GE-01 RESERVOIR SHORELINE EROSION 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

City Light....................Seattle City Light
CoSD..........................City of Seattle datum
FERC..........................Federal Energy Regulatory Commission
ft ....feet
GIS ....Geographic Information System
GPS ....Global Positioning System
ISR ....Initial Study Report
LiDAR........................Light Detection and Ranging
NAVD 88...................North American Vertical Datum of 1988
NPS ....National Park Service
PAD............................Pre-Application Document
Project ....Skagit River Hydroelectric Project
RSP ....Revised Study Plan
SPD ....Study Plan Determination
USGS .........................U.S. Geological Survey
USR............................Updated Study Report

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1.0 INTRODUCTION

The GE-01 Reservoir Shoreline Erosion 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 (which include the 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). The June 9, 2021 Notice included agreed to modifications to the Reservoir Shoreline Erosion Study.

In its July 16, 2021 Study Plan Determination (SPD), FERC approved the Reservoir Shoreline Erosion Study with modifications. Specifically, FERC modified the study by recommending that City Light complete a field inventory and erosion assessment at 10 Mile Island, Lightning Creek, Big Beaver, Rowland Creek, and Arctic Creek in February or March 2022 when Ross Lake is likely at its lowest elevation.

This interim report on the 2021 study efforts is being filed with FERC as part of City Light's Initial Study Report (ISR). City Light will perform additional work for this study in 2022 and include a report in the Updated Study Report (USR) in March 2023.

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

2.0 STUDY GOALS AND OBJECTIVES

The goals of the Reservoir Shoreline Erosion Study are to characterize existing areas of erosion along Project reservoir shorelines and to identify any Project-related factors resulting in erosion at each locale. The study results will facilitate City Light's development of erosion control or monitoring measures, as needed, where Project-related erosion is affecting resources of concern.

Specific objectives include:

- Update and review each reservoir erosion site identified in the 1990 reservoir erosion inventory (Riedel 1990) as well as any newly-identified reservoir erosion sites to identify ongoing areas of reservoir erosion along the shorelines of Ross Lake, Diablo Lake, and Gorge Lake.
- Identify types of erosion and factors (Project and non-Project) contributing to erosion at each location to help categorize areas with similar erosion patterns and rates.
- Estimate shoreline erosion rates to the extent possible at representative un-monitored sites based on existing measured erosion rates, aerial photographs and Light Detection and Ranging (LiDAR), and on-site evidence to better understand erosion rates and processes.
- Correlate existing erosion rate data collected at monitoring sites during the current Project license term and data collected at previously un-monitored sites (see previous bullet) with erosion site characteristics (e.g., underlying geology, slope, aspect, shoreline height, landform, type of erosion) to extrapolate and help estimate ongoing erosion rates at unmeasured sites.
- Evaluate the condition and effectiveness of existing shoreline erosion control measures.

As part of the June 9, 2021 Notice, City Light made the following commitment related to the Reservoir Erosion study: assess deposition and erosion in the drawdown zone. City Light clarified that mapping of the sediment and erosion deposition zone and tributaries are part of the existing scope of the studies (Reservoir Shoreline Erosion Study and GE-03 Sediment Deposition in Reservoirs Affecting Resource Areas of Concern Study [Sediment Deposition Study; City Light 2022b] and will be included in the USR).

3.0 STUDY AREA

The Reservoir Shoreline Erosion Study area includes shorelines at and near normal maximum water surface elevation of Ross Lake (within waters of the United States), Diablo Lake, and Gorge Lake, and riverine sections between the three lakes (Figure 3.0-1). All shorelines are within the FERC Project Boundary.

Five sites where Riedel measured the depth of erosion within the Ross Lake drawdown zone (Table 7 in Riedel 1990) have been added to the study area as recommended in FERC’s SPD to compare erosion as measured by stump/tree root exposure in the field in February, March, or April 2022 when Ross Lake is likely at its lowest elevation:

- 10 Mile Island;
- Lightning Creek;
- Big Beaver;
- Rowland Creek; and
- Arctic Creek.

