State of Oregon
Oregon Department of Geology and Mineral Industries
Ruarri J. Day-Stirrat, State Geologist

OPEN-FILE REPORT O-25-09

DEBRIS FLOW HAZARD, RISK, AND RISK REDUCTION IN THE EAGLE CREEK, BEACHIE CREEK-LIONSHEAD, HOLIDAY FARM, AND ARCHIE CREEK FIRE AREAS, MULTNOMAH, HOOD RIVER, MARION, LANE, AND DOUGLAS COUNTIES, OREGON

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2025

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DISCLAIMER

WHAT IS IN THIS REPORT?

This paper evaluates channelized debris flow hazard and risk within the 2017 Eagle Creek Fire and the 2020 Beachie Creek-Lionshead, Holiday Farm, and Archie Creek fires, Oregon. The intended audience for this paper includes those in government, industry, academia, and the public.

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https://experience.arcgis.com/experience/3da30bdf3b6442d09f5a4937e00245b1

GEOGRAPHIC INFORMATION SYSTEM (GIS) DATA

See the digital publication folder for files.
Geodatabases are Esri® version 10.1 format. Metadata is embedded in the geodatabase and is also provided as separate .xml format files.

Eagle_Creek_Region.gdb, Beachie-Lionshead_Region.gdb, Holiday_Farm_Region.gdb, Archie_Creek_Region.gdb:

Study Area (polygon)
Initiation (raster)
Transport (polyline)
Basins (polygon)
Typical Inundation (raster)
Intermediate Inundation (raster)
Extreme Inundation (raster)
Avulsion Inundation (raster)

Feature dataset: Asset Inventory

Buildings-People (polygon)
Local Roads (polyline)
Highways (polyline)
Campgrounds (polygon)

Feature dataset: Debris Flow Inventory

Prefire Initiation Points (point)
Prefire Transport Lines (line)
Prefire Study Area (polygon)
Postfire Initiation Points (point)*
Postfire Transport Lines (line)*
Postfire Study Area (polygon)*
Deposits (polygon)

**These datasets are not included in the Eagle Creek region. They were previously published and available in Burns and others (2025) Multitemporal Lidar Analysis of Pre- and Post-Eagle Creek Fire Debris Flows, Western Columbia River Gorge, Special Paper 55.*

UNITS OF MEASUREMENT

The intended audience for this report includes government, industry, academia, and the public. Therefore, we selected U.S. Customary units as the primary units. A conversion table for U.S. Customary units to SI (International System) Metric units is included for easier conversion where needed.

SI (International System) Metric to U.S. Customary Units

	Original Units	Conversion Equation	To Obtain
length:	millimeter (mm)	mm × 0.039	inch (in)
	centimeter (cm)	cm × 0.394	inch (in)
	meter (m)	m × 3.281	foot (ft)
	meter (m)	m × 1.094	yard (yd)
	kilometer (km)	km × 0.621	mile (mi)
area:	square kilometer (km^2)	km^2 × 0.386	square mile (mi^2)
volume:	cubic meter (m^3)	m^3 × 35.315	cubic ft (ft^3)
	cubic meter (m^3)	m^3 × 1.308	cubic yard (yd^3)
	cubic kilometer (km^3)	km^3 × 0.240	cubic mile (mi^3)

U.S. Customary Units to SI Metric Units

	Multiply	By	To obtain
length:	inch (in)	in × 25.4	millimeter (mm)
	inch (in)	in × 2.54	centimeter (cm)
	foot (ft)	ft × 0.305	meter (m)
	yard (yd)	yd × 0.914	meter (m)
	mile (mi)	mi × 1.609	kilometer (km)
area:	square mile (mi^2)	mi^2 × 2.590	square kilometer (km^2)
volume:	cubic ft (ft^3)	ft^3 × 0.028	cubic meter (m^3)
	cubic yard (yd^3)	yd^3 × 0.765	cubic meter (m^3)
	cubic mile (mi^3)	mi^3 × 4.168	cubic kilometer (km^3)

EXECUTIVE SUMMARY

Channelized debris flows (CDFs) are one of the most widespread and damaging natural hazards in Oregon. They can destroy buildings and infrastructure and move rapidly, faster than a person can run, and thus pose a threat to life safety. In September 2020, the Labor Day megafires burned a large portion of the debris flow-prone Oregon Cascades and then, only months later in January 2021, a debris flow in the Columbia River Gorge initiating from the area scorched in the 2017 Eagle Creek Fire (termed a postfire debris flow) resulted in a fatality. The combination of the two devastating events encouraged the Oregon Department of Geology and Mineral Industries (DOGAMI) to propose the project described in this report to the Federal Emergency Management Agency (FEMA). Funding for this project was provided by FEMA grant number EMS-2021-CA-00011.

The purpose of this project is to identify areas susceptible to CDFs and postfire CDFs, analyze the potential assets at risk, and develop a road map to risk reduction in collaboration with the communities. To accomplish this purpose, we performed 4 primary tasks:

1. Mapping past CDF events and deposits,
2. Modeling future CDF susceptibility,
3. Risk analysis,
4. Development of a road map to risk reduction.

The mapping revealed 2,009 CDF deposition areas (fans) and hundreds of historic and prehistoric CDF events within each study region. The modeling resulted in the creation of three inundation zones: Typical, Intermediate, and Extreme. We identified the need to add an additional inundation zone to identify areas of potential avulsion. The results of the inundation and avulsion modeling are displayed in each study region in Appendices A-D and via the online interactive map.

For the risk analysis, we compiled and created datasets that included buildings, permanent population distribution, critical facilities, land use, roads, and campgrounds. The asset dataset results are summarized by communities within each of the four study regions. The primary results of the risk reduction activities include:

- Compiled list of previously published reports and fact sheets with recommendations for risk reduction
- Community meetings
- Roadmaps to risk reduction

Although we cannot predict when and where the next CDF events will occur, we were able to provide detailed maps of areas previously impacted by historic and prehistoric CDFs and model where future CDFs are more and less likely to occur. We conclude that central and eastern portions of the study regions are generally more susceptible to CDFs and postfire CDFs, depending on the exact locations burned. We mapped 1,061 CDFs and 450 postfire CDFs in the study area, which indicates a relatively high CDF hazard.

The overall annualized rate of pre-fire CDFs for all four study regions is approximately 44 CDFs/year with a range from 6–20 CDFs/year for the individual study regions. The overall annualized rate of postfire CDFs for all four study regions is approximately 129 CDFs/year with a range from 25–58 CDFs/year for the individual study regions. These rates may be slightly less than reality because of limitations of mapping with aerial photos in Western Oregon, but the differences in rates are likely more accurate. The main conclusion is the CDF rates go up in areas that have burned.

1.0 INTRODUCTION AND BACKGROUND

CDFs are one of the most widespread and damaging natural hazards in Oregon. They can destroy buildings and infrastructure and move rapidly, faster than a person can run, and thus pose a threat to life safety. In September 2020, the Labor Day megafires burned a large portion of the debris flow-prone Oregon Cascades and then only months later in January 2021, a debris flow initiating from the 2017 Eagle Creek Fire scorched Columbia River Gorge (termed postfire debris flow) resulted in a fatality. The combination of the two devastating events encouraged DOGAMI to propose the project described in this report to FEMA. Funding for this project was provided by FEMA grant number EMS-2021-CA-00011.

Several years before and during this project, two related studies (Burns and others, 2022; Burns and others, 2025) were published through DOGAMI. Some of the text from these two studies is repurposed and cited in this report.

1.1 Study Area and Purpose

The study area consists of four discrete regions/fire areas: Eagle Creek Fire, Beachie Creek-Lionshead Fire, Holiday Farm Fire, and Archie Creek Fire (**Figure 1-1**). All four areas are within the Oregon Cascades Range, specifically the Western Cascades Geologic Province, which is generally very prone to CDFs. For example, there were thousands of CDFs in the Cascades during the 1996–1997 storms (Hofmeister, 2000). The province is generally characterized as older, deeply incised volcanic deposits (Darin and others, 2025). The Western Cascades Geologic Province ranges in elevation from approximately 1,000 ft to 6,000 ft. The Appendices of this report have more detailed study area maps for each of the study areas.

The four study areas are all located along east-to-west flowing rivers. They also have primary east-west transportation corridors paralleling the rivers. These transportation corridors connect the Willamette Valley to Eastern Oregon (**Figure 1-1**). There are many communities located along these rivers/transportation corridors, including both cities and unincorporated communities within the counties. For example, in the Archie Creek Fire study area there are 856 buildings and 540 permanent residents (details for all communities are presented in the methods and results sections and appendices of this report). There is also a lot of infrastructure in the study areas, including campgrounds, water reservoirs and distribution conduits, and electric generators and transmission equipment.

Figure 1-1. Map of the four study areas: Eagle Creek Fire, Beachie Creek-Lionshead Fire, Holiday Farm Fire, and Archie Creek Fire.

The Western Cascades Geologic Province receives between 60 in–160 in of precipitation annually, with most falling as rain between October and May (PRISM, 2004) and some falling as snow, especially in the upper elevations. Most historic CDFs in Western Oregon were triggered during long-duration (i.e., 24 hours or more) atmospheric river (AR) storms (Burns and others, 2022). AR storms are relatively long, narrow bands of high water vapor in the atmosphere (rivers in the sky) (https://www.noaa.gov/stories/what-are-atmospheric-rivers). When ARs make landfall, they condense water vapor resulting in precipitation in the form of rain or snow. In Western Oregon, many of the ARs transport large amounts of water vapor from the relatively warmer and wetter tropics. ARs can also bring a rapid and substantial temperature increase because they are sourced from warmer latitudes. ARs can influence snow melt by causing a rapid increase in temperature from below freezing to well above freezing combined with an increase in wind, both of which are known to cause rapid snowmelt and subsequently, the addition of water into the ground (Hatchett, 2018).

The purpose of this project is to identify areas susceptible to CDFs and postfire CDFs, analyze the potential assets at risk, and develop a road map to risk reduction in collaboration with the communities. To accomplish this purpose, we performed four primary tasks:

1. Mapping past CDF events and deposits
2. Modeling future CDF susceptibility
3. Risk analysis
4. Development of a road map to risk reduction

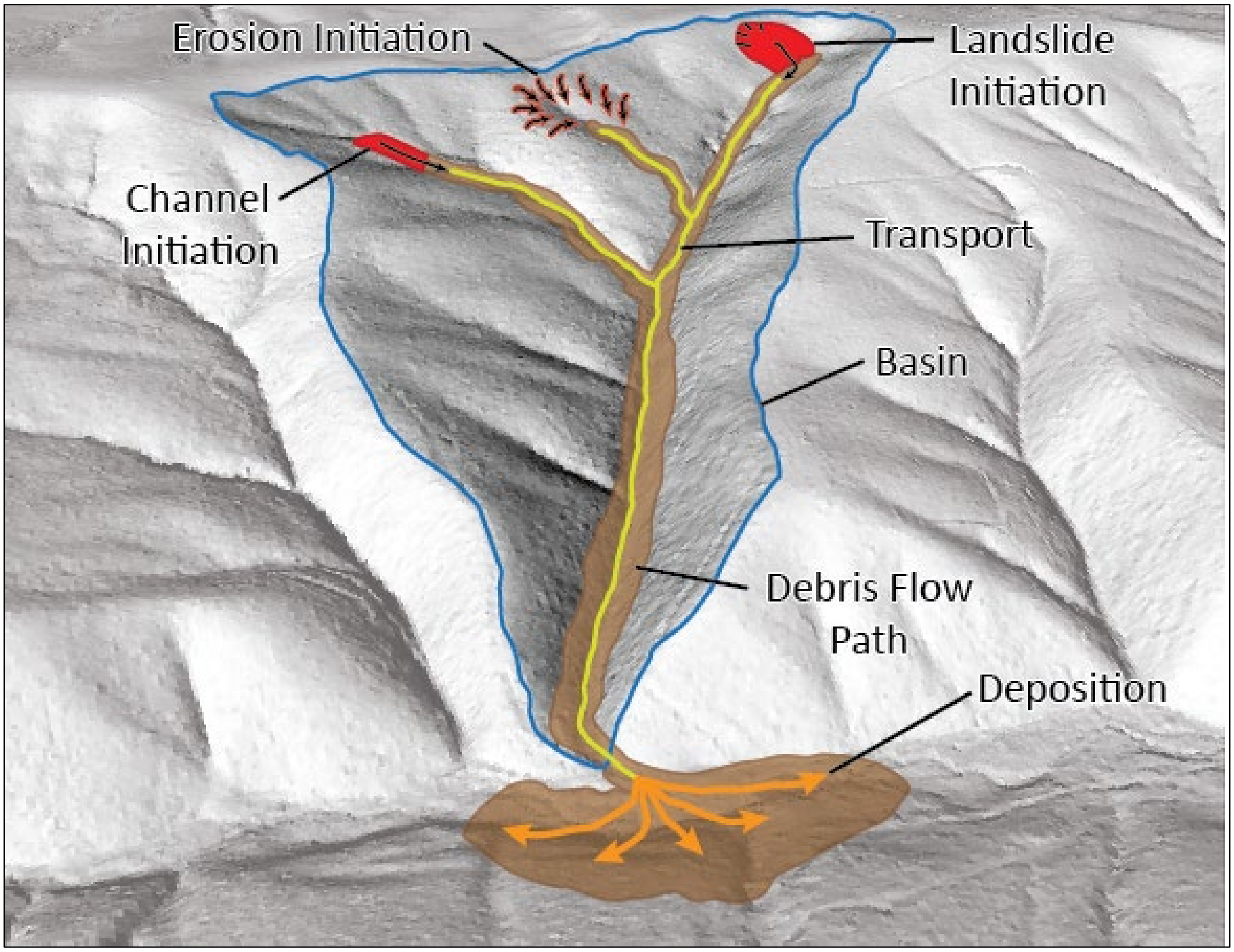
1.2 Debris Flows and Postfire Debris Flows Described

