NATURAL RESOURCES

LANDSLIDE INVENTORY UPDATE OF THE COLUMBIA RIVER GORGE IN CLARK, SKAMANIA, AND KLICKITAT COUNTIES, WASHINGTON

by Mitchell D. Allen, Emilie M. Richard, Kara Fisher, Josh Hardesty, Katherine A. Mickelson, Trent Adams, and Crystal Lambert

WASHINGTON
GEOLOGICAL SURVEY
Report of Investigations 45
November 2023

INTERNALLY REVIEWED

WASHINGTON STATE DEPARTMENT OF
NATURAL RESOURCES
WASHINGTON GEOLOGICAL SURVEY

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This publication has been subject to an iterative review process with Survey editors and cartographers and has been formatted by Survey staff.

WASHINGTON STATE DEPARTMENT OF
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Washington Geology Library Searchable Catalog:
www.dnr.wa.gov/programs-and-services/geology/washington-geology-library

Suggested Citation: Allen, M. D.; Richard, E. M.; Fisher, Kara; Hardesty, Josh; Mickelson, K. A.; Adams, Trent; Lambert, Crystal, 2023, Landslide inventory update of the Columbia River Gorge in Clark, Skamania, and Klickitat Counties, Washington: Washington Geological Survey Report of Investigations 45, 7 p. [https://fortress.wa.gov/dnr/geologydata/publications/ger_ri45_columbia_gorge_landslide_inventory_update.pdf]

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Landslide Inventory Update of the Columbia River Gorge in Clark, Skamania, and Klickitat Counties, Washington

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ABSTRACT

Landslides are common in the Columbia River Gorge due to its geologic setting, high relief, steep slopes, and abundant precipitation. In July 2018, the Washington Geological Survey (WGS) published a lidar-based landslide inventory for a 900-square-mile area on the Washington side of the Columbia River following published protocols. This new project updates that landslide inventory by adding new mapping utilizing more-recent high-resolution lidar and imagery. Additional landslide hazard areas such as alluvial fans, rockfall, and more recent landslides, none of which were considered in the 2018 inventory, are included in this new publication. This updated inventory will increase awareness of landslide hazard areas in the Columbia River Gorge and assist planners, emergency managers, public works departments, and those who live and work where landslides could impact their daily lives.

INTRODUCTION

Landslides are among the most common and devastating natural hazards in Washington State. In the previous 30 years, the state has experienced numerous destructive landslides, including the 2014 SR-530 "Oso" landslide that took 43 lives. The 1998 Aldercrest–Banyon and 1999 Carlyon Beach landslides damaged or destroyed 138 houses near Kelso (Wegmann, 2006) and 41 houses near Olympia (GeoEngineers Inc., 1999), respectively. Thousands of shallow landslides initiated as a result of winter storms in 1996–1997, 2007, and 2009 (Baum and others, 1998; Sarikhan and others, 2008; Sarikhan and others, 2009, respectively).

The natural beauty and recreation opportunities in the Columbia River Gorge (hereinafter referred to as the Gorge) have led to increasing population and home construction. Landslide and rockfall hazards are of particular concern as landowners continue to develop areas on or below the steep slopes, ancient landslides, and cliffs that characterize the topography of the Gorge. Further, public roads and railroad tracks that run along the slopes of the Gorge are subject to rockfall and topple hazards associated with prevalent, steep bedrock exposures. In some cases, rockfall has led to loss of life (KTVZ News Sources, 2022). Alluvial fans are often attractive landforms for development, but may be subject to landslides and debris flows emanating from remote mountainous terrain. Historic wildfire activity throughout the Gorge increases the risk of debris flows on alluvial fans. Recent mapping in Klickitat County highlights the abundance of alluvial fans within portions of the Gorge (Mickelson and others, 2023).

Landslide inventories identify areas that have likely experienced landslide hazards in the past. Areas that have previously experienced these hazards are more susceptible to experiencing them in the future. This inventory has been prepared by geologists trained in identifying areas subject to landslide activity, using the best available science.

This report and accompanying GIS data (Appendix A) provide information about mapped landslides, rockfall, and fans located on the Washington side of the Columbia River Gorge. The GIS data accompanying this report have been added to the Washington State Landslide Inventory Database (WASLID), which is available for viewing and download on the Washington Geologic Information Portal (geologyportal.dnr.wa.gov).