In addition, the normal drawdown zone of Ross Lake is included in the study area where erosion and deposition mapping will take place in March/April 2022 to fulfill a commitment in the June 9, 2021 Notice.

There are locations along the reservoir shorelines, primarily adjacent to Project facilities, where past large rockfall or mass wasting features/hazards exist and have been documented as part of previous dam safety analyses. Rockfall and mass wasting features will be identified as part of the current (reservoir shoreline erosion) study but will be analyzed in more detail as part of the GE-02 Erosion and Geologic Hazards at Project Facilities and Transmission Line Right-Of-Way Study (City Light 2022a).

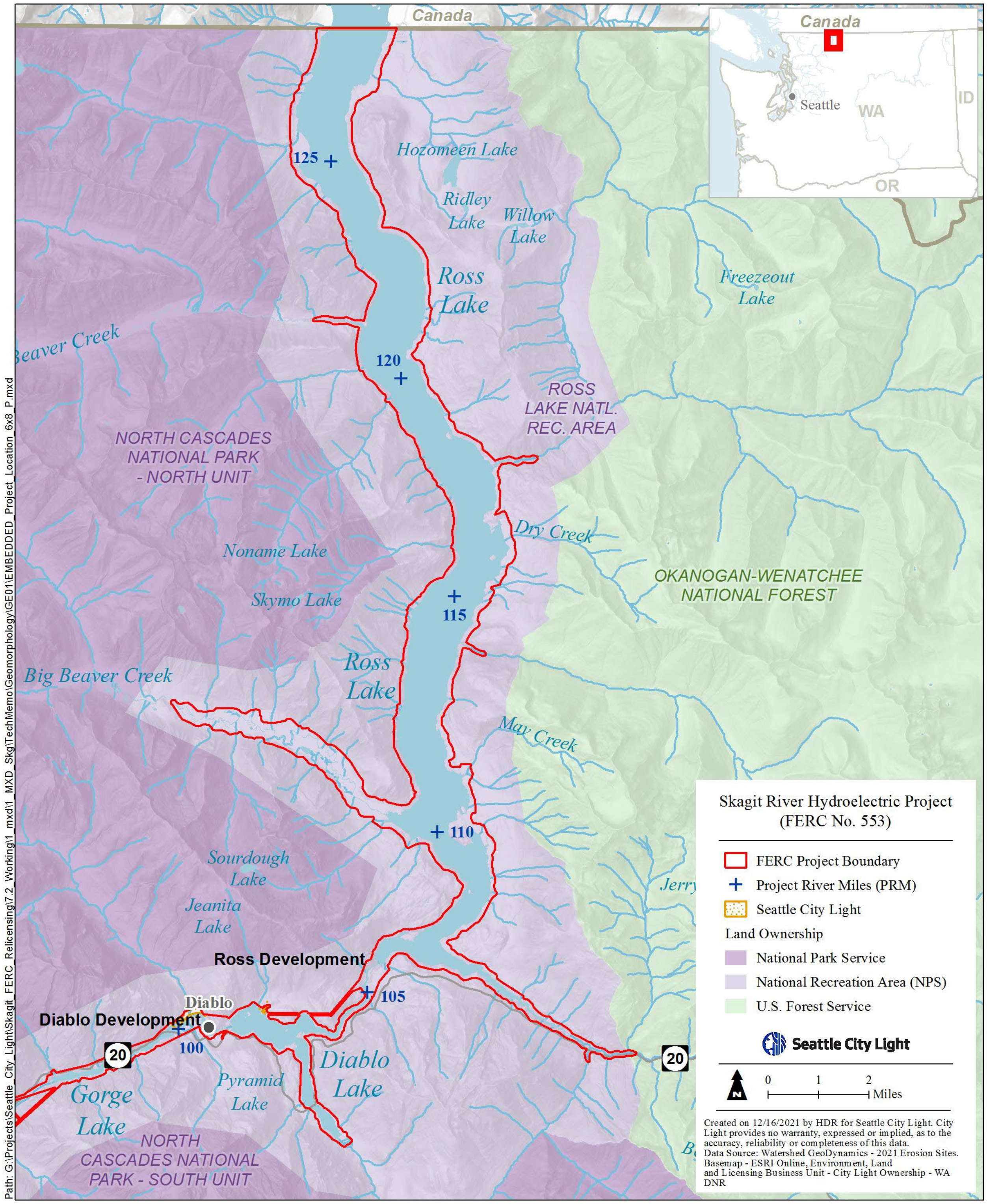


Figure 3.0-1. Reservoir erosion study area.

4.0 METHODS

The Reservoir Shoreline Erosion Study includes pre-field analysis of existing information, two seasons of field work to inventory existing areas of shoreline erosion, and post-field analysis and report writing. This interim study report includes a summary of the pre-field analysis of existing information and first season (2021) of field work. Work on this study will continue in 2022 as described in Section 6.1 of this study report.

4.1 Analysis of Existing Information

Relevant existing reservoir erosion information from NPS, LiDAR, landform mapping, geologic mapping, and aerial photographs were compiled for the reservoir erosion study area. Erosion areas from the 1990 reservoir shoreline erosion inventory were digitized to create a Geographic Information System (GIS) database so that past sites could be identified during the field inventory and compared to existing conditions at these locations. These steps were followed as listed in the RSP:

- Compile relevant existing reservoir erosion information from NPS, LiDAR, landform mapping, geologic mapping, and aerial photographs for the reservoir erosion study area.
- Digitize erosion areas from the 1990 reservoir erosion inventory (Riedel 1990) to create a GIS database so that past sites can be accurately identified during the field inventory and compared to new sites.
