GE-02 EROSION AND GEOLOGIC HAZARDS AT PROJECT FACILITIES AND TRANSMISSION LINE RIGHT-OF-WAY STUDY
INTERIM REPORT

SKAGIT RIVER HYDROELECTRIC PROJECT
FERC NO. 553

Seattle City Light

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Initial Study Report

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List of Acronyms and Abbreviations

AFM .... American Forest Management, Inc.
BMP .... best management practice
CB .... catch basin
City Light .... Seattle City Light
CMP .... corrugated metal pipe
CMZ .... channel migration zone
DEM .... digital elevation model
DNR .... Department of Natural Resources (Washington State)
DOGAMI .... Oregon Department of Geology and Mineral Industries
DPP .... Department Policy and Procedure
EGU .... Engineering Geology Unit
FERC .... Federal Energy Regulatory Commission
GIS .... Geographic Information System
GNSS .... Global Navigation Satellite System
GPS .... Global Positioning System
HDPE .... high-density polyethylene
ISR .... Initial Study Report
IVM .... integrated vegetation management
km .... kilometer
LiDAR .... Light Detection and Ranging
LP .... licensing participant
MP .... milepost
NPS .... National Park Service
O&M .... operations and maintenance
pcf .... pounds per cubic foot
PDMV .... preferred landslide direction of movement
PME .... protection, mitigation, and enhancement
Project .... Skagit River Hydroelectric Project
psf .... pounds per square foot
QSI .... Quantum Spatial, Inc.
RMAP .... Road Maintenance and Abandonment Plan

ROW ....right-of-way
RSP ....Revised Study Plan
SP ....Special Paper
SR...............................State Route
SSC ....Sites of Special Concern
USGS .........................U.S. Geological Survey
USMS.........................Unstable Slope Management System
USR............................Updated Study Report
WARSEM ....Washington Road Surface Erosion Model
WDFW.......................Washington Department of Fish and Wildlife
WGS...........................Washington Geologic Survey
WSDOT ....Washington State Department of Transportation
WSI ....Watershed Sciences, Inc.
ZSC ....Zone of Special Concern

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1.0 INTRODUCTION

The GE-02 Erosion and Geologic Hazards at Project Facilities and Transmission Line Right-Of-Way Study (Erosion and Geologic Hazards Study) is being conducted in support of the relicensing of the Skagit River Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 553, as identified in the Revised Study Plan (RSP) submitted by Seattle City Light (City Light) on April 7, 2021 (City Light 2021). On June 9, 2021, City Light filed a "Notice of Certain Agreements on Study Plans for the Skagit Relicensing" (June 9, 2021 Notice)[1] that detailed additional modifications to the RSP agreed to between City Light and supporting licensing participants (LP) (which include Swinomish Indian Tribal Community, Upper Skagit Indian Tribe, National Marine Fisheries Service, National Park Service [NPS], U.S. Fish and Wildlife Service, Washington State Department of Ecology, and Washington Department of Fish and Wildlife [WDFW]). The June 9, 2021 Notice included agreed to modifications to the Erosion and Geologic Hazards Study.

In its July 16, 2021 Study Plan Determination, FERC approved the Erosion and Geologic Hazards Study without modification.

This interim report on the 2021 study efforts is being filed with FERC as part of City Light's Initial Study Report (ISR). This report includes data collection and analyses completed through October 2021. Additional analyses and data collection are planned for 2022 as described under the "Next Steps" sub-sections at the end of Sections 4, 5, and 6 of this study report to be included in the Updated Study Report (USR) in March 2023.

This report covers several erosion and geologic hazard topics and is organized into three sections by topic with methods, preliminary results, and summary subsections in each:

- Section 4, Mass Wasting: covers landslides and rockfalls, including mapping past mass wasting within, originating from, or affecting areas within the Project Boundary. This section also includes a susceptibility analysis for future events.
- Section 5, Erosion and Runoff from Project-Related Townsites and Study Routes:[2] covers townsite and study route runoff and associated erosion from hydrologically-connected study routes and townsite areas and an inventory of study routes. This section will also include a fish passage assessment at route crossing structures as part of the 2022 work.
- Section 6, Channel Migration and Stream Crossings: provides an analysis of the interaction of streams with the transmission line right-of-way (ROW) and streamside facilities in Project-related townsites, including maintenance procedures near streams and bank protection.

[1] Referred to by FERC in its July 16, 2021 Study Plan Determination as the "updated RSP."

[2] Study routes include segments of road and trail within the Project Boundary maintained by City Light plus non-public roads and trails outside the Project Boundary that City Light uses to access the transmission line right-of-way and other City Light facilities that support the Project that are inside or outside of the Project Boundary. Segments of roads that are abandoned or serve to access private residences or farms were not included as study routes. The specific study routes included in the Erosion and Geologic Hazards Study are based on the defined study area and objectives of this study.

2.0 STUDY GOALS AND OBJECTIVES

The goals of the Erosion and Geologic Hazards Study are two-fold:

- Goal 1: to characterize where Project operations and maintenance (O&M) activities are affecting erosion, mass wasting, and runoff that could affect the following resource areas—cultural; terrestrial; aquatic; fisheries; riparian; and rare, threatened, and endangered plants; and
- Goal 2: to determine where existing erosion, mass wasting, and channel migration/bank erosion have the potential to affect Project facilities.

The Erosion and Geologic Hazards Study includes both elements to evaluate potential Project effects and provide background information that will help inform long-term geologic hazard planning at Project facilities. Specific objectives include:

- Identify, map, inventory, and characterize areas of erosion, runoff, mass wasting, and culvert conditions that are affected by Project facilities, townsites, transmission towers, and study routes (Goal 1).
- Identify where Project maintenance activities (e.g., road grading, ditch maintenance, vegetation management, streambank protection) along the transmission line ROW and study routes have the potential to cause erosion or sedimentation or altered hydrologic connectivity to water bodies (Goal 1).
- Identify the current instream and riparian habitat conditions within and immediately upstream and downstream of transmission line stream crossings where channel migration, bank erosion, or mass wasting are potentially affected by Project operations (Goal 1).
- Identify mass wasting (landslide, rockfall) and channel erosion hazards (e.g., channel migration, bank erosion) that could affect Project facilities, transmission towers, or study routes (Goal 2).
- Characterize study route-stream crossing structures so that hydraulic capacity, erosion, and biological effects (e.g., fish passage) can be assessed (Goals 1 and 2).

This information will be available to inform license application preparation to evaluate how Project O&M may affect slope stability and erosion, how water quality, aquatic, riparian, terrestrial, and cultural resources may be affected, and to inform long term geologic hazard planning at Project facilities.

Several commitments were made pertaining to the Erosion and Geologic Hazards Study as part of the June 9, 2021 Notice. The status of City Light's implementation of commitments in the June 9, 2021 Notice is described in Section 5.3.1 and Section 6.3.1 of this study report.

3.0 STUDY AREA

The Erosion and Geologic Hazards Study area covers land within the Project Boundary from Ross Dam to the Bothell Substation (Figure 3.0-1), including:

- Project dams and powerhouses;
- Project townsites;
- Study routes;
- Transmission line ROW; and
- Fish and wildlife mitigation lands.

Note that erosion and mass wasting areas along Project reservoir shorelines (Ross, Diablo, and Gorge lakes) are not included within this study area as they are covered in the GE-01 Reservoir Shoreline Erosion Study (City Light 2022). However, areas around Project-related facilities near Diablo Dam are included in this study area (e.g., Skagit Tour Dock, Ferry Landing, Boat House, City Light Boat Launch, and City Light Dry Dock).

Also note that for the mass wasting component of the Erosion and Geologic Hazards Study (Section 4), the Project Boundary was expanded to encompass the steep slopes that surround the transmission line ROW and City Light's facilities listed above.[3] These steep slopes may include the potential source areas for mass wasting processes. The mass wasting study area is shown in Figure 3.0-1 and is described in more detail in Section 4 of this study report.

The study area for the channel migration zone (CMZ) analysis and riparian/aquatic habitat assessments at specific stream/transmission line ROW crossings (Section 6 of this study report) extends up to 1,000 feet (10 bankfull channel widths; bankfull channel width varies by stream) upstream and/or downstream from the ROW boundary, depending upon stream size and geomorphic setting. These areas fall within the mass wasting study area shown on Figure 3.0-1.

[3] Day Creek Slough mitigation land is located in a low-lying valley bottom over 1 mile from nearest steep slopes and likely sources of mass wasting hazards; as such this property was not included in the mass wasting portion of the study.

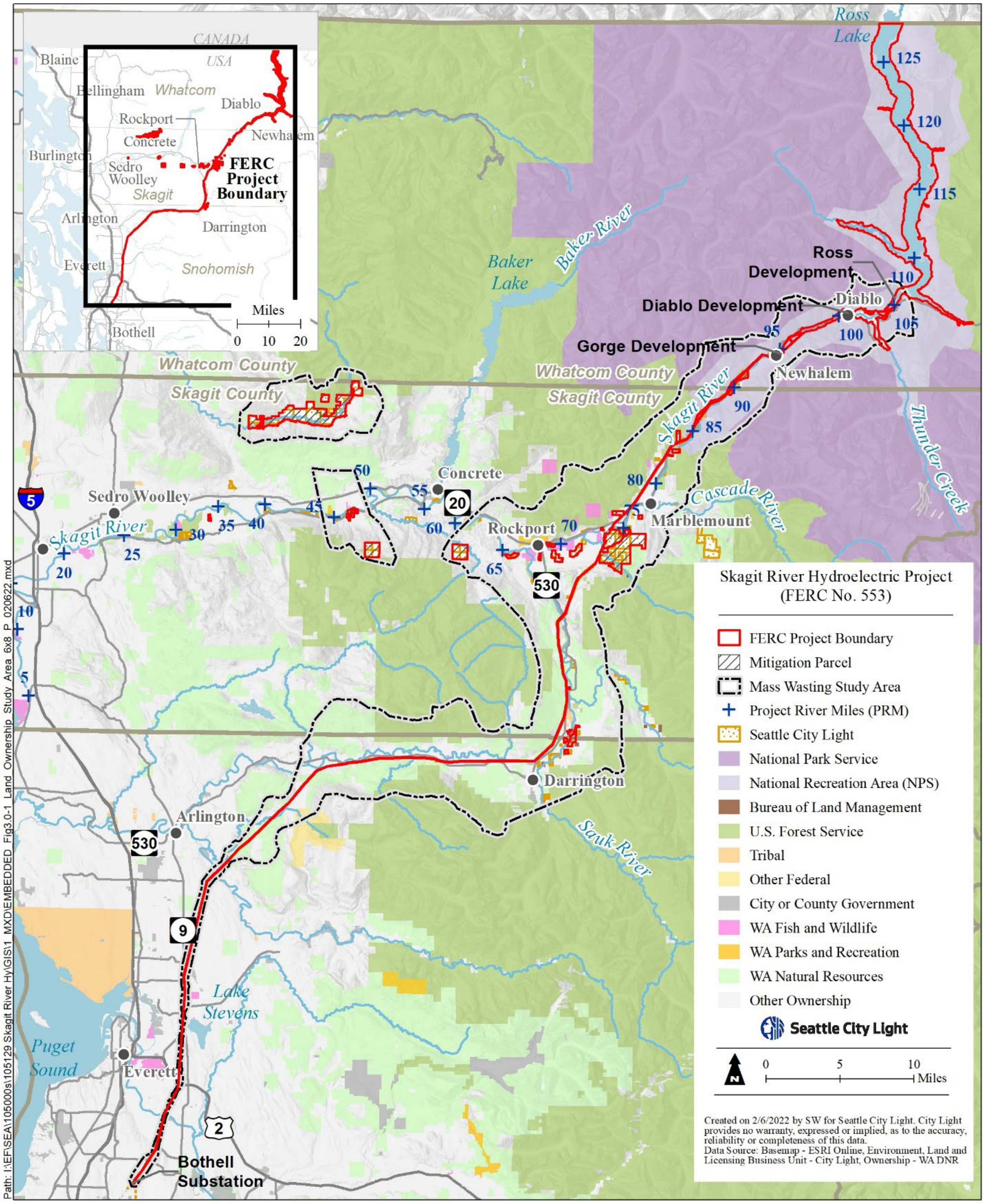

Figure 3.0-1. Location map of the Skagit River Project.

4.0 MASS WASTING

The mass wasting component of the Erosion and Geologic Hazards Study (herein referred to as mass wasting study component) provides: (1) a Geographic Information System (GIS) inventory (Mass Wasting Inventory) of existing mass wasting features (e.g., landslide and rockfall) within the mass wasting study area (defined below) that could affect and/or be affected by City Light facilities and operations; and (2) an initial assessment of the susceptibility of slopes to the dominant types of mass wasting within the mass wasting study area based primarily on existing mass wasting features, slope characteristics, and local geology. The results of this study component will be used during development of the license application and management plans to provide background information for assessing the interactions between mass wasting and Project management, facilities, and resources. This study component is a regional-level study and does not offer site-specific recommendations for City Light facilities within the Project Boundary. Furthermore, as described in Section 4.1.3 of this study report, this study assesses the relative hazards of mass wasting features but does not include formal risk analyses of these mass wasting hazards, nor should it be inferred to do so for this purpose.

The northern section of the mass wasting study area, as shown in Figure 3.0-1 (above), is primarily situated within the lowland areas of the Skagit, Sauk, and the North Fork of the Stillaguamish River (NF Stillaguamish River) valleys. This part of the transmission line ROW is surrounded by steep alpine slopes potentially susceptible to mass wasting. For the purposes of the mass wasting study component, the Project Boundary was expanded to encompass these steep slopes. This expanded boundary defines the mass wasting study area and generally follows the ridgelines above the Skagit, Sauk, and NF Stillaguamish river valleys. Where the transmission line ROW turns south from the mountainous valleys of the NF Stillaguamish River and crosses relatively flat ground between Arlington and Bothell, the mass wasting study boundary follows the Project Boundary, as shown in Figure 3.0-1.

The Mass Wasting Inventory consists of known occurrences of mass wasting, types of mass wasting processes, approximate magnitude of historical landslide/rockfall volumes, and other attributes useful for analyzing areas susceptible to mass wasting. The Mass Wasting Inventory provides a primary input to susceptibility analyses. Mapping of susceptibility zones is based on an understanding of the relative likelihood of the terrain to experience specific types of mass wasting processes. Susceptibility zonation also helps provide some regional context for previous and any future site-specific studies.

In the Erosion and Geologic Hazards Study, the following mass wasting deliverables are provided:

- GIS database (Mass Wasting Inventory) of mapped mass wasting features;
- GIS layers containing results of susceptibility analyses;
- Suites of maps displaying mapped mass wasting features and results of susceptibility analyses:
  - Deep-Seated Landslides and Susceptibility Mapbook (Attachment A);
  - Shallow Landslides and Susceptibility Mapbook (Attachment B);
  - Rockfall and Susceptibility Mapbook (Attachment C); and

- Debris Flow Classification Analysis Mapbook (Attachment D).

- Summary of results that indicate areas of special concern, i.e., areas of high hazards or potentially unstable slopes that overlap Project facilities:
  - Summary Mapbook (Attachment E).

4.1 Methods

4.1.1 Compile and Review Existing Information

The analysis of mass wasting hazards included the compilation of reports, published maps, existing geospatial data, and similar studies (see RSP Section 2.6.1.1) relevant to the identification of unstable slopes in the mass wasting study area.[4] The existing information provided established data points that were used as guidance during the mapping process of the mass wasting study component. Additionally, selected mass wasting features identified and mapped in the existing studies were integrated into the Mass Wasting Inventory. In the following sub-section, the existing datasets are described as two groups: (1) Light Detection and Ranging (LiDAR) and aerial imagery; and (2) previous studies.

4.1.1.1 LiDAR and Aerial Imagery

Composite datasets of LiDAR and aerial imagery were used as primary sources for: (1) identifying, mapping, and characterizing mass wasting features on the landscape; and (2) extracting slope geometry for Mass Wasting Inventory parameters and susceptibility analyses. The majority of these datasets consisted of the following Project data provided by City Light:

- Project LiDAR – Western Washington 3DEP North AOI (Quantum Spatial, Inc. [QSI] 2016); Cedar Watershed Delivery #1 (QSI 2014); Glacier Peak AOI (QSI 2015a); Ross Lake (QSI 2018a); Skagit Topobathy (QSI 2017); Upper Skagit, Gorge Lake and Diablo Lake (QSI 2018b); and
- Project aerial imagery – National Agriculture Imagery Program (2006); NPS (1978 and 1998); Quantum Spatial, Inc. Skagit Orthoimagery (QSI 2018b).

Because the debris flow analyses (described in Section 4.1.3.4 of this study report) require complete watershed areas for each fan, occasionally extending beyond the Project LiDAR limits, LiDAR data downloaded from the Washington Geologic Survey (WGS) LiDAR Portal was added to provide better coverage of the mass wasting study area.[5] Additional LiDAR data was resampled, reprojected, and mosaiced to 3-foot digital elevation model (DEM) grids in Project projection. Table 4.1-1 lists the additional LiDAR data and Figure 4.1-1 shows the footprints of all LiDAR datasets used for the mass wasting study component.

[4] As explained in the RSP, while subsurface geotechnical data can be useful for the study of individual mass wasting features, implementing subsurface information for this study component, a regional hazard study, is not necessary. Reviewing information on existing subsurface explorations therefore was not a part of the study plan, and, indeed, such information was not reviewed as part of this study component.

[5] For some fan watersheds, LiDAR was unavailable for the entire watershed area. Consequently, for those fans with truncated watershed analyses areas, fan classification was approximated.

Table 4.1-1. Additional LiDAR data downloaded from the Washington Geologic Survey LiDAR Portal.

Study Name	DEM Resolution (feet)	Acquisition Year	Source
North Puget / Western Washington 3DEP North AOI 2016[1]	3.0	2016	QSI (2016)
Baker 2015	3.3	2015	QSI (2015b)
Cedar River 2014[1]	3.0	2014	QSI (2014)
Tulalip 2013	3.0	2013	Watershed Sciences, Inc. (WSI 2013)
North Cascades 2009	3.3	2009	WSI (2009)
North Puget 2006	3.0	2006	Sanborn (2008)
Darrington 2003	6.0	2003	Harding (2004)

1 Additional portions of QSI (2016, 2014) LiDAR datasets downloaded that had not been included in Project LiDAR data.

After compiling high-resolution Project and additional DEMs, slope maps and hillshaded relief maps were rendered to allow identification of fine-scale geomorphic features and to make measurements with the accuracy of the DEM resolution.

The Project orthophoto imagery provided a secondary means for identifying features and in some cases allowed for the estimation of relative age of the features. Although most of the slopes are heavily forested, recent slope movement could be detected by identifying bare and freshened slope surfaces, exposed rock as cliffs, fresh debris on slopes and in channels, downed trees, and deformed logging roads on the forested slopes. If these features could be identified on more than one set of orthoimagery, a rough estimate of slope failure timing could be inferred as closely pre-dating the images. These observations were noted in the Mass Wasting Inventory database.

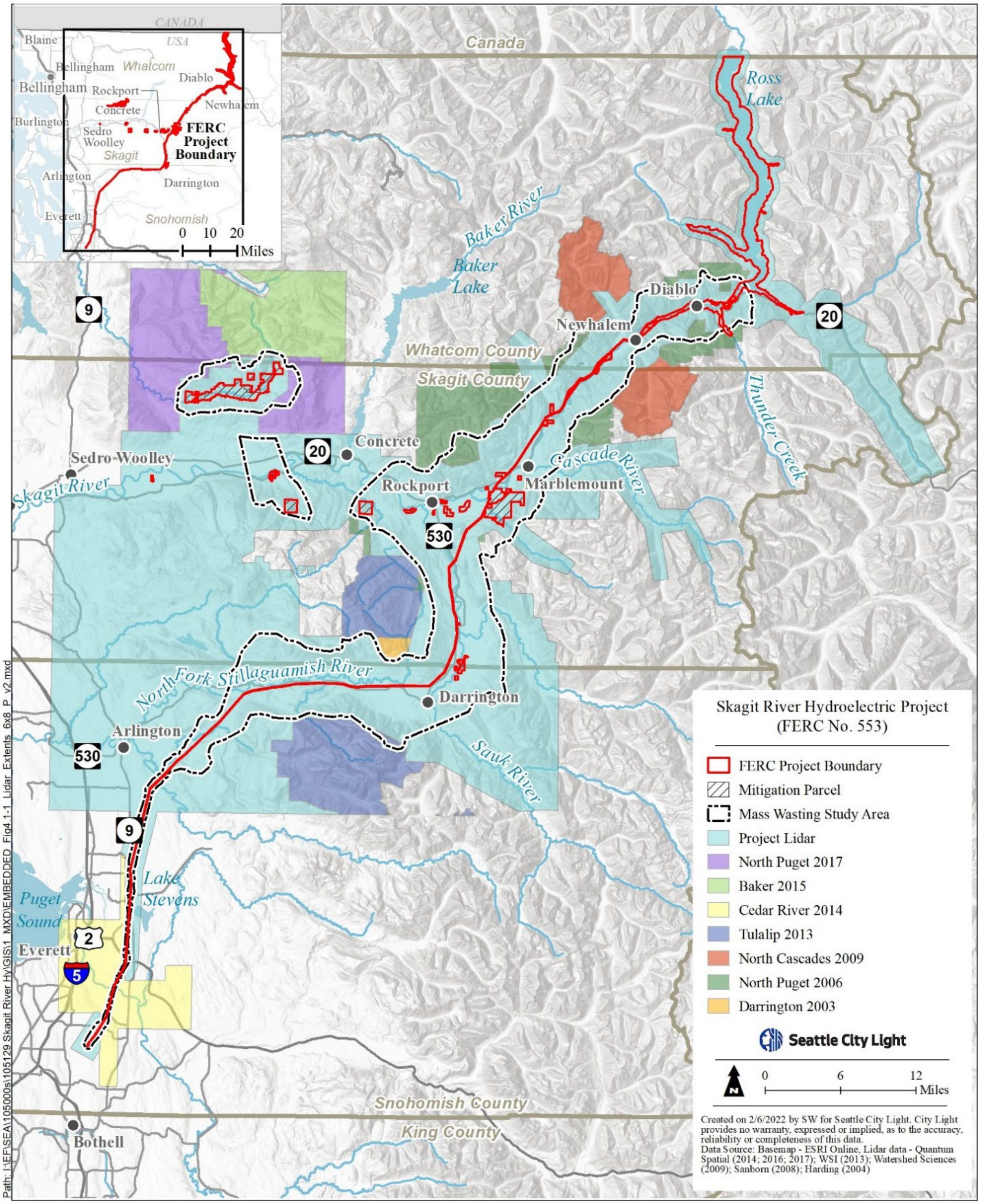

Figure 4.1-1. LiDAR dataset footprints and mass wasting study area.