CDFs are complicated landslide processes, typically associated with periods of heavy rainfall. For a general factsheet giving details on CDF features, see Pierson (2005; https://pubs.usgs.gov/fs/2004/3142/pdf/fs2004-3142.pdf). CDFs commonly start in three basic ways: 1) a shallow landslide entering a channel, 2) erosion of the slopes adjacent to the channel through rilling, or 3) erosion directly within a channel or in colluvium-filled hollows (Reid and others, 2016).

As the CDF continues down the channel, it erodes sediment in the channel, which commonly results in volume growth of the CDF. Additional water and sediment can add to the CDF volume along the channel path or additional CDF pulses can form in adjacent channels and coalesce with the main flow. When the CDF reaches the mouth of the channel, it tends to run out onto the flatter unconfined ground forming a deposit with a consistency similar to wet cement (**Figure 1-2;** Burns and others, 2022). Commonly, as CDFs transport down a channel, they grow in volume through erosion of sediments and debris on the channel bed and/or banks, rilling and surface erosion of slopes adjacent to a channel, or coalescence with neighboring CDFs, along with the addition of water (Reid and others, 2016). As they continue to down the channel, they can accelerate to speeds of tens of miles per hour, depending on material properties, confinement, and channel gradient. The transport process can reach relatively long distances, depending on the morphology of the channel. For example, some CDFs travel more than a mile down a channel before they stop (Burns and others, 2022).

When CDFs reach an unrestricted area, such as a canyon mouth, debris spreads out and slows down over the flatter, unconfined ground surface, commonly forming a fan-shaped run-out deposit (**Figure 1-2**). CDFs tend to occur in the same channels repeatedly, because the factors leading to CDFs are all present. Thus, CDF fans can be made up of material deposited in many events, stacking and accumulating over a long period of time (Burns and others, 2022). Sometimes, when the CDF reaches the fan, the flow path shifts, abandoning the established channel and creating a new flow path in a process termed avulsion.

Figure 1-2. Illustration displaying the three different types of CDF initiation, along with transport and deposition. Note that the different types of CDF initiation do not commonly occur together. If initiation starts in a channel or enters a channel, it can lead to transport. Transport can happen with or without erosion or volume increase. Most commonly, erosion happens during transport and the debris flow grows as it moves down channel. When the debris flow reaches the mouth of the channel, it tends to spread out, forming a fan-shaped deposit (deposition area) (Burns and others, 2022).



The CDF process is part of a continuum of mass movement to riverine processes that range from a CDF, to hyperconcentrated flow, to water flood. For context: CDFs generally have more than 50% sediment, hyperconcentrated flows have 20%–60% sediment, and water floods have less than 5%–10% sediment (Pierson, 2005). Because of this continuum, it is sometimes difficult to use field evidence to determine which process occurred. Sometimes, the process is a combination, changing back and forth from CDF to hyperconcentrated flow during the transport stage (Burns and others, 2022).

Wildfires can contribute to an increased frequency and magnitude of CDFs. The USGS Landslide Hazard Program has a specific team focused on postfire debris flows through its Emergency Assessment of Post-Fire Debris Flow Hazards (https://landslides.usgs.gov/hazards/postfire_debrisflow/) (Burns and others, 2022). The USGS began using operational debris flow hazard assessment models in 2010, based on a suite of data collected from postfire debris flows in the 1990s and early 2000s (Cannon and others, 2010). Most of the research was performed in the drier climate regions of the United States. Postfire landscapes in drier climate regions can produce infiltration-excess overland flow during rainfall stemming from hydrophobicity, a lack of canopy interception, and a reduction in roughness from lack of ground cover (litter or duff, decaying organic matter on the forest floor (Hoch and others, 2021)). These changes to overland flow potentially lead to rilling or progressive surface erosion on a slope, which contribute to debris flow initiation within a channel (Meyer and Wells, 1997). This type of postfire debris flow initiation is triggered by short-duration, high-intensity storms commonly associated with thunderstorms (15-minute intensity; Kean and others, 2011; Santi and Macaulay, 2021). Most of the drier climate region research locations have generally much less vegetation (e.g., dense, large trees, understory, and forest floor) pre-fire and more of that vegetation is consumed during fires. This lack of ground cover is important for debris flow initiation because it promotes runoff and decreases root strength (McGuire and others, 2024). This was evident in the 2018 postfire debris flows in Montecito, California (Lukashova and others, 2019).

In contrast, Western Oregon is densely covered with large trees, brushy understory vegetation, and thick, abundant organic debris on the forest floor (Wondzell and King, 2003). Precipitation patterns in Western Oregon generally consist of cool, wet winters characterized as long-duration, low-intensity rainfall with intermittent AR-type storms that result in long-duration, moderate- to high-intensity precipitation.

The research on postfire CDFs has generally focused on more arid portions of the United States, such as southern California (De Graff and others, 2015). Research on postfire CDFs is needed in Western Oregon to understand the effects of post-fire CDFs better in a wetter and densely vegetated environment. Such research could then be integrated into future updates to CDF modeling. However, the protocol applied in this project does not directly assess postfire CDF hazards (Burns and others, 2022), rather, the protocol identifies the areas of inundation hazard regardless of the initiation type or factors.

Forest management, such as road construction and removal of trees, can cause a loss of root strength and can change natural drainage patterns. This can increase susceptibility to CDFs (Robison and others, 1999). Building roads, removing trees, changing drainage, and other factors involved with human-forest interaction can change over time, can change rapidly, and are site specific. For example, clearcutting an area on private land can happen within weeks or months once a landowner makes that decision (Burns and others, 2022). Thus, site-specific, rapidly changing variables such as these are not included in our assessment.

1.3 Descriptions of the Fires

The Eagle Creek Fire started on September 2, 2017, from the use of fireworks in the Eagle Creek Drainage. The U.S. Forest Service, along with the Multnomah County and Hood River County sheriff's offices, worked to fight the fire and rescued more than 150 hikers. The fire burned almost 50,000 acres and caused the closure of all three primary transportation modes (road, rail, and river) (the Columbia River Gorge National Scenic Area website, https://www.fs.usda.gov/crgnsa, accessed on August 1, 2023). Fortunately, only a handful of buildings burned.

The 2020 Labor Day windstorm propelled five simultaneous fires greater than 100,000 acres in size, termed "megafires." All these fires either started or significantly expanded on September 7 and 8, 2020, and in only a few days 1 million acres burned.

In Marion and Linn Counties, the Lionshead and Beachie Creek fires burned along the Santiam River and the North Santiam Highway (Oregon State Route 22). Nearly 1,000 structures were destroyed in the Beachie Creek-Lionshead Fires.

In Lane County, the Holiday Farm Fire burned along the McKenzie River and the McKenzie River Highway (Oregon State Route 126). More than 1,050 structures were destroyed by the Holiday Farm Fire.

In Douglas County, the Archie Creek Fire burned along the North Umpqua River and North Umpqua Highway (Oregon State Route 138). Approximately 140 structures were destroyed in the Archie Creek Fire. The Oregon Department of Emergency Management created a story map about the 2020 Labor Day Fires that can be accessed here: https://storymaps.arcgis.com/stories/6e1e42989d1b4beb809223d5430a3750.

1.4 Initial Fire Severity Assessments

The U.S. Forest Service Burned Area Emergency Response Team issued a report and datasets following the fires. The first dataset related to postfire CDFs is the soil burn severity (SBS) map. The SBS map is an estimate of the fire's effect on the soil (Parson and others, 2010). These effects commonly include loss of ground cover, change in soil structure (loss of organics and root), and formation of water-repellent layers (Parsons and others, 2010). These changes can cause increased runoff and loss of soil strength, both of which can lead to an increase in CDFs.

Once the SBS map was created, staff at the USGS performed an emergency assessment of postfire debris flow (PFDF) hazards. The model inputs include the differenced normalized burn ratio (dNBR) data and field-validated estimates of SBS in geospatial format (https://usgs.maps.arcgis.com/apps/dashboards/c09fa874362e48a9afe79432f2efe6fe).

Because the 2020 Labor Day Fires were very large and impacted federal, state, local and private lands throughout Oregon, the State of Oregon requested the Federal Emergency Management Agency (FEMA) form a multijurisdictional assessment team to assess the state, local, and private lands of several fires. FEMA coordinated with state and federal agencies to staff the Erosion Threat Assessment and Reduction Team (ETART) to evaluate the fire-affected state and private lands. USGS guidance is that the emergency assessment of debris flow hazard maps only depicts the hazard one to two years following a wildfire because these products do not currently account for postfire vegetation recovery. In addition, the hazard assessment is based on more arid regions, and no data from the Pacific Northwest were used to develop the model (Staley and others, 2017). Consequently, the model results may not be applicable to the fires in this report. The BAER and ETART reports are available at the following links and include the SBS maps, and USGS postfire debris flow emergency assessments:

- Eagle Creek Fire BAER Report Summary: https://www.fs.usda.gov/sites/default/files/media_wysiwyg/eagle_creek_fire_baer_summary_10-10_final_0.pdf
- Lionshead Fire BAER Report Summary: https://www.fs.usda.gov/sites/nfs/files/legacy-media/willamette/Lionshead%20Fire%20BAER%20summary.pdf
- Beachie Creek ETART Reports: https://digitalcollections.library.oregon.gov/nodes/view/276639?keywords=Burned+Area+Emergency+Response+%28BAER%29+report+eagle+creek+fire&type=all&highlights=WyJCdXJuZWQiLCJBcmVhIiwiRW1lcmdlbmN5IiwiUmVzcG9uc2UiLCIoQkFFUikiLCJyZXBvcnQiLCJlYWdsZSIsImNyZWVrIiwiZmlyZSJd&lsk=74c331df4ec8e1b7c21ee3dba6f478d8
- Holiday Farm Fire ETART Report: https://digitalcollections.library.oregon.gov/nodes/view/276618?keywords=Burned+Area+Emergency+Response+%28BAER%29+report+eagle+creek+fire&type=all&highlights=WyJCdXJuZ

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- Archie Creek Fire ETART Report: https://digitalcollections.library.oregon.gov/nodes/view/276638?keywords=ETARTS&highlights=WyJFVEFSVFMiXQ%3D%3D&lsk=21e704965b003338d163089dfc3dc72c

The BAER and ETART reports provide estimates of rainfall intensities that are likely to trigger postfire debris flows. Again, these estimates are based on more arid regions, and no data from the Pacific Northwest were used to develop the threshold rainfall intensities (Staley and others, 2017). Consequently, the values may not be applicable to the fires in this report. However, we provide them in case they are useful. (For more information about these values and the Eagle Creek fire, see the following StoryMap developed by USGS: https://landslides.usgs.gov/storymap/eagle-creek/.)

Table 1-1. Rainfall intensities over 15-, 30-, and 60-minute periods that are likely to trigger postfire debris flows from BAER and ETART reports.