- Review existing NPS landform mapping and update landforms along reservoir shorelines if necessary, based on existing LiDAR. Update large shoreline landslide mapping from existing current LiDAR and aerial photographs as needed (note that this step was completed by NPS and the new landform mapping was obtained from NPS).
- If resolution is sufficient, estimate shoreline bank retreat rates using historic and current aerial photographs and/or LiDAR (see Section 4.3 of this study report).
- Prepare base maps to use for field inventory (laminated high-resolution prints of aerial photographs with past erosion areas identified).

4.2 Field Inventory

A field inventory of reservoir shoreline areas at or near normal maximum water surface elevation was conducted to identify, map, and collect information on the status of erosion areas along the shorelines of Ross and Diablo lakes. The inventory was conducted by boat and foot under near normal maximum water surface elevation conditions on the dates shown in Table 4.2-1. Water levels were rising during the Ross Lake inventory, but this did not affect results since the inventory was focused on the area near normal maximum water surface elevation. (Note that the Gorge Lake field inventory and erosion measurements at five sites within the Ross Lake drawdown zone will take place in 2022.)

Erosion locations were mapped on 2018 aerial photograph base maps which also included erosion sites identified during the 1990 erosion inventory (Riedel 1990). Locations and photographs of each erosion site were collected using ESRI Field Maps on an iPad connected to a Bad Elf GPS Pro GPS (Global Positioning System) receiver.

Table 4.2-1. Field data collection dates and reservoir elevations.[1]

Reservoir	Field Collection Date	Reservoir Elevation[2] (ft CoSD[3])
Ross	6/14/2021	1,583.63
Ross	6/15/2021	1,585.12
Ross	6/16/2021	1,586.23
Ross	6/17/2021	1,586.86
Ross	6/18/2021	1,587.51
Ross	6/19/2021	1,588.31
Ross	6/20/2021	1,589.11
Ross	6/21/2021	1,590.07
Ross	6/22/2021	1,591.27
Ross	6/23/2021	1,592.58
Ross	6/24/2021	1,593.83
Ross	6/25/2021	1,594.95
Ross	6/26/2021	1,596.32
Ross	6/27/2021	1,597.97
Ross	6/28/2021	1,599.46
Ross	6/29/2021	1,600.07
Ross	6/30/2021	1,600.36
Ross	9/1/2021	1,600.22
Ross	9/2/2021	1,600.09
Diablo	8/30/2021	1,200.16
Diablo	8/31/2021	1,200.46
Diablo	9/4/2021	1,200.38

