wall of debris, mud, and water.

Occasionally, floating debris or ice accumulates at a natural or man-made obstruction and restrict the flow of water. Water held back by the ice jam or debris dam can cause flooding upstream. Subsequent flash flooding can occur downstream if the obstruction suddenly releases. Areas subject to flash floods are not as obvious as a typical riverine floodplain. However, flash floods may be associated with recognizable locations such as canyons or arroyos. There is also always some potential for flash floods associated with dam failure.

The most notorious flash flood in Oregon was the June 14, 1903, event in Heppner summarized previously. More recent flash floods have occurred in Wallowa Co. (July 2002) and the City of Rufus (August 2003).

Alluvial fan flooding: 44 CFR Part 59.1 defines alluvial fan flooding as flooding occurring on the surface of an alluvial fan. Alluvial fans are fan-shaped deposits of water-transported material (alluvium) that typically form at the base of steep topographic features where there is a marked break in slope. FEMA notes that alluvial fans can make attractive, but dangerous, development sites. Attractive because they provide commanding views and good drainage, but dangerous because flood flows can happen quickly over unpredictable flow paths, at high velocity, and carry large amounts of debris (FEMA, 1989). The potential for this type of flooding in Oregon is unstudied and past events (if any) have been poorly documented.

Coastal floods: Coastal areas have additional flood hazards. Winds generated by tropical storms or intense off shore low-pressure systems can drive ocean water inland and cause significant flooding. The height of storm surge is dependent on the wind velocity, water depth and the length of open water (the fetch) over which the wind is flowing. Storm surges are also affected by the shape of the coastline and by the height of tides.

Coastal flooding also may result from tsunamis. A tsunami is a series of traveling ocean waves generated by an earthquake or landslide that occurs below or on the ocean floor. Oregon's seven coastal counties and many coastal cities are susceptible to flood damage associated with tsunamis. Both "distant" tsunamis generated from seismic events in the Pacific basin and "near shore" tsunamis generated from activity associated with the Cascadia Subduction Zone can impact Oregon's coast. For more information, see the Tsunami chapter of this Plan.

Shallow area flooding: Some areas are characterized by FEMA as being subject to shallow flooding. These are areas that are predicted to be inundated by the 100-year flood with flood depths of one to three feet. Flooding events are expected to be low velocity events characterized by "sheet flows" of water.

Urban flooding: As land is converted from fields or woodlands to roads, roofs, and parking lots, it loses its ability to absorb rainfall. This transition from pervious surfaces to impervious surfaces results in more and faster runoff of water. During periods of urban flooding, streets can become swift moving rivers, and basements can fill with water. Storm drains may back up with yard waste, causing additional nuisance flooding.

Playa flooding: Playa flooding results from greater than normal runoff into a closed basin. Closed basin systems are those areas that have one or more rivers emptying into one or more lakes that have no outlet. In these situations, water can only leave the system through evaporation. Thus, if annual precipitation in the basin increases significantly, evaporation is not enough to reduce water levels. Lake levels rise and inundate the surrounding properties.

The best-known example of playa basin flooding in Oregon occurs at Malheur and Harney lakes in Harney County. In higher than average precipitation years, the lakes flood adjacent ranches and public roads. Malheur and Harney lakes flooded during the years 1979 to 1986, and then gradually receded. During the wetter years of 1997 to 1999, these lakes again flooded. By 2005, following a number of dry years, they had receded significantly. In spring 2011, as a result of a heavy snowpack and persistent rainfall, Harney Lake's water level increased significantly with flooding observed in low-lying areas.

Ice jams: Ice jams happen in colder regions of the State during winter and early spring while rivers are frozen. Sudden warming at higher altitudes melts snow resulting in increased runoff which breaks the ice from reaches of frozen river below. On the way downstream, the floating ice can "jam" in a narrow reach of the drainage or against a road crossing which then dams melting water. As the ice weakens, water breaches the dam releasing a torrent of water.

Dam failure: Dam failures and accidents, though rare, can result in extreme flooding downstream of the dam. Catastrophic dam failures have occurred in other parts of the country and around the world. The South Fork Dam failure (1889 Johnstown flood) resulted in over 2000 fatalities in western Pennsylvania. The Saint Francis Dam in southern California failed in 1928 with a loss of an estimated 600 people. Oregon's dam safety statutes (ORS 540.350 through 400) came into effect shortly after the Saint Francis disaster. Many historical dam failures were triggered by flood events, others by poor dam construction, and some have been triggered by earthquakes.

Channel Migration in Association with Flooding

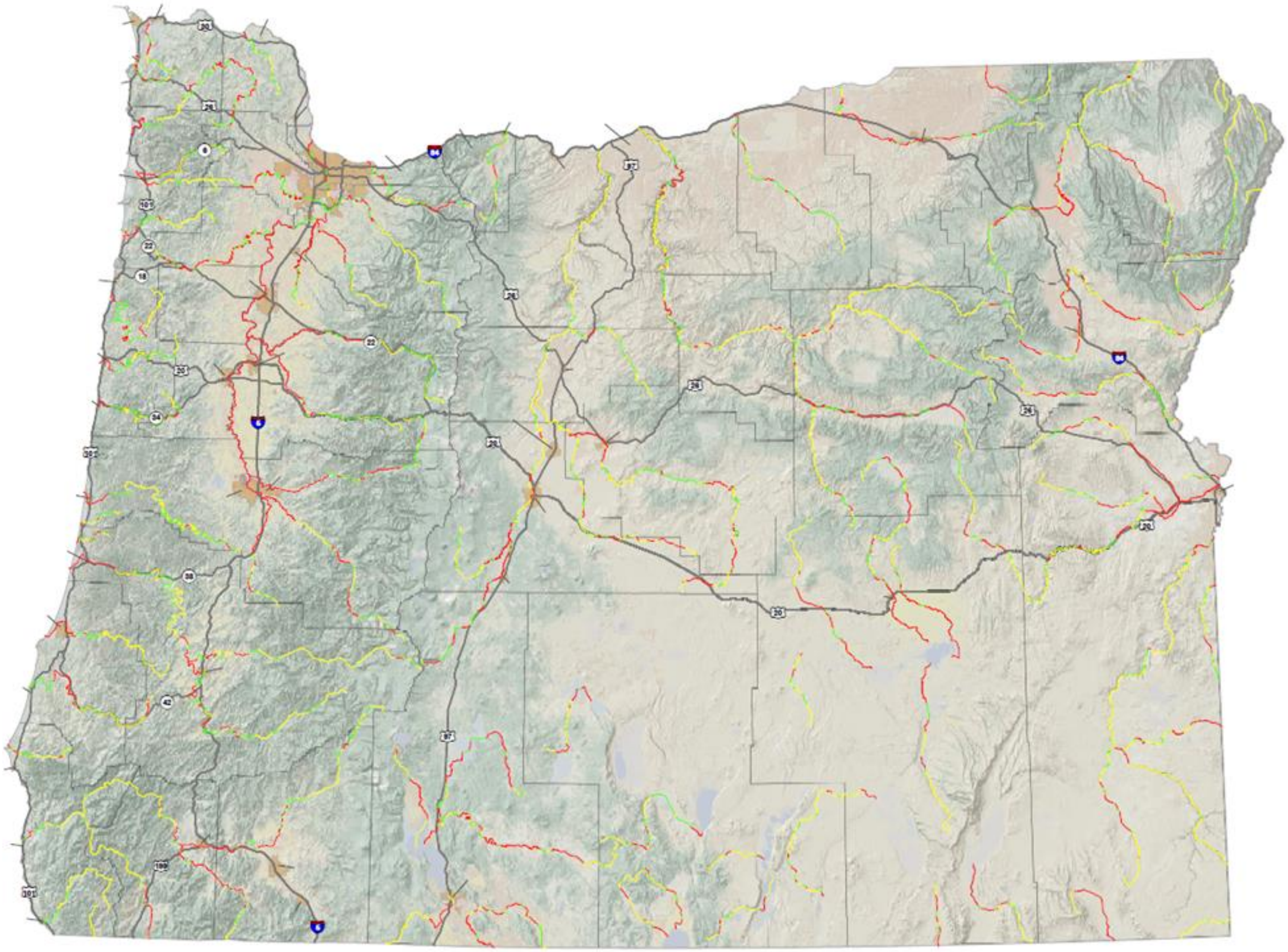
Channel migration is the process by which streams move laterally over time. It is typically a gradual phenomenon that takes place over many years due to natural processes of erosion and deposition. In some cases, usually associated with flood events, significant channel migration can happen rapidly. In high flood flow events stream channels can "avulse" and shift to occupy a completely new channel.

Areas most susceptible to channel migration are transitional zones where steep channels flow from foothills into broad, flat floodplains. The most common physiographic characteristics of a landscape prone to channel migration include moderate channel steepness, moderate to low channel confinement (i.e., valley broadness), and erodible geology.

Channel migration can and has created hazardous conditions within Oregon's developed riparian areas. Rapid migration can undercut structure foundations and damage infrastructure. The upper Sandy River in eastern Clackamas County is an example of where channel migration and development intersect. A recent January 2011 flood resulted in temporary avulsion that washed out section of Lolo Pass Road and also bank erosion that damaged and destroyed several homes.

Channel migration is not a standard consideration of the NFIP and has not been mapped systematically in Oregon. DOGAMI has recently completed a statewide channel migration screening for major rivers in Oregon (Roberts and Anthony, 2017). This study classified nearly 7,000 river miles into high, medium and low potential susceptibility to channel migration based on river and valley characteristics. DOGAMI selected and is currently mapping detailed channel migration zones in four counties in Oregon based on the results of the 2017 screening. The screening will continue to be used to prioritize future detailed channel migration zone mapping as funding becomes available.

Figure 2-66. Channel migration screening overview map of Oregon showing major rivers with low (yellow), moderate (green), and high (red) susceptibility.



Source: Roberts and Anthony (2017)

The El Niño Southern Oscillation (ENSO) Cycle

- El Niño and La Niña are opposite phases of what is known as the El Niño-Southern Oscillation (ENSO) cycle. The ENSO cycle is a scientific term that describes the fluctuations in temperature between the ocean and atmosphere in the east-central Equatorial Pacific.
- La Niña is sometimes referred to as the cold phase of ENSO and El Niño as the warm phase of ENSO. These deviations from normal surface temperatures can have large-scale impacts not only on ocean processes, but also on global weather and climate.
- El Niño and La Niña episodes typically last nine to 12 months, but some prolonged events may last for years. They often begin to form between June and August, reach peak strength between December and April, and then decay between May and July of the following year.
- While their periodicity can be quite irregular, El Niño and La Niña events occur about every 3 to 5 years. Typically, El Niño occurs more frequently than La Niña.

Source: NOAA, What are El Niño and La Niña?, http://oceanservice.noaa.gov/facts/ninonina.html

El Niño and La Niña Events in Oregon and Relationship to Flooding

One of the most prominent aspects of Oregon's weather and climate is its variability. This variability ranges over many time and space scales, from small-scale phenomena such as wind gusts and localized thunderstorms, to larger-scale features like fronts and storms, to even more prolonged features such as droughts and periods of flooding. Fluctuations occur on multi-seasonal, multi-year, multi-decade and even multi-century time scales. Examples of these longer time-scale fluctuations include an abnormally hot and dry summer, an abnormally cold and snowy winter, a consecutive series of abnormally mild or exceptionally severe winters, and even a mild winter followed by a severe winter. Human inputs into our geophysical environment are also imposing cumulative impacts with measurable changes to global climate, sea-level and even localized weather. These human inputs along with the normal climate cycles may be working together in unpredictable ways and lead to future climate scenarios that do not resemble past, historic cycles. Under a warming climate, while it is still uncertain exactly how ENSO variability may change, recent research is more confident that the relationships between ENSO and its impacts around the globe will be stronger.

The terms El Niño and La Niña represent opposite extremes of the ENSO cycle in an otherwise continuum of global climate events, with "average" conditions generally prevailing between those extremes. In the past three decades there have been several El Niños, with the 1982 to 1983 and 1997 to 1998 events having been the strongest on record, while the period between 1990 and 1995 was characterized by persistent El Niño conditions, the longest on record (Trenberth, 1999).

Table 2-43. Recent ENSO Events in Oregon

El Niño Events	La Niña Events
1982-1983	1988-1989
1994-1995	1995-1996
1997-1998	1999-2000
2002-2003	
2004-2005	
2006-2007	2007-2009
2009-2010	2010-2012
2014-2016	2016
	2017-2018
2018-2019	La Niña Events

Source: NOAA, Multivariate ENSO Index (MEI) http://www.esrl.noaa.gov/psd/enso/mei/ and https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php

In general, the longer time-scale phenomena are associated with changes in oceanic and atmospheric circulation that encompass areas far larger than a particular affected region. At times, these persistent features occur simultaneously over vast, and seemingly unrelated, parts of the hemisphere, or even the globe, resulting in abnormal weather, temperature, and rainfall patterns throughout the world. During the past several decades, scientists have discovered that important aspects of this interannual variability in global weather patterns are linked to a global-scale, naturally occurring phenomenon known as the El Niño Southern Oscillation (ENSO) cycle. A measure of this cycle is the Southern Oscillation Index (SOI), which is "calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin, Australia."

Historical El Niño and La Niña events in Oregon

The earliest systematic study of ENSO in the Northwest was Redmond and Koch (1991). The results were sufficiently strong that the authors suggested a cause-effect relationship between the SOI and Oregon weather. They determined that the Southern Oscillation Index (SOI) can be used as a predictor for weather, especially for winter weather. Greatest correlations between SOI and winter weather patterns occur with about a four-month time lag with summer average SOI correlating well with weather in the Northwest during the following winter. SOI values less than zero represent El Niño conditions, near zero values are average, and positive values represent La Niña conditions.

In Oregon El Niño impacts associated with these climate features generally include warmer winter temperatures and reduced precipitation with drought conditions in extreme events.

What Oregonians should especially plan for and monitor, however, is La Niña. Severe flooding during the winters of 1995-96, 1998-99, and 2007-08 are attributable largely to the combination of heavy snows and warm, intense tropical rain. During La Niña events, heavy rain arrives in Oregon from the western tropical Pacific, where ocean temperatures are well above normal, causing greater evaporation, more extensive clouds, and a greater push of clouds across the Pacific toward Oregon. During February 1996, for example, severe flooding — the worst in the state since 1964 — killed several people and caused widespread property damage. Nearly every river in Oregon reached or exceeded flood stage, some setting all-time records. Debris flows and landslides were also numerous. (Note that debris flow events are typically associated with periods of heavy rainfall or rapid snowmelt on steeply sloping ground. The term "mudslide" is often used interchangeably but is poorly defined as a natural hazard. FEMA uses the terms "mudslide" and "mudflow" in the context of the National Flood Insurance Program, e.g., 44 CFR 59.1 and 206.2(a)(17).)

Historic Flood Events

Table 2-44 lists historic damaging floods in Oregon.

Table 2-44. Historic Damaging Floods in Oregon

Date	Location	Notes
Sep. 1861	Klamath, Willamette, and Umpqua	Klamath, Douglas, Lane, Linn, Benton, Marion, Polk, Yamhill, Clackamas, Multnomah Counties
June 1880	Columbia	Clatsop, Columbia, Multnomah, Hood River, Sherman, Gilliam, Morrow
Jan. 1881	Willamette Basin	Lane, Linn, Benton, Marion, Polk, Yamhill, Clackamas, Multnomah Counties
Dec. 1882	Umatilla	Umatilla County
June 1884	John Day	Grant, Wheeler, Wasco, Sherman Gilliam
May-June 1894	Columbia River Basin	Clatsop, Columbia, Multnomah, Hood River, Sherman, Gilliam, Morrow; rain on snowpack; highest flood stage ever recorded at Vancouver, Washington (33.6 ft)
June 1903	Willow Creek	flash flood in Heppner; 247 people killed
Apr. 1904	Silvies and Klamath	Harney, Klamath Counties
Feb. 1907	western Oregon and John Day	Grant, Wheeler, Wasco, Sherman, Gilliam
Nov. 1909	Deschutes, Willamette, Santiam, Umpqua, Coquille, and Rogue	Deschutes, Jefferson, Wasco, Linn, Douglas, Coos, Curry, Josephine, Jackson
Mar. 1910	Powder and Malheur	Baker, Malheur, Harney
June 1913	Columbia	Clatsop, Columbia, Multnomah, Hood River, Sherman, Gilliam, Morrow
Jan. 1923	Clackamas, Santiam, Sandy, Deschutes, Hood, and McKenzie	Clackamas, Linn, Multnomah, Deschutes, Jefferson, Wasco, Hood River, Lane Counties; record flood levels
Feb. 1925	Malheur	Malheur, Harney
Feb. 1927	Klamath, Willamette, Umpqua, Rogue, and Illinois	major flooding
May 1928	Columbia	Clatsop, Columbia, Multnomah, Hood River, Sherman, Gilliam, Morrow
Mar. 1931	Umatilla, Sandy, Clackamas, and Santiam	Umatilla, Clackamas, Multnomah, Linn
Mar. 1932	Malheur, Grande Ronde, John Day, and Umpqua	Malheur, Harney, Union, Wallowa, Grant, Wheeler, Wasco, Sherman, Gilliam, Douglas
Jan. 1933	Coquille	Coos County
Nov.–Dec. 1942	Willamette Basin	Lane, Linn, Benton, Clackamas, Multnomah; 10 deaths; $34 million damage
Dec. 1945	Coquille, Santiam, Rogue, and McKenzie	Coos, Linn, Jackson, Josephine, Curry and Lane Counties; 9 deaths and homes destroyed in Eugene area
Dec. 1946	Willamette, Clackamas, Luckiamute, and Santiam	
May - June 1948	Columbia River	Multnomah County, Wasco County; rain on snow; destruction of the City of Vanport
Mar. 1952	Malheur, Grand Ronde, and John Day	Malheur, Harney, Union, Wallowa, Grant, Wheeler, Wasco, Sherman, Gilliam counties; highest flood stages on these rivers in 40 years
Dec. 1955	Rogue, Umpqua, Coquille	DR-49. Jackson, Josephine, Curry, Douglas, Coos Counties; 11 deaths; major property damage

Date	Location	Notes
July 1956	central Oregon	DR-60. City of Mount Vernon, Grant County and City of Mitchell, Wheeler County; flash floods
Feb. 1957	SE Oregon	DR-69. $ Malheur, Baker, Wallowa Counties; 3.2 million in flood damages
Dec. 1961	Willamette Basin	Lane, Linn, Benton, Clackamas, Multnomah; $3.8 million in flood damages
Dec. 1964–Jan. 1965	Pacific Northwest	DR-184. All 36 counties; rain on snow; record flood on many rivers
Dec. 1967	central Oregon coast	Clatsop, Tillamook, Lincoln Counties; storm surge
Feb 1971	north coast	DR-301. Clatsop and Tillamook counties
Jan. 1972	western Oregon	DR-319. Clackamas, Clatsop, Coos, Douglas, Lane, Lincoln, Linn, Multnomah, Tillamook, Washington counties; record flows on coastal rivers
Jan. 1974	western Oregon	DR-413. Benton, Clackamas, Columbia, Coos, Curry, Douglas, Gilliam, Hood River, Jackson, Josephine, Lane, Lincoln, Marion, Polk, Tillamook, Wallowa, Wasco, Washington, Yamhill counties; $65 million in damages
Nov. –Dec. 1977	western Oregon	Multnomah, Clackamas counties; rain-on-snow event; $16.5 million in damages
1979 to present	Harney County	cyclical playa flooding on Harney and Malheur lakes
Dec. 1981	Umpqua and Coquille	Douglas and Coos Counties
Jan. 1982	Tillamook County	
Feb. 1982	Malheur and Owyhee Basins	Malheur and Harney Counties
Jan. 1990	Clatsop and Tillamook Counties	DR-853
July 1995	Fifteenmile Creek	DR-1061. Flash flood in Wasco County.
Feb. 1996	nearly statewide	DR-1099. Benton, Clackamas, Clatsop, Columbia, Coos, Deschutes, Douglas, Gilliam, Hood River, Jefferson, Josephine, Lane, Lincoln, Linn, Marion, Morrow, Multnomah, Polk, Sherman, Tillamook, Umatilla, Union, Wallowa, Wasco, Washington, Yamhill counties; damages totaling over $280 million
Nov. 1996	SW Oregon	DR-1149. Flooding, landslides, and debris flows; eight deaths in Douglas, Coos, and Lane Counties
Jan. 1997	SW and NE Oregon	DR-1160. Coos, Jackson, Josephine, Baker, Grant, Wallowa, Gilliam, Morrow, Umatilla, Wheeler, and Lake Counties
May–June 1998	Crook County and Prineville	DR-1221. Ochoco River
Dec. 1998	Lincoln and Tillamook Counties	
Nov. 1999	Coastal rivers in Lincoln and Tillamook Counties	heavy rainfall and high tides
Jan. 2000	Curry, Douglas, and Josephine Counties	A Flood Warning was issued for the South fork of the Coquille River from Myrtle Point to Coquille City, North and South Forks of the Coquille River. Brookings recorded 4.72 inches of rain, a record for the date. Two Small Stream Flood Advisories were issued, the first for Elk Creek, the second for Deer Creek. A Flood Warning was issued for the lower Rogue River from Agness to Gold Beach.
Feb. 2000	Coos County	A Flood Warning was issued for the South Fork of the Coquille River at Myrtle Point
July 2000	Deschutes County	A slow moving thunderstorm with heavy rain flooded the Becky Johnson Community Center and Health Clinic Campus.

Date	Location	Notes
Sept. 2000	Clackamas County	Heavy rain, estimated at 3 inches in places, plus glacial melt associated with abnormally warm temperatures, acted together to trigger floods and rock and mud slides on the western slopes of Mount Hood.
Apr. 2001	Wheeler	A slow moving thunderstorm produced an estimated 1 inch of rain over mountainous terrain in southeastern Wheeler County.
June 2001	Grant County	The Oregon Dept. of Transportation reported flash flooding on State Highway 26
July 2001	Douglas, Deschutes and Lake Counties	A Flash Flood Warning was issued for East Central Douglas county. The Boulder Creek area was of special concern. A heavy slow moving thunderstorm dumped one inch of rain in one hour over Sunriver. Lakeview Police reported rock and/or mudslides on State Highway 140 at mileposts 22, 23.2, and 25.1. They also reported .25-inch hail up to an inch deep and 2 feet of water in spots on the same highway.
June 2002	Baker and Malheur Counties	Slow-moving thunderstorms dropped very heavy rainfall over the Rye Valley area near the Baker-Malheur County line.
July 2002	Wallowa County	flash flood above Wallowa Lake damaged Boy Scout Camp facility
August 2003	City of Rufus, Sherman County	flash flood (Gerking Canyon)
Dec. 2005–Jan. 2006	western and central Oregon,	
Nov. 2006	Clatsop, Hood River, Lincoln, and Tillamook Counties	DR-1672. Heavy precipitation and wind resulted in flooding, landslides, and mudslides (DR-1672)
Feb. 2007	western and central Oregon, and the Confederated Tribes of the Siletz Indians	DR-1683. Benton, Clatsop, Columbia, Lincoln, Polk, Tillamook, Wasco, Wheeler, Yamhill counties; severe winter storm and flooding
Dec. 2007	Northwestern Oregon, Southern Coast	DR-1733. Clatsop, Columbia, Polk, Tillamook, Washington, Yamhill counties; heavy precipitation and wind resulted in flooding, landslides, mudslides, and tree blow down
Dec. 2008	Tillamook County	Flooding caused by convergence of heavy precipitation and high tides
Jan. 2009	Tillamook and Washington Counties	severe winter storm/snow event which included snow, high winds, freezing rain, ice, blizzard conditions, mudslides, and landslide (flooding, post DR-1824)
Jan. 2011	Clackamas, Clatsop, Crook, Douglas, Lincoln, and Tillamook Counties	DR-1956. Severe winter storm, flooding, mudslides, landslides, and debris flows
Apr. 2011	Harney County	widespread basin flooding; Oregon DOT closed and breached U.S. 20 at milepost 132.6 on April 8, 2011, for flood relief; the breach was done at the request of Harney County Emergency Operations Center to avoid damage to nearby residences; larger culverts were later installed
May – June 2011	Union and Grant Counties	melting heavy snowpack caused riverine and playa flooding
June 2011	Heppner	persistent showers with heavy rainfall of 1 to 2 inches produced flooding on Willow and Hinton Creeks; flash flooding on Hinton and Willow Creeks damaged roads, bridges, and the Morrow County Fairgrounds; the Heppner elementary school was evacuated as a precaution
Jan. 2012	Columbia, Hood River, Tillamook, Polk, Marion, Yamhill, Lincoln, Benton, Linn, Lane, Douglas, Coos, and Curry Counties	heavy rain and wind; ice (DR-4055); flooding in the Willamette Valley; 130 homes and seven businesses were damaged in the City of Turner; 21 streets were closed in the City of Salem; the state Motor Pool lost 150 vehicles and thousands of gallons of fuel; Thomas Creek in the City of Scio overtopped, damaging several buildings

Date	Location	Notes
Nov. 2012	Curry, Josephine, and Lane Counties	heavy precipitation; the Curry Coastal Pilot reported over 2 million dollars in infrastructure damage in Brookings and another 2 million in Curry County due to recent heavy rains; sinkholes and overflowing sewage facilities were also reported; according to KVAL news, Eugene Public Works has opened its emergency command center to deal with numerous flooding incidents, including two flooded intersections
Sep. 2013	Multnomah and Tillamook Counties	heavy rain resulted in flooding of the Wilson River near Tillamook as well as urban flooding in the Portland Metro area; KPTV-KPDX Broadcasting reported that heavy rain resulted in flooding and damage to the Legacy Good Samaritan Medical Center and several businesses in Northwest Portland; besides damage to the hospital's emergency and operating room, some elective surgeries were cancelled
Feb. 2014	Lane, Coos, Marion and Tillamook and Counties	A series of fronts resulted in a prolonged period of rain for Northwest Oregon, and minor flooding of several of the area's rivers from February 12th through February 17th. Heavy rains caused the Coquille River at Coquille to flood. The flood was categorized as a moderate flood. The Nehalem River near Foss in Tillamook County exceeded flood stage on February 18th, 2014.
Feb. 2014	Douglas County	In Jackson County heavy rains caused a brief flood on Little Butte Creek at Eagle Point.
March 2014	Tillamook County	Heavy rain resulted in the Nehalem River to flood near Foss. The river reached flood stage around 2 pm March 6, and crested at 14.8 feet at 8 pm
March 2014	Union, Umatilla, and Grant Counties	Heavy rain fell across much of the northern Blue Mountains and Wallowa County throughout the first week of March. March 9th received very heavy rain with snow levels around 6000 ft. This allowed for a significant increase in runoff, which led to a quick rise in rivers for the period
August 2014	Clackamas County	Heavy rain caused the Sandy River to rapidly rise. A footbridge near Ramona Falls broke loose sending a man into the turbulent waters. The man drowned in the river.
Dec. 2014	Tillamook, Lincoln, Lane, Polk Clackamas, Benton, Coos, and Douglas Counties	A slow moving front produced heavy rain over Northwest Oregon which resulted in the flooding of eight rivers. The rain also caused a couple of land/rock slides that both blocked two highways. Heavy rain brought flooding to several rivers in southwest Oregon.
Feb. 2015	Curry, Coos, Douglas, Josephine and Jackson Counties	Heavy rains caused flooding on the Rogue River at Agness and along the Coquille River at Coquille.
Nov. 2015	Tillamook County	A very moist frontal system produced heavy rain across the region resulting in flooding. Rain rates of 0.3 to 0.5 inch per hour were observed for several hours at many locations. The 5-day rainfall total ending in the morning on November 17th for Lees Camp, OR was 14.60 inches.

Date	Location	Notes
Dec. 2015	Tillamook, Lincoln, Washington, Clackamas, Multnomah, Lane, Yamhill, Clatsop, Columbia, Hood River, Polk, Coos, Douglas, Jackson, and Curry Counties	DR-4258. A moist Pacific front produced heavy rainfall across Northwest Oregon which resulted in river flooding, urban flooding, small stream flooding, landslides, and a few sink holes. After a wet week (December 5 through Dec 11), several rivers were near bank full ahead of another front on December 12th. Flooding from the Nehalem River and Rock Creek in Vernonia resulted in evacuation of homes and the implementation of the Vernonia Emergency Command Center. Heavy rain resulted in a landslide that closed OR-47 at mile marker 8. More than $15 million dollars in property damage reported in these counties combined.
Jan. 2016	Jackson, Josephine, Curry, and Coos Counties	Heavy rain brought flooding to some areas of southwest Oregon. Minor flooding on the Rogue at Agness and moderate flooding on the Coquille River at Coquille.
March 2016	Coos County	Heavy rains brought flooding to the Coquille River at Coquille
May 2016	Baker County	A strong thunderstorm dumped up to a quarter of an inch of rain over a 15-minute period over terrain scorched by wild fire in August of 2015 causing flash flooding and debris flows.
Oct. 2016	Tillamook County, Northern Oregon Coast	The combination of heavy rain, large swell, and high tides brought minor tidal overflow flooding during high tides to the North Oregon Coast.
Nov. 2016	Columbia, Tillamook, Lincoln, Benton, Washington, Polk, and Yamhill Counties	A moist Pacific front moving slowly across the area produced heavy rainfall, resulting in flooding of several rivers across Northwest Oregon and at least two landslides.
Dec. 2016	Josephine, Jackson, Douglas, Lane, Coos, and Curry Counties	DR-4296. Heavy rain brought some areal flooding to parts of southwest Oregon.
Jan. 2017	Columbia, Deschutes, Hood River, Josephine, Coos, and Curry Counties	An extended period of heavy rain combined with snowmelt to cause flooding of the Coquille River the South Fork of the Coquille River and, the Rogue River flooded at Agness flooded twice that month.
Feb. 2017	Marion, Polk, Yamhill, Washington, Columbia, Benton, Tillamook, Lane, Coos, Curry, Klamath, Wheeler and Malheur Counties	High river flows combined with high tide to flood some areas near the southern Oregon coast. Heavy rain combined with snow melt caused flooding along the Coquille River and the Rogue River twice this month in southwest Oregon. Heavy rain combined with snow melt caused flooding along the Sprague River in south central Oregon. Flows on the John Day river reached flood levels downstream of Monument due to the breaking up of an ice jam.
March 2017	Malheur, Harney, Wallowa, Umatilla, and Wheeler Counties	An extended period of snow melt, combined with a period of heavy rain, caused an extended period of flooding along portions of the John Day River, the Umatilla, and the Silvies Rivers. Flooding occurred on the Snake River near Ontario.
May 2017	Multnomah County and Wallowa County	Heavy rain from a strong thunderstorm in addition to a log jam caused the rapid rise of Oneonta Creek in the Oneonta Gorge. Two hikers were injured in the flash flood. In Wallowa County the Imnaha River at Imnaha had minor flooding early on May 6th, due to snow melt.
June 2017	Umatilla County	In Pendleton, heavy rain cause several small debris flows along Airport Road and several intersections were flooding with water about 5 to 6 inches deep. Rainfall amounts include 1.54 inches of rain at the NWS office at the Pendleton Airport, with 0.88 inch falling in 30 minutes.
Sept. 2017	Baker County	Thunderstorms producing heavy rain over the 2016 Rail Fire burned area on the Wallowa-Whitman National Forest resulted in flash flooding and debris flows.

Date	Location	Notes
Oct. 2017	Tillamook, Benton, and Clackamas Counties	A very potent atmospheric river brought strong winds to the north Oregon Coast and Coast Range on October 21st. What followed was a tremendous amount of rain for some locations along the north Oregon Coast and in the Coast Range, with Lees Camp receiving upwards of 9 inches of rain. All this heavy rain brought the earliest significant Wilson River Flood on record, as well as flooding on several other rivers around the area.
Jan. 2018	Lincoln and Clatsop Counties	A strong stationary low pressure system off the British Columbia coast brought impressively high seas into the Oregon Coast. Wave heights up to 37 feet were recorded at buoys off the coast, with top one-tenth wave heights up to 45 feet. Damaging surf caused severe beach erosion, damaged a couple buildings right along the beach, injured one person, and killed one person.
Feb. 2018	Umatilla County	Two to three inches of rain fell along the west slopes of the Blue Mountains from February 1st through 4th. The increased runoff caused high water levels and minor flooding along the Umatilla and Walla Walla Rivers.
May 2018	Grant and Wallowa Counties	Heavy rain from slow-moving thunderstorms caused rockslides and water on roadways within an area that includes Mount Vernon, John Day and Canyon City
June 2018	Lane County and Baker County	In Lane County an upper-level trough moved across the area from the southwest, generating strong thunderstorms which produced locally heavy rainfall, lightning, hail, and gusty winds. Thunderstorms with heavy rainfall developed over Southwest Baker County on June 20th, leading to flash flooding and debris flow on the Rail and Cornet-Windy Ridge fires' burn scar areas.
Oct. 2018	Morrow County	Moist upslope flow into the Blue Mountains produced heavy rain with rainfall rates of up to one inch per hour and storm total accumulations between one and three inches. Localized flooding was reported near the town of Heppner where water inside a residence forced an evacuation.
Dec. 2018	Tillamook County	A strong low pressure system over the Gulf of Alaska brought a strong cold front through. This generated strong winds across northwest Oregon, and also brought heavy rain which caused flooding on the Tillamook river. Large seas also caused damage in spots along beaches.
Jan. 2019	Coos and Curry Counties	A weekend of very heavy rain led to rivers rising across southern Oregon. The Rogue River at Agness exceeded flood stage and the Coquille River at Coquille flooded as well.
Feb. 2019	Columbia, Washington and Multnomah Counties	Back-to-back low pressure systems dropping south along the coast of British Columbia and Washington brought cold air south into NW Oregon as well as plenty of moisture. There was flooding along Fox Creek in Rainier and 40 county roads in Washington County. In Multnomah County, Northwest Rocky Point Road between U.S. 30 and Skyline Boulevard was closed because of a large crack in the road caused by heavy rains and snowmelt.
Feb. 2019	Douglas, Jefferson, Lane, Coos, and Curry Counties	DR-4432. Very heavy rain along with the melting of recent snowfall caused flooding at several locations in southern Oregon in late February. Deer Creek at Roseburg, South Fork of the Coquille at Myrtle Point, North Fork of the Coquille at Myrtle Point, the Coquille River at Coquille and the Rogue River at Agness all exceeded flood stage.

Date	Location	Notes
April 2019	Lane, Benton, Marion, Clackamas and Linn Counties	DR-4452. Linn County declared. A particularly strong atmospheric river took aim for the south Willamette Valley, sitting over areas south of Salem for two days, producing anywhere from 2.5 to 5 inches of rain over a 48 hour period. Some areas in the Cascades and Cascade Foothills saw 5 to 7 inches of rain over that 48 hour period. Heavy rain combined with snow melt from all the snow from a few weeks prior in this same area caused flooding along most of our rivers in this area as well as along the main-stem Willamette River up to around Oregon City.
April 2019	Douglas, Coos and Curry Counties	DR-4452. Douglas and Curry Counties declared. Two days of very heavy rainfall (compared to April normals) combined with snowmelt led to areal flooding in southwest and south central Oregon.
April 2019	Union, Grant, Umatilla, Wallowa and Wheeler Counties	DR-4452. Grant, Umatilla, and Wheeler Counties declared. Snow water equivalents near 200% of normal in the Blue Mountains coupled with warm temperatures and near record rainfall totals for April produced significant river flooding across eastern Oregon.
April 2019	Wheeler County	Total rainfall of 1.67 inches was recorded just east of Mitchell. This heavy rain over a short period of time triggered a flash flood through Huddleston Heights and Nelson Street, and off of High Street and Rosenbaum with mud and debris blocking roads in and around the town of Mitchell.
July 2019	Deschutes County	Slow moving thunderstorms produced localized flooding and minor mud flows around the Tumalo area during the evening of July 1st.
Aug. 2019	Crook and Wasco Counties	A powerful upper storm system combined with modest low- and mid-level moisture to yield scattered, strong to severe storms and flash flooding. Storms developed first across the higher terrain of central Oregon nearer the Cascades and adjacent Ochoco mountains. Storms then built northward with hail and damaging winds along the way.

Source: NOAA Storm Event Database, (http://www.ncdc.noaa.gov/stormevents/), January 2020; Planning for Natural Hazards: Flood TRG (Technical Resource Guide), July 2000, DLCD, Community Planning Workshop

2.2.5.2 Probability

Flood risk or probability is generally expressed by frequency of occurrence. Since 1960 at least one damaging flood has occurred somewhere in Oregon in 42 of 52 years reported by NOAA (NOAA Storm Events Database, https://www.ncdc.noaa.gov/stormevents/). Probability of flooding is measured as the average recurrence interval of a flood of a given size and place. It is stated as the percent chance that a flood of a certain magnitude or greater will occur at a particular location in any given year.

FEMA's NFIP extends regulation to an area covered by the "base flood," a flood that has a 1% chance of occurring in any year. Flood Insurance Rate Maps depict the inundation area of the 1% annual flood. It is important to recognize, however, that floods occur more frequently near the flooding source. Information regarding the probability of flooding at a given location in the regulated flood zones is provided by Flood Insurance Studies (FIS) for large watersheds. FEMA does not provide information about floods emanating from small watersheds (less than one square mile), or for floods caused by local drainage issues. Probabilities for these types of flood are, as a result, difficult to obtain.

The majority of flood studies in Oregon were conducted in the late 1970s and early 1980s. These studies represent flood risk at a point in time and don't reflect changing conditions in the watershed. Many of Oregon's metropolitan areas have significantly developed during the past twenty years resulting in increased impervious surface which causes higher velocities and increased volume of water. While FEMA's Map Modernization Program did result in updated FIRMs for 14 counties, many of these maps were produced using models from old flood insurance studies. Whether or by how much these old models underestimate current flood potential is unknown.

In 2009 FEMA transitioned from Map Modernization, intended to provide FIRMs in a digital format, to a Risk Mapping, Assessment, and Planning Program (Risk MAP), intended to direct FEMA's investment in new flood models and to provide communities with flood risk management products and services beyond the traditional FIRM. FEMA has initiated Risk MAP watershed-based projects in Clackamas, Clatsop, Curry, Douglas, Harney, Hood River, Jackson, Klamath, Lane, Lincoln, Malheur, and Marion Counties. Not all of these projects will result in new FIRMs. Rather, as part of the Risk MAP program, FEMA will evaluate the need to revised FIRMs based on national metrics. In any case, communities in the studied watersheds are expected to receive non-regulatory mapping products to assist them with floodplain risk management. Mapping projects in Tillamook and Washington Counties, which have yet to receive modernized FIRMs, will be completed under Risk MAP. Effective FIRM dates are presented in each Regional Risk Assessment.

Despite shortcomings of NFIP Flood Insurance Rate Maps, most Oregon communities exclusively rely on them to characterize the risk of flooding. Some jurisdictions use their own flood hazard maps derived from aerial photos of past flood events in conjunction with FEMA FIRMs to better reflect their communities' flood risks. Others have implemented a higher regulatory standard to address changing conditions; for example Metro's balanced cut and fill requirements, and Tillamook County's and the City of Vernonia's requirement that new homes and substantial improvements to existing homes be elevated at least three feet above base flood elevation (BFE).

Base Flood Elevation (BFE)

Base Flood Elevation is the projected depth of floodwater at the peak of a base flood, generally measured as feet above sea level.

Source: DLCD

Channel migration associated with flooding also can be identified with respect to a probability of migration over a period of 100 years. Historic aerial photos are catalogued to calculate past rates of migration which are then projected out to define a channel migration zone. Avulsion (i.e., channel shifting) zones, which are a component of the larger channel migration zone, are an exception to the migration rate approach. Areas of likely avulsion are identified by professional judgment of a fluvial geomorphologist, using high-resolution topographic data, aerial photos, and field observation.

Identification of channel migration susceptibility at the regional level is described in terms of low, moderate, and high relative probabilities. Probability is determined by assessing physiographic parameters of channel gradient, confinement, and pattern.

Probability of Flooding in Each Oregon County

County-level flood probability rankings and statistics were determined by DLCD and DOGAMI using historical flood information. The first step was to compile a list of all recorded floods in Oregon across 146 years of available data, also used to update **Table 2-44**, **Historic Damaging Floods in Oregon**. Data for this list had two sources: DLCD's Technical Resource Guide, Chapter 4, Section 2, Table 1: Historic Flooding in Oregon (Andre et al., 2001; https://oregonexplorer.info/data_files/OE_topic/hazards/documents/04_flood.pdf), which was used to record events that occurred prior to 2000, and the NOAA Storm Event Database (https://www.ncdc.noaa.gov/stormevents/), which captured events from 2000 to the present. Next the list was organized by counties impacted and by decade and the flood frequency was used to calculate the average time between recorded events, or recurrence interval, for each county in Oregon. Probability rankings were assigned according to the recurrence interval, and for the purposes of the 2020 Risk Assessment calculations, the rankings were assigned a value from 1 to 5 indicating least to greatest probability.

Table 2-45. Classifying Flood Probability

Recurrence Interval (Years)	Probability Rank	Probability Value
≤ 10	Very High	5
11–15	High	4
16–20	Moderate	3
21–50	Low	2
> 50	Very Low	1

Source:

The methods used to assign county-level flood probability rankings and statistics have several limitations. First, the data are not based on a consistent metric or minimum magnitude defining a flood. Further, the data do not reflect the duration, watershed location, or magnitude of flood events. DLCD's Technical Resource Guide, Chapter 4, Section 2, Table 1: Historic Flooding in Oregon (Andre et al., 2001) typically records at most 12 events in a single region in a decade. In comparison, the NOAA Storm Event Database records as many as 45 storm-driven flooding events in one region within a decade. By compiling data from two different sources, neither of which has a consistent or quantitative metric for defining a flood, has resulted in a list that is inconsistent and likely incomplete. As a result, the recurrence intervals and probability rankings potentially underestimate the chance of flooding across Oregon.

Table 2-46. Probability of Flooding by County for the 2020 Risk Assessment Methodology

Region	County	Recurrence Interval (Years)	Probability Rank	Probability Value
Region 1	Clatsop	9	Very High	5
	Coos	5	Very High	5
	Curry	8	Very High	5
	Douglas Coastal	ND	ND	5*
	Lane Coastal	ND	ND	5*
	Lincoln	9	Very High	5
	Tillamook	5	Very High	5

Region	County	Recurrence Interval (Years)	Probability Rank	Probability Value
Region 2	Clackamas	7	Very High	5
	Columbia	10	Very High	5
	Multnomah	7	Very High	5
	Washington	15	High	4
Region 3	Benton	10	Very High	5
	Lane	7	Very High	5
	Linn	9	Very High	5
	Marion	15	High	4
	Polk	11	High	4
	Yamhill	12	High	4
Region 4	Douglas	6	Very High	5
	Jackson	12	High	4
	Josephine	10	Very High	5
Region 5	Gilliam	11	High	4
	Hood River	13	High	4
	Morrow	15	High	4
	Sherman	12	High	4
	Umatilla	15	High	4
	Wasco	11	High	4
Region 6	Crook	29	Low	2
	Deschutes	21	Low	2
	Jefferson	25	Low	2
	Klamath	37	Low	2
	Lake	49	Low	2
	Wheeler	11	High	4
Region 7	Baker	18	Moderate	3
	Grant	13	High	4
	Union	21	Low	2
	Wallowa	12	High	4
Region 8	Harney	16	Moderate	3
	Malheur	16	Moderate	3

*Note: The events impacting Coastal Lane and Coastal Douglas Counties could not be separated from the full county data and were given No Data (ND) rankings. For the purposes of the 2020 Risk Assessment calculations, the coastal portions of Douglas and Lane Counties were assigned a probability value consistent with the other coastal counties.

Source: DOGAMI and DLCD

Climate Change

Riverine flood risk is strongly associated with the dominant form of precipitation in a basin, with mixed rain-snow basins in Oregon already seeing increases in flood risk. Generally, western Oregon basins are projected to experience increased precipitation, including extreme precipitation, which is likely to result in increased extreme river flows in future decades. It is very likely (>90%) that Oregon will experience an increase in the frequency of extreme precipitation events (high confidence). It is very likely that Oregon will experience an increase in the frequency of extreme river flows (high confidence). Extreme river flow, while affected by extreme precipitation, is also driven by antecedent conditions (soil moisture, water table height), snowmelt, river network morphology, and spatial variability in precipitation and snowmelt. Most projections of extreme river flows show increases in flow magnitude at most locations across Oregon. However, when considering rain-on-snow events, which cause some of the biggest floods in Oregon, there are some contradictory results as to how the changes in rain-on-snow events will affect flood magnitudes in different areas of the state and at different elevations. Overall, it is more likely than not (>50%) that increases in extreme river flows will lead to an increase in the incidence and magnitude of damaging floods (low confidence), although this depends on local conditions (site-dependent river channel and floodplain hydraulics).

2.2.5.3 Vulnerability

Damage and loss of life occur when flood waters come into contact with the built environment or where people congregate. Flood can have secondary effects of causing stream bank erosion and channel migration, or precipitating landslides.

Every Oregon County has suffered flood losses at one time or another. Some counties are more susceptible to both flood events and damages. There are several ways to consider vulnerability. We have assessed vulnerability several different ways using data from FEMA's National Flood Insurance Program. We have also considered vulnerability with respect to state assets and local critical facilities, historic and archaeological resources, and social vulnerability.

Table 2-47. Top 10 Oregon Counties Vulnerable to Flooding as Measured by NFIP Claims

County	NFIP Claims Paid ($)	Population (2011)	Claim $ Per Capita	Unmitigated Repetitive Loss Buildings	Vulnerability Score
Clackamas	23,282,552	378,480	62	70	9
Columbia	19,925,386	49,625	402	17	8
Tillamook	12,989,179	25,255	514	163	11
Marion	5,664,119	318,150	18	22	5
Lincoln	5,439,319	46,155	118	108	6
Lane	3,736,028	353,155	11	71	6
Washington	3,305,600	536,370	6	121	5
Coos	2,408,653	62,960	38	28	7
Jackson	2,334,687	203,950	11	16	6
Clatsop	1,824,264	37,145	49	18	6

Sources: PSU Population Center 2012; FEMA Community Information System, 2014

The top 10 vulnerable cities, as measured by dollar amount paid on NFIP flood insurance claims, are shown in **Table 2-48**. The most vulnerable counties and cities within them are shown in boldface type.

Table 2-48. Top 10 Oregon Cities Vulnerable to Flooding as Measured by Dollar ($) Amount Paid on NFIP Claims

City	County	NFIP Claims Paid ($)	Population	$ Per Capita	Unmitigated Repetitive Loss Buildings
Vernonia	**Columbia**	$13,733,794	2,080	6,603	2
Tillamook	**Tillamook**	$7,551,192	4,880	1,547	17
Lake Oswego	Multnomah/**Clackamas**	$3,583,026	36,760	97	0
Salem	Marion	$3,390,250	156,455	22	3
Portland	Multnomah/**Clackamas**	$2,581,748	586,307	4	9
Milwaukie	**Clackamas**	$1,904,200	20,435	93	6
West Linn	**Clackamas**	$1,886,683	25,370	74	2
Oregon City	**Clackamas**	$1,467,600	32,500	45	1
Tualatin	Washington/**Clackamas**	$1,390,381	26,120	53	5
Coos Bay	Coos	$1,355,071	16,060	84	6

Note: The most vulnerable counties and cities within the group are shown in boldface type.

Sources: PSU Population Center 2012; FEMA Community Information System, 2014

The top 10 vulnerable cities, as measured by number of paid NFIP flood insurance claims, are shown in Table 2-49.

Table 2-49. Top 10 Oregon Cities Vulnerable to Flooding as Measured by Total Number of Paid NFIP Claims

City	County	Number of NFIP Paid Claims	Population	Per Capita	Unmitigated Repetitive Loss Buildings
Vernonia	**Columbia**	223	2,080	11%	2
Portland	Multnomah/**Clackamas**	198	586,307	<1%	9
Salem	Marion	190	156,455	<1%	3
Tillamook	**Tillamook**	180	4,880	1%	17
Lake Oswego	**Clackamas**	64	36,760	<1%	0
Milwaukie	**Clackamas**	57	20,435	<1%	6
Sheridan	Yamhill	57	6,180	<1%	1
Coos Bay	Coos	56	16,060	<1%	6
Lincoln City	Lincoln	53	7,965	1%	5
West Linn	**Clackamas**	52	25,370	<1%	1

Note: The most vulnerable counties and cities within them are shown in boldface type.

Sources: PSU Population Center 2012; FEMA Community Information System, 2014

Cities with a high proportion of FEMA-defined Special Flood Hazard area within their city boundaries are shown in Table 2-49. The area of Special Flood Hazard Area within city limits for each NFIP city was estimated by calculating the area of the Special Flood Hazard Area minus bodies of water to estimate normally dry Special Flood Hazard Area within city limits. We assumed that highest population densities are in cities due to Oregon's requirement to site most residential development inside Urban Growth Boundaries. All of the cities identified in this analysis have small populations, however, and therefore don't help identify a significant proportion of the population at risk from flooding.

2.2.5.4 Repetitive Losses

Recently FEMA has migrated its repetitive loss (RL) and severe repetitive loss (SRL) property and claims information from BureauNet to a new database, PIVOT, and tightened its policy on sharing this information. To obtain access to PIVOT, state and local governments must now have an intergovernmental agreement (IGA) with FEMA in place. For a state with an IGA to share information from PIVOT with a local government, the local government must also have an IGA with FEMA in place. Currently, the State of Oregon is engaged in negotiating the required IGA with FEMA and the draft IGA is with FEMA for review. Therefore, the State of Oregon is unable to access PIVOT and accurately update or report on RL and SRL properties at this time. The information herein is the most current and accurate the State of Oregon is able to obtain and share at this time. When the IGA is executed, the State of Oregon will update this information.