Fire Area	Inches of Rainfall over 15 Minutes	Inches of Rainfall over 30 Minutes	Inches of Rainfall over 60 Minutes
Archie Creek	0.20	0.30	0.50
Beachie Creek	0.25	0.40	0.65
Holiday Farm	0.20	0.30	0.60
Lionshead	0.35	0.55	1.00
Eagle Creek	1.57	—	—

For values more representative of Western Oregon conditions, we referenced the Wiley (2000) map of 24-hour rainfall intensities that are likely to trigger debris flows for regions in Western Oregon, which can be accessed here: https://pubs.oregon.gov/dogami/og/OGv62n02.pdf. Although postfire effects are not included in the DOGAMI thresholds, it is another resource that should be reviewed before future storms. Below are the range of rainfall intensities likely to trigger debris flows for each fire area as estimated from the map (Wiley, 2000).

Table 1-2. Rainfall intensities over 24-hour periods that are likely to trigger postfire debris flows from Wiley (2000) map.

Fire Area	Inches of Rainfall over 24 Hours
Archie Creek	3–4
Beachie Creek	4–5
Holiday Farm	3–4
Lionshead	2–3
Eagle Creek	5–8

In addition to these estimates of CDF-triggering rainfall, Oregon has a statewide landslide alert system triggered by the National Weather Service (NWS). When the NWS issues a flood watch or flash flood watch, they include language about the potential for landslides and debris flows. At the same time several Oregon state agencies (Oregon Emergency Management [OEM], Oregon Department of Transportation [ODOT], and DOGAMI) disseminate the alert. The current alert system could be used by the communities in the fire area.

2.0 METHODS

To accomplish the purpose of this project, we performed four primary tasks:

1. Mapping past debris flow events and deposits
2. Modeling future debris flow susceptibility
3. Risk analysis
4. Development of a road map to risk reduction

The first two tasks (mapping and modeling) followed the methods outline in Burns and Madin (2009) Protocol for Inventory Mapping of Landslide Deposits from Light Detection and Ranging (lidar) Imagery, Special Paper 42 (https://d3itl75cn7661p.cloudfront.net/dogami/sp/p-SP-42.htm) and Burns and others (2022) Protocol for Channelized Debris Flow Susceptibility Mapping, Special Paper 53 (https://d3itl75cn7661p.cloudfront.net/dogami/sp/SP-53/p-SP-53.htm). The risk analysis was performed in a GIS by overlapping the hazard and asset layers, which results in exposure or at risk. The risk reduction planning was performed through literature review and meetings with community representatives. All these methods are described in detail in the following sections.

2.1 Historic and Prehistoric Debris Flow Mapping

The first step in Burns and others (2022) is to create an inventory dataset of historic and prehistoric debris flow deposits (fans) and historic debris flow events (initiation, transport, and deposition) in the proposed study areas. This was divided into two tasks: mapping of historic and prehistoric debris flow deposit areas and mapping of historic pre-fire and postfire debris flow events.

To map the past historic debris flow deposits, we followed the methods in Burns and Madin (2009). Because of limited time and budget, we did not map the other non-debris flow landslide deposit types as outlined in Burns and Madin (2009), just the debris flow deposits.

To map the historic debris flow events, we followed the methods in Burns and others (2022). We used historic serial orthophotos that span the period from 1995 to 2022 (U.S. Department of Agriculture) and are spaced approximately every five years to create debris flow inventory datasets. The following years of orthophotos were used: 1995, 2000, 2005, 2009, 2014, 2018, 2020, and 2022 (the last of which is postfire in the Beachie-Lionshead, Holiday Farm, and Archie fires of 2020).

In general, this resulted in the mapping of initiation sites (points) and transport extents (lines). After each landslide was mapped, two fields, landslide type and date range, were attributed for each polygon.

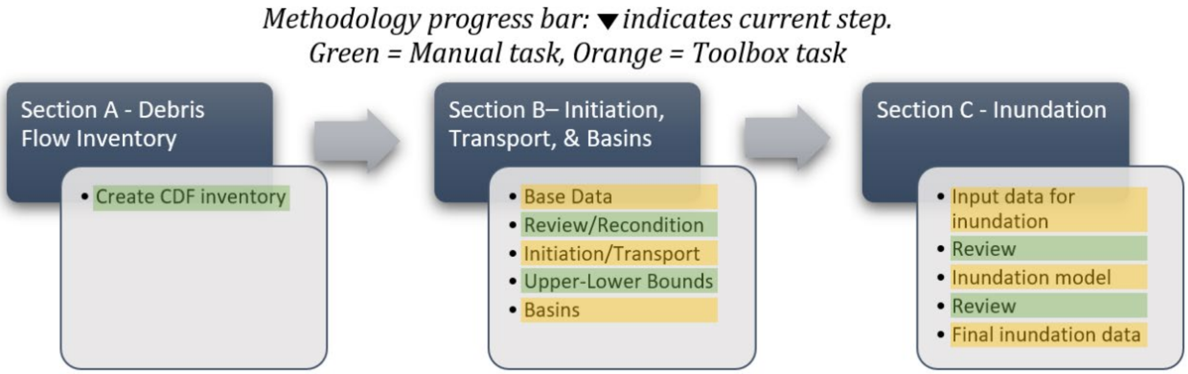
In the Eagle Creek area, instead of using orthophotos, serial lidar data was collected and analyzed to better understand pre-fire and postfire historic debris flow events. The methods are described in detail in Burns and others (2025), Multitemporal Lidar Analysis of Pre- & Post-Eagle Creek Fire Debris Flows, Western Columbia River Gorge, Hood River and Multnomah counties, Oregon, Special Paper 55 (https://www.oregon.gov/dogami/pubs/Pages/sp/SP-55.aspx).

2.2 Modeling Future Debris Flow Susceptibility

After mapping the inventory of historic and prehistoric debris flow deposits and historic debris flow events following Burns and others (2022) (Step 1), we completed Sections B and C (Steps 2–11) (**Figure**

2-1). Some of the steps are automated by the Toolboxes and some are manual. The manual ones are discussed in more detail below.

Figure 2-1. Graphical representation and list of the CDF susceptibility protocol steps (Burns and others, 2022).



Section A – Debris Flow Inventory

1. Create an inventory dataset of historic and prehistoric CDF deposits (fans) and historic CDF events (initiation, transport, and deposition) in the proposed study area.

Section B – Initiation, Transport, and Basin Susceptibility

2. Create base datasets using DF_ArcPRO_Toolbox Part 1_Base Maps.
3. Review base datasets. Perform digital elevation model (DEM) reconditioning of erroneous channels. If reconditioning (filling in sinks or removing artificial fills) is needed, rerun Step 2 with a reconditioned DEM (see further detail below).
4. Create initiation and transport susceptibility zones using DF_ArcPRO_Toolbox Part 2_Initiation and Transport.
5. Map basin upper-lower bounds. This will result in a polygon that crosses the channels, creating an intersection that becomes the pour points to define the basins.
6. Create the basins with basin overall susceptibility using DF_ArcPRO_Toolbox Part 3_ Basins.

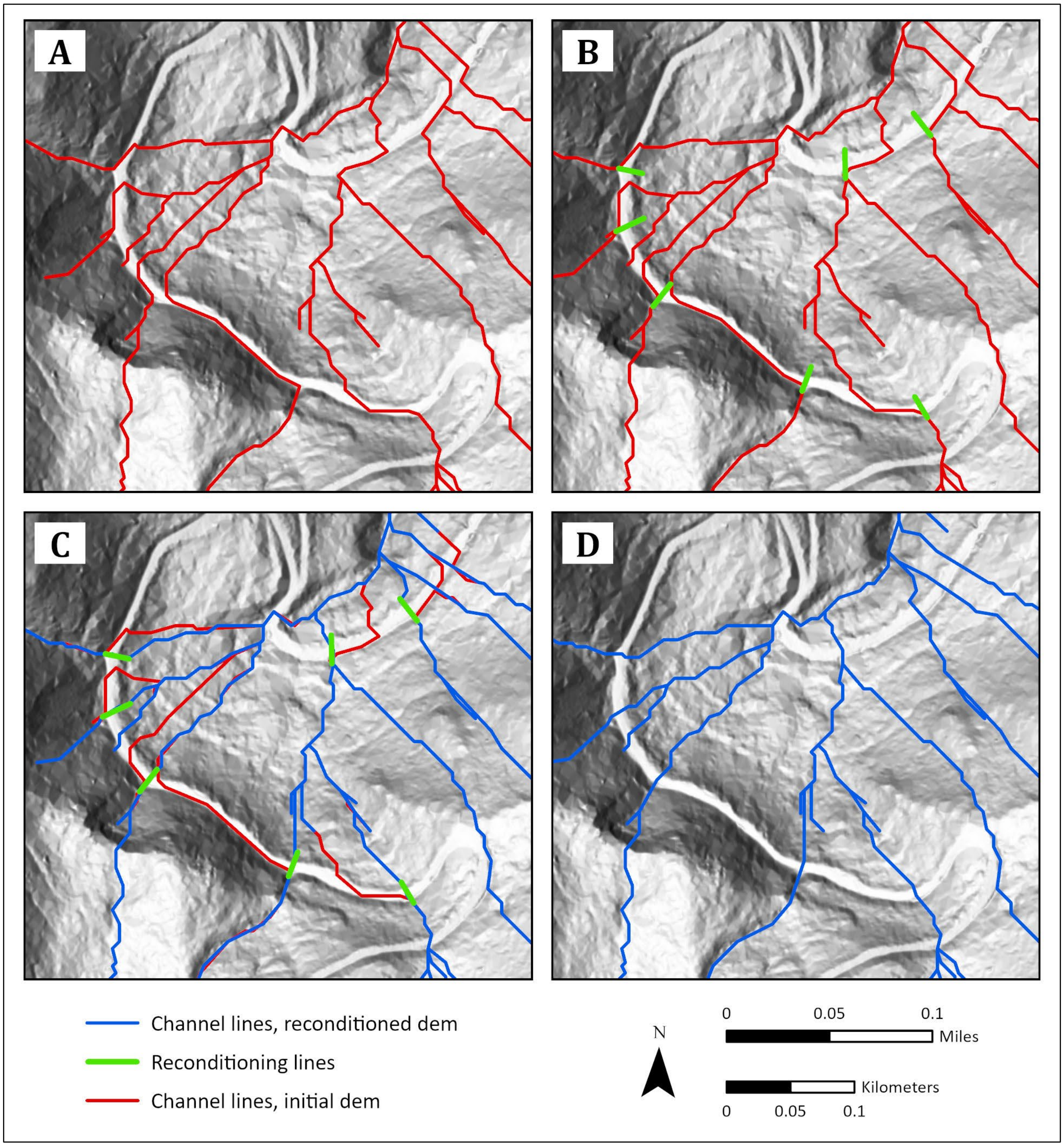
Section C – Inundation Susceptibility

7. Create input data for inundation modeling using DF_Growth_ArcGIS_Toolbox Part 4_Debris-Flow Growth Pre-Processor.
8. Review and clean up preprocessor data.
9. Create inundation zones using DF_Growth_ArcGIS_Toolbox Part 5_Multi-Point Laharz_py.
10. Review Typical inundation susceptibility zones and compare to CDF Inventory (Step 1). If zones are too small or too large, select new, more appropriate growth factor and rerun Steps 7–10.
11. Create final datasets for inundation zones using DF_ArcPRO_Toolbox Part 6_Inundation Zones Post-Processing (clean up).

To model CDFs using GIS, first a channel system must be developed. After Steps 1–2 were completed, Step 3 (DEM reconditioning) was required to ensure that channels would go down slope continuously (**Figure 2-2**). The channels need reconditioning because a DEM is a surface model that does not identify human-constructed underground water conveyance systems like culverts. For example, without reconditioning, the model results for a channel that intersects a road on a slope might turn 90° and follow the road ditch instead of continuing down channel below the road (likely through a culvert) (**Figure 2-2**).

We followed the method described in Burns and others (2022) for DEM reconditioning, except in a few special cases: Interstate I-84 in Eagle Creek and a couple small portions of Highway 126 in Holiday Farm. In special cases, because the reconditioning need was spatially extensive, the reconditioning was performed using a polygon instead of lines as performed following Burns and others (2022). The polygons were drawn to define the area of reconditioning. The original DEM was removed in the polygon area. The elevations along the edges of the polygon were used to create a triangular irregular network (TIN) across the area removed. The TIN was converted to a DEM and merged into the original DEM. This resulted in a planar surface that continued downslope and thus, channel lines that continue downslope (**Figure 2-2**).