INTENDED USE

Landslide inventories assist planners, emergency managers, public works departments, and those who live and work where landslides could impact their daily lives by identifying areas that have likely experienced landslide hazards in the past. Some example uses include:

- Public works—A landslide inventory can identify areas where underground utilities or transportation networks may be impacted. Areas with a history of maintenance issues may benefit from a review of the landslide inventory, which may identify previously unrecognized landslide hazards.

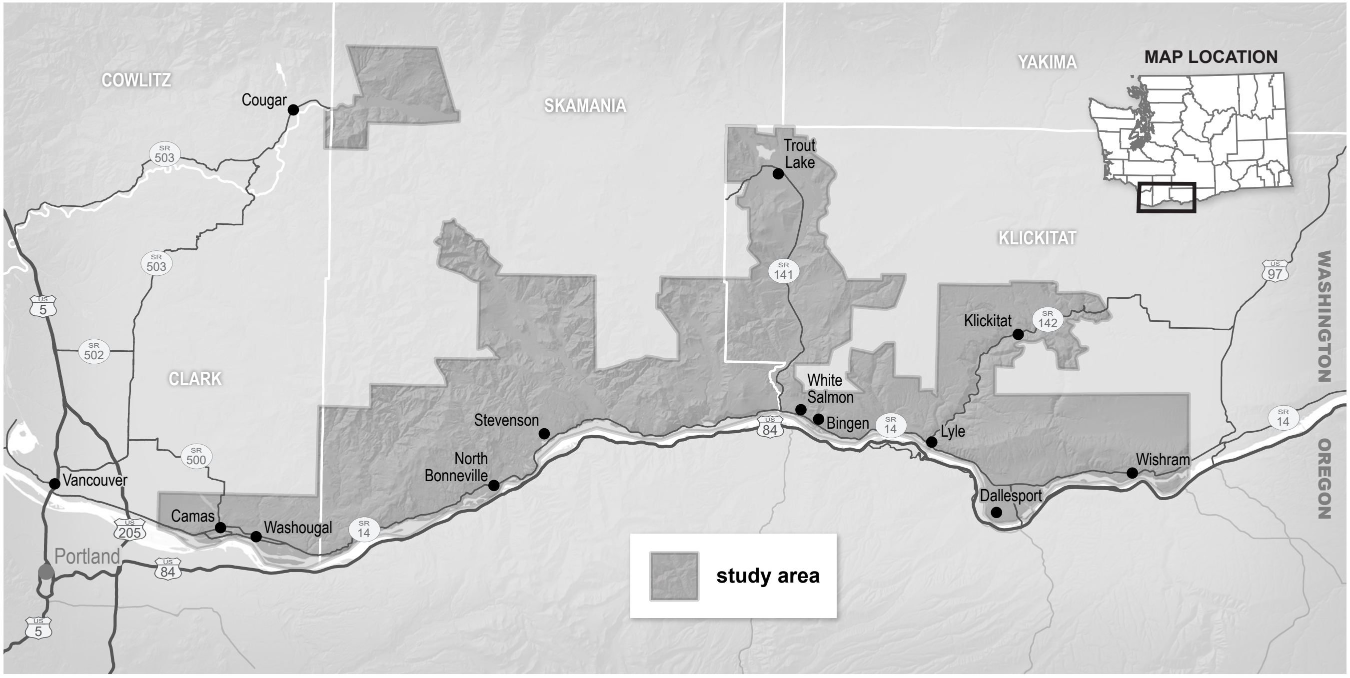

Figure 1. Study area for the Columbia River Gorge landslide mapping project.

- Planning—Landslide inventory mapping can identify areas where proposed land use intersects with landslide hazards. These areas need additional geotechnical review to ensure that the proposed land use will not be adversely impacted by the landslide hazard(s). Improperly graded slopes and (or) disturbances of sensitive geological materials may contribute to destabilization. Poor surface-water management can reactivate old landslides, potentially affecting homes, businesses, or entire neighborhoods.
- Emergency management—Access to landslide inventory mapping can help emergency managers assess the likelihood that a reported incident may be landslide-related. When planning evacuation routes (such as for a tsunami or lahar), roads that cross existing landslides should be avoided due to an increased likelihood of landslide reactivation, which may block or hinder emergency response and (or) evacuation routes. During intense precipitation events, roads that cross fans may be impassable due to flooding and debris on the roadway.
- Public—Individuals purchasing or renting property or a home, or currently living on or near a landslide, should be aware of landslide hazards. It is critical that the public manages stormwater and runoff on their property and recognizes the signs of potential landslide activity. During intense or prolonged precipitation events, homes and roads on fans may be impacted by flooding and debris. Hazards on fans may also be temporarily increased downstream of areas impacted by wildfires.