1 Source: U.S. Geological Survey (USGS) National Water Information System: Web Interface. https://waterdata.usgs.gov/wa/nwis/uv?station=12175000 https://waterdata.usgs.gov/wa/nwis/uv?site_no=12176500, accessed 10/5/2021.
2 Normal maximum water surface elevation: Ross Lake = 1,602.5 ft CoSD; Diablo Lake = 1,205 ft CoSD
3 CoSD = City of Seattle datum.

An eroding area of at least 200 square feet was the minimum size included as an erosion site for practical purposes. For example, a bare bank that was 20 feet long and 10 feet high was included in the inventory, but a bare bank 10 feet long and 10 feet high was not. Sites smaller than 200 square feet exist but were not considered to be as critical to overall resource concerns due to their small size. In several places, banks had erosion in some locations interspersed with stable or bedrock areas. These eroding areas were grouped into a single erosion site, and it was noted approximately how much of the site length was eroding (e.g., 60 percent of total length was eroding, the remaining 40 percent of the length was stable). These locations are marked with a dashed line on map products to indicate that the erosion was not continuous along the length of the feature.

A unique identifier was assigned to each erosion site during the 2021 inventory. If the site was identified as part of the 1990 erosion inventory (Riedel 1990), the 1990 site number was also recorded on the data sheet for correlation between the two inventories. Relevant characteristics for each site were collected, including: eroding length; average bank height (or area as appropriate); disturbed and undisturbed bank gradient; bank composition (underlying geology); type of erosion process; vegetation characteristics (life form [e.g., tree, shrub, herbaceous, etc.], tree diameter, condition, age); factors that appear to be affecting erosion; any evidence of seepage/groundwater; condition, type, and effectiveness of any stabilization measures; any evidence of recent erosion (e.g., fresh or old tree fall, fresh soil at base of bluff); percent cover by type for the disturbed and surrounding undisturbed areas (tree, shrub, herbaceous, other such as rocks/moss); and large wood present on the bank or extending into the water at normal maximum water surface elevation. Data for each site was recorded on a field form shown in Attachment A. One or more photographs were taken of each erosion site. Field data were entered into an Excel file and erosion locations were digitized into GIS as line features as appropriate for each site based on locations identified in the field using GPS. The field data, including location, site characteristics, and photographs were compiled into a geodatabase. Aspect for each feature was determined using the Aspect function in GIS following the field work.

A field inventory and assessment of existing erosion control measures was also made including location, type, condition, effectiveness, and repair/maintenance needs. A photograph was taken of each erosion control site. This data is supplemental to surveys conducted by NPS staff of erosion control sites.

4.3 Shoreline Bank Retreat Rates

Shoreline position was digitized using 1990 and 2018 digital aerial photographs (Table 4.3-1). The edge of the shoreline was mapped as the edge of vegetation visible on the aerial photograph; the middle of tree crowns was used for the shoreline position if large trees were present at the edge of the shoreline, a convention that is used for mapping streambank position from aerial photographs. Resolution on the 2018 photographs was much higher than on the 1990 photographs (Table 4.3-1). To minimize mapping errors due to differences in resolution, the 2018 shoreline was mapped first and used as the basis for the 1990 mapping. Areas with marked shoreline position differences on the 1990 aerials were edited to the different 1990 shoreline location; areas with minimal difference in shoreline position were not changed on the 1990 shoreline layer. Shoreline position differences of 10 or more feet were able to be mapped, but shoreline position differences of less than 10 feet could not be reliably mapped due to the resolution of the 1990 aerials. Because there were so few locations where differences were noted between the 1990 and 2018 aerial photographs, no aerial photographs analysis of intervening years was made.

Table 4.3-1. Aerial photographs and LiDAR used in analysis.