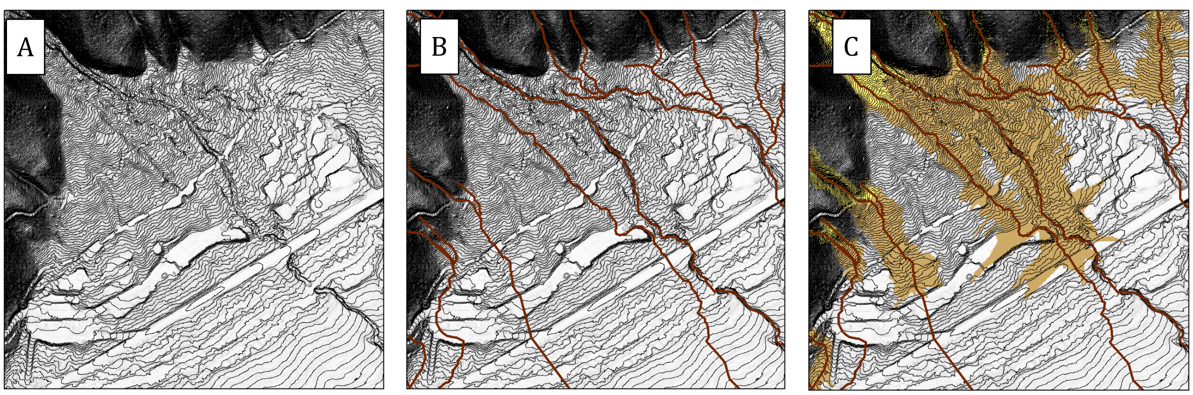
Figure 2-2. Example of DEM reconditioning. A) Original channel lines (red lines). B) Areas with DEM reconditioning needs (green lines) where channels do not continue downstream. C) New channels (blue lines) compared to original channels (red lines). D) Final reconditioned channels.



Next, Step 4 (create initiation and transport susceptibility zones), Step 5 (map upper-lower bounds), and Step 6 (create the basins with overall susceptibility) were completed following Burns and others (2022). Step 7 (create input data for inundation modeling), Step 8 (review and clean up preprocessor data), Step 9 (create inundation zones), and Step 10 (review Typical inundation susceptibility zones) were completed following Burns and others (2022) but required local calibration of the model inputs using the mapped historic events and fans. We started with the recommended values from Table 16 in Burns and others (2022), for Typical, Intermediate, and Extreme CDF inundation susceptibility zones. Initially, we tested predictions using the Typical parameters in each study region and compared the inundation results to the historic events and fans. If the results were longer or shorter than the historic events, we decreased or increased the Typical Intermediate, and Extreme values. Finally, sections with selected values were delineated for each study region (Appendix Figures A-6, B-6, C-6, and D-6) and used to perform the inundation modeling (Steps 7–9).

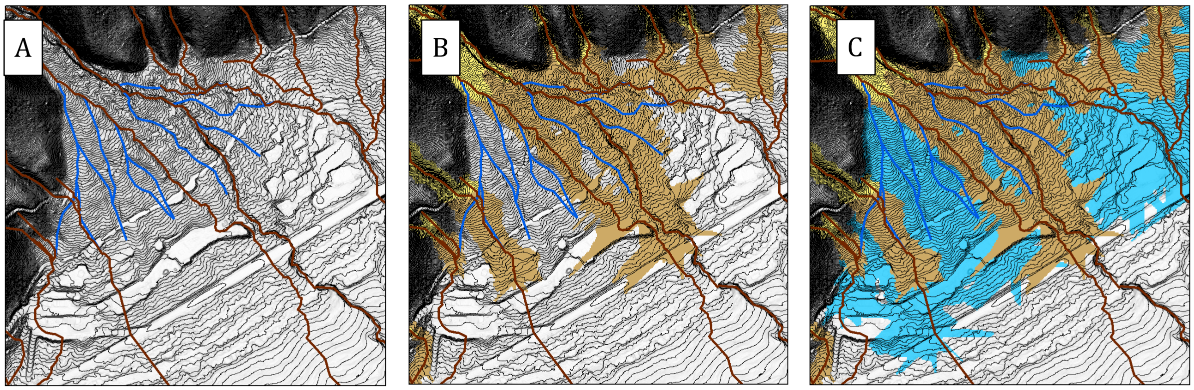
Debris flow avulsion commonly happens when the debris flow blocks the active channel (termed a channel plug), or erodes the channel banks, resulting in the debris flow leaving the active channel and establishing a new path (Hass and others, 2018). Paleochannels or abandoned channels that are remnants of past avulsion can be easily seen in the high resolution lidar data (**Figure 2-3**). The need to add an additional inundation zone to identify areas of potential future avulsion was recognized due to the fan extents and paleochannels. Most hydro-based GIS tools are created for convergent topography and therefore do not perform well on fans because of the divergent topography. The results using Burns and others (2022) captured the current active channels well and these channels are the ones that received inundation modeling (**Figure 2-3**).

Figure 2-3. Examples of inundation modeling without avulsion. A) 3-ft contours add visual clarity to identify active and paleochannels. B) Model results of Burns and others (2022) channels (brown lines). C) Extreme zone inundation results (yellow is transport/growth and tan is deposition).



To add the Avulsion hazard areas, first the paleo channels were identified using 3 ft contours (**Figure 2-4A**). The paleo channels were mapped starting at the intersection of active channels. In addition, we examined where paleochannels and active channels had minimal elevation differences (<10 ft) and thus, higher potential for avulsion to identify starting points for the paleochannel lines. The paleochannels were extended down channel to the location where inundation modeling would generally match the downstream extent of the Extreme inundation modeling on the active channels (**Figure 2-4B**). The Extreme inundation points (volumes) used as input to Step 7 were copied from the active channels and placed onto the avulsion channels. We selected the Extreme scenario volumes for the avulsion to provide contingency for the unpredictability of avulsion.

Figure 2-4. Example of identified paleochannels and avulsion inundation modeling. A) Paleochannels mapped in blue lines. B) Model results of Burns and others (2022) channels (brown lines) and Extreme zone inundation results (yellow is transport/growth and tan is deposition). C) Avulsion model results (blue zone).



2.3 Risk Analysis

We compiled and created asset datasets that included information concerning buildings, permanent population distribution, critical facilities, land use, roads, and campgrounds. These asset datasets, along with mapped debris flow deposits and inundation-susceptibility datasets were overlaid to evaluate exposure of the assets to the debris flow hazard (risk).

2.3.1 Asset Dataset Creation

The building inventories for the Eagle Creek, Beachie-Lionshead, and Archie Creek study areas consist of all buildings larger than 100 ft^2, as determined from existing building footprints (Williams, 2021). The building inventory was developed from the Statewide Building Footprints for Oregon, release 1 (SBFO-1) (Williams, 2021). Williams (2021) defined “buildings” to be permanent structures with walls and a roof that can be occupied by people. Other structures, such as dams, water tanks/towers, sewage and water treatment tanks, tents, small garden sheds, hoop-houses or other plastic-covered greenhouses, and grain silos, were not considered buildings and were not included in this analysis. The building inventory for the Holiday Farm region was created from LCOG GIS datasets.

Assessment offices from each county supplied tax assessor data was acquired and formatted for use in this study. The tax assessor data contains an array of information about each improvement (e.g., building). Tax lot data, which contains property boundaries and other information regarding the properties spatial attributes, was obtained from the county assessors and was used to link the buildings with assessor data. The linkage between the two datasets resulted in a database that contains attributes for each building.

Some buildings are defined as critical facilities because they function in support of public safety, disaster recovery, relief efforts, and other emergency operations before, during, and after a natural disaster. Typical critical facilities include hospitals, schools, fire stations, police stations, emergency operations, and military facilities. We embedded identifying critical facilities characteristics into the buildings database so they could be highlighted in the results. Critical facilities data came from the DOGAMI Statewide Seismic Needs Assessment (SSNA) (Lewis, 2007). We updated the SSNA data through coordination with county officials.

Within the buildings database, the Portland State University Population Research Center estimates of permanent residents were distributed proportionally among residential buildings based on building area.

We did not examine the impacts of natural hazards on nonpermanent populations (e.g., tourists), whose total numbers fluctuate seasonally. Due to lack of information within the assessor and census databases, we cannot distinguish between vacation homes and primary residences. Therefore, our method distributes some of the permanent residents into possible vacation homes.

Zoning refers to the permitted land-use designation such as agricultural, industrial, residential, recreational, or other land-use purposes. Zoning data are commonly included in tax lot databases along with land-use designations. Data from tax lot databases also include information about any improvements, such as houses. To evaluate land assets for this project, we combined county and city tax lot databases to create a layer that identifies generalized land use (residential, commercial, or public) information for each piece of property.

The sources of road data varied by area. The roads in the Eagle Creek region were created starting with the ODOT statewide GIS dataset. The road network was split into highways (I-84 and Oregon State routes) and local roads (everything else).

The roads datasets in the Archie Creek and Beachie-Lionshead regions were created starting with the Bureau of Land Managements (BLM) statewide GIS dataset. The road network was split into highways (Oregon State Routes) and local roads (everything else). All gravel roads with no names were removed, unless they were associated with at least one building footprint or inside of a campground.

The roads dataset in the Holiday Farm region was created starting with a roads dataset from the LCOG GIS dataset. The roads were classified as U.S. Forest Service, Lane County, ODOT, BLM, Local Access Roads, and private. We also included four bridges: Mill Creek, Hwy 15 at MP 46.34, Montgomery Creek, EWEB Power Canal Johnson Creek Rd., and Goodpasture Covered Bridge. The Blue River Dam was also included in the Holiday Farm exposure analysis.

Campgrounds were created by scouring the internet and from GIS basemaps such as the national USGS topographic maps and Open Street Map. Each boundary was digitized from the campground map provided by each facility operator.

2.3.2 Exposure/Risk Analysis

When debris flows affect assets, they become natural hazards. A risk assessment is the characterization of the overlap of natural hazards and assets. Risk analysis can range from simple to complicated. In this project we selected one type of regional risk analysis termed exposure or at-risk analysis.

An asset is considered to be exposed to the debris flow hazard if it is located within a selected hazard area. We performed exposure analysis with Esri ArcGIS software. We determined exposure through a series of spatial and tabular queries between hazards and assets. In other words, we used GIS to find which community assets fell in which debris flow hazard zones (erosion and deposition areas). For example, we superimposed the buildings layer for the study areas on the Typical inundation susceptibility zone layer to determine which buildings are exposed to that level of hazard. The result of this analysis is both a map of the community assets exposed to the hazard and a table with the corresponding numbers of community assets exposed. We then summarized the results by community. The debris flow hazard datasets used in the exposure analysis are:

- Mapped debris flow deposition areas (fans)
- Typical debris flow inundation
- Intermediate debris flow inundation
- Extreme debris flow inundation
- Avulsion debris flow inundation

Asset data used in the exposure analysis are:

- Buildings with three generalized use classes: residential, commercial, and public
- Permanent population
- Critical facilities: fire stations, police stations, and school buildings
- Roads with two classes: highways and local roads
- Campgrounds

LCOG included some additional selected assets for the exposure/risk analysis in the Holiday Farm study area, for example bridges. These datasets and results are not included in this report for consistency between the other three study areas. These additional selected assets can be viewed on the LCOG web map. https://www.arcgis.com/apps/dashboards/b5a8a9aff2c540df86402633214da73a

2.4 Risk Reduction

CDF risk reduction strategies vary depending on the type and size of landslide hazard, including CDFs. Mitigation of landslide hazards may require cooperating efforts from both private and public entities (e.g., city, county, federal) as landslides can travel long distances impacting multiple properties or may even cross entire neighborhoods or major roadways.

Our approach to landslide risk reduction, with emphasis on debris flows, focused on community needs, as relayed by relevant community partners (for example, representatives from county and city emergency management, public works, and planning) in combination with established recommendations from published reports. To develop recommendations for continued landslide risk reduction we began by compiling a list of recommendations from published reports (for example, Burns and others, 2018).