In Washington, city or county governments regulate land-use planning. While the Washington Geological Survey (WGS) updates landslide inventories to ensure that city and county planners have the best data available to them, WGS does not revise building codes or evaluate development permits. Those decisions are controlled by county- and city-level governments.

STUDY AREA

Portions of the Gorge are a federally designated National Scenic Area on the Oregon and Washington border stretching 72 mi (120 km) across the Cascade Range. The 900-square-mile study area focuses on the Washington side of the Gorge, encompassing portions of three counties, Clark, Skamania, and Klickitat, and the cities of Camas (partial), Washougal, North Bonneville, Stevenson, White Salmon, and Bingen (Fig. 1). Predominant highway access is via WA-14, WA-141, and WA-142. The Gorge contains high-tension power lines, hydroelectric dams, and pipelines, and is a major rail corridor (Calhoun and others, 2019). This study revisits the same study area inventoried by Mickelson and others (2018).

METHODS

Lidar

Lidar datasets collected between 2002 and 2019 cover the entire study area. Table 1 summarizes the lidar datasets used and their specifications. Where datasets overlapped, the data with the greatest number of pulses per square meter were used to identify and map landslides. In some cases, this may not have been the most recent dataset.

Lidar-derived Digital Elevation Models (DEMs) were processed to create slope gradient maps for each dataset. Geologists used these layers to interpret and delineate landslides, rockfall, and alluvial fans following the protocol for landslide inventory mapping from lidar in Washington State (Slaughter and others, 2017). Lidar data were supplemented with aerial imagery collected between 1976 and 2022 to aid in interpretation of mapped landforms and identify recent or shallow landslide activity not visible in lidar.

Detailed Landslide Inventory Mapping

This publication expands on previous landslide inventory mapping published by Mickelson and others (2018) by mapping new landslides and modifying previously mapped landslides utilizing newly released lidar data and orthoimagery. Additionally, this study maps rockfall hazards, alluvial fans, and recent landslide points. None of these features were mapped by Mickelson and others (2018). These newly mapped features have been added to WASLID. Any modifications to the previously published landslide inventory database were internally reviewed and documented in the related GIS information for each landslide feature. Modified features supersede the previously published feature while maintaining the same unique identification number in the database. Superseded features are preserved in the downloadable GIS data, but are not displayed in the landslide inventory as shown on the Washington Geologic Information Portal.

Landslides were mapped using the landslide inventory mapping protocol of Slaughter and others (2017), a slight modification of Burns and Madin (2009). Geologists digitized landslides from lidar derivatives and mapped the deposit, scarp(s), and flank(s) (Fig. 2). Any present internal scarps were digitized. The landslide deposits were assigned unique identification numbers and described using 16 attributes, including material involved, movement type, identification confidence, age, year of movement (if known), field verification status, slope steepness, headscarp height, failure depth, movement direction, volume, and average scarp spacing. For more details about these attributes, refer to Slaughter and others (2017).

Alluvial fans were mapped where lidar shows cone-shaped deposits at the mouth of a drainage (Fig. 3). Sediment on a fan is deposited by streams, floods, and (or) debris flows and is typically sourced from a single channel. Mapped fan deposits were assigned unique identification numbers along with attributes, including identification confidence, age, year of movement (if known), field verification status, slope steepness, fan height, and volume.

Rockfall deposits are generally found below steep slopes or cliffs. Using a combination of orthoimagery and lidar, geologists digitized scarps, which depict rockfall source areas, and rockfall deposits, which represent where the fallen rocks have collected. (Fig. 4). Mapped rockfall deposits were assigned unique identification numbers along with attributes, including identification confidence, age, year of movement (if known), field verification status, slope steepness, and movement direction. Rockfall scarps are typically mapped along the uppermost rock scarp likely to contribute rock to the downslope deposit. In addition to natural rockfall features, this study also mapped rockfall hazards along roadways where road-construction has produced man-made rockfall hazards but road maintenance activities routinely clear away any fallen rocks. Historic activity along these areas was informed by communication with representatives from the Washington State Department of Transportation, which is responsible for maintaining impacted roadways.