4.1.1.2 Previous Studies

Previous studies were integrated into the mapping program and, by extension, into the susceptibility analyses. These studies include published reports, geotechnical reports, geologic maps, agency study reports, and mass wasting event records. Event records of mass wasting were compiled from multiple sources: City Light; the Washington State Department of Transportation (WSDOT) Unstable Slope Management database; and geotechnical reports. Based on information provided in previous studies, select data were integrated into the Mass Wasting Inventory, either as background information or as mapped features. When source data were integrated into the Mass Wasting Inventory, the sources were cited in a dedicated field in the Mass Wasting Inventory attribute tables. For example, if a particular mass wasting feature was identified and mapped based on a previous study, that source was added as a feature attribute.

In general, mass wasting features included in the geologic maps were used as background information and served as guides to mapping on LiDAR. For this study component, suites of geologic maps compiled into GIS databases by the WGS at the 1:24,000 scale (WGS 2019) and the 1:100,000 scale (Washington Department of Natural Resources [DNR] 2016b) were used. In many cases, refinements were made to the geologic map linework for landslide deposits with the aid of the high resolution of the LiDAR data. With the 3-foot-resolution LiDAR data as a mapping background, study features were mapped up to a scale of 1:4,000 or better. Other studies also used high-resolution LiDAR for mapping following procedures generally similar to City Light's. The North Cascades NPS conducted landform mapping studies (Riedel et al. 2012; 2020) and combined desktop mapping using LiDAR and field mapping. The NPS datasets were reviewed and selected features relevant to the mass wasting study component were adapted to incorporate into the Mass Wasting Inventory.

Additionally, the WGS is in the process of mapping mass wasting features for all of Snohomish County (Mickelson 2021). The WGS study followed the same protocols, described below, for mapping as this study component and mapped to approximately the same scale. Most of the mapped mass wasting features in Snohomish County are derived to some degree from the WGS dataset. All features from this dataset that are incorporated into the Mass Wasting Inventory were reviewed and revised based on interpretation of the LiDAR datasets available for this study component, and these features are attributed to the WGS. Note that the WGS dataset is in draft form and has not been reviewed, finalized by the agency, or published.

The geologic maps and landform mapping databases provided limited information regarding the age of mass wasting features. The event records from City Light and WSDOT included information related to specific mass wasting events. Relevant information from these reports, which, in some cases, provided timing of the most recent mass wasting event, were integrated in the Mass Wasting Inventory. Note that the level of detail and precision of the locations given in the reports varied. Additionally, the magnitude of slope failures ranged widely from a few boulders falling on State Route (SR) 20 to landslides, debris flows, or rockfall of sufficient severity to require mitigative measures. These event records were compiled into a GIS point dataset that is displayed in the final summary map (Attachment E). Site-specific geotechnical rockfall reports[6]

[6] Geotechnical data provided in these reports (e.g., rock mass quality, discontinuity mapping, rock strength, etc.) describe local rock conditions that cannot be extrapolated to the entire region of this study component.

also provided estimates of mass wasting timing, along with rockfall location and slope failure extent.

Identification and mapping of existing mass wasting features existing hazards were mapped and inventoried based on visual interpretation of the LiDAR-derived topographic imagery and aerial imagery described in Section 4.1.1 of this study report (see RSP Section 2.6.1.2). As described in Section 4.1.1, existing information from the NPS, WGS, and event records from WSDOT and City Light were also incorporated. The results were compiled into a GIS database. The information was then applied as inputs for subsequent mass wasting susceptibility analyses. A list of data sources used during the mapping of mass wasting features is included in Table 4.1-2.

Information was collected and interpreted according to a generally accepted protocol from the WGS (Slaughter et al. 2017) regarding compiling mass wasting feature inventories. The WGS protocol provides guidelines for identifying, characterizing, mapping, and inventorying landslides, fans, and rockfall by mapping the following geomorphic features:

- Landslide deposits;
- Landslide headscarps, flank scarps, and internal scarps;
- Fan deposits;
- Rockfall deposits and scarps; and
- Recent landslides (typically less than 150 years since occurrence).

In addition to mapping the features listed above, the protocol also extends to collecting additional quantitative and qualitative data of each feature including, but not limited to, material composition, movement type, identification confidence, and a general relative age of movement (e.g., pre-historic, historic, active). The mapping procedure is described in more detail in Sections 4.1.2.1 through 4.1.2.3 of this study report.

Table 4.1-2 Previous studies included in mass wasting study.

Study	Study Name[1]	Level of Integration into Current Mapping Dataset	Type of Dataset	Map Scale
Dragovich et al. (2002a)	Geologic map of the Darrington 7.5-minute quadrangle, Skagit and Snohomish Counties, Washington	Background data	Geologic Map	1:24,000
Dragovich et al. (2002b)	Geologic map of the Fortson 7.5-minute quadrangle, Skagit and Snohomish Counties, Washington	Background data	Geologic Map	1:24,000
Dragovich et al. (2003a)	Geologic map of the Mount Higgins 7.5-minute quadrangle, Skagit and Snohomish Counties, Washington	Background data	Geologic Map	1:24,000
Dragovich et al. (2003b)	Geologic map of the Oso 7.5-minute quadrangle, Skagit and Snohomish Counties, Washington	Background data	Geologic Map	1:24,000
Minard (1985a)	Geologic map of the Arlington East quadrangle, Snohomish County, Washington	Background data	Geologic Map	1:24,000
Minard (1985b)	Geologic map of the Bothell quadrangle, Snohomish and King Counties, Washington	Background data	Geologic Map	1:24,000
Minard (1985c)	Geologic map of the Everett 7.5-minute quadrangle, Snohomish County, Washington	Background data	Geologic Map	1:24,000
Minard (1985d)	Geologic map of the Lake Stevens quadrangle, Snohomish County, Washington	Background data	Geologic Map	1:24,000
Minard (1985e)	Geologic map of the Snohomish quadrangle, Snohomish County, Washington	Background data	Geologic Map	1:24,000
Tabor et al. (2003)	Geologic map of the Mount Baker 30- by 60-minute quadrangle, Washington	Background data	Geologic Map	1:100,000
Tabor et al. (2002)	Geologic map of the Sauk River 30- by 60-minute quadrangle, Washington	Background data	Geologic Map	1:100,000
Riedel et al. (2012)	Geomorphology of the Upper Skagit watershed: Landform mapping at North Cascades National Park Service Complex, Washington	Reviewed by study team and selected features integrated into Mass Wasting Inventory	Report and GIS Database	N/A
Riedel et al. (2020)	Skagit River Geomorphology Inventory (Draft) Report	Reviewed by study team and selected features integrated into Mass Wasting Inventory	Report and GIS Database	N/A

Study	Study Name[1]	Level of Integration into Current Mapping Dataset	Type of Dataset	Map Scale
WGS (Mickelson 2021)[2]	Landslide Inventory of Snohomish County, Washington (Draft): Washington Geological Survey Report of Investigations	Reviewed by study team and selected features integrated into Mass Wasting Inventory	Draft Map GIS Database	N/A
Golder Associates (2001)	Response to FERC Comments: Gorge Dam Right Abutment Stability, Skagit River Project, Washington	Mass wasting event record	Geotechnical report	N/A
Golder Associates (2014)	Ross Dam Powerhouse Slope Stability Evaluation and Cross Over Adit Evaluation	Mass wasting event record	Geotechnical report	N/A
Keaton et al. (2014)	The 22 March 2014 Oso Landslide, Snohomish County, Washington	Mass wasting event record	Report	N/A
Landslide Technology (2007)	Phase 1 Site Reconnaissance Memorandum: Diablo Dam Powerhouse Rock Slope Areas 1 and 2, Diablo, Washington	Mass wasting event record	Memorandum	N/A
Landslide Technology (2011)	Ross Powerhouse Rock Slide Emergency: Phase 4 – Reconnaissance	Mass wasting event record	Geotechnical report	N/A
Landslide Technology (2013)	Ross Powerhouse Rock Slide Stabilization: Daily Field Report 06-19-13	Mass wasting event record	Memorandum	N/A
Raytheon Engineers & Constructors Inc. (1996)	Windy Cut Road Slide Stabilization Task No. 24: Multidisciplinary Consulting Services Final Report	Mass wasting event record	Geotechnical report	N/A
City Light (Tressler 2021)[3]	City Light event records	Mass wasting event records	Event records compiled for this report	N/A
Shannon & Wilson Inc. (1999)	Rock Discontinuity and Geological Reconnaissance Report: Diablo Dam Powerhouse Rock Slope, Diablo, Washington	Mass wasting event record	Geotechnical report	N/A
Strouth et al. (2006)	The Afternoon Creek Rockslide near Newhalem, Washington	Mass wasting event record	Research report	N/A
WSDOT (2021b)	Unstable Slope Management System (USMS)	Mass wasting event records	Online GIS database	N/A

1 Geologic maps compiled into a GIS database by WGS at 1:24,000 scale (WGS 2019) and 1:100,000 scale (Washington DNR 2016b); individual maps listed here.
2 Draft data—not reviewed by agency and not published.
3 Event records and related information emailed to report authors.

4.1.2 Identification and Mapping of Existing Mass Wasting Features

4.1.2.1 Landslide Deposits and Scarps

Landslide deposits, headscarps, and flanks were digitized as polygon feature classes. Scarps were delineated with lines. All features were identified through visual interpretation of aerial imagery and LiDAR-derived hillshade and slope products. Mapped landslide deposits were assigned attributes including material, movement type, confidence in identification, and relative age. The following geometric parameters from the LiDAR-derived DEM and slope maps for each landslide feature were measured and added to the attribute database:

- Headscarp height;
- Average internal scarp distance;
- Landslide movement direction;
- Slope angle of pre-failed surface;
- Landslide material and movement type; and
- Relative age of landslide—pre-historic/historic (< 150 years).

The measurements for headscarp height and slope angle were used to calculate approximate landslide failure depth and landslide deposit volume. Shallow and deep landslides were classified based on a threshold failure depth of 10 feet, following Section 16 of the Washington Forest Practices Board Manual (Washington DNR 2016a). Landslides with a failure depth greater than 10 feet are considered deep-seated landslides in this study component. Landslide features mapped on LiDAR imagery are shown in Figure 4.1-2. For comparison, the mapped features are shown on a photograph in Figure 4.1-3 of the same landslide shown in Figure 4.1-2, the 2014 Oso landslide.

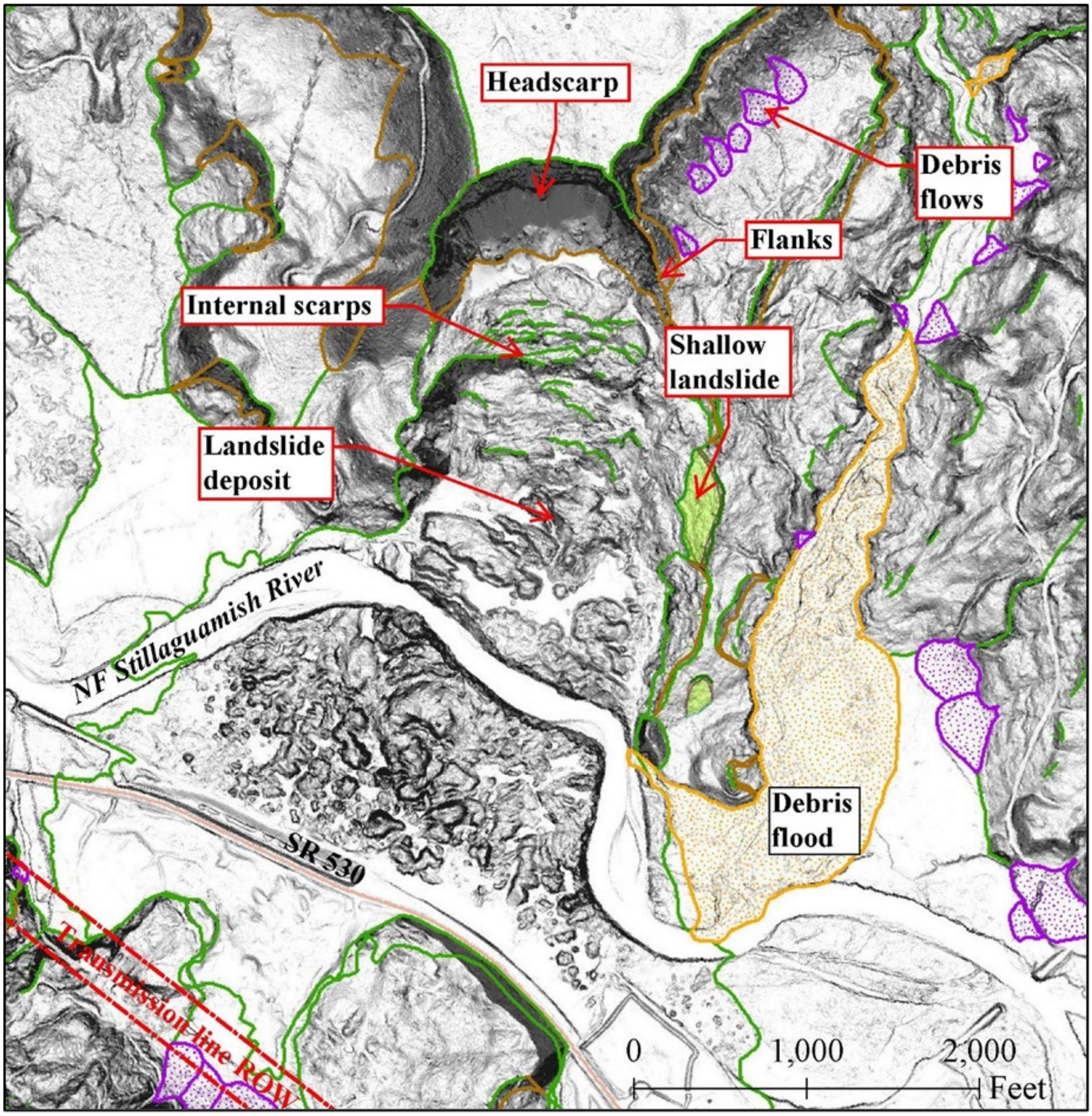

Figure 4.1-2. March 2014 Oso landslide and Mass Wasting Inventory features visible on LiDAR imagery, located near milepost (MP) 37.3 of SR 530.

Figure 4.1-3. Photograph of the 2014 Oso Landslide and Mass Wasting Inventory landslide features (photograph from AP Photo/Ted S. Warren).

Observations that did not fit within a prescribed attribute of the WGS protocol were recorded in a comment field or in supplemental fields added for the purposes of the mass wasting study component. These fields include: (1) distance and direction of mapped feature (e.g., landslide, debris flow fan, etc.) to nearest City Light facility; (2) references of aerial images used during mapping of the feature; (3) citations of mapping products that assisted delineation of the feature; (4) a reference to the GIS file containing information on that facility; and (5) the feature ID of the given facility.

4.1.2.2 Fan Deposits

Following the WGS protocol (Slaughter et al. 2017) to map and characterize fans, polygons that exhibited cone- or fan-shaped geomorphic features at the mouths of drainages were digitalized on LiDAR. Attributes were added to the polygons including fan type (debris flow, debris flood, alluvial), relative age, confidence in identification, slope angle, fan height, and fan volume. The fan apex point(s) were mapped as a point feature class and were used in the debris flow analysis to delineate watershed areas per fan. In this study component, 1,177 fans have been identified in the mass wasting study area. Additionally, debris flow deposits entrained on slope and associated scarps and flanks in the source area were mapped where debris flow features could be differentiated from landslide features. Debris flow features mapped on LiDAR imagery are shown in Figure 4.1-4.

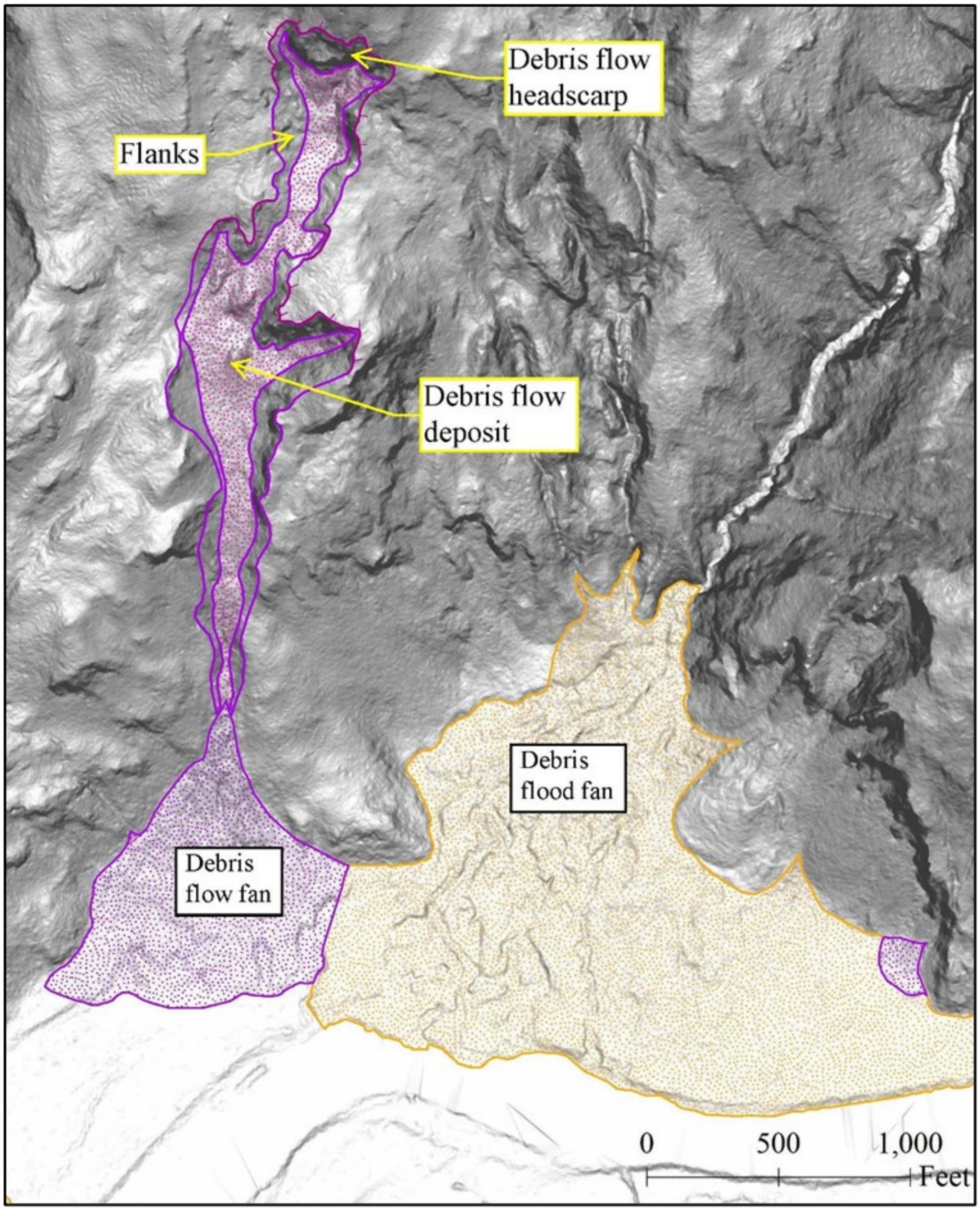

Figure 4.1-4. Debris flow features visible on LiDAR imagery, located along the Copper Creek drainage that enters the south side of the Skagit River near MP 111.7 of SR 20.

4.1.2.3 Rockfall Deposits and Scarps

The WGS mapping protocol of Slaughter et al. (2017) was generally followed to identify and map rockfall scarps and talus pile deposits on LiDAR and aerial imagery and to add these features to the Mass Wasting Inventory. The LiDAR slope grids were reclassified to highlight the potential exposed rock cliffs sources for rockfall to aid in identifying potential rockfall scarps, which are commonly steeper than 60 degrees (Stock et al. 2012; Guzzetti et al. 2003). Figure 4.1-5 presents an example of rockfall mapping features in the mass wasting study area.