2.4.1 Participants

We assembled a broad roster of stakeholders from the four regions impacted by the fires. The stakeholders were contacted and invited to join in the process, though not all were able to participate directly. Participants included professionals from federal government agencies and state government agencies, including U.S. Army Corp of Engineers, BLM, USGS, National Oceanic and Atmospheric Administration, and the Department of Agriculture, the Forest Service and the Columbia River Gorge National Scenic Area. State agencies included DOGAMI, DLCD, the Department of Forestry, Department of Environmental Quality, Department of Transportation, Department of Emergency Management, and the Division of Financial Regulation with the Department of Consumer and Business Services. County and city government representatives in attendance included professionals working in emergency management, public works, planning, public health, and GIS. Other local government or special district representatives consisted of rural fire districts, sewer and water districts, school districts, soil and water conservation districts, regional councils of government, and rural transportation districts. In addition, numerous community organizations were on the roster and included representatives from commercial utilities and electric cooperatives; non-governmental organizations addressing conservation, sustainability, resiliency, and fire recovery; watershed councils; chambers of commerce or visitor bureaus; medical centers; and unincorporated communities.

2.4.2 Process

A series of small-group brainstorming meetings were held with each of the four study area stakeholder groups. Organization of the meetings formed around four themes that overlap with previously published recommendations for CDF risk reduction. These themes were: 1) awareness and education, 2) emergency preparedness (in particular, warning systems), 3) planning and regulation, and 4) structural and nonstructural mitigation. The meetings yielded information about risk reduction specific to the debris flow hazard and to the nature of the risk in the four different study areas. We used the detailed information obtained from these meetings to compile the action item lists for each of the four study areas. Input from each of the four stakeholder groups had commonalities regarding risk reduction pathways and obstacles and thus, we combined the lists to cover all affected areas.

Two additional meetings brought the four study area stakeholder groups together to evaluate common pathways and obstacles in reaching solutions that reduce risk from potentially lethal debris flows. In the two combined group meetings we elicited discussions that established common pathways to risk reduction action and common roadblocks to reaching the solution to obstacles across multiple areas. Prioritization of these pathways was not completed. However, it is something that would complement the use of the roadmaps. Most of these meetings were recorded.

A summary of the common pathways coupled with the obstacles informed the four roadmaps (awareness and education, emergency preparedness (warning systems), planning and regulation, and structural and non-structural mitigation) to risk reduction (roadmaps). In general, the structuring of the roadmap's pathways and obstacles are in the following order.

- Category and Topic (for example, emergency preparedness and warning systems),
- Existing publications, programs, or regulations related to the category and topic,
- Suggestions to the existing publications, programs, or regulations,
- Obstacles (Level 1) to the identified suggestions,
- Solutions to Level 1 obstacles, and
- Obstacles (Level 2), if applicable, identify potential obstacles to the solutions.

Participants from each of the four study areas were also asked to take a survey. The purpose of the survey was to provide an alternative method of obtaining feedback on the same topics discussed at the small and large group meetings. The questions encompassed the four main themes—awareness and education, emergency preparedness (warning systems), planning and regulation, and structural and non-structural mitigation. Responses received were similar or the same as those received during the group meetings. Responses were incorporated into the roadmaps.

The roadmaps were shared back to the whole group when the results of the mapping were complete.

3.0 RESULTS

The results of this study are summarized in the following sections. Additional details are provided for each study region in Appendices A-D. An online web map was created in lieu of a series of map plates. The map can be accessed here (web map).

3.1 Debris Flow Hazard Mapping

The first step was to create an inventory dataset of historic and prehistoric debris flow deposits (fans) and historic debris flow events (initiation, transport, and deposition) in the study areas. This was divided into two tasks: mapping of historic and prehistoric debris flow deposit areas (sometime referred to as fans) and mapping of historic pre-fire and postfire debris flow events. The mapping revealed 2,009 CDF deposition areas (fans) and hundreds of historic and prehistoric CDF events within each study area. Maps of both historic events and the fans are provided for each study region in Appendices A-D and via web map (web map). **Table 3-1** summarizes the results of the mapping for each study area.

Table 3-1. Summary mapped historic pre-fire and postfire CDF events for each of the four study areas.

Study Region	Historic CDF Events (Pre-Fire)	Historic CDF Events (Postfire)	Mapped Fans
Eagle Creek	155	—	462
Eagle Creek (lidar change analysis)	29*	204*	—
Beachie Creek-Lionshead	214	49	568
Holiday Farm	508	116	675
Archie Creek	155	81	304
Total	1,061	450	2,009

*Data is from Burns and others (2025).

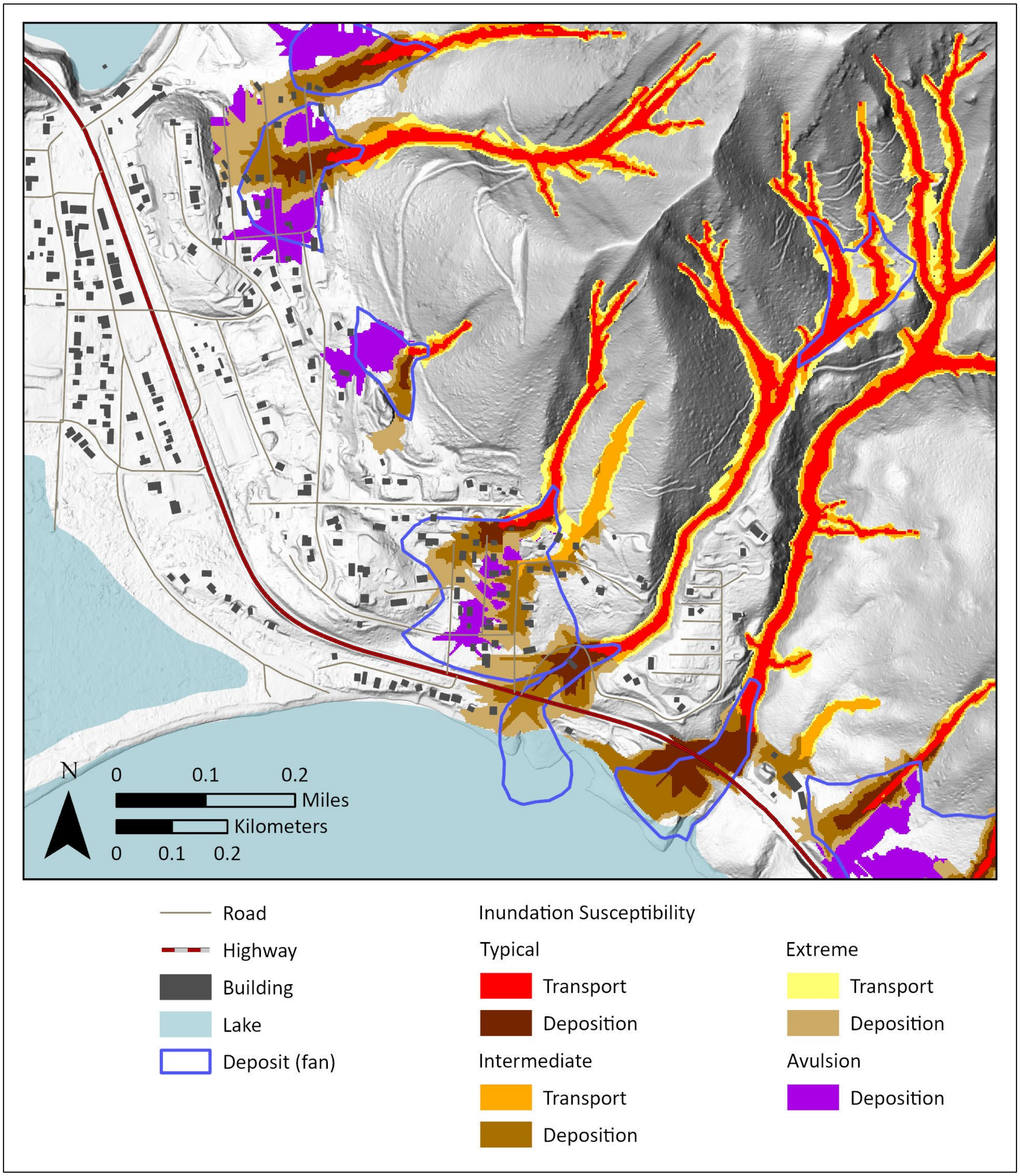
3.2 Modeling Future Debris Flow Susceptibility

As previously stated, we followed Burns and others (2022) to perform the modeling of future debris flow susceptibility areas. The results of Step 3 (DEM reconditioning) using lines and polygons are displayed in each study region in the Appendices A-D. Step 4 (create initiation and transport susceptibility zones) was completed next and the results are displayed in each study region in Appendices A-D and via the web map (web map).

Step 5 (map basin upper-lower bounds) was completed, and the results are displayed in each study region in Appendices A-D. The upper-lower bounds were an input into Step 6, which resulted in the creation of the basins with overall susceptibility. The basins results are displayed in each study area in Appendices A-D and via the web map (web map).

Step 7 (create input data for inundation modeling) resulted in the creation of sections of the study regions with selected values that were delineated for each study region and used to perform the inundation modeling. The section results are displayed in each study region in Appendices A-D. Step 9 resulted in the creation of the inundation zones: Typical, Intermediate, and Extreme. As previously discussed, we identified the need to add an additional inundation zone to identify areas of potential avulsion. The results of the inundation and avulsion modeling are displayed in each study region in Appendices A-D and via the web map (web map). A small portion of the inundation modeling results in the Beachie Creek-Lionshead study region is provided here for context (**Figure 3-1**).

Figure 3-1. Example of typical, Intermediate, Extreme, and Avulsion inundation modeling in the Beachie Creek-Lionshead study area region.



3.3 Risk Analysis

We compiled and created datasets that included buildings, permanent population distribution, critical facilities, land use, roads, and campgrounds. The asset dataset results are summarized by communities within each of the four study regions (**Table 3-2**). Detailed maps and tables of the inventory of assets for each study region are included in the Appendices A-D and via the web map (web map).

Table 3-2. Number of buildings and permanent residents for each region.

Region	Buildings	Permanent Residents
Archie Creek	749	994
Beachie Creek-Lionshead	6,147	6,762
Eagle Creek	2,031	3,203
Holiday Farm	4,442	3,644

The asset datasets along with mapped debris flow deposits (fans) and inundation susceptibility datasets were overlaid to evaluate exposure of the assets to the debris flow hazard. The results of the exposure/at-risk analysis are summarized in **Table 3-3** and via the web map (web map).

Table 3-3. Summary of assets exposed/at risk to debris flow hazards in the regions.

Asset & Region	Mapped Debris Flow Deposition Areas (Fans)	Typical Debris Flow Inundation	Intermediate Debris Flow Inundation	Extreme Debris Flow Inundation	Avulsion Debris Flow Inundation
Buildings (count)	—	—	—	—	—
Archie Creek	56	45	86	118	8
Beachie Creek-Lionshead	373	43	130	233	91
Eagle Creek	148	44	86	110	80
Holiday Farm	129	76	216	349	3
Permanent population (count)	—	—	—	—	—
Archie Creek	76	63	117	164	17
Beachie Creek-Lionshead	446	45	144	256	91
Eagle Creek	213	61	126	172	122
Holiday Farm	80	63	168	265	6
Critical facilities (count)	—	—	—	—	—
Archie Creek	0	0	0	0	0
Beachie Creek-Lionshead	1	0	0	0	1
Eagle Creek	0	0	0	0	0
Holiday Farm	0	0	0	0	0
Roads (mi)	—	—	—	—	—
Archie Creek	4	37	52.6	64.2	0.8
Beachie Creek-Lionshead	28.9	47.6	72.2	91.2	14.6
Eagle Creek	29.1	20.9	36.6	52.9	32.1
Holiday Farm	12	35	54	65	1
Campgrounds (count)	—	—	—	—	—
Archie Creek	3	5	5	5	2
Beachie Creek-Lionshead	3	3	5	7	3
Eagle Creek	3	3	4	4	2
Holiday Farm	3	3	5	7	3

3.4 Risk Reduction

The primary results of the risk reduction activities include:

- Compiled list of previously published reports and fact sheets with recommendations for risk reduction,
- Community meetings, and
- Roadmaps to risk reduction.

The compilation of previously published reports and fact sheets is listed below.