FEMA has identified 268 buildings in Oregon as RL properties. The NFIP defines an RL property as any insurable building for which two or more claims of more than $1,000 were paid by the NFIP within any rolling 10-year period since 1978. At least two of the claims must be more than 10 days apart but within 10 years of each other. Or, the property has incurred flood-related damage on two occasions, in which the cost of the repair, on the average, equaled or exceeded 25% of the market value of the structure at the time of each such flood event.

In Oregon, RL properties represent about 1% of all insured properties, and account for about 14% of all claims paid (21% of the dollar amount paid). RL properties in Oregon have suffered on average less than 3 losses each. Most (80%) of Oregon's repetitive loss properties were built in floodplains before FEMA FIRMs became available (FEMA NFIP BureauNet, http://bsa.nfipstat.fema.gov/, accessed 7/11/2014). The majority of Oregon's 268 repetitive loss buildings appear to be residential structures, but the State has yet to verify all of the repetitive loss buildings. Building type will be assigned to each RL property as part of the annual review described below.

Beyond identifying vulnerable buildings, the RL list normally provided by FEMA but currently unavailable to the State of Oregon has value for hazard mitigation planning because the location of these buildings may indicate areas of persistent flood or drainage problems.

FEMA reports RL counts for unincorporated Clackamas (38), Lane (13), Lincoln (20), Tillamook (23), and Washington (22) in the double digits (FEMA NFIP Community Information System (CIS), accessed 6/16/2020). The following cities show RL buildings in the double digits: City of Tillamook (13), City of Portland (19), City of Milwaukie (17), City of Vernonia (12), and City of Salem (31) (FEMA NFIP Community Information System, accessed 6/16/2020). Together these counties and cities account for over half of Oregon's repetitive losses. The State should focus on conducting future flood mitigation planning and project development within these communities. Any mitigation of repetitive loss buildings along the coast also should address exposure to tsunami hazards.

Severe Repetitive Losses

Severe repetitive loss (SRL) properties are a subset of RL properties. SRL properties:

1. Are covered under a contract for flood insurance made available under the NFIP; and

2. Have incurred flood related damage:
   - For which four or more separate claims payments have been made under flood insurance coverage with the amount of each such claim exceeding $5,000, and with the cumulative amount of such claims payments exceeding $20,000; or
   - For which at least two separate claims payments have been made under such coverage, with the cumulative amount of such claims exceeding the market value of the insured structure.

Oregon is fortunate to have fewer than a dozen (11) SRL properties. Four of the SRL buildings are located in a county identified as most vulnerable to flood damages.

RL and SRL Mitigation Strategy

The State's strategy for selecting properties for flood hazard mitigation projects is four-fold. Priority projects are (a) are geographically balanced; (b) in communities with a FEMA-approved local hazard mitigation plan; (c) on buildings that have sustained substantial damages or repetitive losses, (d) located in jurisdictions capable of managing Federal grants. Buy-outs are the preferred mitigation action in areas affected by tsunami and in floodways.

The state, will work with local jurisdictions that take it upon themselves to sign an information sharing agreement with FEMA and request repetitive loss data for their communities. When requested or during Community Assistance Visit (CAV) or Community Assistance Contact (CAC) processes the state will work with local communities that have obtained their repetitive loss data from FEMA to establish a priority ranking for properties that would benefit most from hazard mitigation by means of acquisition, relocation, elevation, or demolition. The state will conduct verification of the FEMA repetitive loss data in these situations (assuming the state has access to the PIVOT database where that data is held at that time). Verification of properties is needed because the State has found that FEMA's RL list contains many address and geolocation errors, and in some cases the building has already been mitigated. The state will maintain and review the verified list of repetitive loss properties once established as a basis for selecting and funding hazard mitigation projects.

DLCD will work with communities to determine whether potential mitigation projects are cost-effective, environmentally sound, and technically feasible. Cost-effectiveness of mitigation must be proven for RL properties and unfortunately the dollar losses suffered by many properties in Oregon may not allow mitigation to be funded using the Federal mitigation grant programs. Even FEMA's Greatest-Savings-to-the-Fund (GSTF) calculation may not provide sufficient benefits to mitigate many properties.

OEM will then work with these communities to turn qualified potential projects into sub-grant applications. In addition to this routine work, Notice of Funding Availability letters will be sent directly to jurisdictions with validated RL and SRL properties whenever funding opportunities become available. The State will continue to encourage owners of SRL properties to participate in FEMA mitigation programs.

State-Owned/Leased Buildings and Critical Facilities and Local Critical Facilities

For the 2020 Risk Assessment, DOGAMI used a combination of FEMA effective and preliminary flood zone data (FEMA National Flood Hazard Layer, 2019) and FEMA Q3 data (an unpublished digital dataset of paper flood insurance rate maps). All FEMA data that DOGAMI used was current as of 2019. The flood hazard was not divided in to High, Moderate, or Low categories due to the wide variety of flood data, its variable absolute and relative accuracy, and its variable geographic coverage and completeness. Rather, when a building was located within a floodway, 100-year floodplain, or 500-year floodplain, a "High" flood hazard was designated. When there was insufficient information to determine whether a flood hazard exists for a given site, the flood hazard was designated "Other." Sites with "Other" designations could conceivably face relatively high flood hazards or no flood hazard at all.

Of the 5,350 state facilities evaluated, 632 were located within a flood hazard zone and had an estimated total value of over $900M. Of these, 165 were identified as state critical facilities. In addition, 683 local critical facilities were exposed to flood hazard, with a total value of $1.6B.

Historic Resources

Of the 58,872 historic resources statewide, 4,538 are located in areas of high flood hazard, with the greatest concentration (52%) in Region 3 and 62% of those in Lane County. The next greatest concentration is in Region 2, with 869 historic resources in areas of high flood hazard. Forty-five percent of those resources are located in Multnomah County; 41% in Clackamas County.

Archaeological Resources

Three thousand seven hundred ninety-two (3,792) archaeological resources are located in areas of high flood hazard statewide, with the greatest concentrations in Region 6 (27%) and Region 3 (23%). Statewide, 112 (3%) are listed on the National Register of Historic Places and 254 (7%) are eligible for listing.

Social Vulnerability

The Centers for Disease Control and Prevention (CDC) has calculated a social vulnerability index to assess community resilience to externalities such as natural hazard events. It employs fifteen social vulnerability factors and uses data from the US Census Bureau's American Community Survey. The index is reported in quintiles (1-5). Social vulnerability scores do not vary by hazard. The counties with the greatest social vulnerability statewide are Marion, Morrow, Umatilla, Wasco, Jefferson, Klamath, and Malheur.

Most Vulnerable Communities

DLCD supplemented the countywide assessment of vulnerability by looking at cities that received the most NFIP claims by dollar amount and count. We also identified cities with a large proportion of their land area identified as Special Flood Hazard Area. Eight of the 10 cities with highest number and dollar amount of NFIP paid claims are within the three most vulnerable counties (Clackamas, Columbia, and Tillamook).

2.2.5.5 Risk

With respect to natural hazards, risk can be expressed as the probability of a hazard occurring combined with the potential for property damage and loss of life. The 2020 risk assessment combined the probability with the vulnerability assessment to arrive at a composite risk score. According to the 2020 risk assessment, Coos County and the coastal portions of Douglas and

Lane Counties (Region 1); Multnomah County (Region 2); Lane, Linn, and Marion Counties (Region 3); Douglas, Jackson, and Josephine Counties (Region 4); and Morrow, Umatilla, and Wasco Counties (Region 5) face the greatest risk statewide from the impacts of flood events.

2.2.5.6 Dam Safety

The Oregon Water Resources Department (OWRD) is the state authority for dam safety with specific authorizing laws and implementing regulations. Oregon's dam safety laws were re-written by HB 2085 which passed through the legislature and was signed by Governor Brown in 2019. This law becomes operative on July 1, 2020, with rules and guidance have been drafted and are currently in the public review and comment period.

OWRD coordinates on but does not directly regulate the safety of dams owned by the United States or most dams used to generate hydropower. OWRD has the following authorities:

- Review designs for dams proposed to store water and wastewater prior to construction, as OWRD approval is required prior to dam construction after design safety is demonstrated, and again prior to filling the reservoir;
- Review and condition plans for removal of dams rated high or significant hazard
- Maintain design, construction and inspection information in its files (many electronic);
- Conduct dam breach inundation analysis for hazard rating (consequence of failure);
- Inspect dams with a frequency based mostly on hazard but which can also consider the condition of dams;
- Evaluate the general condition of dams;
- Take regulatory action on dams that are unsafe, potentially unsafe, or need maintenance action;
- Require an Emergency Action Plan (EAP) for high hazard dams, providing a template for owners to develop these plans;
- Respond to unusual conditions and potential emergencies;
- Take certain actions on dams in an actual emergency; and
- Coordinate with federal agencies on emergency inspection and response.

OWRD is the Oregon Emergency Response System contact in the event of a major emergency involving a state-regulated dam, or any dam in the State if the regulating agency is unknown. The Program also coordinates with the National Weather Service and the Oregon Office of Emergency Management on severe flood potential that could affect dams and other infrastructure.

The OWRD has been striving to inspect the over 900 dams under its jurisdiction are schedule, with recommendations sent to dam owners. At times, urgent dam safety notices are needed, and for uncooperative dam owners may lead to an administrative hearing and formal order. The program meets the minimum FEMA standard for Emergency Action Plans and sometimes exceeds FEMA guidance for dam safety inspections on schedule and for condition classification.

Analysis and Characterization

As of December 2019, there were 945 state-regulated dams and another 252 federally-regulated dams that met Oregon's statutory size threshold (at least 10 feet high and storing at least 3 million gallons) for regulation by OWRD. The largest dams are under federal ownership or regulation. An additional 12,000 or so dams that fall below that threshold have water right permits for storage from OWRD.

Under normal loading conditions dams are generally at very low risk of failure. Specific events are associated with most dam failures. Events that might cause dams to fail include:

- An extreme flood that exceeds spillway capacity and causes an earthen dam to fail;
- Extended high water levels in a dam that has no protection against internal erosion;
- Movement of the dam in an earthquake; and
- A large rapidly moving landslide impacting the dam or reservoir.

Most of the largest dams, especially those owned or regulated by the Federal Government are designed to safely withstand these events and have been analyzed to show that they will. However, there are a number of dams where observations, and sometimes analysis indicates a deficiency that may make those dams susceptible to one or more of the events. The large majority of state regulated dams do not have a current risk assessment or analysis, and safe performance in these events is uncertain.

Failures of some dams can result in loss of life, damage to property, infrastructure, and the natural environment. The impacts of dam failures range from local impacts to waters below the dam and the owners property to community destruction with mass fatalities. The 1889 Johnston Flood in Pennsylvania was caused by a dam failure, and resulted in over 2000 lives lost. Oregon's first dam safety laws were developed in response to the St. Francis dam failure in California in 1928. That failure was attributed to unsafe design practice, and because of this about 500 persons perished. In modern times (2006) a dam owner filled in the spillway of a dam on the island of Kauai causing dam failure that killed 7 people. This dam had no recent dam safety inspections because the hazard rating was incorrect.

Where a dam's failure is expected to result in loss of life downstream of the dam, an Emergency Action Plan (EAP) must be developed. The EAP contains a map showing the area that would potentially be inundated by floodwaters from the failed dam. These dams are often monitored so that conditions that pose a potential for dam failure are identified to allow for emergency evacuations.

Historic Significan Dam Failures

Oregon has records of at least 55 dam failures in the State. Many of these failures had very little or no impacts on people, structures or properties. The 21 dams with more serious to tragic effects are listed in **Table 2-50**.

Table 2-50. Historic Significant Dam Failures

Year	Location	Description
1896	Goodrich dam west of Baker City in Baker Co.	Flood wave killed entire family of 7
1917	Killamacue dam west of Haines in Baker Co.	Property damaged
1920	Bonneyview dam east of Prineville in Crook Co.	Property damaged
1925	Bully Creek dam west of Vale in Malheur Co.	Multiple homes badly damaged, loss of livestock
1927	Cottonwood creek dam northwest of Lakeview in Lake Co.	Property damaged
1937	Spaulding Vaughn dam in Baker Co.	Property damaged
1941	Willow Creek (Malheur) dam west of Vale in Malheur Co.	Near catastrophic failure with more than 100 persons at risk, extreme flooding prevented
1949	Kern Brothers dam south of Burns in Harney Co.	Property damaged
1951	N. Indian Creek dam in northern Malheur Co.	Property damaged
1952	Rock Creek dam east of Burns in Harney Co.	Property damaged
1956	Goodrich dam west of Baker City in Baker Co.	Property damaged in the second failure of a dam at this site
1956	Sams Valley dam east of Gold Hill in Jackson Co.	Landslide related to reservoir filling threatened homes
1958	Vaughn Reservoir in rural Malheur Co.	Property damaged
1959	Currant Creek dam east of Antelope in Wasco Co.	Property damaged
1961	Woodrat Knob dam near Lake Creek in Jackson Co.	Major landslide on dam with persons evacuated, flooding prevented
1978	Kern Brothers dam south of Burns in Harney Co.	Property damaged including failure of Krumbo dam, second failure at this dam site
1982	Mann creek dam near Sweet Home in Linn Co.	Washed out multiple forest roads
1983	Star Mountain dam near Riverside in Malheur Co.	Washed out railroad and roads, damaged homes
1996	Powers Log Pond in Powers in south Coos Co.	Damaged road and limited damage to dwellings
2005	Simplot Lagoon south of Hermiston in Umatilla Co.	Washed out State Highway, major irrigation ditch and made 1 home unrepairable
2016	Heater Reservoir near Sublimity in Marion Co.	Flooded area occupied by Christmas tree packers, flooded paved road

Source: Oregon Water Resources Department Dam Safety Program records, accessed 2020

Dam Hazard Ratings

Oregon's new dam safety laws were developed considering the joint Association of State Dam Safety Officials and FEMA's Model State Dam Safety Program. Oregon follows national guidance for assigning hazard ratings to dams and for the contents of Emergency Action Plans, which are now required for all dams rated as "high hazard." Each dam is rated according to the anticipated impacts of its potential failure. The state has adopted these definitions (ORS 540.443–491) for state-regulated dams:

- "High Hazard" means loss of life is expected if the dam fails.
- "Significant Hazard" means loss of life is not expected if the dam fails, but extensive damage to property or public infrastructure is.
- "Low Hazard" is assigned to all other state-regulated dams.
- "Emergency Action Plan" means a plan that assists a dam owner or operator, and local emergency management personnel, to perform actions to ensure human safety in the event of a potential or actual dam failure.

OWRD conducts hazard rating reviews as its limited resources permit. Correction of hazard ratings is a Program priority, and therefore hazard ratings can and do change. Ratings may change for a number of reasons. For example, a dam's original rating may not have been based on current inundation analysis methodologies, or new development may have changed potential downstream impacts. Since 2013, OWRD has formally reviewed the hazard ratings of over 25 state-regulated dams, resulting in the ratings of about 16 being elevated to high hazard status. Federal agencies conduct similar analyses to determine hazard ratings of federally regulated dams.

Table 2-51. Summary: High Hazard and Significant Hazard Dams in Oregon

Region / County	Hazard Ratings		
	State		Federal
	High	Significant	High
Region 1	12	5	0
Clatsop	4	1	0
Coos	2	4	0
Curry	1	0	0
Lincoln	5	0	0
Tillamook	0	0	0
Region 2	10	34	10
Clackamas	2	13	7
Columbia	0	2	0
Multnomah	6	4	2
Washington	2	15	1
Region 3	9	38	19
Benton	1	1	0
Lane	1	5	13
Linn	1	0	6
Marion	2	13	0
Polk	2	8	0
Region 4	20	27	13
Douglas	9	10	5
Jackson	9	16	8
Josephine	2	1	0
Region 5	7	6	10
Gilliam	0	0	0
Hood River	0	2	1
Morrow	0	2	1
Sherman	0	0	1
Umatilla	0	2	4
Wasco	7	0	3
Region 6	8	17	11
Crook	3	7	2
Deschutes	1	2	2
Jefferson	0	3	4
Klamath	1	0	3
Lake	3	5	0
Wheeler	0	0	0
Region 7	5	11	7
Baker	0	8	5
Grant	0	0	1
Union	4	3	0
Wallowa	1	0	1
Region 8	5	13	5
Harney	0	10	0
Malheur	5	3	5

Source: Oregon Water Resources Department, 2019

Table 2-52 shows all "High Hazard" and "Significant Hazard" dams in Oregon, the County in which they are located, and the regulatory government level. Since hazard ratings are always subject to change, this table is current as of December 1, 2019. The Oregon Water Resources Department regulates dams shown as "State." "Federal" dam regulators/owners of high hazard rated dams include the US Army Corps of Engineers, USDI Bureaus of Reclamation and Land Management, USDA Forest Service, and Federal Energy Regulatory Commission.

Table 2-52. High Hazard and Significant Hazard Dams in Oregon, by County

	Name	County	Rating	Regulator
1	Brownlee Dam	Baker	High	Federal
2	Mason Dam	Baker	High	Federal
3	Oxbow Hydro Dam	Baker	High	Federal
4	Thief Valley Reservoir	Baker	High	Federal
5	Unity Reservoir	Baker	High	Federal
6	Bull Run Dam 2 (Lower)	Clackamas	High	Federal
7	Faraday Diversion Dam	Clackamas	High	Federal
8	Faraday Forebay	Clackamas	High	Federal
9	North Fork Dam (Clackamas)	Clackamas	High	Federal
10	River Mill Dam	Clackamas	High	Federal
11	Timothy Lake	Clackamas	High	Federal
12	Willamette Falls	Clackamas	High	Federal
13	Ochoco Reservoir	Crook	High	Federal
14	Prineville Reservoir (Bowman)	Crook	High	Federal
15	Crane Prairie	Deschutes	High	Federal
16	Wickiup Reservoir (USBR)	Deschutes	High	Federal
17	Creekside Dam #1	Douglas	High	Federal
18	Creekside IWR	Douglas	High	Federal
19	Galesville Reservoir	Douglas	High	Federal
20	Lemolo Lake Dam	Douglas	High	Federal
21	Soda Springs Dam	Douglas	High	Federal
22	Olive Lake	Grant	High	Federal
23	Clear Branch Creek Dam	Hood River	High	Federal
24	Agate Dam	Jackson	High	Federal
25	Applegate Lake	Jackson	High	Federal
26	Emigrant	Jackson	High	Federal
27	Fish Lake (Jackson-USBR)	Jackson	High	Federal
28	Howard Prairie	Jackson	High	Federal
29	Hyatt Reservoir	Jackson	High	Federal
30	Lost Creek Reservoir (COE)	Jackson	High	Federal
31	Reeder Gulch Reservoir	Jackson	High	Federal
32	Haystack Equalizing Pond	Jefferson	High	Federal
33	Pelton Dam	Jefferson	High	Federal
34	Pelton Regulating Dam	Jefferson	High	Federal
35	Round Butte Dam	Jefferson	High	Federal
36	Gerber Reservoir	Klamath	High	Federal
37	JC Boyle Dam	Klamath	High	Federal
38	Upper Klamath Lake	Klamath	High	Federal
39	Blue River Dam	Lane	High	Federal
40	Cottage Grove	Lane	High	Federal
41	Cougar Reservoir	Lane	High	Federal
42	Dexter	Lane	High	Federal
43	Dorena	Lane	High	Federal
44	Fall Creek Reservoir	Lane	High	Federal
45	Fern Ridge	Lane	High	Federal
46	Hills Creek Reservoir	Lane	High	Federal
47	Hult Log Storage Pond	Lane	High	Federal
48	Leaburg Dam	Lane	High	Federal
49	Lookout	Lane	High	Federal
50	Walterville Power Intake	Lane	High	Federal
51	Walterville Pumped S. Pond	Lane	High	Federal
52	Big Cliff Dam	Linn	High	Federal
53	Detroit Reservoir	Linn	High	Federal
54	Foster Reservoir	Linn	High	Federal
55	Green Peter Reservoir	Linn	High	Federal
56	Smith River	Linn	High	Federal
57	Trail Bridge Reg. Reservoir	Linn	High	Federal
58	Agency Valley Dam	Malheur	High	Federal
59	Bully Creek Dam	Malheur	High	Federal
60	Owyhee	Malheur	High	Federal
61	Rock Creek (Malheur)	Malheur	High	Federal
62	Warm Springs Reservoir (USBR)	Malheur	High	Federal

	Name	County	Rating	Regulator
63	Willow Creek (Morrow)	Morrow	High	Federal
64	Bonneville Dam	Multnomah	High	Federal
65	Bull Run Dam 1 (Upper)	Multnomah	High	Federal
66	John Day Dam	Sherman	High	Federal
67	Cold Springs Reservoir (USBR)	Umatilla	High	Federal
68	Indian Lake Dam	Umatilla	High	Federal
69	Mckay Reservoir (USBR)	Umatilla	High	Federal
70	Mcnary Dam	Umatilla	High	Federal
71	Hells Canyon Dam	Wallowa	High	Federal
72	Happy Canyon	Wasco	High	Federal
73	The Dalles Dam	Wasco	High	Federal
74	Wasco Dam	Wasco	High	Federal
75	Scoggins	Washington	High	Federal
76	North Fork	Benton	High	State
77	Buche (Clackamas)	Clackamas	High	State
78	Mompano	Clackamas	High	State
79	Bear Creek	Clatsop	High	State
80	Middle	Clatsop	High	State
81	Seaside City	Clatsop	High	State
82	Wickiup Lake (Astoria)	Clatsop	High	State
83	Pony Creek - Lower	Coos	High	State
84	Pony Creek - Upper	Coos	High	State
85	Barnes Butte	Crook	High	State
86	Joe Fisher	Crook	High	State
87	Johnson Creek (Crook)	Crook	High	State
88	Ferry Creek	Curry	High	State
89	North Canal Diversion	Deschutes	High	State
90	Bear Creek 3	Douglas	High	State
91	Berry Creek	Douglas	High	State
92	Cooper Creek (Sutherlin)	Douglas	High	State
93	Hayhurst Road	Douglas	High	State
94	Paris	Douglas	High	State
95	Plat I	Douglas	High	State
96	Updegrave	Douglas	High	State
97	Wageman	Douglas	High	State
98	Winchester	Douglas	High	State
99	Duggan	Jackson	High	State
100	Lake Creek	Jackson	High	State
101	Osborne Creek	Jackson	High	State
102	Sams Valley	Jackson	High	State
103	Wade	Jackson	High	State
104	Walch Dam	Jackson	High	State
105	Willow Creek	Jackson	High	State
106	Woodrat Knob	Jackson	High	State
107	Yankee	Jackson	High	State
108	Mcmullen Creek	Josephine	High	State
109	Strong	Josephine	High	State
110	Crescent Lake	Klamath	High	State
111	Bullard Creek F.R.S. (Lake)	Lake	High	State
112	Cottonwood	Lake	High	State
113	Drews	Lake	High	State
114	Santa Clara	Lane	High	State
115	Big Creek #1 (Lower)	Lincoln	High	State
116	Big Creek #2 (Upper)	Lincoln	High	State
117	Mill Creek	Lincoln	High	State
118	Olalla	Lincoln	High	State
119	Spring Lake	Lincoln	High	State
120	Foster Log Pond	Linn	High	State
121	Antelope	Malheur	High	State
122	Crowley	Malheur	High	State
123	Lonesome Lake	Malheur	High	State
124	Pole Creek	Malheur	High	State
125	Willow Creek 3 (Malheur)	Malheur	High	State
126	Franzen	Marion	High	State
127	Silver Creek	Marion	High	State
128	Portland #1 (Mt.Tabor)	Multnomah	High	State
129	Portland #3 (Washington Park)	Multnomah	High	State
130	Portland #4 (Washington Park)	Multnomah	High	State
131	Portland #5 (Mt.Tabor)	Multnomah	High	State
132	Portland #6 (Mt.Tabor)	Multnomah	High	State
133	Van Raden	Multnomah	High	State
134	Croft	Polk	High	State
135	Mercer	Polk	High	State
136	Jubilee Lake	Union	High	State
137	Morgan Lake	Union	High	State
138	Pilcher Creek	Union	High	State
139	Wolf Creek	Union	High	State
140	Wallowa Lake	Wallowa	High	State

	Name	County	Rating	Regulator
141	Crow Creek	Wasco	High	State
142	Currant Creek	Wasco	High	State
143	Pine Hollow	Wasco	High	State
144	Rock Creek (Wasco)	Wasco	High	State
145	Younglife Waste A (Lower)	Wasco	High	State
146	Younglife Waste B (Middle)	Wasco	High	State
147	Younglife Waste C (Upper)	Wasco	High	State
148	Barney	Washington	High	State
149	Kay Lake	Washington	High	State
150	Baker, Er	Yamhill	High	State
151	Mcguire	Yamhill	High	State
152	Balm Creek Reservoir	Baker	Significant	State
153	Camp Creek Reservoir (Baker)	Baker	Significant	State
154	Clear Creek Reservoir-West Fork	Baker	Significant	State
155	Goodrich Reservoir	Baker	Significant	State
156	Killamacue Reservoir	Baker	Significant	State
157	Love Reservoir (Baker)	Baker	Significant	State
158	Salmon Creek Reservoir	Baker	Significant	State
159	Whited Reservoir (Baker)	Baker	Significant	State
160	Thompson (Benton)	Benton	Significant	State
161	Beyer Reservoir	Clackamas	Significant	State
162	Cedar Grove Lake	Clackamas	Significant	State
163	Day Reservoir	Clackamas	Significant	State
164	Deardorff, Betty Jane	Clackamas	Significant	State
165	Drescher Reservoir	Clackamas	Significant	State
166	Haberlach Dam	Clackamas	Significant	State
167	Oswego Lake Dam	Clackamas	Significant	State
168	Rogers - Joseph Reservoir	Clackamas	Significant	State
169	Rose Reservoir	Clackamas	Significant	State
170	Sandy Farms No. 1-A	Clackamas	Significant	State
171	Teasel Creek	Clackamas	Significant	State
172	Veterans Reservoir	Clackamas	Significant	State
173	Zielinski Farm Reservoir	Clackamas	Significant	State
174	Fishhawk Lake	Clatsop	Significant	State
175	Rainier City Reservoir	Columbia	Significant	State
176	Salmonberry Reservoir	Columbia	Significant	State
177	Jackson Farms Dam	Coos	Significant	State
178	Powers Log Pond	Coos	Significant	State

	Name	County	Rating	Regulator
179	Rink Creek Reservoir	Coos	Significant	State
180	Windhurst	Coos	Significant	State
181	Bear Creek (Crook)	Crook	Significant	State
182	Bonnie View Dam	Crook	Significant	State
183	Dick Dam	Crook	Significant	State
184	Mainline 1	Crook	Significant	State
185	Mainline 2	Crook	Significant	State
186	Mainline 3	Crook	Significant	State
187	Wampler-Werth	Crook	Significant	State
188	Bend Hydro (Mirrorpond)	Deschutes	Significant	State
189	Mckenzie Canyon Dam	Deschutes	Significant	State
190	Canyonville Reservoir	Douglas	Significant	State
191	Dillard Lumber Co Dike	Douglas	Significant	State
192	Dixonville Log Pond	Douglas	Significant	State
193	Dollar Mill Pond	Douglas	Significant	State
194	Drain Plywood Log Pond	Douglas	Significant	State
195	Drain Sewage Lagoon	Douglas	Significant	State
196	Gardiner	Douglas	Significant	State
197	Kinnan, Frank Reservoir	Douglas	Significant	State
198	Sun Studs Log Pond	Douglas	Significant	State
199	Sutherlin Log Pond	Douglas	Significant	State
200	Beede North	Harney	Significant	State
201	Beede South	Harney	Significant	State
202	Chickahominy Reservoir	Harney	Significant	State
203	Corcoran	Harney	Significant	State
204	Cottonwood (Drewsey)	Harney	Significant	State
205	Griffin Creek Dam	Harney	Significant	State
206	Hunter Reservoir (Harney)	Harney	Significant	State
207	Moon Reservoir	Harney	Significant	State
208	South Fork Reservoir	Harney	Significant	State
209	Stinking Water Creek	Harney	Significant	State
210	Green Point-Lower (No. 1)	Hood River	Significant	State
211	Green Point-Upper (No. 2)	Hood River	Significant	State
212	Bounds Reservoir	Jackson	Significant	State
213	Bradshaw	Jackson	Significant	State
214	Bradshaw 2	Jackson	Significant	State
215	Frog Pond #1	Jackson	Significant	State
216	Gardener Reservoir	Jackson	Significant	State
217	Hammel No. 2	Jackson	Significant	State

	Name	County	Rating	Regulator
218	Harrison	Jackson	Significant	State
219	Hoover Pond 1	Jackson	Significant	State
220	Hoover Pond 2	Jackson	Significant	State
221	Hoover Pond 3	Jackson	Significant	State
222	Lester James #1	Jackson	Significant	State
223	Lester James Reservoir 2	Jackson	Significant	State
224	Lester James Reservoir 3	Jackson	Significant	State
225	Mccormick Reservoir	Jackson	Significant	State
226	Skou Reservoir	Jackson	Significant	State
227	Woolfolk Reservoir	Jackson	Significant	State
228	Brewer Reservoir (Jefferson)	Jefferson	Significant	State
229	Fuston Ranch Dam	Jefferson	Significant	State
230	Gillworth Reservoir	Jefferson	Significant	State
231	Sowell Dam	Josephine	Significant	State
232	Cottonwood Meadows	Lake	Significant	State
233	Micke	Lake	Significant	State
234	Muddy Creek Reservoir	Lake	Significant	State
235	Thompson Valley Diversion (Slid)	Lake	Significant	State
236	Thompson Valley Reservoir	Lake	Significant	State
237	Farnam Creek Reservoir	Lane	Significant	State
238	Forcia And Larsen Log Pond	Lane	Significant	State
239	Ford Farms Reservoir	Lane	Significant	State
240	Schwartz Reservoir	Lane	Significant	State
241	Vaughn Log Pond	Lane	Significant	State
242	Love Reservoir (Malheur)	Malheur	Significant	State
243	Parsnip Creek Diversion	Malheur	Significant	State
244	Star Mountain Reservoir	Malheur	Significant	State
245	Barnes Bros. Reservoir	Marion	Significant	State
246	Berger Lake	Marion	Significant	State
247	Fredericks Pond	Marion	Significant	State
248	Funrue	Marion	Significant	State
249	Heater Dam	Marion	Significant	State
250	Heater Reservoir #2	Marion	Significant	State
251	Koinenia Lake Dam	Marion	Significant	State
252	Lorence Lake	Marion	Significant	State
253	Neil Creek Reservoir	Marion	Significant	State
254	Peterson, Floyd	Marion	Significant	State
255	Pettit Reservoir	Marion	Significant	State

	Name	County	Rating	Regulator
256	Spring Lake Estates	Marion	Significant	State
257	Waldo Lake	Marion	Significant	State
258	Carty Reservoir	Morrow	Significant	State
259	Sand Dunes Wastewater Lagoon Dam	Morrow	Significant	State
260	Binford Dam	Multnomah	Significant	State
261	Mt. Hood Community College Dam	Multnomah	Significant	State
262	Peyralans Reservoir	Multnomah	Significant	State
263	Sester, William H. Reservoir 1	Multnomah	Significant	State
264	Deraeve Reservoir #1 (Lower)	Polk	Significant	State
265	Eola Hills Reservoir	Polk	Significant	State
266	Fern Creek	Polk	Significant	State
267	Kennel Reservoir	Polk	Significant	State
268	Koning "E" Reservoir	Polk	Significant	State
269	Mt. Springs Ranch Dam	Polk	Significant	State
270	Olson Reservoir (Mark)	Polk	Significant	State
271	Shaffer Reservoir	Polk	Significant	State
272	Meacham Lake Dam	Umatilla	Significant	State
273	Simplot Waste Lagoon #1	Umatilla	Significant	State
274	Elgin Mill Trmt. Lagoon #2	Union	Significant	State
275	Jimmy Creek Reservoir	Union	Significant	State
276	Little Park Dam	Union	Significant	State
277	Burkhalter #2	Washington	Significant	State
278	Cook Reservoir (Wash)	Washington	Significant	State
279	Dierickx	Washington	Significant	State
280	Dober Reservoir	Washington	Significant	State
281	Ettinger Pond	Washington	Significant	State
282	Hoefer-Pierson Reservoir	Washington	Significant	State
283	Jesse Enlargement	Washington	Significant	State
284	Lind Reservoir	Washington	Significant	State
285	Maple Headquarters Reservoir	Washington	Significant	State
286	Paul Chobin Dam	Washington	Significant	State
287	Pierson-Upper	Washington	Significant	State
288	Tualatin Park	Washington	Significant	State
289	Unger-Bill Dam	Washington	Significant	State
290	Walters, Glenn #1 - Large	Washington	Significant	State
291	Walters, Glenn #5	Washington	Significant	State
292	Amity Hills Dam	Yamhill	Significant	State

	Name	County	Rating	Regulator
293	Haskins Creek Dam	Yamhill	Significant	State
294	Hickory Hill Farm	Yamhill	Significant	State
295	Jensen (Yamhill Farm)	Yamhill	Significant	State
296	Katz Farm	Yamhill	Significant	State
297	Kuehne Dam	Yamhill	Significant	State
298	Muhs Quarry Dam	Yamhill	Significant	State
299	Olson Flashboard Dam	Yamhill	Significant	State
300	Panther Creek Reservoir	Yamhill	Significant	State
301	Walker (Bryan Creek)	Yamhill	Significant	State
302	Yamhill Vista Dam #5	Yamhill	Significant	State

Source: Oregon Water Resources Department, 2019

Probability

Engineering risk assessment and analysis of a dam is the best indicator of the probability of failure. Without that, the condition of a dam as determined by OWRD engineering staff is a helpful indicator OWRD has for of the failure potential of a dam. OWRD will be conducting such risk assessments on 16 of the state-regulated high hazard dams in poor or unsatisfactory condition (**Table 2-53**) over the next several years.

Dam safety regulators determine the condition of high hazard rated dams, both state- and federally-regulated. A dam's condition is considered public information for state-regulated dams, but the conditions of federally-regulated dams are generally not subject to disclosure. Therefore, the condition of federally-regulated high hazard dams is summarized (**Table 2-54**). State-regulated significant hazard dams do not yet have condition ratings.

Oregon uses FEMA's condition classifications. These classifications are subject to change and revisions are being considered at the national level. Currently, FEMA's condition classifications are:

- "Satisfactory" means no existing or potential dam safety deficiencies are recognized. Acceptable performance is expected under all loading conditions (static, hydrologic, seismic) in accordance with the applicable regulatory criteria or tolerable risk guidelines.
- "Fair" means no existing dam safety deficiencies are recognized for normal loading conditions. Rare or extreme hydrologic and/or seismic events may result in a dam safety deficiency. Risk may be in the range to take further action.
- "Poor" means a dam safety deficiency is recognized for loading conditions that may realistically occur. Remedial action is necessary. A poor rating may also be used when uncertainties exist as to critical analysis parameters that identify a potential dam safety deficiency. Further investigations and studies are necessary.
- "Unsatisfactory" means a dam safety deficiency is recognized that requires immediate or emergency remedial action for problem resolution.
- "Not Rated" means the dam has not been inspected, is not under State jurisdiction, or has been inspected but, for whatever reason, has not been rated.

Fifty-six of the seventy-six state-regulated high hazard dams are in satisfactory or fair condition; 20 are in poor or unsatisfactory condition.

Table 2-53. Summary: Condition of Oregon's State- and Federally-Regulated High Hazard Dams

	High Hazard Dams		
Condition	**State**	**Federal**	**Total**
Satisfactory	30	15	45
Fair	25	27	52
Poor	13	22	35
Unsatisfactory	7	3	10
Not Rated	1	8	9
Total	76	75	151

Source: Oregon Water Resources Department, 2019

Table 2-54. Summary: Condition of Oregon's State-Regulated High Hazard Dams by County

	Condition of State-Regulated High Hazard Dams					
Region/County	**Satisfactory**	**Fair**	**Poor**	**Unsatisfactory**	**Not Rated**	**Total**
Region 1	**2**	**5**	**2**	**3**	**0**	**12**
Clatsop	0	3	1	0	0	4
Coos	1	0	1	0	0	2
Curry	0	0	0	1	0	1
Lincoln	1	2	0	2	0	5
Tillamook	0	0	0	0	0	0
Region 2	**8**	**2**	**0**	**0**	**0**	**10**
Clackamas	1	1	0	0	0	2
Columbia	0	0	0	0	0	0
Multnomah	5	1	0	0	0	6
Washington	2	0	0	0	0	2
Region 3	**5**	**4**	**0**	**0**	**0**	**9**
Benton	1	0	0	0	0	1
Lane	1	0	0	0	0	1
Linn	0	1	0	0	0	1
Marion	1	1	0	0	0	2
Polk	1	1	0	0	0	2
Yamhill	1	1	0	0	0	2
Region 4	**4**	**9**	**5**	**2**	**0**	**20**
Douglas	3	4	2	0	0	9
Jackson	1	4	3	1	0	9
Josephine	0	1	0	1	0	2
Region 5	**4**	**3**	**0**	**0**	**0**	**7**
Gilliam	0	0	0	0	0	0
Hood River	0	0	0	0	0	0
Morrow	0	0	0	0	0	0
Sherman	0	0	0	0	0	0
Umatilla	0	0	0	0	0	0
Wasco	4	3	0	0	0	7
Region 6	**4**	**3**	**1**	**0**	**0**	**8**
Crook	1	1	1	0	0	3
Deschutes	0	1	0	0	0	1
Jefferson	0	0	0	0	0	0
Klamath	1	0	0	0	0	1
Lake	2	1	0	0	0	3
Wheeler	0	0	0	0	0	0
Region 7	**2**	**0**	**3**	**0**	**0**	**5**
Baker	0	0	0	0	0	0
Grant	0	0	0	0	0	0
Union	2	0	2	0	0	4
Wallowa	0	0	1	0	0	1
Region 8	**1**	**0**	**2**	**2**	**0**	**5**
Harney	0	0	0	0	0	0
Malheur	1	0	2	2	0	5
TOTAL	**30**	**26**	**13**	**7**	**0**	**76**

Source: Oregon Water Resources Department, 2019

Table 2-55. Condition of State-Regulated High Hazard Dams in Oregon

Region	County	Dam Name	Condition
Region 1	Clatsop	Middle	Fair
	Clatsop	Seaside City	Fair
	Clatsop	Wickiup Lake (Astoria)	Fair
	Clatsop	Bear Creek	Poor
	Coos	Pony Creek - Upper	Satisfactory
	Coos	Pony Creek - Lower	Poor
	Curry	Ferry Creek	Unsatisfactory
	Lincoln	Spring Lake	Satisfactory
	Lincoln	Mill Creek	Fair
	Lincoln	Olalla	Fair
	Lincoln	Big Creek #1 (Lower)	Unsatisfactory
	Lincoln	Big Creek #2 (Upper)	Unsatisfactory
Region 2	Clackamas	Mompano	Satisfactory
	Clackamas	Buche (Clackamas)	Fair
	Multnomah	Portland #1 (Mt.Tabor)	Satisfactory
	Multnomah	Portland #3 (Washington Park)	Satisfactory
	Multnomah	Portland #4 (Washington Park)	Satisfactory
	Multnomah	Portland #5 (Mt.Tabor)	Satisfactory
	Multnomah	Portland #6 (Mt.Tabor)	Satisfactory
	Multnomah	Van Raden	Fair
	Washington	Barney	Satisfactory
	Washington	Kay Lake	Satisfactory
Region 3	Benton	North Fork	Satisfactory
	Lane	Santa Clara	Satisfactory
	Linn	Foster Log Pond	Fair
	Marion	Franzen	Satisfactory
	Marion	Silver Creek	Fair
	Polk	Croft	Satisfactory
	Polk	Mercer	Fair
	Yamhill	Mcguire	Satisfactory
	Yamhill	Baker, Er	Fair
Region 4	Douglas	Berry Creek	Satisfactory
	Douglas	Plat I	Satisfactory
	Douglas	Updegrave	Satisfactory
	Douglas	Bear Creek 3	Fair
	Douglas	Hayhurst Road	Fair
	Douglas	Paris	Fair
	Douglas	Wageman	Poor
	Douglas	Winchester	Poor
	Douglas	Cooper Creek (Sutherlin)	Fair
	Jackson	Willow Creek	Satisfactory
	Jackson	Lake Creek	Fair
	Jackson	Sams Valley	Fair
	Jackson	Wade	Fair
	Jackson	Yankee	Fair

Region	County	Dam Name	Condition
	Jackson	Duggan	Poor
	Jackson	Osborne Creek	Poor
	Jackson	Walch Dam	Poor
	Jackson	Woodrat Knob	Unsatisfactory
	Josephine	Strong	Fair
	Josephine	Mcmullen Creek	Unsatisfactory
Region 5	Wasco	Pine Hollow	Satisfactory
	Wasco	Younglife Waste A (Lower)	Satisfactory
	Wasco	Younglife Waste B (Middle)	Satisfactory
	Wasco	Younglife Waste C (Upper)	Satisfactory
	Wasco	Crow Creek	Fair
	Wasco	Currant Creek	Fair
	Wasco	Rock Creek (Wasco)	Fair
Region 6	Crook	Joe Fisher	Satisfactory
	Crook	Johnson Creek (Crook)	Fair
	Crook	Barnes Butte	Poor
	Deschutes	North Canal Diversion	Fair
	Klamath	Crescent Lake	Satisfactory
	Lake	Bullard Creek F.R.S. (Lake)	Satisfactory
	Lake	Cottonwood	Satisfactory
	Lake	Drews	Fair
Region 7	Union	Pilcher Creek	Satisfactory
	Union	Wolf Creek	Satisfactory
	Union	Jubilee Lake	Poor
	Union	Morgan Lake	Poor
	Wallowa	Wallowa Lake	Poor
Region 8	Malheur	Antelope	Satisfactory
	Malheur	Lonesome Lake	Poor
	Malheur	Pole Creek	Poor
	Malheur	Crowley	Unsatisfactory
	Malheur	Willow Creek 3 (Malheur)	Unsatisfactory

Source: Oregon Water Resources Department, 2019

State-Regulated High Hazard Dams not Meeting Safety Standards

There are 20 state-regulated high hazard dams in Oregon that are currently assessed to be below accepted safety standards (in Poor or Unsatisfactory Condition). These dams and the population at risk, based on a screen using the screening tool DSS-WISE, are shown in **Table 2-56**. As the dam safety program conducts analysis over time, the number of dams in less than satisfactory condition may change. Currently dams that are in poor or unsatisfactory condition are in need of rehabilitation or other action to bring them into a fully safe condition. As of December 2019, these are the Oregon dams that are not yet demonstrably unsafe, but that do pose unacceptable risk. When Oregon's new dam safety laws take effect July 1, 2020, the condition of some of these dams may be reclassified as unsafe or potentially unsafe.

It is important to note that many state regulated dams have not received a deep level of risk analysis and review, so the number of dams not meeting minimum standards may increase as additional analyses are performed.

OWRD is working to complete a comprehensive risk of failure assessment protocol. This will include clear written documentation of methods consistent with FEMA guidelines for dam safety risk management. The program will develop dam-specific risk of failure for each of the following hazards with analysis specific to Oregon conditions if applicable to the identified or likely vulnerabilities at the dam:

A. Overtopping in flood exceeding spillway capacity
B. Spillway blockage or erosion
C. General internal erosion
D. Internal erosion conduit
E. Seismic deformation - Cascadia subduction zone
F. Landslide into dam or reservoir

Table 2-56. State-Regulated High Hazard Dams Not Meeting Safety Standards

Dam	NID#	Condition Rating	Daytime PAR (number of people)	Nighttime PAR (number of people)	County
Bear Creek (Astoria)	OR00449	POOR	20	57	Clatsop
Pony Creek Lower	OR00070	POOR	687	408	Coos
Barnes Butte Reservoir	OR00284	POOR	1,787	1,648	Crook
Ferry Creek	OR00437	UNSAT	84	25	Curry
Wageman	OR00496	POOR	6	12	Douglas
Winchester		POOR	Small	Small	Douglas
Duggan Dam	OR00475	POOR	6	11	Jackson
Osborne Creek Dam	OR00401	POOR	227	500	Jackson
Walch Dam		POOR	Small	Small	Jackson
Woodrat Knob	OR00357	UNSAT	123	229	Jackson
McMullen Creek	OR00513	UNSAT	85	243	Josephine
Big Creek Reservoir #1 (Lower)	OR00225	UNSAT	16	35	Lincoln
Big Creek Reservoir #2 (Upper)	OR00473	UNSAT	26	52	Lincoln
Crowley Reservoir	OR00132	UNSAT	3	3	Malheur
Lonesome Lake		POOR	Small	Small	Malheur
Pole Creek	OR00239	POOR	37	103	Malheur
Willow Creek 3 (Malheur)	OR00390	UNSAT	3,426	3,518	Malheur
Jubilee Lake		POOR	Small	Small	Union
Morgan Lake Dam	OR00653	POOR	11,128	6,362	Union
Wallowa Lake (Top of Dam)	OR00465	POOR	1,131	1,334	Wallowa

Note: "PAR" is number of "Persons At Risk" in the dam failure inundation zone based on a conservative estimate using DSS-WISE dam breach estimator. It includes all persons that normally could be in the inundation area. Actual impacts depend on the velocity and depth of water, and will be determined as part of Oregon's HHPD grant tasks.

Source: DSS-Wise output

Without an engineering risk analysis, the condition of a dam is the best indicator OWRD has of the failure potential of most of the high hazard dams it regulates. Much of Oregon's dam infrastructure is aging, and many dams were designed prior to the current understanding of earthquake hazard, especially the risk associated with the expected Magnitude 9 Cascadia Subduction Zone earthquake.

The federal government owns or regulates the largest dams. For homeland security reasons, we do not know and therefore cannot discuss the condition of those dams or their likelihood of failure. Many state-regulated dams are privately owned, others are owned by local governments and a few by the State. The state classifies dams as high, significant, or low hazard. The condition of each high hazard dam is rated. About 12,000 dams are smaller than the state statutory threshold for regulation so their conditions are unknown.

As of December 2019, almost 75% of the state-regulated high hazard dams in Oregon were in satisfactory or fair condition, meaning that they should probably perform acceptably in rare hydrologic and/or seismic events. The other approximately 25% need remedial action and of those, roughly half need action prior to those extreme events (which will occur, but when is unknown). Those needing remediation as quickly as feasible are located in Curry, Lincoln, Jackson, Josephine, and Malheur Counties. The recurrence interval of events that could trigger failure is a necessary factor in determining the probability and risk of failure at these specific dams.

Climate Change

Most climate change models indicate there may be more extreme precipitation due to the increased energy in the oceanic and atmospheric systems. Of main concerns for dams is the potential for larger floods than experienced in the past. Almost half of the historical dam failures around the world have been due the floods that exceed the flow capacity of the spillway and overtop the dam. Another issue for the Pacific coast is the shorter record of precipitation and flood events in the data records. Even without climate change there is uncertainty in the extreme storms that could occur in an extreme atmospheric river event (about which there is much to learn). If the actual flood is larger than the design flood, spillway capacity may be exceeded and the dam may overtop, or the spillway may erode so that it can rapidly empty the reservoir. These scenarios can present real risks to some dams in Oregon, risks that depending on the location may be greater than earthquake related risks.

Vulnerability

Table 2-56, State-Regulated High Hazard Dams Not Meeting Safety Standards, indicates the number of people currently anticipated to be impacted by potential failure of the state-regulated high hazard dams in poor or unsatisfactory condition. OWRD plans to do more analysis to determine the number and value of structures that may be impacted as well.

Most Vulnerable Communities

Given the information presented about state-regulated high hazard dams (county and condition; failure expected to result in loss of life) and significant hazard dams (county; failure expected to result in extensive property or infrastructure damage), the counties with high hazard dams in poor or unsatisfactory condition are considered most vulnerable: Clatsop, Coos, Crook, Curry, Douglas, Jackson, Josephine, Lincoln, Malheur, Union, and Wallowa. Of those, by far the greatest number of people in potentially dangerous locations if a dam were to fail are in Union County.

As with high hazard dams, whether counties with significant hazard dams are actually “most vulnerable communities” depends on the conditions of those dams. Since the dams’ conditions have not yet been rated, we cannot determine the counties’ vulnerability with respect to significant hazard dams. The counties with the most state-regulated significant hazard dams are:

Jackson (16), Washington (15), Clackamas and Marion (13 each) followed by Yamhill (11), Douglas and Harney (10 each).