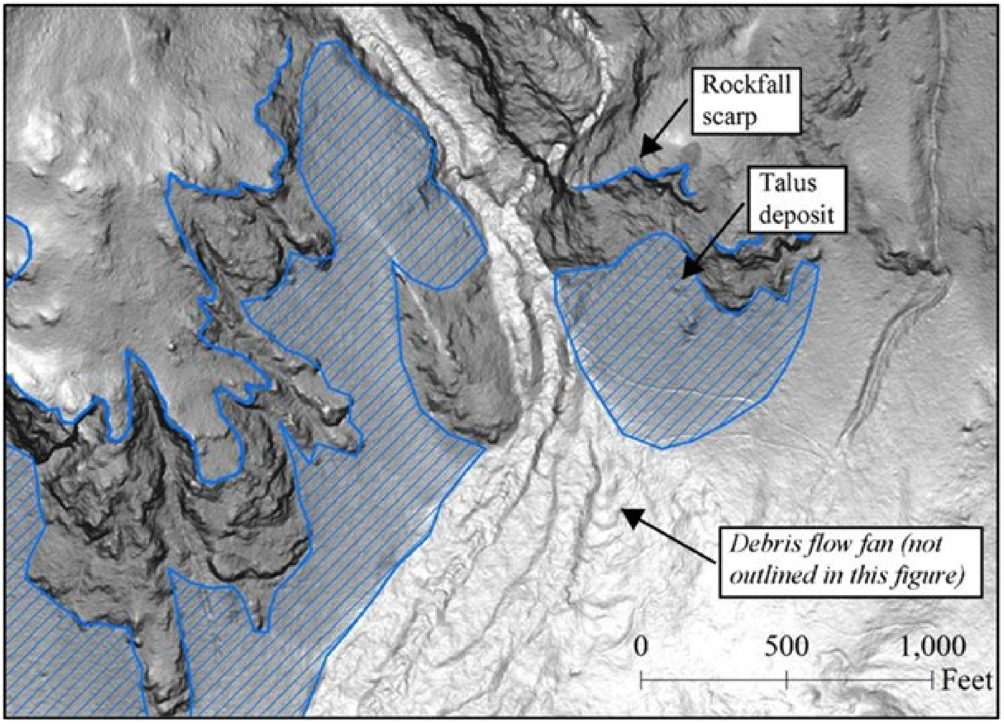

Figure 4.1-5. Rockfall features mapped in Mass Wasting Inventory, located on the north side of Diablo Lake, in the vicinity of the Diablo Lake Trailhead.

Mapping of scarps and talus piles was completed as follows:

- Scarps:
  - Scarps with associated talus pile mapped with a line feature.
  - Scarp line extended continuously along uppermost scarp (internal scarps not mapped), such that it may span multiple talus piles.
- Talus Piles:
  - Talus piles mapped with polygon encompassing the pile.
  - Adjacent talus piles mapped in one continuous polygon unless clear distinction could be made.
- Attributes:
  - Scarp and talus pile inclination and azimuth (direction of rockfall);[7]
  - Scarp height;
  - Geology;
  - Total height from top of scarp to bottom of talus pile; and
  - Relative age.

[7] Python scripting was used to extract values for scarps in an automated fashion.

Note that a computer-generated random subsample (30 percent) of attributes that required manual measurement were collected due to the large number of talus piles/scarps. Relative age was mapped as less than or greater than 150 years, as specified in the WGS protocol, using aerial imagery and Google Earth imagery. Ages less than 150 years are generally considered historic. In addition to the attributes collected, commentary was added to features when useful, such as to denote where observations of rockfall were made by others. A confidence rating was also assigned to each feature.

Summary statistics of scarp and talus pile attribute values were calculated for different drainage basins within the mass wasting study area to assess the need for basin-specific rockfall susceptibility parameters. In general, attributes of the various regions were found to be similar, i.e., no statistically significant difference in attribute values was found between regions. A single set of rockfall susceptibility parameters was developed for the entire mass wasting study area based on the summary statistics provided in Table 4.1-3.

Table 4.1-3 Summary statistics of measured rockfall attributes for the entire mass wasting study area.

Attribute	Range	Median
Scarp inclination	27 – 78 degrees	53 degrees
Talus pile inclination	21 – 48 degrees	35 degrees
Scarp height	10 – 939 feet	98 feet
Total height	51 – 4,695 feet	433 feet
Relative age	49% < 150 years; 51% > 150 years	

4.1.3 Landslide and Rockfall Susceptibility Analyses

The landslide and rockfall susceptibility analyses described below provide the spatial distribution and relative likelihood of slope failures within the mass wasting study area at a regional scale (see RSP Section 2.6.1). These studies imply relative levels of hazard since areas of higher susceptibility are likely to experience slope failures with greater frequency than those of lower susceptibility, even though not quantified. Susceptibility studies are distinct from risk analyses, as defined technically in the literature, in that susceptibility studies do not explicitly consider the timing, intensity, or probable consequences of mass wasting events but only the spatial distribution (Corominas et al. 2014). In the mass wasting study component, susceptibility is extrapolated from the following factors and sources: past slope failures (Mass Wasting Inventory), current slope geometry (LiDAR), and geologic and engineering properties of the soil and rock that make up the slope (engineering geology information). The basic premises of these analyses include: (1) landslides, debris flows, and rockfall are likely to occur where they have occurred before; and (2) if characteristics of slopes that have failed are compared, it can be inferred where other slopes might fail given some combination of similar slope geometry and soil/rock characteristics. Combining premises (1) and (2) provides a means to interpret the types and relative magnitudes of mass wasting hazards on slopes that do not exhibit mapped mass wasting features, i.e., slopes that have not failed.

In the susceptibility studies, susceptibility for the following mass wasting processes were quantified and classified: deep-seated landslides, shallow landslides, debris flows, and rockfall.

For each susceptibility study, methodologies were followed that have been developed in peer-reviewed studies and Oregon Department of Geology and Mineral Industries (DOGAMI) Special Papers (SP) with appropriate modifications as described in the RSP at Section 2.6.1.2. Table 4.1-4 lists the mass wasting susceptibility study and corresponding methodology.

Table 4.1-4. Mass wasting susceptibility study and corresponding methodology.

Mass Wasting Study	Methodology
Deep-Seated Landslide	DOGAMI SP 48 (Burns et al. 2016)
Shallow Landslide	DOGAMI SP 45 (Burns et al. 2012)
Debris Flow	Melton Ratio (Melton 1965) and Revised Melton Ratio (Wilford et al. 2004); Slaughter et al. (2017)
Rockfall	Generally based on DOGAMI SP 48 and SP 45

Based on these methodologies, susceptibility of landslides and rockfall were quantified and classified using a combination of three approaches that vary in detail depending on the type of mass wasting process being analyzed:

- Spatial analysis of landslide/rockfall density from the Mass Wasting Inventory;
- Spatial analysis of the slope failure factor of safety; and
- Spatially distributed weighted sums of mapped variables, such as geologic units, soil cohesion, landform, slope angle and aspect, and geologic structure.

Debris flow susceptibility analysis does not follow these methods. Instead, this analysis focuses on identifying fans related to debris flow-type processes, as opposed to alluvial processes, and comparing related watershed geometry parameters. Susceptibility analyses are described for each mass wasting process below. Specific details of the processes can be found in the studies listed in Table 4.1-4.

4.1.3.1 Deep-Seated Landslides

In the SP-48 susceptibility model, deep-seated landslide[8] susceptibility is divided into relative "high," "moderate," and "low" zones. A graphical representation of the SP-48 model is shown in Figure 4.1-6. The high susceptibility zone is directly based on LiDAR-mapped landslide features following the premise that the highest likelihood of failure occurs where slopes have failed in the past. Accordingly, the landslide deposit polygons and the headscarp and flank polygons in the Mass Wasting Inventory compose the high susceptibility zones, as shown in Step 1 of Figure 4.1-6. A moderate susceptibility zone accounts for the continuum of hazard between high and low zones and, as shown in Step 2 of Figure 4.1-6, is developed by combining together: (1) a calculated buffer zone around the high susceptibility zone features; and (2) a set of "factor layers," or calculated raster models that represent susceptible geology and slope geometry. For this study, these factor layers include:

[8] For this analysis, a deep-seated landslide is defined as having a failure depth of greater than 10 feet, following Section 16 of the Forest Practices Board Manual (Washington DNR 2016a), not 15 feet as adopted in SP-48.

- Susceptible geology units,[9]
- Susceptible slope angles, and
- Preferred direction (slope aspect) of landslide movement.

Areas not included in high or moderate susceptibility zones are low susceptibility zones, as shown in Step 3 of Figure 4.1-6. More details of these steps are provided below.

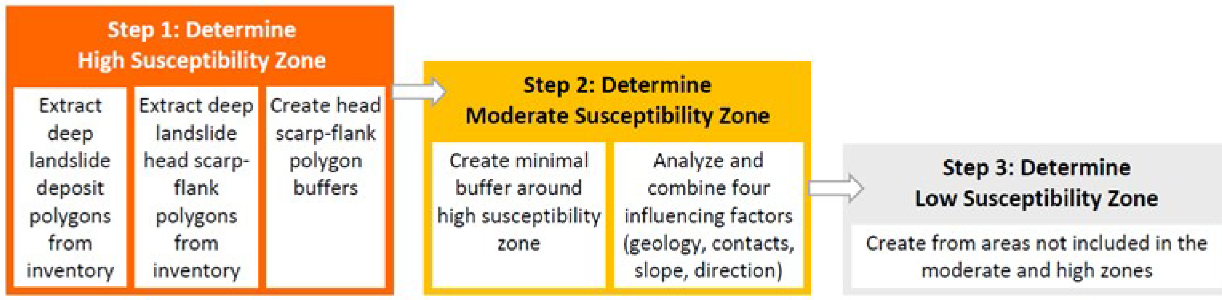

Figure 4.1-6. Graphical representation of developing susceptibility zones, from Burns et al. (2016).

High Susceptibility Zones: Where Slopes are Most Likely to Fail

The high susceptibility zone is developed by extracting all deep-seated landslide deposits and associated headscarps and flanks from the Mass Wasting Inventory. To account for retrogressive slope failure along the headscarp and flanks, a high susceptibility buffer zone was added around these polygons. The horizontal distance of the buffer zone is the greater value of: (1) the headscarp height multiplied by 2; or (2) the average distance between internal scarps. The former value is based on a 2:1 ratio distance of length versus height. A slope formed at this 26-degree angle is commonly used as a proxy for a stable slope. Internal scarps may provide physical records of repeated retrogressive failures. Measuring the average separation is a method for approximating potential future retrogressive failures of the given slide. Horizontal distances between scarps were measured manually and the average assigned to each landslide feature.

Moderate Susceptibility Zones: Potential Slope Failures Between Mapped Landslides

The moderate susceptibility zones surround and border the high susceptibility zones. Landslides may not be mapped on slopes in these areas but are considered moderately likely to occur in the future within the region. The moderate susceptibility zone is composed of a minimal buffer region surrounding the high susceptibility zones and factor layers accounting for the influences of geology, spatial density of existing landslides, and slope geometry. Each factor was evaluated in three simple models, converted into factor rasters, and factor rasters were combined with the minimal buffer region into a single raster defining moderate susceptibility.

[9] Note, susceptible geological contacts were not included in this analysis, though adopted in SP-48. Given the scale of the mass wasting study area, this step in the determination of the moderate susceptibility zone was deemed impractical. The susceptible geological units factor layer provided adequate information regarding geology for this analysis.

Minimal Moderate Zone

A minimal moderate zone was created around the high susceptibility zones so that any high zone did not transition directly into a low zone regardless of the results of the factors analysis. The horizontal buffer distance around the high zones equaled the headscarp height multiplied by 2.

Engineering Geology Map

Several of the moderate susceptibility models were based on an engineering geology map that was developed. The geologic maps compiled in GIS layers by the WGS (Washington DNR 2016b; WGS 2019) provided the basis for a generalized engineering geology map of the mass wasting study area. Individual maps are listed in Table 4.1-2. In the absence of engineering data for the different rock and soil types, the map geologic units were reclassified into Engineering Geology Units (EGU) by: (1) qualitatively comparing geologic units of each geologic map; and (2) grouping the units by rock and soil types, general geologic origins, grain size, and relative degrees of weathering. All of the geologic unit characteristics were extracted from the geologic maps; the level of detail provided by these maps varied. The goal was to group together material (i.e., geological units) with similar characteristics that would likely behave in a comparable manner when subjected to forces driving mass wasting and disadvantageous hydrologic conditions. For verification, the spatial densities of landslides for each geology unit that had been grouped together into an EGU were compared and confirmed to be similar.

Susceptible Engineering Geology Units

To evaluate the susceptibility of rock or soil types in the mass wasting study area, the landslide density was calculated (or the ratio of total area of landslides within each EGU area to the total area of the unit within the mass wasting study area). The landslide densities of each EGU were compared and grouped into 3 bins[10] based on the median (50th percentile) and third quartile (75th percentile) values. Each bin was assigned a score between 0 and 2, increasing in value with prescribed susceptibility:

- Low = Landslide Density less than 6.67 percent.
- Moderate = Landslide Density between 6.7 and 21.1 percent.
- High = Landslide Density greater than 21.1 percent.

Susceptible Slope Angles

The pre-failure slope angle for each landslide, as measured on adjacent slopes within the same geologic unit in the Mass Wasting Inventory, is inferred to be the critical slope value at which the slope failed. The mean and standard deviations of all pre-failure slope angles measured in each EGU area were calculated. The LiDAR slope map was subsequently reclassified into four moderate classes with scores of 0 to 3, using the landslide slope statistics as divisions.

10 SP-48 recommends determining bins based on the mean and standard deviations of the landslide density values. In this study component, however, dividing the dataset into quartiles with the central tendency taken as the median was more effective at describing the dataset due to the high variability of the landslide density values (inferred to be the result of the wide variation in rock and soil types within the mass wasting study area). The bin ranges calculated in this study component were comparable to the ranges recommended in SP-48.

SP-48 also applies a simple filter to remove areas with higher slope angles but very low relief. Short, steep slopes, such as road cuts, shallow stream channels, and retaining walls are unlikely to produce deep-seated landslides. The intent of the filter is to reduce the inclusion of these features in the final hazard delineation. Focal statistics on the LiDAR DEM were used to build a grid that filtered a 100 square-foot neighborhood of cells with relief less than 15 feet and apply this filter to the reclassified slope map.

Preferred Landslide Direction of Movement

The preferred direction of movement (PDMV) for a given future landslide is estimated based on the measured orientations of nearby features, including: (1) existing landslides compiled in the Mass Wasting Inventory; and (2) geologic structural discontinuities documented in published geologic maps. For each landslide, the azimuth of the observed movement of the failure was measured on the LiDAR DEM and recorded in the Mass Wasting Inventory. Mass Wasting Inventory measurements were supplemented by measured orientations (strikes and dips) of the bedding planes and major fractures in bedrock selected from geologic maps. SP-48 infers that these planes denote zones of weakness along which slope material could fail in the down-dip direction. As such, the structural data was integrated into the analysis as a complementary set of PDMV data points together with the Mass Wasting Inventory data. An assumption of this analysis is that future landslides that occur near any of these combined PDMV data points will likely fail in a direction similar to nearby existing landslides and/or along bedding planes and bedrock fractures. In order to interpolate PDMV on slope areas between the PDMV data points, an inverse distance weight calculation generated 1,000-foot zones around each PDMV data point and assigned to the zones the PDMV value of its associated point. Where these zones overlapped, the assigned PDMV value was based on proximity to the PDMV data point. These PDMV zones were then compared to a LiDAR-derived slope aspect raster. Where the aspect raster values were most similar to the PDMV zones, that area was assigned a score of 2. Where the aspect values were less similar or did not overlap with the PDMV zones, those areas were scored a 1 or 0.

Combining the Factor Layers

Each factor layer raster contains grid cell values ranging from 0 to 2. All three rasters were added together so that the sum raster contained values from 0 to 6. Following the SP-48 protocol, grid cells with values 2 or greater were reclassified into a final factor layer as 2 (the moderate susceptibility zone). This is the preliminary moderate zone raster. Cells with values less than 2 constitute low susceptibility zones and were not included in the preliminary moderate zone raster.

In order to merge the factor layers, the components were re-sampled from 3-foot resolution to 10-foot resolution. The spatial extent of the mass wasting study area is considerably larger than the area for which the DOGAMI protocol was initially designed. As a result, the products produced using the 3-foot resolution are much more computationally demanding. Reducing the resolution provided multiple advantages in storage and management of the data without significantly affecting the appearance or utility of the factor layers or final hazard map.

Final Landslide Susceptibility Map: Low, Moderate, and High Zones

The final maps, compiled in Attachment A, show zones of “high,” “moderate,” and “low” landslide susceptibility. The high zones correspond to existing landslides. The moderate zones correspond to locations where slopes, based on existing conditions, past landslides, and proximity to existing landslides, may be prone to future landslides. Low zones consist of areas where slope conditions are dissimilar to slope conditions of existing landslides and/or landslides are not mapped in those areas.

4.1.3.2 Shallow Landslides

The shallow landslide[11] susceptibility analysis followed the approach of SP 45, which integrates the following: shallow landslides in the Mass Wasting Inventory, a simplified factor of safety analysis using a LiDAR DEM, and geotechnical parameters developed from published geologic mapping (Burns et al. 2012).

Following SP-45, shallow landslide susceptibility was delineated by a combination of four factor layers listed below and described in the subsequent sections:

- Mapped shallow landslide areas (high susceptibility);
- Headscarp buffer around mapped scarps (high susceptibility);
- Clipped factor of safety class map (high or moderate susceptibility); and
- Buffered factor of safety map (moderate susceptibility).

The shallow landslide mapping and susceptibility analyses are summarized in the Shallow Landslides and Susceptibility Mapbook (Attachment B).

Mapped Shallow Landslide Areas and Headscarp Buffer

In the SP-45 protocol, the highest likelihood of failure occurs where slopes have failed in the past. Areas mapped as shallow landslide headscarps, flanks, and deposits extracted from the landslide Mass Wasting Inventory are given a high susceptibility rating. To account for potential retrogressive failure of oversteepened headscarps, a high susceptibility buffer of 20 feet is applied around the mapped headscarp polygons. The headscarp buffer represents a 2 Horizontal to 1 Vertical (2H:1V) set back from the top of mapped headscarp, based on the defined maximum failure depth of 10 feet for shallow landslides.

Clipped Factor of Safety Class Map

Factor of safety values were calculated for each DEM grid cell in the mass wasting study area using the infinite slope equation (Duncan et al. 2014). Following SP-45, the conservative assumption was made that groundwater was coincident with the ground surface, and the failure depth was 10 feet (i.e., equal to the maximum depth defined for shallow landslides). Geotechnical soil strength parameters were assigned based on the engineering geology map and EGUs developed in the deep-seated landslide susceptibility analysis (Section 4.1.3.1 of this study report), following values provided in a shallow landslide study in the Puget Sound region (Harp et al. 2006; Table 4.1-5).

In mountainous regions, shallow landslides typically occur in a thin mantle of weathered colluvium over relatively intact bedrock (Transportation Research Board 1996). For the factor of safety

[11] For this analysis, a shallow landslide is defined as having a failure depth of less than 10 feet, following Section 16 of the Forest Practices Board Manual (Washington DNR 2016a), not 15 feet as adopted in SP-45.

calculation, the EGUs developed in the deep-seated landslide study were used. EGUs that are mapped as rock were assigned strength parameters associated with rock-derived colluvium (EGU Rc in Table 4.1-5) rather than the intact rock strength parameters of the parent bedrock. However, only cells with a slope of less than 60 degrees are included in the factor of safety calculation because material standing at or greater than 60 degrees is assumed to be exposed rock with little to no colluvial cover. Loose, previously failed landslide material often remobilizes in subsequent shallow landslides. Therefore, the deep-seated landslide polygons from the Mass Wasting Inventory were incorporated into the engineering geology map and assigned strength parameters associated with landslide debris (EGU label SNNls in Table 4.1-5). Deep-seated landslide areas in rock EGUs were assigned the strength parameters of rock colluvium. Note the cohesion value for glacial till (EGU label SOGt / SOGtv / SOGtp in Table 4.1-5) of 2,000 pounds per square foot (psf), as recommended by Harp et al. (2006), was adjusted because the analyses indicated that, for the mass wasting study area, this value was too high and precluded slope failures in till, even where shallow slope failures are known to have occurred. Instead, the WSDOT Geotechnical Design Manual (WSDOT 2021a) was followed, and the cohesion value was reduced from 2,000 to 800 psf. The raw factor of safety map was classified into categories of high, moderate, and low susceptibility according to Table 4.1-6.

Table 4.1-5. Engineering geologic unit properties for shallow landslide factor of safety calculation. Values from Harp et al. (2006) and are associated to EGUs in this study. All units were assigned a saturated unit weight of 122 pounds per cubic foot (pcf).

EGU Label (this study)	Geologic description of unit	Geology unit from Harp et al. (2006) associated to EGU	Friction Angle (degrees)	Cohesion (psf)
SNNav	Volcanic flood deposits (lahar)	Qal	32	0
SNNas / SNNa	Younger alluvium	Qal	32	0
SNNaf	Fan deposits	Qf	30	200
SNNao	Terrace deposits	Qt	30	0
SNNls	Mass-wasting deposits	Qls	32	400
SNNp	Peat	Qp	24	500
SNAG	Alpine glacial deposits (undifferentiated)	Qvi	30	600
SNRd	Vashon ice-contact deposits	Qvi	30	600
SNRo	Vashon recessional / Everson outwash	Qvr	34	300
SNRgl	Everson recessional glaciolacustrine deposits	Qrvl	24	400
SOGgl	Vashon advance glaciolacustrine deposits	Qvlc	26	600
SOGo	Vashon advance outwash	Qva	38	400
SOGt / SOGtv / SOGtp	Vashon glacial till	Qvt[1]	40	800
SONsg	Pre-Fraser nonglacial deposits	Qpfn	34	400
SONf	Fraser to pre-Fraser transitional beds	Qpff	26	600
Rc	Rock colluvium	Tb	40	600
RAls	Rock avalanche deposits	Tb	40	600

1 Values from WSDOT Geotechnical Design Manual (WSDOT 2021a).

Table 4.1-6. Classification of factor of safety values.

Susceptibility Class	Factor of Safety
High	< 1.25
Moderate	1.25 – 1.5
Low	> 1.5

Buffered Factor of Safety Map

Grid-based factor of safety maps consider the stability of each cell independently and do not account for the relative stability or instability of the surrounding terrain. Because landslides may extend into flat terrain above and below a steep slope, a 20-foot buffer (twice the defined depth of failure for shallow landslides) was applied around all areas with a factor of safety ≤ 1.5, and the buffered area was classified as moderate susceptibility. Note that landslide runout is not explicitly modeled in the shallow landslide susceptibility analysis protocol, although a small degree of runout is implicitly included in the factor of safety buffering process.