- DOGAMI Open-File Report O-20-13, Landslide hazard and risk study of Tillamook County, Oregon (Calhoun and others, 2020), https://pubs.oregon.gov/dogami/ofr/p-O-20-13.htm.
- DOGAMI Open-File Report O-23-02, Landslide inventory and risk reduction of the north and central portions of Wasco County, Oregon (Burns and others, 2023), https://pubs.oregon.gov/dogami/ofr/O-23-02/p-O-23-02.htm.
- DOGAMI and DLCD, Preparing for Landslide Hazards: A Land Use Guide for Oregon Communities (Sears, 2019), https://www.oregon.gov/dogami/Landslide/Documents/Landslide_Hazards_Land_Use_Guide_2019.pdf
- Washington Geologic Survey and DOGAMI, A Homeowner's Guide to Landslides for Washington and Oregon, https://www.oregon.gov/dogami/Landslide/Documents/ger_homeowners_guide_landslides.pdf
- National Weather Service, Post Wildfire Flash Flood and Debris Flow Guide, 2015 https://www.weather.gov/media/lox/DebrisFlowSurvivalGuide.pdf
- Silver Jackets, Oregon Post-Wildfire Flood Playbook, 2018 https://www.nwp.usace.army.mil/Portals/24/docs/flood/Post_WildFire_Playbook.pdf.
- DOGAMI, Oregon Geology Fact Sheet: Landslide Hazards in Oregon (Burns, 2008), https://pubs.oregon.gov/dogami/fs/landslide-factsheet.pdf.
- USGS Fact Sheet 2004-3072, Landslide Types and Processes (Highland, 2004), https://pubs.usgs.gov/fs/2004/3072/pdf/fs2004-3072.pdf.
- U.S. Geological Survey Fact Sheet FS-071-00, *Landslide Hazards* (Detra, 2000), https://pubs.usgs.gov/fs/fs-0071-00/fs-0071-00.pdf.
- U.S. Geological Survey Fact Sheet 176-97, Debris Flow Hazards in the United States (Detra, 1997), https://pubs.usgs.gov/fs/fs-176-97/fs-176-97.pdf.

The recordings of the small group brainstorming meetings can be accessed here: https://www.oregon.gov/dogami/landslide/Pages/PostFireDebrisFlow.aspx. The recordings include the kickoff meeting and brainstorm meetings about awareness and education, emergency preparedness (warning systems), planning and regulation, and structural and non-structural mitigation. Two additional meetings with the four geographic groups together evaluated pathways and obstacles in risk reduction.

In addition to the existing publications and programs available to the whole community, the four groups shared the following suggestions during the brainstorming sessions. These suggestions held similarities among the four regions, however, there were some ideas that were region specific:

- Launch personal preparedness campaign

- Utilize hazard and risk maps
- Customize existing information for local community
- Establish a web page for the local community and traveling public
- Direct communication with most at-risk areas
- Hold rural Fire Department events or announcements
- Add warning signage along roads to capture local and traveling public
- Transferable development rights (voluntary)
- Property acquisition in very high hazard areas
- Expand Oregon Department of Motor Vehicle education to include hazard sign information
- ODOT TripCheck with alerts
- Conduct a safe Growth Audit

The final task was to create the four roadmaps to risk reduction, including potential obstacles and solutions to those obstacles. The roadmaps are organized by topics. The first one is focused on awareness and education (**Figure 3-2**). The second roadmap is focused on emergency preparedness and warning systems (**Figure 3-3**). The third roadmap is focused on planning and regulation (**Figure 3-4**). The fourth roadmap is focused on physical mitigation (**Figure 3-5**).

Figure 3-2. Roadmap to risk reduction—awareness and education.

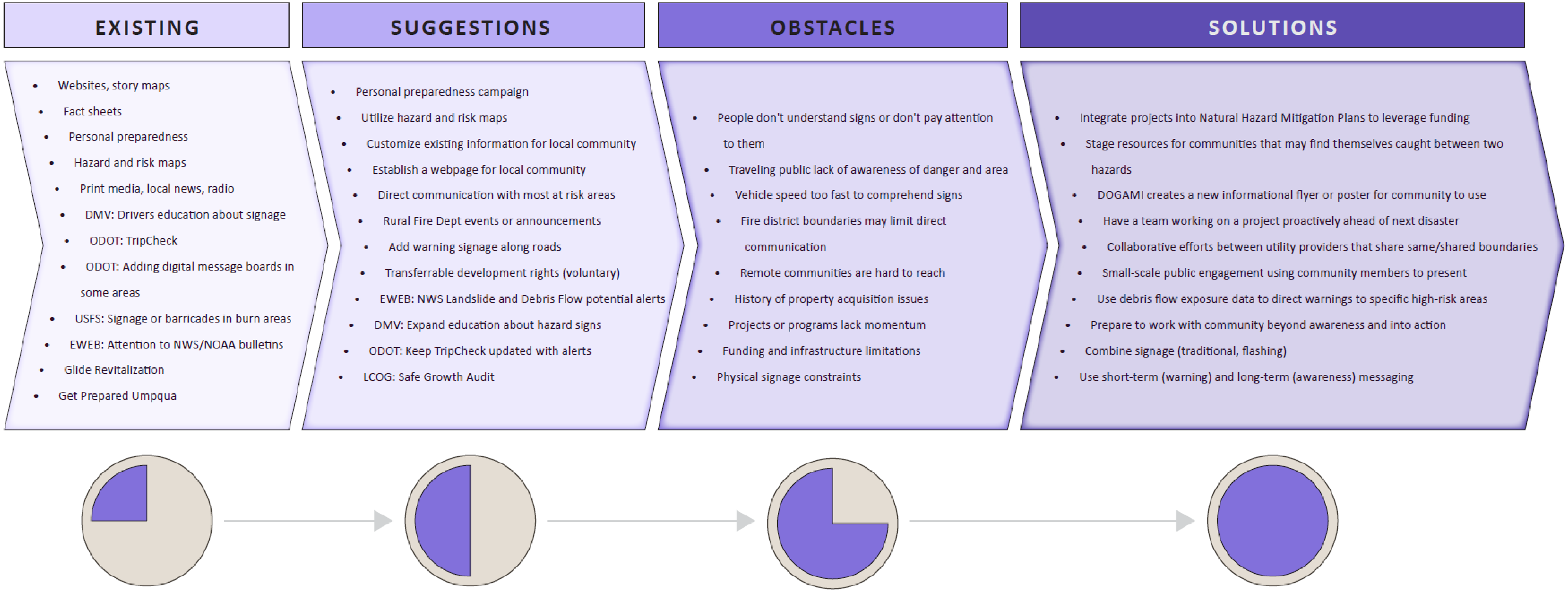


Figure 3-3. Roadmap to risk reduction—emergency preparedness and warning systems.

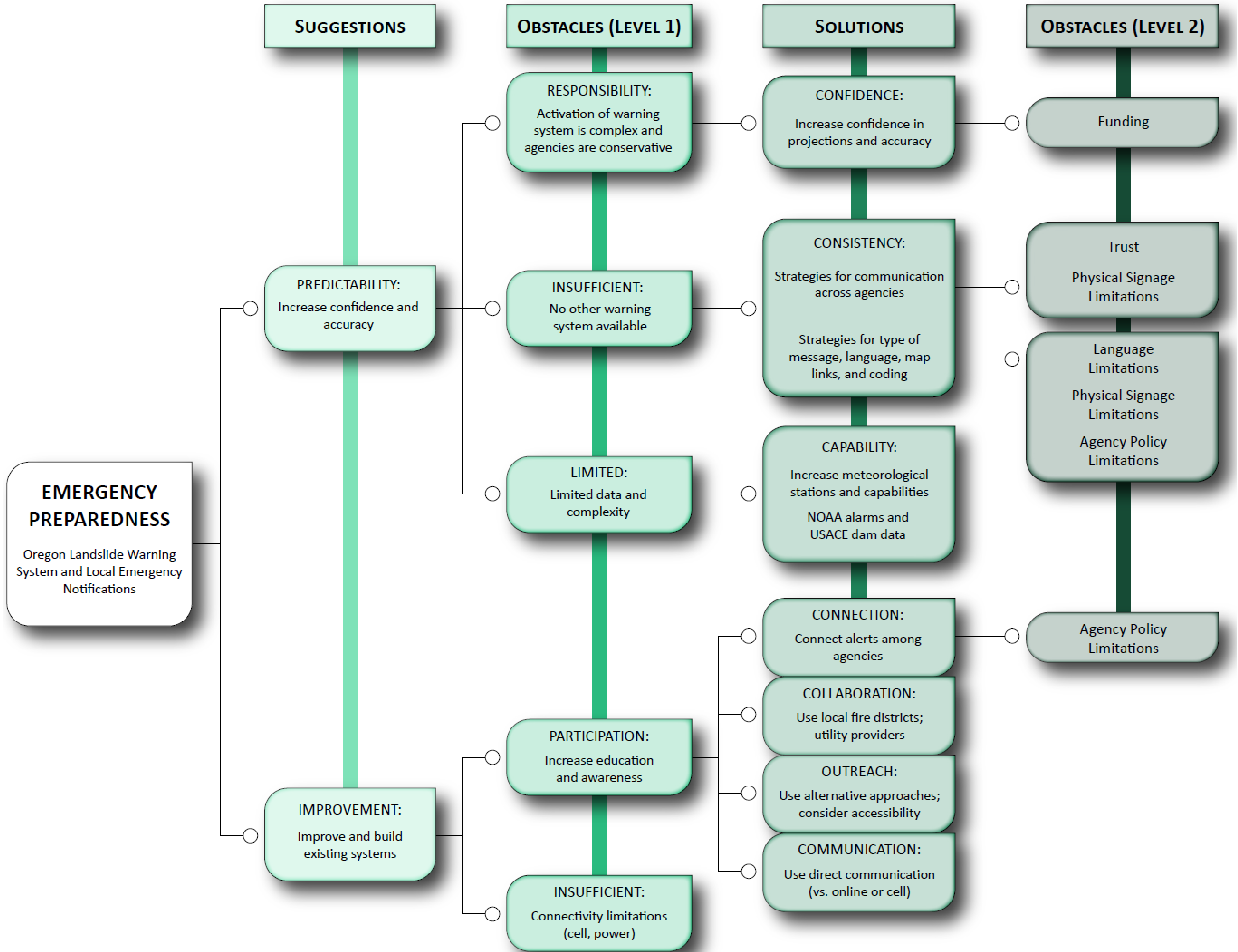


Figure 3-4. Roadmap to risk reduction—planning and regulation.