Risk

The term "risk" is defined somewhat differently with respect to dam safety than it is for natural hazards mitigation. FEMA's "Federal Guidelines for Dam Safety Risk Management," (FEMA P-1025, January 2015) provides this brief overview:

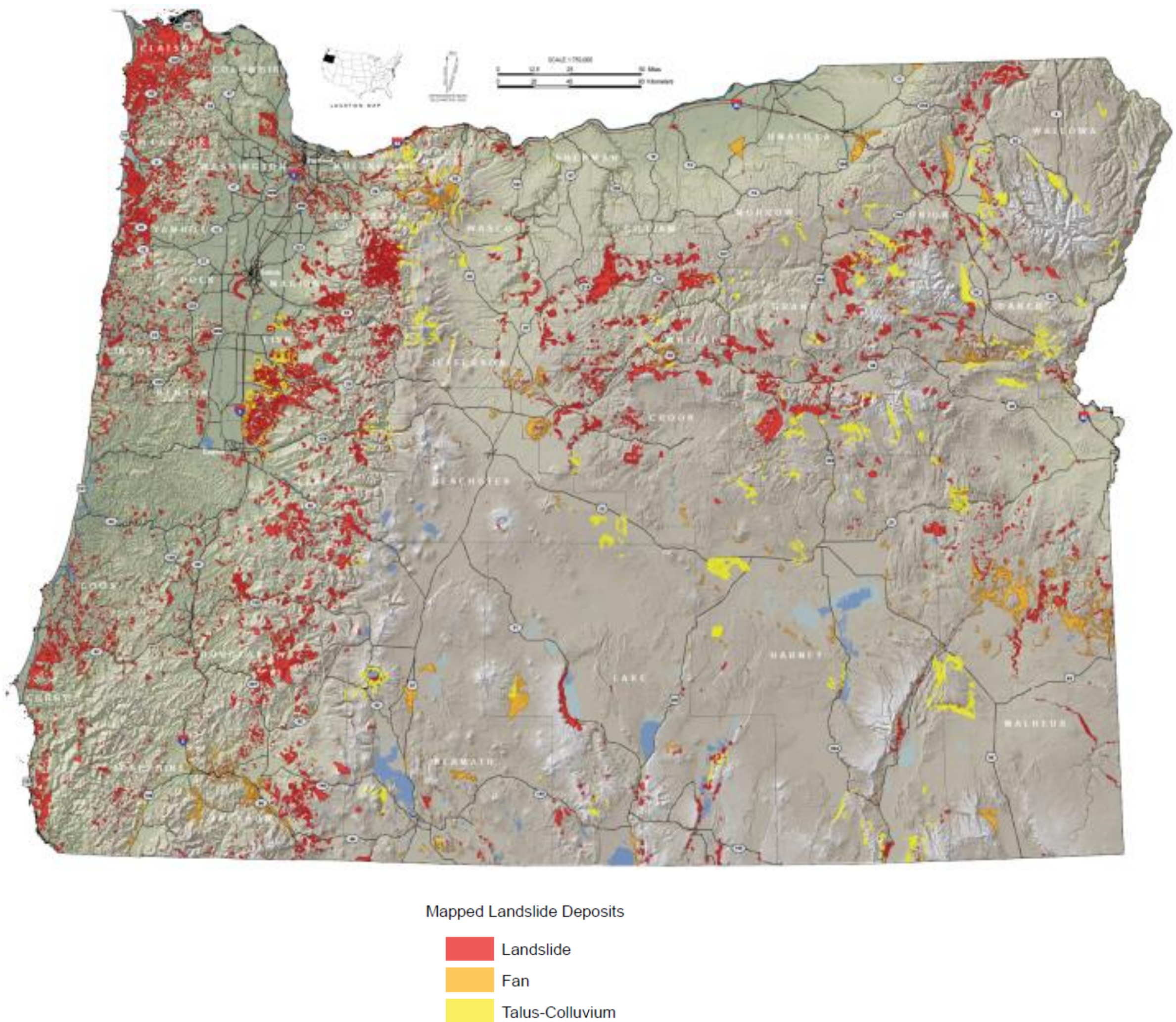
> The term risk, when used in the context of dam safety, is comprised of three parts: (1) the likelihood of occurrence of a load (e.g., flood, earthquake, etc.), (2) the likelihood of an adverse structural response (e.g., dam failure [Failure characterized by the sudden rapid and uncontrolled release of impounded water or liquid-borne solids], damaging spillway discharge, etc.), and (3) the magnitude of the consequences resulting from that adverse event (e.g., life loss, economic damages, environmental damages, etc.). Typically, the direct consequences of dam failure are estimated. Indirect consequences could also result, in which failure of the dam results in loss or failure of key facilities, which can ultimately lead to additional economic consequences or loss of life. If indirect consequences can be identified and estimated, they can be incorporated into the risk estimates.

With FEMA and State funding, OWRD will be completing risk assessments for 16 of the state-regulated high hazard dams in poor or unsatisfactory condition over the next several years. For now, the potential for damage to the dam from extreme floods, lack of protection against internal erosion, earthquakes, or landslides and debris indicates greater potential for failure. Coupled with the potential for loss of life and extensive damage to property and public infrastructure, risk is qualitatively determined.

2.2.6 Landslides

Landslides can be found throughout the state of Oregon, as seen in the current statewide landslide inventory database, SLIDO-2, in **Figure 2-67** and **Table 2-57** (Burns et al., 2011a). While these are not derived from the most up-to-date data, they are still valid indicators of the geographic distribution of landslides throughout the state. Systematic statewide landslide mapping has not been performed; however in general the areas of the state with more relief and steeper slopes, such as the Coast Range Mountains and the Cascade Mountains, tend to have more landslides. In general counties in Oregon have hundreds to thousands of existing landslides as shown in **Table 2-57** derived from the SLIDO-2 database.

Figure 2-67. Statewide Landslide Inventory



Note: Clackamas County has many more landslides than most other counties, which is partially because new very detailed lidar based mapping was completed in the NW portion of this county.

Source: Burns et al. (2011a)

Table 2-57. Number of Identified Landslides within or Touching Each County in Oregon

County	Number of Identified Landslides	County	Number of Identified Landslides
Baker	499	Lake	204
Benton	885	Lane	1,353
Clackamas	3,013	Lincoln	773
Clatsop	774	Linn	1528
Columbia	212	Malheur	737
Coos	1,524	Marion	622
Crook	397	Morrow	56
Curry	384	Multnomah	1,330
Deschutes	83	Polk	52
Douglas	1,526	Sherman	18
Gilliam	35	Tillamook	1,332
Grant	477	Umatilla	151
Harney	435	Union	483
Hood River	178	Wallowa	62
Jackson	809	Wasco	237
Jefferson	274	Washington	538
Josephine	380	Wheeler	413
Klamath	582	Yamhill	187

Source: Burns et al. (2011a)

DOGAMI found that in order to truly understand the landslide hazard in Oregon, lidar (light detection and ranging) topographic data must be collected and used during the mapping of existing landslides and modeling of future susceptibility. In fact, DOGAMI estimates that SLIDO-2 captures between 0% and 25% of the existing landslides in Oregon. This variance in landslide detail can be seen when examining the small NW portion of Clackamas County which has been recently mapped.

One of the most common and devastating geologic hazards in Oregon is landslides. Average annual repair costs for landslides in Oregon exceed $10 million and individual severe winter storm losses can exceed $100 million (Wang et al., 2002). As population growth continues to expand and development into landslide susceptible terrain occurs, greater losses are likely to result.

Landslides in Oregon are typically triggered by periods of heavy rainfall and/or rapid snowmelt. Earthquakes, volcanoes, and human activities also trigger landslides.

Three main factors influence an area's susceptibility to landslides: geometry of the slope, geologic material, and water. Certain geologic formations are more susceptible to landslides than others. In general, locations with steep slopes are most susceptible to landslides, and the landslides occurring on steep slopes tend to move more rapidly and therefore may pose life safety risks.

2.2.6.1 Analysis and Characterization

The term "landslide" encompasses a wide range of geologic processes and a variety of nomenclatures that can lend itself to confusion. The general term landslide refers to a range of mass movement including rock falls, debris flows, earth slides, and other mass movements. One very important thing to understand is the fact that all landslides have different frequencies of movements, triggering conditions, and very different resulting hazards.

All landslides can be classified into one the following six types of movements: (a) slides, (b) flows, (c) spreads, (c) topples, (d) falls, and (f) complex (**Figure 2-68**). Most slope failures are complex combinations of these distinct types, but the generalized groupings provide a useful means for framing discussion of the type of hazard associated with the landslide, the landslide characteristics, identification methods, and potential mitigation alternatives.

El Niño Southern Oscillation and Effects on Landslides

The strongest impacts of intra-seasonal variability on the U.S. occur during the winter months over the western U.S. During the winter this region receives the bulk of its annual precipitation. Storms in this region can last for several days or more and are often accompanied by persistent atmospheric circulation features. Of particular concern are the extreme precipitation events which are linked to flooding and landslide. There is strong evidence for a linkage between weather and climate in this region from studies that have related the El Niño-Southern Oscillation (ENSO) to regional precipitation variability. From these studies it is known that extreme precipitation events can occur at all phases of the El Niño-Southern Oscillation (ENSO) cycle, but the largest fraction of these events occur during La Niña episodes and during ENSO-neutral winters. During La Niña episodes much of the Pacific Northwest experiences increased storminess, increased precipitation and more overall days with measurable precipitation. The risk of flooding and rain-induced landslides (and debris flows) in this region can be related to La Niña episodes.

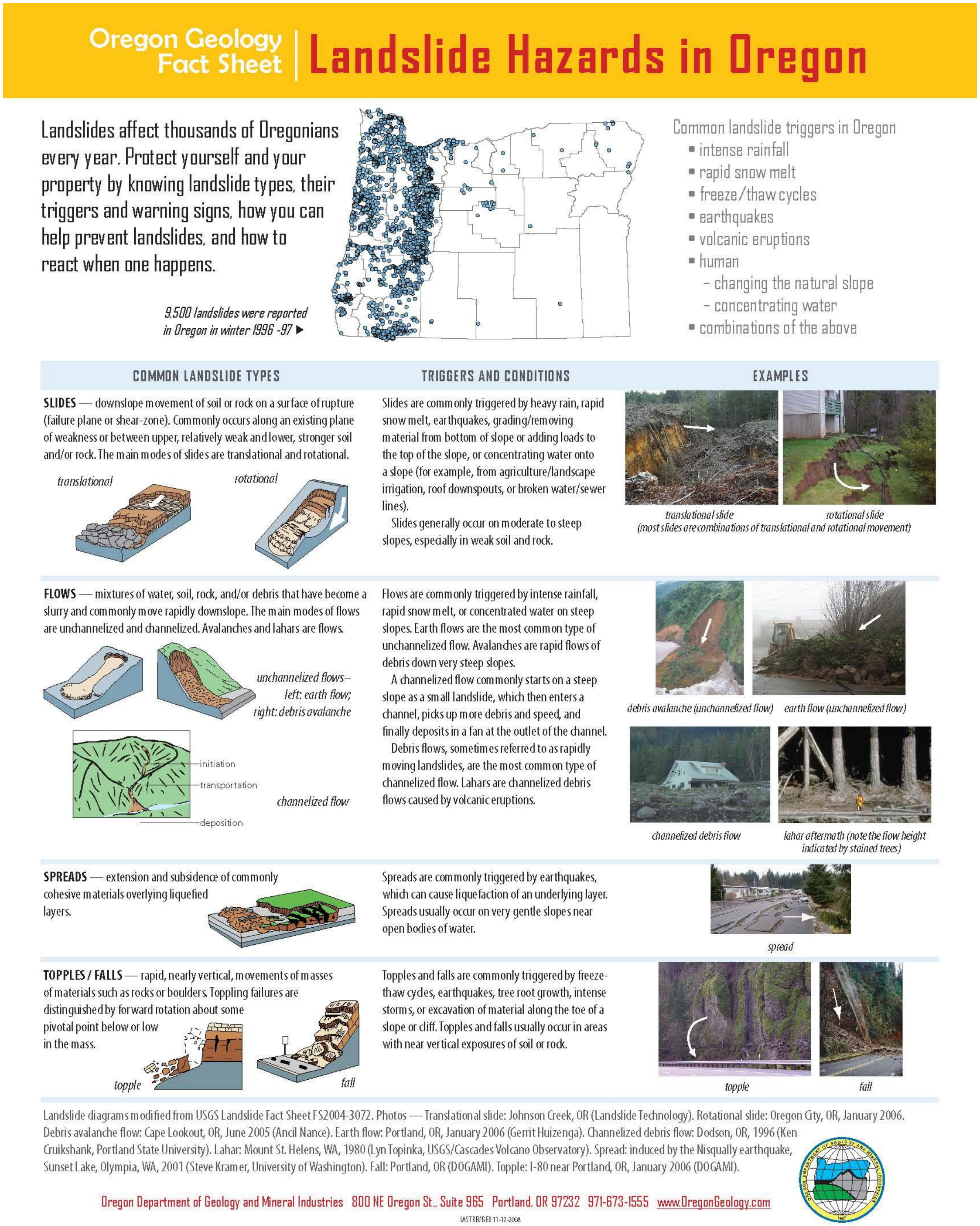
Source: NOAA/Climate Prediction Center, http://www.cpc.noaa.gov/products/intraseasonal/intraseasonal_faq.html#usimpactsSource: NOAA/Climate Prediction Center, http://www.cpc.noaa.gov/products/intraseasonal/intraseasonal_faq.html#usimpacts

These types of movements can be combined with other aspects of the landslide such as type of material, rate of movement, depth of failure, and water content for a better understanding of the type of landslide.

One potentially life-threatening type of landslide is the channelized debris flow or "rapidly moving landslide," which initiates upslope, moves into and down a steep channel (or drainage) and deposits material, usually at the mouth of the channel. Debris flows are also commonly initiated by other types of landslides that occur on slopes near a channel. They can also initiate within the channel in areas of accelerated erosion during heavy rainfall or snowmelt. Rapidly moving landslides have caused most of the recent landslide related injuries and deaths in Oregon. Debris flows or rapidly moving landslides following storms caused eight deaths in Oregon in 1996, a La Niña year.

Areas that have failed in the past often remain in a weakened state, and many of these areas tend to fail repeatedly over time. This commonly leads to distinctive geomorphology that can be used to identify landslide areas, although over time the geomorphic expression may become subtle, making the landslide difficult to identify. Other types of landslides tend to occur in the same locations and produce distinctive geomorphology, such as channelized debris flows, which form a fan at the mouth of the channel after repeated events. This is also true for the talus slopes, which form after repeated rock fall has taken place in an area.

Figure 2-68. Common Types of Landslides in Oregon



Oregon Geology Fact Sheet | Landslide Hazards in Oregon

Landslides affect thousands of Oregonians every year. Protect yourself and your property by knowing landslide types, their triggers and warning signs, how you can help prevent landslides, and how to react when one happens.

9,500 landslides were reported in Oregon in winter 1996 -97 ▶

Common landslide triggers in Oregon
- intense rainfall
- rapid snow melt
- freeze/thaw cycles
- earthquakes
- volcanic eruptions
- human
  - changing the natural slope
  - concentrating water
- combinations of the above

COMMON LANDSLIDE TYPES	TRIGGERS AND CONDITIONS	EXAMPLES
SLIDES — downslope movement of soil or rock on a surface of rupture (failure plane or shear-zone). Commonly occurs along an existing plane of weakness or between upper, relatively weak and lower, stronger soil and/or rock. The main modes of slides are translational and rotational. *translational* *rotational*	Slides are commonly triggered by heavy rain, rapid snow melt, earthquakes, grading/removing material from bottom of slope or adding loads to the top of the slope, or concentrating water onto a slope (for example, from agriculture/landscape irrigation, roof downspouts, or broken water/sewer lines). Slides generally occur on moderate to steep slopes, especially in weak soil and rock.	*translational slide* *rotational slide* *(most slides are combinations of translational and rotational movement)*
FLOWS — mixtures of water, soil, rock, and/or debris that have become a slurry and commonly move rapidly downslope. The main modes of flows are unchannelized and channelized. Avalanches and lahars are flows. *unchannelized flows– left: earth flow; right: debris avalanche* initiation, transportation, deposition *channelized flow*	Flows are commonly triggered by intense rainfall, rapid snow melt, or concentrated water on steep slopes. Earth flows are the most common type of unchannelized flow. Avalanches are rapid flows of debris down very steep slopes. A channelized flow commonly starts on a steep slope as a small landslide, which then enters a channel, picks up more debris and speed, and finally deposits in a fan at the outlet of the channel. Debris flows, sometimes referred to as rapidly moving landslides, are the most common type of channelized flow. Lahars are channelized debris flows caused by volcanic eruptions.	*debris avalanche (unchannelized flow)* *earth flow (unchannelized flow)* *channelized debris flow* *lahar aftermath (note the flow height indicated by stained trees)*
SPREADS — extension and subsidence of commonly cohesive materials overlying liquefied layers.	Spreads are commonly triggered by earthquakes, which can cause liquefaction of an underlying layer. Spreads usually occur on very gentle slopes near open bodies of water.	*spread*
TOPPLES / FALLS — rapid, nearly vertical, movements of masses of materials such as rocks or boulders. Toppling failures are distinguished by forward rotation about some pivotal point below or low in the mass. *topple* *fall*	Topples and falls are commonly triggered by freeze-thaw cycles, earthquakes, tree root growth, intense storms, or excavation of material along the toe of a slope or cliff. Topples and falls usually occur in areas with near vertical exposures of soil or rock.	*topple* *fall*

Landslide diagrams modified from USGS Landslide Fact Sheet FS2004-3072. Photos — Translational slide: Johnson Creek, OR (Landslide Technology). Rotational slide: Oregon City, OR, January 2006. Debris avalanche flow: Cape Lookout, OR, June 2005 (Ancil Nance). Earth flow: Portland, OR, January 2006 (Gerrit Huizenga). Channelized debris flow: Dodson, OR, 1996 (Ken Cruikshank, Portland State University). Lahar: Mount St. Helens, WA, 1980 (Lyn Topinka, USGS/Cascades Volcano Observatory). Spread: induced by the Nisqually earthquake, Sunset Lake, Olympia, WA, 2001 (Steve Kramer, University of Washington). Fall: Portland, OR (DOGAMI). Topple: I-80 near Portland, OR, January 2006 (DOGAMI).

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LAST REVISED 11-12-2008

Source: DOGAMI, Landslides in Oregon fact sheet (http://www.oregongeology.org/pubs/fs/landslide-factsheet.pdf)

Previously impacted areas are particularly important to identify, as they may pose a substantial hazard for future instability and help identify areas that are susceptible to future events. Large, slow moving landslides frequently cause significant property damage, but are far less likely to result in serious injuries. The 1998 Kelso, Washington, the 1997 Tillamook County, and the 2005 Oregon City slides are examples.

The velocity of landslides varies from imperceptible to over 35 miles per hour. Some volcanic induced landslides have been known to travel between 50 to 150 miles per hour. On less steep slopes, landslides tend to move slowly and cause damage gradually. Debris flows typically start on steep hillsides as shallow landslides, enter a channel, then liquefy and accelerate. Canyon bottoms, stream channels, and outlets of canyons can be particularly hazardous. Landslides can move long distances, sometimes as much as several miles. The Dodson debris flows in 1996 started high on Columbia River Gorge cliffs, and traveled down steep canyons to form debris fans in the Dodson-Warrendale area.

Landslide recurrence interval is highly variable. Some large landslides move continuously at very slow rates. Others move periodically during wet periods. Very steeply sloped areas can have relatively high landslide recurrence intervals (10 to 500 years on an initiation site basis).

Because debris flows can be initiated at many sites over a watershed, in some cases recurrence intervals can be less than 10 years. Slope alterations can greatly affect recurrence intervals for all types of landslides, and also cause landslides in areas otherwise not susceptible. Most slopes in Western Oregon steeper than 30 degrees (about 60%) have a risk of rapidly moving landslide activity regardless of geologic unit. Areas directly below these slopes in the paths of potential landslides are at risk as well.

Based on the Oregon Department of Forestry Storm Impacts Study, the highest debris flow hazard occurs in western Lane County, western Douglas County, and Coos County. The combination of steep slopes and geologic formation (sedimentary rock units) contributes to the increased hazard. The debris flow hazard is also high in much of the Coast Range and Cascade Mountains and in the Columbia River Gorge.

Deep landslides are generally defined as having a failure plane within the regional bedrock unit (generally greater than 15 feet deep), whereas the failure plane of shallow landslides is commonly between the thin soil mantle and the top of the bedrock. Deep landslide hazard is high in parts of the Coast Range. Deep landslides are fairly common in pyroclastic rock units of the Western Cascade Mountains, and in fine-grained sedimentary rock units of the Coast Range. Deep landslides also occur in semi-consolidated sedimentary rocks at or near the Oregon coast particularly around Newport, Lincoln County, and Tillamook County, and in the Troutdale Formation around the Portland area.

Infrequent very large landslides and debris flows may occur in any of the larger mountain ranges or in deep gorges throughout Oregon.

During 1996 and 1997, heavier than normal rains caused over 700 landslides within the Portland Metropolitan region, which totaled over $40 million for mitigation (Burns et al., 1998). In the City of Portland, 17 homes were completely destroyed and 64 were badly damaged. There were no serious injuries associated with the landslides in Portland or in other urban areas within Oregon during the 1996 storms.

The Oregon Department of Forestry Storm Impacts Study estimated that tens of thousands of landslides occurred on steep slopes in the forests of Western Oregon during 1996. The Oregon Department of Geology and Mineral Industries Slope Failures in Oregon inventoried thousands of reports of landslides across the state resulting from the 1996-1997 storms. There are a significant number of locations in Oregon that are impacted frequently (every 10 to 100 years) by dangerous landslides. The number of injuries and deaths in the future will be directly related to vulnerability: the more people in these areas, the greater the risk of injury or death.

Historic Landslide Events

Oregon has declared 28 major disaster declarations from 1955 through 2012. Most of these are related to storm events causing flooding and landslides. One of the most significant of these disasters is the 1996 and 1997 storms, which caused thousands of landslides in Oregon.

Table 2-58. Historic Landslides in Oregon from SLIDO-2

Date	No. of Landslides	Comments
1931–1935	2	
1946–1950	1	
1951–1955	2	Presidential DR-49
1956–1960	1	Presidential DR-60, -69
1961–1965	14	Presidential DR-136, -144, -184
1966–1970	1	
1971–1975	11	Presidential DR-301, -319, -413
1976–1980	24	
1981–1985	9	
1986–1990	8	Presidential DR-853
1991–1995	42	Presidential DR-985, -1004, -1036, -1061
1996–2000	7,903	Presidential DR-1099, -1107, -1149, -1160, -1221
2001–2005	648	Presidential DR-1405, -1510
2006–2010	1,960	*Presidential DR-1632, -1672, -1683 -1733, -1824
2011-2015	384	*Presidential DR-1956, -1964, -4055, -4169
2016-2019	140	*Presidential DR-4258, -4296, -4328, -4432, -4452

Note: Presidential Disaster Declarations marked with an asterisk (*) were based in part on the impact of landslides.

Source: Burns et al. (2011a, 2013)

2.2.6.2 Probability

Landslides are found in every county in Oregon as shown in **Table 2-57**. There is a 100% probability of landslides occurring in Oregon in the future. Although we do not know exactly where and when they will occur, they are more likely to happen in the general areas where landslides have occurred in the past. Also, they will likely occur during heavy rainfall events which are projected to increase in frequency under future climate change, or during a future earthquake.

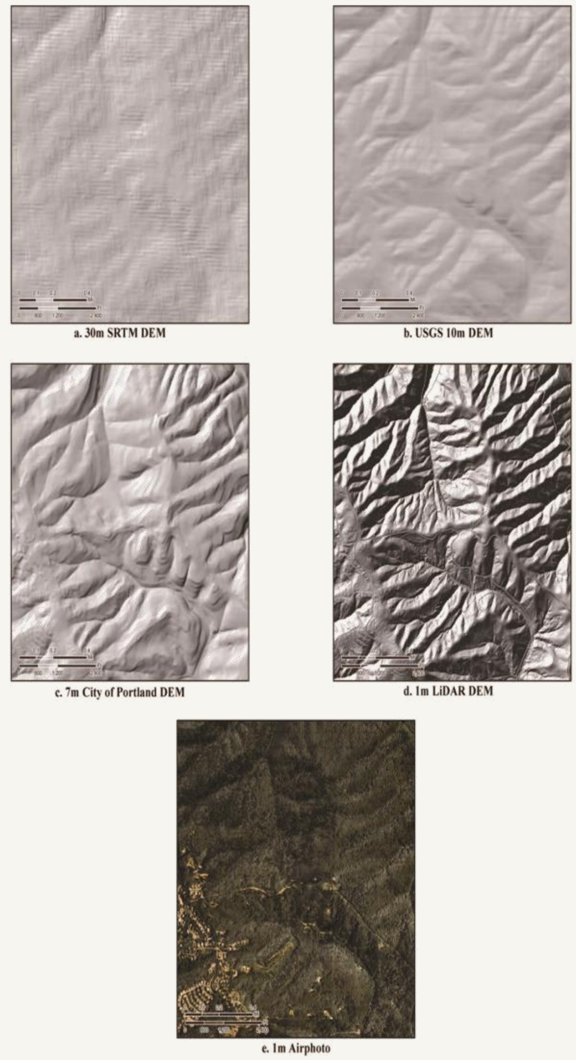
In order to reduce losses from landslides, areas of landslide hazard must first be identified. The first step in landslide hazard identification is to create an inventory of past (historic and prehistoric) landslides. Once this inventory is created, it can be used to create susceptibility maps which display areas that are likely to have landslides in the future. Once the landslide hazards are identified on inventory and susceptibility maps, the risk can be quantified, mitigation projects prioritized and implemented.

In 2005, DOGAMI began a collaborative landslide research program with the U.S. Geological Survey (USGS) Landslide Hazards Program to identify and understand landslides in Oregon. In order to begin the extensive undertaking of mapping existing landslides throughout Oregon, a pilot project area was selected to compare remote sensing data/images for effectiveness. The remote sensing data sets compared included (Burns, 2007) (**Figure 2-69**):

1. 30-m (98 ft) digital elevation model (DEM) from the Shuttle Radar Topography Mission;
2. 10-m (33 ft) DEM derived from USGS topographic quadrangles;
3. Photogrammetric and ground-based 1.5-m (5 ft) interval contour data;
4. Stereo aerial photographs from 1936 to 2000; and
5. Lidar imagery with an average of 1 data point per square meter (3.2 ft) and with a vertical accuracy of about 5 cm (6 in).

Two key findings of the pilot project were: (a) the use of the lidar data resulted in the identification of between 3 to 200 times the number of landslides identified using the other data sets, and (b) the ease and accuracy of mapping the spatial extent of the landslides identified from lidar data were greatly improved compared to other mapping methods.

Figure 2-69. Visual Comparison of Five Remote Sensing Data Sets



Note: The air photo is draped over a DEM so that it appears to have the 3-dimensional view provided by a stereo-pair

Source: Burns (2007)

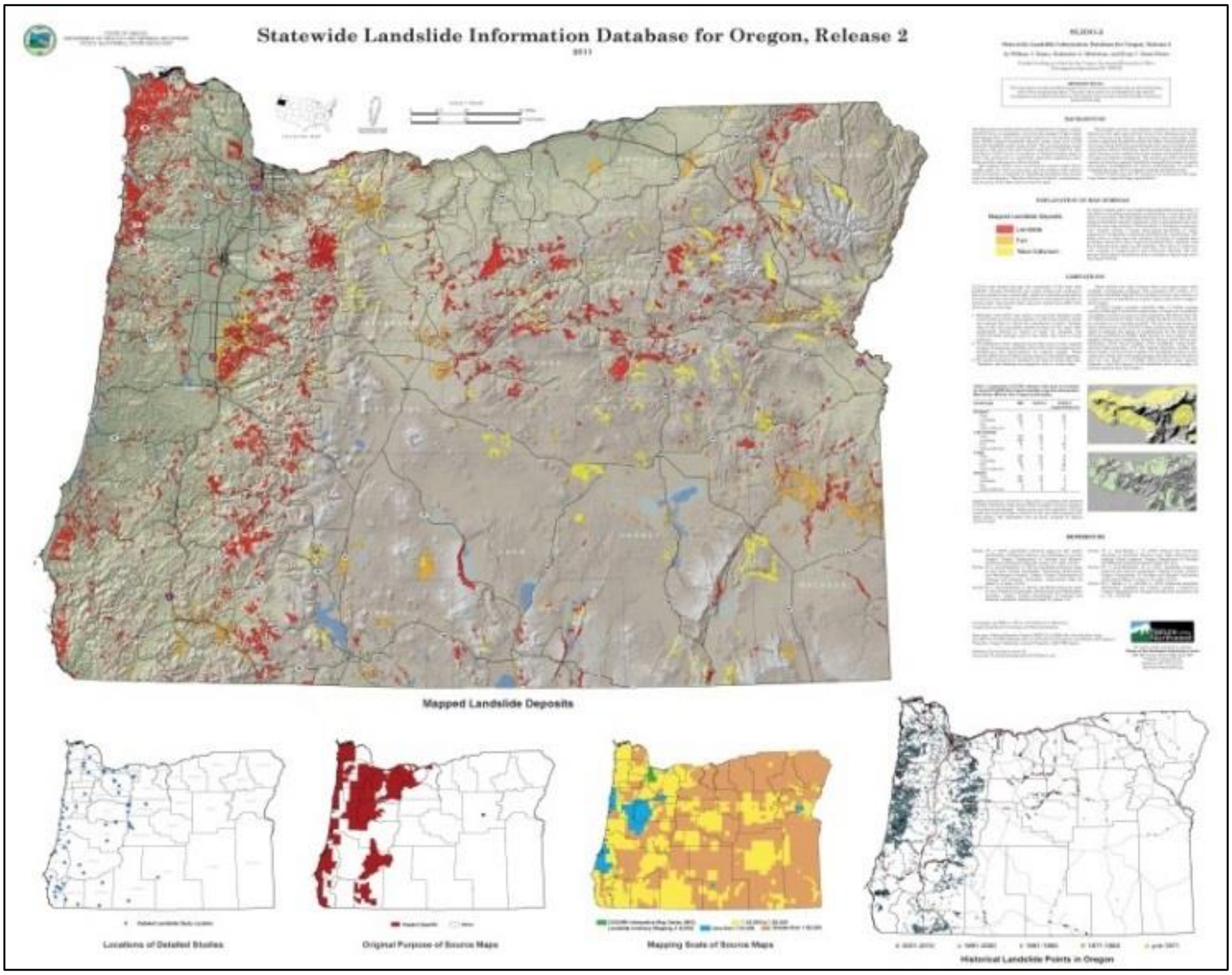
When examining the results of the comparison of remote sensing data, several debris flow fans at the mouths of channels or potential channelized debris flow deposits, were identified with serial stereo-pair aerial photos, which did not get identified on the lidar-derived DEMs. Dense development has taken place in Oregon in the last 40 years, which can mask landslide features, especially if major earthwork has taken place. In most of the populated areas of Oregon, if historic air photos are available, at least one review of (greater than 40 years old) photos should be performed (Burns, 2007).

In order to develop accurate large-scale landslide inventory maps, DOGAMI recommends the following minimal requirements:

1. All previously identified landslides from geologic maps, previous landslide studies, and other local sources should be compiled.
2. The mapper should have experience identifying all types and ages of landslides within the area being studied.
3. Lidar data should be used to identify landslides and accurately locate the extents of previously mapped landslides (from step 1).
4. An orthophoto of similar age to the lidar data should be used to minimize the misidentification of man-made cuts and fills as landslides.
5. The mapper should use at least one set of historical stereo-pair aerial photography to locate landslides in the area being studied.
6. Non-spatial data should also be collected at the time of the mapping so that a comprehensive database can be formed. Non-spatial data should generally include confidence of interpretation, movement class, direction of movement, etc. and are described in detail in section 6.0 of this paper. A comprehensive check of spatial (map) and non-spatial data should be developed and implemented including technical review of mapped landslides and field checks where possible.

Step 1 was accomplished in 2008 with the publication of SLIDO-1. This publication has been updated and again published as SLIDO-2 (**Figure 2-70**).

Figure 2-70. Statewide Landslide Information Database for Oregon, Release 2

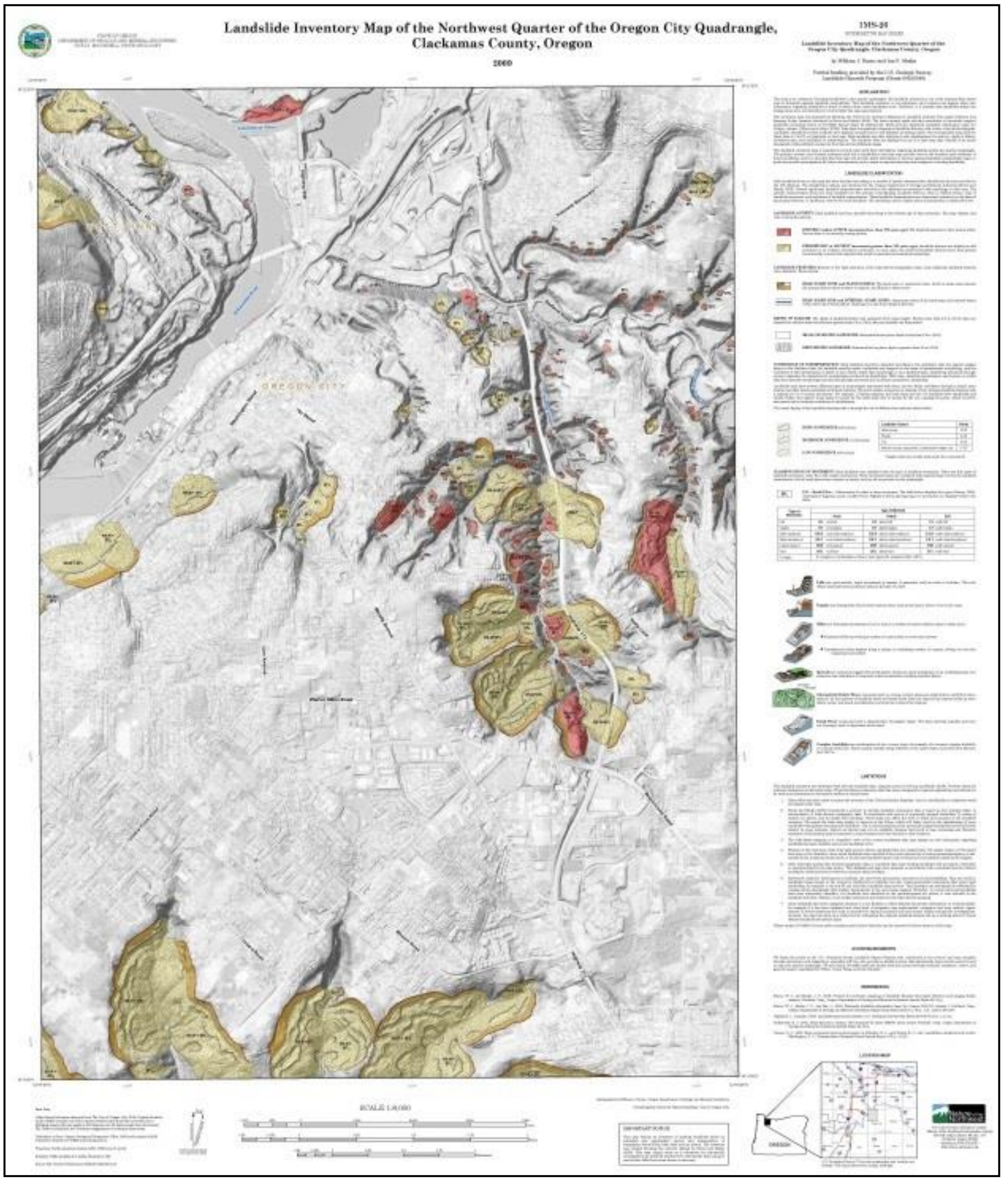


Note: The resulting SLIDO-2 geodatabase includes 22,542 landslide deposit polygons and landslide-related features from 313 published and unpublished studies, 10,636 historical landslide point locations (including all points from the 1996-97 events), and 72 locations of detailed studies on individual landslides, a significant increase over SLIDO-1.

Source: Burns et al. (2011a)

A protocol was developed by DOGAMI so that we can produce consistent lidar-based landslide inventory maps at an accelerated rate without having to describe how the mapping was done every time a new area is mapped (Burns and Madin, 2009). The results of following this protocol in any particular area include a very detailed database and map of the landslide inventory (**Figure 2-71**).

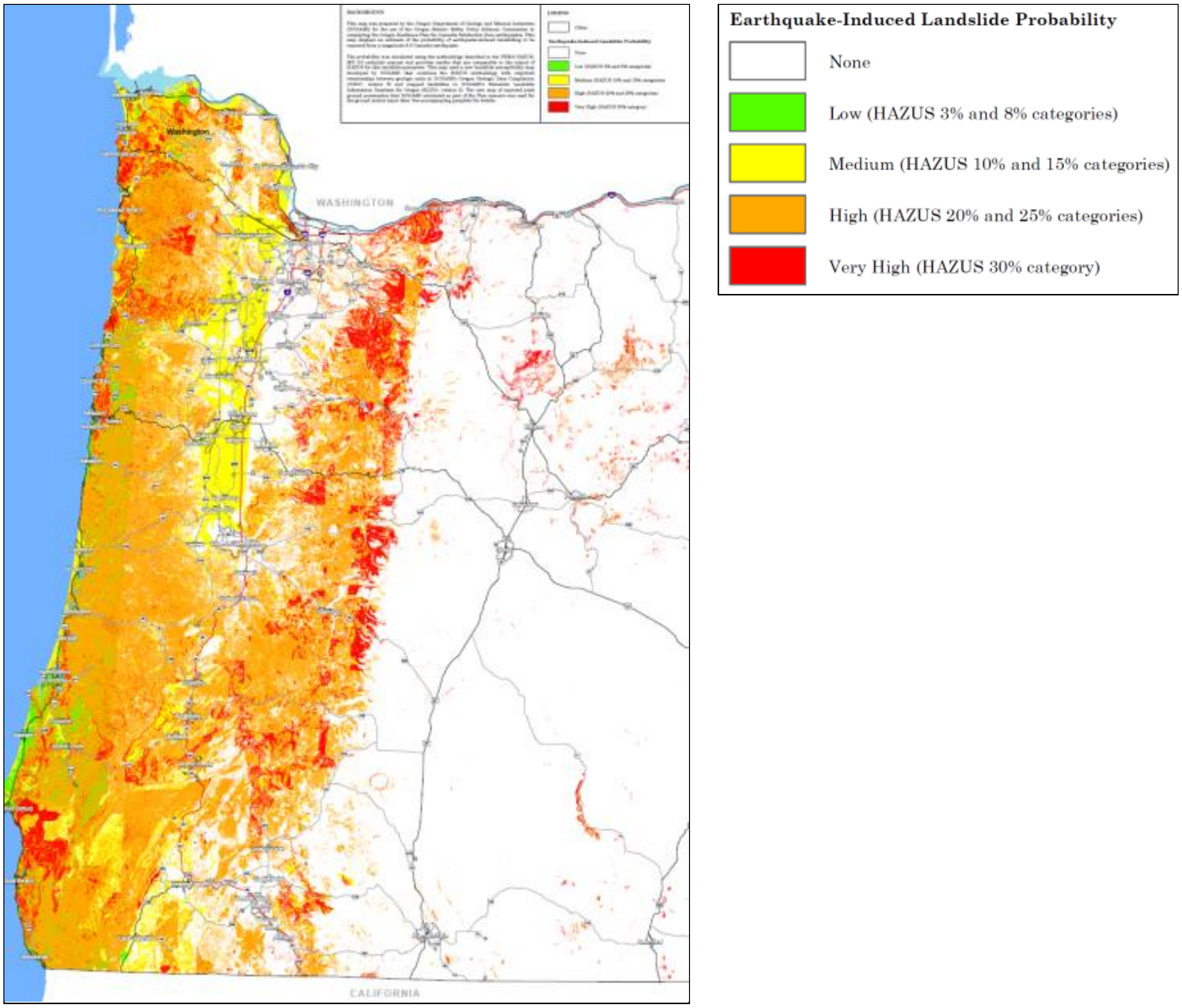
Figure 2-71. Example of a Lidar-Based Landslide Inventory (Oregon City, Oregon)



Source: Burns and Mickelson (2010)

With an accurate landslide inventory in hand, the next step in a complete landslide hazard mapping program is developing susceptibility maps for common types of landslides (see **Figure 2-72**). DOGAMI has completed a shallow landslide susceptibility protocol and is in progress of completing deep landslide and channelized debris flow susceptibility mapping protocols.

Figure 2-72. Example of an Earthquake-Induced Landslide Susceptibility Map



Source: Madin and Burns (2013)

Probability of Landslides in Each Oregon County

Climate, geology, and topography combine to make portions of Oregon landslide-prone. Precipitation, earthquakes, and human activity are the main triggers of landslides. The growing Oregon population has pushed development into landslide-prone areas, putting people and infrastructure at risk.

In order to produce the **Table 2-60,** Future Probability of Landslides in Each County in Oregon, we used the *Landslide Susceptibility Overview Map of Oregon* (Burns et al., 2016). The landslide susceptibility overview map of Oregon uses three statewide data sets: 1) geologic map (Oregon Geologic Data Compilation, release 6), 2) landslide inventory (Statewide Landslide Information Layer for Oregon [SLIDO], release 3.2), and 3) slope map (lidar-derived data and U.S. Geological Survey national elevation data). We combined generalized geology and landslide inventory to determine landslide area per geologic unit area and to establish classes of low, moderate, and high landslide density. Then we calculated spatial statistics of the slope map to determine classes of low, moderate, and high slopes prone to landsliding within each geologic unit. Using a hazard matrix, we combined these two data sets, landslide density and slopes prone to landsliding, with the original landslide inventory to establish final landslide susceptibility overview map zones.

The statewide overview map zones classify Oregon into the following susceptibility zones: 37% low, 28% moderate, 30% high, and 5% very high (the very high zone by definition consists of mapped landslides). Most areas classified as moderate or higher landslide susceptibility are located in the Cascade Mountains, the Coast Range, and the Klamath Mountains and portions of central and northeastern Oregon.

Figure 2-73. How Data Sets are Combined to Create Final Landslide Susceptibility Zones

Graphic display of how dataset are combined to create the final landslide susceptibility zones.		**Landslide Density** Combine: ❶ Generalized Geologic Map + ❷ Landslide Inventory			**Landslides** ❷ Landslide Inventory
		Low (less than 3%)	Moderate (between 3% and 17%)	High (Greater than 17%)	Existing Landslides
Slope Prone to Landsliding Combine: ❷ Landslide Inventory + ❸ Slope Map	Low (less than 1 STD)	Low	Moderate	High	Very High
	Moderate (between the mean and 1 STD)	Moderate	Moderate	High	Very High
	High (Equal to or greater than mean)	High	High	High	Very High

Source: Burns et al. (2016)

We defined each susceptibility class as:

Low: Landsliding unlikely. Areas classified as Landslide Density = Low (less than 7%) and areas classified as Slopes Prone to Landsliding = Low. Note that landslide density and slopes prone to landsliding data were not considered in this category because existing slides are inherently prone to instability. Note also that the inventory quality of existing landslides varies highly across the state.

Moderate: Landsliding possible. Areas classified as Landslide Density = Low to Moderate (less than 17%) and areas classified as Slopes Prone to Landsliding = Moderate OR areas classified as Landslide Density = Moderate (7%-17%) and areas classified as Slopes Prone to Landsliding = Low.

High: Landsliding likely. Areas classified as Landslide Density = High (greater than 17%) and areas classified as Slopes Prone to Landsliding = Low and Moderate OR areas classified as Landslide Density = Low and Moderate (less than 17%) and areas classified as Slopes Prone to Landsliding = High.

Very High: Existing landslides. Landslide Density and Slopes Prone to Landsliding data were not considered in this category. Note: the quality of landslide inventory (existing landslides) mapping varies across the state.

The statewide results for the classes are:

- 37% low
- 28% moderate
- 30% high
- 5% very high (mapped landslides)

These previously developed hazard zones were related then used, along with experienced based judgment, to develop the probability table.

Table 2-59. Classifying Landslide Probability

Statewide OFR O-16-02		
Percent of County with High + V High	**Probability**	**# 1 - 5**
0–10	Unlikely	1
10–20	Possible	2
20–30	Likely	3
30–50	Very Likely	4
50+	Extremely Likely	5

This relationship was then used to establish the final probability of landslide hazard per county table.

Table 2-60. Future Probability of Landslides in Each County in Oregon

Region/County		Landslide Probability	# 1 - 5
Region 1	Clatsop	Extremely Likely	5
	Coos	Extremely Likely	5
	Curry	Extremely Likely	5
	Douglas Coastal	Extremely Likely	5
	Lane Coastal	Extremely Likely	5
	Lincoln	Extremely Likely	5
	Tillamook	Extremely Likely	5
Region 2	Clackamas	Very Likely	4
	Columbia	Extremely Likely	5
	Multnomah	Very Likely	4
	Washington	Very Likely	4
Region 3	Benton	Very Likely	4
	Lane	Extremely Likely	5
	Linn	Very Likely	4
	Marion	Very Likely	4
	Polk	Very Likely	4
	Yamhill	Extremely Likely	5
Region 4	Douglas	Extremely Likely	5
	Jackson	Extremely Likely	5
	Josephine	Extremely Likely	5
Region 5	Gilliam	Very Likely	4
	Hood River	Extremely Likely	5
	Morrow	Possible	2
	Sherman	Likely	3
	Umatilla	Likely	3
	Wasco	Very Likely	4
Region 6	Crook	Likely	3
	Deschutes	Possible	2
	Jefferson	Very Likely	4
	Klamath	Possible	2
	Lake	Possible	2
	Wheeler	Extremely Likely	5
Region 7	Baker	Very Likely	4
	Grant	Very Likely	4
	Union	Very Likely	4
	Wallowa	Extremely Likely	5
Region 8	Harney	Possible	2
	Malheur	Possible	2

Burns, W.J., Mickelson, K.A., Madin, I.P., 2016. Statewide landslides susceptibility overview map of Oregon: Oregon Department of Geology and Mineral Industries, Open-File Report O-16-02, http://www.oregongeology.org/pubs/ofr/p-O-16-02.htm

Climate Change

Landslides are often triggered by heavy rainfall events when the soil becomes saturated. It is *very likely* (>90%) that Oregon will experience an increase in the frequency of extreme precipitation events (*high confidence*). Because landslide risk depends on a variety of site-specific factors, it is *more likely than not* (>50%) that climate change, through increasing frequency of extreme precipitation events, will result in increased frequency of landslides.

2.2.6.3 Vulnerability

Landslides occur statewide in Oregon, although areas with steeper slopes, weaker geology, and higher annual precipitation tend to have more landslides. In general, the coast and Coast Range Mountains and the Cascade Mountains have the most landslides. On occasion, major landslides sever major transportation routes such as U.S. or state highways and rail lines, causing temporary but significant economic damage to the state. Less commonly, landslides and debris flows in this area cause loss of life.

Most Vulnerable Communities

The Department of Geology and Mineral Industries is the agency with primary oversight of the landslide hazard. After agency staff review of available hazard data including SLIDO-4 and based on the 2020 vulnerability scores, DOGAMI lists Clatsop, Coos, Curry, Douglas Coastal, Lincoln, Tillamook, Lane Coastal, Clackamas, Columbia, Multnomah, Washington, Lane, Linn, Marion, Benton, Yamhill, Douglas, Jackson, Josephine, Hood River, Wasco, Jefferson, Wheeler and Wallowa Counties as having the highest hazard and risk to landslide in the state. Because of their importance to the state's economy, landslides occurring in Multnomah, Clackamas, and Washington Counties present the greatest vulnerability to impacts from this type of disaster. Landslides that close US-101 or any of the many highways connecting the I-5 corridor to the coast have a significant effect on commerce in the Oregon Coast Region.

In performing the 2020 vulnerability analysis, potential dollar losses from damage to state-owned and -leased buildings and state and local critical facilities exposed to landslide hazards were combined with the CDC's social vulnerability index. All elements were weighted equally.

State-Owned/Leased Buildings and Critical Facilities and Local Critical Facilities

DOGAMI analyzed the potential dollar loss from volcanic hazards to state-owned and –leased buildings and critical facilities as well as to local critical facilities statewide. Over $777.5M in value of state buildings, state and local critical facilities is exposed to landslide hazards statewide.

Historic Resources

Of the 58,872 historic buildings throughout the state, 58,835 are exposed to landslide hazards – only 37 are not. The vast majority of those exposed are in low landslide hazard areas. 3,751 are in high landslide hazard areas. See Appendix X for details.

Archaeological Resources

Of the 22,060 archaeological resources located in landslide hazard areas statewide, 12,943 are in areas of high earthquake hazards. Of those, 296 are listed on the National Register of Historic

Places and 1,438 are eligible for listing. Five hundred seventy have been determined not eligible, and 10,639 have not been evaluated as to their eligibility for listing.

Social Vulnerability

The Centers for Disease Control and Prevention (CDC) has calculated a social vulnerability index to assess community resilience to externalities such as natural hazard events. It employs fifteen social vulnerability factors and uses data from the US Census Bureau's American Community Survey. The index is reported in quintiles (1-5). Social vulnerability scores do not vary by hazard. The counties with the greatest social vulnerability statewide are Marion, Morrow, Umatilla, Wasco, Jefferson, Klamath, and Malheur.

For the 2020 vulnerability assessment, DLCD combined this index with the vulnerability scores for state buildings, state critical facilities, and local critical facilities to calculate an overall vulnerability score for each county. According to this limited assessment, Lincoln, and Wasco, Counties are the most vulnerable to impacts from landslide hazards.

Currently, there is no method to evaluate statewide vulnerability to landslides. The list of most vulnerable communities is primarily based on the 2020 vulnerability scores and are in alignment with the landslide susceptibility data in SLIDO-4. DOGAMI has performed landslide risk analysis of some individual communities in Oregon including Astoria, part of the US-30 transportation corridor, the Mount Hood region, parts of the Portland Metro area, and Silverton, Eugene-Springfield. The Mount Hood multi-hazard risk study provides details on the methods used to evaluate landslide and other hazard risk (Burns et al., 2011b).

2.2.6.4 Risk

With respect to natural hazards, risk can be expressed as the probability of a hazard occurring combined with the potential for property damage and loss of life. The 2020 risk assessment methodology combined the probability of landslide hazards occurring with the potential cost of damage to exposed state buildings and state and local critical facilities and with an assessment of the social vulnerability of the local population.