Date	Image Type	Resolution	Notes
Aerial Photography			
1990	Orthophoto quads	1 meter	Source: U.S. Forest Service (1990) aerials. Update to 7.5-minute series various quads
2018	4 band RGB-NIR	6-inches	Source: Quantum Spatial 2018
LiDAR			
2018	LiDAR	1 meter	City Light topobathymetry Source: Quantum Spatial 2018

NPS has been measuring bank retreat in the field at five locations by measuring the distance between ground stakes and the edge of the bank. Measurements have been made in 1994, 1998, 2000, 2008, 2015, 2018, and 2021 (Figure 4.3-1; NPS 2020). NPS selected these locations to represent different underlying soil conditions, sides of the reservoir, and bank heights (Riedel 2021).

The shoreline retreat between 1990 and 2018 based on the aerial photograph analysis was measured in ArcMap to allow comparison of the field-measured and GIS-based bank retreat rate methods.

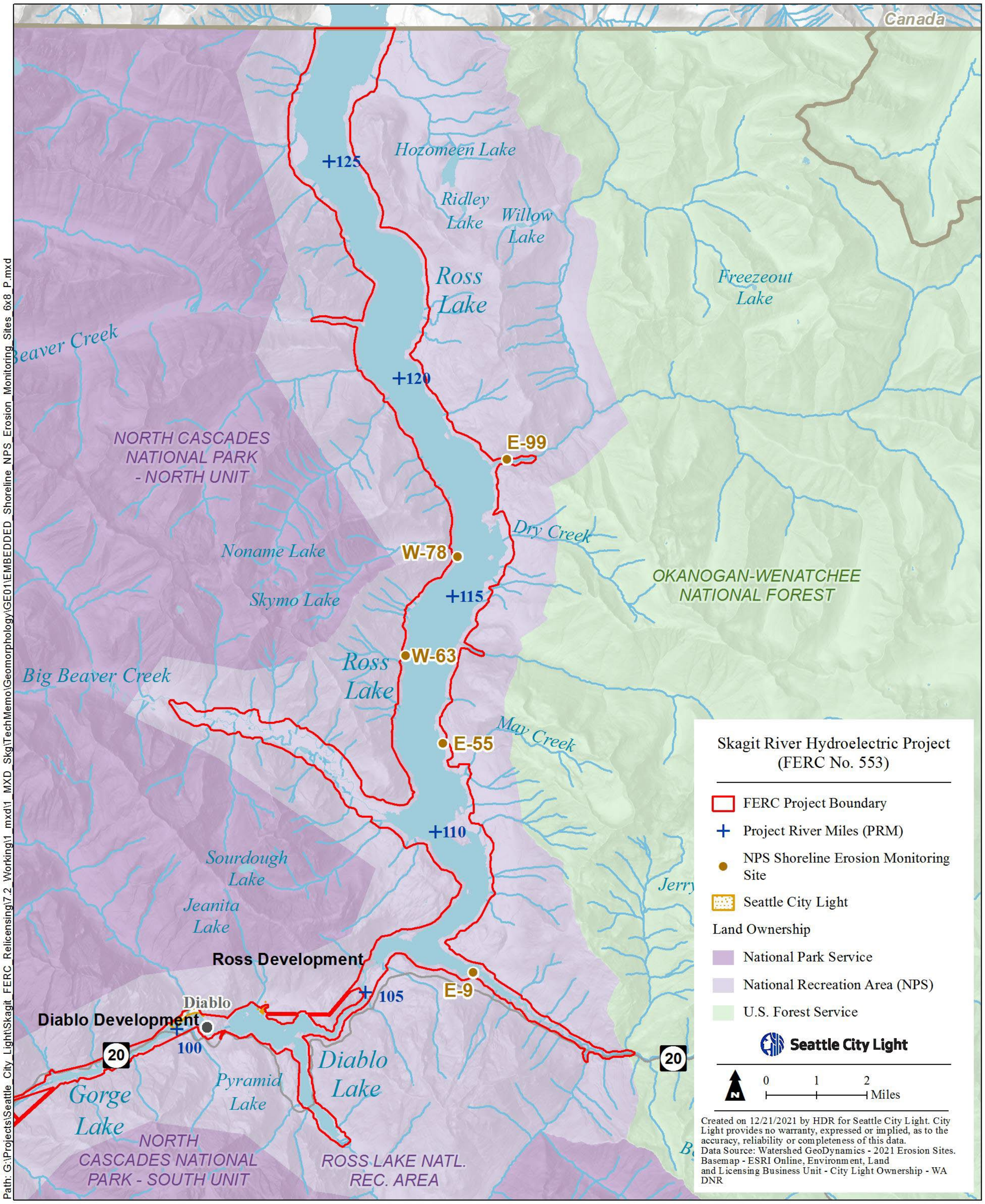


Figure 4.3-1. NPS reservoir erosion monitoring locations.

5.0 PRELIMINARY RESULTS

This interim study report includes results from Ross and Diablo lakes collected during the 2021 season field work. The Gorge reservoir shoreline erosion inventory and erosion measurements at the five sites in the Ross Lake drawdown zone specified in the FERC SPD will be collected in 2022 and reported on in the study report to be included in the USR.

5.1 Reservoir Setting

The three Project reservoirs are located in the North Cascades Range, a geomorphically active, geologically diverse, and climatically cool and wet area. Dominant factors affecting the erodibility of a given portion of reservoir shorelines include the underlying geologic/soil material (e.g., stable bedrock vs. easily erodible glacial outwash); vegetative cover/root mats; and erosive forces acting on the shoreline.