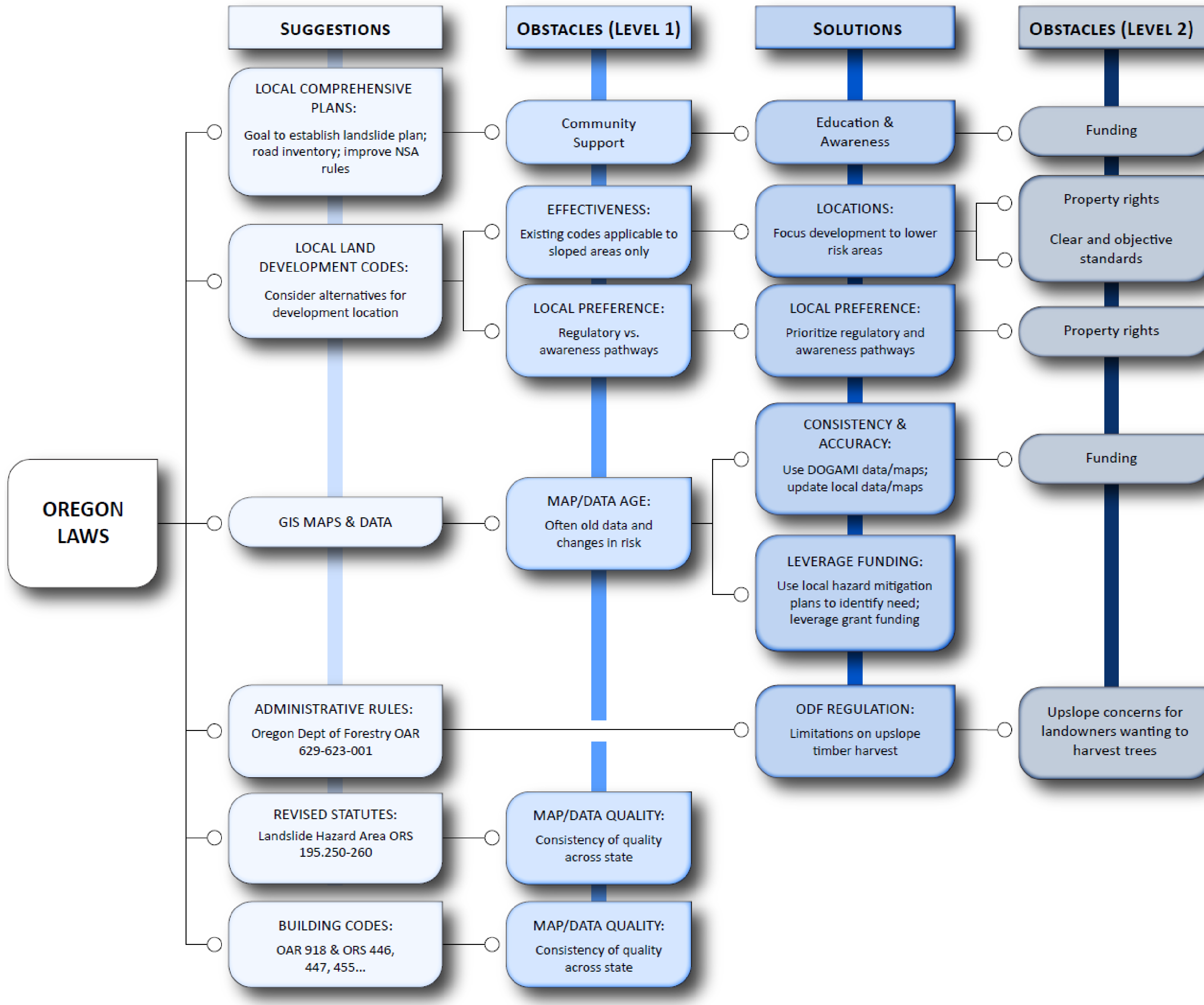
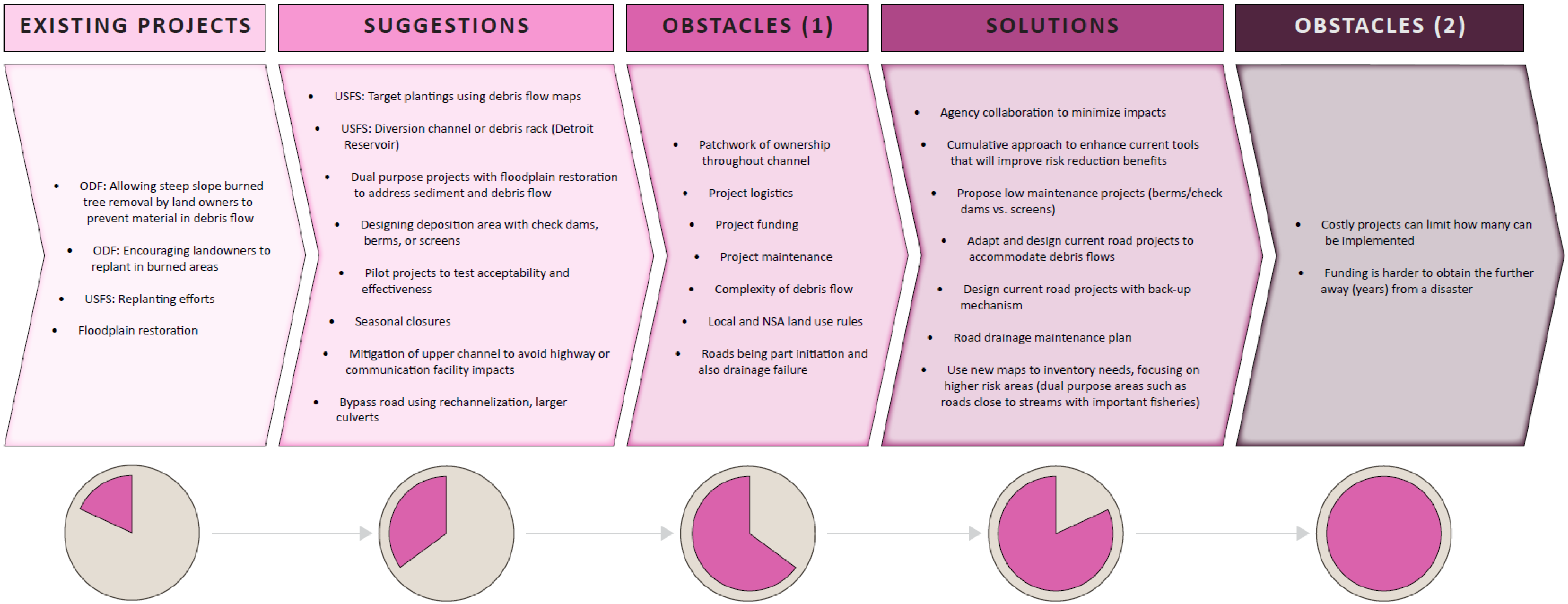


Figure 3-5. Road map to risk reduction—physical mitigation.



4.0 CONCLUSIONS AND DISCUSSION

Although we cannot predict when and where the next CDF events will occur, we were able to provide detailed maps of areas previously impacted by historic and prehistoric CDFs and model where future CDFs are more and less likely to occur. We conclude that the central and eastern portions of the study regions are generally more susceptible to CDFs and postfire CDFs. We mapped 1,061 CDFs and 450 postfire CDFs in the study area, which indicates a relatively high CDF hazard.

The overall annualized rate of pre-fire CDFs for all four study regions is approximately 44 CDFs/year with a range from 6–20 CDFs/year for the individual study regions. The overall annualized rate of postfire CDFs for all four study regions is approximately 129 CDFs/year with a range from 25–58 CDFs/year for the individual study regions. The exact rates above may be slightly less than reality because of limitations of mapping with aerial photos in Western Oregon, but the rates and the differences in rates are likely more accurate. The CDF rates appear to go up in areas that have burned. For additional information, Burns and others (2025) performed a detailed analysis of the pre-fire and postfire CDFs in the Eagle Creek region. This means additional caution should be carried out in areas that are prone to CDFs and have recently burned.

The modeling of future CDF hazard areas resulted in several main datasets, including:

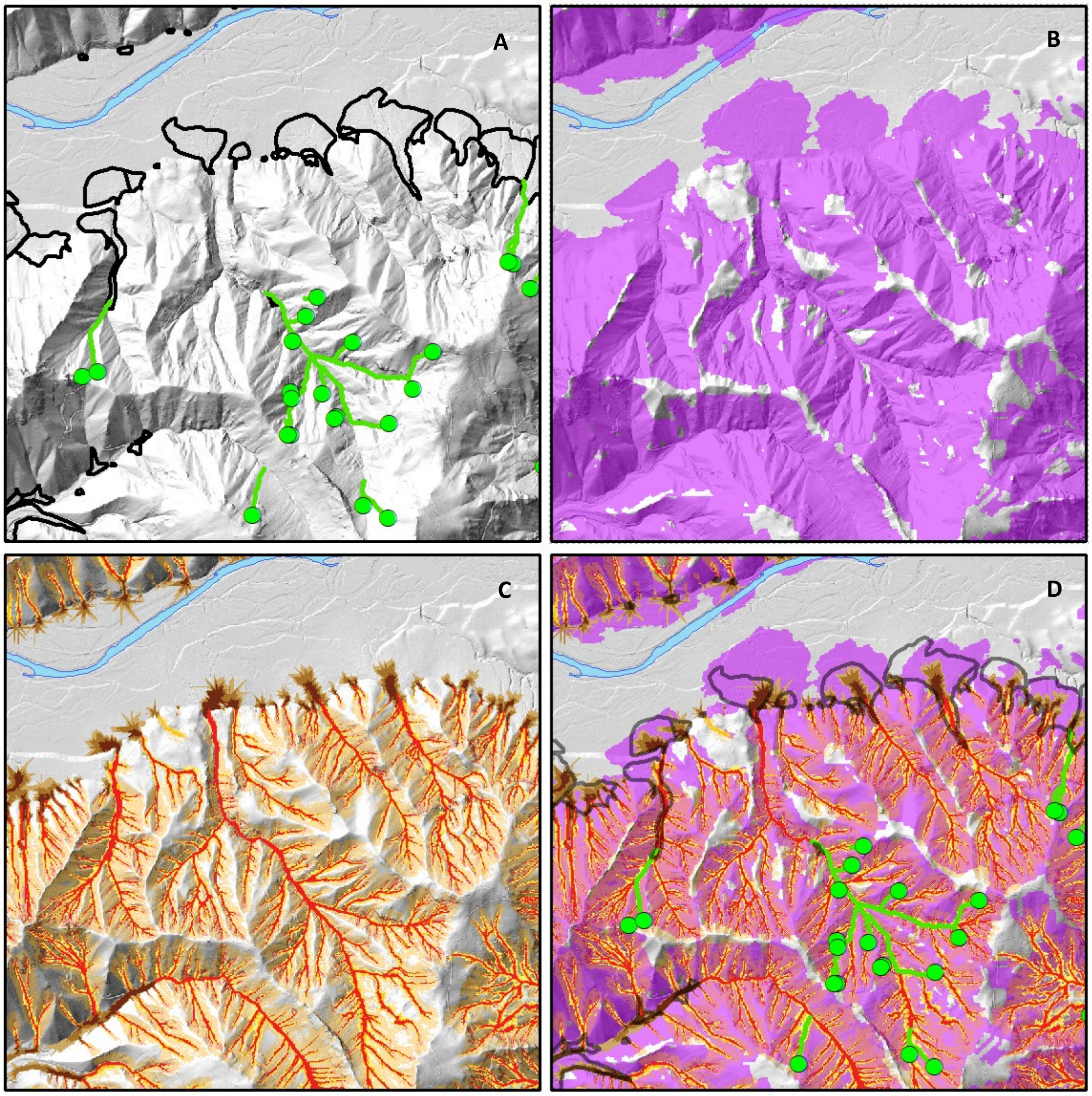
- Initiation Susceptibility
- Transport Susceptibility
- Basin Susceptibility
- Inundation zones
    - Typical
    - Intermediate
    - Extreme
    - Avulsion

These datasets can be used directly to assess the susceptibility of a site. Although the maps are broadly accurate, we still recommend site-specific evaluations to determine the site-specific level of hazard, risk, and risk reduction.

Previous CDF-type modeling, termed rapidly moving landslide hazard delineation in Western Oregon by Hofmeister and others (2002; referred to as IMS-22) was visually compared to the new data produced in this publication. The older modeling is limited to in or out of the hazard zones (purple zone on **Figure 4-1**) as opposed to the new modeling produced in this project, which provides additional detail within the zones, for example, CDF initiation susceptibility zones has four classes: none, low, moderate, high. A visual comparison of IMS-22 versus the new mapping found the following:

- The new mapping reduces the area of hazard zones, while still capturing most Typical hazard areas, and
- The new mapping has multiple zones, which provides additional detail related to the process (initiation, transport, deposition) and the frequency and magnitude of future CDFs.

Figure 4-1. Visual comparison of A) mapped past CDF deposits (black outline) and historic events (green points and lines), B) DOGAMI IMS-22, Hofmeister and others (2002) modeling (purple), C) model results from this study, and D) combination of A, B, and C.



The people (permanent residents), buildings, roads, and campgrounds were analyzed to determine which are at risk to CDF hazards. Understanding risk is a significant improvement that will help communities and individuals understand not just the hazard but also the potential impact areas. This will help motivate communities and individuals to perform risk reduction, which is the ultimate goal of this project. Before the project started, we were concerned that we would find a great percentage of buildings and permanent population exposed to CDF hazards. We found 555 people and 208 buildings across the four fire areas exposed to the Typical inundation zone.

We worked with community members to develop risk reduction actions and roadmaps to risk reduction. The primary results of the risk reduction activities include:

- Compiled list of previously published reports and fact sheet with recommendations for risk reduction (see results section of this report),
- Community brainstorm meetings (see link to recorded meetings), and
- Roadmaps to risk reduction.

Additional details on risk reduction are provided in the following paragraphs.

4.1 Risk Reduction

The risk reduction actions were grouped into awareness and education, insurance, emergency preparedness and warning systems, planning and regulation, physical mitigation, and emergency response and are described in additional detail in the following paragraphs.

4.1.1 Awareness and Education

Awareness of local hazards is crucial to understanding associated dangers and how to prepare for them. This study was initiated to alert communities in the study area of the need to be prepared for CDFs. It is vital to plan and prepare for this type of hazard to prevent and reduce the loss of life and property and develop community resilience. Once residents and landowners better understand the hazard, work can begin to reduce risk. To increase awareness, this report and an interactive web map viewer is available on the DOGAMI website. In addition, informational fact sheets are also available on the DOGAMI website with the purpose of educating the public about activities and actions that can be taken to reduce landslide risk. Informational fact sheets and other resources are listed in the results section of this report.