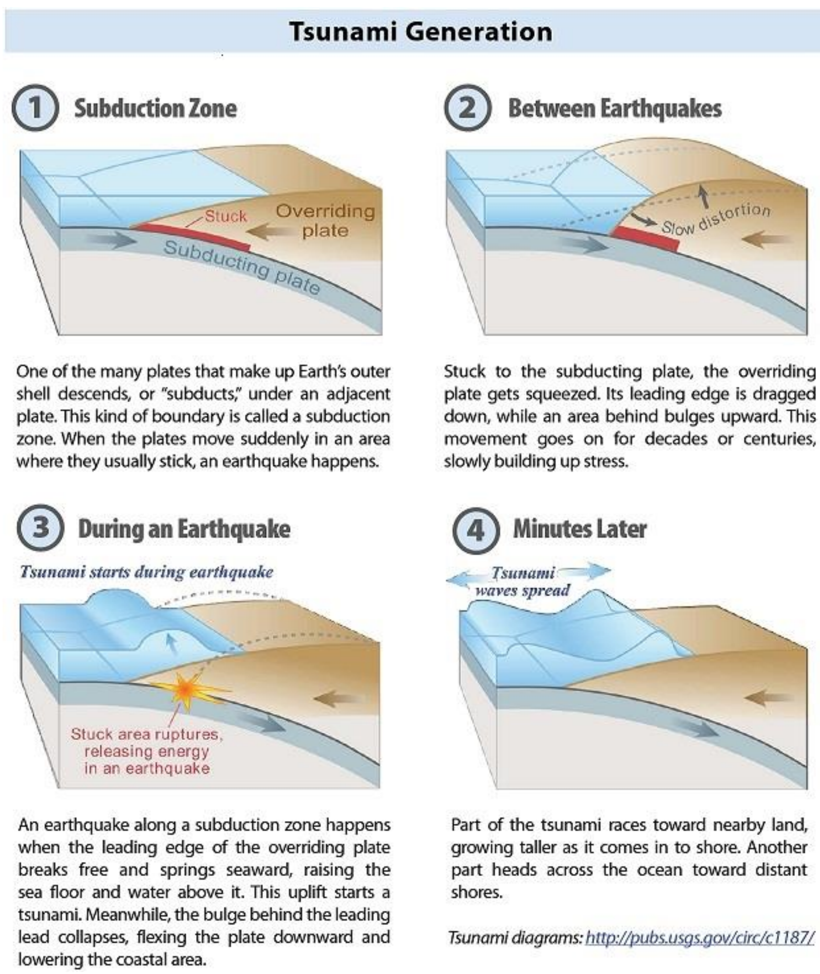
In the case of landslide hazards, the 2020 risk scores were generally greater than the vulnerability scores, elevated primarily due to very high probability of landslides occurring. According to the 2020 risk scores and DOGAMI's professional expertise, Regions 1, 2, 3, 4, 5, and 6 carry highest risk of landslides.

2.2.7 Tsunamis

Tsunamis are a low frequency natural hazard in Oregon and are restricted almost exclusively to coastal areas. Tsunamis are most often caused by the abrupt change in the seafloor accompanying an earthquake (**Figure 2-74**). The most common sources of the largest tsunamis are earthquakes that occur at subduction zones like the Cascadia Subduction Zone (CSZ), where an oceanic plate descends beneath a continental plate (**Figure 2-75**). Other important processes that may trigger a tsunami include underwater volcanic eruptions and landslides (includes landslides that start below the water surface and landslides that enter a deep body of water from above the water surface). Tsunamis can travel thousands of miles across ocean basins, so that a particular coastal area may be susceptible to two different types of tsunami hazard caused by:

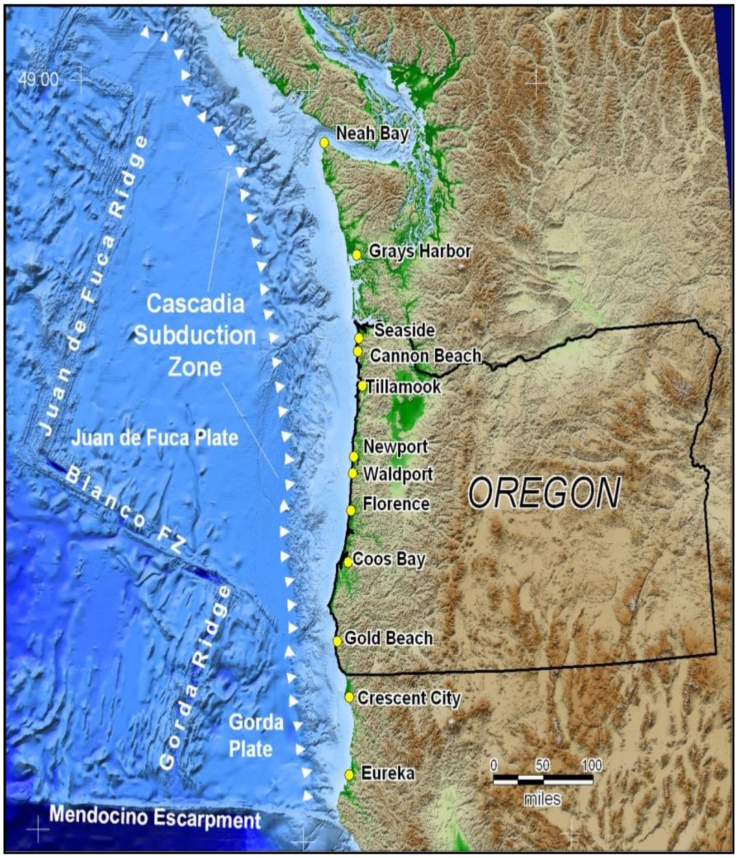
1. Distant sources across the ocean basin, and
2. Local sources that occur immediately adjacent to a coast.

Figure 2-74. Generation of a Tsunami by Subduction Zone Earthquakes



Source: DOGAMI, *Cascadia,* Winter 2012 (http://www.oregongeology.org/pubs/cascadia/CascadiaWinter2012.pdf)

Figure 2-75. Cascadia Subduction Zone (CSZ) Active Fault Map



Note: The fault, indicated by the triangles, is the contact where the Juan de Fuca Plate plunges beneath the North American continental plate.

Source: DOGAMI

Distant tsunamis that may threaten the Oregon Coast are usually generated by a subduction zone earthquake elsewhere in the Pacific and would take at least 4 hours to reach the Oregon coastline from the closest source, the subduction zone in the Gulf of Alaska. For example, the 1964 Alaska tsunami reached the Oregon Coast in four hours after the magnitude 9.2 earthquake that generated it. In contrast, a local tsunami generated by a CSZ earthquake, would take about 10-20 minutes to reach most of the coast.

Most locally-generated tsunamis will be higher and travel farther inland (overland and up river) than distant tsunamis. By the time the tsunami wave hits the coastline, it may be traveling at 30 mph and have heights of 20 to about 100 feet, depending on the local coastal bathymetry (water depths), shape of the shore, and the amount of fault movement on the subduction zone. The tsunami wave will break up into a series of waves that will continue to strike the coast for a day or more, with the most destructive waves arriving in the first 4-5 hours after the local earthquake. As was seen in the 2004 Sumatra tsunami, the first wave to strike the coast is not always the most destructive. This was again the case during the 2011 Japan tsunami.

The coasts of Washington, Oregon, and northern California are particularly vulnerable to tsunamis from magnitude 9+ earthquakes that occur about every 500 years on the CSZ (**Figure 2-75**). Additionally, smaller tsunamis and earthquakes occur in the subduction zone south of Bandon on the southern Oregon coast. The recurrence for these smaller rupture events can be as low as about 230 years in Curry County.

The initial tsunami wave mimics the shape and size of the sea floor movement that causes it, but quickly evolves into a series of waves that travel away from the source of disturbance, reflect off of coastlines, and then return again and again over many hours. The tsunami is thus "trapped" owing to the processes of reflection and refraction. In the deep ocean, tsunami waves may be only a few feet high and can travel at wave speeds of 300–600 mph. As a tsunami approaches land where the water depth decreases, the forward speed of the wave will slow and the wave height increase dramatically. When the wave makes landfall, the water is mobilized into a surging mass that floods inland until it runs out of mass and energy. The wave then retreats, carrying all sorts of debris. Successive waves then batter the coast with this debris. Swimming through such turbulent debris-laden water is next to impossible.

Tsunamis are more destructive than the earthquake that caused them. Loss of lives from the tsunami can often be many times the loss from the earthquake ground shaking. This was highlighted by the December 26, 2004 tsunami, associated with a magnitude 9.3 earthquake, which occurred offshore from the Indonesian island of Sumatra. The tsunami impacted almost every country located around the Indian Ocean rim and claimed the lives of approximately 350,000 people. The greatest loss of life occurred along the coast of Sumatra, close to the earthquake epicenter. The event displaced some 2 to 3 million people and its economic impact continues to be felt to the present.

In addition, fires started by the preceding earthquake are often spread by the tsunami waves, if there is a gasoline or oil spill. As was seen in the Sumatra 2004 tsunami, flood inundation from a tsunami may be extensive, as tsunamis can travel up rivers and streams that lead to the ocean. Delineating the inland extent of flooding, or inundation, is the first step in preparing for tsunamis.

2.2.7.1 Analysis and Characterization

The entire coastal zone is highly vulnerable to tsunami impact. Distant tsunamis caused by earthquakes on the Pacific Rim strike the Oregon coast frequently but only a few of them have caused significant damage or loss of life. Local tsunamis caused by earthquakes on the Cascadia Subduction Zone (CSZ) happen much less frequently but will cause catastrophic damage and, without effective mitigation actions, great loss of life.

On March 11, 2011, a magnitude (Mw) 9.0 earthquake struck off the east coast of Japan. This caused a massive tsunami that inundated much of the eastern coastline of Japan and reached the west coast of the U.S. many hours later. There was one death and millions of dollars of damage to ports and harbors in Oregon and California (**Figure 2-76**). In contrast, Japan suffered approximately 18,000 deaths as well as a nuclear catastrophe which will continue to be a hazard far into the future; destruction from the tsunami and earthquake resulted in about $250 billion in damages. Oregon received a Presidential Declaration of Disaster (DR-1964) which brought millions of dollars of financial aid to repair and mitigate future tsunami damage. Debris from tsunami-damaged buildings in Japan floated across the Pacific Ocean and began arriving on the Canadian and U.S. West Coast in December 2011 and continued to arrive several years after the event.

Figure 2-76. Tsunami Damage on the Chetco River, Oregon from the Tsunami Generated by an Earthquake Offshore Japan in 2011

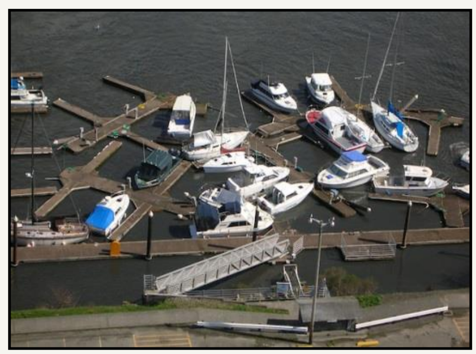


Photo source: U.S. Coast Guard

In March 1964, a tsunami struck southeastern Alaska following an earthquake beneath Prince William Sound and arrived along the Alaska coastline between 20 and 30 minutes after the quake, devastating villages. Damages were estimated to be over $100 million (1964 dollars). Approximately 120 people drowned. The tsunami spread across the Pacific Ocean and caused damage and fatalities in other coastal areas, including Oregon. The tsunami killed five people in Oregon and caused an estimated $750,000 to $1 million in damage. In Crescent City, California, there were 10 fatalities, while damage to property and infrastructure was estimated to range from $11 to 16 million.

Going still further back in time, there is scientific consensus that the Pacific Northwest experienced a subduction zone earthquake estimated at magnitude 9 on January 26, 1700. The earthquake generated a tsunami that caused death and damage as far away as Japan, where it was well-documented in the literature of the time. The earthquake and tsunami left behind geologic "footprints" in the form of (a) tsunami sand sheets in marshes, (b) layers of marsh vegetation covered by tide-borne mud when the coast abruptly subsided, and (c) submarine sand and silt slurries shaken off the continental shelf by the earthquake (turbidites). The widespread and large body of oral traditional history of the Thunderbird and Whale stories passed down by First Nations people depict both strong ground shaking and marine flooding that may have been inspired by this event. Although this earthquake undoubtedly produced tsunamis that reached on the order of 30–40 feet at the coast, geologic evidence from study of 10,000 years of turbidite deposits suggests that the 1700 earthquake was just an average event.

Some Cascadia earthquakes have been many times larger, so, while devastating, the earthquake and tsunami were far from the worst case.

In 2013 the Oregon Department of Geology and Mineral Industries (DOGAMI) completed an analysis of the full range of Cascadia tsunamis and earthquakes, separating the results into five size classes with "T-shirt" names, S, M, L, XL, and XXL. The XL or XXL events probably only happened once or twice in the last 10,000 years, but estimated tsunami heights were comparable to those of the 2011 Japan and 2004 Sumatra tsunamis, the largest known.

The tsunami wave tends to arrive at the coast as a fast moving surge of rising water. As the tsunami enters coastal bays and rivers, it may move as a high-velocity current or a breaking wave that travels up an estuary as a bore (wall of turbulent water like the waves at the coast after they break). This inland wave of water can often cause most or all of the damage, and the current may be just as destructive when it is retreating from the land as when it is advancing. For example, in Seaside the damage from the 1964 Alaskan tsunami occurred along the Necanicum River and Neawanna Creek, well inland from the coast. In addition, storm waves and wind waves may ride on top of the tsunami waves, further compounding the level of destruction.

During Cascadia earthquakes there is also the added effect of coastal subsidence, or the drop in elevation of the land relative to sea level, during the earthquake. This is due to the release of the accumulated strain that caused the western edge of the North American Plate to bend and bulge. The new earthquake models used for the local tsunami scenarios indicate that portions of the Oregon coast could drop by a several feet to approximately 15 feet.

Seven tsunami flooding (inundation) zones were mapped by DOGAMI between 2009 and 2013: five local Cascadia tsunami scenarios, S, M, L, XL, XXL, and two maximum-considered distant tsunami scenarios (the 1964 Alaska tsunami and a larger hypothetical maximum Alaska tsunami, AKmax). All 7 are depicted on DOGAMI tsunami inundation maps (TIMs, **Figure 2-77**) plus digital files for use in geographic information systems (GIS). The five local CSZ-sourced inundation scenarios involve greater and greater amounts of movement on the subduction zone fault, ranging from 30 feet (S scenario) to 144 feet (XXL scenario). The seven inundation lines are reduced to two for evacuation planning: AKmax inundation is the distant tsunami evacuation zone, and XXL is the local tsunami evacuation zone (**Figure 2-77**). Brochures illustrating these zones and evacuation routes are available for all population centers, but both zones can also be viewed for any part of the coast using an interactive map portal and mobile phone apps at www.oregontsunami.org. The evacuation zones are critical for life safety planning and preparation. All seven scenarios were modeled on a mean higher high tide (MHHW) and include the effects of subsidence from the earthquake fault process (release of strain on the North American Plate).

Figure 2-77. Examples of DOGAMI Tsunami Inundation Maps (TIMs) and Tsunami Evacuation Maps for North Bend (Coos Bay Area)

The top map illustrates inundation for five "T-shirt" size CSZ scenarios (S, M, L, XL, and XXL); the middle map shows inundation from two maximum considered distant tsunamis from subduction zone earthquakes in the Gulf of Alaska, a hypothetical maximum (termed Alaska Maximum or AKmax in DOGAMI databases), and the largest historical event that struck the Oregon coast in 1964. Note the close similarity of Alaska Maximum to the Small CSZ inundation.

Source: DOGAMI, *Cascadia* Winter 2012 (http://www.oregongeology.org/pubs/cascadia/CascadiaWinter2012.pdf)

Historic Tsunami Events

Table 2-61. Historic Distant Tsunamis in Oregon

Date	Origin of Event	Affected Oregon Community	Damage	Remarks
Apr. 1868	Hawaii	Astoria		observed
Aug. 1868	N. Chile	Astoria		observed
Aug. 1872	Aleutian Islands	Astoria		observed
Nov. 1873	N. California	Port Orford		debris at high tide line
Apr. 1946	Aleutian Islands	Bandon		barely perceptible
Apr. 1946		Clatsop Spit		water 3.7 m above MLLW
Apr. 1946		Depoe Bay		bay drained; water returned as a wall
Apr. 1946		Seaside		wall of water swept up Necanicum River
Nov. 1952	Kamchatka	Astoria		observed
Nov. 1952		Bandon	log decks broke loose	
May 1960	S. Cent. Chile	Astoria		observed
May 1960		Seaside	bore on Necanicum River damaged boat docks	
May 1960		Gold Beach		observed
May 1960		Newport		observed for about 4 hours
May 1960		Netarts	some damage observed	
Mar. 1964	Gulf of Alaska	Cannon Beach	bridge and motel unit moved inland; $230,000 damage	
Mar. 1964		Coos Bay	$20,000 damage	
Mar. 1964		Depoe Bay	$5,000 damage; 4 children drowned at Beverly Beach	
Mar. 1964		Florence	$50,000 damage	
Mar. 1964		Gold Beach	$30,000 damage	
Mar. 1964		Seaside	1 fatality (heart attack); damage to city: $41,000; private: $235,000; four trailers, 10–12 houses, two bridges damaged	
May 1968	Japan	Newport		observed
Apr. 1992	N. California	Port Orford		observed
Oct. 1994	Japan	coast		tsunami warning issued, but no tsunami observed
Mar. 2011	Japan	coast	$6.7 million; extensive damage to the Port of Brookings	tsunami warning issued, observed ocean waves
Oct. 2012	Haida Gwaii, BC	coast		M 7.7 caused a tsunami with local runup of more than 7 meters and amplitudes up to 0.8 meter on tide gauges 4000 kilometers away in Hawaii. Source: NOAA

Date	Origin of Event	Affected Oregon Community	Damage	Remarks
Jan. 2018	Kodiak Is., AK	coast		minor tsunami impacts in AK, HI and US west coast; the largest tsunami amplitude was recorded at 25cm in Crescent City CA 4-5 hrs after the magnitude 7.9 earthquake

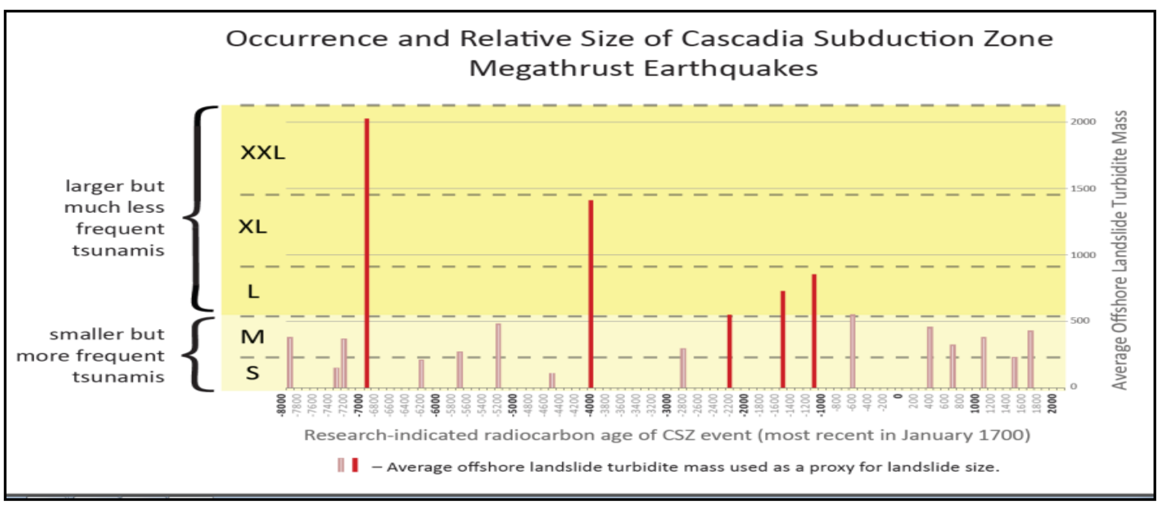
Sources: Lander et al., 1993; FEMA, 2011, Federal Disaster Declaration; NOAA, https://www.ngdc.noaa.gov/hazel/view/hazards/tsunami/event-more-info/5673, downloaded on 4/15/20; NOAA https://www.ngdc.noaa.gov/hazel/view/hazards/tsunami/event-more-info/5673 downloaded on 4/15/20

In addition to the historical distant tsunamis of **Table 2-61**, the last CSZ tsunami struck at 9 PM on January 26, 1700. This may be considered a historic event, because the tsunami was recorded in historical port records in Japan. The date and time of occurrence here in Oregon were inferred by Japanese and USGS researchers from a tsunami and earthquake model.

2.2.7.2 Probability

While large (about magnitude 9) CSZ earthquakes and associated tsunamis have occurred on average every 500 years over the last 10,000 years, the time interval between events has been as short as a century and as long as 1,150 years. Smaller earthquakes on the southern part of the CSZ have occurred about as often as larger earthquakes, making CSZ events in southernmost Oregon about twice as likely as in northern Oregon. The size and frequency of the 19 large earthquakes on the CSZ are inferred from offshore turbidite deposits and are shown in **Figure 2-78**. All 19 of these large CSZ events were likely magnitude 8.7–9.2 earthquakes.

Figure 2-78. Occurrence and Relative Size of Cascadia Subduction Zone Megathrust Earthquakes



Source: DOGAMI *Cascadia*, Winter 2012 (http://www.oregongeology.org/pubs/cascadia/CascadiaWinter2012.pdf)

In April 2008 the USGS estimated that the probability of a magnitude 8-9 earthquake somewhere along the 750-mile-long Cascadia Subduction Zone was about 10% in the next 30 years. In 2012 USGS Professional Paper 1661-F (http://pubs.usgs.gov/pp/pp1661f/) showed that the southern part of the CSZ also ruptures in segments **Figure 2-79**, resulting in a greater probability of a rupture taking place in southern Oregon. Southern segment earthquakes and tsunamis will generally be smaller than full-margin events, and by the time they travel north along the coast are similar in size to distant tsunamis with the largest waves striking 2 hours or more after the earthquake (Priest et al., 2014; http://link.springer.com/article/10.1007/s11069-014-1041-7). New tsunami inundation maps from DOGAMI illustrate the range of inundation from all full-margin and significant segment ruptures on the CSZ. Most recently, Goldfinger and others (2017) completed revised estimates for the probability of a great earthquake taking place on the CSZ, estimated at 16-22% in the next 50 years, and approximately 43% for a southern Oregon partial rupture.

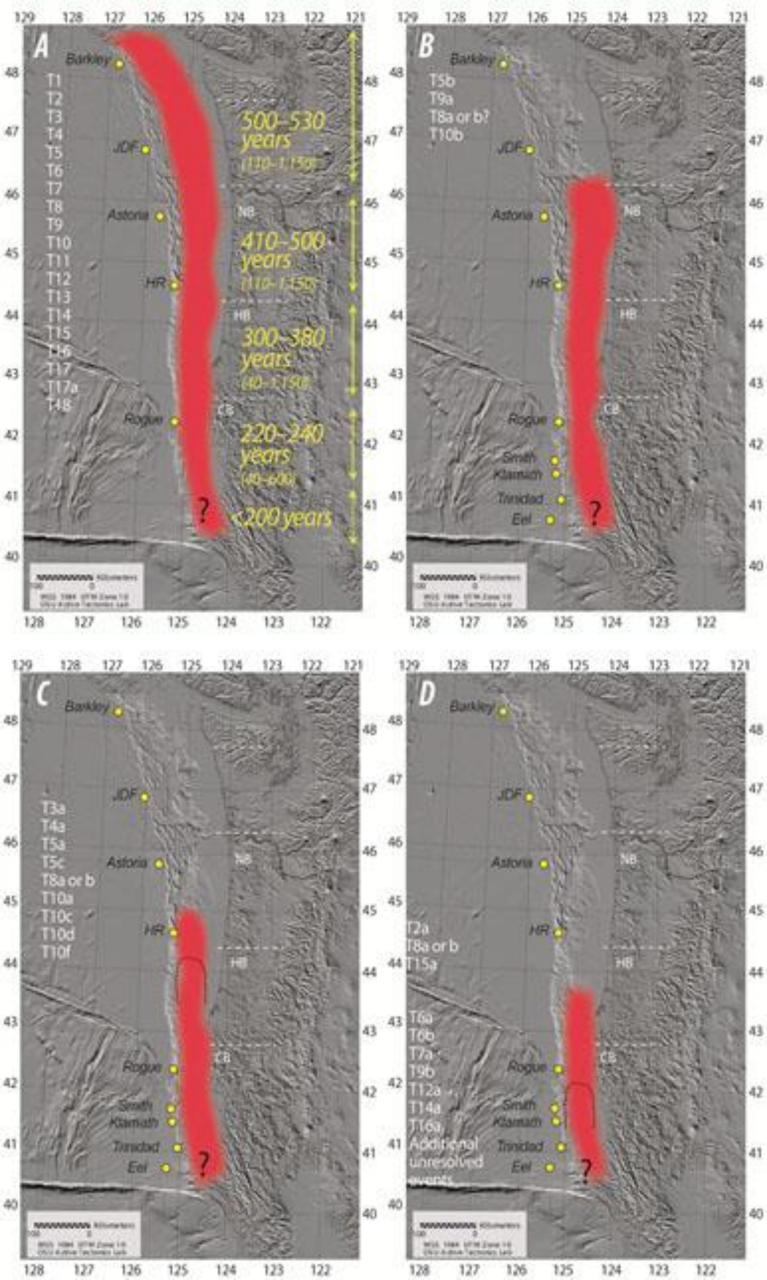


Figure 2-79. Hypothetical Rupture Patches of Cascadia Subduction Zone (CSZ) Earthquakes over Last 10,000 Years

White line with triangles marks the CSZ deformation front also visible as boundary between smooth to rough terrain. Numbers with "T" prefixes are offshore turbidite layers correlated with each rupture patch and arranged with youngest at the top. The white dashed lines are inferred segment boundaries of CSZ ruptures designated segments A (full-margin rupture), B (rupture north to Nehalem Bank [NB]), C (rupture north to Heceta Bank [HB]), and D (rupture north to Coquille Bank [CB]). Northern extents of segment D events break into two groups, one terminating south of the Rogue submarine canyon, indicated by dashed line. The second group extends north of Rogue but is not observed at Hydrate Ridge (HR). Although presumed to extend no further south than the southern terminus of the CSZ at Cape Mendocino, southern rupture limits are poorly known for all events indicated by query, limited by temporal coverage of turbidites and probable non-seismic turbidites in the early Holocene. Uncertainty in the northern extent of segments C and D are shown as the difference between the red patches and the black dashed lines. In the map of segment A, mean return in years of CSZ earthquakes is listed at each latitude and is calculated by dividing the number of turbidite layers into 10,000 years; minimum and maximum time intervals between turbidites at each latitude is given in parentheses. See Priest et al. (2014; http://link.springer.com/article/10.1007/s11069-014-1041-7) for estimates of height and arrival times of Segment C and D tsunamis.

Note: Red areas depict hypothetical rupture patches of Cascadia subduction zone (CSZ) earthquakes over the last 10,000 years inferred by Goldfinger et al. (2012) from marine and onshore paleoseismic data plus geological and geophysical data
Source: Goldfinger et al. (2012)

Probability of Coastal Hazards in Each Coastal County

Coastal paleoseismic records document the impacts of as many as 13 major subduction zone earthquakes and associated tsunamis over the past ~7,000 years, while recent studies of turbidite records within sediment cores collected in deep water at the heads of Cascadia submarine canyons provide evidence for at least 46 distinct tsunami events over the past approximately 10,200 years (Goldfinger et al., 2017). The length of time between these events varies from as short as 100 years to as long as 1,200 years, with the average recurrence interval for major Cascadia earthquakes (magnitude >[Mw] 9) estimated to be about 530 years (Witter et al., 2010); the last great (full-margin rupture) Cascadia earthquake took place on January 26th, 1700. Given that the subduction zone is presently locked and the rate of convergence of the Juan de Fuca against the North American plates is about 1.5 inches per year, this suggests that approximately 12.1 m of strain has accumulated since the 1700 earthquake as it builds to the next rupture.

Recently, Goldfinger et al. (2017) provided a revised assessment for the central to northern Oregon coast, which was found to have a mean recurrence time of about 340 years. Furthermore, they defined a conditional probability of the next Cascadia event taking place in the next 50 years of approximately 16 to 22%. Goldfinger et al. (2012) indicated that the chance of a partial rupture occurring and impacting the southern Oregon coast is approximately 43% in the next 50 years. Using these data, we assign a higher probability risk of a Cascadia event occurring on the southern Oregon coast (i.e. Coos and Curry counties) compared with the remainder of the coast. The final probability was assigned a number from 1 to 5 for use in the 2020 risk assessment developed by DOGAMI and DLCD. This method combines the probability score with the vulnerability scores to arrive at the relative risk score.

Table 2-62. Probability and Exposure Rankings of Tsunami Hazards

		Probability	Exposure	Probability Score
Region 1	Clatsop	Likely	Very High	4 = H
	Coos	Very likely	Very High	5 = VH
	Curry	Very likely	Very High	5 = VH
	Douglas Coastal	Likely	Very High	4 = H
	Lane Coastal	Likely	Very High	4 = H
	Lincoln	Likely	Very High	4 = H
	Tillamook	Likely	Very High	4 = H

2.2.7.3 Vulnerability

The entire coastal zone is highly vulnerable to tsunami impact. Distant tsunamis caused by earthquakes on the Pacific Rim strike the Oregon coast frequently but only a few of them have caused significant damage or loss of life. Local tsunamis caused by earthquakes on the Cascadia Subduction Zone (CSZ) happen much less frequently but will cause catastrophic damage and, without effective mitigation actions, great loss of life.

Because tsunamis in Oregon typically occur as a result of earthquakes, the unknown time and magnitude of such events adds to the difficulty in adequately preparing for such disasters. If a major earthquake occurs along the CSZ, a local tsunami could follow within 10 to 20 minutes.

Although tsunami evacuation routes have been posted all along the Oregon Coast, damage to bridges and roadways from an earthquake could make evacuation difficult even if a tsunami warning were given. In addition, if a major earthquake and tsunami occur during the “tourist season,” causalities and fatalities from these disasters would be far greater than if the same events occurred during the winter months.

It is also important to consider where the impact of a tsunami would be the greatest. Owing to relatively large resident and visitor populations located at very low elevations, cities facing the Pacific Ocean on the northern Oregon Coast are more vulnerable to inundation and have the greater potential for loss of life than coastal cities in central and southern Oregon. USGS (Wood, 2007) estimated vulnerable populations using a tsunami inundation zone similar to the Medium CSZ event, which is the most likely event to occur. That study found that:

1. 22,201 residents and 10,201 households are in the zone, with the largest numbers in the northern coast;
2. the City of Seaside had the highest number of residents in the zone (4,790); and
3. 7,912 residents (36% of all residents in the zone) are in unincorporated communities, the balance in 26 incorporated communities.

Inventories that utilize 2010 census data and updated population modeling are currently being developed by DOGAMI in order to update the work of Wood (2007). Results indicate that for the L1 scenario, there are 32,630 people in the tsunami zone, comparable to results obtained by Wood & Schmidtlein (2011). For the XXL1 scenario, the number of people in the tsunami zone increases to approximately 56,500. Distant tsunamis, except for the most extreme events, will not affect significant numbers of residents, since they flood principally beaches and low-lying waterfront areas. Loss of life from distant tsunamis will also be far less than for local tsunamis, because there will be at least four hours to evacuate prior to wave arrival, compared with rather than 10–20 minutes for a local Cascadia tsunami.

That said, visitors are more vulnerable than residents to both distant and locally generated tsunamis, because they are more likely to be at beaches and shoreline parks and are generally less aware of hazard response and preparedness. During the summer and holidays, visitors can greatly outnumber residents in the small coastal towns. In a pilot project of five coastal communities (Gearhart, Rockaway Beach, Lincoln City, Newport and Port Orford), DOGAMI found that the visitor population may be about 2 to 5 times the local permanent population; differences here are entirely a function of the availability of the number of hotel/motels and holiday homes in each community. While intensive education and outreach programs led by DOGAMI and OEM have greatly increased awareness and preparedness, residents are much more likely to have received this education than visitors.

The Oregon Resilience Plan (ORP) uses the impact of a “Medium” or “M” CSZ earthquake and tsunami for planning purposes, because this was judged the most likely CSZ event (see DOGAMI Special Paper 43 [Witter et al., 2011] for explanation). The ORP describes the “M” impact:

> *Following the Cascadia event, the coastal communities will be cut off from the rest of the state and from each other. The coastal area’s transportation system, electrical power transmission and distribution grid, and natural gas service will be fragmented and offline, with long-term setbacks to water and wastewater services. Reliable communications will be similarly affected. Because so many of*

these connecting systems are single lines with little or no redundancy, any break or damage requiring repair or replacement will compromise the service capacity of the entire line.

The loss of roads and bridges that run north and south will make travel up and down the coast and into the valley difficult, if not impossible, due to the lack of alternate routes in many areas. Reestablishing the roads and utility infrastructure will be a challenge, and the difficulties will be exacerbated in the tsunami inundation area by its more complete destruction. Even businesses outside of the tsunami inundation may not recover from the likely collapse of a tourist-based economy during the phased and complicated recovery and reconstruction period.

Based on the resilience targets provided by the Transportation, Energy, Communications, and Water/Wastewater task groups, current timelines for the restoration of services up to 90-percent operational levels will take a minimum of one to three years, and often over three years in the earthquake-only zone. Restoration in the tsunami zone will take even longer than that... The most critical infrastructure is the road and highway system. Without functioning road systems, none of the infrastructure can be accessed to begin repairs.

The tsunami will also create an enormous amount of debris that needs to be gathered, sorted, and managed. The recent experience of Japan, with a similar mountainous coastline, has shown that debris management competes with shelter and reconstruction needs for the same flat land that is often in the inundation zone.

The ORP estimates that times for recovery of the coastal infrastructure for a Medium CSZ event will be: electricity and natural gas, 3–6 months; drinking water and sewer systems, 1–3 years; and Healthcare facilities, 3 years. The ORP gives no estimate for times to recover police and fire stations or the coastal transportation system, but times for the latter would no doubt be measured in years. Economic recovery would also be many years, since much of the coast is dependent on tourism that is directly dependent on the transportation system. According to the ORP:

Even if a business had sufficient capital to relocate, it is unlikely that the tourist industry will recover rapidly enough to support business start-up. Local authorities may need to keep tourists out of the inundation zones, for safety reasons, for months or years after a tsunami.

Most Vulnerable Communities

For the 2020 vulnerability assessment, DOGAMI considered all Cascadia Subduction Zone (CSZ) tsunami hazard zones as high hazard areas.

State-Owned/Leased Buildings and Critical Facilities and Local Critical Facilities

DOGAMI analyzed the potential dollar loss from tsunami hazards to state buildings and critical facilities as well as to local critical facilities statewide. Over $248M in value of state buildings and state critical facilities are located in tsunami hazard areas, and 67% of that value is located in Clatsop County. More than $351K of value in local critical facilities is located in tsunami hazard areas. Again, most of that value, 49%, is located in Clatsop County.

Historic Resources

Of the 3,121 historic resources located in Oregon's coastal counties, 794 are located in tsunami hazard areas. Seventy-three percent (582) are located in Clatsop County and 21% (170) in Coos County. None are located in the coastal portions of Douglas or Lane Counties.

Social Vulnerability

The Centers for Disease Control and Prevention (CDC) has calculated a social vulnerability index to assess community resilience to externalities such as natural hazard events. It employs fifteen social vulnerability factors and uses data from the US Census Bureau's American Community Survey. The index is reported in quintiles (1-5). Social vulnerability scores do not vary by hazard. The counties with the greatest social vulnerability statewide are Marion, Morrow, Umatilla, Wasco, Jefferson, Klamath, and Malheur.

For the 2020 vulnerability assessment, DLCD combined this index with the vulnerability scores for state buildings, state critical facilities, and local critical facilities to calculate an overall vulnerability score for each county. According to this limited assessment, Clatsop County, Coos County, and the coastal portion of Lane County are the most vulnerable to the CSZ tsunami hazard followed by the coastal portion of Douglas County.

The entire coastal region is highly vulnerable to tsunamis, but some areas are especially vulnerable owing to geographic and demographic factors. The Oregon Office of Emergency Management (OEM) is the agency with primary oversight of emergency response to the tsunami hazard. A 1990 revision of DOGAMI's enabling statutes added geologic hazard mitigation to its responsibilities, but other state agencies such as OEM and local governments share this responsibility. Based on agency staff review of the available hazard data, OEM lists Clatsop and Tillamook Counties as having the greatest vulnerability to the tsunami hazard in the state. As previously mentioned, Seaside is the town most vulnerable to tsunamis on the coast, but Gearhart, Cannon Beach, Rockaway Beach, Pacific City, Neskowin, Salishan Spit, Cutler City in Lincoln City, South Beach in Newport, and downtown Waldport are all extremely difficult to evacuate owing to local geographic factors (marshes or lakes limiting evacuation, long distances to evacuation routes, and limited high ground for evacuees) and significant percentages of retirees with limited mobility.

Vulnerability of communities is based primarily on difficulty of evacuation in the 10-20 minutes between a CSZ earthquake and arrival of the tsunami. A community is considered highly vulnerable if the population is large with high ground located a long distance away accessible by only a few routes that could be compromised by earthquake damage.

2.2.7.4 Risk

In the 2020 update, DOGAMI and DLCD developed a new risk ranking system that combines the probability of the hazard with the limited vulnerability assessment to arrive at a composite risk score referred to as the 2020 Risk Score.

According to the 2020 risk assessment, the counties at greatest risk from the tsunami hazard are Clatsop County, Coos County, and the coastal portions of Douglas and Lane Counties.

2.2.8 Volcanoes

Volcanoes are potentially destructive natural phenomena, constructed as magma ascends and then erupts onto the earth's surface. Volcanic eruptions are typically focused around a single vent area, but vary widely in explosivity. Therefore volcanic hazards can have far reaching consequences. Volcanic hazards may occur during eruptive episodes or in the periods between eruptions.

Volcanic hazards may be divided into two categories based on the range of their impact from the eruptive center or active vent. *Proximal* hazards have an impact limited to a distance of about 30 miles or less from the active vent. *Distal* hazards have an impact far beyond the active vent. Proximal and distal hazards are individual to each volcano. In addition to the 30-mile threshold, proximal and distal zone boundaries are based on:

- Frequency and magnitude of past events at the volcano, as recorded by their deposits;
- Modeling that predicts the extent, depth, and travel time of future events; and
- Experience and judgment derived from observations and understanding of events at other volcanoes.

Eruptive events may include proximal hazards such as:

- Lava flows;
- Pyroclastic surges and flows (fast-moving combination of very hot ash, lava, and gases);
- Lahars (volcanic mudflows or debris flows);
- Debris avalanches (landslides);
- Release of volcanic gases; and
- Tephra fall (shower of ejected rock fragments and particles);

As well as distal hazards such as:

- Lahars;
- Eruption columns and clouds; and
- Ashfall.

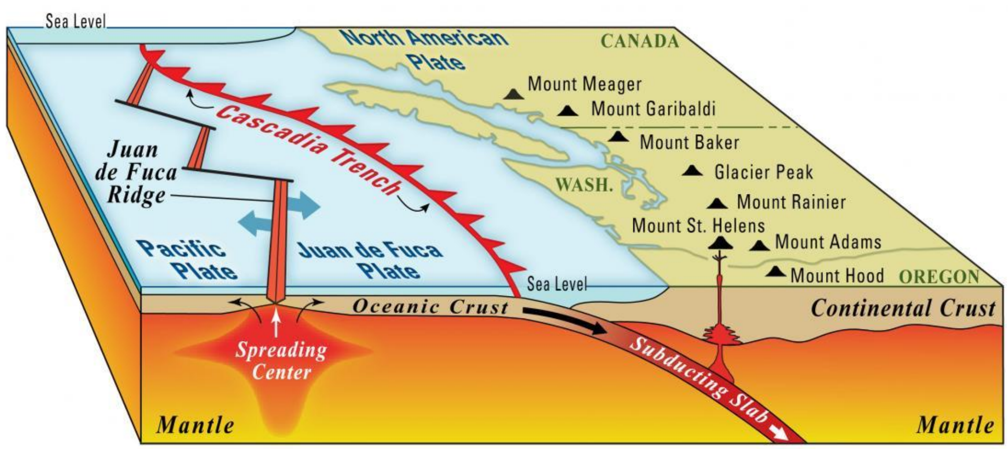
Eruptions may last from days to weeks or years, and have the potential to dramatically alter the landscape for decades. Unlike other geologic hazards (e.g., earthquakes, tsunamis), impending eruptions are often foreshadowed by a number of precursors including ground movements, earthquakes, and changes in heat output and volcanic gases. Scientists use these clues to recognize a restless volcano and to prepare for events that may follow. Hazards occurring between eruptive periods are typically related to earthquakes or natural erosion, which may trigger debris avalanches or debris flows on the flanks of the volcano. Such events often occur without warning.

Potentially hazardous volcanoes in Oregon are present along the crest of the Cascade Range and to a lesser extent in the High Lava Plains. The volcanoes within these regions provide some of Oregon's most spectacular scenery and popular recreational areas, yet the processes that led to their formation also present significant challenges and hazards to communities within the region. The catastrophic eruption of Washington's Mount St. Helens in 1980 and subsequent activity demonstrate both the power and detrimental consequences that Cascade-type volcanoes can have on the region. Lessons learned at Mount St. Helens led the U.S. Geological Survey (USGS) to establish the Cascades Volcano Observatory (CVO) in Vancouver, Washington. Scientists at CVO continually monitor volcanic activity within the Cascade Range, and in cooperation with the Oregon Department of Geology and Mineral Industries (DOGAMI), study the geology of volcanic terrains in Oregon (Ewart et al., 2018).

2.2.8.1 Analysis and Characterization

The volcanic Cascade Range extends southward from British Columbia into northern California. The volcanoes are a result of the complex interaction of tectonic plates along the Cascadia Subduction Zone (CSZ). Subduction is the process that results in the Juan de Fuca plate (oceanic crust) subducting, or sinking, underneath the North American plate (continental crust) on which we live (**Figure 2-80**). As the subducted plate descends, it heats up and begins to melt. This provides the reservoir of heat and molten rock needed to create the magma chambers that lie kilometers deep, beneath the Cascades.

Figure 2-80. Generalized Subduction Zone Setting



Source: Cascades Volcano Observatory Popular Graphics image gallery, http://volcanoes.usgs.gov/vsc/multimedia/cvo_popular_graphics_gallery.html

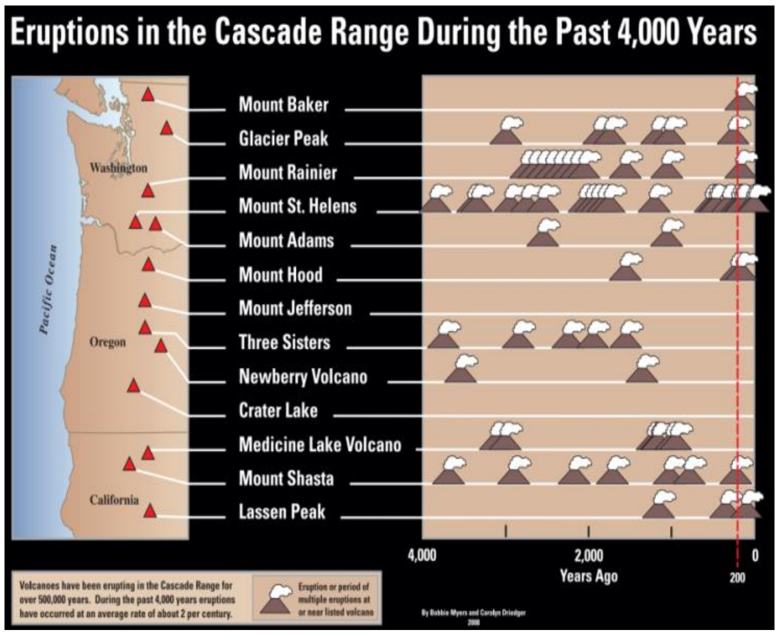
Stratovolcanoes like Mount Hood, also called composite volcanoes, are generally tall, steep, conical shaped features, built up through layering of volcanic debris, lava, and ash. Eruptions tend be explosive, for example, the violent 1980 eruption of Mount St. Helens, and they produce volcanic mudflows (lahars) that can travel far from the mountain. Future eruptions are likely to be similar and present a severe hazard to the surrounding area.

> **Orographic lifting**
> The lifting of an air current caused by its passage up and over a mountain.
> *Source: Glossary of Geology*, 4th ed.

Volcanoes also pose other hazards because of their geology and resulting geomorphology. The relatively high elevation of volcanoes usually results in the meteorological effect called *orographic lifting*, which causes high precipitation and snow on the mountains that can result in flooding. The geologic material tends to be relatively weak and, when combined with the steep slopes, can cause frequent and hazardous landslides. Cascade Mountain Range volcanoes are also located near the active CSZ and nearby potentially active crustal faults, which contribute to moderate seismic hazard in the area.

The volcanoes of the Cascade Range have a long history of eruption and intermittent quiescence. Note that in **Figure 2-81**, each volcano has a different frequency of eruption. Not all Cascade volcanoes have been active in the recent past. This is typical of a volcanic range and is one of the reasons forecasting eruptions can be difficult.

Figure 2-81. Eruptions in the Cascade Range During the Past 4,000 Years



Source: Myers and Driedger (2008)

Several smaller volcanoes, including Diamond Craters and Jordan Craters, in the High Lava Plains of southeast Oregon have experienced eruptions in the last 6,000 years. Generally nonexplosive eruptions at these sites have built complexes of lava flow fields and cinder cones. Unlike the far-reaching effects that may be generated by large, potentially explosive stratovolcanoes in the Cascade Range, hazards associated with future eruptions in sparsely populated southeast Oregon are most likely limited to localized lava flows.

Eruptive Hazards

Each eruption is a unique combination of hazards. Not all hazards will be present in all eruptions, and the degree of damage will vary. It is important to know that during an active period for a volcano many individual eruptions may occur and each eruption can vary in intensity and length. For example, while Mount St. Helens is best known for its catastrophic May 1980 eruption, periodic eruptions of steam and ash and the growth of a central lava dome have continued to pose a hazard since that time.

Proximal Hazards

Lava Flows

Lava flows are streams of molten rock that erupt relatively non-explosively from a volcano and move downslope. Hazards associated with lava flow events include ashfalls near vents; extensive damage or total destruction of objects in the lava flow path(s) by burning, crushing, or burial; and disruption of local stream drainages. Lava flows are generally not life threatening because people can usually outwalk or outrun them. The Parkdale Lava Flow, located along the north flank of Mount Hood, erupted from a small vent about 7,600 years ago (**Figure 2-82**).

Figure 2-82. Oblique Air-View of the Parkdale Lava Flow

Note: The flow erupted around 7,600 years ago from a small vent located about 6 miles south of Parkdale, Oregon.
Image source: Bill Burns, DOGAMI

Pyroclastic Flows and Surges

Pyroclastic flows are avalanches of rock and gas at temperatures of 600 to 1,500 ˚F. They typically sweep down the flanks of volcanoes at speeds of up to 150 miles per hour. Pyroclastic surges are a more dilute mixture of gas and rock. They can move even more rapidly than a pyroclastic flow and are more mobile. Both generally follow valleys, but surges especially may have enough momentum to overtop hills or ridges. Because of their high speed, pyroclastic flows and surges are difficult or impossible to escape. If it is expected that they will occur, evacuation orders should be issued as soon as possible for the hazardous areas. Objects and structures in the path of a pyroclastic flow are generally destroyed or swept away by the impact of debris or by accompanying hurricane-force winds. Wood and other combustible materials are commonly burned. People and animals may also be burned or killed by inhaling hot ash and gases. The deposit that results from pyroclastic flows is composed of a combination of ash, pumice, and rock fragments. These deposits may accumulate to hundreds of feet thick and can harden to a resistant rock called tuff. Pyroclastic flows and surges are considered a proximal hazard, but in some instances may extend tens or even hundreds of miles from the volcanic vent.

Lahars

Cascade Range volcanoes and the floodplains that drain them contain abundant evidence for past lahar events. Lahars or volcanic debris flows are water-saturated mixtures of soil and rock fragments originating from a volcano. These sediment gravity flows can travel very long distances (over 62 miles) and travel as fast as 50 miles per hour in steep channels close to a volcano; further downstream, where they reach gently sloping valley floors, speeds generally slow to 10 to 20 miles per hour. The largest of these flows are known to transport boulders exceeding 30 ft in diameter. Lahars are often associated with eruptions, but they can also be generated by rapid erosion of loose rock during heavy rains or by sudden outbursts of glacial water. Highly erodible, unconsolidated lahar deposits may be easily remobilized by normal rainfall, snowmelt, and streams for years after their deposition.

Hazards associated with lahars include direct impact and burial by the advancing flow (**Figure 2-83**), burial of valuable infrastructure or agricultural land, and secondary flooding due to temporary damming and breakouts along tributary streams. Because of their relatively high viscosity, lahars can move, or even carry away, vehicles and other large objects such as bridges. Municipalities, industries, and individuals who take their water from streams affected by lahars may have water quality and/or quantity issues. Wildlife could be adversely affected by changes in streams, including the deposition of debris in streambeds and floodplains. For example, salmonids trying to spawn could find it impossible to swim upstream. Long-term drainage pattern alteration and increased sedimentation rates downstream may persist for decades following such an event.