5.1.1 Geology and Landforms

The Ross, Diablo and Gorge lakes are located in the North Cascades Range. The North Cascades Range is an extremely complex mosaic of geologic terranes that were formed as the Pacific Ocean plate and the North American continental plate collided, breaking off pieces of volcanic island arcs, deep ocean sediments, ocean floor, continental rocks, and subcrustal mantle over the past 400 million years (Haugerud and Tabor 2009). These terranes were then uplifted, thrust on top of each other, eroded, or buried to further complicate the geology in the area. About 40 million years ago, volcanoes developed on this mosaic of terranes, covering some areas with lava and ash and intruding granite and granodiorite that were subsequently eroded and exposed.

During the Quaternary Period, starting about 2.6 million years ago, continental and alpine glaciers covered much of the area in the Project vicinity, with several major advances of thick continental ice from the north and smaller alpine glaciers originating from mountain peaks. The most recent continental glacial advance, culminating approximately 15,000 years ago, resulted in many of the surficial geologic features and deposits in the North Cascades.

5.1.1.1 Bedrock Geology

Bedrock geology along reservoir shorelines can be grouped into two major domains bounded by fault zones: the Metamorphic Core Domain of higher grade metamorphic rocks under the dams and transmission line from Marblemount to the middle of Ross Lake; and the Methow Domain under the northern part of Ross Lake as well as recent sediments that occur in all domains (Figure 5.1-1 and Table 5.1-1).