Combining the Factor Layers

Each factor layer contains gridded values of 0, 2, or 3, corresponding to "low," "moderate," and "high" susceptibility, respectively. The layers were merged to preserve the highest value at each grid cell, producing a preliminary shallow susceptibility map with the same range (0, 2, or 3) of gridded values.

4.1.3.3 Rockfall

Rockfall susceptibility protocols are generally based on the structure and methods used in the DOGAMI protocol for deep landslide susceptibility mapping (SP 48 [Burns et al. 2016]) and the protocol for shallow landslide susceptibility mapping (SP 45 [Burns et al. 2012]). Use of DOGAMI protocols is consistent with susceptibility mapping performed for other mass wasting features on the Project. The protocol developed and used for the mass wasting study component is described in the following sections.

Rockfall Susceptibility Protocol

Consistent with the DOGAMI protocol, rockfall susceptibility is mapped as high, moderate, or low susceptibility zones. Figure 4.1-6, from the DOGAMI deep landslide susceptibility protocol, highlights the general framework. Protocols for each susceptibility level are described in the following sections.

High Susceptibility

The high susceptibility zones were developed based on mapped rockfall features, including headscarp and talus piles or other runout zones below the scarps. The high susceptibility area was defined by creating a polygon that spans from the mapped headscarp to the farthest downslope edge of the talus piles or observable runout from rockfall. In essence, cliff forming areas already impacted by rockfall are considered highly susceptible.

Moderate Susceptibility

Zones of moderate susceptibility were determined through two processes:

- Applying a buffer around the high susceptibility zones based on rockfall characteristics and analyses; and
- Mapping slopes > 60 degrees, with a slope height > 10 feet within a 15-foot moving window, and without observable rockfall features.

For the latter process, observable rockfall features consist of visible signs of movement, such as destruction downslope, lack of vegetation, or dislodged boulders. The lack of a talus pile (unless removed through natural processes or human actions) indicates that rockfall may not have occurred at this location or occurs infrequently relative to processes that would remove rockfall or would allow vegetation to grow that could obscure rockfall. However, as noted previously, slopes ≥ 60 degrees are more likely to be a rockfall source. For these cases, the moderate susceptibility zone was mapped as the steep cliff face with a 30-foot buffer, consistent with the scarp regression buffer developed as described below.

To define the moderate susceptible buffer zones around the high susceptibility zone, a suite of rockfall analyses were performed for representative slope conditions. The profiles of four representative slopes were determined through collection and evaluation of summary statistics for the following attributes:

- Talus slope inclination;
- Scarp slope inclination;
- Scarp height; and
- Overall height from scarp to bottom of talus.

These attributes were randomly selected for approximately 30 percent of the mapped scarp and talus deposit features. Summary statistics are presented in Table 4.1-7. The median talus slope, scarp slope, scarp height, and total height for the measured dataset are 36 degrees, 53 degrees, 98 feet, and 433 feet, respectively. These median values were used to select four representative slope profiles for rockfall runout modeling. The selection was performed by holding the median value constant for one attribute and allowing the other parameters to vary. For example, one profile has a talus slope inclination of 36 degrees, with all other parameters non-median values; one has a scarp inclination of 53 degrees with all other parameters non-median values, and so on.

Table 4.1-7. Summary statistics for rockfall.

Slope Characteristic	Value
Talus Feature Count	170
Min Talus Slope (deg)	21
Max Talus Slope (deg)	47
Median Talus Slope (deg)	36
Min Total Height (feet)	51
Max Total Height (feet)	4695
Median Total Height (feet)	433
Scarp Feature Count	224
Min Scarp Slope (deg)	27
Max Scarp Slope (deg)	78
Median Scarp Slope (deg)	53
Min Scarp Height (feet)	10
Max Scarp Height (feet)	939
Median Scarp Height (feet)	98

Using the four selected profiles, analyses were performed using the computer program Rockfall (version 8.010, Rocscience, Inc. 2020) to estimate the distance of expected rockfall beyond the existing talus piles. The lump mass rockfall model and literature-based material properties were used for the normal and tangential coefficient of restitution, and friction angle for three deposit materials: bedrock outcrop, talus pile, and vegetated slope (beyond the talus pile). Analyses included running 10,000 simulated rocks downslope from the headscarp region and measuring the distance of the rock that rolled the farthest beyond the edge of the mapped talus deposit. Based on these analyses, a talus buffer equal to the average distance of these simulations plus two standard deviations was selected. This distance of 110 feet was applied as a downslope buffer beyond the talus pile.

To buffer the headscarp, the horizontal distance was calculated between the upper and lower quartiles of headscarp slope inclination for the median scarp height. The upper and lower quartile headscarp slope inclinations are 57 and 47 degrees, respectively. For a slope with a height of 98 feet (median scarp height), the horizontal distance manifested at the ground surface between a 57-degree line and 47-degree line is approximately 30 feet. This 30-foot distance was used for both the headscarp buffer (distance above/beyond the crest of the slope) and the lateral/side buffer along the headscarp and talus pile regions.

Low Susceptibility

The “low” susceptibility zone includes features not mapped as “high” or “moderate” susceptibility. This category generally includes shallow rock slopes and areas with no identifiable rockfall features.

4.1.3.4 Debris Flow/Fan Classification Analysis

Fans originate from different torrential, hydrogeomorphic processes including debris flows, debris floods, and alluvial floods, each of which imparts different levels of potential hazard and risk.

Debris flows are highly mobile, surging flows of saturated debris and are differentiated from flood processes by a typical volume concentration of solids of greater than 60 percent in the fronts of boulder-laden surges (Hungr et al. 2014). Due to the high impact forces, debris flows are particularly destructive mass wasting events and, when compared to typical flood processes, represent greater potential hazard. Debris flows often initiate as shallow landslides that fall into a confined channel and entrain further water and saturated material from the flow path. Alluvial floods typically have volume concentration of solids of less than 20 percent, while debris floods represent a transitional process between debris flows and alluvial floods (Wilford et al. 2004).

There are several empirical calculations used to differentiate between alluvial- and debris flow-dominated fans. WGS (Slaughter et al. 2017) recommends combining the Melton Ratio (Melton 1965) and the Relative Relief Ratio (Wilford et al. 2004) to classify fans, in order of increasing hazard: alluvial flood, debris flood, and debris flow. These ratios describe numerical relationships between watershed parameters. The Melton Ratio is the watershed relief divided by the square root of the watershed area. The Relative Relief Ratio refines the Melton Ratio by factoring in watershed length. The ratios used in fan classification are provided in Table 4.1-8.

Table 4.1-8 Class boundaries for differentiating between hydrogeomorphic processes.

Alluvial Flood	Debris Flood	Debris Flow
Melton ratio < 0.3	Melton ratio 0.3 to 0.6 Melton ratio > 0.6 and watershed length > 2.7 km[1]	Melton ratio > 0.6 Watershed length < 2.7 km

1 km = kilometer

A Melton watershed analysis was performed for each mapped fan within the study area north of the Siberia Creek Watershed, near the city of Arlington, Washington. (Fans within the mass wasting study area south of Siberia creek are associated with generally large, low-relief watersheds in the Puget Lowlands considered unlikely to produce debris flows.) For each mapped fan, a watershed analysis was performed using the LiDAR DEM to derive the parameters for the Melton Ratio and Relative Relief Ratio and to classify the fan types. Studies suggest that watershed delineation in mountainous areas is insensitive to changes in DEM resolution below approximately 30 feet (Goulden et al. 2014). The base 3-foot resolution DEM to 15-foot resolution was down-sampled to improve computational efficiency and reduce artificial flow distortion due to LiDAR artifacts.

Figure 4.1-7 shows features produced in the watershed analysis. The Python library Pysheds (Bartos 2020) was used to preprocess the DEM, including sink-filling and resolving flat areas to allow continuous flow routing. Flow directions and associated flow accumulations were computed according to the D8 algorithm (O'Callaghan and Mark 1984). Mapped fan apex points were converted to gridded pour points, defining the outlet of each watershed. Mapped apex points did not always coincide with flow lines (i.e., grid cells of highest flow accumulation), so a snapping algorithm was used to move the pour points to the cell with the highest flow accumulation within 30 feet of the mapped apex point. Watershed boundaries were delineated using Pysheds. Watershed length was measured as the straight-line distance between the highest and lowest relief vertices along each watershed boundary.

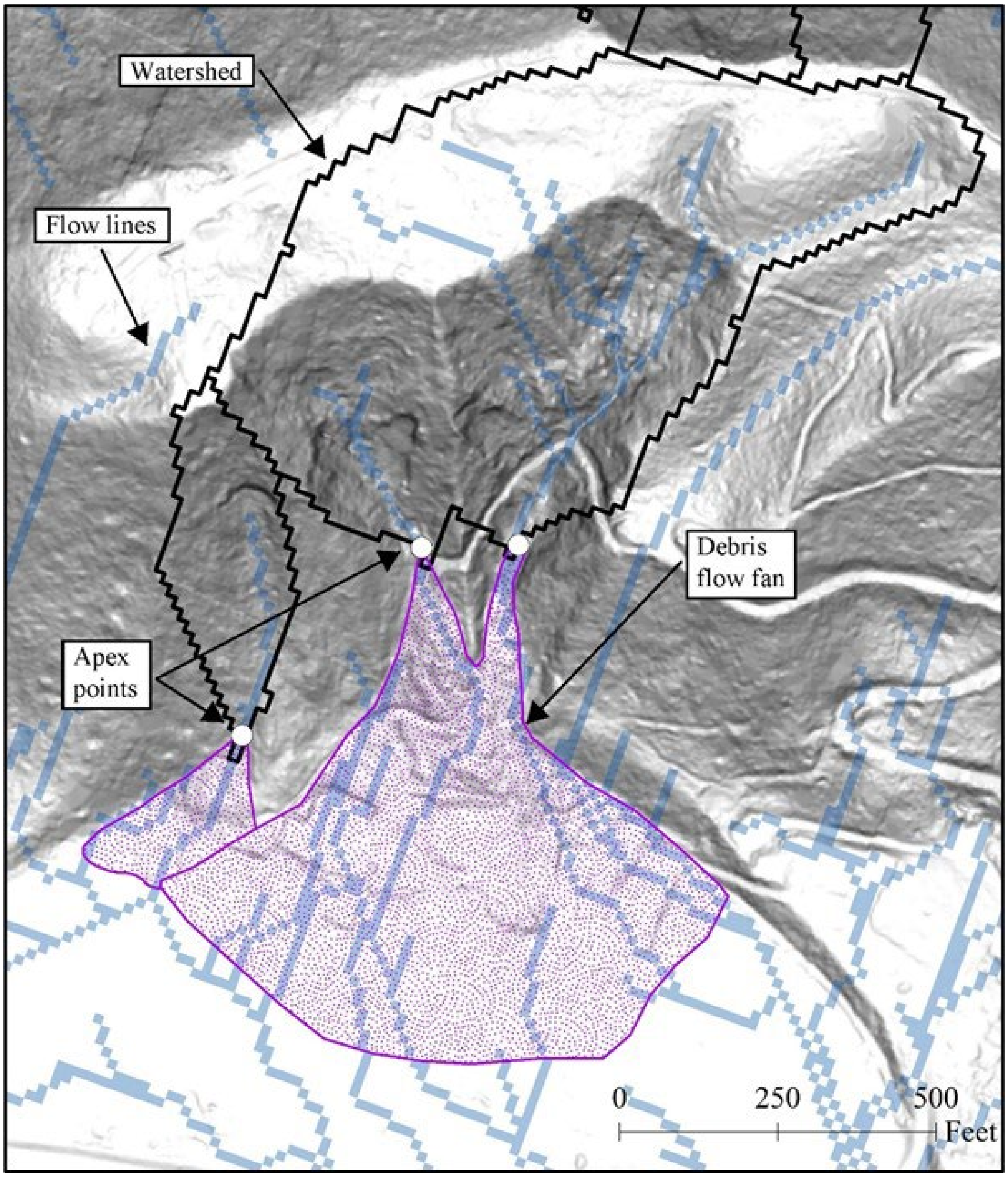

Figure 4.1-7. Debris flow fans and features produced during watershed analyses, located along the south side of NF Stillaguamish River, near MP 39.7 of SR 530.

4.1.4 Quality Control

Quality control methods varied depending on the task. Review of the mapping process consisted of multiple review sessions conducted by the Lead Author. Every mapped feature was reviewed at least once. Review was tracked in the form of GIS layers. For example, for every feature in the Mass Wasting Inventory that required comment and/or revision, a polygon was created in the review layer around the mapped feature and comments and mapper responses were recorded in the layer attributes. The layer attribute tables were exported into spreadsheets. This same procedure was implemented during review of the WGS Snohomish County landslide database features (Mickelson 2021) before the WGS datasets were added to the Mass Wasting Inventory.

4.1.5 Field Verification

No field verification was needed to meet the goals and objectives of this study plan, and, as such, field verifications were not conducted during this study component. As further described in Section 4.3.1 of this study report, sites were identified and summarized that may warrant further study and/or future verification of mass wasting hazards, based on mapping and analyses.

4.2 Preliminary Results

In this mass wasting study component an Inventory of known mass wasting features was developed. This dataset provides a snapshot of all known landslides, fans, and rockfall identifiable using 3-foot resolution LiDAR imagery at a mapping scale of 1:4,000 or better. The Mass Wasting Inventory is a primary input to the susceptibility analyses conducted in the mass wasting study component. Based on the identification of existing landslides, the susceptibility (or likelihood of slopes to fail) can be estimated for slopes that do not have mappable mass wasting features. The susceptibility analyses provide an initial assessment of the unique combination of geo-environmental factors that predispose slopes in the mass wasting study area to fail. Based on the results of the analyses, the mass wasting study area was divided into zones of "high," "moderate," and "low" susceptibility. These susceptibility levels imply relative levels of hazard within the study area since areas of higher susceptibility are likely to experience slope failures with greater frequency than those of lower susceptibility. Combining the Mass Wasting Inventory and the susceptibility analyses provides a means to evaluate where slopes are likely to fail based on where they failed in the past and where they share characteristics with existing mass wasting features within the vicinity of Project facilities.

Upon completion of the mass wasting mapping and susceptibility analyses, Mass Wasting Inventory and susceptibility data were compiled into five suites of mapbooks, grouped by mass wasting feature and analysis theme. The mapbooks are listed in Table 4.2-1.

Table 4.2-1. List of mapbooks presented in the mass wasting component of the Erosion and Geologic Hazards Study.

Location	Theme
Attachment A	Deep-Seated Landslides and Susceptibility
Attachment B	Shallow Landslides and Susceptibility
Attachment C	Rockfall and Susceptibility
Attachment D	Debris Flow Fan Analysis
Attachment E	Summary

4.2.1 Mass Wasting Study Component Limitations

Delineation of mass wasting features was based on interpretation of LiDAR derivatives, aerial imagery, and cross comparison with existing reports and datasets. No site visits have been performed as part of this study. Existing data have been compiled for the analysis from previous studies including ones with field verification. Although the high-resolution LiDAR provided the capability to capture the majority of mass wasting features, this Mass Wasting Inventory likely is an underestimation of the mass wasting features present within study area. In some cases, features were either too small or too subtle to be identified on LiDAR and aerial imagery (e.g., some rockfall and shallow landslides). In other cases, although less common, features may have been misidentified as a landslide or a rockfall feature but instead might have a different geomorphic origin not related to mass wasting.

The Mass Wasting Inventory provides a snapshot of current and near-past conditions. Where possible, the most recent landslide and rockfall activity was estimated by identifying fresh surfaces on mass wasting features or human-developed structures, such as roads, that had been deformed by landslides or rockfall. WSDOT and City Light event records, which were reviewed as part of this study component, provided supplemental information regarding mass wasting events along major roads and near some City Light facilities. Note these reports do not provide historic information and context, and, as such, historic recurrence of these features is not presented in this mass wasting study component. By extension, the susceptibility analyses, in part based on the Mass Wasting Inventory, do not attempt to establish the temporal probability of failure.

The susceptibility analyses present a simple, screening-level means to assess relative mass wasting hazards for the entire mass wasting study area. As estimates at a regional scale, these analyses do not attempt to assess at the site-specific level the intensity of potential mass wasting processes or the level of consequent damage to Project facilities (known as “landslide risk”).

4.2.2 Geology Setting

The mass wasting study area is a complex region, and its geology records most of the major geologic events that have formed and impacted the North Cascades. Stretching back to the Paleozoic era, these events, roughly from oldest to most recent, include:

- Terrane assemblage along the western margin of North America and related thrust faulting;
- Region-wide pluton emplacement and metamorphism;
- Strike-slip faulting and basin extension;
- Development of the Cascade Volcanic Arc;
- Advance of continental and alpine glaciers;
- Volcanism from Glacier Peak in recent time; and
- Ongoing regional active faulting and seismicity (e.g., Darrington-Devils Mountain fault) (e.g., Brown et al. 1987; Misch 1966; Dragovich et al. 2002a; Tabor et al. 2002; Dragovich et al. 2003b; Tabor et al. 2003; Riedel et al.; 2010; Personius et al. 2014).

Multiple glaciations during the Pleistocene sculpted the ridges, slopes, and valleys in the mass wasting study area and left thick deposits of debris. Glacial deposits are most pronounced along the valley walls and valley bottoms of the Skagit River (mostly west of Marblemount), the Sauk River, and the North and South Forks of the Stillaguamish rivers. Additionally, glaciers oversteepened valley walls, subjecting slopes to increased weathering and erosion. Since the recession of the last glacial ice, rivers, debris flows, landslides, and mud flows have continued to erode the rock and soil.

The variation in types of bedrock and soil deposits in the mass wasting study area reflects the wide variety of origins and deep time those events represent. The slope material also contributes to the susceptibility of the slope to erosion and failure. The geologic composition of the mass wasting study area can be simplified and generalized as follows:

- **Upper Skagit River North of Rockport**: Between roughly Babcock Creek, south of Newhalem, and Ross Lake the rocky slopes surrounding the upper Skagit River are primarily composed of the Skagit Gneiss Complex rocks. Between Babcock Creek and Rockport, a mixture of Napeequa and Shuksan greenschist rocks and plutonic rocks (Tabor et al. 2003) form the valley walls. Where the slopes are not steep rocky cliffs, they are typically mantled by slope colluvium and vegetation below the alpine level. Alluvium and colluvium line the lower slopes and valley bottom.
- **Sauk River between Rockport and NF Stillaguamish River**: Between the confluence of the Skagit and Sauk rivers to the north and the NF Stillaguamish River valley to the south, the rocky slopes along the east side of the Sauk River valley are composed of Shuksan greenschist rocks to the north of the Suiattle River and largely Chilliwack Group metasedimentary rocks to the south. The dominant rock type of the slopes along the west side of the valley consists of Darrington Phyllite rocks. The lower slopes of the valley are lined with glacial till from the Vashon Stade of the Fraser Glaciation, Vashon recessional deposits, and volcaniclastic deposits expelled during eruptions of Glacier Peak and fluvially transported to the Sauk River (e.g., Dragovich et al. 2002a; Tabor et al. 2002 and 2003).
- **NF Stillaguamish roughly between Darrington and Arlington**: The upper slopes on the north side of the NF Stillaguamish River valley are composed of Chuckanut Formation sedimentary rocks and metamorphosed mafic rocks of the Helena-Haystack mélange. Much of the latter is mantled by Vashon glacial till. Slopes on the south side of the valley largely consist of metasedimentary rocks of the eastern and western mélange belts. Large swaths of these slopes are also mantled by Vashon glacial till. Prominent features of this valley include the broad benches that border and sit above the modern river channel. These benches typically consist of Vashon-age glaciolacustrine clay and silt overlain by Vashon sandy glacial advance outwash, all overlain by Vashon glacial till. In places, Vashon recessional outwash deposits form discontinuous patches on the older glaciated surfaces. Terraces that sit above the active Sauk and NF Stillaguamish river channels consist of Glacier Peak lahar deposits representing multiple eruptions between the late Pleistocene through mid-Holocene (e.g., Dragovich et al. 2002a, 2002b, 2003a, and 2003b). Near Darrington, lahar deposits piled into an alluvial fan complex form the drainage divide between the Sauk River and NF Stillaguamish River. This divide is the remnant of extensive lahar deposits that choked the Suiattle River forcing the Sauk River to change course from flowing west out the NF Stillaguamish to flowing north into the Skagit River (Booth et al. 2003).
- **Arlington to the Bothell Substation**: Near the town of Arlington, the steep slopes that border the NF Stillaguamish River diminish into rounded foothills that are cored by pre-Tertiary metamorphic rocks and mantled by Vashon glacial till. Where the South Fork Stillaguamish River (SF Stillaguamish River) joins the NF Stillaguamish River, the valley is blanketed by Vashon recessional outwash. South of the SF Stillaguamish River, the transmission line ROW crosses the relatively flat and gently undulating Vashon glacial till plain that borders the Cascade Range to the west and the Puget Sound to the east. Between Arlington and the Bothell Substation, the geology largely consists of glacial deposits (Minard 1985a; 1985b; 1985c; 1985d; and 1985e). Former glacial channels incised into the till and low-lying areas on the till

surface are partially filled by glacial recessional outwash deposits. Vashon advance glacial outwash and pre-Vashon glacial deposits are exposed in incised stream channels, notably in the valley walls where the transmission line ROW crosses the Snohomish River. The only mapped exposure of bedrock, consisting of Chuckanut Formation rocks, is along the channel banks of the SF Stillaguamish River.