Figure 2-83. Trees Buried in Volcanic Sediment, Sandy River, Oregon

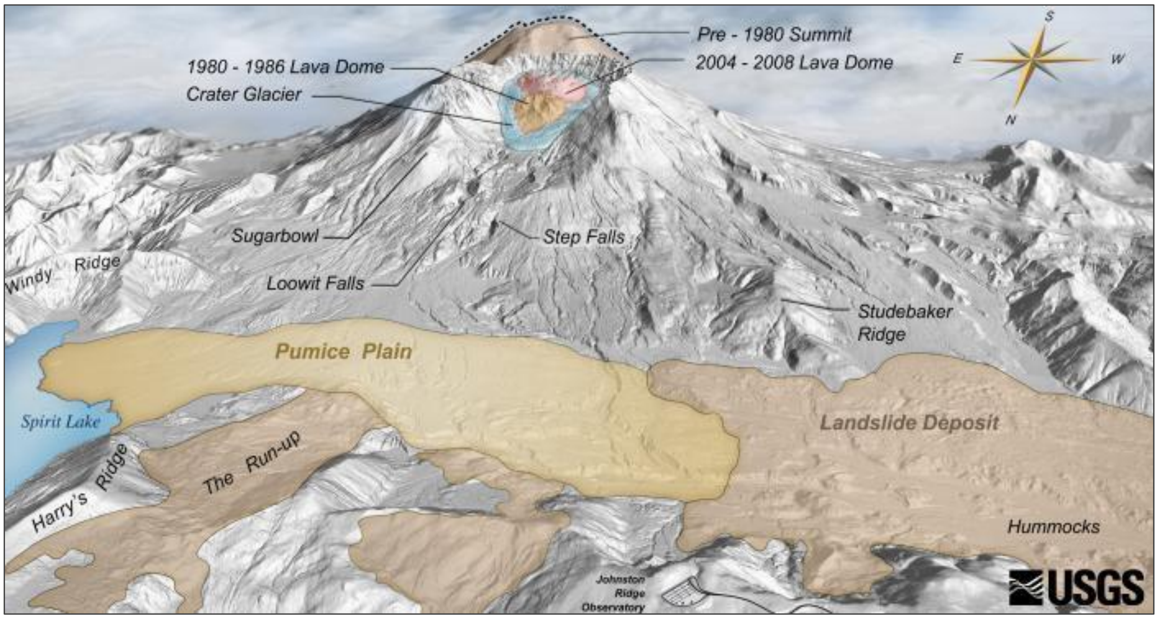
Note: Trunks of forest trees, initially growing on a terrace above the Sandy River (Oregon) at Oxbow Regional Park, were buried by rapid deposition of sediment following a dome-building eruption at Mount Hood in 1781. Erosion during a flood about a week before the photo was taken exposed this "ghost forest."

Photo source: T.C. Pierson, U.S. Geological Survey, 1/15/2009

Landslides

Because the stratovolcanoes that form the Cascade Mountains are composed of layers of weak fragmented rock and lava, they are prone to landslides. Landslides range in size from small to massive summit or flank failures like the one in May 1980 at Mount St Helens (**Figure 2-84**). They may be triggered by volcanic activity or during times of excessive rainfall or snowmelt. Speeds of movement range from slow creep to more catastrophic failure. If enough water is incorporated into the material, the failure will become a lahar.

Figure 2-84. Mount St. Helens



Source: USGS, Geology and history summary for Mount St. Helens, http://volcanoes.usgs.gov/volcanoes/st_helens/st_helens_geo_hist_101.html

Volcanic Gases

Magma contains dissolved gases that provide the driving force causing most volcanic eruptions. As magma rises towards the surface and pressure decreases, gases are released from the liquid portion of the magma (melt). These gases continue to travel upward and are eventually released into the atmosphere, both during and between eruptions. The majority of the gas emitted at volcanoes is water vapor (steam), derived from recent precipitation and groundwater. However, toxic gases including carbon dioxide, sulfur dioxide, hydrogen sulfide, hydrogen halides, and fluorine may also be released. Depending on their concentrations, toxic gases can have both short-term effects and long-term effects on human and animal lives, property, agriculture, and the natural environment. Some examples of gas hazards:

- Carbon dioxide is heavier than air and can be trapped in low areas in concentrations that are deadly to people and animals;
- Sulfur dioxide, Hydrogen sulfide, and Fluorine are respiratory poisons;
- Sulfur Dioxide reacts with atmospheric water to create acid rain, causing corrosion and harming vegetation; and
- Fluorine can be absorbed onto volcanic ash particles that later fall to the ground, poisoning livestock grazing on ash-coated grass and also contaminating domestic water supplies.

Tephra

Tephra includes both solid and molten rock fragments, ranging in size from fine ash dust to larger "volcanic bombs" up to 3 feet in diameter. The largest rock fragments and volcanic bombs usually fall back to the ground within 2 miles of the vent. Tephra deposits pose significant risks to lives, structures, and property in the proximity of volcanic vents. Fine tephra is extremely slippery, hampering driving and walking, and can damage the lungs of small infants, the elderly, and those with respiratory problems. Fist-sized and larger bombs, flying as airborne projectiles, can cause significant injury or death. Tephra is disorienting by reducing visibility. If tephra accumulates in sufficient thickness it may collapse roofs, may topple or short-circuit electric transformers and power lines and clog other infrastructure such as water and sewage treatment facilities. Tephra clouds also commonly generate lightning that can interfere with electrical and communication systems and start fires.

Distal Hazards

Lahars

Lahars are both proximal and distal volcanic hazards. Please see the discussion of lahars in the *Proximal Hazards* section (above).

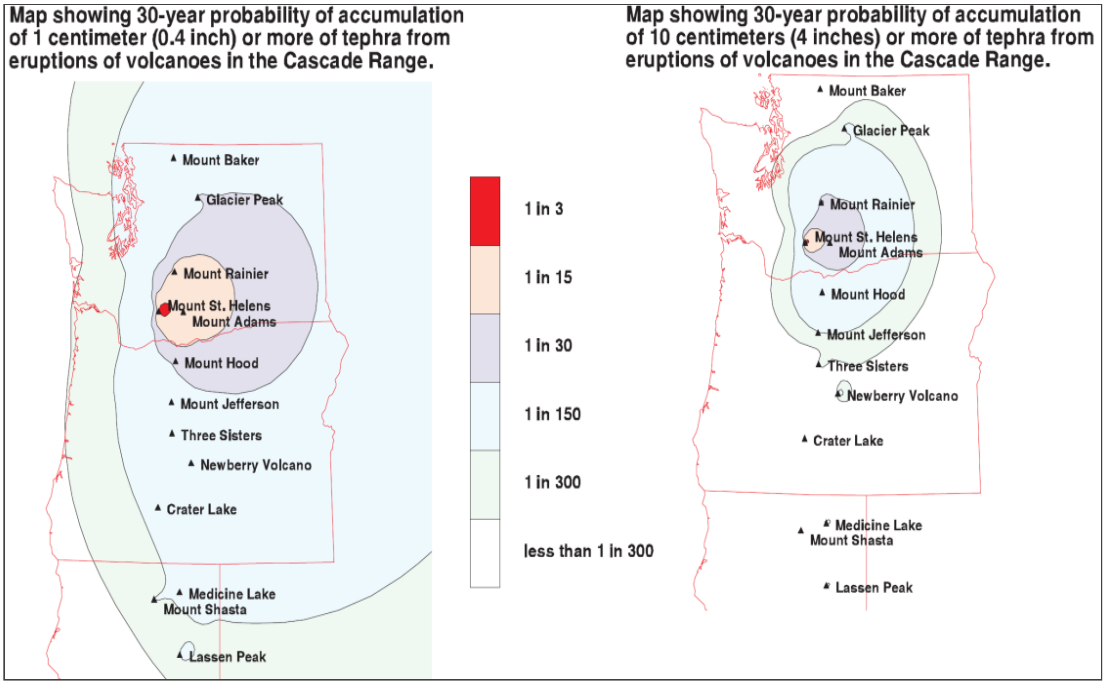
Eruption Columns And Clouds

Eruption columns and clouds occur during explosive volcanic eruptions as small fragments of volcanic glass, minerals, and rock, less than about 0.1 inch across, rise high into the air. Depending on the power of the eruption, columns can grow rapidly and reach more than 12 miles above a volcano, forming an eruption cloud. Large eruption clouds can extend hundreds of miles downwind, resulting in falling ash over enormous areas; the wind carries the smallest ash particles the farthest.

Ashfall

Dust-sized ash particles are the by-products of many volcanic eruptions. Ash, when blown into the air, can travel large distances causing significant problems for distal hazard zones. During ash-dominated eruptions, deposition is largely controlled by the prevailing wind direction. The predominant wind pattern over the Cascade Range is from the west to the east. Previous eruptions documented in the geologic record indicate most ashfall drifting to and settling in areas to the east of the Cascade volcanoes. The probable geographic extent of volcanic ashfall from select volcanic eruptions in the Pacific Northwest is shown in **Figure 2-85**.

Figure 2-85. Probable Geographic Extent of Volcanic Ashfall from Select Volcanic Eruptions in the Pacific Northwest



Source: Scott et al. (1997)

Within a few miles of the vent, the main ashfall hazards to man-made structures and humans include high temperatures, being buried, and being hit by falling fragments. Within 10–12 miles, hot ashfall may set fire to forests and flammable structures.

Structural damage can also result from the weight of ash, especially if it is wet. Four inches of wet ash may cause buildings to collapse. Accumulations of a half inch of ash can impede the movement of most vehicles, disrupt transportation, communication, and utility systems, and cause problems for human and animal respiratory systems. It is extremely dangerous for aircraft, particularly jet planes, as volcanic ash accelerates wear to critical engine components, can coat exposed electrical components, and erodes exposed structure. Ashfall may severely decrease visibility, or even cause darkness, which can further disrupt transportation and other systems. Recent work by the Volcano Hazards Group of the U.S. Geological Survey has attempted to rank the relative hazard of volcanoes in North America. According to this study, Oregon has four Very High Threat Volcanoes: Crater Lake, Mount Hood, Newberry Volcano, and South Sister (Ewert et al., 2005).

Ashfall can severely degrade air quality and trigger health problems. In areas with considerable ashfall, people with breathing problems might need additional services from doctors or emergency rooms. In severe events an air quality warning could be issued, informing people with breathing problems to remain inside

Ashfall can create serious traffic problems as well as road damage. Vehicles moving over even a thin coating of ash can cause clouds of ash to swell. This results in visibility problems for other drivers, and may force road closures. Extremely wet ash creates slippery and hazardous road conditions. Ash filling roadside ditches and culverts can prevent proper drainage and cause shoulder erosion and road damage. Blocked drainages can also trigger debris flows if the blockage causes water to pool on or above susceptible slopes. Removal of ash is extremely difficult as traditional methods, such as snow removal equipment, stir up ash and cause it to continually resettle on the roadway.

Non-Eruptive Hazards

Earthquakes

Earthquake effects are a significant threat along the Cascade Mountains and come from three main sources: the CSZ, crustal faults, and volcanic activity. The CSZ is generally over 150 miles away, but it produces earthquakes as a large as M9.0 every 240 to 500 years. Crustal earthquakes occur in the North American plate at relatively shallow depths of approximately 6 to12 miles below the surface. However, some can rupture through the surface. The distance from a potentially active fault is critical to the evaluation of the earthquake shaking hazard. Volcanic earthquakes are usually small and frequent, but they can be as large as or larger than the M4.5 earthquake on Mount Hood in 2002. During 2002, a swarm of earthquakes ranging from M3.2 to M4.5 occurred on the southeast flank of Mount Hood. The damaging effects of all three kinds of earthquakes can be enhanced by amplification of shaking in soft soils, liquefaction, or induced landslides.

Flooding and Channel Migration

The relatively high elevation of volcanoes usually results in the meteorological effect called orographic lifting, which causes high precipitation and snow on the mountains. The result can be very high levels of rainfall and/or rapid snowmelt that can result in flooding.

Floods cause damage to assets through inundation of water and by erosion and deposition of soil and/or large objects. Defining the hazard associated with inundation by flooding is done by calculating the area that is likely to be flooded during different levels of flooding. Larger floods are less frequent than smaller floods, so flood levels may be defined by their return period. The longer the return period, the deeper the flood waters, and hence the larger the area that is inundated. Some common return periods used in flood hazard mapping include 10-year, 25-year, 100-year, and 500-year floods. Most flooding on Cascade Range volcanoes occurs when heavy, warm rain during large winter or spring storms falls on accumulations of low-elevation snow. Channel migration hazards can occur slowly, for example, by continuous erosion along a cutbank meander and deposition onto a point bar during high flows, or very rapidly during storm events through avulsion or rapid abandonment of the current river channel for a new one. Such rapid migration can not only destroy structures but even remove the land beneath structures.

For more information on flooding and channel migration zones see the **Flood** section.

Landslides

The general term *landslide* refers to a range of geologic events including rock falls, debris flows, earth slides, and other mass movements. Most landslides that occur on volcanoes are large deep-seated landslide complexes or debris flows. Deep-seated landslides have failure surfaces usually tens of feet below the surface and can cover large areas from acres to square miles. These types of landslides tend to move relatively slowly, but they can lurch forward if shaken by an earthquake or if disturbed by removal of material from the toe, by addition of material to the head, or by addition of water into the slide mass. Debris flows tend to initiate in the upper portion of a drainage, picking up water, sediment, and speed as they come down the drainage. As they reach the mouth of the confined or steep portion of the drainage, they tend to spread out and deposit the majority of the material, generally creating a fan. Debris flows are also commonly initiated by other types of landslides that occur on slopes near a channel. They can also initiate within the channel in areas of accelerated erosion during heavy rainfall or snowmelt.

Characterization of Individual Volcanoes

The history of volcanic activity in the Cascade Range is contained in its geologic record. The ages, eruptive history, and hazards associated with each volcano vary considerably. Cascade volcanoes may be characterized by intermittent periods of activity, followed by longer periods of relative quiescence. The incompleteness of eruptive records, even at relatively well-studied volcanoes, makes prediction of probability and recurrence intervals of future eruptions difficult to determine. **Table 2-63** lists Cascade Volcanoes in southwest Washington and Oregon that can affect Oregon communities. The discussion that follows further details those volcanic centers from **Table 2-63** for which the U.S. Geological Survey has developed hazard assessments and ranked as having a high to very high threat potential. Threat potential is described as very high, high, moderate, low, or very low based upon eruption history, distance to population centers, and potential impacts to aviation (Ewert et al., 2005). From north to south these high-threat volcanoes are: Mount St. Helens (Wolfe and Pierson, 1995), Mount Adams (Scott et al., 1995), Mount Hood (Scott et al., 1997; Burns et al., 2011b), Mount Jefferson (Walder et al., 1999), the Three Sisters Region (Scott et al., 2001), Newberry Volcano (Sherrod et al., 1997), and Crater Lake (Bacon et al., 1997). Digital hazard data for some of these volcanoes have been produced by Schilling (1996); Schilling et al. (1997), Schilling et al. (2008a,b, c). For a detailed inventory of each volcano's history and hazards, please refer to the appropriate report referenced above or **Table 2-63**. Further information can also be obtained from the U.S. Geological Survey Cascade Volcano Observatory at http://volcanoes.usgs.gov/observatories/cvo/.

Table 2-63. Prominent Volcanoes in the Cascade Range of Oregon and Southwest Washington

Volcano Name	Elevation	Volcano Type	Most Recent Eruptions	USGS Threat Potential	Nearby Towns	Remarks/Hazard Study
Mount St. Helens (Washington)	8,363 ft	strato-volcano	1980–1986; 2004–2008	high to very high	Portland, Castle Rock (Washington), Olympia (Washington), Vancouver (Washington), Yakima (Washington)	major explosive eruption and debris avalanche in 1980; widespread ashfall; Wolfe and Pierson (1995)
Mount Adams (Washington)	12,277 ft	strato-volcano	about 520,000 to 1,000 YBP	high to very high	Portland, Hood River, Vancouver (Washington), Yakima (Washington)	numerous eruptions in last 15,000 year; major debris avalanches effecting White Salmon River at 6,000 and 300 YBP; Scott et al. (1995)
Mount Hood	11,240 ft	strato-volcano	1760–1865	high to very high	Portland, Sandy, Welches, Brightwood, Parkdale, Hood River	pyroclastic flows in the Upper White River drainage; lahars in Old Maid Flat; lava dome at Crater Rock; steam explosions; Scott et al. (1997); Schilling et al. (2008a)
Mount Jefferson	10,495 ft	strato-volcano	280,000 to 15,000 YBP	low to very low	Idanha, Detroit, Warm Springs, Madras, Lake Billy Chinook	potentially active and capable of large explosive eruptions; recent history of lava domes, small shields, and lava aprons; Walder et al. (1999); Schilling et al. (2007).
Mount Washington	7,796 ft	mafic volcano		low to very low		no hazard study
North Sister	10,085 ft	mafic volcano	300,000 to 120,000 YBP	high to very high	Sisters, Bend, Redmond, Sunriver, La Pine, Blue River, McKenzie Bridge, Vida, Springfield	deep glacial erosion; ashfall, pyroclastic flows, lava flows and domes, and lahars; Scott et al. (2001); Schilling et al. (2008c)
Middle Sister	10,047 ft	strato-volcano	about 40,000 to 14,000 YBP	high to very high	Sisters, Bend, Redmond, Sunriver, La Pine, Blue River, McKenzie Bridge, Vida, Springfield	potentially active, capable of large explosive eruptions, ashfall, pyroclastic flows, lava flows and domes, and lahars; Scott et al. (2001); Schilling et al. (2008c)

Volcano Name	Elevation	Volcano Type	Most Recent Eruptions	USGS Threat Potential	Nearby Towns	Remarks/Hazard Study
South Sister	10,358 ft	strato-volcano	about 50,000 to 2,000 YBP	high to very high	Sisters, Bend, Redmond, Sunriver, La Pine, Blue River, McKenzie Bridge, Vida, Springfield	potentially active, capable of large explosive eruptions, ashfall, pyroclastic flows, lava flows and domes, and lahar; most silicic of the cones in the Three Sisters complex; phase of uplift started in 1997 within a broad area about 6 km west of South Sister; Scott et al. (2001); Schilling et al. (2008c)
Broken Top	9,152 ft	strato-volcano	300,000–100,000 YBP	low to very low	Bend, Sunriver, La Pine	deep glacial erosion; lava flows, pyroclastic flows, ashfall; no hazard study
Mount Bachelor	9,068 ft	mafic volcano	about 18,000 to 7,700 YBP	moderate	Bend, Sunriver, La Pine	lava flows and near vent cinder and ashfall; no hazard study
Newberry Volcano	7,986 ft	shield volcano/ caldera	about 400,000 to 1,300 YBP	high to very high	Bend, Sunriver, La Pine	potentially active and capable of large explosive eruptions; lava flows and near vent cinder and ashfalls; present-day hot springs; Sherrod et al. (1997); Schilling et al. (2008b)
Mount Thielsen	9,187 ft	shield volcano	> 250,000	low to very low	Chemult	Deep glacial erosion; Lava flows, pyroclastic eruptions; no hazard study.
Crater Lake Caldera (Mount Mazama)	8,159 ft	caldera	about 420,000 to 7,700 YBP	high to very high	Grants Pass, Roseburg, Chemult, La Pine, Fort Klamath, Chiloquin, Klamath Falls	lava flows, pyroclastic flows, ashfall; source of the widespread Mazama ash; Bacon et al. (1997)
Mount McLaughlin	9,496 ft	strato-volcano	>80,000 YBP	low to very low	Medford, Grants Pass, Klamath Falls	lava flows, pyroclastic flows; no hazard study

Note: YBP is years before present.

Sources: U.S. Geological Survey, Cascades Volcano Observatory: http://volcanoes.usgs.gov/observatories/cvo/;
Wolfe and Pierson (1995); Scott et al. (1995, 1997, 2001); Sherrod et al. (1997); Bacon et al. (1997); Walder et al. (1999)

Mount St. Helens (Washington)

The May 18, 1980, eruption of Mount St. Helens is the best-known example of volcanism to most Oregonians. That eruption included a debris avalanche, as part of the volcanic edifice collapsed (**Figure 2-84**). This caused a lateral blast of rock, ash, and gas that devastated areas to the north of the volcano. Lahars rushed down the Toutle and Cowlitz River valleys, reaching the Columbia River and halting shipping for some time. All other river valleys on the volcano experienced smaller lahars. Pyroclastic flows devastated an area up to five miles north of the volcano. Ashfall deposits affected people as far away as Montana, and ash circled the earth in the upper atmosphere for over a year.

Except for the debris avalanche and lateral blast, the events of this eruptive period are typical of a Mount St. Helens eruption and can be expected to occur again (**Table 2-63**). The primary hazards that will affect Oregonians are ashfall and lahars that affect the Columbia River. Since the major eruptive activity in the early 1980s, Mount St. Helens has experienced two episodes of dome building activity. The latest activity lasted from 2004 until 2008. Another eruption from Mount St. Helens is very likely in the near future.

Mount Adams (Washington)

Mount Adams, located 35 miles north of Hood River, Oregon, is the largest active volcano in Washington State and among the largest in the Cascade Range (**Table 2-63**). The volcano was active from about 520,000 to about 1,000 years ago. Eruptions from Mount Adams within the last 500,000 years have mainly consisted of effusive lava flows; highly explosive events are rare in the geologic record of Mount Adams. Eruptions have also occurred from 10 vents in the vicinity of Mount Adams since the last period of glaciation about 15,000 years ago. Approximately 6,000 and 300 years ago, debris avalanches from the southwest face of Mount Adams generated clay-rich lahars that traveled down the White Salmon River. The summit of Mount Adams contains a large section of unstable altered rock that can spawn future debris avalanches and lahars.

Potential hazards from Mount Adams include lava flows near the central vent area and lahars that could reach and disrupt the Columbia River channel. Such lahars may have little or no advanced warning.

Mount Hood

The last major eruption of Mount Hood occurred in approximately 1781 (232 years ago) (**Table 2-63** and **Table 2-64**). The Sandy River that drains the volcano's northwest side was originally named the Quicksand River by Lewis and Clark, who traversed the area only a couple of years after an eruption. Lahars had filled the river channel with debris, much of which has now been scoured away. There were two other minor periods of eruptions during the last 500 years, the last in the mid-1800s. Typically, these involved lava flows near the summit, pyroclastic flows, and lahars but little ashfall. From its recent eruptive history, the volcano is most likely to erupt from the south side, but planning should be done assuming eruptions could be centered anywhere on the mountain. A large eruption could generate pyroclastic flows and lahars that could inundate the entire length of the Sandy and White River valleys. An eruption from the north flank could affect the Hood River Valley.

Due to its proximity to the Portland Metro area, major east-west highways, the Bull Run Reservoir (which supplies water to a majority of Portland area residents), and ski and summer recreation areas, Mount Hood poses the greatest potential volcanic hazard to Oregonians. In addition, a large volume of debris and sediment in lahars could affect shipping lanes in the Columbia River and operation of Bonneville and The Dalles dams.

In recent years, numerous debris flows caused by winter storms have flowed down river drainages. OR-35 is periodically closed for repair work after these events damaged the bridge over the White River. If a volcanic event occurred, the same drainages would be affected.

Table 2-64. Notable Geologic Events near Mount Hood

Date or Age	Event	Deposits
A.D. 1859, 1865, 1907?	minor explosive eruptions of Mount Hood	scattered pumice
late 19th century	late neoglacial advance	prominent, sharp-crested moraines
late 18th century	Old Maid eruptive period	lava dome, pyroclastic-flow and lahar deposits, tephra
about 500 years ago	debris flows in Zigzag River	debris-flow deposits
1,000 years ago	debris flows in upper Sandy River	debris-flow deposits
1,500 years ago	Timberline eruptive period	lava dome, pyroclastic-flow and lahar deposits, tephra
7,700 years ago	eruptions from vent near Parkdale; Mount Mazama ashfall	Basaltic andesite of Parkdale lava flow; about 5 cm of Mazama ash
11,000 to 20,000 years ago	waning phases of Evans Creek glaciation	moraines
13,000 to 20,000 years ago	Polallie eruptive period	lava domes, pyroclastic-flow and lahar deposits, tephra
20,000 to 25,000 years ago	maximum of Evans Creek glaciation	belts of moraines in most valleys
20,000 to 30,000 years ago	Mount Hood dome eruptions	lava domes, pyroclastic-flow and lahar deposits
30,000(?) to 50,000(?) years ago	Mount Hood lava-flow eruptions	andesite lava flows of Cathedral Ridge and Tamanawas Falls

Source: Bill Burns, DOGAMI, modified from Scott et al. (1997b)

Mount Jefferson

Mount Jefferson is located in a relatively unpopulated part of the Cascade Range. The last eruptive episode at Mount Jefferson was about 15,000 years ago. Research at stratovolcanoes around the world indicates that Mount Jefferson should be regarded as dormant, not extinct.

The steep slopes of the volcano provide the setting for possible debris flows and lahars, even without an eruption. These would be confined to valleys, generally within 10 miles of the volcano.

A major eruption, however unlikely in the short term, could generate pyroclastic flows and lahars that would travel up to a few dozen miles down river valleys. Two reservoirs could be affected by pyroclastic flows from a major eruption: Detroit Lake and Lake Billy Chinook. An explosive eruption could spew ash for hundreds of miles in the downwind direction.

Many smaller volcanoes are located between Mount Jefferson and Mount Hood to the north and Three Sisters to the south. Eruptions from any of these would be primarily erupt *cinders* and ash to form cinder cones.

Three Sisters Region

North Sister has probably been inactive for at least 100,000 years (**Table 2-63**). Middle Sister last erupted between 25,000 and 15,000 years ago. South Sister had a very small ongoing uplift, which began in 1996 and became undetectable by 2003. The uplift was about one inch a year and likely indicated movement of a small amount of magma. At this writing, there is no indication that the uplift will ever develop into a volcanic eruption. However, that possibility cannot be ruled out. Hence, the Cascade Volcano Observatory has increased their monitoring of the area over the past several years.

Future eruptions at South Sister (and possibly Middle Sister) are likely to include lava flows, pyroclastic flows, and lahars. The possibility exists for lahars to travel many miles down valley floors, if an eruption melts a large amount of snow and ice. Ashfall would likely be contained within 20 miles of the vent.

Newberry Volcano

Newberry Volcano, unlike the stratovolcanoes of the Cascade Range, is a shield volcano with broad, relatively gently sloping flanks composed of stacked basaltic lavas flows (**Table 2-63**). The volcano is about 400,000 years old and has had thousands of eruptions both from the central vent area and along its flanks. The present 4 by 5 mi wide caldera at Newberry Volcano's summit formed about 75,000 years ago by a major explosive eruption and collapse event. This was the most recent of at least three caldera-forming eruptions that lofted pumice and ash high into the air and spread pyroclastic flows across the volcano's surface. The most recent eruption was 1,300 years ago when the "Big Obsidian Flow," a glassy rhyolitic lava flow, erupted within the caldera. Future eruptions are likely to include lava flows, pyroclastic flows, lahars, and ashfall. Newberry Volcano has attracted interest for its geothermal potential. The heat under the volcano, with temperatures in some areas in excess of 509 ˚F, is evidence that it is only dormant.

Crater Lake Caldera

About 7,700 years ago, Mount Mazama erupted with great violence, leaving the caldera that Crater Lake now occupies (**Table 2-63**). Layers of ash produced from that eruption have been found in eight western states and three Canadian provinces. The countryside surrounding Crater Lake was covered by pyroclastic flows. Wizard Island is the result of much smaller eruptions since that cataclysm. The most recent eruption was about 5,000 years ago and occurred within the caldera. No eruptions have occurred outside the caldera since 10,000 years ago.

This potentially active volcanic center is contained within Crater Lake National Park. The western half of the caldera is considered the most likely site of future activity. Effects from volcanic activity (e.g., ashfall, lava flows) are likely to remain within the caldera. If an eruption occurs outside the caldera, pyroclastic flows and lahars could affect valleys up to a few dozen miles from the erupting vent. The probability of another caldera-forming eruption is very low, as is the probability of eruptions occurring outside the caldera.

Other Volcanic Areas of Oregon

On the scale of geologic time, volcanic eruptions may occur in other parts of Oregon. However, on a human time scale, the probability of an eruption outside the Cascades is so low as to be negligible.

Although the high, snow-topped mountains of the Cascades are Oregon's most visible volcanoes, other potential eruptive centers exist. These include smaller peaks, such as the Belknap shield volcano in central Oregon, which had a lava flow about 1,400 years ago. Several smaller volcanoes, including Diamond Craters and Jordan Craters, in the High Lava Plains of southeast Oregon have experienced recent eruptions in the last 7,000 years. Generally non-explosive eruptions at these sites have built complexes of lava flow fields and cinder cones. Hazards associated with future eruptions in sparsely populated southeast Oregon would most likely include lava flows covering many square miles; ash and volcanic gases derived from these eruptions may be regionally significant.

Historic Volcanic Events

Table 2-65. Historic Volcanic Events in Oregon over the Last 20,000 Years

Date	Location	Description
about 18,000 to 7,700 YBP	Mount Bachelor, central Cascades	cinder cones, lava flows
about 20,000 to 13,000 YBP	Polallie Eruptive episode, Mount Hood	lava dome, pyroclastic flows, lahars, tephra
about 13,000 YBP	Lava Mountain, south-central Oregon	Lava Mountain field, lava flows
about 13,000 YBP	Devils Garden, south-central Oregon	Devils Garden field, lava flows
about 13,000 YBP	Four Craters, south-central Oregon	Four Craters field, lava flows
about 7,780 to 15,000 YBP	Cinnamon Butte, southern Cascades	basaltic scoria cone and lava flows
about 7,700 YBP	Crater Lake Caldera	formation of Crater Lake caldera, pyroclastic flows, widespread ashfall
about 7,700 YBP	Parkdale, north-central Oregon	eruption of Parkdale lava flow
<7,000 YBP	Diamond Craters, eastern Oregon	lava flows and tephra in Diamond Craters field
< 7,700 YBP; 5,300 to 5,600 YBP	Davis Lake, southern Cascades	lava flows and scoria cones in Davis Lake field
about 10,000 to <7,700 YBP	Cones south of Mount Jefferson; Forked Butte and South Cinder Peak	lava flows
about 4,000 to 3,000 YBP	Sand Mountain, central Cascades	lava flows and cinder cones in Sand Mountain field
< 3,200 YBP	Jordan Craters, eastern Oregon	lava flows and tephra in Jordan Craters field
about 3,000 to 1,500 YBP	Belknap Volcano, central Cascades	lava flows, tephra
about 2,000 YBP	South Sister Volcano	rhyolite lava flow
about 1,500 YBP	Timberline eruptive period, Mount Hood	lava dome, pyroclastic flows, lahars, tephra
about 1,300 YBP	Newberry Volcano, central Oregon	eruption of Big Obsidian flow
about 1,300 YBP	Blue Lake Crater, central Cascades	Spatter cones and tephra
1760–1810	Crater Rock/Old Maid Flat on Mount Hood	pyroclastic flows in upper White River; lahars in Old Maid Flat; dome building at Crater Rock
1859/1865	Crater Rock on Mount Hood	steam explosions/tephra falls
1907 (?)	Crater Rock on Mount Hood	steam explosions
1980	Mount St. Helens (Washington)	debris avalanche, ashfall, flooding on Columbia River
1981–1986	Mount St. Helens (Washington)	lava dome growth, steam, lahars
1989–2001	Mount St. Helens (Washington)	hydrothermal explosions
2004–2008	Mount St. Helens (Washington)	lava dome growth, steam, ash

Note: YBP is years before present.

Sources: U.S. Geological Survey, Cascades Volcano Observatory: http://volcanoes.usgs.gov/observatories/cvo/; Wolfe and Pierson (1995); Sherrod et al. (1997); Scott et al. (1997, 2001); Bacon et al. (1997); Walder et al. (1999)

2.2.8.2 Probability

Geologists can make general forecasts of long-term volcanic activity from careful characterization of past activity, but they cannot supply a timeline. Several U.S. Geological Survey open-file reports provide the odds of certain events taking place at particular volcanoes. However, the U.S. Geological Survey stresses that government officials and the public must realize the limitations in forecasting eruptions and be prepared for such uncertainty.

Short-range forecasts, on the order of months or weeks, are often possible. There are usually several signs of impending volcanic activity that may lead up to eruptions. The upward movement of magma into a volcano prior to an eruption generally causes a significant increase in small, localized earthquakes and an increase in emission of carbon dioxide and compounds of sulfur and chlorine that can be measured in volcanic springs and the atmosphere above the volcano. Changes in the depth or location of magma beneath a volcano often cause changes in elevation. These changes can be detected through ground instrumentation or remote sensing. This, in fact, was how the South Sister Bulge uplift was discovered).

The Cascades Volcanic Observatory (CVO) employs scientists from a range of disciplines to continually assess and monitor volcanic activity in the Cascade Ranges. If anomalous patterns are detected (for example, an increase in earthquakes), CVO staff coordinate the resources necessary to study the volcano.

Probability of Volcanic Hazard Events

One method of evaluating probability of volcanic hazard events in Oregon is to consider the proximity of a county to the Cascade Range volcanoes along with the probability of tephra accumulation over a 30-year period and apply professional expertise and judgment. **Table 2-66** presents available information.

Table 2-66. Proximity to Cascade Range Volcanoes and 30-Year Probability of Tephra Accumulation

Region	County	Proximity to Cascade Range Volcanoes	30-Year Probability of Tephra Accumulation	
		Cross, West, East	At least 1 cm	At least 10 cm
Region 1	Clatsop	West	1:300	NA
	Coos	West	1:300	NA
	Curry	West	1:300	NA
	Douglas Coastal	West	1:300	NA
	Lane Coastal	West	1:300	NA
	Lincoln	West	1:300	NA
	Tillamook	West	1:300	NA
Region 2	Clackamas	Cross	1:30	1:150
	Columbia	West	NA	NA
	Multnomah	Cross	1:30	1:150
	Washington	West	NA	NA
Region 3	Benton	West	NA	NA
	Lane	Cross	NA	NA
	Linn	Cross	NA	1:150
	Marion	Cross	NA	1:150
	Polk	West	NA	NA
	Yamhill	West	NA	NA
Region 4	Douglas	Cross	NA	NA
	Jackson	Cross	NA	NA
	Josephine	West	NA	NA
Region 5	Gilliam	East	1:30	1:150
	Hood River	Cross	1:30	1:150
	Morrow	East	1:30	1:150
	Sherman	East	1:30	1:150
	Umatilla	East	1:30	1:300
	Wasco	Cross	1:30	1:150
Region 6	Crook	East	NA	1:300
	Deschutes	Cross	NA	1:300
	Jefferson	Cross	NA	1:150
	Klamath	Cross	NA	NA
	Lake	East	1:150	NA
	Wheeler	East	1:30	1:150
Region 7	Baker	East	1:150	NA
	Grant	East	1:30	1:300
	Union	East	1:150	NA
	Wallowa	East	1:150	NA
Region 8	Harney	East	1:150	NA
	Malheur	East	1:150	NA

Note: NA = Not Available

Source: Scott, W.E., Pierson, T.C., Schilling, S.P., Costa, J.E., Gardner, C.A., Vallance, J.W., and Major, J.J., 1997, Volcano Hazards in the Mount Hood region, Oregon: U.S. Geological Survey Open-File Report 97-89, 14 p. Web: http://vulcan.wr.usgs.gov/Volcanoes/Hood/Hazards/ OFR97-89/OFR97-89.pdf

DOGAMI executed the 2020 Risk Assessment methodology using the information in Table 2-66. Each county was assigned a number from 1 to 5 indicating very low to very high probability, respectively (Table 2-67). Counties that cross the Cascade Range were assigned moderate probability (3) for both proximal and distal events. Coastal counties far west of the Cascade Range were assigned very low probability (1) for both proximal and distal events. Other counties were assigned values based on their location relative to the Cascade Range, the probability of tephra accumulation over a 30-year period, and DOGAMI's professional expertise and judgment. Proximal and distal probabilities were weighted equally in deriving the overall probability.

Table 2-67. Probability of Volcanic Hazards

		Probability of Volcanic Hazards		
Region	**County**	**Proximal**	**Distal**	**Overall**
Region 1	Clatsop	1	1	1
	Coos	1	1	1
	Curry	1	1	1
	Douglas Coastal	1	1	1
	Lane Coastal	1	1	1
	Lincoln	1	1	1
	Tillamook	1	1	1
Region 2	Clackamas	3	3	3
	Columbia	2	1	1.5
	Multnomah	3	3	3
	Washington	2	1	1.5
Region 3	Benton	2	1	1.5
	Lane	3	3	3
	Linn	3	3	3
	Marion	3	3	3
	Polk	2	1	1.5
	Yamhill	2	1	1.5
Region 4	Douglas	3	3	3
	Jackson	3	3	3
	Josephine	2	1	1.5
Region 5	Gilliam	1	3	2
	Hood River	3	3	3
	Morrow	1	3	2
	Sherman	1	3	2
	Umatilla	1	3	2
	Wasco	3	3	3
Region 6	Crook	1	2	1.5
	Deschutes	3	3	3
	Jefferson	3	3	3
	Klamath	3	3	3
	Lake	1	2	1.5
	Wheeler	1	2	1.5
Region 7	Baker	1	2	1.5
	Grant	1	3	2
	Union	1	2	1.5
	Wallowa	1	2	1.5
Region 8	Harney	1	2	1.5
	Malheur	1	2	1.5

2.2.8.3 Vulnerability

Oregon's vulnerability to volcanic events varies statewide. The Cascade Mountains, which separate Western Oregon from Central Oregon, pose the greatest threat for volcanic activity. Oregon Natural Hazard Mitigation Planning Regions that include the Cascade Mountains are most vulnerable to the effects of a volcanic event. Within the State of Oregon, there are several volcanoes that may pose a threat of future eruption. These include Mount Hood, which most recently erupted about 200 years ago, Newberry Volcano with recent eruptions about 1300 years ago, and the Three Sisters and Mount Jefferson with eruptions about 15,000 years ago. Eruptions from volcanoes in Washington State, like the Mount St. Helens eruption in 1980, can also significantly impact Oregon.

Most Vulnerable Communities

The Oregon Department of Geology and Mineral Industries (DOGAMI) is the agency with primary oversight of the volcanic hazards. According to the 2020 Risk Scores and agency staff review of the available hazard data, DOGAMI lists Marion, Hood River, Jefferson, Lane, Linn, Wasco, and Klamath Counties as having the greatest vulnerability to volcanic hazards in the state. Deschutes County is most vulnerable in the Central Oregon Region because the region's most populous city, Bend, is located there and the greatest concentration of volcanoes, including Newberry Caldera, is located near the Deschutes County's population centers. Klamath and Jefferson Counties are also vulnerable within this region. Other regions are vulnerable to damage from volcanic eruptions as well. If Mount Hood were to erupt, the Northern Willamette Valley, Portland Metro Region, and the Mid-Columbia Region would all be impacted. Because of Mount Hood's proximity to Portland, the Columbia River, the I-84 freeway, and major dams on the Columbia River, the potential for a significant disaster exists.

In performing the 2020 vulnerability analysis, potential dollar losses from damage to state-owned and -leased buildings and state and local critical facilities exposed to volcanic hazards were combined with the CDC's social vulnerability index.

State-Owned/Leased Buildings and Critical Facilities and Local Critical Facilities

DOGAMI analyzed the potential dollar loss from volcanic hazards to state-owned and –leased buildings and critical facilities as well as to local critical facilities statewide. Close to $306M in value of state buildings, state and local critical facilities is exposed to volcanic hazards statewide, all of it in Regions 2, 3, 5, and 6. The greatest amount of exposure is in Region 3, in Lane County. In addition, of the 58,872 historic buildings throughout the state, 693 are exposed to volcanic hazards: 140 in a high hazard area, 443 in a moderate hazard area, and 110 in a low hazard area. See Appendix 2-X for details.

Social Vulnerability

The Centers for Disease Control and Prevention (CDC) has calculated a social vulnerability index to assess community resilience to externalities such as natural hazard events. It employs fifteen social vulnerability factors and uses data from the US Census Bureau's American Community Survey. The index is reported in quintiles (1-5). Social vulnerability scores do not vary by hazard. The counties with the greatest social vulnerability statewide are Marion, Morrow, Umatilla, Wasco, Jefferson, Klamath, and Malheur.

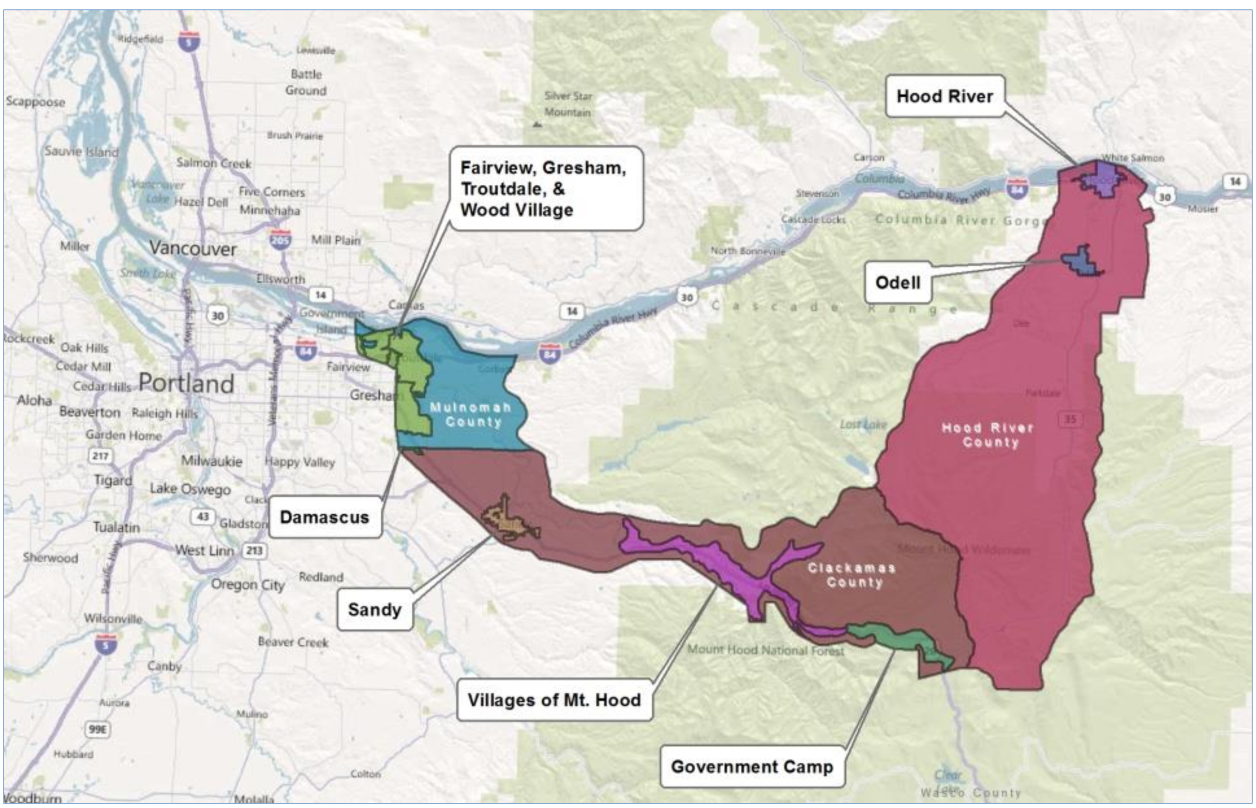
For the 2020 vulnerability assessment, DLCD combined this index with the vulnerability scores for state buildings, state critical facilities, and local critical facilities to calculate an overall vulnerability score for each county. According to this limited assessment, Marion, Hood River, and Jefferson Counties are the most vulnerable to impacts from volcanic hazards.

Marion, Hood River, and Jefferson Counties scored very high for vulnerability to volcanic hazards. In each case, the very high score is attributable to a combination of a significant amount of potential damage to state and local buildings and critical facilities with significant social vulnerability. Lane, Linn, Morrow, Umatilla, Wasco, Klamath, and Harney Counties scored high (H). For the Eastern Oregon counties, social vulnerability was the driving factor. In Lane County, potential damage to state buildings was also a significant factor, as was potential damage to local critical facilities in Linn County.

2.2.8.4 Risk

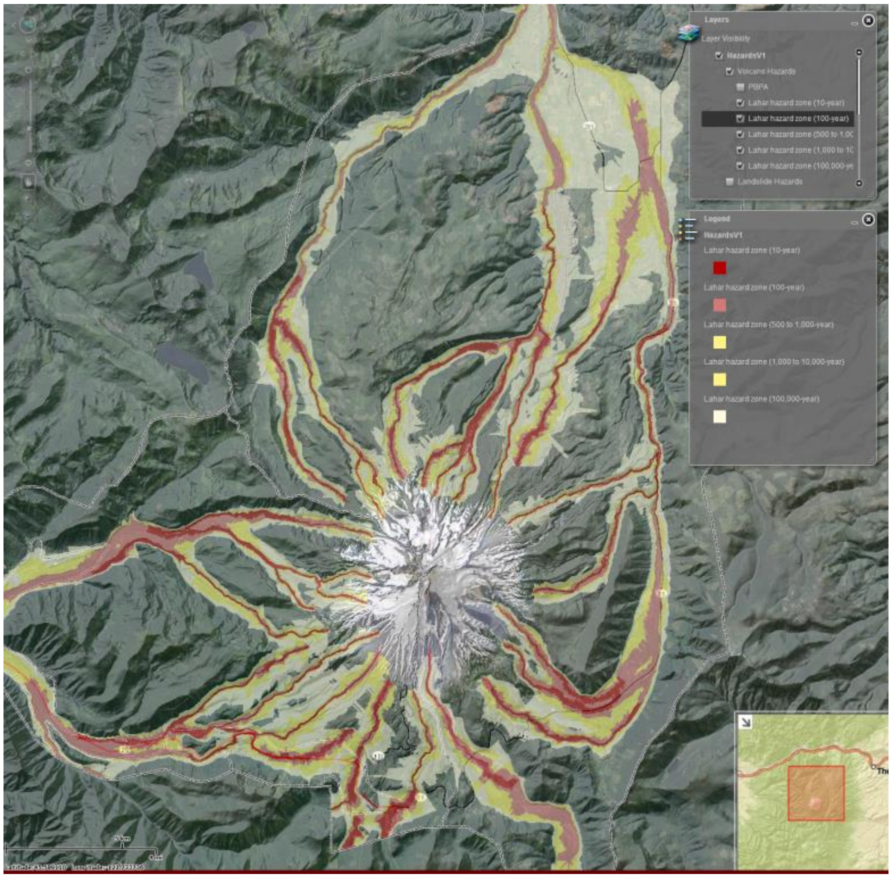
With respect to natural hazards, risk can be expressed as the probability of a hazard occurring combined with the potential for property damage and loss of life. Little has been done to evaluate risk of volcanic hazards. One of the first studies to evaluate risk for the Mount Hood region was by Burns et al. (2011b) (**Figure 2-86**, **Figure 2-87**, and **Table 2-68**). The main purpose of this study was to help communities on or near Mount Hood become more resilient to geologic hazards by providing accurate, detailed, and up-to-date information about the hazards and the community assets at risk. A second purpose was to explore hazard and risk analysis methodologies that would be applicable to other volcanic areas. The study examined volcano, landslide, flood, channel migration, and earthquake hazards on Mount Hood, along US-26 and the Sandy River Corridor, and along OR-35 and the Hood River Corridor (**Figure 2-86**). Two types of risk analysis were performed: (a) hazard and asset exposure, and (b) Hazus-MH (FEMA, 2005). **Figure 2-87** and **Table 2-68** are a summary of volcano and community asset exposure for the study area.

Figure 2-86. Mount Hood Risk Study Project Area



Source: Burns et al. (2011b)

Figure 2-87. Interactive Web Map for Mount Hood Risk Study



Source: DOGAMI. Map generated at Hazards and Assets Viewer for Mount Hood website: http://www.oregongeology.org/MtHood/

This study also found approximately 5,000 people are located in the 500-year volcano hazard zones, which is a large amount of people to evacuate in an event. Although the report estimated 6% to 22% of the total study area community assets will be damaged or lost, this percentage is significantly more within some individual communities, especially The Villages at Mount Hood. Both risk methods resulted in ranges of percent damage and losses that appear reasonable. For example, we found 11% to 34% loss ratios for the volcano exposure method and 5% to 35% loss ratios for the Hazus-MH volcano analyses are all in the same approximate range of 10% to 35%. The report estimates the loss ratio for the 500-year volcano hazard to be approximately 18% for the study area from these ranges of percent loss from the various portions of the two risk analyses.

Table 2-68. Summary of Community Asset Exposure to Volcano Hazards for Mount Hood

Hazard	Population	Buildings		Generalized Land Use / Zoning Parcels		Critical Facilities	Primary Infrastructure—Roads (miles)
		Count	$ Value	Count	$ Value		
Proximal	2,129	1,604	$242 million	2,995	$208 million	8	287
Lahar, 10-year	163	120	$32 million	520	$19 million	0	22
Lahar, 100-year	473	531	$92 million	1,633	$71 million	0	91
Lahar, 500- to 10,000 year	3,843	3,731	$663 million	7,120	$402 million	7	271
Lahar, 100,000-year	14,635	9,897	$1,510 million	13,082	$1,364 million	21	525

Source: Burns et al. (2011b)

The 2020 risk assessment methodology combined the probability of volcanic hazards occurring with the potential cost of damage to exposed state buildings and state and local critical facilities as well as with an assessment of the social vulnerability of the local population.

In the case of volcanic hazards, the counties assessed as being at greatest risk – Marion, Hood River, and Jefferson (VH) followed by Lane, Linn, Wasco, and Klamath (H) – tracked closely with those assessed as most vulnerable.