Field verification, performed on approximately 9 percent of newly mapped landslides, fans, and rockfall areas, focused on landforms that were difficult to interpret from lidar and were in, or around, populated areas and (or) infrastructure. In the field, any visible landslide indicators (for example, headscarps, sag ponds, internal cracks, springs or seeps, and pistol-butted trees) were noted. Visible indicators of debris flow activity on alluvial fans (for example, large boulders, accumulated woody debris, and levees) were noted. Field observations are considered in the final determination of landslide confidence and relative age for landslides, alluvial fans, and rockfall.

Geologists reviewed orthoimagery and historical data to compile recent landslide points within the study area. These points record recent landslides that are not visible in lidar but are visible in orthoimagery (possibly because they occurred after the lidar data were collected), or that are not visible in either lidar or orthoimagery but have been identified in the field.

Table 1. Lidar projects used for landslide interpretation. All lidar data were obtained from the Washington Lidar Program repository (lidarportal.dnr.wa.gov).

Lidar Project	Year Collected	Lidar Ground Returns (Pulses/m^2)	Raster Cell Size (ft)
Clark 2002	2002	unknown	6
St Helens Nov 2004	2004	unknown	6
Yacolt 2005	2005	unknown	6
Lower Columbia 2005	2005	unknown	6
Gorge 2006	2006	unknown	3
Siouxon 2006	2006	unknown	3
Columbia 2010 E	2010	unknown	3
Conduit Dam 2011	2011	12	3
Clark 2013	2013	unknown	3
Metro 2014	2014	12.24	3
Wasco Del4 2014	2014	13.77	3
Klickitat 2015	2015	20.11	3
Wasco B 2015	2015	15.09	3
Mount Adams 2016	2016	17.42	3
Swwa Foothills 2017	2017	12.29	3
Southwest State Lands 2017	2017	14	3
Wind River Forest 2017*	2017	unknown	3
Rock Creek Clark 2017*	2017	unknown	3
Wind River Forest 2018*	2018	unknown	3
Rock Creek Clark 2018*	2014	12.41	3
Rock Creek Clark 2018*	unknown	3	3
Klickitat 3DEP 2019	2019	3.82	3
Cascades South 2019	2019	4.85	3
Wind River Forest 2019*	2019	unknown	3

* At the time of publication, the indicated lidar projects were not publicly available on the lidar portal. Please contact geology@dnr.wa.gov for more information.