The geology of the mass wasting study area was factored into the landslide susceptibility analyses. As described in Section 4.1.3.2 of this study report, geologic units (from geologic maps) were grouped into EGUs based on the general rock and soil characteristics. The analyses for shallow landslides also factored in the physical, or engineering, characteristics of the geologic units. As shown in Table 4.1-3, engineering properties were assigned to geologic units, based on soil type, developed in previous studies (Harp et al. 2006). The susceptibility analyses generally describe which geologic units, rock and soil, are more susceptible to slope failure. Rock type also influences rockfall propensity; however, the rockfall susceptibility analyses in the mass wasting study component only factored in existing rockfall and slope geometry. General conclusions can be drawn regarding the rockfall susceptibility of rock types by comparing the spatial density of rockfall deposits and geologic units in an area, as described in Section 4.2.4.3.

4.2.3 Mass Wasting Features in the Inventory

During this study component, 3,612 mass wasting features were identified on LiDAR and included in the Mass Wasting Inventory. This number includes features from the WGS Snohomish County landslide dataset (Mickelson 2021) located within Snohomish County; these features were reviewed and revised, as needed, by the study team. Table 4.2-2 lists by type the number of mass wasting features included in the Mass Wasting Inventory.

Table 4.2-2. Mass wasting features included in the Mass Wasting Inventory.

Mass Wasting Feature[1]	Number	Median Area (Range) (ft^2)
Deep-seated Landslide	1,210 (1,210 scarps)	216,000 (2200 – 84,638,000)
Shallow Landslide[2]	58 (58 scarps)	36,000 (3300 – 559,000)
Rockfall	567 talus piles (745 scarps)	193,000 (1200 – 27,792,000)
Debris Flood Fan	301	138,000 (1900 – 24,107,000)
Debris Flow Fan	813	61,000 (900 – 8,181,000)
Alluvial Fan	63	70,000 (1800 – 30,518,000)

1 26 fans were not classified as described in Section 4.2.6 of this study report because they were located partially outside of the analysis area; instead, they were classified using fan morphology.

2 Most shallow landslides are small, and their scarps and deposits are quickly obscured by erosion and revegetation. For these reasons, relatively few shallow landslide features were identifiable in this desktop evaluation using LiDAR and aerial imagery data.

General patterns of where mass wasting features tend to occur within the mass wasting study area are summarized below. These observations are generally organized by the regions described in the Section 4.2.1 of this study report.

4.2.3.1 Upper Skagit River North of Rockport

Rockfall is the most prevalent mass wasting feature along the steep and rocky slopes of the Upper Skagit River area (pages 1 through 9, Attachment C). Talus piles and associated scarps are concentrated along the slopes that are composed of Skagit Gneiss rocks between Ross Lake and Babcock Creek, south of the Gorge Dam. Rockfall size ranges from small (less than 3-ft resolution of the LiDAR data) boulder piles too small to detect on LiDAR (but are reported in WSDOT and City Light event records) to expansive fields of talus piles and scarps that span one to two square miles of tributary headwater areas near the ridge lines above the Skagit River (e.g., upper Gorge Creek, Pyramid Creek, and tributaries south of Martin Creek). Note that mapped rockfall deposits and scarps most often represent multiple episodes over time instead of single events. Single-event, large, and catastrophic rock slope failures are considered rock (or rock debris) avalanches. These features were mapped and included in the landslide subset of the Mass Wasting Inventory and were classified by landslide type in the feature attribute table. Rock avalanches were also identified by the NPS and included in their landform mapping studies (Riedel et al. 2012; 2020). Within the mass wasting mapping area, rock avalanches are most common in the Upper Skagit area and were concentrated along the steep slopes between the Gorge Dam and Newhalem. One notable rock avalanche in this area was the 2003 Afternoon Creek rock avalanche (Strouth et al. 2006).

Between the Gorge powerhouse and Rockport, non-rock avalanche, deep-seated landslides become more common where the rocks of the Shuksan Greenschist and Chilliwack Group form the slopes surrounding the Skagit River (pages 7-15, Attachment A). These landslides are generally concentrated in the steep-walled and deeply-incised valleys of the Skagit River tributaries. Nearly all of these tributaries empty into debris flow and debris flood fans that line the Skagit River valley. These fans are periodically fed by saturated debris from rockfall and landslides upslope that is funneled into the steep stream channels that empty into Skagit River. Where the debris flow chutes and source areas could be identified on LiDAR, these features were mapped and included in the Mass Wasting Inventory (and featured in Attachments C and D).

4.2.3.2 Sauk River Between Rockport and NF Stillaguamish River

Between the confluence of the Skagit River and Sauk River to the north and the Suiattle River to the south, rockfall is common along the lower, steep rocky slopes that are composed of Shuksan Greenschist rocks. South of the Suiattle River, rockfall deposits become sparse. Conversely, the deep-seated landslide spatial density dramatically increases south of the Suiattle River where the slopes surrounding the Sauk River are composed of the Darrington Phyllite rocks along the upper slopes and glacial deposits that line the lower slopes. In particular, between the Suiattle River and the town of Darrington, landslides are very common along the broad benches that are formed by glaciolacustrine deposits overlain by glacial till, both mantled in places by younger recessional outwash.

4.2.3.3 NF Stillaguamish River Between Darrington and Arlington

The highest spatial density of deep-seated landslides in the mass wasting study area is exhibited along the slopes that border the NF Stillaguamish River. Large slope failures are common both in the rocks that compose the upper slopes and the in the glacial deposits that form broad and continuous benches that line the lower slopes both north and south of the NF Stillaguamish. Along the upper slopes on the north side of the valley, landslides are particularly concentrated where numerous tributaries of the NF Stillaguamish River have deeply incised into the rocks of the

Helena-Haystack mélange and overlying glacial till. Landslides are also concentrated along the benches above the valley floor. Much of the bench slopes facing the river have been carved up by landslides failing along headscarps that are retrogressing upslope. These slope failures commonly occur where permeable sandy outwash overlies low-permeability clay. LaHusen et al. (2016) and Badger et al. (2015) describe these conditions relative to the 2014 Oso landslide. Nearly all streams that drain the high ridges that surround the NF Stillaguamish River terminate in debris flow fans. Relatively high densities of rockfall were identified along the steep slopes above Darrington that are composed of Helena-Haystack mélange rocks and the Chuckanut Formation bedded sandstone exposed in the upper slopes north of the NF Stillaguamish River. Streams that drain the north slopes transport debris flow material onto the benches above the river forming many large fans above the valley floor.

4.2.3.4 Town of Arlington to the Bothell Substation

After the transmission line ROW passes south out of the NF Stillaguamish River valley and traverses over the low-relief glacial till plain between Arlington and the Bothell Substation, rockfall, landslide, and debris flow deposits greatly diminish. Small landslides were identified only in a few stream channels.

4.2.4 Mass Wasting Susceptibility Analyses

Multiple factors contribute to the capability of a slope to stand or fail. Primary contributing factors include: (1) the geologic rock and/soil types of the slopes; (2) geomorphic processes that sculpt the slopes and potentially increase susceptibility to weathering (and both factors contribute to slope steepness and geometry); (3) past and current climate and vegetation cover; and (4) human modification.[12] The preceding is only a partial list of contributing factors, and, because this study component is a regional and desktop evaluation, only two of them were accounted for in the mass wasting susceptibility analyses: geology (from geologic maps) and slope geometry (from LiDAR). As such, the results from the susceptibility analyses in this study report should be considered screening-level and should be used to complement the Mass Wasting Inventory data—not used in place of the Mass Wasting Inventory or alone.

Based on the susceptibility results, relative hazard levels of “low,” “moderate,” and “high” for landslides and rockfall were assigned to the mass wasting study area. In most cases, high hazard zones were based on the mapped mass wasting features in the Mass Wasting Inventory. Moderate susceptibility zones were largely extrapolated from parameters characterized in the Mass Wasting Inventory database, with the exception of the shallow landslide susceptibility analyses, which were based on slope inclination and soil and rock properties.

4.2.4.1 Deep-Seated Landslide Analyses Results

In the deep-seated landslide susceptibility analysis, the most significant factor in determining which slopes are susceptible to failure is the identification of existing landslides. This is based on the assumption that where slopes have failed in the past they will likely fail again. Accordingly,

[12] Note that several small, localized mass wasting features along study routes were identified as part of the study route inventory—see discussion in Section 5.2.1. These small features are related to local cutslope/fillslope issues on the roads and are too small to be included in the regional analysis completed for the Section 4.0 mass wasting analysis.

the high susceptibility zones in the mass wasting mapping area are concentrated where landslides have been mapped. These zones of high susceptibility and, by extension, elevated relative hazard follow the geospatial trends described in Section 4.2.2 of this study report. The moderate susceptibility zones are based on the combination of several factor layers, as described in Section 4.1.3.1 of this study report, including slope geometry and geology. In order for a slope area to be rated as moderate, two or more susceptibility factors spatially overlap (e.g., susceptible slope value plus susceptible geology unit). As a result, slopes between landslides that are formed of geology rock/soil types that exhibit high concentrations of landslides tend to be classified as moderate.

In the mass wasting study area, the area with the highest concentration of susceptible slopes is the NF Stillaguamish River valley. Due to the high spatial density of landslides along the benches that line the lower slopes, nearly all of the bench slopes that face the NF Stillaguamish River are zoned as high susceptibility. As described in Section 4.2.3.3 of this study report, the layering in these benches of clastic glacial sediments over impermeable fine-grain glacial deposits creates conditions that are favorable to slope failures, as exemplified by the Oso landslide (e.g., LaHusen et al. 2016). Along the north side of the NF Stillaguamish River, upper slopes that consist of glacial till overlying Helena-Haystack mélange rocks exhibit large, nested landslides that tend to form within deeply-incised tributaries that drain these slopes. In the Sauk River valley, between Darrington and the Suiattle River, slopes composed of Darrington Phyllite or Chilliwack Group rocks are largely classified as moderate to high susceptibility. North of the Suiattle River, slopes along the west side of the Sauk River are classified as moderate susceptibility zones, although there are far fewer landslides. It is likely that to the south there are additional factors contributing to slope failures that are unaccounted for in this mass wasting study component. As noted in Section 4.2.3.1 of this study report, landslides are relatively less common along slopes above the Upper Skagit River valley. Consequently, moderate and high zones are generally concentrated around mapped landslides commonly classified as rock/debris avalanches.

4.2.4.2 Shallow Landslide Analyses Results

Zones of high and moderate shallow landslide susceptibility are widespread across the mass wasting study area and are especially concentrated in incised channels and old landslide headscarps, along the margins of glacial basins, and below cliff-forming rock bands along valley walls. Local, event record-based landslide inventories outside of the study area indicate that the majority of landslides that occur in the Puget Lowland area of western Washington are shallow landslides (e.g., City of Seattle 2020;[13] Sarikhan et al. 2008; Baum et al. 1998). Despite widespread potential for shallow landslides, only 58 shallow landslides were mapped within the mass wasting study area. This is likely because small, shallow landslides are difficult to identify even with high-resolution LiDAR due to: (1) these failures typically consist of surface sloughing that can be widespread and frequent but too subtle to detect with LiDAR (in contrast to deep-seated landslides); and (2) the rapid erosion of characteristic landslide features, such as shallow scarps and hummocky deposits. Thus, in this mass wasting study component, shallow landslide susceptibility is primarily based on factor of safety values derived from geological units and slope geometry. Note that shallow susceptibility is also influenced by the location of deep-seated

[13] Note the City of Seattle study (2020) is largely based on a combination of event records, site-specific reports (i.e., geotechnical reports), and field observations for an urban area. The primary dataset for this study component is LiDAR data and very few site-specific event records and reports in comparison.

landslides and the presence of re-mobilized slope material (landslide deposits) that is prone to shallow slope failures.

Many of the high elevation rock slopes in the NF Stillaguamish, Sauk, and Upper Skagit river valleys are mapped as highly susceptible to shallow landslides. This is driven primarily by the extreme inclination at which much of this material stands. Although the 60-degree slope threshold differentiating soil and rock failure mechanisms is supported in literature (see Section 4.1.2.3 of this report), it should be noted that in reality the transition between rock and soil is gradational, and many near-60-degree slopes are unlikely to develop the 10-foot thick colluvial cover assumed in the factor of safety calculation. However, this does not mean that these areas are not susceptible to shallow landslides. Even slopes with a very thin veneer of colluvium (1-3 feet thick) and which are temporarily supported at steep inclinations by the apparent cohesion of roots can, and frequently do, fail in shallow landslides. Furthermore, when shallow landslide debris falls into drainages and becomes saturated, it may develop into destructive debris flows, one of the most widespread and damaging mountain hazards. (Note the numerous debris flow fans in the Mass Wasting Inventory.)

It should also be noted that even though slopes steeper than 60 degrees were assumed to be exposed rock scarps and excluded from the factor of safety calculation in Section 4.1.3.1 of this study report, they may be included in the moderate susceptibility zones due to the factor of safety buffering process. This reflects the fact that shallow landslides may initiate in colluvium above a rock scarp and subsequently runout over the scarp.

4.2.4.3 Rockfall Analyses Results

High susceptibility zones are defined by the mapped rockfall features in the Mass Wasting Inventory. For each feature identified on LiDAR, the high susceptibility zone extends from the headscarp, where the rockfall initiated, downslope to the base of the talus pile or observed rockfall runout. As described in Section 4.2.2.1 of this study report, these high susceptibility zones, or areas of elevated relative hazard, are most concentrated along the steep and rocky slopes of the Upper Skagit River area, between the Ross Dam and Rockport. Less extensive concentrations of rockfall are exhibited along west-facing slopes on the east of the Sauk River and along north- and south-facing slopes along the NF Stillaguamish River, roughly between Dicks Creek to the west and Segelsen Creek to the east. Note that the Mass Wasting Inventory features offer a minimum estimate of the rockfall present in the mass wasting study area. Some rockfall may consist of small groups of boulders or of thin veneers of debris too small or too subtle and with low-relief relative to the slope to detect on LiDAR.

The moderate susceptibility zones are primarily based on slope steepness and average rockfall feature characteristics provide moderate zone buffers around mapped rockfall features (see Section 4.1.3.3 of this study report). Broad swaths of the Upper Skagit area slopes are either high or moderate susceptibility slopes, indicating that either these slopes have already failed and/or they are steep enough to provide cliffs that could be sources for future (or ongoing) rockfall. In this area, the moderate and high susceptibility zones are consistent with each other. In other areas, the distribution of high and moderate susceptibility areas is less consistent with each other. The south-facing slopes along the NF Stillaguamish River exhibit high susceptibility zones that are disproportionately large compared to the moderate susceptibility of the same area. The opposite is true for the north-facing slopes on the other side of the river—there appears to be less rockfall than might be anticipated based on the moderate susceptibility zones. This lack of consistency might be explained by many factors, but one that can be accounted for in this study is geology. Whereas much of the Upper Skagit slopes are relatively consistently composed of Skagit Gneiss rocks, the NF Stillaguamish River slopes are formed by a patchwork of different rock types that likely have contrasting susceptibility to rockfall. Additionally, rock discontinuities and bedding orientations can play a major role in rockfall susceptibility but integrating those characteristics into analyses is generally more appropriate in the site-specific study, not a regional study, such as this one.

All regions downslope of mapped high or moderate rockfall susceptibility zones, but classified as low susceptibility, do not have a non-zero rockfall hazard and should be further evaluated for rockfall as appropriate for specific projects. Rockfall analyses results are in the mapbook included in Attachment C.

Although geology was not explicitly factored into the susceptibility analyses, general conclusions can be drawn regarding the rockfall susceptibility of rock types by comparing the spatial density of rockfall deposits and the productivity of rockfall-producing scarps between geologic units. The spatial density of rockfall was calculated as the ratio of talus deposit area to the total area of the geologic unit represented in the mass wasting study area. Note geologic units were assigned to each talus deposit according to the location of their associated scarp(s) rather than the location of the talus deposit itself, since rockfall may run out a considerable distance from its source, crossing geologic unit boundaries. The ratio of talus deposit area to scarp length was used as an approximation of scarp productivity, describing the average area of rockfall deposit produced per unit length of scarp. The prevalence of a geologic unit was calculated as its area percentage of the total area of all rock geologic units within the study area.

Density, productivity, and prevalence were ranked for all geologic units associated with mapped rockfall, as listed below in Table 4.2-3. The density, productivity, and prevalence rankings were averaged, and the averages were subsequently ranked to create a relative hazard index. The hazard index identifies the geologic units within the mass wasting study area that are likely to expose the City Light facilities to the most rockfall, due to both their high production of rockfall deposits and large spatial extent.

Table 4.2-3. Rockfall relative hazard index per geologic unit in the mass wasting study area.

Map Geologic Unit(s)[1]	Geologic Unit Description[2]	Source	Percent of Study Area	Density (Talus Area/ Geologic Unit Area)	*Density Rank*	Productivity (Deposit Area [ft^2]/ Scarp Length [ft])	*Productivity Rank*	Prevalence (Geologic Unit Area/ Total Rock Unit Area)	*Prevalence Rank*	*Relative Hazard Index*[3]
TKSbg, TKso	Orthogneiss and gneiss rocks of the Skagit Gneiss Complex	Tabor et al. (2003)	9.26%	0.1815	1	474	3	16.74%	1	1
Jph(dj)	Darrington Phyllite (50–90%), semischist of Mount Josephine (10–50%)	Dragovich et al. (2002a)	0.57%	0.1349	2	1288	1	1.03%	12	2
TKns	Napeequa Schist	Tabor et al. (2003)	2.28%	0.0952	4	385	5	4.12%	6	2
Ec(h)	Sedimentary rocks of the Chuckanut Formation, Mount Higgins unit	Dragovich et al. (2003a)	1.46%	0.1317	3	496	2	2.65%	11	4
PDc	Mixed metamorphic rocks of the Chilliwack Group of Cairnes (1944)	Tabor et al. (2002, 2003)	2.88%	0.0612	9	354	7	5.20%	5	5
TKao	Orthogneiss rocks of the Alma Creek unit	Tabor et al. (2003)	0.50%	0.0817	6	396	4	0.91%	13	6
Kes	Shuksan Greenschist	Tabor et al. (2002, 2003)	8.44%	0.0436	11	284	11	15.25%	2	7
Tcdg	Granodiorite rocks of the Mount Despair unit	Tabor et al. (2003)	3.02%	0.0353	12	343	8	5.45%	4	7
JTRmc(e) JTRmt(e) JTRmv(e)	Low-grade metamorphic rocks of the Eastern mélange Belt	Dragovich et al. (2002b, 2003a)	1.71%	0.0505	10	376	6	3.10%	9	9
Kmd	Meta-quartz diorite	Tabor et al.	1.71%	0.0638	8	165	13	3.09%	10	10

Map Geologic Unit(s)[1]	Geologic Unit Description[2]	Source	Percent of Study Area	Density (Talus Area/ Geologic Unit Area)	*Density Rank*	Productivity (Deposit Area [ft^2]/ Scarp Length [ft])	*Productivity Rank*	Prevalence (Geologic Unit Area/ Total Rock Unit Area)	*Prevalence Rank*	*Relative Hazard Index*[3]
	rocks of the Marblemount Pluton	(2003)								
Jigb(h)	Metagabbro rocks of the Helena-Haystack mélange	Dragovich et al. (2003a)	0.08%	0.0895	5	321	10	0.14%	18	11
byan	Yellow Aster Complex of Misch (1966)	Tabor et al. (2002)	0.24%	0.0797	7	333	9	0.43%	17	11
Jph(d)	Darrington Phyllite	Dragovich et al. (2002a)	6.32%	0.0032	16	152	15	11.43%	3	13
Jmv(h)	Greenstone rocks of Helena-Haystack mélange	Dragovich et al. (2003a)	0.41%	0.0054	14	194	12	0.75%	14	14
PDc	Sedimentary rocks of the Chilliwack Group	Tabor et al. (2002)	2.25%	0.0004	17	92	17	4.07%	7	15
Jar(e)	Meta-argillite rocks of the Eastern mélange Belt	Dragovich et al. (2002b)	0.32%	0.0174	13	165	14	0.57%	16	16
Jph(jd)	Semischist of Mount Josephine (50–100%), Darrington Phyllite (0–50%)	Dragovich et al. (2002a)	1.83%	0.0002	18	91	18	3.31%	8	17
TKcs	Cascade River Schist	Tabor et al. (2003)	0.39%	0.0045	15	124	16	0.71%	15	18

1 Geologic units listed in this column follow the naming scheme of the source maps listed in Source column.
2 Geologic unit description is the formal named unit from the source maps listed in Source column.
3 If more than one unit has the same average ranking, they are given the same index value.

4.2.4.4 Debris Flow and Fan Analyses Results

Due to the steep, high-relief terrain within the mass wasting study area, 69 percent of the mapped fans are classified as debris flow fans. Only 63 fans (5 percent) are classified as alluvial fans, with the remaining 26 percent classified as debris flood fans. However, the watershed areas of 21 fans classified as debris flow or debris flood fans are truncated by incomplete LiDAR coverage, which tends to artificially inflate the values of the Melton Ratio.

Debris flows, debris floods, and alluvial floods are episodic, re-occurring at a specific location such as a gulley or channel. Of these hydrogeomorphic processes, debris flows are especially destructive. An example of the impact of a debris flow on the SR 20 roadway and drainage ditch is shown in Figure 4.2-1.

Figure 4.2-1. November 2017 debris flow at Rhode Creek, Colonial Creek Campground, near MP 130.21 of SR 20. Note this debris flow occurred approximately 1,000 feet outside of the mass wasting mapping boundary, but it is representative of events within the study component area. Image from WSDOT USMS database (2021b).

While the fan analyses did not produce susceptibility maps delineating zones of hazard, the fan classification of debris flood fans identifies stream channels that may periodically impose elevated debris torrential hazards to downstream Project facilities. Note that potentially damaging debris flows, debris floods, and alluvial floods may initiate in drainages not considered in the mass wasting study component due to an absence of an observable fan deposit. Debris flow analysis results are in the mapbook included in Attachment D.