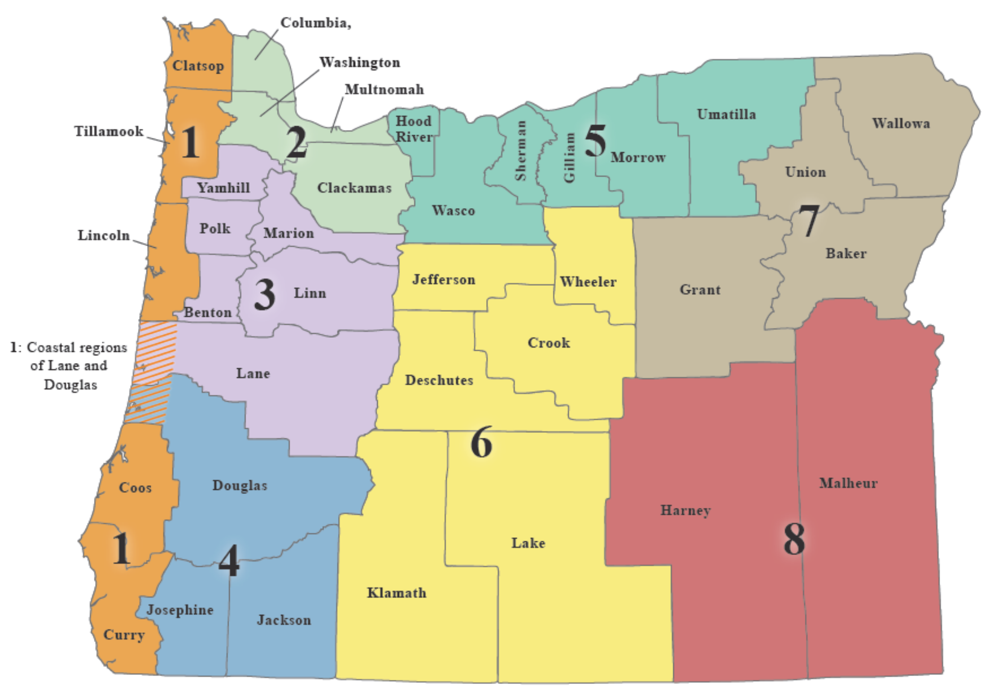
2.2.9 Wildfires

Wildfires are a common and widespread natural hazard in Oregon; the state has a long and extensive history of wildfire. A significant portion of Oregon's forestland is dominated by ecosystems dependent upon fire for their health and survival. In addition to being a common, chronic occurrence, wildfires frequently threaten communities. These communities are often referred to as the "wildland-urban interface" (WUI), the area where structures and other human development meet or intermingle with natural vegetative fuels.

Oregon has in excess of 41 million acres (more than 64,000 square miles) of forest and rangeland that is susceptible to damage from wildfire. In addition, significant agricultural areas of the Willamette Valley, north central, and northeastern Oregon grow crops such as wheat that are also susceptible to damage by wildfire.

The majority of wildfires take place between June and October, though fire season has been increasing in length since 1970 and is now, on average, 78 days longer than it used to be. This lengthening of the fire season is largely due to declining mountain snowpack and earlier spring snowmelt—a result of warming temperatures (Dalton et al., 2017). These fires primarily occur in Oregon NHMP Natural Hazard Regions 4, 5, 6, and 7 (**Figure 2-88**); however, even areas classified as low or moderate are susceptible to wildfires if the right combination of fuels, weather, and ignition conditions exist. Historically, Oregon's largest wildfires have burned in the Coast Range (Regions 1 and 2) where the average rainfall is high, but heavy fuel loads created a low-frequency, high-intensity fire environment during the dry periods.

Figure 2-88. Oregon NHMP Natural Hazards Regions



According to OEM, extreme winds are experienced in all of Oregon's eight regions. The most persistent high winds occur along the Oregon Coast and the Columbia River Gorge. The Columbia River Gorge is the most significant east-west gap in the mountains between California and Canada. It serves as a funnel for east and west winds, where direction depends solely on the pressure gradient. Once set in motion, the winds can attain speeds of 80 mph. Wind is a primary factor in fire spread, and can significantly impede fire suppression efforts. This was exemplified in the Eagle Creek Fire of 2017 that burned almost 50,000 acres and lasted for about three months before being declared fully contained in the Columbia River Gorge area. This fire started with a firework lit by a 15-year-old boy on forestland.

El Niño Southern Oscillation and Wildfire Hazards

El Niño winters are often warmer and sometimes drier than average. Sometimes this leads to above average fire seasons.

Unfortunately, El Niño is not a great predictor of above average fire seasons. Long-term drought is a much more accurate predictor.

Source: Oregon Department of Forestry

Historically, 70% of the wildfires suppressed on lands protected by the Oregon Department of Forestry (ODF) result from human activity. The remaining 30% result from lightning. Typically, large wildfires result primarily from lightning in remote, inaccessible areas.

Large wildfires can have significant financial and social costs. Not only can they impact lives and property, they can also have negative short- and long-term economic and environmental consequences.

According to Oregon Forest Resources Institute which gathered information on the "Impacts of Oregon's 2017 Wildfire Season," large wildfires caused significant economic impacts from smoke alone. There were cancellations of cultural, social, and athletic events. Tourism and recreation were negatively impacted. People couldn't get to work because they were sick or roads were impassable. Over 665,000 acres of wildfire across the state in both forests and rangelands sent particulates and hazardous compounds into the air. The over 2,000 fires that caused this smoke problem diminished air quality for everyone, especially children, pregnant women and the elderly. Aftereffects of the fires included landslides, flooding, and reduced drinking water quality.

Life safety enhancement and cost savings may be realized by appropriate mitigation measures, starting with coordinated fire protection planning by local, state, tribes, federal agencies, the private sector, and community organizations. Additionally, and often overlooked, is the role that individual WUI property owners play in this coordinated effort.

Wildfire suppression costs escalate dramatically when agencies must adjust suppression tactics to protect structures. The cost of mobilizing personnel and equipment from across the state is significant. Non-fire agencies may also incur costs for providing or supporting evacuations, traffic control, security, public information, and other services during WUI fire incidents. These costs vary widely and have not been well documented.

The number of people living in Oregon's WUI areas is increasing. Where people have moved into these areas, the number of wildfires has escalated dramatically. Many people arriving from urban settings expect an urban level of fire protection. The reality is many WUI homes are located in portions of the state with limited capacity for structural protection and sometimes no fire protection whatsoever. Many Oregon communities (incorporated and unincorporated) are within or abut areas subject to serious wildfire hazards. In Oregon, there are 700,000-900,000 homes within the WUI, which has greatly complicated firefighting efforts and significantly increased the cost of fire suppression. While Oregon's Emergency Conflagration Act helps protect WUI communities that have depleted their local resources when threatened by an advancing wildfire, the escalating number of fires has led to the recognition that citizens in high fire risk communities need to provide mitigation and an appropriate level of local fire protection. Oregon's seller disclosure law requires a statement of whether or not property is classified as forestland-urban interface. Collaboration and coordination is ongoing among several agencies to promote educational efforts through programs like Firewise USA®, the Oregon Forestland-Urban Interface Fire Protection Act, and Fire Adapted Communities from the National Cohesive Wildfire Strategy.

Construction in vulnerable areas increases risk for certain populations. Oregon's Statewide Planning Goal 4 and Goal 7 play critical roles in guiding development in these areas. Measures to enhance life safety enhancement and save costs include Community Wildfire Protection Plans (CWPPs), coordinated fire protection planning, and coordination by local, state, tribal, federal agencies, the private sector, and community organizations. Many communities incorporate their CWPPs into their Natural Hazards Mitigation Plans (NHMPs).

Wildfire mitigation discussions are focused on reducing overabundant, dense forest fuels, particularly on public lands. The Healthy Forest Restoration Act aims to create fuel breaks by reducing overly dense vegetation and trees. It provides funding and guidance to reduce or eliminate hazardous fuels in National Forests, improve forest fire fighting, and research new methods to reduce the impact of invasive insects.

Oregon continues to make efforts in fuels management and forestry resilience and health in and near WUI areas. Sustaining the work over the years requires a substantial, ongoing capacity and financial commitment. Progress is often challenging because fuel mitigation methods vary and are often up to landowners to maintain. Recurring WUI fires continue to bring the issue into public focus, work as a catalyst to unite communities and stakeholders in a common set of objectives, and create collaborative approaches to mitigate fuels.

2.2.9.1 Analysis and Characterization

History of Wildfire

Wildfires have been a feature of the Oregon landscape for thousands of years. Prehistoric fires resulted from lightning events and in controlled forms of active management practices by Native Americans. The Blue Mountains in northeastern Oregon were named so by early immigrants because of the existence of a perpetual, blue-colored wildfire smoke haze that lingered over the region. Between 1840 and 1900, wildland fires burned at least two million acres of forestland in western Oregon. It is believed settlers caused many of these fires. Following the establishment of the U.S. Forest Service and Oregon Department of Forestry, in 1905 and 1911, respectively, an aggressive and coordinated system of fire prevention and suppression emerged. However, it took several decades before significant gains were made.

Major wildfires in 1933, 1939, 1945, and 1951 burned across more than 355,000 acres in the northern Coast Range and became known collectively as the "Tillamook Burn."

Better suppression and more effective fire prevention campaigns combined to reduce large wildfire occurrences following World War II. Suppression improvements included the establishment of organized and highly trained crews, which replaced the previous system of hiring firefighters on an as-needed basis. Additional improvement resulted from construction of an extensive system of forest roads, lookouts and guard stations, the use of aircraft for the detection of fires and the delivery of fire suppression retardant, the invention and modification of modern and efficient fire suppression equipment, and refinements in weather forecasting and fire reporting. Prevention benefited from war-era campaigns, which united prevention activities with patriotism, and birthed movements such as the Smokey Bear campaign and the Keep Oregon Green Association.

A pattern of frequent, large WUI fires emerged during the 1970s as people began flocking to more rural settings. Suburban growth increased and continued through the 1980s. This introduced substantially more structures into what had previously been wildland areas that historically depended on periodic fires to sustain a healthy forest ecosystem.

Project Wildfire

Project Wildfire is the result of a Deschutes County effort to create long-term wildfire mitigation strategies and provide for a disaster-resistant community. Project Wildfire is the community organization that facilitates, educates, disseminates and maximizes community efforts toward effective fire planning and mitigation.

Project Wildfire achieves its mission by:

- Developing long-term wildfire prevention and education strategies designed to reach an ever-changing community.
- Creating disaster 5 resistant communities through collaboration with community members and a network of specialized partners.
- Reducing the severity and amount of damage caused by wildfire in wildland urban interface (WUI) areas through hazardous fuels reduction programs.
- Reducing the impact of fuels reduction on the environment by recycling the woody biomass resulting from hazardous fuels reduction projects.

Source: Oregon Department of Forestry, Project Wildfire (http://www.projectwildfire.org/http://www.projectwildfire.org/)

By the early 1990s, frequent, destructive WUI fires had become a major concern of the State Forester, the State Fire Marshal, and the Oregon Legislature. By the mid-1990s, over 100 structures had been destroyed by wildfires. Thousands more had been threatened and suppression costs were increasing sharply. The same trends were occurring in surrounding states, at an even greater pace.

Oregon Forestland-Urban Interface Fire Protection Act

In 1988, following the very difficult and expensive fire season of 1987, Oregon developed “An Action Plan for Protecting Rural/Forest Lands from Wildfire.” The work was funded by FEMA’s Fire Suppression Assistance (FSA) Program. The action plan was updated in 1991 with an Awbrey Hall Fire Appendix, in response to a fire that burned 22 structures on the western fringe of Bend. The 1988 action plan and the 1991 update led to the Legislature’s attachment of a Budget Note to ODF’s 1995-1997 budget, which required an examination of the WUI situation and the development of *“…recommendations which may include…statutory changes on how to minimize the costs and risks of fire in the interface.” Spurred by the loss of additional homes during the 1996 Skeleton Fire, these recommendations became the basis for passage of the Oregon Forestland-Urban Interface Fire Protection Act of 1997*.

The Act recognized that "…*forestland-urban interface property owners have a basic responsibility to share in a complete and coordinated protection system*..." In addition, during the 1990s, prevention and mitigation of WUI fires included enactment of the Wildfire Hazard Zone process and the inclusion of defensible space requirements in the land use planning process. Significant efforts were made to increase voluntary landowner participation, through aggressive awareness campaigns, such as FireFree, Project Wildfire, Project Impact, Firewise USA®, and other locally driven programs.

Through the years, Oregon's wildfire suppression system continued to improve. Firefighters benefited from improved training, coordination, and equipment. Better interagency initial attack cooperation, the growth of private crew and fire engine wildfire suppression resources, formation of structural incident management teams, and regional coordination of fire suppression are additional examples of these continued improvements. Technology has improved as well with the addition of lightning tracking software and fire detection cameras to support or replace deteriorating lookout towers.

Nevertheless, the frequency of wildfires threatening WUI communities continues to underscore the need for urgent action. The summer of 2002 included 11 Emergency Conflagration Act incidents, with as many as five running concurrently. More than 50 structures burned and, at one point, the entire Illinois Valley in Josephine County seemed under siege from the Biscuit Fire, Oregon's largest wildfire on record. This wildfire threatened the homes of approximately 17,000 people, with over 4,000 homes under imminent evacuation alert. At almost 500,000 acres, it was the nation's largest wildfire of the year. The summer of 2013 once again brought to bear one of the worst fire season's in Oregon. For the first time since 1951, more than 100,000 acres burned on lands protected by the Oregon Department of Forestry. Five incident management teams were deployed in a period of three days following a dry lightning thunderstorm event in late July that sparked nearly 100 fires in southern Oregon from more than 300 lightning strikes. Another storm that passed over central and eastern Oregon in mid-August produced significant fires that threatened the communities of John Day and The Dalles. Since 1996, Oregon has had 62 declared Conflagrations under the Act. Oregon's mitigation efforts since 2002 have influenced a dramatic decrease in these types of fires, resulting in none to four per year through 2014 (See **Appendix 9.1.2** for more information on Conflagrations from 1996 to 2019.)

Types of Wildfire

Wildfires burn primarily in vegetative fuels located outside highly urbanized areas. Wildfires may be broadly categorized as agricultural, forest, range, or WUI fires.

Agricultural: Fires burning in areas where the primary fuels are flammable cultivated crops, such as wheat. This type of fire tends to spread very rapidly, but is relatively easy to suppress if adequate resources are available. Structures threatened are usually few in number and generally belong to the property owner. There may be significant losses in terms of agricultural products from such fires.

Forest: The classic wildfire; these fires burn in fuels composed primarily of timber and associated fuels, such as brush, grass, and logging residue. Due to variations of fuel, weather, and topography, this type of fire may be extremely difficult and costly to suppress. In wilderness areas these types of fires are often monitored and allowed to burn for the benefits brought by the ecology of fire, but also pose a risk to private lands when these fires escape these wilderness areas.

Range: Fires that burn across lands typically open and lacking timber stands or large accumulations of fuel. Such lands are used predominantly for grazing or wildlife management purposes. Juniper, bitter-brush, and sage are the common fuels involved. These fires tend to spread rapidly and vary from being easy to difficult to suppress. They often occur in areas lacking both wildland and structural fire protection services.

Wildland-urban interface (WUI): These fires occur in portions of the state where urbanization and natural vegetation fuels are mixed together. This mixture may allow fires to spread rapidly from natural fuels to structures and vice versa. Such fires are known for the large number of structures simultaneously exposed to fire. Especially in the early stage of WUI fires, structural fire suppression resources may be quickly overwhelmed, which may lead to the destruction of a large number of structures. Nationally, wildland interface fires have frequently resulted in catastrophic structure losses.

Secondary Hazards

Increased risk of landslides and erosion are secondary hazards associated with wildfires that occur on steep slopes. Wildfires tend to denude the vegetative cover and burn the soil layer creating a less permeable surface prone to sheetwash erosion. This - in turn - increases sediment load and the likelihood of downslope failure and impact.

Wildfires can also impact water quality (e.g., drinking water intakes). During fire suppression activities some areas may need coordinated efforts to protect water resource values from negative impact.

Wildfire smoke may also have adverse effects on air quality and visibility, and create nuisance situations. Strategies to limit smoke from active wildfires are limited, but interagency programs exist to alert the public of potential smoke impact areas where hazardous health or driving conditions may occur.

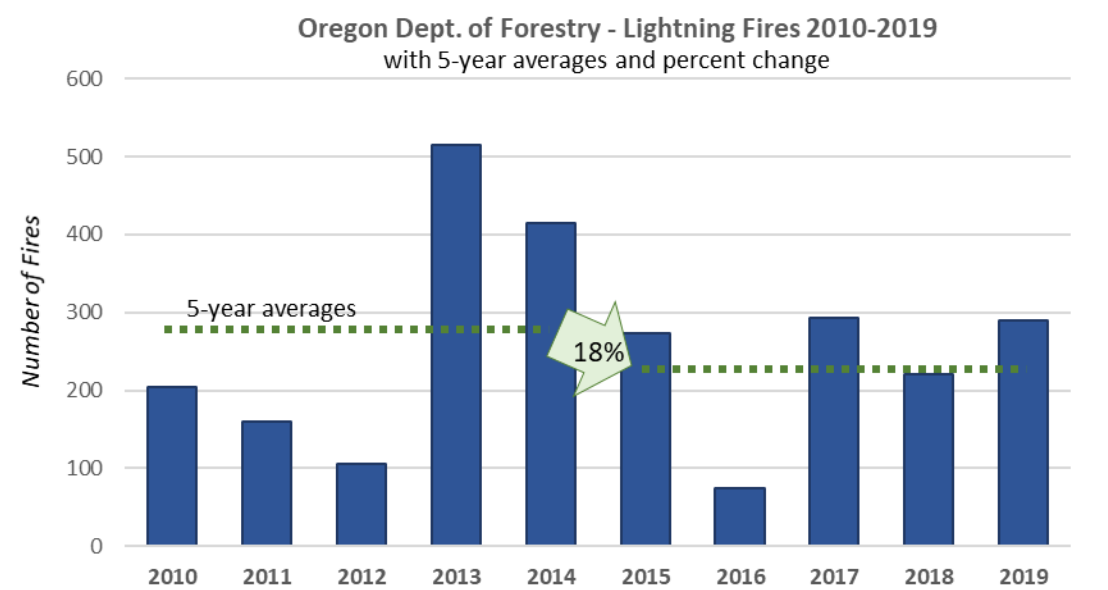
Source: Unknown

Common Sources of Wildfire

For statistical tabulation purposes, wildland fires are grouped into nine categories based on historically common wildfire ignition sources.

Lightning: There are tens of thousands of lightning strikes in Oregon each year. Of the nine categories, lightning is the leading ignition source of wildfires. In addition, lightning is the primary cause of fires which require activation of Oregon's Conflagration Act.

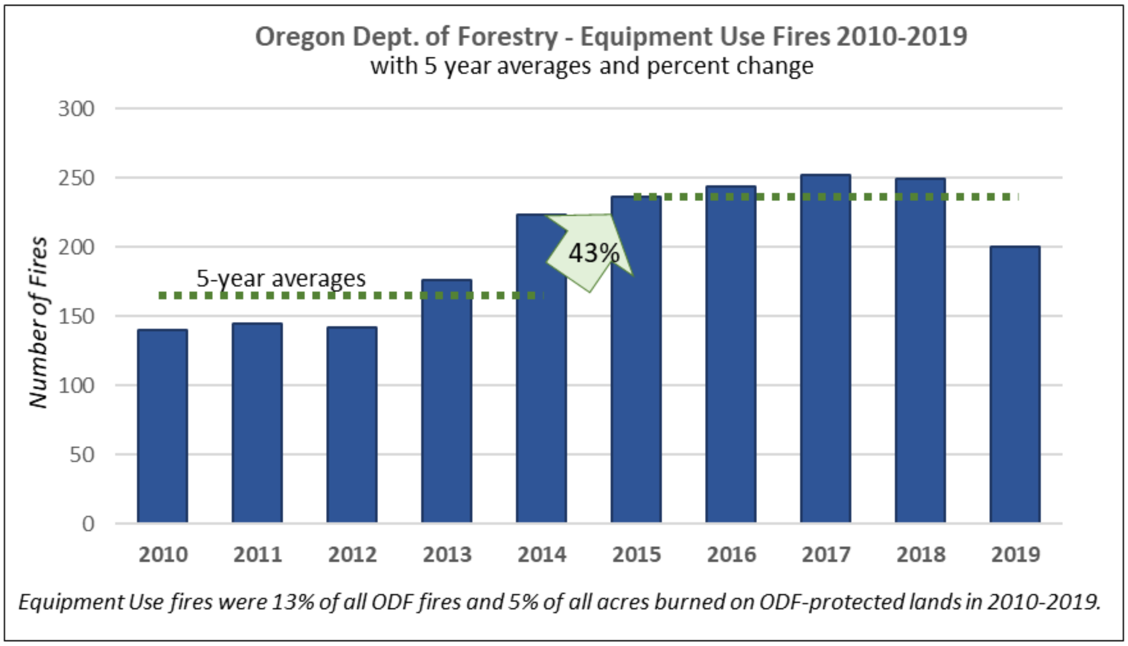
Figure 2-89. Lightning Fires 2010-2019



Lightning fires were 17% of all ODF fires and 60% of all acres burned on ODF-protected lands in 2010-2019.

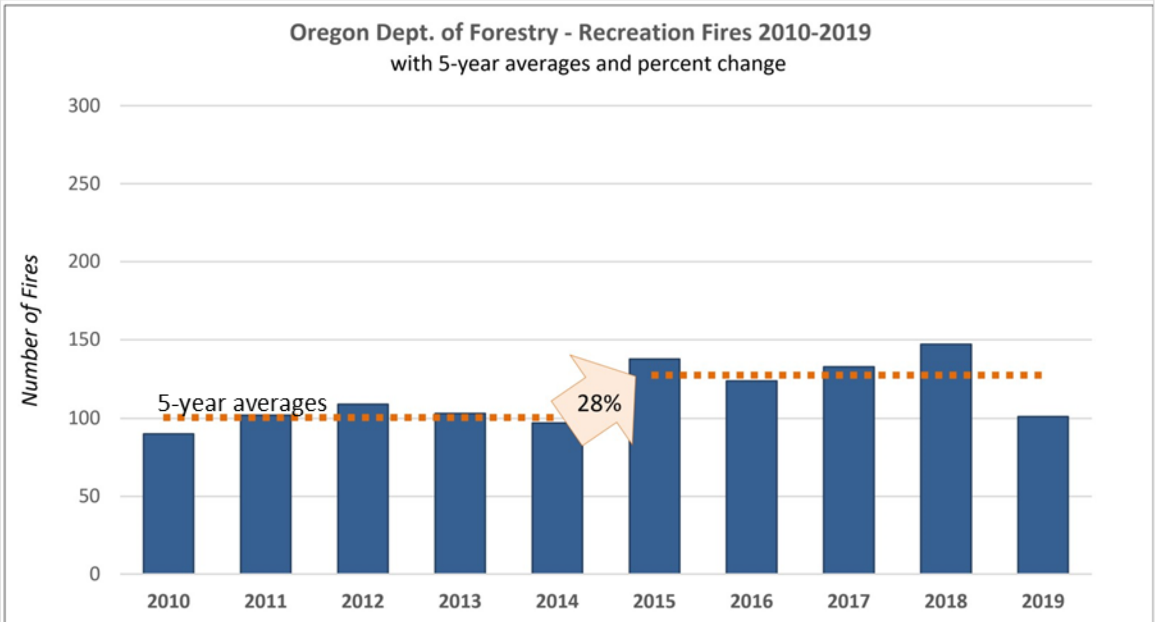
Equipment use: This source ranges from small weed eaters to large logging equipment; many different types of equipment may readily ignite a wildfire, especially if used improperly or illegally. Although fire agencies commonly limit or ban certain uses of fire-prone equipment, the frequency of fires caused by equipment has increased. Increases in fires from this source may be related to the expansion of the wildland interface, which results in more people and equipment being in close proximity to forest fuels.

Figure 2-90. Equipment Use Fires 2010-2019



Recreation: The trend in fires caused by people recreating in and near Oregon's forests has risen over the past 10 years. This trend may reflect the state's growing population and as well as a greater interest in outdoor recreation opportunities.

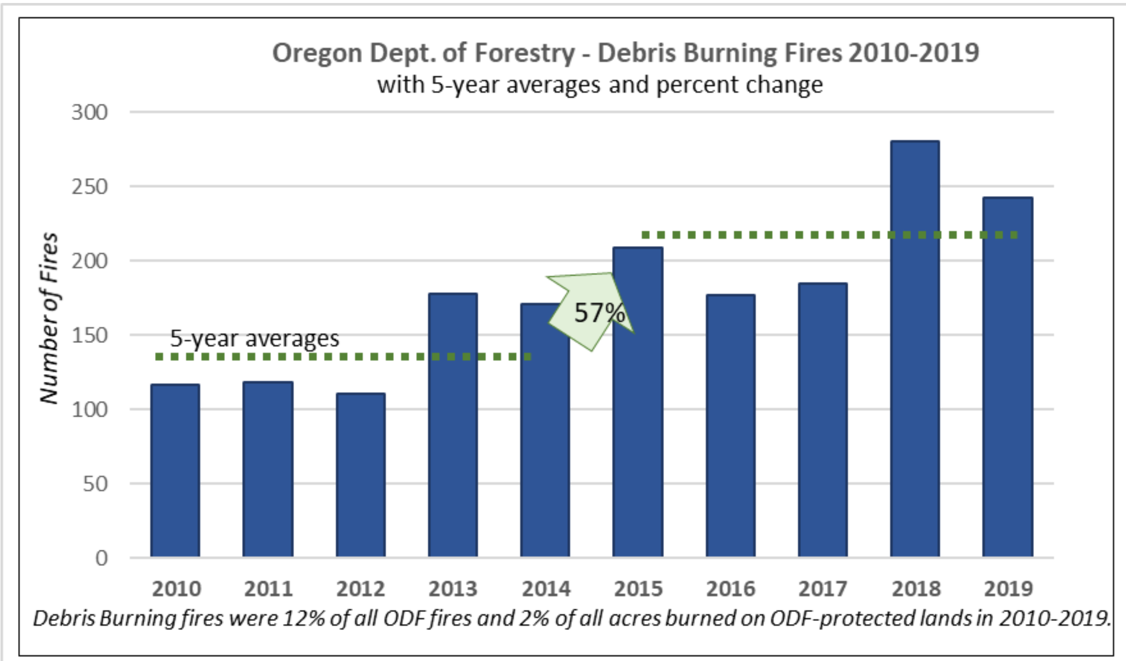
Figure 2-91. Recreation Fires 2010-2019



Recreation fires were 8% of all ODF fires and 3% of all acres burned on ODF-protected lands in 2010-2019.

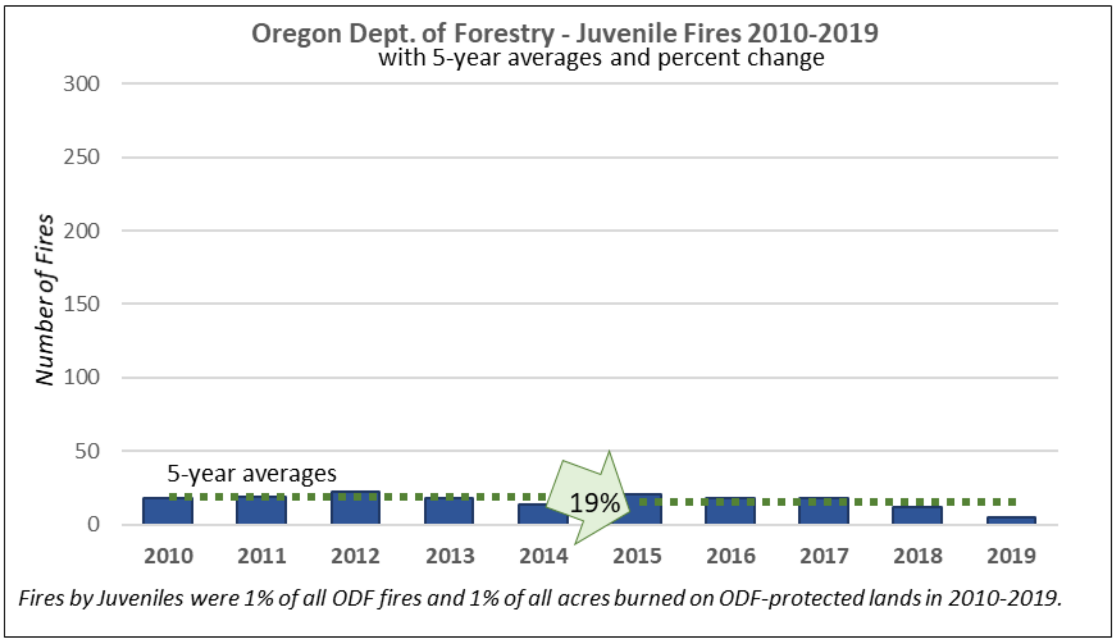
Debris burning: Historically, debris burning activities have been a leading source of human-caused wildfires. Partnering fire protection agencies, primarily through local fire defense boards, continue to seek solutions to curb ignitions and escapements. Besides consistent messaging during fire season that draws attention to the illegal activity, fire prevention professionals are beginning to provide additional education to encourage alternatives to burning and safe burning practices during fall and winter months when fire danger is less severe. Despite these efforts we have still seen a rise in the last 5 years.

Figure 2-92. Debris Burning Fires 2010-2019



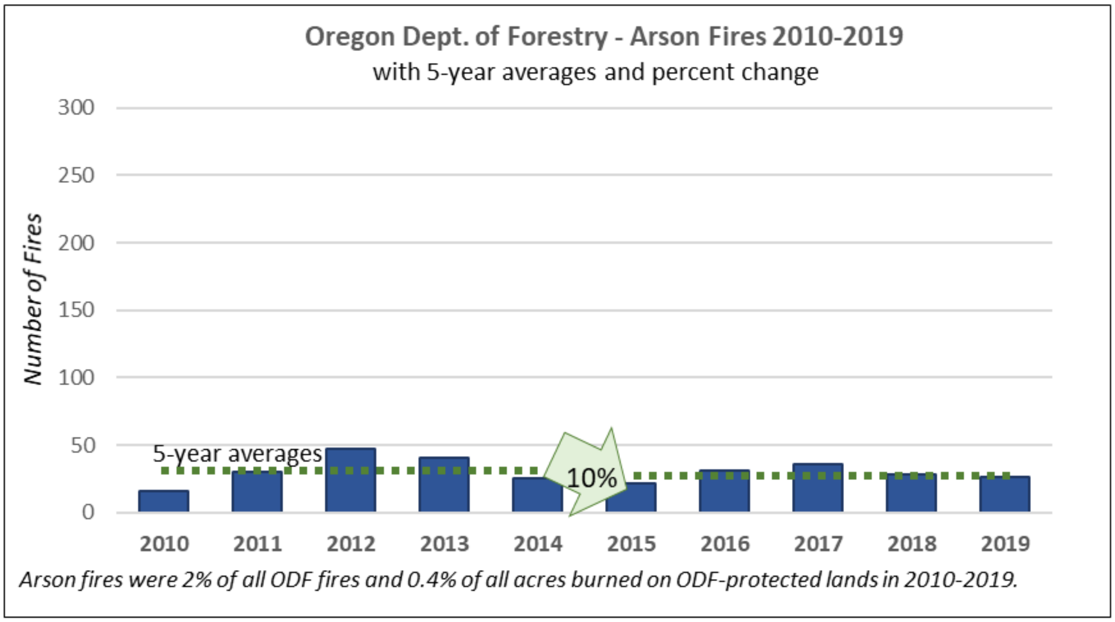
Juvenile: Concerted efforts by local fire prevention cooperatives to deliver fire prevention messages directly to school classrooms and the Office of the State Fire Marshal's (OSFM's) aggressive youth intervention program has helped address this ignition source. In 1999, according to the ODF, juveniles were reported to have started 60 wildland fires. Conversely, juveniles accounted for just 4 fires in 2019. Additionally, parents or guardians, under Oregon Law, are responsible for damages done by fires started by their children. ORS 30.765 covers the liability of parents; ORS 163.577 holds parents or guardians accountable for child supervision, ORS 477.745 makes parents liable for wildfire suppression costs of a fire by a minor child, and ORS 480.158 holds a parent liable for fireworks-caused fires. Additionally, parents may be assessed civil penalties.

Figure 2-93. Juvenile Fires 2010-2019



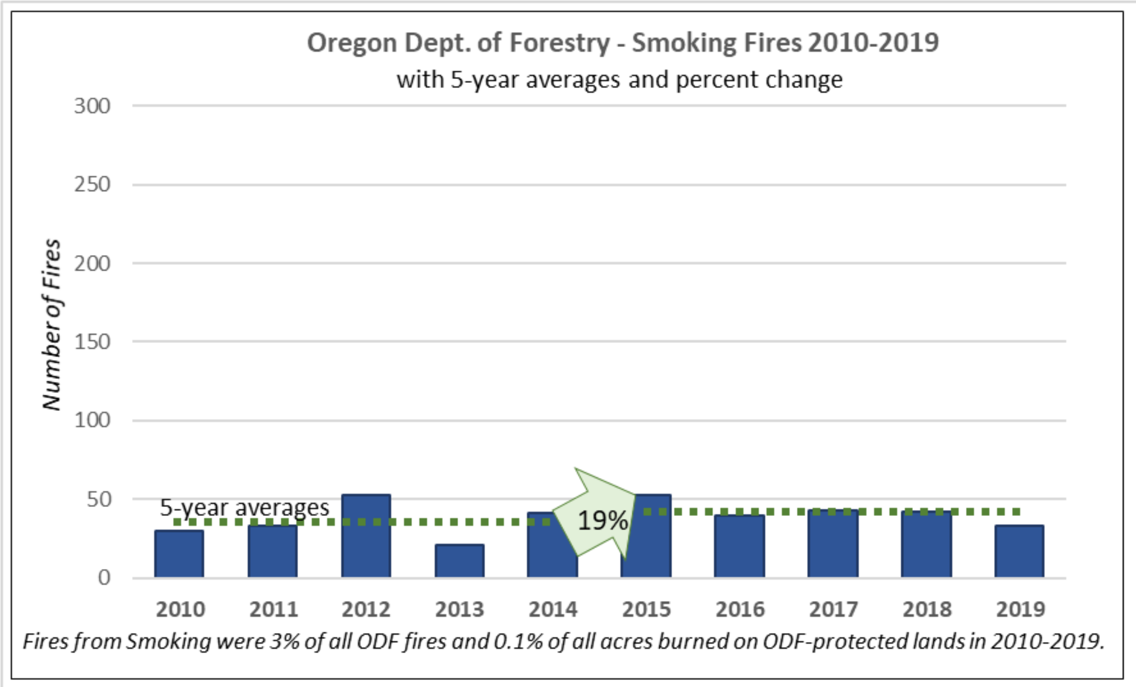
Arson: Oregon experienced a rapid rise in the frequency of arson caused fires in the early '90s. 1992 was the worst fire season for arson with 96 fires attributed to the category. In response, the state instituted aggressive arson prevention activities with solid working relationships with local law enforcement and the arson division of the Oregon State Police. The result has seen a decline in numbers with just 19 fires in 2019.

Figure 2-94. Arson Fires 2010-2019



Smoking: Fires caused by smoking and improperly discarded cigarettes has slightly risen in the last 5 years.

Figure 2-95. Smoking Fires 2010-2019



Railroad: Wildfires caused by railroad activity are relatively infrequent. In the early twentieth century, this had been a major cause of fires, but has been decreasing for many years. Over the past 10-year period, the number of railroad-caused fires has leveled out close to 0%. In the past few decades, Oregon has responded to railroad-caused fires with aggressive fire investigation and cost recovery efforts. Oregon Department of Forestry works with the railroad on hazard abatement along tracks and requires water cars and chase vehicles during high fire danger. The resulting quick return to normal fire incidence showed that railroad fires are very preventable.

Miscellaneous: Wildfires resulting from a wide array of causes: automobile accidents, burning homes, pest control measures, shooting tracer ammunition and exploding targets, and electric fence use are a few of the causes in this category. The frequency of such fires has been rising in recent years.

Historic Wildfire Events

Table 2-69. Historic Wildfires in Oregon

Date	Location	Description
1902	Clackamas, Multnomah	**Columbia Fire/Yacolt Burn** 170,000 acres caused 38 deaths in the Lewis River area, 9 deaths in Windy River, and 18 deaths in the Columbia River Gorge.
1933-1951	Tillamook, Washington, Yamhill and Clatsop	**Tillamook Burn** was a series of large fires that struck in 6 year intervals burning a combined total of 355,000 acres and killing 35 people.
1936	Coos	**Bandon Fire** was a 287,000 acre fire that destroyed 100's of homes and killed 10 people.
2002	Josephine	**Biscuit fire** burned nearly 500,000 acres starting from lighting strikes and the product of the joining of 4 different fires and burned over 4 months long.
2006	Harney	**South End Complex** burned 117,553
2010	Jackson	**Oak Knoll Fire** in Ashland destroyed 11 homes in less than 45 minutes
2011	Wasco	**High Cascade Complex** burned on the east side of Mount Hood into **Warm Springs**, consuming 101,292 acres
2012	Tillamook, Washington, and Yamhill	**Holloway Fire** burned more than 245,000 acres in Oregon from a lighting strike and also burned more than 215,000 acres in Nevada. One firefighter was killed.
2012	Malheur and Harney	**Long Draw Fire** consumed 557,648 acres and was started by lightning.
2013	Josephine, Douglas	**Douglas Complex** burned about 49,000 acres started by lightning strikes. Made up of 3 fires: Rabbit Mountain, Dad's Creek, and Farmer's Fire.
2013	Jefferson	**Sunnyside Turnoff** started by a firecracker that was thrown into vegetation. It grew to 51,480 acres on the Warm Springs Indian Reservation.
2014	Wallowa	**Buzzard Complex** burned over 400,000 acres and significantly impacted rangeland and cattle farms.
2014	Grant	**South Fork Complex** started with lightning strikes burning 62,476 acres.
2015	Grant	**Canyon Creek Complex** burned 110,422 acres started by lightning. It destroyed more private property than any Oregon wildfire for 80 years before it. It destroyed 43 homes and almost 100 other structures.
2015	Wallowa	**Grizzly Bear Complex** burned 82,659 acres started by lightning. Destroyed 2 homes and dozens of other structures.
2015	Jefferson	**County Line 2** burned over 67,000 acres.
2015	Baker	**Cornet Windy Ridge** burned 103,887 Acres started by lightning strike.
2017	Curry	**Chetco Bar** burned 191,125 acres and started by lightning strike.
2017	Multnomah and Hood River	**Eagle Creek Fire** burned 48,831 acres and was caused by a 15-year- old playing with fireworks.
2017	Lake and Harney	**Cinder Butte** burned over 52,000 acres of rangeland that was human caused and threatened Tribal Archaeological Sites.
2017	Wasco	**Nena Springs** burned more than 68,000 acres, was human cause and did significant damage to the Confederate Tribes of Warm Springs.

Date	Location	Description
2018	Josephine	**Klondike** burned more than 175,258 acres and eventually merged into the Taylor Creek Fire that had burned 52,839 acres.
2018	Wasco	**Boxcar** burned 100,207 acres and started due to lightning.
2018	Jackson and Douglas	**Miles** burned 54,134 acres and was a combination of merged fires: Sugar Pine, South Umpqua Complex, and the Miles fire.
2018	Josephine	**Taylor Creek** burned 52,839 acres started by a lightning strike.
2018	Wasco	**Substation** burned 78,425 acres moving over 18 miles in just days.
2018	Lake	**Watson Creek** burned over 58,900 acres.

Source: Oregon Department of Forestry, 2020

Figure 2-96. Large Fire Costs & Acres Burned

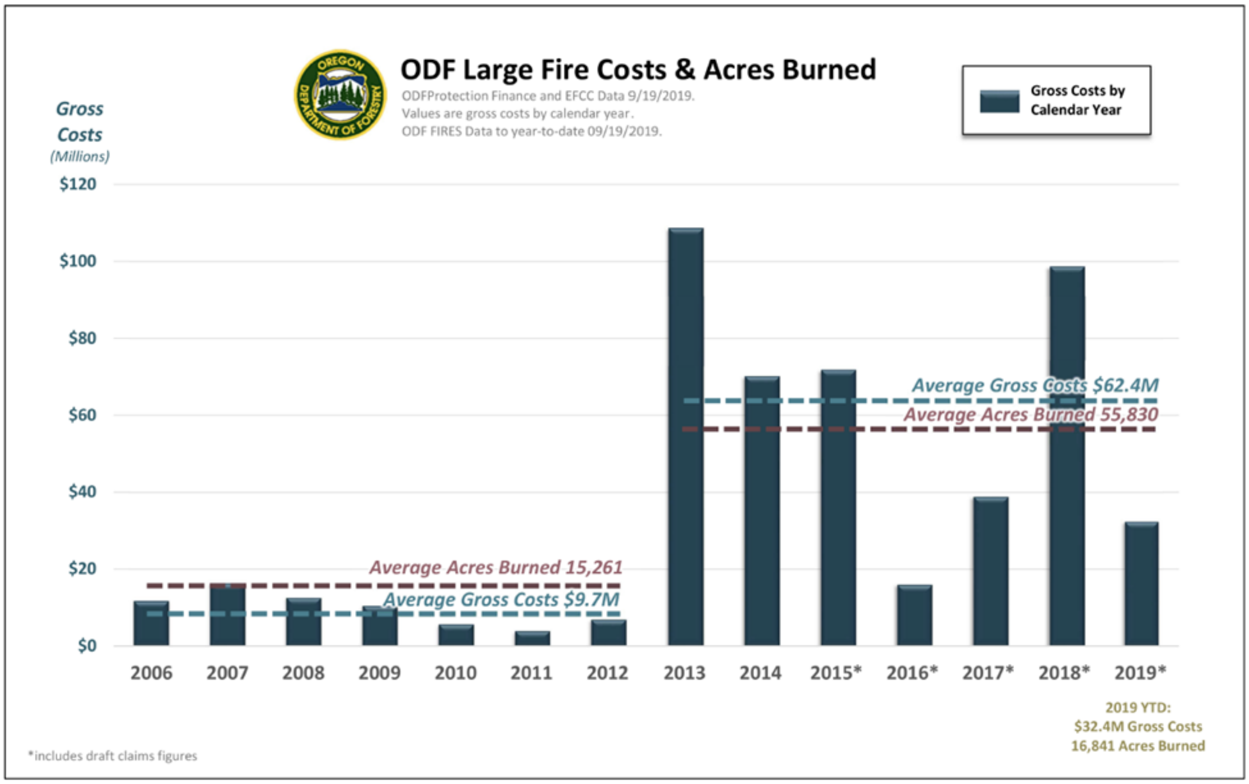


Figure 2-96 presents large fire costs and acres burned for ODF protected lands since 2006. This shows a significant shift in 2013 when the cost and burned acreage severely increased. Clearly an overall trend towards more intense fire events has emerged in the last 7 years. This observation is consistent with the trend over the last several decades of warmer and drier conditions during the summer months that have contributed to an increase in fuel aridity enabling more frequent large fires and an increase in the total area burned across the western United States. Human-caused climate change is partially responsible for these trends, which are expected to continue increasing under continued climate warming (Dalton et al., 2017).

2.2.9.2 Probability

Fire is a natural component of forest and rangeland ecosystems found in all portions of the state. Many of these ecosystems are dependent upon frequent fires or a viable substitute for their continued existence. Even western Oregon forests, in the "wet" northwestern portion of the state, depend upon fire. It is a common myth that an unbroken carpet of old growth timber blanketed western Oregon prior to the beginning of European American settlement. In fact, fire and other natural forces had created a mosaic of different aged timber stands across the region. Factors now influencing the occurrence and severity of wildfires include poor forest health, invasive plant and tree species, great amounts of vegetation from long-term fire exclusion, changes in weather patterns including warmer and drier summers, and the presence of humans and human development.

Although usually thought of as being a summer occurrence, wildland fires can occur during any month of the year. The vast majority of wildfires burn during the June to August time period but in recent years have extend into September or even October months. The decline mountain snowpack and earlier spring snowmelt due to climate change has resulted in a lengthening of the fire season over the last several decades (Dalton et al., 2017). Dry spells during the winter months, especially when combined with winds and dead fuels, may result in fires that burn with an intensity and rate of spread that surprises many people.

During a typical year, in excess of 2,000 wildland fires are ignited on protected forestlands in Oregon. Due to growth in the WUI and changes in climate, the number of wildfires on ODF protected lands has trended upward. This trend is expected to continue increasing under continued climate warming.

The US Forest Service recently completed the Quantitative Wildfire Risk Assessment (QWRA). The Oregon Department of Forestry (ODF) has recently taken this assessment data and worked with Oregon State University Extension and Pyrologix, LLC (http://pyrologix.com) to create a portal to maps that can identify wildfire risk in the state of Oregon. The Oregon Wildfire Risk Explorer (OWRE) project makes data available for the Pacific Northwest, replacing the West-Wide Risk Assessment (WWRA) of 2013. The site will allow the user to view data through an interactive mapping tool, generate maps and reports specific to their area of interest, and access information to interpret the data for homeowners and planners. The goals of this site are to:

- Increase wildfire awareness, prevention activities, and local capacity for developing and updating Community Wildfire Protection Plans (CWPPs).
- Help communities identify and prioritize fuel treatment and other wildfire risk reduction projects.
- Improve wildfire risk planning and decision making across broad landscapes at all levels.
- Increase the number of fire adapted communities.
- Reduce losses by implementing effective coordinated emergency response

The OWRE is intended to support strategic planning at regional, state, and landscape scales. It was conducted at the dual state (Oregon and Washington) level so data is more accurate and specific than a regional assessment. Since the data is at the state level, finer-scale data may hold inaccuracies. When looking at probability, though, the OWRE is a great resource.

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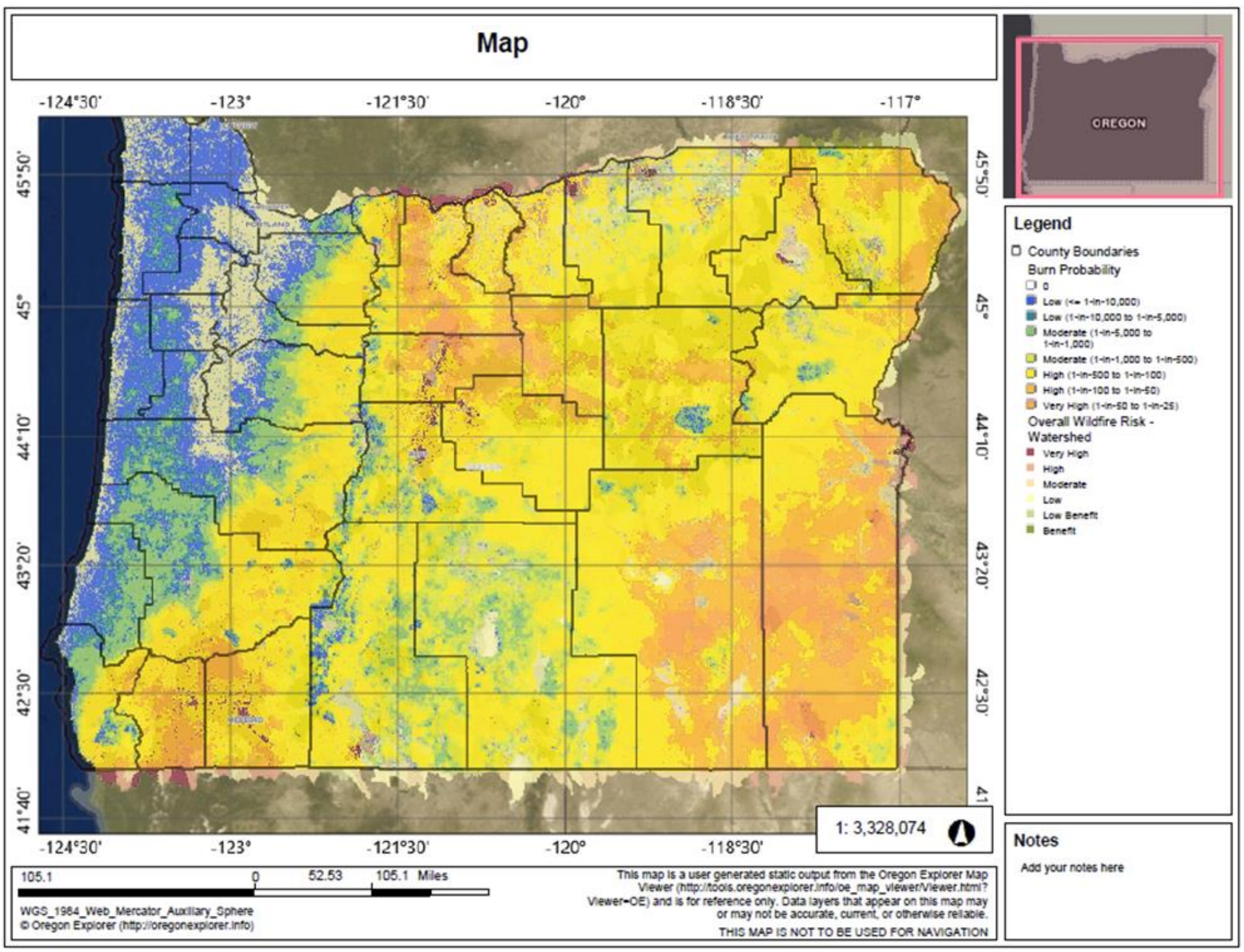
Burn Probability: Burn probability is calculated as the likelihood of a wildfire greater than 250 acres to burn a given location, based on wildfire simulation modeling. This is an annual burn probability, adjusted to be consistent with the historical annual area burned. Viewing local small fires in conjunction with wildfire >250 acres, burn probability can give a more comprehensive view of local fire history and potential. Be aware that conditions vary widely with local topography, fuels, and weather, especially local winds. In all areas, under warm, dry, windy, and drought conditions, expect higher likelihood of fire starts, higher fire intensities, more ember activity, a wildfire more difficult to control, and more severe fire effects and impacts.

Figure 2-97. Burn Probability



Source: Oregon Wildfire Risk Explorer, March 2020

Low: The annual probability that a wildfire will burn a given point on the landscape. Low burn probability indicates less than approximately 1 in 5,000 chance of a wildfire >250 acres in a single year. Low represents up to the 11th percent of values across the landscape.