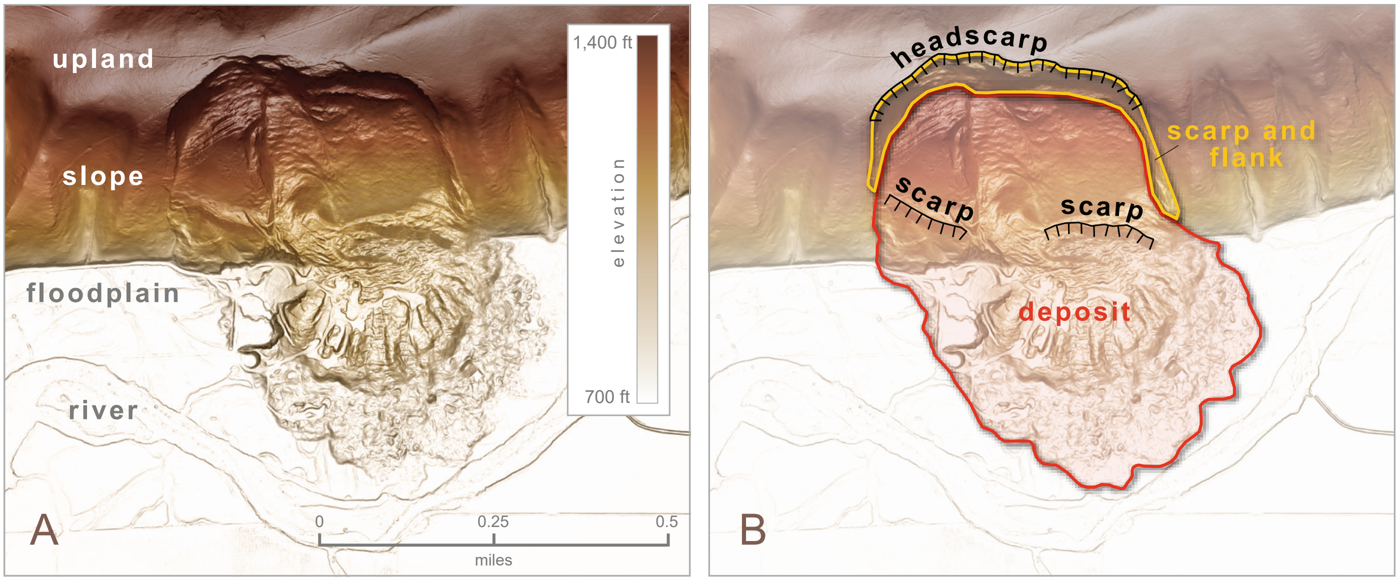

Figure 2. **A.** An example of the geomorphic expression of a landslide in lidar. **B.** Digitized components of the landslide. See Appendix A for information about the landslide data in GIS format.

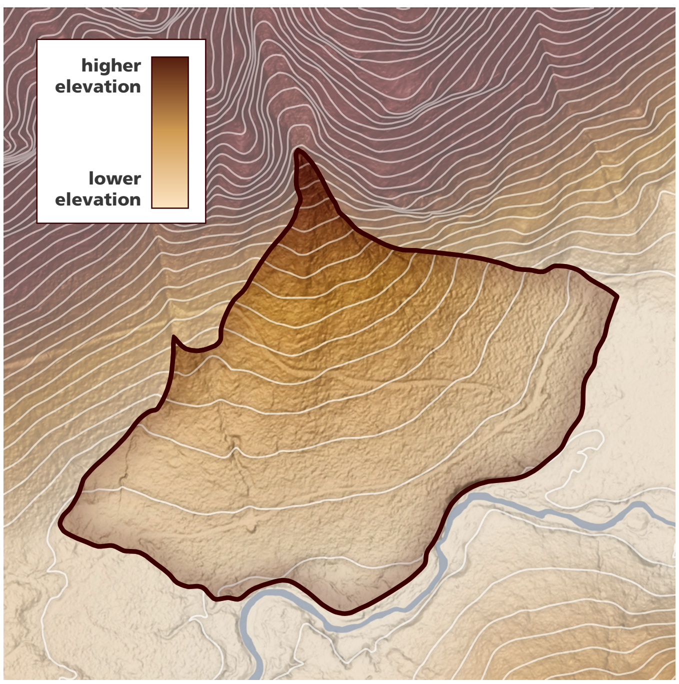

Figure 3. An example of a mapped fan deposit (dark brown line) with 40-ft contours to better distinguish the depositional surface from the valley bottom.

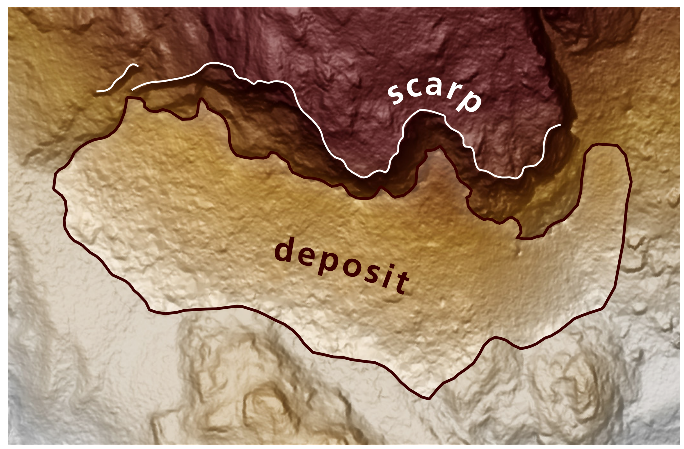

Figure 4. An example of a mapped rockfall deposit (dark brown line). White lines indicate rockfall source areas (scarps).