4.2.5 Compilation of Results into Summary Maps and Recommendations for Future Studies

While a formal risk assessment is not part of this mass wasting study component, by overlaying the mapped mass wasting features on Project facilities, a basic picture of the proximity and severity of hazards to facilities can be drawn and some of the related elements of risk inferred. Attachment E consists of a suite of maps in which mapped mass wasting features overlay Project facilities. To supplement Mass Wasting Inventory data, locations of event records of recent slope failures (City Light, WSDOT, and geotechnical reports) are included. In order to maintain the graphical simplicity of this mapbook, the susceptibility grids were not included as backgrounds, but the reader is instead referred to Attachments A through D to review the landslide and rockfall susceptibility analyses.

To aid in the interpretation of the summary mapbook, 67 sites were selected within the Project Boundary where Project facilities overlap or are located nearby multiple mapped mass wasting features and areas of high susceptibility. These sites are referred to as Sites of Special Concern (SSC) (teal stars in Attachment E). Where sites spatially cluster, zones called Zones of Special Concern (ZSC), shown as thick pink lines in Attachment E, were created. These zones delineate elevated mass wasting hazard within the Project Boundary. A companion table to the mapbook in Attachment E includes the following details about each SSC—corresponding ZSC, description of nearby City Light facilities, and a description of the hazard.

Below are two examples of SSC locations grouped into Zones of Special Concern:

- Gorge Dam to the Newhalem Area (Figure 4.2-2): This zone is subject to multiple mass wasting hazards and most slopes exhibit compounded hazards. For example, the Afternoon Creek drainage is subject to landslides, rockfall, and debris flows. The Afternoon Creek rock avalanche occurred in 2003 and debris temporarily blocked SR 20. WSDOT event records document a history of rockfall and debris flows in the same drainage. Other sites in this zone include locations where Mass Wasting Inventory mass wasting spatially overlap event records that document recent slope failures. In general, rockfall and debris flows produce the primary hazards within this zone.
- NF Stillaguamish River, South Bank between Boulder River and Fry Creek (Figure 4.2-3): The City Light transmission line traverses the south bank of the NF Stillaguamish River and multiple mapped landslides. Thirteen sites were identified within this ZSC. All of these sites are located within mapped landslides. Event records document recent slope failures, including sites where mitigative measures were required (e.g., MW-65). The majority of the landslides in this area occur along the steep north-facing slope that fronts a broad, flat bench composed of glaciolacustrine clay mantled by sandy outwash. In the NF Stillaguamish valley, landslides are relatively common in similar conditions where permeable sandy outwash overlies low-permeability clay. LaHusen et al. (2016) and Badger et al. (2015) describe these conditions relative to the 2014 Oso landslide.

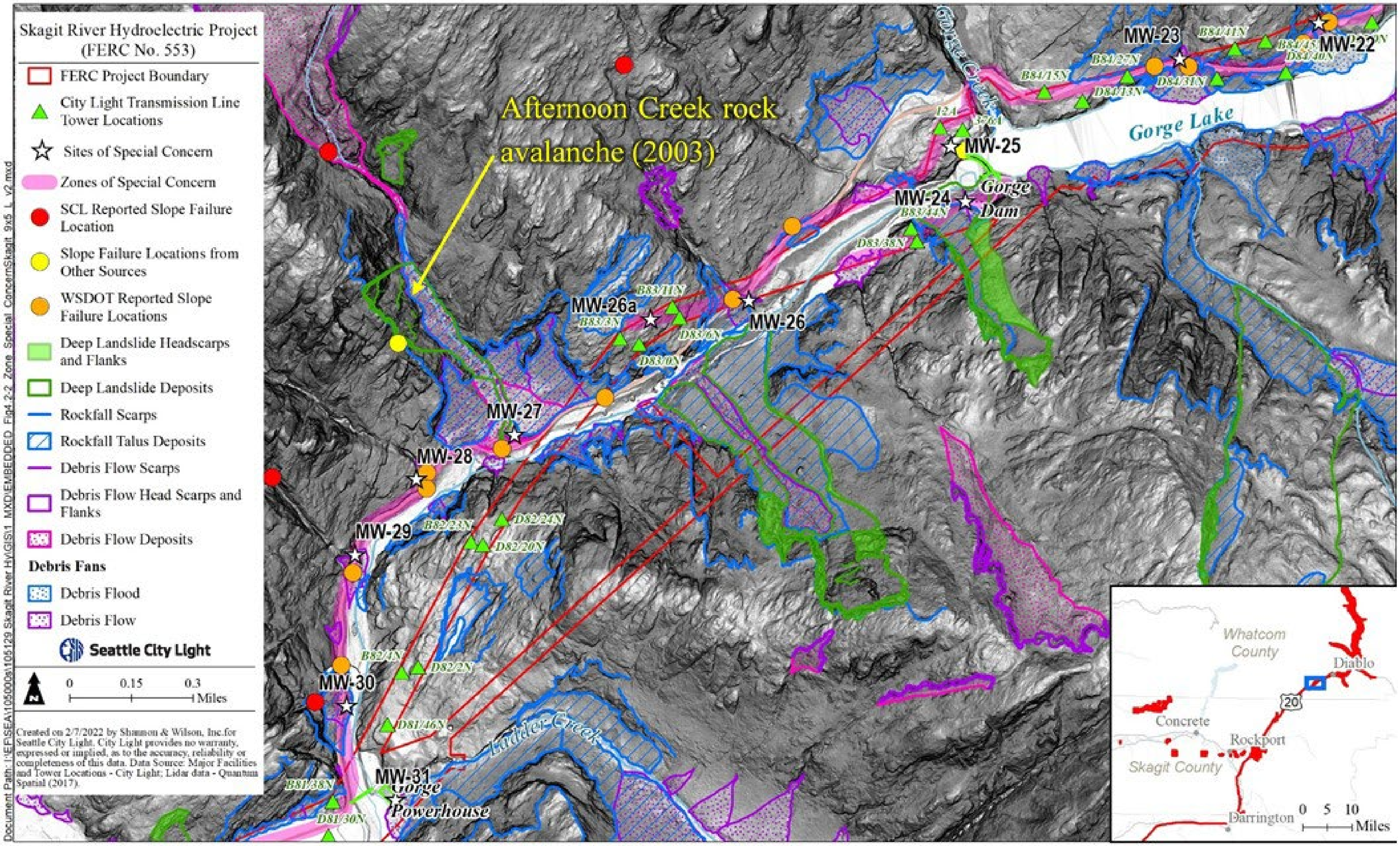

Figure 4.2-2. **Sites within Zone of Special Concern between Newhalem and Gorge Dam. Map view is north.**

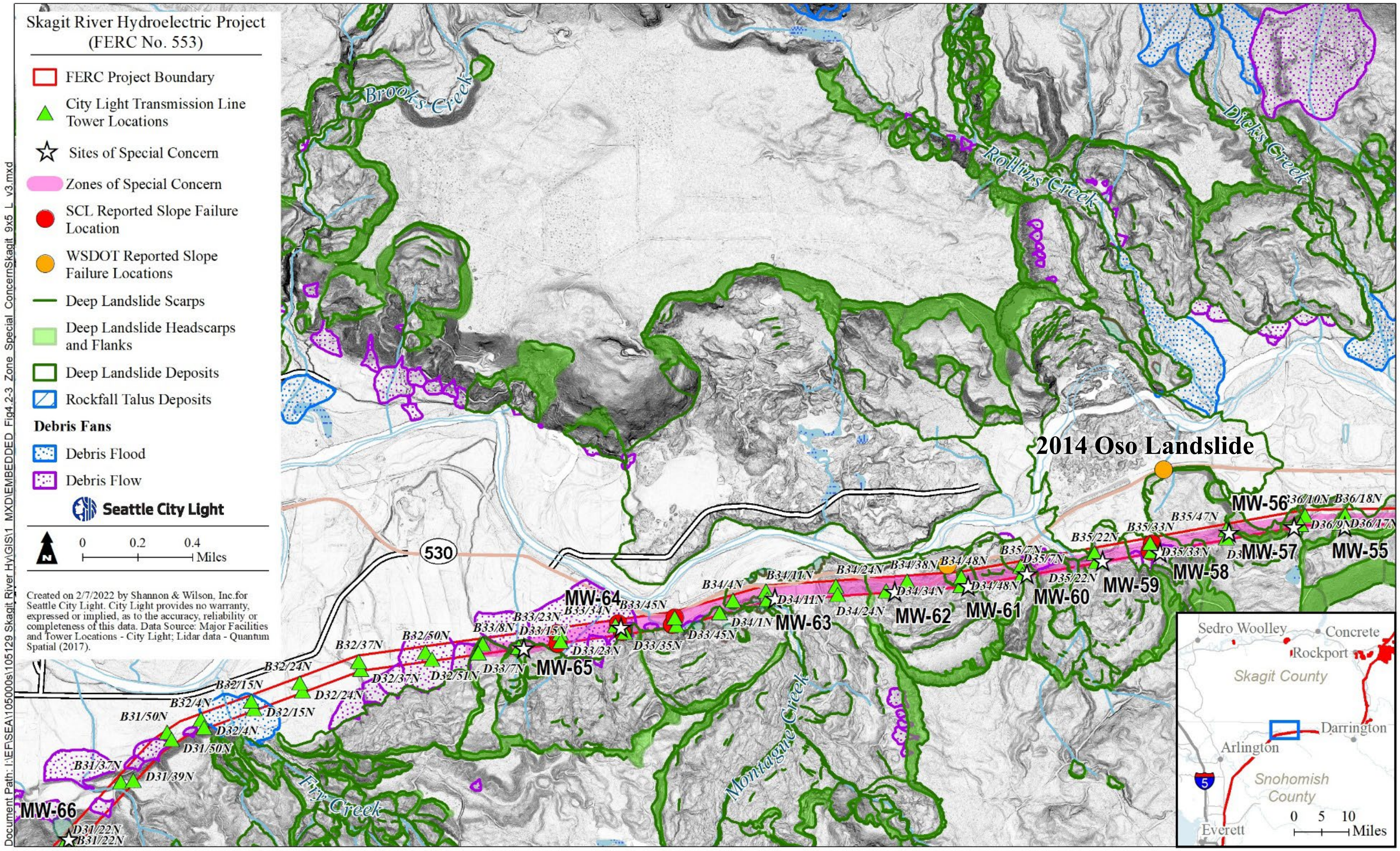

Figure 4.2-3 Zone of Special Concern, NF Stillaguamish River, South Bank between Boulder River and Fry Creek. Map view is north.

4.3 Summary

The two main objectives for the mass wasting component of the Erosion and Geologic Hazards Study have been met: (1) develop an Mass Wasting Inventory of existing mass wasting features (e.g., landslide and rockfall) within the mass wasting study area that could affect and/or be affected by City Light facilities and operations; and (2) provide a regional assessment of susceptibility of slopes to the dominant types of mass wasting based primarily on existing mass wasting features, slope characteristics, and local geology. The results of the mass wasting study component provide an initial assessment of hazards near Project facilities that could inform future decisions regarding mass wasting hazard planning and mitigation.

As described in this mass wasting study component, landslides, rockfall, and debris flows are generally prevalent within the mass wasting study area (see Attachments A through E). However, the geospatial distribution of these features is not uniform and, as demonstrated by the susceptibility analyses, slope failures tend to concentrate in areas that exhibit specific conditions that predispose a slope to fail. These conditions include, but are not limited to, specific combinations of geology type and slope geometries. Based on the Mass Wasting Inventory and the susceptibility analyses, some generalizations can be made about patterns of slope failures in the mass wasting study area and contributing factors, focusing on areas that overlap Project facilities.

For example, as described in Section 4.2.5 of this study report, two ZSC delineate areas of high mass wasting feature concentrations that coincide with Project facilities. Slopes along the Skagit River between Rockport and City Light’s Skagit River Project are mostly rocky and steep with local glacial and colluvial deposits concentrated in the catchment areas of drainages and swales. Based on the Mass Wasting Inventory, rockfall is the dominant mass wasting process along the Skagit slopes. However, steep drainages incised in the slopes provide effective debris flow chutes that rapidly transport colluvium from source areas near the ridge tops to the base of the slopes, where most infrastructure is concentrated, including SR 20 and the City Light transmission line. Deep-seated landslides tend to be less common in the upper Skagit River valley than in the rest of the mass wasting study area, but, where they have occurred, they often take the form of large, highly mobile rock avalanches, which are among the most damaging types of mass wasting events (Hungr et al. 2014).

To the south and west, mass wasting in the NF Stillaguamish River valley reflects the unique signature of the area’s glacial history. The NF Stillaguamish River valley includes broad swaths of glacial deposits that tend to be susceptible to deep-seated landslides. The pattern of permeable sandy outwash over fine-grained glaciolacustrine soil generates a perched water table that has likely contributed to the hundreds of deep-seated landslide deposits that line the valley margins (Booth et al. 2017). The 2014 Oso landslide demonstrated the ability of glacial stratigraphy of the NF Stillaguamish River to generate catastrophic, extremely rapid flow-type landslides, but even the ongoing, slow deformation of old landslide deposits can pose a risk to fixed infrastructure (Badger 2015).

4.3.1 Next Steps

Although these desktop-based analyses are complete, following up the mapping and susceptibility analyses with site visits to selected mass wasting features would supplement and expand upon the information provided in this report. As described above, the Mass Wasting Inventory provides limited information regarding the timing of slope failures of Mass Wasting Inventory features. Understanding landslide or rockfall timing for features located near Project facilities can inform hazard mitigation planning by designating features as potentially active or less likely to be active. Additionally, a mass wasting feature may not be active within its full LiDAR-mapped extent; instead, only portions of it might be exhibiting ongoing slope failure (e.g., shallow sloughing within a deep-seated landslide). Conversely, the feature might be expanding (e.g., headscarp retrogressing upslope). The current conditions of a mass wasting area can be assessed by identifying geomorphic features or local conditions (e.g., local groundwater conditions) on the ground during a site visit that are indicative of recent or ongoing slope movement. Examples of conditions that might indicate slope movement include but are not limited to:

- Fresh fractures or set downs in the ground or recent sloughing within or near landslide;
- Fresh surface along rockfall scarp or piles of rock that appear to be recent;
- Soft ground relative to areas outside of the landslide footprint;
- Leaning or pistol-butted trees, or trees with broken tops;
- Water springs or seeps, sag ponds, saturated ground;
- Debris downslope of landslide toe or rockfall talus slope;
- Debris-choked stream channels and/or fresh debris on debris flow fan surface; and
- Recent stream undercutting of slope below landslide or rockfall slope.

As described in Section 4.2.5 of this study report, Table E-1 provides a list of locations where mass wasting hazards overlap with Project facilities (Attachment E). This information will be used to inform the management of Project facilities.

5.0 EROSION AND RUNOFF FROM PROJECT-RELATED TOWNSITES AND STUDY ROUTES

The analysis of erosion and runoff from Project-related townsites and study routes includes compiling existing data and GIS layers; a pre-field analysis of routes and stream connectivity; a field inventory of study routes, culvert, and townsite erosion and runoff conditions (referred to in this report at the Phase I Study Route Inventory); a culvert/bridge fish passage assessment (referred to in this report as the Phase II Fish Passage Assessment); and a post-field summary and analysis. This study report includes the results of the Phase I Study Route Inventory and townsite assessments conducted in 2021. The Phase II Fish Passage Assessment will be completed in 2022 and reported in the USR. Methods describing 2022 efforts are included under "Next Steps" in Section 5.3.2 of this study report.

5.1 Methods

During 2021, existing information was collected and the Phase I Study Route Inventory was conducted, compiling information on routes, culverts, and townsite erosion and runoff conditions. The 2021 analysis of erosion and sedimentation along study routes and townsites included assessing:

- Hydrologic connectivity of study route segments;
- Erosion potential (surface erosion, gullying, and mass wasting);
- Culvert, bridge, and drainage structure characteristics and condition; and
- Project townsite runoff and erosion.

5.1.1 Existing Information and Pre-field Analysis

The following existing information and data were compiled for use as part of the analysis per Section 2.6.2.1 of the RSP:

- Study route, stream, and townsite areas identified in 1990 erosion inventory (Riedel 1990);
- Recent LiDAR data and aerial photographs;
- Geology and soils GIS layers;
- Stream and wetland GIS layers; and
- Study routes GIS layer.

This information was used to prepare field maps for pre-field planning purposes and during the analysis of field data.

5.1.2 Study Route and Townsite Drainage Field Inventory

A field inventory of study routes, including townsite routes, and culvert conditions was made during the summer of 2021 per Section 2.6.2.2 and Section 2.6.2.3[14] of the RSP. Information was

[14] Note that the bank armoring and levee erosion in Project townsites described in RSP Section 2.6.3.3 is included in Section 6 of this study report.

collected for the following attributes (see Attachment F for details of the field protocol and information that was collected):

- Hydrologic connectivity of each route segment/drainage structure (route drainage to streams, lakes/ponds, or wetlands and storm drain locations in townsites);
- Road/trail condition (tread, cutslope, surfacing, width, gradient, configuration, length hydrologically connected, any erosion or mass wasting issues, oversteepened sidecast or fillslopes, etc.);
- Culvert condition (type, diameter, length, plugged, crushed, shotgun, stream crossing, or cross-drain culvert, etc.);
- Bridge characteristics (span, width, etc.);
- Condition information on any fords or other non-culvert stream crossings; and
- Project townsite runoff and erosion. This information was collected as part of the Phase I Study Route Inventory since roads in Project townsites are included as study routes.

Field work at study routes identified and numbered each drainage structure (e.g., culvert, bridge, ford). For each drainage structure, a Global Positioning System (GPS) point was collected using a Trimble Geo7x GPS recorder or Bad Elf Pro GPS unit. The Washington DNR stream typing map was consulted to determine if the crossing has been previously mapped as a stream and the water type (e.g., Fish, Non-fish, Unknown). Each crossing was assessed based on field data (collected over a length equivalent to 10 bankfull widths upstream of the crossing and outside of the immediate zone of influence of the crossing structure) to identify if it is or is not a stream and its potential for fish-bearing based on:

- If there was a defined bed and banks and water-washed sediment, the crossing was considered a stream.
- If the crossing was a stream and was not mapped as a Type F on the Washington DNR stream typing map, the potential for fish use was determined based on field assessment of scour width and gradient. If the stream had a scour width of over 2 feet and a gradient of less than 20 percent it was characterized as potentially fish-bearing (WDFW 2019). If the scour width was less than 2 feet or the gradient was over 20 percent, it was categorized as not potentially fish-bearing (WDFW 2019). Note that stream/fish-bearing potential may be different upstream and downstream from a structure, and each was assessed and determined separately.

Route observations, such as presence of springs and seeps along the study routes, areas that were extremely rutted, or that appeared to need specific maintenance, were also marked and noted.

Details of the Phase I Study Route Inventory field protocol are included in Attachment F and, as described in the RSP, were similar to those used in the Cedar River watershed (Seattle Public Utilities 2005) and the Boundary Hydroelectric Project relicensing.

The Phase II Fish Passage Assessment described in Section 2.6.2.2 of the RSP will be completed in 2022 as described in Section 5.3.2 of this study report.

5.1.3 Washington Road Surface Erosion Model

The Washington Road Surface Erosion Model (WARSEM) was run on the study route segment/delivery field data to estimate the average annual sediment delivered to connected waterbodies from road/trail surface erosion per RSP Section 2.6.2.2 (Dubé et al. 2004; https://www.dnr.wa.gov/washington-road-surface-erosion-model). Field data was converted from GIS to Excel and formatted for WARSEM input. Two factors were assigned following the field work: (1) the geologic erosion factor and the traffic factor, based on underlying geology; and (2) estimated traffic use, respectively. Estimated surface erosion is highly dependent on the traffic factor assigned. Two different factors were used for the Ross Lake-Diablo Lake Road because actual traffic loads likely vary seasonally (higher use in the summer with Ross Lake Resort shuttle service and lower use during the rest of the year).

5.2 Preliminary Results

The Phase I Study Route Inventory data presented in this study report includes field data collected through October 31, 2021. This includes the Phase I inventory of study routes and route/stream crossing structures. Additional field data will be collected in 2022 and the Phase II Fish Passage Assessment will be completed as described in Section 5.3.2 of this study report.

5.2.1 Phase I Study Route Inventory

The Phase I Study Route Inventory covered approximately 124 miles of roads/trails in 2021 and included the majority of study roads and the more accessible portions of study trails. Approximately 13 miles of the study routes were not examined in 2021 due to access issues or lack of time prior to the cut-off date for this study report. These segments will be assessed and included in the USR.[15]

As described in Attachment F, five different types of data points were collected as part of the Phase I Study Route Inventory. These data are shown on the maps in Attachment G.

- Drain Points (road/trail segments that drain to waterbodies);
- Culverts;
- Bridges;
- Mass Movements; and
- Road Observations.

Note that the type of drainage structure for each delivering segment was recorded along with the route attributes for each Drain Point (e.g., bridge, culvert, ford, dispersed). Culvert point features include both stream-crossing culverts and relief (non-stream) culverts.

15 Study road segments scheduled for assessment in 2022 total less than 3 miles and are mostly short in length and scattered within five separate Wildlife Mitigation Lands (Nooksack, Savage Slough, Finney Creek, Lucas, and Barnaby areas) located west of the transmission lines. Study trail segments scheduled for 2022 Phase I Study Routes Inventory work include 9.73 miles of foot trails—6.8 miles are trails leading to towers located in isolated/rugged terrain, and 2.9 miles of the Diablo Lake Trail that begins at the North Cascades Environmental Learning Center and ends at Ross Dam.