Moderate: The annual probability that a wildfire will burn a given point on the landscape. Moderate burn probability indicates between 1 in 5,000 and 1 in 500 chance of a wildfire >250 acres in a single year. Moderate represents the 11th up to the 29th percent of values across the landscape.

High: The annual probability that a wildfire will burn a given point on the landscape. High burn probability indicates between 1 in 500 and 1 in 50 chance of a wildfire >250 acres in a single year. High represents the 29th up to 96th percent of values across the landscape.

Very High: The annual probability that a wildfire will burn a given point on the landscape. Very High burn probability indicates greater than 1 in 50 chance of a wildfire >250 acres in a single year. Very High represents the 96th through 100th percent of values across the landscape.

Burn Probability and Exposure

To find the overall probability of wildfire for each County plus the two coastal areas of Lane and Douglas County for for the 2020 Risk Assessment Methodology, we first established communities in the Wildland Urban Interface and their risk ratings using the following data and procedure. A "Community at Risk" is a geographic area within and surrounding permanent dwellings with basic infrastructure and services, under a common fire protection jurisdiction, government, or tribal trust or allotment, for which there is a significant threat due to wildfire.

The "Communities at Risk" were identified and named by using a combination of resources:

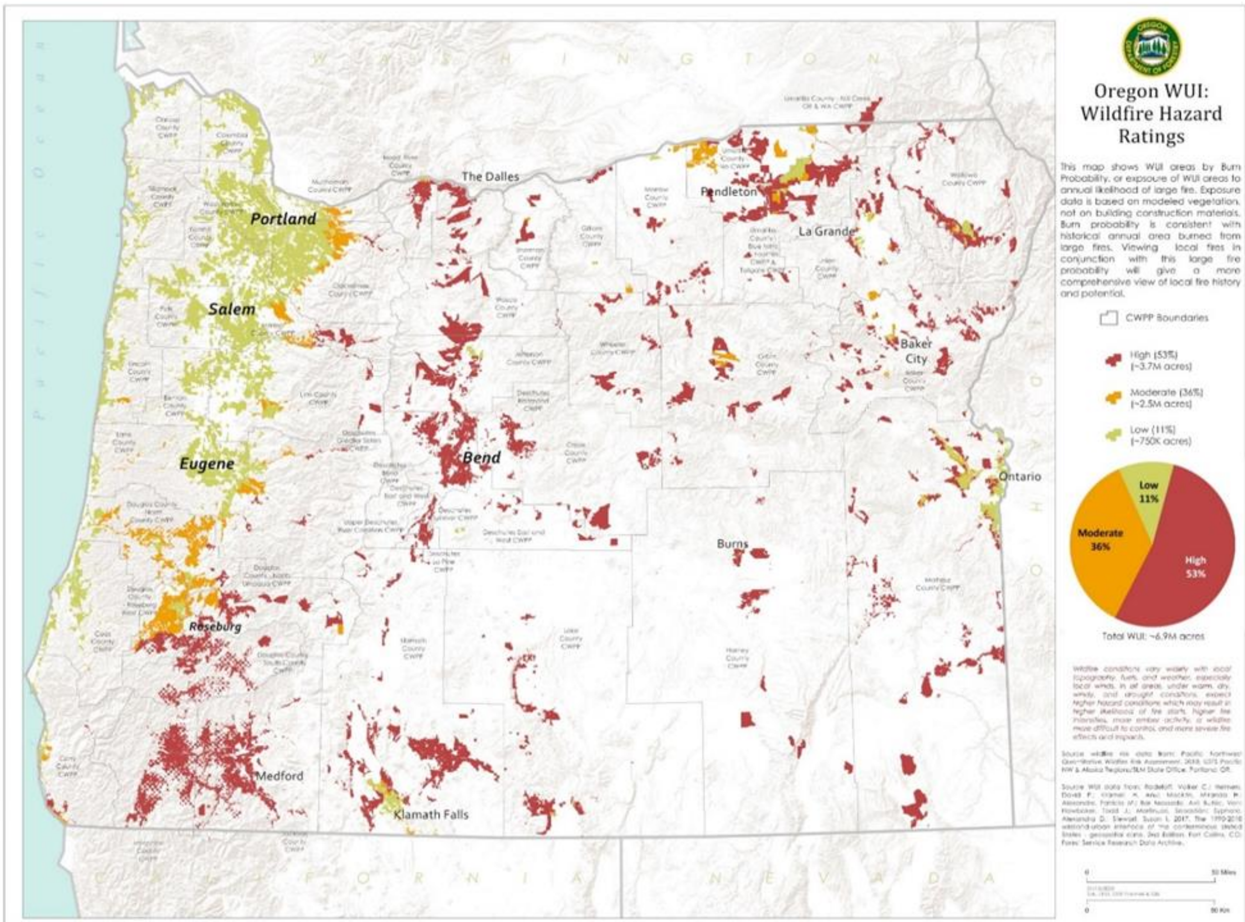
- University of Wisconsin SILVIS WUI dataset as a primary source for WUI interface and intermix areas (University of Wisconsin-Madison Silvis Lab (2010) Retrieved from http://silvis.forest.wisc.edu/maps-data/)
- Oregon "Locally Named Communities at Risk" identified in Community Wildfire Protection Plans (Oregon Department of Forestry (January 2020) Retrieved from https://www.oregon.gov/odf/Fire/Pages/CWPP.aspx)
- Listed communities at risk in the Federal Register (Federal Register, January 4, 2001 (66 FR 751))
- Added City Limits,
- Added Structural Fire District areas, and
- Created a 5 mile buffer of all Oregon town points to capture rural towns without established boundaries.

The identified community data was joined and cross checked with Department of Land Conservation and Development's (DLCD's) Oregon 2017 Land Use Zoning map. Polygons that were not locally named communities, Federal Register, or land use zones that appeared to be built-environments were deleted from the WUI. The mean was calculated from the Pacific Northwest Quantitative Wildfire Risk Assessment (2018) *Hazard to Structures and Burn Probability* value for each WUI polygon to show actual wildfire hazard (**Figure 2-98**). West Wide Risk Assessment was reviewed, assessed, and found to not be statistically different, so there was no need to adjust data outcomes. This created a Wildland Urban Interface layer which is associated with all administrative geographies. To create maps, the data was classified per Pyrologix/USFS/ODF/Oregon Wildfire Risk Explorer symbology themes.

[Figure 2-98](#) shows WUI areas by burn probability, or exposure of WUI areas to annual likelihood of large fire. Exposure data is based on modeled vegetation, not on building construction materials. Burn probability is consistent with historical annual area burned from large fires. Viewing local fires in conjunction with this large fire probability provides a more comprehensive view of local fire history and potential.

All of this data will be integrated into the Oregon State University's Oregon Explorer online mapping application (known as the Oregon Wildfire Risk Explorer) by the end of 2020 as a primary data source in the Wildfire Explorer module.

Figure 2-98. Oregon Wildland-Urban Interface (WUI): Wildfire Hazard Ratings



Once the Communities at Risk were identified, they were listed by county and the number of Communities at Risk in each adjective class (Low, Medium, High) in each county was tallied. To assign a probability score from 1 to 5 (Very Low to Very High) for the purposes of the 2020 Risk Methodology, the following criteria were used:

- Counties with 10 or more Communities at Risk in the high class were considered very high due to the significant number of communities at risk in that area.

- Communities with less than 10 communities in the low class were considered very low as they had less communities at risk of wildfire in that county.
- Douglas and Lane Coastal areas were assessed individually (rather than through the model) based on the ratings of Communities at Risk in the coastal portions of those counties.

Table 2-70. Communities at Risk: Burn Probability, Adjective Classes, and Exposure Ratings

		Burn Probability	# Communities at Risk (CAR) in Each Adjective Class				Exposure Ratings	
		Low/Medium/High	Low	Medium	High	Total	# 1-5	Exposure
Region 1	Clatsop	Low	11	1	1	13	2	Low
	Coos	Low	18	0	0	18	2	Low
	Curry	High	6	2	4	12	1	Very Low
	Douglas Coastal	Medium	—	—	—	—	3	Moderate
	Lane Coastal	Low	—	—	—	—	2	Low
	Lincoln	Low	9	1	0	10	1	Very Low
	Tillamook	Low	15	1	0	16	2	Low
Region 2	Clackamas	Low	19	3	2	24	2	Low
	Columbia	Medium	8	0	0	8	1	Very Low
	Multnomah	Low	10	0	0	10	2	Low
	Washington	Low	8	1	1	10	1	Very Low
Region 3	Benton	Low	10	1	0	11	2	Low
	Lane	Medium	18	10	1	29	3	Moderate
	Linn	High	10	3	2	15	2	Low
	Marion	High	18	2	4	24	2	Low
	Polk	Low	5	0	0	5	1	Very Low
	Yamhill	Low	11	0	0	11	2	Low
Region 4	Douglas	High	13	13	22	48	5	Very High
	Jackson	High	0	4	19	23	5	Very High
	Josephine	High	0	0	8	8	4	High
Region 5	Gilliam	High	1	2	0	3	3	Moderate
	Hood River	High	1	2	0	3	3	Moderate
	Morrow	High	1	2	6	9	4	High
	Sherman	High	0	2	1	3	3	Moderate
	Umatilla	High	2	8	9	19	4	High
	Wasco	High	1	2	12	15	5	Very High
Region 6	Crook	High	1	0	3	4	4	High
	Deschutes	High	1	5	6	12	4	High
	Jefferson	High	0	0	10	10	5	Very High
	Klamath	High	2	13	5	20	3	Moderate
	Lake	High	0	8	0	8	3	Moderate
	Wheeler	High	0	1	5	6	4	High
Region 7	Baker	High	1	4	24	29	5	Very High
	Grant	High	0	2	10	12	5	Very High
	Union	High	0	8	13	21	5	Very High
	Wallowa	High	3	8	6	17	3	Moderate
Region 8	Harney	High	0	0	3	3	4	High
	Malheur	High	3	4	8	15	4	High

Note: This table shows burn probability as taken from the PNW Quantitative Wildfire Risk Assessment (2018) along with the Communities at Risk assessment (2020). Combined they were used to arrive at the exposure ratings which represented probability in the 2020 Risk Assessment Methodology and are presented in the Regional Risk Assessments as vulnerability ratings.

Source: ODF Communities at Risk Report, 2020; Oregon Wildfire Risk Explorer, 2020; PNW Quantitative Wildfire Risk Assessment

Climate Change

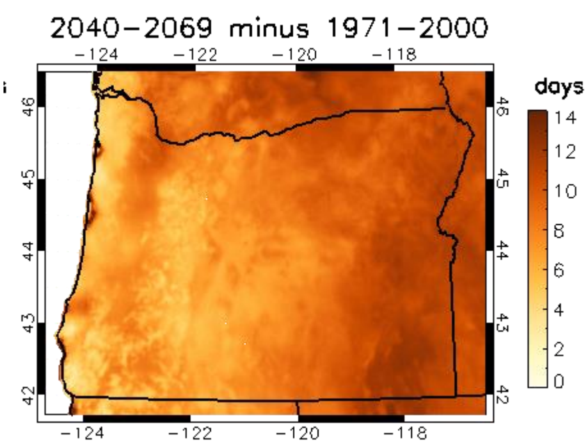
All eight regions in Oregon are projected to be affected by an increased incidence of wildfire.

Increasing wildfire frequency and intensity is greatest (very likely, >90%) in the lower elevations of the Coast and Cascade Ranges (Region 1-3) and southern Oregon (Region 4). Increasing wildfire frequency is likely (>66%) in the rest of the state as well.

Increased risk of wildfire is greater at lower elevation wildlands than at higher elevation wildlands. Areas considered wetter with higher vegetation accumulation will be at higher risk due to intensive fuel loading and drier materials.

One proxy for future change in wildfire risk is a fire danger index called 100-hour fuel moisture (FM100), which is a measure of the amount of moisture in dead vegetation in the 1–3 inch diameter class available to a fire. It is expressed as a percent of the dry weight of that specific fuel. FM100 is a common index used by the Northwest Interagency Coordination Center to predict fire danger. A majority of climate models project that FM100 would decline across Oregon by the 2050s (2040–2069) under the higher (RCP 8.5) emissions scenario (Gergel et al., 2017). This drying of vegetation would lead to greater wildfire risk, especially when coupled with projected decreases in summer soil moisture. The number of "extreme" fire danger days—in which fuel moisture is below the 3rd percentile—is projected to increase across the state (**Figure 2-99**), with the largest increases in the eastern third of Oregon (Region 5, 7, 8), the Willamette Valley (Region 2, 3), and lowland areas in southern Oregon (Region 4) (Mote et al., 2019). See Regional Risk Assessments for region-specific projections. Additional prevention and mitigation activities on private, state and federal lands will become more and more crucial as fire seasons change.

Figure 2-99. Projected Change in Frequency of Extreme Fire Danger Days in Summer for 2040–2069 Relative to 1971–2000 under RCP 8.5



Note: "Extreme" fire danger is defined as the number of days when the 100-hour fuel moisture in June- July-August is below the 3rd percentile of days in the baseline period.

Source: Mote et al., 2019

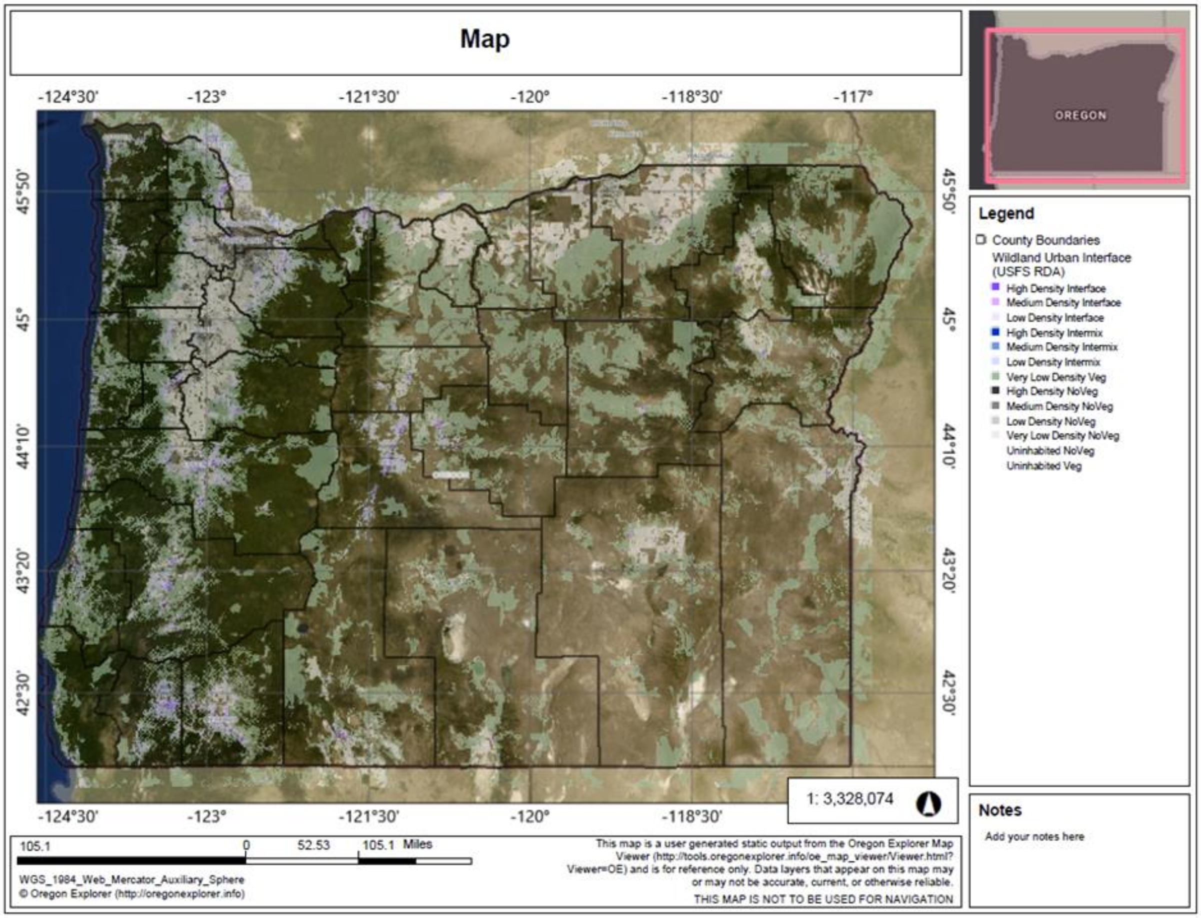
2.2.9.3 Vulnerability

Wildfires are a common and widespread natural hazard that happen annually in Oregon. Fire is a critical component of the forest and rangeland ecosystems found in all regions of the state. Over 41 million acres of forest and rangeland in Oregon are susceptible to wildfire, which now may occur during almost every month of the year. On average, 97% of the fires are suppressed at 10 acres or less. Unfortunately, the remaining 3% of the fires tend to be damaging and very difficult to manage.

The principal type of wildfire affecting Oregon communities is a wildland-urban interface (WUI) fire, which occurs where wildland and developed areas intermingle with both vegetation and structures to provide perfect fuel conditions. As more people have moved into WUI areas, the number of large wildfires impacting homes has escalated dramatically. In addition to WUI fires, Oregon experiences wildland fires that do not threaten structures but may have impacts on timberlands, economy, and habitat.

The wildland-urban interface (WUI) is a focal area for human-environment conflicts such as wildland fires, habitat fragmentation, invasive species, and biodiversity decline. This WUI map (**Figure 2-100**) was made using geographic information systems (GIS), integrating U.S. Census and USGS National Land Cover Data, to map the Federal Register definition of WUI (Federal Register 66:751, 2001) for the conterminous United States from 1990-2010.

Figure 2-100. Wildland-Urban Interface



Source: Oregon Explorer, 2020

Most Vulnerable Communities

In 2006, the Oregon Department of Forestry conducted a Statewide Forest Assessment of the communities at risk to wildfire to determine priorities for delivering landowner assistance. That assessment how now been updated with a new 2020 Communities at Risk Assessment. The new update was done with information taken from the PNW Quantitative Wildfire Risk Assessment (QWRA), Community Wildfire Protection Plans (CWPPs), Federal Registry, University of Wisconsin Silvis WUI data, city limits, towns, and Structural Fire District areas to characterize Oregon wildfire risk and vulnerabilities.

In total, five hundred and four (504) Communities at Risk were identified and assessed for their wildfire risk in Oregon. The number of structures, exposure, burn probability, and hazard were all taken into account in rating the communities.

According to **Table 2-70**, the regions most vulnerable to wildfire are Region 4 and Region 7, followed by Region 6, Region 8, and Region 5.

State-Owned/Leased Buildings and Critical Facilities and Local Critical Facilities

For the 2020 vulnerability assessment, DOGAMI evaluated building exposure to wildfire using the Burn Probability dataset which was classified by ODF in "High," "Moderate," and "Low" categories. Urban areas, lake surfaces, and areas bare of vegetation do not have fire risk classifications in the data and are also represented here as "Low."

Of the 5,530 state facilities evaluated, 1,111 are within the High or Moderate wildfire hazard zone and total about $950 million in value. Three hundred sixty-five state critical facilities are within the High or Moderate wildfire hazard zone. Of the 8,757 local critical facilities evaluated, 955 were in High or Moderate hazard zones with a total value over $775 million.

Historic Resources

Of the 58,872 historic resources statewide, 1,824 are located in areas of high wildfire hazard, with the greatest concentration (38%) in Region 4 and over half of those in Jackson County. Many fewer are located in areas of moderate wildfire hazard. The vast majority are in areas of low wildfire hazard.

Social Vulnerability

The Centers for Disease Control and Prevention (CDC) has calculated a social vulnerability index to assess community resilience to externalities such as natural hazard events. It employs fifteen social vulnerability factors and uses data from the US Census Bureau's American Community Survey. The index is reported in quintiles (1-5). Social vulnerability scores do not vary by hazard. The counties with the greatest social vulnerability statewide are Marion, Morrow, Umatilla, Wasco, Jefferson, Klamath, and Malheur.

For the 2020 vulnerability assessment, DLCD combined this index with the vulnerability scores for state buildings, state critical facilities, and local critical facilities to calculate an overall vulnerability score for each county. According to this limited assessment, Morrow, Wasco, Jefferson, Klamath and Malheur Counties are the most vulnerable to impacts from wildfire hazards. These counties are located in Regions 5, 6, and 8 which are among those identified by ODF as most vulnerable to wildfire.

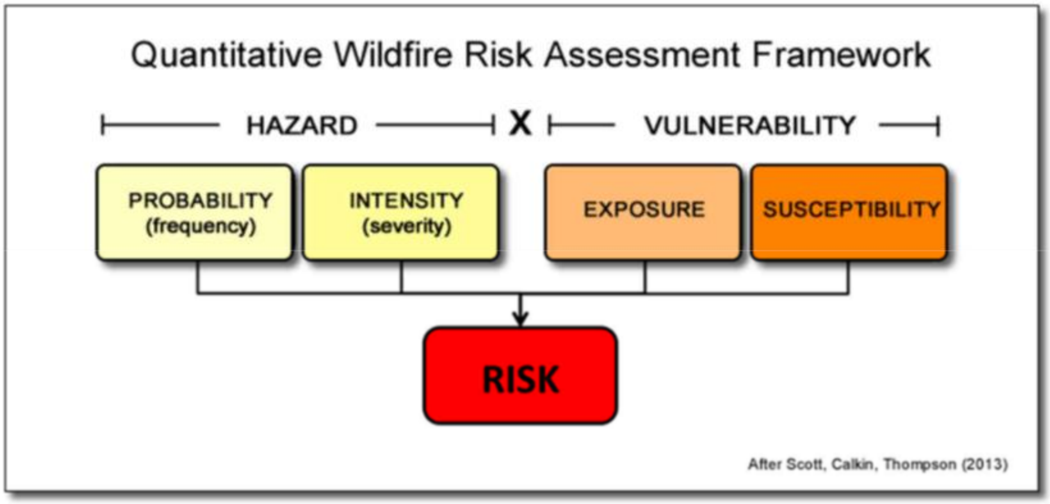
2.2.9.4 Risk

Pacific Northwest Quantitative Wildfire Risk Assessment (QWRA)

At this time, the QWRA is the most up to date assessment for fire risk utilizing the best available science across a range of disciplines for the State of Oregon. The Pacific Northwest QWRA provides foundational information about wildfire hazard and risk to highly valued resources and assets across the region.

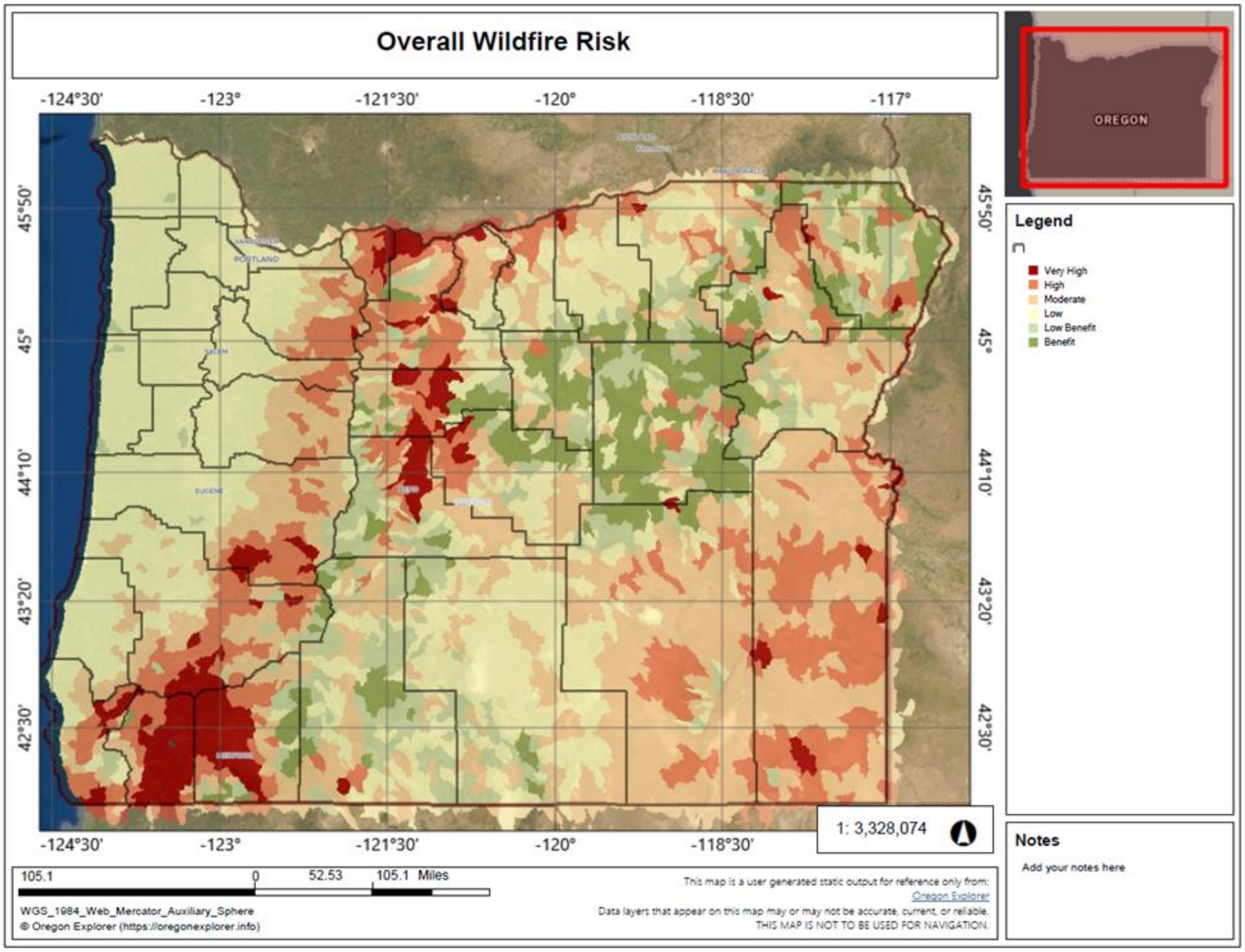
Figure 2-101 shows the general factors that contribute to risk from wildfire according to the QWRA.

Figure 2-101. Quantitative Wildfire Risk Assessment Framework



Overall Wildfire Risk is the product of the likelihood and consequence of wildfire on all mapped highly valued resources and assets combined: critical infrastructure, developed recreation, housing unit density, seed orchards, sawmills, historic structures, timber, municipal watersheds, vegetation condition, and terrestrial and aquatic wildlife habitat. This dataset considers the likelihood of wildfire >250 acres (likelihood of burning), the susceptibility of resources and assets to wildfire of different intensities, and the likelihood of those intensities. The data values reflect a range of impacts from a very high negative value, where wildfire is detrimental to one or more resources or assets (for example, structures, infrastructure, early seral stage and/or sensitive forests), to positive, where wildfire will produce an overall benefit (for example, vegetation condition/forest health, wildlife habitat).

Figure 2-102. Overall Wildfire Risk

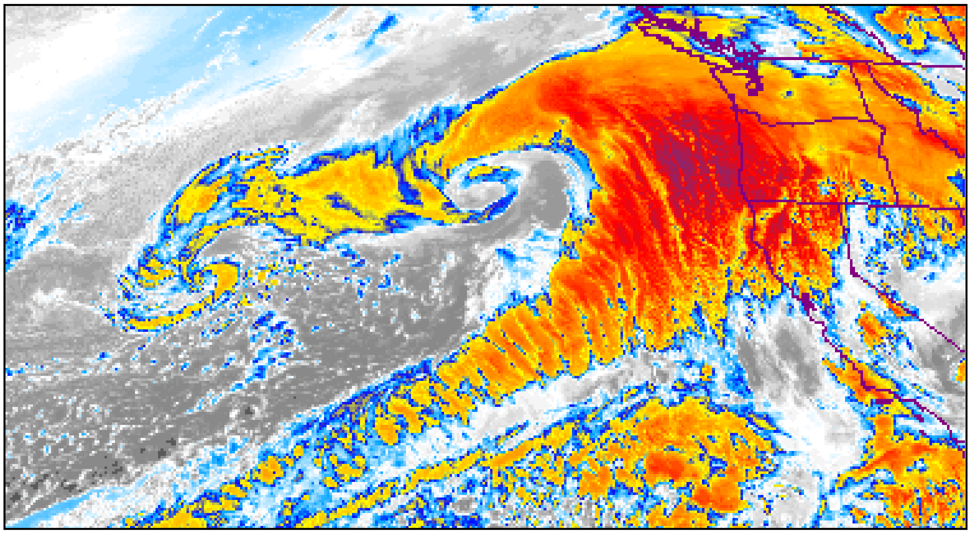


In the 2020 update DOGAMI and DLCD developed a new risk ranking system that combines the probability of the hazard with the limited vulnerability assessment to arrive at a composite risk score referred to as the 2020 Risk Score.

According to the 2020 risk assessment, Regions 4, 5, 6, 7, and 8 are at greatest risk from wildfire hazards. The counties at greatest risk are Douglas, Jackson, Josephine, Hood River, Morrow, Umatilla, Wasco, Crook, Jefferson, Klamath, Lake, Wheeler, Baker, Grant, Union, Harney, and Malheur. This is mostly consistent with **Figure 2-102**, Overall Wildfire Risk.

2.2.10 Windstorms

Figure 2-103. Satellite Image of the Type of Severe Pacific Storm that Can Bring High Winds to Western Oregon



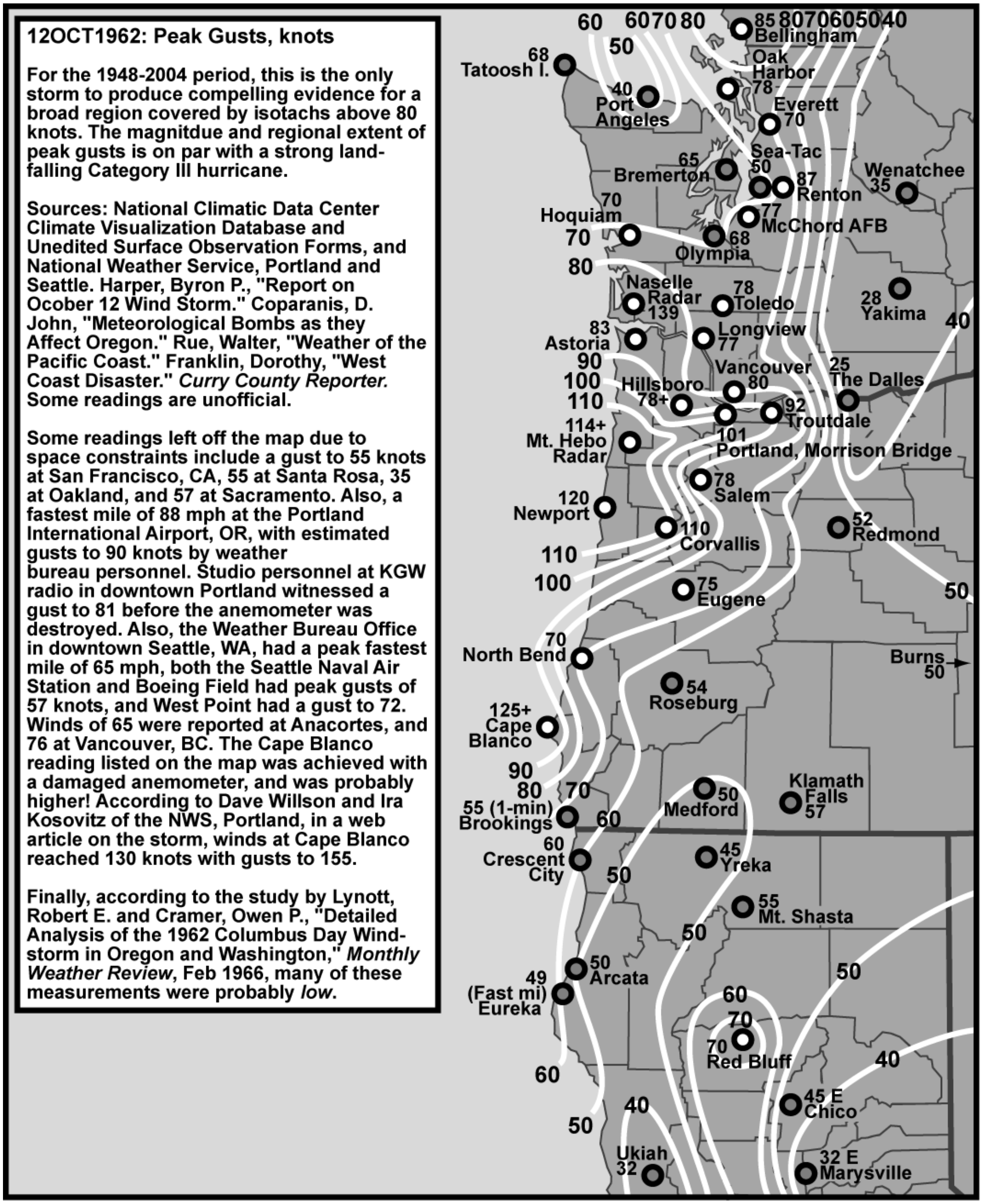
Source: NOAA

This section covers most kinds of windstorm events in Oregon, including the wind aspects of Pacific storm events. The precipitation aspects of Pacific storm events are covered earlier in the **Flood** section. Winds specifically associated with blizzards and ice storms are covered in the **Winter Storm** section.

2.2.10.1 Analysis and Characterization

High winds can be among the most destructive weather events in Oregon; they are especially common in the exposed coastal regions and in the mountains of the Coast Range. Most official wind observations in Oregon are sparse, taken at low-elevation locations where both the surface friction and the blocking action of the mountain ranges substantially decrease the speed of surface winds. Furthermore, there are few long-term reliable records of wind available. Even the more exposed areas of the coast are lacking in any long-term set of wind records. From unofficial, but reliable observations, it is reasonable to assume that gusts well above 100 mph occur several times each year across the higher ridges of the Coast and Cascades Ranges. At the most exposed Coast Range ridges, it is estimated, that wind gusts of up to 150 mph and sustained speeds of 110 mph will occur every 5–10 years.

Figure 2-104. Peak Gusts for Windstorm on October 12, 1962



Source: Wolf Read, Climatologist, Oregon Climate Center, Oregon State University

Pacific storms can produce high winds and often are accompanied by significant precipitation and low barometric pressure. These storms usually produce the highest winds in Western Oregon, especially in the coastal zone. These storms are most common from October through March. The impacts of these storms on the state are influenced by storm location, intensity, and local terrain.

Figure 2-105. Unstable Trees Near Electric Lines Left after a Logging Operation

Note: Unstable trees near electric lines left after a logging operation near electric lines pose a serious threat of personal injury, forest fire, and outages should high winds develop. Forest owners and workers need to coordinate their "leave trees" with electric utilities to prevent dangerous conditions as depicted here.

Photo source: Randy Miller, PacifiCorp

The historian Lancaster Pollard documented exceptional storms that occurred in 1880, 1888, 1920, 1931, and 1962. On January 29, 1920 a hurricane off the mouth of the Columbia River had winds estimated at 160 miles per hour (Pitzer, 1988).

One easterly windstorm that affected much of Oregon, particularly northern Oregon, was the northeasterly gale of April 21-22, 1931. This storm proved to be very destructive. Dust was reported by ships 600 miles out to sea. "While officially recorded wind speeds were not extreme, sustained wind speeds observed were 36 mph at Medford, 32 mph at Portland, 28 mph at Baker, and 27 mph at Roseburg. Unofficial wind measuring equipment reported winds of up to 78 mph. Damage was heavy to standing timber and fruit orchards." (http://www.wrh.noaa.gov/Portland/windstorm.html; for more information on this 1931 storm, see **Appendix 9.1.6**.)

Effects

The damaging effects of windstorms may extend for distances of 100 to 300 miles from the center of storm activity. Isolated wind phenomena in the mountainous regions have more localized effects. Near-surface winds and associated pressure effects exert loads on walls, doors, windows, and roofs, sometimes causing structural components to fail.

Positive wind pressure is a direct and frontal assault on a structure, pushing walls, doors, and windows inward. Negative pressure also affects the sides and roof: passing currents create lift and suction forces that act to pull building components and surfaces outward. The effects of high-velocity winds are magnified in the upper levels of multi-story structures. As positive and negative forces impact and remove the building protective envelope (doors, windows, and walls), internal pressures rise and result in roof or leeward building component failures and considerable structural damage.

Debris carried along by extreme winds can directly contribute to loss of life and indirectly to the failure of protective building envelope components. Upon impact, wind-driven debris can rupture a building, allowing more significant positive and internal pressures. When severe windstorms strike a community, downed trees, power lines, and damaged property are major hindrances to response and recovery.

The most destructive winds are those which blow from the south, parallel to the major mountain ranges. The Columbus Day Storm of 1962 was a classic example of a south windstorm. The storm developed from Typhoon Freda remnants in the Gulf of Alaska, deepened off the coast of California and moved from the southwest, then turned, coming into Oregon directly from the south. This was the most damaging windstorm in Oregon of the last century. Winds in the Willamette Valley topped 100 mph, while in the Coast Range they exceeded 140 mph. The Columbus Day Storm was the equivalent of a Category IV hurricane in terms of central pressure and wind speeds.

In terms of damage, "throughout the Willamette Valley, undamaged homes were the exception, not the rule. In 1962 dollars, the Columbus Day Storm caused an estimated $230 280 million in damage to property in California, Oregon, Washington and British Columbia combined, with $170 200 million happening in Oregon alone. This damage figure is comparable to eastern hurricanes that made landfall in the 1957–1961 time period... The Columbus Day Storm was declared the worst natural disaster of 1962 by the Metropolitan Life Insurance Company. In terms of timber loss, about 11.2 billion board feet was felled... in Oregon and Washington combined" (http://www.climate.washington.edu/stormking/) "The storm claimed 46 lives, injured hundreds more, and knocked power out for several million people" (http://www.wrh.noaa.gov/pqr/info/pdf/pacwindstorms.pdf).

Other Issues

The Hazard Mitigation Survey Team (HMST) Report developed in response to the February 7, 2002 windstorm the recommended that "differences in definitions of easements and allowable practices within them ('easement language') for private versus public, and urban forests vs. rural forests should be resolved." Recent wildfires, particularly the Camp Fire in California (2018), have brought attention to the importance of vegetation management within and adjacent to utility power line right of ways. Many stakeholders are now coming to the table to address the following issues that were highlighted in the report as well as newly identified.

- "Land use actions being proposed by agencies with non-utility interests, which would affect land for which utilities have an interest, should be coordinated and should address vegetation management as it affects utility system operations."
- "Agencies and organizations should be identified to work with federal and state landowners to streamline processes by which electric utilities conduct hazard mitigation work on those lands..." Currently, ODOT issues permits for right-of-way work and ODF issues permits for the use of power equipment in forested areas.

Other areas of ongoing concern from this HMST Report are:

- Under Coordination — Utility providers should receive notification, from property owners, of planned tree-harvesting operations near utility lines.
- Under Vegetation Management — Diseased, damaged, and hazard trees near power lines that could fall or hit utility lines should be removed. Some "leave trees" remaining after new building developments and tree harvesting operations pose a threat to utility line safety and reliability. See **Appendix** 9.1.7, *How to Recognize and Prevent Tree Hazards*, for progress that has been made toward vegetation management issues.
- Under Engineering, Construction, and Compliance — "During initial planning and design of utility lines, identify types of geographic areas already known to pose hazards during windstorms. Inventory and analyze areas of repetitive failures to determine alternate designs and construction methods that will mitigate future damages... Consider selective undergrounding of lines where repetitive tree damage occurs, keeping in mind excavations can undermine tree root zones and create new hazards."

Increasing wildfire probability due to climate change has accelerated the need to resolve the following:

- Access to State and Federal Lands – Many utilities have identified difficulty in gaining access to these lands for vegetation management. The Oregon Department of Forestry is improving its processes to accelerate issuing permits. The Bureau of Land Management (BLM) recently updated and simplified its process for granting access to utility right-of-ways on its lands. BLM processes are consistent across all of the properties it owns. US Department of Forestry has been the most challenging to work with and there is now pressure at the Federal level to simplify and accelerate the permitting process.
- Ability to Remove Vegetation Outside of the Utility Easement — This issue is controversial in forest lands, urban areas, and rural areas. Managers of protected lands are hesitant to disturb the natural ecosystems by removing vegetation that has been identified as a potential hazard. Likewise, individuals in both urban and rural areas are very protective of vegetation that adds beauty and character to an area.

Historic Windstorm Events

Table 2-71. Historic Windstorms in Oregon

Date	Location	Comments
Oct. 1962	W. Oregon and locations east of Cascades, Oregon	Columbus Day Storm: Oregon's most famous and most destructive windstorm; barometric pressure low of 960 mb*
Mar. 1963	W. Oregon	second strongest windstorm in the Willamette Valley since 1950
Oct. 1967	most of western and central Oregon	an intense 977 mb low produced a sudden, destructive blow (*)
Nov. 1981	Oregon coast and N. Willamette Valley, Oregon	back-to-back storms on Nov. 13 and 15
Jan. 1993	North Coast Range, Oregon	Inauguration Day Storm; major disaster declaration in Washington State
Dec. 1995	NW Oregon	FEMA-1107-DR-Oregon (*); strongest windstorm since Nov. 1981; barometric pressure of 966.1 mb (Astoria), and Oregon record low 953 mb (off the coast)
Feb. 2002	south and central coast, Southern Willamette Valley, Oregon	FEMA-1405-DR-Oregon; surprise windstorm
Feb. 2007	NW and central coast and north central Oregon	FEMA-1683-DR-Oregon; severe winter storm with a wind component
Dec. 2007	Oregon coast and Willamette Valley, Oregon	FEMA-1733-DR-Oregon; severe winter storm, including flood and landslide events
Dec. 2015	Regions 1-4	FEMA-4258-DR: severe winter storms, straight-line winds, flooding, landslides, and mudslides
Oct. 2016	Manzanita, Oceanside in Tillamook County	tornadoes; EF2 in Manzanita with estimated damages of $1M; EFU in Oceanside with no damage
Jul. 2018	Portland, Multnomah County	tornado; EF0; damage to trees and homes
Apr. 2019	Curry, Douglas, Linn, Wheeler, Grant, and Umatilla	FEMA-4452-DR: Severe storms, straight-line winds, flooding, landslides, and mudslides
Feb. 2020	Regions 5 and 7: Umatilla, Union, Wallowa Counties	FEMA-4519-DR: Severe storms, tornadoes, straight-line winds and flooding

*For comparison, surface barometric pressures associated with Atlantic hurricanes are often in the range of 910 to 960 mb. The all-time record low sea level barometric pressure recorded was associated with Typhoon Tip in the Northwest Pacific Ocean on October 12, 1979 at 870 mb.

Sources: Oregon Climate Service, http://www.ocs.oregonstate.edu/; Pitzer (1988); https://www.fema.gov/disaster/; https://www.ncdc.noaa.gov/stormevents/; https;//www.weather.gov/pqr/07-01-2019

2.2.10.2 Probability

Extreme weather events are experienced in all regions of Oregon. Areas experiencing the highest wind speeds are the Central and North Coast under the influence of winter low-pressure systems in the Gulf of Alaska and North Pacific Ocean, and the Columbia River Gorge, when cold air masses funnel down through the canyon in an easterly direction. For example, at Crown Point, located about 20 miles east of Portland, easterly winds with a 24-hour average of more than 53 mph and gusts in excess of 120 mph were recorded.

More recently, the coast has seen several tornados. None have been as strong as those experienced in other parts of the country but it is significant to note for Oregon.

Table 2-72. Probability of Severe Wind Events by State of Oregon Natural Hazard Region (One-Minute Average, 30 Feet above the Ground)

Location	25-Year Event *(4% annual probability)*	50-Year Event *(2% annual probability)*	100-Year Event *(1% annual probability)*
Region 1 - Oregon Coast	75 mph	80 mph	90 mph
Region 2 - Northern Willamette Valley	65 mph	72 mph	80 mph
Region 3 - Mid/Southern Willamette Valley	60 mph	68 mph	75 mph
Region 4 - Southwest Oregon	60 mph	70 mph	80 mph
Region 5 - Mid-Columbia	75 mph	80 mph	90 mph
Region 6 - Central Oregon	60 mph	65 mph	75 mph
Region 7 - Northeast Oregon	70 mph	80 mph	90 mph
Region 8 - Southeast Oregon	55 mph	65 mph	75 mph

Source: Oregon Public Utilities Commission

Additional wind hazards occur on a very localized level, due to several down-slope windstorms along mountainous terrain. These regional phenomena known as foehn-type winds, result in winds exceeding 100 mph, but they are of short duration and affect relatively small geographic areas. A majority of the destructive surface winds in Oregon are from the southwest. Under certain conditions, very strong east winds may occur, but these are usually limited to small areas in the vicinity of the Columbia River Gorge or in mountain passes.

The much more frequent and widespread strong winds from the southwest are associated with storms moving onto the coast from the Pacific Ocean. If winds are from the west, they are often stronger on the coast than in interior valleys due to the north-south orientations of the Coast Range and Cascades. These mountain ranges obstruct and slow the westerly surface winds.

High winds occur frequently in Oregon, and they are especially common in coastal regions and in the mountains of the Coast Range between October and March. From unofficial but reliable observations, it is reasonable to assume that gusts well above 100 mph occur several times each year across the higher ridges of the Coast and Cascades Ranges. At the most exposed Coast Range ridges, it is estimated that wind gusts of up to 150 mph and sustained speeds of 110 mph will occur every 5 to 10 years. The Willamette Valley may face 40 to 60 mile per hour winds from a 100 mph+ storm on the coast. Also, the Columbia River Gorge funnels very strong winds, often from east to west.

Climate Change

There is insufficient research on changes in the likelihood of wind storms in the Pacific Northwest as a result of climate change. While climate change has the potential to alter surface winds through changes in the large-scale free atmospheric circulation and storm systems, there is as yet no consensus on whether or not extratropical storms and associated extreme winds will intensify or become more frequent along the Pacific Northwest coast under a warmer climate.

2.2.10.3 Vulnerability

The damaging effects of windstorms may extend for distances of 100 to 300 miles from the center of storm activity. Isolated wind phenomena in the mountainous regions have more localized effects. Near-surface winds and associated pressure effects exert loads on walls, doors, windows, and roofs, sometimes causing considerable damage. When severe windstorms strike a community, downed trees, power lines, and damaged property are major hindrances to response and recovery.

Major windstorms that can impact large areas of the state, like the Columbus Day windstorm of 1962, are relatively rare. These storms can cause major damage to many areas of the state with the Oregon coastal counties typically suffering the most damage from this type of hazardous event.

Most Vulnerable Communities

The Oregon Coast has several relatively harsh storms during the winter months. The seven coastal counties along the Oregon Coast (Region 1) often face 60 to 100 mile an hour winds sometime during the year. Although major damage from these storms is infrequent, the Oregon Coast Region of the state is the most vulnerable to windstorms.

While the coast is experiencing severe winds, the Willamette Valley may also face 40 to 60 mile per hour winds from the same storm. Also, the Columbia River Gorge funnels very strong winds, often from east to west. The Northern Willamette Valley/Portland Metro (Regions 3 and Region 2, respectively) and the Mid-Columbia Region (Region 5) are most vulnerable to the effects of cold and damage from this type of wind event.

Historically, the Oregon communities most vulnerable to windstorm damage and loss overall are Benton, Clatsop, Coos, Columbia, Curry, Douglas, Gilliam, Hood River, Lane, Lincoln, Linn, Marion, Morrow, Multnomah, Polk, Sherman, Tillamook, and Washington.

The identification of communities most vulnerable to windstorms is based on PUC agency staff and OCCRI/OCS staff review.

Social Vulnerability

The Centers for Disease Control and Prevention (CDC) has calculated a social vulnerability index to assess community resilience to externalities such as natural hazard events. It employs fifteen social vulnerability factors and uses data from the US Census Bureau’s American Community Survey. The index is reported in quintiles (1-5). Social vulnerability scores do not vary by hazard. The counties with the greatest social vulnerability statewide are Marion, Morrow, Umatilla, Wasco, Jefferson, Klamath, and Malheur.

Table 2-73. Counties Historically Most Vulnerable to Windstorms and Social Vulnerability

	County	Windstorm Type	Social Vulnerability
Region 1	Clatsop	W, SW, S winds from the Pacific Ocean	2 = Low
	Coos	W, SW, S winds from the Pacific Ocean	4 = High
	Curry	W, SW, S winds from the Pacific Ocean	2 = Low
	Coastal Douglas	W, SW, S winds from the Pacific Ocean	4 = High
	Coastal Lane	W, SW, S winds from the Pacific Ocean	3 = Moderate
	Lincoln	W, SW, S winds from the Pacific Ocean	3 = Moderate
	Tillamook	W, SW, S winds from the Pacific Ocean	2 = Low
Region 2	Columbia	W, SW, S winds from the Pacific Ocean	1 = Very Low
	Multnomah	East winds from the Columbia River Gorge	3 = Moderate
	Washington	Foehn winds	1 = Very Low
Region 3	Benton	Foehn winds	2 = Low
	Lane	Foehn winds	3 = Moderate
	Linn	Foehn winds	4 = High
	Marion	Foehn winds	5 = Very High
	Polk	Foehn winds	3 = Moderate
Region 5	Gilliam	East winds from the Columbia River Gorge	1 = Very Low
	Hood River	East winds from the Columbia River Gorge	3 = Moderate
	Morrow	East winds from the Columbia River Gorge	5 = Very High
	Sherman	East winds from the Columbia River Gorge	1 = Very Low

2.2.10.4 Risk

With respect to natural hazards, risk can be expressed as the probability of a hazard occurring combined with the potential for property damage and loss of life.

The regions and counties listed in **Table 2-73** are not only the most likely to experience windstorms, but also the most vulnerable to their adverse impacts.