After the completion of mapping, a licensed engineering geologist provided quality control by reviewing the entire landslide inventory and associated attributes.

RESULTS AND CONCLUSIONS

This update to the landslide inventory of the Columbia River Gorge study area adds 1,335 fans, 1,498 rockfall deposits, 129 recent landslide points, and 590 landslides. Additionally, 80 landslides were modified from the previously published inventory of Mickelson and others (2018). Alluvial fans located within Klickitat County (Fig. 1) were recently published in a separate inventory (Mickelson and others, 2023), and are thus not considered part of this study.

Rockfall deposits cover 1.3 percent of the study area and are prevalent along major transportation corridors throughout the study area. Roughly one quarter of WA-14 within the study area intersects, or is located immediately downslope of, mapped rockfall deposits. Rockfall deposits are particularly prevalent within the communities of Wishram and Bingen (Fig. 1), where several structures are located within mapped features. Of all rockfall deposits, we observed evidence suggesting 78 (5%) are historical, meaning that all or portions of the rockfall deposits have been active in the past 150 years. Due to the limitations of orthoimagery (areas obscured by vegetation, limited image resolution, and limited availability of older photos) as well as maintenance removal of rocks along roadways, our historical designation could underrepresent historically active rockfall areas.

Fan deposits cover about 1 percent of the study area. Estimated fan volumes range from 9.5 cubic yards to 3.5 million cubic yards, with an average of 39,000 cubic yards. Of the mapped fans considered in this study, we observed evidence suggesting 24 (~2%) are historical, meaning that all or portions of the fans have been active in the past 150 years. Due to the limitations of orthoimagery, our historical designation could underrepresent historically active fans.

The map area encompasses 129 identified recent landslide points, most of which are in the western half of the study area, where total annual precipitation is greatest. Many of these landslide events mobilized into channelized flows that ran out to fans mapped downstream. These recent landslides were identified from available aerial imagery spanning the last several decades, as well as field observations. Debris flows and floods occur episodically in the study area and pose a significant hazard to people and infrastructure on fans during intense and prolonged rainfall, especially when this rain melts snow in the uplands.

High-quality hazard maps and dissemination of information about landslide hazards are essential to the establishment of a landslide-hazard reduction program. This updated landslide inventory aims to help inform communities in the study area about landslide hazards, so they may become more resilient to these events. People living on landslides may recognize the potential hazard and take appropriate actions to reduce the likelihood of reactivation or impacts of landslide activity. Planners can use the new data to guide land-use decisions when updating hazard ordinances and local building codes. By identifying areas that may need further site-specific investigations and mitigation, planners can also use these hazard maps to evaluate the risk to people and property when considering future development.

ACKNOWLEDGMENTS

We would like to thank Cody Chaussee of the Washington State Department of Transportation for his assistance in the field, knowledge of hazards along highway corridors, and sharing of data to aid our interpretations. This project benefitted from field assistance and sharing of local knowledge by John Jenkins of the Washington Department of Natural Resources. Thank you to Becca Goughnour for helpful assistance in the field. Jim O'Connor and Charles Cannon of the United States Geological Survey shared their draft geologic mapping and valuable insights into landslide issues within the study area. Thank you to Bigfoot Coffee Roasters in the town of Stevenson, our informal 'Field Office,' for the smiling faces, delicious refreshments, and welcoming environment to start our field days.

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Appendix A. Landslide Inventory Data

An Esri file geodatabase containing the mapped landslides, fans, and rockfall areas is available for download from the Washington Geological Survey website (www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases). It is also viewable on the interactive Washington Geologic Information Portal (geologyportal.dnr.wa.gov). Note that this geodatabase is a combined dataset. It contains landslide data for all the counties in Washington that have been inventoried. The combined inventory is known as the Washington State Landslide Inventory Database (WASLID). WASLID contains both detailed mapping (conducted using the protocol referred to in this publication), and a compilation of other landslides mapped by various groups and for various purposes over the past few decades. These compiled landslides were not mapped using the protocol of Slaughter and others (2017).

Mapped features within WASLID that have been modified by subsequent mapping efforts are marked as superseded. Superseded features are preserved in their previous state as a separate feature within the downloadable geodatabase but are not displayed on the Washington Geologic Information Portal. Attributes for the modified features document the type of modification and when it occurred.