A total of 264 separate Drain Points are shown on the maps in Attachment G and designate the locations where study routes are hydrologically connected to streams, lakes, or wetlands (16.8 miles or 14 percent of the total surveyed road/trail length). Of these, 138 drained directly to a waterbody, 114 drained to the forest floor within 100 feet of a waterbody, and 12 were between 100 and 200 feet away from a waterbody. The majority of these study route segments drained to streams (167), 31 to lakes/ponds, 59 to wetlands, and the remainder to other locations, such as storm drains in townsites. The type of drainage structure at each Drain Point was noted and included culverts (158), bridges (7), fords (4), ditch-outs (4), outsloped close to waterbodies (71), and 20 that delivered to other delivering study route segments.

The study route segments associated with Drain Points were primarily surfaced with good quality gravel (51 percent of total surveyed length), with 21 percent of the delivering length covered with worn gravel (gravel with substantial wear/break down to fine material), 15 percent asphalt, and 14 percent native or unsurfaced routes. Most of the roads/trails had tread widths of 10 to 15 feet in width (62 percent of the segments) with 16 percent between 15-20 feet wide and 19 percent over 20 feet wide; 3 percent were narrower than 10 feet. Road/trail issues noted along the study route segments included 12 segments with oversteepened fill, 18 segments with sidecast berms, 11 segments with washboarding or potholes, one culvert fill failure, and one washout. Fourteen segments had raveling cutslopes, and 10 had small slumps in the cutslope. Thirteen locations with seepage were found. Ten locations where road drainage would be improved by the installation of relief culverts were noted.

The culvert inventory included both stream crossing culverts and relief culverts. A total of 303 culverts were found. The majority were corrugated metal pipes (CMP) or high-density polyethylene (HDPE), but a few cast iron, concrete, and one wood stave pipe were found. There were also 3 arch pipes and 23 road drains inventoried. The majority of culverts were 18-inch diameter pipes, with 12-, 24-, 36-, 48-inch, and larger diameter pipes as well.

The majority (67 percent) of culvert inlets were clear but 28 of the culverts had inlets that were over halfway blocked by debris or sediment. Outlet blockages were less common, with 79 percent of the culverts having no outlet blockage and seven percent (22 culvert outlets) that were over halfway blocked. Seventy-two percent of the culverts had no physical or functional issues. The most common issues were crushed inlets/outlets (10 percent), rusted pipes (10 percent), bent pipes (4 percent), catch basins full of sediment (7 percent), and negative slopes (2 percent; culverts sloping upstream).

Seventeen bridges were included in the inventory and no issues were noted at bridge locations.

Eight mass wasting locations were found along the inventoried study routes. Six were marked as active, with one inactive and one potential site noted. Three sites had a high treatment urgency; potential treatments included revegetation, pulling back fill, replacing the retaining wall/buttress, and adding mesh to help control falling and raveling rocks. These mass wasting sites are generally small features on route cutslopes or fillslopes and are not large enough to be recognized in the Section 4.0 regional-scale mass wasting analysis.

5.2.2 Washington Road Surface Erosion Model Results

The WARSEM results were used to estimate the average annual sediment delivered to connected waterbodies from road/trail surface erosion (Table 5.2-1). Study route segments were grouped by road/trail name or, in the case of the transmission line ROW, by general location area as shown on Figures 5.2-1 – 5.2-4 (e.g., the Transmission Line Sauk area includes roads in the vicinity of the Sauk River and in the transmission line ROW). Study routes with the longest length draining directly to a stream, lake, or wetland were the transmission line ROW routes in the Darrington, Arlington, and Skagit areas and the study route system connecting Ross Dam to Diablo Lake. Study routes predicted to deliver the most sediment to streams are the Ross Dam to Diablo Lake Road and the ROW roads/trails in the Sauk, Skagit, Darrington areas.

Table 5.2-1. Study route lengths hydrologically connected to waterbodies and estimated sediment delivery.

Study Route Location Area	Study Route Segment Length (feet)			Estimated Average Annual Sediment Delivered to a Waterbody (tons/year)
	Drains Directly to Waterbody	1-100 ft from Waterbody	100-200 ft from Waterbody	
Newhalem Ponds	0	824	54	1.4
Babcock Creek	2,844	841	0	10.6
Diablo Dam	339	2,379	0	<0.1
Diablo Road	2	0	0	<0.1
Diablo Village	0	2,577	0	0.5
Gorge Dam Road West	0	121	817	1.2
Illabot Creek	2,722	228	0	8.3
Newhalem Facilities	0	201	0	1.1
Newhalem Trails	83	139	0	<0.1
Newhalem Village	0	1,964	0	<0.1
Ross Dam to Diablo Lake	5,960	470	190	90-435
Rumsey Creek	0	286	0	<0.1
Skagit Transmission Line ROW	8,546	10,011	426	26.8
Stetattle Creek/ Hollywood	0	1,138	0	<0.1
Transmission Line ROW Arlington	8,143	1,812	85	1.1
Transmission Line ROW Darrington	12,281	7,755	1,965	16.8
Transmission Line ROW Illabot	1,038	687	0	2.1
Transmission Line ROW Mill-Snohomish	1,138	0	0	1.4
Transmission Line ROW Sauk	4,135	0	0	27.4
Transmission Line ROW Stevens	636	1,609	0	0.1
Transmission Line ROW Ross-Diablo	2,984	0	69	10.2

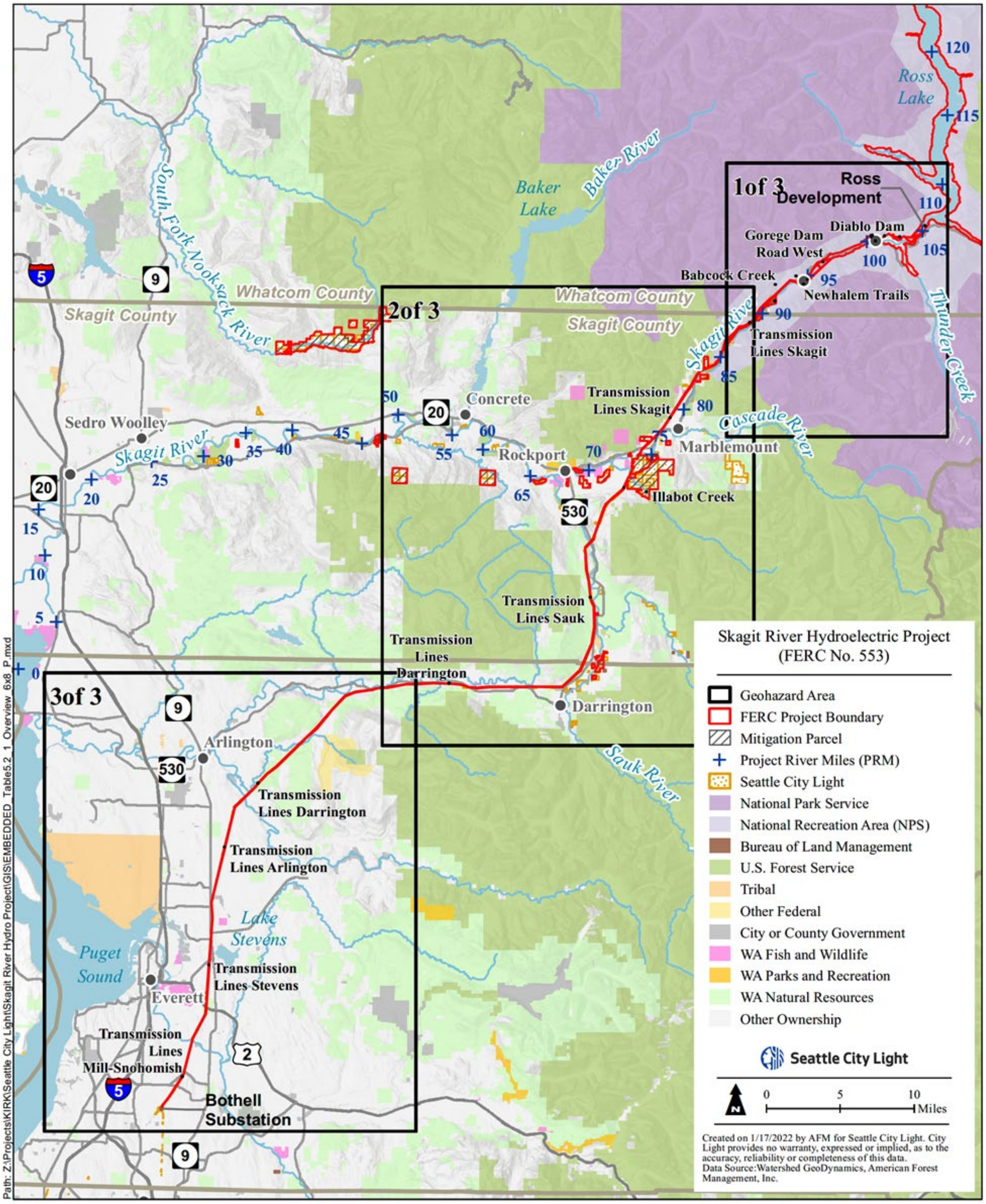

Figure 5.2-1. Phase I Study Route Inventory location areas overview.

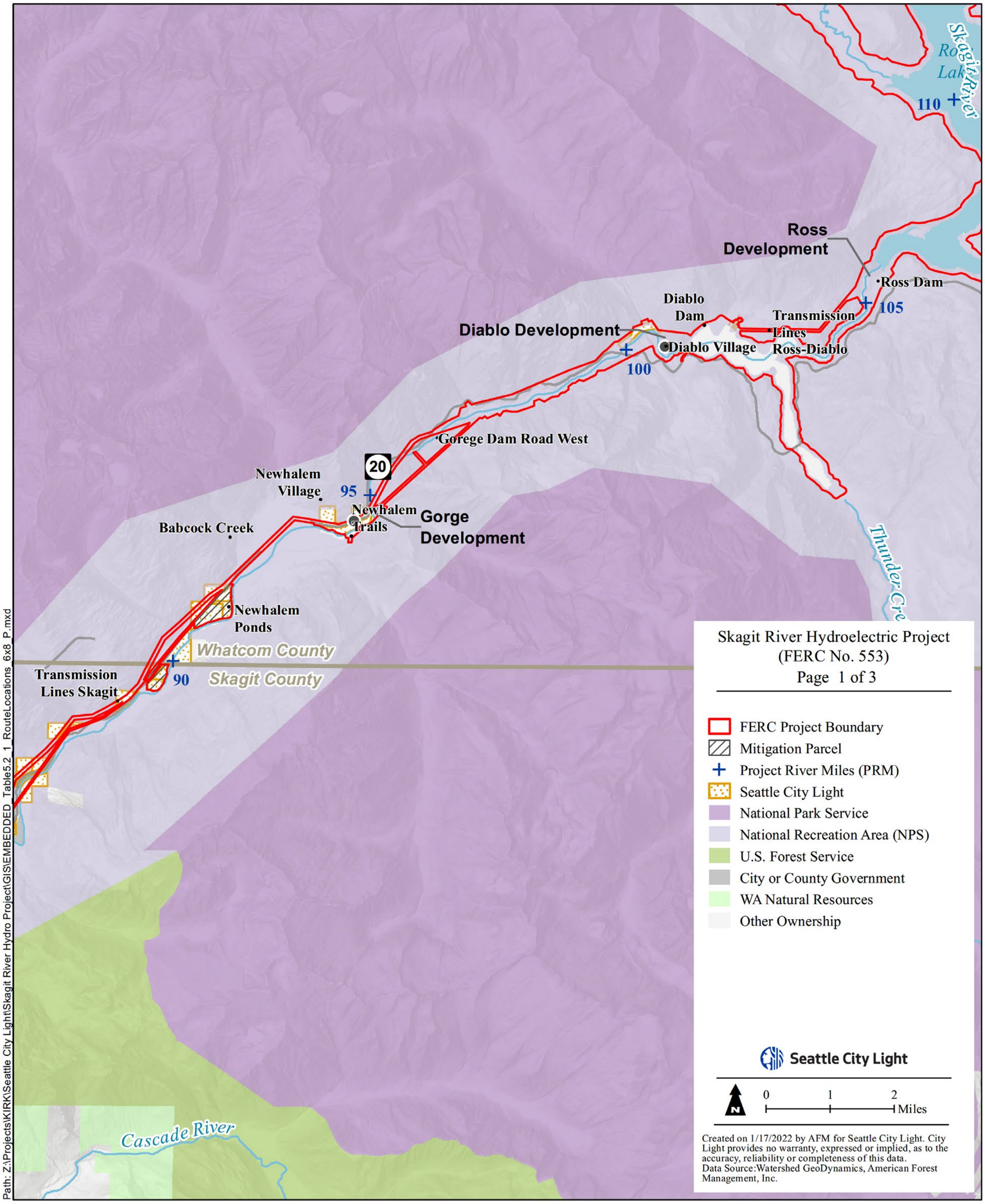

Figure 5.2-2. Phase I Study Route Inventory location areas (1 of 3 - north).

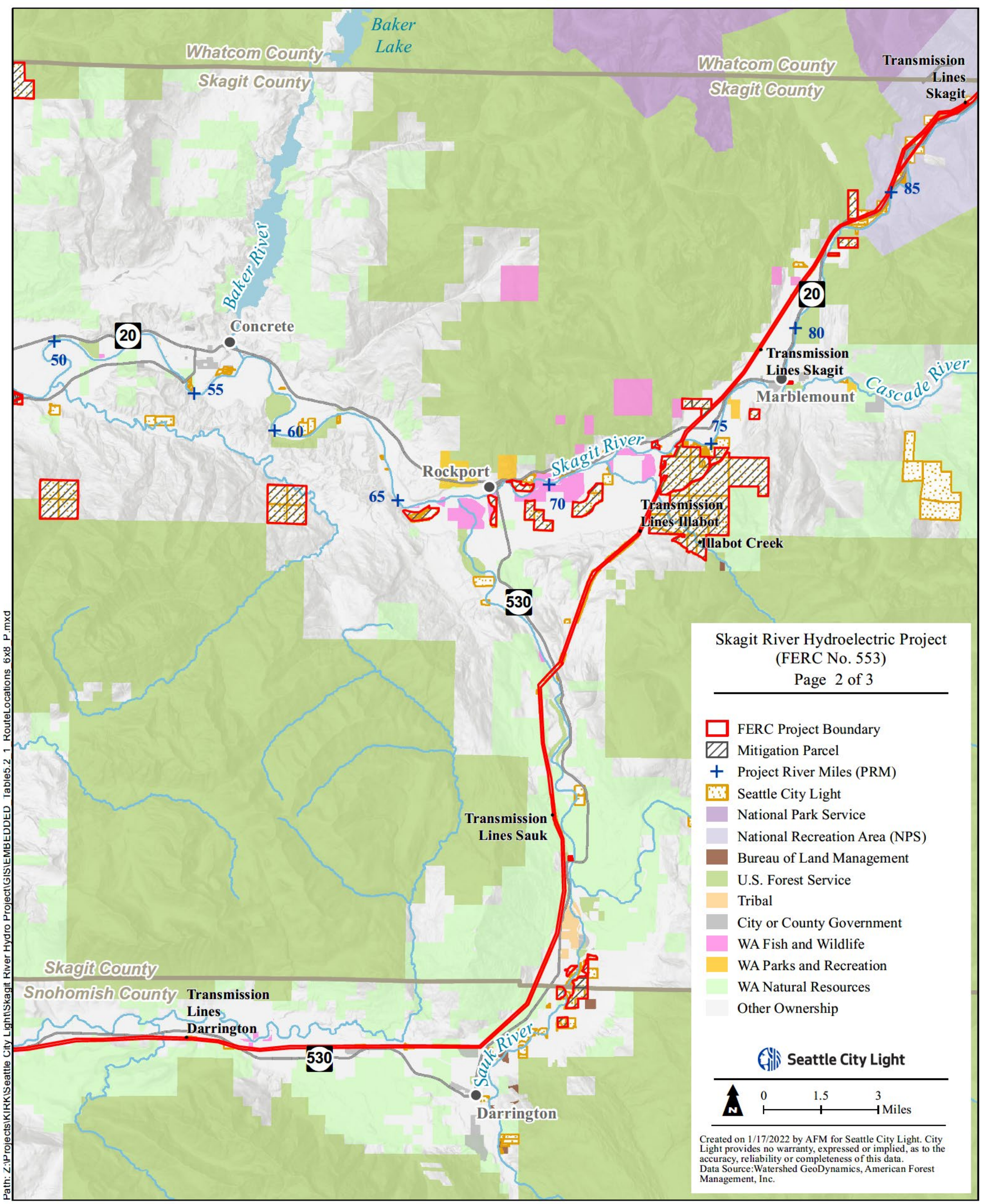

Figure 5.2-3. **Phase I Study Route Inventory location areas (2 of 3 - central).**

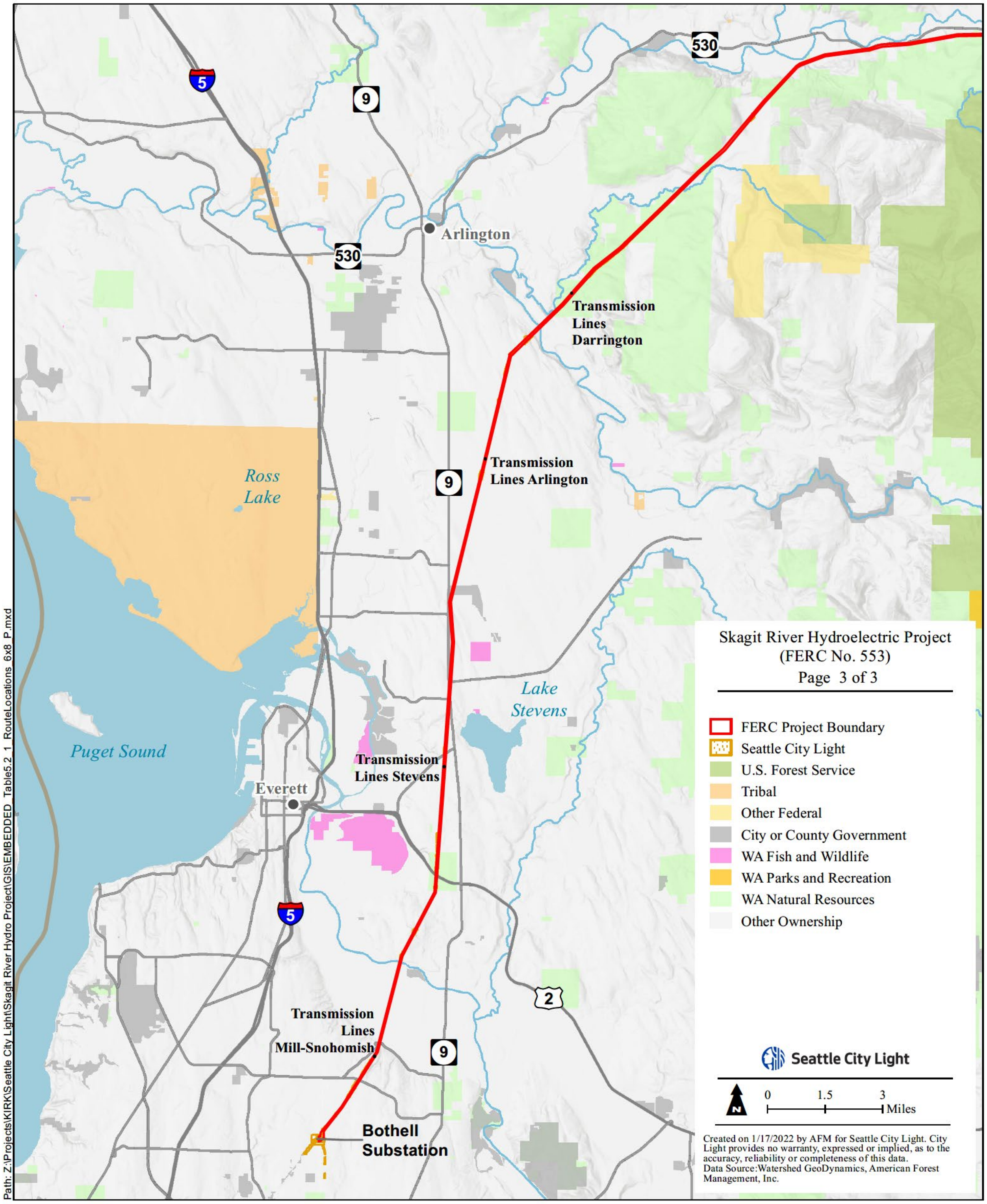

Figure 5.2-4. Phase I Study Route Inventory location areas (3 of 3 - south).

5.2.3 Screening of Crossing Structures for the Phase II Fish Passage Assessment

Study route/stream crossing structures that are potential fish passage barriers will be assessed using the WDFW Fish Passage Inventory, Assessment, and Prioritization Manual methodology (WDFW 2019) in 2022. As stated in the RSP Section 2.6.2.2, fish passage attributes will be collected at Washington DNR designated fish-bearing stream crossings and at any field-identified crossings identified as potentially fish-bearing upstream and downstream from the crossing where recent (less than 5 years old) passage data is unavailable. The Phase I Study Route Inventory results will be used to help determine which structures are (or are not) potentially fish-bearing based on field-measured characteristics of the waterway upstream and downstream from the crossing. The following structures do not require assessment:

- Structures with no stream or waterbody (e.g., no defined bed and banks); and
- Structures with a stream where the stream both upstream and downstream is over 20 percent gradient and has a scour width of less than 2 feet.

Structures that crossed a stream designated as fish-bearing on the Washington DNR stream typing map or that are less than 20 percent gradient and having a scour width of 2 or more feet upstream or downstream of the structure will be assessed. Data will be collected to complete a Level A or B fish passage assessment as appropriate based on Washington DNR 2019 (see decision tree in Washington DNR 2019 to identify if Level A or B is necessary) per study plan.

The total number of structures in the potential Phase II Fish Passage Assessment categories are shown in Table 5.2-2. Final screening and Phase II Fish Passage Assessment will take place in 2022.