Of these counties, Coos County, the coastal portion of Douglas County, and Linn County have high social vulnerability; Marion and Morrow Counties very high. This means that the adverse effects of cold and the damage caused by windstorms will be experienced more intensely among their populations and require more resources for preparation, mitigation, and response.

Therefore, Marion and Morrow Counties are considered the most at risk to windstorms in the state, followed by Coos County, the coastal portion of Douglas County, and Linn County.

2.2.11 Winter Storms

Winter storms are among nature's most impressive spectacles. Their combination of heavy snow, ice accumulation, and extreme cold can totally disrupt modern civilization, closing down roads and airports, creating power outages, and downing telephone lines. Winter storms remind us how vulnerable we are to nature's awesome powers.

For the most part, the wind aspects of winter storms are covered in the **Windstorm** section. Heavy precipitation aspects associated with winter storms in some parts of the state, which sometimes lead to flooding, are covered in the **Flood** section. This winter storms section instead generally addresses snow and ice hazards, and extreme cold.

2.2.11.1 Analysis and Characterization

According to the National Weather Service (2003) —

"Most snowstorms need two ingredients: cold air and moisture. Rarely do the two ingredients occur at the same time over western Oregon, except in the higher elevations of the Coast Range and especially in the Cascades. But snowstorms do occur over eastern Oregon regularly during December through February. Cold arctic air sinks south along the Columbia River Basin, filling the valleys with cold air. Storms moving across the area drop precipitation, and if conditions are right, snow will occur.

However, it is not that easy of a recipe for western Oregon. Cold air rarely moves west of the Cascades Range. The Cascades act as a natural barrier, damming cold air east of the range. The only spigot is the Columbia River Gorge, which funnels the cold air into the Portland area. Cold air then begins deepening in the Columbia River valley, eventually becoming deep enough to sink southward into the Willamette valley. If the cold air east of the Cascades is deep, it will spill through the gaps of the Cascades and flow into the western valleys via the many river drainage areas along the western slope. The cold air in western Oregon is now in place. The trick is to get a storm to move near or over the cold air, which will use the cold air and produce freezing rain, sleet, and/or snow. Sometimes, copious amounts of snow are produced. Nearly every year, minor snowfalls of up to six inches occur in the western interior valleys. However, it is a rare occurrence for snowfalls of over a foot in accumulations [sic]."

Figure 2-106. Troutdale Area—December 1996

Photo source: National Weather Service

Snow is relatively rare along the coast in Oregon. There is, however, a noticeable relationship between latitude and snowfall. **Appendix 9.1.8** shows average annual snowfall at various Oregon stations. Notice, in particular, Crater Lake, one of the snowiest measurement stations in the United States, which once reported nearly 900 inches of snow in one season (Taylor & Hannan, 1999).

Ice storms and freezing rain can cause severe problems when they occur. The most common freezing rain events occur in the proximity of the Columbia Gorge. The Gorge is the most significant east-west air passage through the Cascades. In winter, cold air from the interior commonly flows westward through the Gorge, bringing very cold air to the Portland area. Rain arriving from the west falls on frozen streets, cars, and other sub-freezing surfaces, creating severe problems. As one moves away from the Gorge, temperatures moderate as the marine influence becomes greater and cold interior air mixes with milder west-side air. Thus freezing rain is often confined to areas in the immediate vicinity of the Gorge: Corbett, Troutdale, perhaps as far west as Portland Airport. Downtown Portland and the western and southern suburbs often escape with no ice accumulation (Taylor & Hannan, 1999).

Figure 2-107. Shielded Snow Gauge Used in the Pacific Northwest to Register Snowfall, 1917

Source: National Weather Service

Freezing rain (also known as an ice storm) is rain that falls onto a surface with a temperature below freezing. The cold surface causes the rain to freeze so the surfaces, such as trees, utilities, and roads, become glazed with ice. Even small accumulations of ice can cause a significant hazard to property, pedestrians, and motorists.

Sleet is rain that freezes into ice pellets before reaching the ground. Sleet usually bounces when hitting a surface and does not stick to objects; however, it can accumulate like snow and cause roads and walkways to become hazardous.

Black ice can fool drivers into thinking water is on the road. What they may not realize is that condensation, such as dew, freezes when temperatures reach 32 ˚F or below, forming a thin layer of ice. This shiny ice surface is one of the most dangerous road conditions. Black ice is likely to form under bridges and overpasses, in shady spots and at intersections.

Meteorologists define *heavy snow* as six inches or more falling in less than twelve hours, or snowfall of eight inches or more in twenty-four hours. A *blizzard* is a severe winter weather condition characterized by low temperatures and strong winds blowing a great deal of snow. The National Weather Service defines a blizzard as having wind speeds of 35 mph or more, with a visibility of less than a quarter mile. Sometimes a condition known as a *whiteout* can occur during a blizzard. This is when the visibility drops to zero because of the amount of blowing snow.

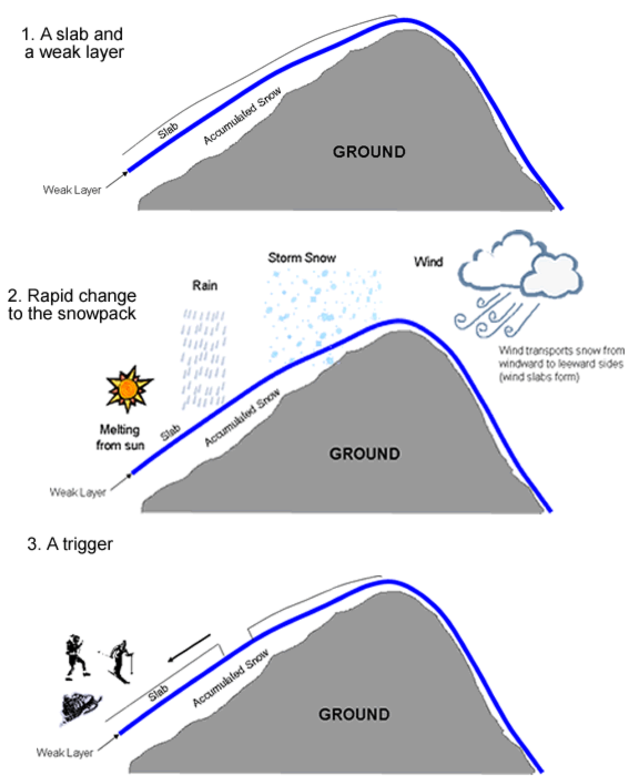
Wind blowing across your body makes you feel colder. The *wind chill* factor is a measure of how cold the combination of temperature and wind makes you feel. Wind chill of 50 °F or lower can be very dangerous: exposed skin can develop frostbite in less than a minute, and a person or animal could freeze to death after just 30 minutes of exposure.

A snow avalanche is a mass of snow falling down a mountain or incline. Three variables interact to determine whether an avalanche is possible:

- *Terrain:* the slope must be steep enough to avalanche,
- *Snowpack:* the snow must be unstable enough to avalanche, and
- *Weather:* changing weather can quickly increase instability.

According to the Northwest Weather and Avalanche Center, avalanches don't happen by accident and most human involvement is a matter of choice, not chance. Most avalanche accidents are caused by slab avalanches that are triggered by the victim or a member of the victim's party. However, any avalanche may cause injury or death and even small slides may be dangerous.

Figure 2-108. Ingredients for a Slab Avalanche



Source: Northwest Weather and Avalanche

On average, about 30 people in the United States are killed in avalanches each year. For the 21 years between 1985 and 2006. With five fatalities, Oregon ranks 10th among the states for avalanche fatalities. This is based on statistics from the Colorado Avalanche Information Center. Avalanche victims are almost exclusively backcountry recreationists — snowmobilers, climbers, snowboarders, snowshoers, skiers, and hikers. Nationally snowmobilers lead the list with twice as many fatalities as any other activity.

According to Portland Mountain Rescue, most avalanche victims triggered the very avalanche that caught them. The group advises people to be aware of the constantly changing conditions in the backcountry and take a certified avalanche class to increase their avalanche awareness.

Ski areas are different from the backcountry. It is very rare for someone to get caught in an avalanche within a ski area. Professional snow safety crews rely on explosives and ski compaction to stabilize ski area snowpack.

Historic Winter Storm Events

Table 2-74. Historic Winter Storms in Oregon

Date	Location	Description
Dec. 16–18, 1884	Linn, Marion, Washington, Multnomah, Hood River and Wasco Counties	heavy snow in the Columbia River Basin from Portland to The Dalles and along the Cascades foothills in the Willamette Valley; 1-day snow totals: Albany, 16.0 inches; The Dalles, 29.5 inches; Portland, 12.4 inches
Dec. 20–23, 1892	Linn, Marion, Washington, Multnomah, and Umatilla Counties	substantial snow across most of northern Oregon; greatest snowfall in the northwest part of the state; totals from 15 to 30 inches with Albany, 15.0 inches; Corvallis, 14.0 inches; Portland, 27.5 inches; Forest Grove, 28.0 inches; Pendleton, 8.0 inches
Jan. 5–10, 1909	Josephine, Jackson, Douglas Lane, Linn, Marion, Clackamas, Hood River, and Wasco Counties	heavy snowfall in mountainous areas; 34.5 inches at Siskiyou Summit; many locations, particularly in western Oregon, received more snow in this 6-day period than they normally would receive in an entire year; snow totals: Ashland, 9.1 inches; Eugene, 15.1 inches; Forest Grove, 29.0 inches; Lakeview, 17.0 inches; Portland, 19.3 inches; The Dalles, 14.5 inches
Jan. 11–15, 1916	Josephine, Jackson, Douglas Lane, Linn, Marion, Clackamas, Hood River, and Waco Counties	5-8 inches of snow in western Oregon, except for the southwestern interior and the coastal areas; McMinnville had the most snow in one day, with 11 inches falling on January 12; another 24 inches at Siskiyou Summit; higher elevations in the Cascades received very heavy snowfall
Jan. 30–Feb. 3, 1916	Hood River, Clackamas, Marion, Wasco, Jefferson, and Multnomah Counties	snow and ice storm along the northern Oregon border; heaviest snowfall in the Hood River Valley with 29.5 inches in one day at Parkdale, and 81.5 inches total; heavy snow especially in the higher Cascades with Government Camp 41.0 inches in a day and storm total of 87.5 inches; the ice inflicted severe damage to electric light, telephone and telegraph companies, fruits and ornamental trees; many locations, earlier snow had not melted, resulting in substantial snow depths
Dec. 9–11, 1919	statewide	one of three heaviest snowfall-producing storms to hit Oregon on record; lowest statewide average temperature since record keeping began in 1890; the Columbia River froze over, closing the river to navigation from the confluence with the Willamette River upstream; nearly every part of the state affected; snow totals (inches): Albany, 25.5; Bend, 49.0; Cascade Locks, 21.5; Eugene, 8.5; Heppner, 16.0; Parkdale, 63.0; Pendleton, 15.0; Siskiyou Summit, 50.0
Feb. 10, 1933	statewide	cold outbreak across state; the city of Seneca, in northeast Oregon, recorded the state's all-time record low temperature of -54 °F; the next day high was nearly 100 degrees warmer at 45 °F

Date	Location	Description
Jan. 31–Feb. 4, 1937	statewide	heavy snowfalls in the western slopes of the Cascades and the Willamette Valley; deep snowdrifts blocked major highways and most minor roads in northern Oregon and passes of the Cascade Mountains for several days
Jan. 5–7, 1942	Columbia, Clackamas, Multnomah, Washington, Marion, Linn, Yamhill, and Polk Counties	considerable sleet, followed by freezing rain in some areas; freezing rain, resulting in heavy accumulations of ice in upper and middle Willamette Valley; roads and streets dangerous for travel, orchard and shade trees damaged, and telephone, telegraph, and power wires and poles broken down.
Mid Jan.–Feb, 1950	statewide	extremely low temperatures injured a large number of orchard and ornamental trees and shrubs, and harmed many power and telephone lines and outdoor structures; severe blizzard conditions and a heavy sleet and ice storm together caused several hundred thousand dollars damage and virtually halted traffic for two to three days; Columbia River Highway closed between Troutdale and The Dalles leaving large numbers of motorists stranded, removed to safety only by railway; damage to orchard crops, timber, and power services, costing thousands in damages.
Jan. 9–20, 1950	Columbia, Washington, Multnomah, Hood River, Wasco, Clackamas, Yamhill, Marion, Polk, Linn, Benton, and Lane Counties	frequent snowstorms throughout January; snow heavier during this January than ever before on record; snow plus high winds created widespread blowing and drifting of snow; deep snowdrifts closed all highways west of the Cascades and through the Columbia River Gorge; sleet 4-5 inches in northwestern Oregon; sleet turned to freezing rain, creating havoc on highways, trees, and power lines; hundreds of motorists stranded in the Columbia River Gorge, only rescued by train; hundreds of thousands of dollars of damage occurred; winds reached 60–70 mph in gusts along the coast and excess of 40 mph in Portland and Grants Pass; outdoor work and school halted due to impeded traffic, down power lines, and community isolation; in Portland 32.9 inches of snow fell (5.8 inches was the January average)
Dec. 5–7, 1950	Washington, Multnomah, Hood River, Wasco, Sherman, Gilliam, Morrow, and Umatilla Counties	severe ice storm with light freezing rain over the Columbia Basin east of the Cascades; heavy ice accretions on trees, highways, power and telephone lines causing accidents due to broken limbs, slippery pavements, and down power lines; heavy snowfall across Oregon; Crater Lake reported 93 inches of snow for December
Jan. 18, 1956	Washington, Multnomah, Hood River, Wasco, Sherman, Gilliam, Morrow, and Umatilla Counties	freezing rain mixed with snow. Ice coated trees, highways, and utility lines; traffic accidents due to slick surfaces; trees heavy with ice broke, sometimes on top of houses
Jan. 11–12, 1960	Columbia, Clackamas, Multnomah, Washington, Marion, Linn, Yamhill, and Polk Counties	light to moderate snows and freezing rain produced dangerous highway conditions; automobile accidents, but no known fatalities; accidents blocked arterial highways, creating serious traffic jams
Jan. 30–31, 1963	Columbia, Clackamas, Multnomah, Washington, Marion, Linn, Yamhill, Polk, Hood River, Waco, Jefferson, and Deschutes Counties	substantial snowfall amplified by moderate to severe icing created hazardous conditions on highways; power lines downed due to ice or felled trees; injuries, one reported death, and statewide school closures due to the icy streets and highways

Date	Location	Description
Jan. 25–31, 1969	Douglas, Coos, Josephine, Jackson, Columbia, Clackamas, Multnomah, Washington, Marion, Linn, Yamhill, and Polk Counties	snowfall records throughout Lane, Douglas, and Coos Counties were surpassed by incredible numbers; 2-3 feet on the valley floors; heavier amounts at higher elevations; at Eugene, a snow depth of 34 inches. Total January snowfall was 47 inches, nearly 7 times the normal monthly snowfall. Roseburg reported 27 inches and monthly snowfall of 35.2 inches; along the coast, where the average snowfall is generally less than 2 inches, January snowfall totals ranged 2-3 feet, with snow depths of 10–20 inches reported; hundreds of farm buildings and several large industrial buildings collapsed under the weight of the heavy wet snow; heavy losses in livestock; entire communities completely isolated for nearly a week; traffic on major highways west of the Cascades and central Oregon halted; total losses estimated $3 to $4 million
Jan. 17–19, 1970	Washington, Multnomah, Hood River, Wasco, Sherman, Gilliam, Morrow, and Umatilla Counties	Stagnant and cold air in the Columbia River Basin east of the Cascades had surface temperatures well below freezing for a week. Ice accumulated on tree branches up to 1.5 inches. Damage was mostly destroyed orchards and utilities.
Nov. 22-23, 1970	Columbia, Washington, Multnomah, Hood River, Wasco, Clackamas, Yamhill, Marion, Polk, Linn, Benton, and Lane Counties	freezing rain across western Oregon, especially in Corvallis, Albany, Salem, Independence, and Dallas; ice accumulations up to 0.5 inches broke thousands of tree limbs and telephone lines; hazardous traffic conditions, power and phone outages, and felled trees
Feb. 4–6, 1972	Columbia, Clackamas, Multnomah, Washington, Marion, Linn, Yamhill, and Polk Counties	several days of sub-freezing temperatures across Oregon followed by warm moist air across northwestern Oregon; glazed roads were hazardous; 140 persons in Portland treated for sprains, fractures or head injuries; some ambulance services doing twice their normal business
Jan. 11–12, 1973	Columbia, Clackamas, Multnomah, Washington, Marion, Linn, Yamhill, and Polk Counties	rains beginning in the Willamette Valley glazed streets and highways in the Portland area and into the Gorge; auto, bus and truck accidents and persons injured in falls; hospitals reported “full house” conditions; glaze of 0.25–0.75 inches in the Portland area
Jan. 1978	Columbia Gorge, Willamette Valley, Portland, Oregon and Vancouver, Washington	over an inch of rain froze, covering everything with ice; power outages (some for more than 10 days); areas east of Portland hit hardest
Jan. 9–10, 1979	Portland and Multnomah Counties	severe ice storm in Portland area as a Pacific storm moved across the state; temperatures ranged from low teens to 33 °F; half inch of rain turned to ice
Jan. 5, 1986	Multnomah, Hood River, Wasco Counties	roads covered with ice and caused power outages to several thousand houses
Feb. 1–8, 1989	statewide	heavy snow across state; up to 6–12 inches of snow at the coast, 9 inches in Salem, more than a foot over the state; numerous record temperatures set; wind chill temperatures 30–60 degrees below 0 °F; power failures throughout state, with home and business damage resulting from frozen plumbing; several moored boats sank on the Columbia River because of ice accumulation; five weather-related deaths (three auto accidents caused by ice and snow, and two women froze to death); damage estimates exceeded one million dollars
Feb. 14–16, 1990	Columbia, Clackamas, Multnomah, Washington, Hood River, Wasco, Marion, Linn, Yamhill, and Polk Counties	24–35 inches of snow in Cascade Locks and Hood River; up to 28 inches in the North Coast Range, 16 inches at Timberline Lodge; the Willamette Valley had 2–4 inches with up to 1 foot in higher hills around Portland; 10-15 inches of snow in the North Coast Range, 20–35 inches in the North Cascades, 1-2 feet in the South Cascades; snow in south-central areas included 9 inches at Chemult, 6–8 in Klamath Falls and Lakeview; 6 inches at Tipton Summit in the northeast mountains and Juntura in the southeast.
Jan. 6-7, 1991	all of eastern Oregon	constant precipitation all over Oregon; freezing rain in Willamette Valley made transportation difficult; two auto fatalities; 1–6 inches of new snow in high ground of eastern Oregon; 12 inches of snow in the Columbia Gorge

Date	Location	Description
Jan. 16–18, 1996	Columbia Gorge, Willamette Valley, Portland, Oregon Columbia, Clackamas, Multnomah, Washington, Hood River, Wasco, Marion, Linn, Yamhill, and Polk Counties	freezing rain with heavy accumulations of glaze ice in the Gorge, Northern Cascades and extreme eastern Portland Metro area; numerous minor traffic accidents due to power outages; freezing rain in the Willamette Valley as far south as Eugene
Feb. 2–4, 1996	Columbia Gorge, Willamette Valley, Portland, Oregon Columbia, Clackamas, Multnomah, Washington, Hood River, Wasco, Marion, Linn, Yamhill, and Polk Counties	ice storm caused disruption of traffic and power outages in the Willamette Valley and Coast Range valleys; freezing rain in the Willamette Valley; traffic accidents, including a 100 car pileup near Salem; one traffic fatality near Lincoln City
Dec. 26–30, 1996	Columbia Gorge, Willamette Valley, Portland, Oregon Columbia, Clackamas, Multnomah, Washington, Hood River, Wasco, Marion, Linn, Yamhill, and Polk Counties	ice storm paralyzed the Portland Metro area and the Columbia Gorge; ice accumulations of 4-5 inches in the Columbia Gorge; I-84 through the Gorge closed for 4 days; widespread electricity outages and hundreds of downed trees and power lines in the Portland area

Date	Location	Description
Dec.28, 2003–Jan. 9, 2004	statewide storm	

DR-1510. $10,289,394 of assistance. Baker, Benton, Clackamas, Clatsop, Columbia, Crook, Deschutes, Douglas, Gilliam, Grant, Harney, Hood River, Jefferson, Lake, Lane, Lincoln, Linn, Malheur, Marion, Morrow, Multnomah, Polk, Sherman, Tillamook, Umatilla, Union, Wallowa, Wasco, Wheeler, Yamhill declared. The most significant winter storm in several years brought snowfall to most of Oregon. The largest snowstorm to hit the Siskiyou Pass in Jackson County in a quarter century. I-5 shut down for nearly a day as ODOT maintenance crews and Oregon State Police troopers dug stranded motorists out of snowdrifts reaching 5-6 feet. Two feet of snow in the Blue Mountains in eastern Oregon. Roadside snow levels exceeded six feet along the Tollgate Highway, OR-204. The eastbound lanes of I-84 closed at Ladd Canyon east of La Grande. Additional segments of I-84 eastbound at Pendleton closed as stranded motorists filled truck stops, motels and restaurants in the La Grande area.

Wet snow on highways in the Willamette Valley, toppled power lines and trees. Oregon 34 east of Philomath closed for 30 hours while crews removed trees. Snow on the Siskiyou Pass made national news and was a top story on the CNN website. 150 miles of I-5 from Ashland to south of Redding, California closed, leaving 100 to 200 vehicles stranded on the Siskiyou Pass overnight. The American Red Cross opened a shelter on the Southern Oregon University campus, and reports out of cities from Redding to Medford confirmed that all motels were full. Emergency service delivered gasoline, food, and water to stranded motorists and hard-to-reach areas. One fatality related to the storm. (Heart attack after helping a stranded motorist.)

I-5 North on the Siskiyou Pass closed for 19 hours. The snow event turned into a major ice storm. Icy roads made driving hazardous. Trees damaged or destroyed by ice adhering to the branches. Downed power lines, often due to falling trees, caused power outages. Businesses, school districts, and government offices closed or hours shortened. Several hundred flights cancelled at the Portland International Airport. Thousands of passengers stranded at the airport. The MAX light rail system also was shut down by the storm. ODOT closed I-84 through the Columbia Gorge twice, for almost 70 hours total. Freight trucks and passenger cars had to detour over Mount Hood where, ironically, road conditions were better than they were in downtown Portland where all vehicles were required to chain up. ODOT closed US-101 over the Astoria Megler Bridge for about 14 hours as large chunks of ice fell off the bridge's superstructure. Many other highways in the state were closed. Freezing rain also in eastern Oregon. Minus 30 degrees reported in Meacham. 60 mph wind gusts in Union County created whiteout conditions, prompting the closure of I-84 between La Grande and Baker City. 2 fatalities.

President Bush issued a major disaster declaration for 26 Oregon counties affected by the winter storm, later extended to 30 of Oregon's 36 counties.

Estimated the cost of damages to public property at $16 million. A frigid arctic air mass, heavy snow, sleet and freezing rain, strong east winds and blizzard conditions through and near the Columbia River Gorge snarled travel, forced school and business closures, and resulted in widespread power outages and properly damage in Northwestern Oregon. 2-6 inches of snow along the North Oregon Coast, 2–8 inches in the Willamette Valley, 5–8 inches in the Portland Metro area, and up to 27 inches in the Cascade Mountains. Up to 2 inches of sleet and freezing rain followed the snowfall.

In Portland this winter storm:

- limited or halted most forms of travel
- resulted in the cancellation of over 1,300 flights at Portland International Airport, stranding 90,000 passengers
- shut down Portland's light rail train system
- closed most businesses and schools

Blizzard conditions in the Columbia River Gorge:

- closed I-84 between Troutdale and Hood River
- closed Washington State Route 14 between Washougal, and White Salmon, Washington
- Halted east-west travel through the Gorge and stranded hundreds of trucks at both ends of the Gorge

Weight from snow and ice buildup:

- downed trees and power lines, leaving 46,000 customers without power, and collapsed roofs at Portland's Gunderson Steel and Rail, Fred Meyer stores in Gateway and Clackamas, and a barn in Forest Grove that killed 4 horses
- collapsed a Scappoose marina roof, sinking 4 boats and damaging many others
- snowfall in the Cascades ranged from 8 inches at Blue Box Pass and Bennett Pass to 27 inches at Timberline Lodge and White River

Date	Location	Description
Mar. 8–10, 2006	Lane, Linn, Benton, Marion, Jefferson, Polk, Yamhill, Clackamas Counties	snow fell up to a few inches at the coast and through the Willamette Valley; 2–4 feet in the Coast Range, Cascades, and Cascade Foothills; many school closures
Jan. 2–Feb. 9, 2008	Hood River, Wasco, Sherman, Gilliam, Morrow, Umatilla, Union, Grant, Baker, Wheeler, Jefferson Deschutes, Crook Counties	heavy snow and freezing rain across eastern Oregon; 5–13 inches of snow; a multi-vehicle accident closed I-84, 15 miles west of Arlington, for 5 hours; 36 Oregon National Guard personnel helped with snow removal in Detroit and Idanha with over 12 feet of record snow. Inmate crews removed snow that cracked walls and collapsed roofs
Dec. 2008	northern Oregon coast	third unusually cold storm system that season with heavy snow in northwest Oregon; heavy snowfall across northwest Oregon; 11–24 inches of snow in the north Oregon Coast Range
Dec. 9–11, 2009	Marion, Linn, Lane Counties	freezing rain covered the central valley with a coating of ice; south of Salem, numerous road closures due to accidents caused by icy roadway; I-84 from Troutdale to Hood River closed for 22 hours
Nov. 29-30, 2010	Hood River, Multnomah, Wasco Counties	4-5 inches of snow reported in Cascade Locks and Hood River; 1/2 inch of ice in Corbett
Jan. 12–18, 2012	Hood River, Wasco Counties	4.5 inches of new snow reported in Hood River; I-84 closed due to ice and snow east of Troutdale
Jan. 2012	Multnomah County	snow and ice east of Troutdale; I- 84 closed for 9 hours
Feb. 6–10, 2014	Lane, Benton, Polk, Yamhill, Columbia, Clackamas, Multnomah, Washington, Linn, Marion, Hood River, Lincoln, Tillamook and Clatsop Counties	DR-4169 Linn, Lane, Benton and Lincoln Counties declared. A strong winter storm system affected the Pacific Northwest during the February 6–10, 2014 time period bringing a mixture of arctic air, strong east winds, significant snowfall and freezing rain to several counties in northwest Oregon; a much warmer and moisture-laden storm moved across northwest Oregon after the snow and ice storm (Feb. 11-14), which produced heavy rainfall and significant rises on area rivers from rain and snowmelt runoff; during the 5-day period Feb. 6–10, 5 to 16 inches of snow fell in many valley locations and 2 to10 inches in the coastal region of northwest Oregon; freezing rain accumulations generally were 0.25 to 0.75 inches; the snowfall combined with the freezing rain had a tremendous impact on the region
Feb. 11–14, 2014	Lane, Benton, Polk, Yamhill, Columbia, Clackamas, Multnomah, Washington, Linn, Marion, Hood River, Lincoln, Tillamook and Clatsop Counties	another weather system moved across northwest Oregon during the February 11–14 time frame; this storm was distinctly different from the storm that produced the snow and ice the week prior and brought abundant moisture and warm air from the sub-tropics into the region; as this storm moved across the area, 2 to 7 inches of rain fell across many counties in western Oregon; the heavy rainfall combined with warm temperatures led to snowmelt and rainfall runoff that produced rapid rises on several rivers, which included flooding on three rivers in northwest Oregon
March 2, 2014	Hood River County, Upper Hood River Valley, Central Columbia River Gorge	East winds brought very cold air from east of the Cascades through the Columbia River Gorge as a moist front pushed in from the Pacific. The combination of the cold air mass and frontal precipitation resulted in snow and ice for the Gorge. There were numerous reports of snow and ice in the Central Columbia River Gorge with generally 6 to 8 inches of snow. There was a quarter of an inch of ice on top of the snow in Hood River and White Salmon, and as much as 0.4 to 0.5 inch of ice in Parkdale where the cold air held on the longest.

Date	Location	Description
Nov. 13, 2014	Clackamas, Marion, Linn, Multnomah and Hood River Counties (North Cascade foothills and Western Columbia River Gorge)	An early cold snap hit the Pacific Northwest before moist Pacific air moved in and resulted in one of the earliest snow, sleet, and freezing rain events in northwestern Oregon. Sleet and freezing rain in particular created hazardous commutes for tens of thousands in the western and eastern suburbs of Portland. Farther south, 1/2 of freezing rain accumulated on trees in the coast range foothills outside of Corvallis and Dallas, Oregon. Upwards of a quarter of an inch of ice fell around Dallas, Oregon. Some snow fell, but accumulations were primarily restricted to the Cascade valleys and the central Columbia River Gorge. Spotters reported around 6 to 8 inches of snow for the Cascade Foothills followed by a quarter of an inch of ice. A combination of heavy snow and ice resulted in slick driving conditions for the Western Columbia River Gorge. Areas in the gorge measured a quarter of an inch of ice whereas other areas had 5 to 8 inches of snow.
Dec. 6–23, 2015	Statewide	DR-4258. Clatsop, Columbia, Multnomah, Clackamas, Washington, Tillamook, Yamhill, Polk, Lincoln, Linn, Lane, Douglas, Coos, and Curry Counties declared. Severe winter storms, straight-line winds, flooding, landslides, and mudslides. On December 12, A series of systems brought heavy precipitation to southern Oregon. Several pacific storm systems moved across the region over the Dec 12-13 weekend from southern Oregon to northeast Oregon. Another series of storms moved across Oregon on Dec 16-17 and Dec 21-23. Each storm system brought several inches of snow to the mountain areas. Snowfall amounts in inches include: 21.0 10 miles west of La Pine, 14.0 at Tollgate, 12.0 13 miles southwest of Mitchell, and 9.0 6 miles east southeast of Granite. Another in a long series of storms brought heavy snow to portions of south central Oregon. The cooperative observer at Chemult reported 17 inches of snow in 24 hours ending Dec. 17th. A narrow but long-lived band of precipitation moved across Wallowa County the morning of December 19th. Several reports of moderate snow occurred over the Joseph and Enterprise areas. Snowfall amounts in inches ranged from 5 to 6 inches, with northern Wallowa County receiving reports of up to 9 inches just outside of Flora. On December 21st heavy snow fell over portions of central Washington and Oregon due to a cold front. Snowfall amounts are as followed: 14" recorded at the Milk Shakes Snotel and 10" in 24 hours 5 miles north northwest of La Pine. Also on the 21st a series of storms made for a long lasting winter storm over southwest and south central Oregon. Initially the heavy snows were limited to higher altitudes...but a colder air mass moved in towards the end of the event and snow fell in areas that rarely see snow...such as the southwest Oregon valley floors. Moist onshore winds produced a steady stream of showers over the foothills of the Cascades with snow levels between 1000 and 2000 feet. This resulted in heavy snow for the Northern Oregon Cascades and Coast Range. At one point after the storm, 25,000 people were without power. Several highways around Crater Lake were closed for a week due to heavy snow and fallen trees blocking the roads.
Mar. 13, 2016	Clackamas, Marion, Linn and Lane Counties (North Oregon Cascades and Cascades in Lane County)	A strong low pressure system generated frequent and persistent snow showers over the northern and central Oregon Cascades. Several SNOTEL stations measured 16 to 24 inches of snow over a 24 to 30 hour period above 3500 feet.

Date	Location	Description
Dec. 8, 2016	Multnomah, Clackamas, Washington, Columbia, and Hood River Counties (Greater Portland Area and Western Columbia River Gorge)	A strong frontal system brought strong east winds to the North Willamette Valley and a mix of snow, sleet, and freezing rain down to the Valley Floor. Four to six inches of snow fell along interstate 84 before turning to sleet and freezing rain. One to 1.5 inches of ice accumulation was also reported. The Portland Metro area generally had 1-2 inches of snow, with 0.2 to 0.3 inch of ice accumulation. Ice accumulations were higher in the West Hills and near the Columbia River Gorge, with 0.8 inch of ice accumulation reported at Council Crest in SE Portland. The NWS Office in Parkrose had 0.4 inch of ice accumulation.
Dec. 14–17, 2016	Lane, Lincoln, Benton, Marion, Clackamas Josephine and Linn Counties (Central Coast Range, Southern Willamette Valley, Cascade foothills in Lane County, Northern Cascade foothills)	DR-4296. Lane and Josephine counties declared. Severe winter storm and flooding. East winds ahead of an approaching low pressure system brought temperatures down below freezing across the area ahead of the approaching precipitation. This lead [sic] to a mix of freezing rain, sleet, and snow across the area. While areas farther north saw more of a snow/sleet mix before a changeover to freezing rain then rain, areas in Lane County saw freezing rain for most of this event, causing power outages, damage to trees, and many car accidents around Eugene and Springfield. Snow [was] followed by sleet and freezing rain. The freezing rain turned into a major ice storm occurred in Eugene and the vicinity with 0.5 to 1.0 inch of ice accumulation observed. There was significant damage to trees and power lines, and fairly widespread power outages across the region. 15,000 people were without power. There was a report of 0.4 inch of ice accumulation near Sodaville.
Dec. 19, 2016	Hood River County (Upper Hood River Valley and Central Columbia River Gorge)	A warmer low pressure system moved into to Northwest Oregon, bringing high winds along the North and Central Oregon Coast. Cold east winds through the Columbia River Gorge continued for the first part of the event, leading to light accumulations of snow and sleet in portions of far northwest Oregon and higher accumulations in the Columbia River Gorge and Hood River Valley. Estimate the Columbia Gorge had around 0.2 to 0.5 inch of ice accumulation as temperatures in the lower 30s with reports of snow and freezing rain in Hood River. A frontal system brought high winds to the Central Oregon Coast, heavy snow to the Cascades and a mix of ice and snow in the Columbia River Gorge and Hood River Valley. SNOTELs and other stations reported a range of 12 to 25 inches of snow. Some specific reports include 25 inches at Mt Hood Meadows, 22 inches at Timberline, 14 inches at Government Camp and 12 inches at McKenzie Snotel.
Dec. 26-27, 2016	Linn, Marion, Clackamas Counties (North Oregon Cascades)	A frontal system brought high winds to the Central Oregon Coast, heavy snow to the Cascades and a mix of ice and snow in the Columbia River Gorge and Hood River Valley. Estimate the Columbia Gorge had around 0.2 to 0.5 inch of ice accumulation as temperatures in the lower 30s with reports of snow and freezing rain in Hood River. SNOTELs and other stations reported a range of 12 to 25 inches of snow in the Cascades. Some specific reports include 25 inches at Mt Hood Meadows, 22 inches at Timberline, 14 inches at Government Camp and 12 inches at McKenzie Snotel.

Date	Location	Description
Jan. 7–10, 2017	Multnomah, Clackamas, Washington, Columbia, Lane, Benton, Polk, Yamhill, Linn, Marion, Josephine and Hood River Counties (Greater Portland Area, Central Coast Range, Central and Southern Willamette Valley, North Cascades foothills, Western and Central Columbia Gorge, Upper Hood River Valley and the Siskiyou Mountains)	DR-4328. Columbia, Hood River, Deschutes and Josephine Counties declared. Severe Winter Storms, Flooding, Landslides, And Mudslides. A storm system moving across southern Oregon produced heavy snow across portions of central and northeast Oregon. Also heavy snow fell over portions of the Columbia River Gorge. A broad shortwave trough brought multiple rounds of precipitation, including a wintry mix of snow and ice for many locations across Northwest Oregon. Strong easterly pressure gradients generated high winds through the Columbia River Gorge as well on January 8. General snowfall totals of 2-4 inches were reported, with the greatest total being 4.5 inches. Major ice accumulations occurred after the snow, with several locations reporting 0.50-1.00. The combination of snow and ice resulted in significant power outages and closures across the area.
Feb. 3-4, 2017	Multnomah and Hood River Counties (Western and Central Columbia River Gorge, Upper Hood River Valley)	Fronts associated with a low pressure system passing north into the Olympic Peninsula brought heavy snow and ice to the Columbia Gorge. The Hood River area reported 4 to 6 inches of snow turning to ice in the western-most part of this zone.
Feb. 8-9, 2017	Wasco, Sherman, Gilliam, Wheeler, Jefferson, Crook, and Grant Counties (Eastern Columbia River Gorge, Eastern Cascades, Central Oregon, Ochoco-John Day Highlands)	A strong Pacific storm system brought snow, sleet and freezing rain to many areas of the Interior Northwest February 7th through 9th. Winter storm produced a total snow accumulation of 5.25 inches with an ice accumulation of 0.25 inches on top of the snow. Occurred 5 miles SSW of Chenoweth in Wasco county.
Dec. 24, 2017	Multnomah and Hood River Counties (Western Columbia River Gorge	Low pressure system moving into the Pacific Northwest pulled cold air from the Columbia Basin west into the Willamette Valley, through the Columbia River Gorge. As this system started to bring moisture and precipitation into NW Oregon, temperatures were around or below freezing, allowing for a mix of snow and ice to fall all the way to the Valley Floor around the Portland Metro, in the Columbia River Gorge, and the Hood River Valley. Local Broadcast Meteorologist reported getting 2.5 inches of snow and 0.2 inch of ice in Corbett. Also, a Skywarn Spotter in Cascade Locks reported getting 4.8 inches of snow.
Feb. 22–26, 2019	Coos, Curry, Douglas, Lane, Deschutes, Jefferson, Wheeler, Wasco, Sherman, Gilliam, Morrow, Umatilla, Crook, Grant, Baker, Malheur and Union Counties (Oregon Coast Range, South and Central Coast, North Central and Central Oregon, Blue Mountains, Eastern Columbia River Gorge, Eastern Cascades, Grand Ronde Valley, Lower Columbia Basin, John Day Basin)	DR-4432. Jefferson, Lane, Douglas, Coos and Curry Counties declared. Severe Winter Storms, Flooding, Landslides, And Mudslides. Persistent troughing off the coast of the Pacific Northwest focused a stream of mid-level moisture over the Inland Northwest resulting in a long duration snow event as the plume drifted north and south several times between the 22nd and 27th of February. Snowfall rates were greatly enhanced over central Oregon with the proximity of a nearly stationary surface boundary where snowfall rates were in excess of 1 inch per hour. The low pressure system moved south into eastern Washington, bringing a cold front southeastward across western Oregon. The front then stalled across the southern Willamette Valley and Lane County Cascades as colder and colder air moved in aloft. What started as rain at low elevations turned to snow during the afternoon of the 23rd. The stalled front kept producing snow over the same areas through the next 24 hours with a direct tap of moisture from the Pacific Ocean. Storm total snowfall amounts were measured at: 40 inches in Sisters, 33 inches in Bend, 30 inches in Redmond, 26 inches in Meacham, 22 inches in Prineville, 21 inches in Elgin, 16 inches in Mitchell, 14 inches in Lostine and La Grande, 12 inches in Pendleton and Joseph and 10 inches in John Day. In Bend a few roofs collapsed under the weight of the snow.

Date	Location	Description
Jan. 15-16, 2020	Multnomah, and Hood River Counties (Western and Central Columbia River Gorge)	A 980 mb low located near 45N/130W along with an attendant warm front moved into the southern Oregon Coast and overran a cold air mass originating from the Columbia River Gorge. This resulted in snow that gradually transitioned to freezing rain in the Gorge on Wednesday night into Thursday. The amounts of snow and ice varied greatly across the Columbia River Gorge, with heaviest amounts in the Central Columbia River Gorge zone. The combination of snow, ice, and wind resulted in the closure of I-84 between Troutdale and Cascade Locks. Based on ODOT and spotter reports, 4 to 10 inches fell in the stretch from Corbett to Cascade Locks, followed by a few hours of light freezing rain. Additionally, east winds gusted to 56 mph at Corbett, with higher gusts at Crown Point (although the anemometer was frozen).

Source: The National Weather Service; https://www.fema.gov/disaster; https://www.ncdc.noaa.gov/stormevents

Figure 2-109. Rescuing Snowbound Vehicles, Old Oregon Trail Highway between Kamela and Meacham, 1923

Source: ODOT

Figure 2-110. Stranded Motorists on I-5 Southbound at Siskiyou Pass, Late December 2003

Note: Vehicles being towed out the "wrong way."
Source: ODOT

Figure 2-111. Detroit, Oregon, February 2, 2008, Buried from the 12 Feet of Snow

Source: ODOT

Figure 2-112. Trees Collapse from Weight of the Snow on Oregon 62 near Prospect, February 2, 2008

Source: ODOT

2.2.11.2 Probability

Winter storms occur annually in Oregon bringing snow to Oregon's mountains and much of Eastern Oregon. These winter storms are welcomed by Oregon's skiers and the ski industry and are tolerated by people traveling the numerous mountain passes and Eastern Oregon highways kept open during the winter by the Oregon Department of Transportation. Approximately every 4 years, winter storms bring extreme cold temperatures, snow, sleet and ice to Oregon's western valley floors. Because these storms are infrequent and tend to last only a few days, residents in western Oregon are often unprepared for such events.

One issue concerns the fact that there is not a statewide effort regarding winter storm impacts, either historical or for future planning. There are only limited snowfall sensors distributed mainly through the mountain ranges of the state and there is not an annual tracking system in place for snowfall statewide. A program of statewide snowfall sensors would allow us to better understand the impact of winter storms on Oregon and have a better means of predicting potential impacts in the future.

The American Society of Civil Engineers has developed a 50-year recurrence interval map of Oregon showing probabilities for ice thickness caused by freezing rain (ASCE-7-02, 2003a), found at: http://www.americanlifelinesalliance.com/pdf/PipecommFinalPosted061705.pdf

According to the Northwest Weather and Avalanche Center (NWAC), experts on the subject aren't able to predict, nor do they completely understand each and every avalanche occurrence. Regional avalanche centers across the country do have the technology to forecast avalanche danger. These forecasts are valuable tools in reducing danger to people. However, no matter what forecasts indicate even the smallest avalanche can be injurious or life threatening!

Avalanche danger ratings levels have been adopted within North America (with slight changes in Canada) and are generally accepted internationally. These levels are:

Low Avalanche Danger (green): Natural avalanches very unlikely. Human triggered avalanches unlikely. Generally stable snow. Isolated areas of instability. Travel is generally safe. Normal caution advised.

Moderate Avalanche Danger (yellow): Natural avalanches unlikely. Human triggered avalanches possible. Unstable slabs possible on steep terrain. Use caution in steeper terrain on certain aspects.

Considerable Avalanche Danger (orange): Natural avalanches possible. Human triggered avalanches probable. Unstable slabs probable on steep terrain. Be increasingly cautious in steeper terrain.

High Avalanche Danger (red): Natural and human triggered avalanches likely. Unstable slabs likely on a variety of aspects and slope angles. Travel in avalanche terrain is not recommended. Safest travel on windward ridges of lower-angle slopes without steeper terrain above.

Extreme Avalanche Danger (red with black border): Widespread natural or human triggered avalanches certain. Extremely unstable slabs certain on most aspects and slope angles. Large destructive avalanches possible. Travel in avalanche terrain should be avoided and travel confined to low-angle terrain well away from avalanche path runouts.

Based on the information in Table 2-26, Regions 2, 3, and 5, are considered to have very high probability of severe winter storm occurrence, followed Regions 6, 7, and 8 with high probability, Region 4 with moderate probability, and Region 1 with low probability.

Climate Change

There is no current research available about changes in the incidence of winter storms in Oregon due to changing climate conditions. However, the warming climate will result in less frequent extreme cold events and high-snowfall years.

Figure 2-113. Trucks Wait Out Winter Storm

Note: Trucks wait at a truck stop in Troutdale after ice, wind, and snow caused ODOT to close I-84 through the Columbia River Gorge – January 2004

Photo source: William Hamilton, *The Oregonian*

2.2.11.3 Vulnerability

A major winter storm can last for days and can include high winds, freezing rain or sleet, heavy snowfall, and cold temperatures. People can become marooned at home without utilities or other services. Severe cold can cause much harm. It can damage crops and other vegetation and freeze pipes, causing them to burst. Unusually cold temperatures are especially dangerous in areas not accustomed to them because residents are generally unprepared and may not realize the dangers severe cold presents.

Heavy snowfall and blizzards can trap motorists in their vehicles and make walking to find help a deadly mistake. Heavy snow can immobilize a region and paralyze a city, stranding commuters, closing airports, stopping the flow of supplies, and disrupting emergency and medical services. Accumulations of snow can cause roofs to collapse and knock down trees and power lines. Homes and farms may be isolated for days. In rural areas, unprotected livestock can be lost. In urban areas, the cost of snow removal, damage repair, and lost business can have severe economic impacts.

When an ice storm strikes, some landscape trees seem to be able to come through with only minor damage, while others suffer the loss of large limbs or sizable parts of their branching structure. In the worst cases, trees may be completely split in two or may have nothing left standing but a trunk. If a tree has been weakened by disease, there may be little that can be done to prevent major breakage or loss when the stresses of a storm occur. However, there are preventive measures that cities and property owners can take to help their trees be stronger and more resistant to storm damage. For more information, see **Appendix 9.1.9**, *Reducing Ice Storm Damage to Trees*.

Heavy accumulations of ice can bring down trees and topple utility poles and communication towers. Ice can disrupt power and communication for days while utility companies repair extensive damage. Even small accumulations of ice can be dangerous to motorists and pedestrians. Bridges and overpasses are particularly dangerous because they freeze before other surfaces.

Exposure to cold can cause frostbite and life-threatening hypothermia. Frostbite is the freezing of body tissue. It most frequently affects fingers, toes, earlobes, and the tip of the nose. Hypothermia begins to occur when a person's body temperature drops three degrees below normal temperature. On average, a person begins to suffer hypothermia if his or her temperature drops to 96 °F (35.6 °C). Cold temperatures can cause hypothermia in anyone who is not adequately clothed or sheltered in a place with adequate heat. Hypothermia can kill people, and those who survive hypothermia are likely to suffer lasting ill effects. Infants and elderly people are the most susceptible. Elderly people account for the largest percentage of hypothermia victims, many of whom freeze to death in their own homes. Most of these victims are alone and their heating systems are working improperly or not at all. People who take certain medications, who have certain medical conditions, or who have been drinking alcohol also are at increased risk for hypothermia.

Driving can be tricky in the snow, but once a storm has passed, there is another danger: flying snow from trucks and cars. When snow is warmed by the vehicle, it will begin to melt. Wind and motion cause sections to break off and hit other vehicles. The snow can also fall on the road, melt, and later turn into ice.

Winter storms are considered deceptive killers because most winter storm deaths are related only indirectly to the storms. Overall, most winter storm deaths result from vehicle or other transportation accidents caused by ice and snow. Exhaustion and heart attacks brought on by overexertion are two other common causes of deaths related to winter storms. Tasks such as shoveling snow, pushing a vehicle, or even walking in heavy snow can cause a heart attack, particularly in people who are older or who are not used to high levels of physical activity. Home fires occur more frequently in the winter because people do not take the proper safety precautions when using alternative heat sources. Fires during winter storms present a great danger because water supplies may freeze and it may be difficult for firefighting equipment to get to the fire. In addition, people can be killed by carbon monoxide emitted by fuels such as charcoal briquettes improperly used to heat homes (National Disaster Education Coalition, 2004).

One issue is the lack of a statewide effort regarding winter storm impacts, either historical or for future planning. There are only a few snowfall sensors distributed mainly through the mountain ranges of the state and there is not an annual tracking system in place for snowfall statewide. A program to install snowfall sensors and track snowfall statewide would allow us to better understand the impact of winter storms on Oregon and have a better means of predicting potential impacts in the future.

Most Vulnerable Communities

The Oregon Department of Transportation (ODOT) is the agency with primary oversight of the winter storm hazard. Based on agency staff review of the available hazard data, ODOT lists the Northern Willamette Valley (Linn, Benton, Marion, Polk, and Yamhill Counties), the Portland

Metro Region (Columbia, Washington, Multnomah, and Clackamas Counties), and the Mid/Southern Willamette Region (Lane, Douglas, Josephine, and Jackson Counties) as the most vulnerable to damage and loss associated with winter storms because Oregon's most densely populated cities are located within these regions.

The Portland Metro area is the most vulnerable not only because it is the most densely populated but also because of its proximity to the Columbia River Gorge. It is not uncommon to have severe ice and sleet storms occurring as cold artic winds blow down the Gorge over east Multnomah County and Portland. These storms have delayed air traffic and even closed the Portland International Airport in the past, thus negatively affecting Oregon's economy. Winter storms often bring ice and sleet that makes driving extremely dangerous. Ice and sleet storms can cripple the movement of goods and services, thus negatively impacting Oregon's economy.

National Weather Service winter storm reports were used as the basis for determining community vulnerabilities. Unfortunately there is only the NWS storm information available for analysis. There is no statewide winter storm program to study the impacts of these storms statewide. There is no program to identify annual average snowfalls across the state either historical or for planning purposes. Hydrological precipitation information is available but not winter storm and snowfall information.

Social Vulnerability

The Centers for Disease Control and Prevention (CDC) has calculated a social vulnerability index to assess community resilience to externalities such as natural hazard events. It employs fifteen social vulnerability factors and uses data from the US Census Bureau's American Community Survey. The index is reported in quintiles (1-5). Social vulnerability scores do not vary by hazard. The counties with the greatest social vulnerability statewide are Marion, Morrow, Umatilla, Wasco, Jefferson, Klamath, and Malheur.

Marion County, being very vulnerability to property damage and loss of life from winter storms as well as having very significant social vulnerability, is the county most vulnerable in the state to the effects of winter storms.

2.2.11.4 Risk

With respect to natural hazards, risk can be expressed as the probability of a hazard occurring combined with the potential for property damage and loss of life. Regions 2 and 3 have the greatest probability and greatest vulnerability, and therefore are at the greatest risk from the adverse effects of winter storms. Marion County carries the greatest risk of any Oregon county.