County, city, neighborhood, and other local community leaders can implement awareness campaigns to educate neighborhoods, businesses, individual homeowners, and visitors about the locations of hazards and how to reduce risk. The four geographical regions see varying levels of visitors and traveling public. Capturing the attention of visitors and traveling public will be difficult, however, some strategies may be available such as visitor bureau and campground websites, roadway signage, or notices listed with popular trail online applications.

When development already exists on land identified as a CDF hazard zone, it warrants neighborhood-scale educational efforts. Undertaking a public awareness campaign is beneficial to educate homeowners and landowners about the landslide hazard and risk in their areas and to prioritize future risk reduction actions. Residents on mapped CDF areas could participate in a neighborhood risk reduction program where all affected entities work together to help reduce the overall risk.

4.1.2 Insurance

It is extremely rare that homeowners' insurance covers landslides or CDF induced damage. CDFs are like flash floods and in some cases flood insurance should be considered. Flood insurance from FEMA (NFIP) or private insurance covers "mudflow" events, which must have a certain water content to be defined as a mudflow by the insurance companies or FEMA. We recommend property owners contact the Oregon State Division of Financial Regulation – Home Insurance and insurance agents about coverage details. This should include reviewing current insurance policies and becoming familiar with what is covered and ensure the limits adequately protect their building and personal belongings.

4.1.3 Emergency Preparedness

Together with awareness of local hazards, it is also crucial to be aware of and understand local and regional warning systems currently in place intended to alert residents and travelers of existing or potential disaster situations. There are several ways to prepare for emergency situations such as storm events and landslides. One can assess the level of readiness and preparedness to handle a disaster before disaster occurs by estimating damage and losses before they occur. Preparing a specific CDF community response plan is something that should be done prior to events. Other ways to prepare include making an emergency kit, planning evacuation routes, storing important papers in a safe, waterproof place, and itemizing and taking pictures of possessions.

To help prepare for CDFs, scientists from the USGS Landslide Hazards Program conducted research and developed the following lists of activities to do prior to and during intense storms that can trigger CDFs (Highland and others, 1997):

Prior to intense storms, residents can:

1. Become familiar with the land around you. Identify if you live, work, or travel in potential debris flow zones. See new DOGAMI maps (web map) and/or hire a certified engineering geologist to evaluate your property. Areas where debris flows have occurred in the past are likely to experience them in the future. People in the four regions of this study can review the new detailed maps published with this study.
2. These new maps should be used to create evacuation routes (web map). Establish evacuation routes and practice prior to events. A storm could happen at night!
3. Survey your property and the property around. Watch the hillsides around your home for any signs of land movement, such as small landslides or debris flows or progressively tilting trees.
4. Contact your local emergency manager to learn about the emergency response and evacuation plans for your area and develop your own emergency plans for your family and business.

During intense storms, residents can:

1. Stay alert and stay awake! Many debris flow fatalities occur when people are sleeping. Listen to the radio for warnings of intense rainfall. Be aware that intense short bursts of rain may be particularly dangerous, especially after longer periods of heavy rainfall and damp weather. Heed alerts from emergency officials.
2. If you are in areas susceptible to landslides and debris flows, consider leaving if it is safe to do so. Remember that driving during an intense storm can itself be hazardous.
3. Listen for any unusual sounds that might indicate moving debris, such as trees cracking or boulders knocking together. A trickle of flowing or falling mud or debris may precede larger flows. If you are near a stream or channel, be alert for any sudden increase or decrease in waterflow and for a change from clear to muddy water. Such changes may indicate landslide activity upstream, so be prepared to move quickly. Don't delay! Save yourself, not your belongings.
4. Be especially alert when driving. Embankments along roadsides are particularly susceptible to landslides. Watch the road for collapsed pavement, mud, fallen rocks, and other indications of possible debris flows.

Another way to prepare is through a landslide and debris flow warning system, which improves understanding when these events might happen. Oregon currently has a landslide and debris flow warning system operated in partnership by the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS), DOGAMI, ODOT, and the Oregon Department of Emergency Management (Burns and Franczyk, 2021). NWS initiates the system by sending out landslide and debris flow watches, and the state agencies help citizens become aware of the heightened potential for landslides.

In the future, streamlining this information to the local municipalities (counties and cities) via RSS feeds and live web pages could be helpful. During these periods of increased landslide and debris flow potential, the public could then access hazard maps to find locations where this potential is most likely. A specific local warning strategy should also be considered to alert residents in areas where cell service, landline phones, internet, or similar services are limited or nonexistent. During the small group brainstorming meetings with each of the four geographic groups, there was concern about conveying the emergency message to residents in these areas with limited communication services. Moreover, the suggestion of predictability together with increasing confidence and accuracy was important, as was improving existing warning systems.

A monitoring system that tracks rainfall thresholds at expected landslide and debris flow initiation areas could be developed by monitoring precipitation and resulting slide activity. Knowing when there will be periods of increased landslide and debris flow potential will help communities prepare, respond, and recover, should earth movement occur. If the location is a known high hazard area, such as debris flow fans, that have potential for life safety issues, evacuation could be considered, recommended, or required.

4.1.4 Planning and Regulation

4.1.4.1 Land-Use Measures

Regional and local land-use planning and regulation in Oregon is an effective method to work on risk reduction. There are a variety of ways to continue landslide risk reduction planning by using the maps and data produced in this project. There are two types of planning that engage leaders, residents, and landowners, including 1) focus on future development and 2) focus on existing infrastructure. A joint publication by DOGAMI and DLCD entitled Preparing for Landslides: A Land Use Guide for Oregon Communities (Sears and others, 2019) identifies various land-use tools and strategies to help communities reduce potential losses from landslides.

CDF inventories, like produced here for the four geographical areas, are essential in long-term planning. Long-term planning in Oregon includes urban growth boundary expansions and comprehensive plans that most cities and counties use to identify community goals. Planning can result in the avoidance of proposed development in high hazard areas and even public buyouts in very high or life-threatening hazard areas.

Connecting CDF inventory maps and data to regulations, such as development codes and ordinances, can be very effective at limiting future loss of property and life due to CDFs. Such regulations require consulting hazard maps when identifying areas for proposed development and limiting or preventing activities that may increase CDF risk in high hazard areas. Examples of development code are provided in Preparing for Landslides: A Land Use Guide for Oregon Communities (Sears et al., 2019). These regulations will usually require site-specific geotechnical analysis and mitigation design.

Developing appropriate regulations or conditions of approval for land-use permits in CDF hazard areas involves clear guidelines about when more stringent conditions apply based on the use proposed, who can conduct a geotechnical analysis, and how a local planner can determine that such an analysis contains all the needed information. Some rules, such as those within the Columbia River Gorge National Scenic Area, could be seen as barriers to mitigation. However, this just means that relationships are critical based on the additional layers within that area. Carefully developing land-use regulations are important to ensure that there are clear and objective standards provided for future housing.

4.1.4.2 Forestry Measures

Oregon Department of Forestry oversees the protection and promotion of resilient forests within the state. Some of this includes considering public safety within forest practices. Oregon Administrative Rule (OAR) 629-623-0000, Shallow, Rapidly Moving Landslides and Public Safety, addresses public safety as it relates to shallow, rapidly moving landslides (CDFs and other fast-moving landslides) and forest practices. There are high natural landslide hazards throughout Oregon and the purpose of this rule is to reduce the risk—short term and long term—of serious bodily injury or death caused by such landslides that could be directly related to forest practices. This is based on the best scientific and monitoring information currently available and includes various screening criteria (exposure categories, impact ratings, public safety risk levels, and restrictions on timber harvesting and road constructions, etc.). Similarly, OAR 629-630-0000, contains regulations for protecting wildlife and fish habitat. The new maps produced in this study will assist with these OARs.

4.1.4.3 Nonregulatory Measures

Nonregulatory measures can be considered an effective approach for mitigating the risk of CDF hazards. The so-called transferable development rights method provides an opportunity for property owners or developers to purchase the development rights of certain lots or parcels within a designated high hazard area, for example, and transfer those rights to an area with a lower hazard risk. This complements land-use planning and zoning by very effectively limiting future loss of property and life due to CDFs. Property acquisitions are common with floodplain buyouts in which a government agency purchases private property, removes any structures, and preserves the land as open space. This is another example of limiting future loss of property and life due to CDFs.

4.1.5 Physical Mitigation

CDF hazard risk reduction strategies, such as structural and nonstructural mitigation methods, are used to reduce the risks and impacts of CDF hazards. As CDFs can cover multiple properties or may even cross entire neighborhoods or major roadways, structural or engineered mitigation are effective measures that can prevent significant damage that could occur to critical infrastructure, communities (urban and rural), natural ecosystems, and result in the loss of life. The four geographic areas, all of which are prone to heavy rainfall and include major roadways or highways, can benefit by implementing effective landslide mitigation measures to ensure public safety.

There are various structural and nonstructural measures for mitigating CDFs in these regions, ranging from reinforced slopes to natural reinforcement techniques. These vary depending on where along the path of the CDF they are constructed. The path of a CDF consists of initiation area, transport area (travel channel), and depositional area (**Figure 1-2**). Mitigation measures are associated with the process, for example in the initiation areas the goal is to slow down or stop the CDF from initiating, in the transport areas the goal is to reduce or stop the transport before it reaches the deposition area, and in the deposition areas the goal is to reduce or stop impacts to assets. The following are structural and nonstructural mitigation measures for each of the three areas.

4.1.5.1 Initiation Area Measures

The following measures can be used for short-term mitigation of CDFs (immediately after wildfire):

- Seeding, using seeds of fast-growing plants in burned areas
- Mulching with straw

- Installing log erosion barriers may be effective by laying perpendicular to the slope to slow erosion
- Installing silt fences

The following measures can be used for long-term mitigation of CDFs:

- Planting trees in the initiation zones
- Not removing trees/vegetation in the initiation zones. This could also be applied through regulations.
- Performing geotechnical evaluations and implementing design to reduce risk especially in areas changed by humans such as roads, surface water concentration, and grading

4.1.5.2 Transport Area Measures

To mitigate the impacts of CDFs in transports areas, the following measures can be taken:

- Installing check dams, commonly built in a series in channels, to decrease channel gradients and retain the larger material within the flow
- Installing debris racks can promote deposition of large, coarser debris while allowing fine sediment and water to pass
- Installing debris flow nets can stop the larger material of the debris flow before the flow continues to grow

4.1.5.3 Depositional Area Measures

Finally, these mitigation measures can be taken in CDF depositional areas:

- Establishing voluntary or regulatory prohibition of development in the direct path of a potential debris flow
- Allowing new structures to be farther away from the debris flow channels
- Moving buildings out of the high hazard zones. This could also be done through property buyouts.
- Installing debris basins and nets may be effective at protecting areas changed by humans such as roads and existing or new structures
- Installing deflection walls, berms, and channelization may be effective measures to protect areas changed by humans such as roads and existing or new structures

In addition to the measures discussed above, the four groups developed the following suggestions during the brainstorming sessions. These are incorporated into the roadmaps, along with potential obstacles and solutions to those obstacles.

- Design dual purpose projects that involve, for example, floodplain restoration to address sediment and debris flow mitigation.
- Use new maps and risk analysis to inventory needs and focus on higher risk areas, looking at dual purpose areas such as road closures that are near streams with important fisheries.
- Road drainage maintenance plan
- Seasonal closures of higher risk areas (for example, Ainsworth State Park located in the Eagle Creek study area is closed in the winter-rainy season when most CDFs occur)
- Agency collaboration to minimize impacts

4.1.6 Emergency Response

We recommend that neighborhoods and communities create CDF emergency response plans before a CDF disaster. One component of such plans could include identifying local engineering geologists and geotechnical engineers and establishing working relationships with them so they can be asked to quickly evaluate areas of interest during and/or directly after a CDF disaster. Their evaluations would help determine what actions to take immediately following the event. For example, whether a neighborhood should be evacuated or if the area is stable enough to perform an emergency response.

In addition, creating a specific local warning strategy is beneficial in alerting residents in areas where cell service, landline phones, internet, or similar services are limited or nonexistent. During the small group brainstorming meetings with each of the four geographic groups, there was concern about conveying the emergency message to residents in these hard-to-reach areas where service can be limited and is discussed under Emergency Preparedness.

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