Table 5.2-2. Total number of potential Phase II Fish Passage Assessment crossing structures.

Structure Type	Potential fish-bearing streams based on field analysis[1]		Not potential fish-bearing streams based on field analysis
	Washington DNR Stream Type		
	Fish Bearing	Non-Fish	Fish Bearing
Bridge	3	2	1
Culvert	28	39	1
Ford	1	2	0

1 Some of these stream crossing structures may be on roads that are used by City Light but are owned and maintained by others.

5.3 Summary

The Phase I Study Route Inventory has been completed and road/trail surface erosion has been estimated using WARSEM. A total of 264 study route segments that drained to waterbodies were identified along with 303 culverts, 17 bridges, and 8 mass wasting sites along the study routes. An initial screening of road/trail crossing structures that will require Phase II Fish Passage Assessment has been made; additional screening will take place in 2022.

5.3.1 Status of June 9, 2021 Notice Pertaining to Project-related Townsites and Study Routes

As part of the June 9, 2021 Notice, several commitments were made by City Light to augment the Erosion and Geologic Hazards Study. The status of each of these commitments is summarized in Table 5.3-1.

Table 5.3-1. Status of Project-related townsites and study routes modifications identified in the June 9, 2021 Notice.

Study Modifications identified in the June 9, 2021 Notice: As Written	Status
SCL will clarify the study plan to provide that it will follow WDFW guidelines for determining fish-use potential. See WDFW, 2019 Fish Passage Inventory Assessment, and Prioritization Manual at 2-4. Olympia, Washington.	This commitment is incorporated into the methods for this study and will be completed during the 2022 analysis period (see Section 5.1.2 of this study report referring to WDFW, 2019 Fish Passage Inventory Assessment, and Prioritization Manual at 2-4. Olympia, Washington).
SCL will clarify the study plan to include a barrier inventory and assessment on mitigation lands and maintenance areas. With respect to mitigation lands, the inventory will be limited to active roads and will not include abandoned roads (which have been abandoned pursuant to Washington State Forest Practice Standards).	The barrier inventory and assessment is being conducted on mitigation lands and maintenance areas as well as other roads study routes associated with the Project as described in Section 3.0 of this study report. With respect to mitigation lands, the inventory is limited to active roads and will not include abandoned roads (which have been abandoned pursuant to Washington State Forest Practice Standards).
SCL will consult with the LPs to clarify the barrier status for specific fill and levee locations during study implementation (Goodell Creek alluvial fan, Stetattle Creek, and other sites identified by the LPs).	City Light will consult with the LPs in 2022 to clarify the barrier status for specific fill and levee locations.
SCL proposes to develop an inventory of culverts and potential stream miles of habitat (through LiDAR analysis) for consultation with the LPs on the need for habitat surveys. SCL cannot commit to field-based habitat surveys of blocked habitat because of the volume of culverts and uncertainties as to the number of culverts that are fish-blocking barriers and the amount of habitat above those barriers. Because of this, SCL proposes to report on the results of the studies in the Initial Study Report and confer with the LPs on the need for habitat surveys based upon the results of the studies.	The Phase II Fish Passage Assessment, which will be completed in 2022, will identify culverts and other study route stream crossing structures that are potential barriers to fish migration. Using this data, City Light will develop a map and GIS database showing potential stream miles of habitat that are upstream of barriers through LiDAR analysis. City Light proposes to report on the results of the assessment and LiDAR-based map of streams in the USR and confer with the LPs on the need for additional ground-based habitat surveys.

5.3.2 Next Steps

Additional existing information will be collected and analyzed during 2022, including:

- Road Maintenance and Abandonment Plan (RMAP) information, where available;
- Available City Light road and trail maintenance records;
- Townsite road/trail and drainage layer; snow dump locations; and

- Existing culvert fish passage information (including WDFW Fish Passage website https://geodataservices.wdfw.wa.gov/hp/fishpassage/index.html; Skagit System Cooperative fish passage database at road culverts; and other available data such as from NPS).

The Phase II Fish Passage Assessment will be completed in 2022 following methods in the WDFW manual (WDFW 2019) and reported in the USR.

As noted in the June 9, 2021 Notice, following the Phase II Fish Passage Assessment, City Light will develop a list of potential stream miles of habitat that are inaccessible due to passage blockages through LiDAR analysis and will consult with LPs on the need for field-based habitat surveys upstream of potential blockages.

As noted in the June 9, 2021 Notice, City Light also will consult with LPs to clarify the barrier status for specific fill and levee locations in 2022 (e.g., Goodell Creek alluvial fan and Stetattle Creek).

The following deliverables listed in RSP Section 2.6.2.2 will be included in the USR:

- Culvert condition/fish passage along study roads;
- A table summarizing road/culvert locations with erosion issues or fish passage concerns;
- Report sections summarizing assessment; and
- A GIS database with roads and culvert conditions.

The following deliverables listed in RSP Section 2.6.2.4 will be included in the USR:

- A map and assessment of runoff or erosion issues at Project townsites; and
- A table listing any issues.

The work products will be available during development of the license application and protection, mitigation, and enhancement (PME) measures to assess effects on other resources.

6.0 CHANNEL MIGRATION AND STREAM CROSSINGS

The channel migration and stream crossing part of the study includes four elements:

- Channel migration analysis;
- Compilation of transmission line maintenance procedures near stream crossings;
- Collecting information on Project-related townsite streambank conditions; and
- Collecting information on stream/riparian/bank conditions at channel migration and transmission line maintenance locations.

In 2021, maintenance procedures were compiled and information on Project-related townsite streambank conditions was collected. The channel migration analysis and stream/riparian/bank conditions will be collected in 2022.

6.1 Methods

6.1.1 Channel Migration Analysis

The channel migration analysis will be completed in 2022 per the methods in the FERC-approved study plan at Section 2.6.3.1 of the RSP and will be reported in the USR.

6.1.2 Compilation of Transmission Line Maintenance Procedures near Stream Crossings

City Light maintenance staff were queried to obtain a list of study route/vegetation maintenance procedures used along the transmission line ROW as described in RSP Section 2.6.3.2. Locations where bank armoring has been installed at transmission line crossings/tower locations will be identified in 2022.

6.1.3 Project-Related Townsite Streambank Conditions

The Upper Skagit Indian Tribe mapped hydromodifications along the Skagit River (downstream from the upper bridge accessing the Gorge Powerhouse) in 2015. Bank conditions in Project townsites were assessed in the field during 2021 per the RSP Section 2.6.2.3 and areas with hydromodification were noted and marked on field maps and using GPS points. Areas visited included the Skagit River adjacent to the Diablo and Newhalem townsites, and the Hollywood levee along Stetattle Creek in the Diablo townsite. Mature vegetation covered many of the banks, which made it difficult to determine the exact extent of older areas of potential bank stabilization. The LiDAR hillshade data were used to help assess areas with possible older, informal bank stabilization based on bank shape (e.g., the steep banks in the Diablo townsite that were adjacent to the river may have old, less formal rock stabilization measures that are now covered in vegetation).

6.1.4 Stream/Riparian/Bank Condition at Channel Migration Zone and Transmission Line Maintenance Locations

The stream/riparian/bank condition field work and analysis will be completed in 2022 using methods from the FERC-approved study plan in Section 2.6.3.3 of the RSP and will be reported in the USR. Information on aquatic habitat, bank conditions, and riparian habitat will be collected.

Details of remote sensing and field methods and analysis for this study component are being developed in consultation with LPs.

6.2 Preliminary Results

These preliminary results include data collected through October 31, 2021.

6.2.1 Transmission Line Maintenance Procedures near Stream Crossings

Routine maintenance, such as vegetation clearing and study route maintenance in the transmission line ROW, has the potential to affect riparian vegetation and streambank stability. A list of general maintenance procedures for transmission line ROW areas is included in the following sections.

6.2.1.1 Departmental Policy and Procedure (DPP 500 P 1-506)

City Light Departmental Policy and Procedure, DPP 500 P 1-506 (City Light 1983), was initially established in 1983 for the maintenance of City Light transmission line ROWs and continues to set these goals:

- To maintain the integrity of the transmission system to ensure there are no outages due to interference with the conductors from vegetation or human-made objects.
- To provide access, where reasonable, to all structures in the transmission system.
- To utilize an integrated vegetation management (IVM) approach to vegetation control.
- To utilize maintenance methods which are legal, safe, and economically acceptable to the utility industry, and generally acceptable to the public.
- To encourage compatible multiple use of the transmission line ROW where feasible.
- To maintain the transmission line ROW in cooperation with governmental agencies having jurisdiction over adjacent property.

6.2.1.2 Roads/Trails

City Light uses some ROW trails to access transmission towers and conduct vegetation management in those areas where vehicle access is not possible, mostly steep areas within the Ross Lake National Recreation Area. These trails are intentionally kept obscure to the general public to prevent conflicts with NPS management objectives. As such, maintenance is extremely minimal. No trail tread surface work is performed for these ROW access trails.

The following procedures are used to maintain study roads in the transmission line ROW:

- Grading – using heavy machinery to grade the road surface to smooth out ruts, rills, and potholes.
- Gravel – applying a layer of crushed rock to the road surface.
- Ditch cleaning – removing dirt and debris from roadside ditches.

6.2.1.3 Vegetation Management within the Transmission Line ROW

The following procedures are used to maintain vegetation in the transmission line ROW (Seattle City Light 2016):

- Selective removal – cutting down individual trees. This method is the most common approach used by City Light. Trees are generally cut down before they grow within 20 feet of a line. Depending on wire height and topography, this can range from trees less than 5 feet to greater than 100 feet tall.
- Topping – removing tops of individual trees. This practice is used minimally as it is difficult, can be more dangerous, and kills the tree in the long run. However, it can be useful when screening or some shading from the remaining tree is desired.
- Girdling – removing a band of cambium from the entire circumference of the tree trunk to kill the tree. This method is only used on conifers when a snag is desired for either aesthetics or habitat value.
- Side trimming – pruning tree limbs growing in from areas adjacent to the transmission line ROW.
- Herbicide – Several different selective herbicide application techniques are used, including spot spray, basal bark, EZ-ject, and cut and treat. Broadcast herbicide application (i.e., non-selective herbicide application to all vegetation) was used extensively before the City of Seattle adopted a pesticide-reduction program in 1999. This program was designed to reduce overall pesticide use, particularly pesticides with higher toxicity. Herbicides are now only selectively applied to fast-growing tree species (e.g., black cottonwood [*Populus trichocarpa*]) and invasive plants such as Scot's broom (*Cytisus scoparius*).
- Brush cutting – Using a side arm tractor-mounted flail mower to mow down woody vegetation. This approach was greatly increased after adoption of the pesticide reduction program to decrease herbicide use. However, based on independent research and City Light field work, City Light has concluded that annual brush cutting generally facilitates the spread of invasive plant species (e.g., common tansy [*Tanacetum vulgare]*) and is now limiting use to immediately along patrol roads/trails (within 3 feet of roadway) and 20 feet around transmission towers. Use of a reticulated arm allows vegetation to be cut at different heights. City Light plans to test the efficacy and effects of mowing Scot's broom and some tree species over lower-growing native species (e.g., salal [*Gaultheria shallon*]).
- Mowing – Using a tractor-mounted rotary cutter (i.e., field deck) to mow herbaceous and small-diameter woody vegetation. There are several stream crossings (e.g., Montague Creek) where this method was commonly used. This method was used in relatively flat riparian areas below the Sauk crossing. However, this method has resulted in increased reed canarygrass (*Phalaris arundinacea*) and has been largely discontinued to allow appropriate native woody species to grow.

6.2.1.4 Slash Management

The following procedures are used to maintain slash in the ROW:

- Lop and scatter – cutting slash wood into smaller segments and scattering pieces such that they are spread relatively homogenously and most wood is in contact with the ground. This technique generally promotes faster decomposition of woody debris but can also result in buildup of wildfire fuels.
- Brush pile – piling slash into small piles to provide habitat for wildlife and reduce contiguity of wildfire fuels.

6.2.1.5 Bank Protection

Bank protection and habitat restoration measures have been installed by City Light at several transmission line ROW stream crossings where channel migration or erosion threatened transmission towers. These locations include:

- Boulder River – In 2015, emergency rip rap repairs were made to protect transmission towers from bank erosion. The rip rap was subsequently covered with engineered log structures and a flanking structure composed of logs and root wads installed to provide bank protection and habitat improvements.
- Diobsud Creek – An engineered log jam was installed as mitigation for cutting pieces of large woody debris from a channel-spanning jam that was causing erosion of the streambank near two transmission line towers (Figure 6.2-1).
- French Creek – transmission towers were re-located.

Figure 6.2-1. Diobsud Creek rip rap and log jam installations to protect transmission line tower.

6.2.2 Project-Related Townsite Streambank Conditions

There are two townsites associated with Project facilities—Newhalem and Diablo. Diablo includes two areas: Reflector Bar (north of the Diablo Powerhouse) and Hollywood (south of the Diablo Powerhouse and adjacent to Stetattle Creek). Hydromodifications included rip rap and rip rap covered in shotcrete.

6.2.2.1 Newhalem

Boulders and coarse sediment line the banks of the Skagit River along the terrace adjacent to Newhalem. Rip rap protects short sections of the left bank around the Gorge Powerhouse.

6.2.2.2 Diablo

Bank protection in the Diablo townsite area includes rip rap at a few locations near the Diablo Powerhouse, one short section at the upstream end of the townsite, and along the left bank of Stetattle Creek (Figure 6.2-2). There is possibly old bank stabilization along sections of the right bank of the Skagit River from Reflector Bar through Hollywood, but soil and thick vegetation covering the streambank makes it difficult to make a determination with certainty.

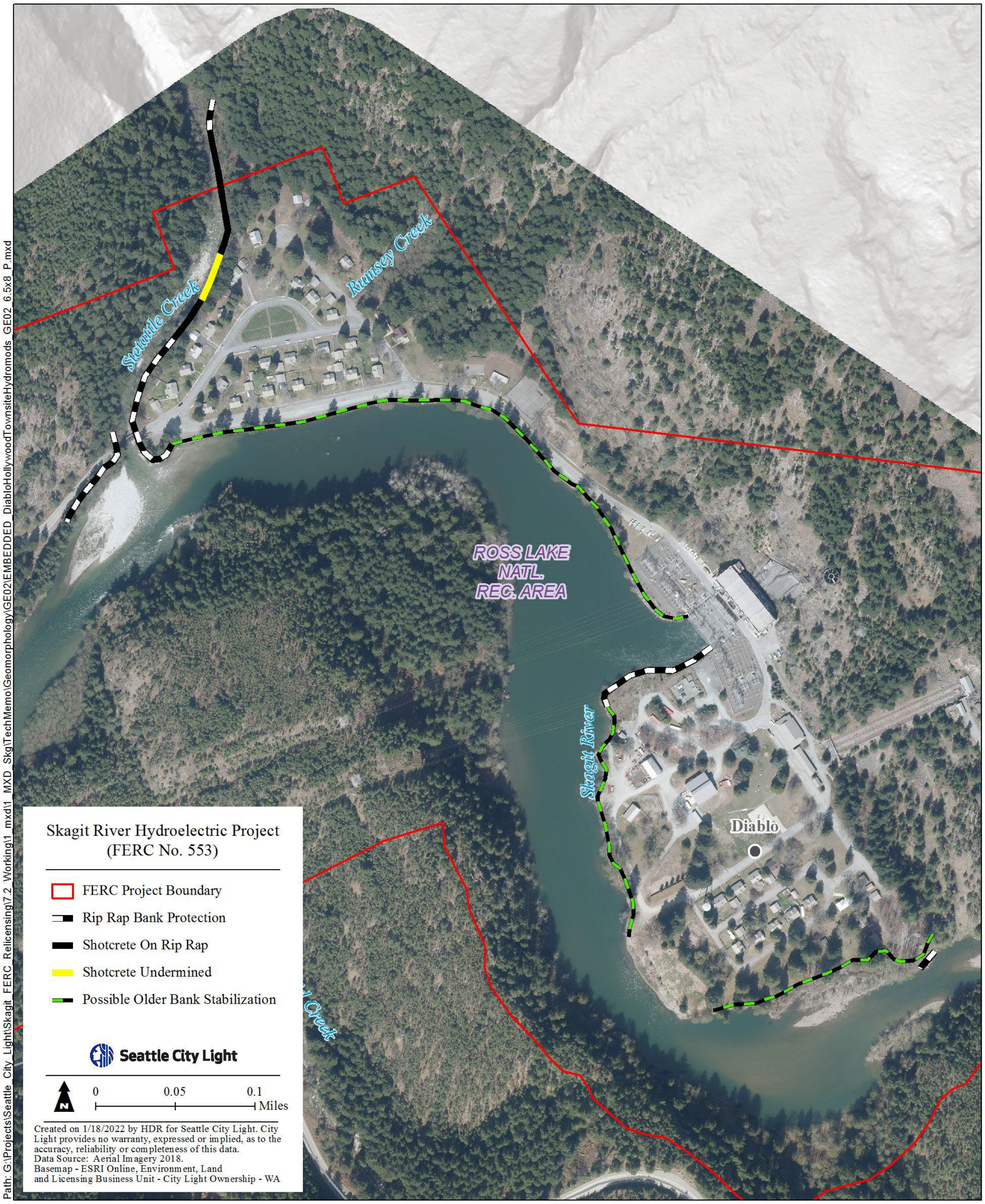

Figure 6.2-2. Diablo-Hollywood townsite area hydromodifications.

The Diablo townsite rip rap is in varying stages of revegetation. Rip rap around Diablo Powerhouse appears to be maintained most frequently and has minimal vegetation growth. A 75-foot-long section of rip rap at the toe of the bank at the upstream end of the Reflector Bar area protects the end of the road and is unvegetated. There is potential old bank stabilization, or at least large toe rocks, from the switchyard to the mouth of Stetattle Creek and on the west bank of Reflector Bar. These areas are covered with soil or vegetation, and any bank protection appears to be informal. Vegetation growth along the Hollywood Skagit River bank is sparse in many areas, and soil covers much of the bank (Figure 6.2-3). It is possible there is underlying rock on the southern end of Reflector Bar based on the steep bank visible on the LiDAR hillshade map, but the area is set back from the river channel and heavily vegetated; rip rap was not observed on the surface of the bank.

Figure 6.2-3. Hollywood (Diablo) area Skagit River bank condition showing possible older, informal bank protection.

Rip rap has been placed along a levee on the left bank of Stetattle Creek from the top of the alluvial fan to the mouth of the stream. Mature vegetation has become established on the levee and streambank. Approximately 750 feet of the rip rap has been reinforced with slush grout to further stabilize the bank and levee face (Figure 6.2-4). Growth of a mid-channel cobble/boulder bar approximately 600 feet upstream from the bridge crossing has resulted in erosion and undercutting of approximately 160 feet of the shotcrete (Figure 6.2-5). In one spot the slush grouted section has been undercut enough that a section has broken and dropped into the stream (Figure 6.2-6).

Figure 6.2-4. Stetattle Creek levee – slush-grouted section in foreground and rip rap in background.

Figure 6.2-5. Stetattle Creek levee bank shotcrete – undercut.

Figure 6.2-6. Stetattle Creek levee bank shotcrete – undercut and fallen.

6.3 Summary

In 2021, City Light's transmission line ROW vegetation, study route, and slash management practices were compiled. Current practices include trail and road maintenance (grading, improving gravel surfaces, and ditch cleaning); vegetation management techniques to keep trees/shrub heights short enough that limbs are more than 20 feet from transmission lines; brush cutting and mowing, slash management, and bank protection around transmission line towers.

Information on streambank conditions in Project townsites was also collected, including the presence and condition of hydromodifications (rip rap and slush-grouted rip rap). Hydromodifications in the Diablo/Hollywood areas include rip rap and older, more informal bank protection along portions of the Skagit River, and rip rap and shotcreted rip rap along the Stetattle Creek levee. Portions of the Stetattle Creek shotcrete are failing due to undercutting by the stream.

6.3.1 Status of June 9, 2021 Notice Pertaining to Channel Migration and Stream Crossings

As part of the June 9, 2021 Notice, several commitments were made by City Light to augment the Erosion and Geologic Hazards Study. The status of each of these commitments related to channel migration and stream crossings is summarized in Table 6.3-1.

Table 6.3-1. Status of channel migration and stream crossing modifications identified in the June 9, 2021 Notice.

Study Modifications identified in the June 9, 2021 Notice: As Written	Status
City Light proposes that the existing geographic scope is adequate to cover relevant geomorphic processes and controls at the reach level in order to screen for geomorphic impacts associated with the Project. SCL will confer with the LPs to determine whether there is a need at specific locations to adjust the geographic scope to implement this screening. At specific locations identified through the study that will require interventional management, SCL will commit to assess the risk to towers and facilities, watershed-scale influences on fluvial processes, potential channel changes, sediment delivery, and other elements through discussion with the LPs towards developing site specific plans.	The geographic scope of the study at specific locations is under discussion with LPs within resource workgroups.

6.3.2 Next Steps

The CMZ analysis and stream/riparian/bank condition field work will be completed in 2022 and reported in the USR. Deliverables for the CMZ analysis will include: CMZ GIS-based map and report sections analyzing potential channel migration effects on Project-related transmission towers, facilities, and study routes.

The deliverables for the stream/riparian/bank conditions will include:

- Report sections summarizing aquatic habitat and riparian conditions at the selected stream crossing locations; and
- A GIS-based map of locations of stream crossings affected by maintenance procedures.

7.0 VARIANCES FROM FERC-APPROVED STUDY PLAN AND PROPOSED MODIFICATIONS

There are no variances from or proposed modifications to the FERC-approved methodology for the Erosion and Geologic Hazards Study; however, to fulfill all study goals and objectives, field work will continue into 2022, which is a modification of the study plan schedule. City Light will provide a study report that includes a second year of study and reporting as part of the USR, which it will submit in March 2023.

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