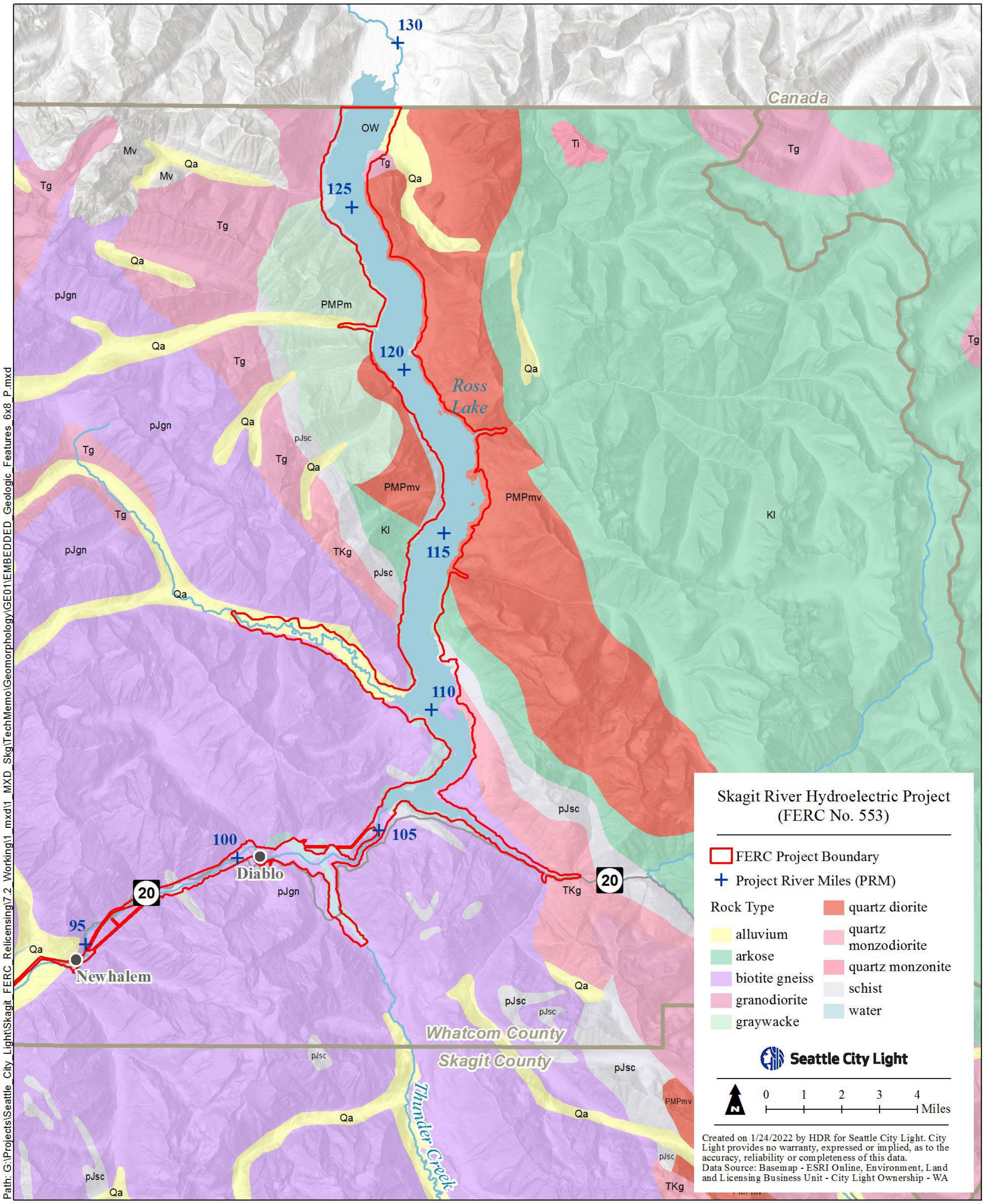


Figure 5.1-1. Geology along Project reservoirs.

Table 5.1-1. Major geologic units near reservoir shorelines.

Domain	Map Symbol	Name	Age	Description
Recent Sediments	Qa, Qad	River valley alluvium	Holocene, Pleistocene	Valley bottom sand and gravel in rivers and streams
	Qls	Landslide deposits	Holocene, Pleistocene, Tertiary	Rocks, soil, and debris derived from landslides
	Qvt, Qvr	Glacial till and outwash	Holocene, Pleistocene	Glacial deposits ranging from consolidated boulders, sand, gravel, and finer particles to sand and gravel deposits of glacial outwash rivers
Metamorphic Core	Kg	Granodiorite plutons	Cretaceous	Granodiorite and orthogneiss to tonalite plutons
	Kmd	Marblemount plutons	Cretaceous	Quartz diorite, metatonalite, gneiss with light colored dikes
	TKsg	Skagit Gneiss Complex	Tertiary to Cretaceous	Schist, amphibole, rare marble and ultramafic rocks intruded by sills of igneous rocks; metamorphosed to orthogneiss
	TKso	Othogneiss	Tertiary to Cretaceous	Gneissic hornblende-biotite tonalite
	TKgo	Granodioritic orthogneiss	Tertiary to Cretaceous	Granodioritic orthogneiss grading to tonalite
	TKns	Napeequa Schist	Tertiary to Cretaceous	Fine-grained hornblende-mica schist and amphibolite-quartz schist
	TKsx	Skymo Complex	Tertiary to Cretaceous	Metamorphosed gabbro and ultramafic rocks
	TKm	Metamorphosed rocks of the Methow Ocean	Tertiary to Cretaceous	Metamorphosed shale, sandstone, and conglomerate
Methow	Tcas	Intrusive rocks of the Snoqualmie family	Tertiary (Miocene and Oligocene)	Tonalite, granodiorite, granite, and rare gabbro
	Tcao	Volcanic and sedimentary rocks of the Ohanapecosh episode	Tertiary (Oligocene)	Basalt, andesite, and rhyolite
	MzPzh	Hozomeen Group	Mesozoic and Paleozoic	Basalt, sandstone, shale, and chert

Rocks of the Metamorphic Core Domain display high levels of metamorphism, and are resistant to weathering and erosion, resulting in the high peaks of the North Cascades. These geologic units include gneiss, orthogneiss, and schist that underlie the Project dams, Gorge Lake, Diablo Lake, and the southern part of Ross Lake. While resistant to erosion, the steep valleys formed in these hard rocks are subject to rockfalls, landslides, and avalanches. North of Ross Dam, rocks of the Skymo Complex and Methow Ocean metamorphic rocks form the shoreline of Ross Lake, and include metamorphosed units of gabbro, ultramafic rocks, shale, sandstone, and conglomerate.

Several areas of Tertiary intrusive volcanic rocks occur in the Metamorphic Core Domain and include granodiorite, orthogneiss, and quartz diorite.

Rocks of the Methow Domain around the northern part of Ross Lake include the Hozomeen Group as well as Tertiary volcanic intrusive and extrusive rocks. The Hozomeen Group consists of ocean-floor basalt, sandstone, shale, and chert.

5.1.1.2 Surficial Geology

Surficial geology around Project reservoirs includes Quaternary and Holocene glacial deposits, alluvial fan/debris cone deposits, and colluvium derived from local soils and underlying geologic units. These surficial materials are generally unconsolidated and subject to shoreline erosion. Unconsolidated alpine till (material deposited in contact with glacial ice), outwash (glacial river deposits), lacustrine (lake) deposits as well as stream alluvium and fine-grained colluvium are the most erodible units observed along reservoir shorelines. Consolidated till was observed in a few reservoir shoreline locations and was interpreted to have been overridden by thick glacial ice resulting in a compact deposit that was relatively resistant to erosion and formed vertical bluffs. Talus deposits, formed from rockfall under bedrock cliffs, were generally boulder- to cobble-sized and relatively resistant to erosion. Alluvial fan and debris fan deposits were rarely subject to shoreline erosion, likely due to the low gradient and coarse-grained nature of these deposits. Smaller thinner debris cone deposits at the base of small bedrock chutes were observed in several locations along portions of the reservoir in steep, narrow canyon areas (e.g., Diablo canyon, Thunder Creek canyon, Devil's canyon). These deposits were subject to shoreline erosion due to their precarious location on extremely steep canyon walls.

5.1.1.3 Landforms

Landforms have been mapped by NPS for areas within the Ross Lake National Recreation Area (Riedel et al. 2012 and updated by NPS 2021). Landform mapping provides information on surficial geologic features and processes by grouping areas of the landscape into units formed by discrete geologic processes. Landforms include features that are depositional in nature (e.g., moraines, alluvial fans) or erosional (e.g., horns, bedrock benches). Mapped landforms are shown on Figure 5.1-2.

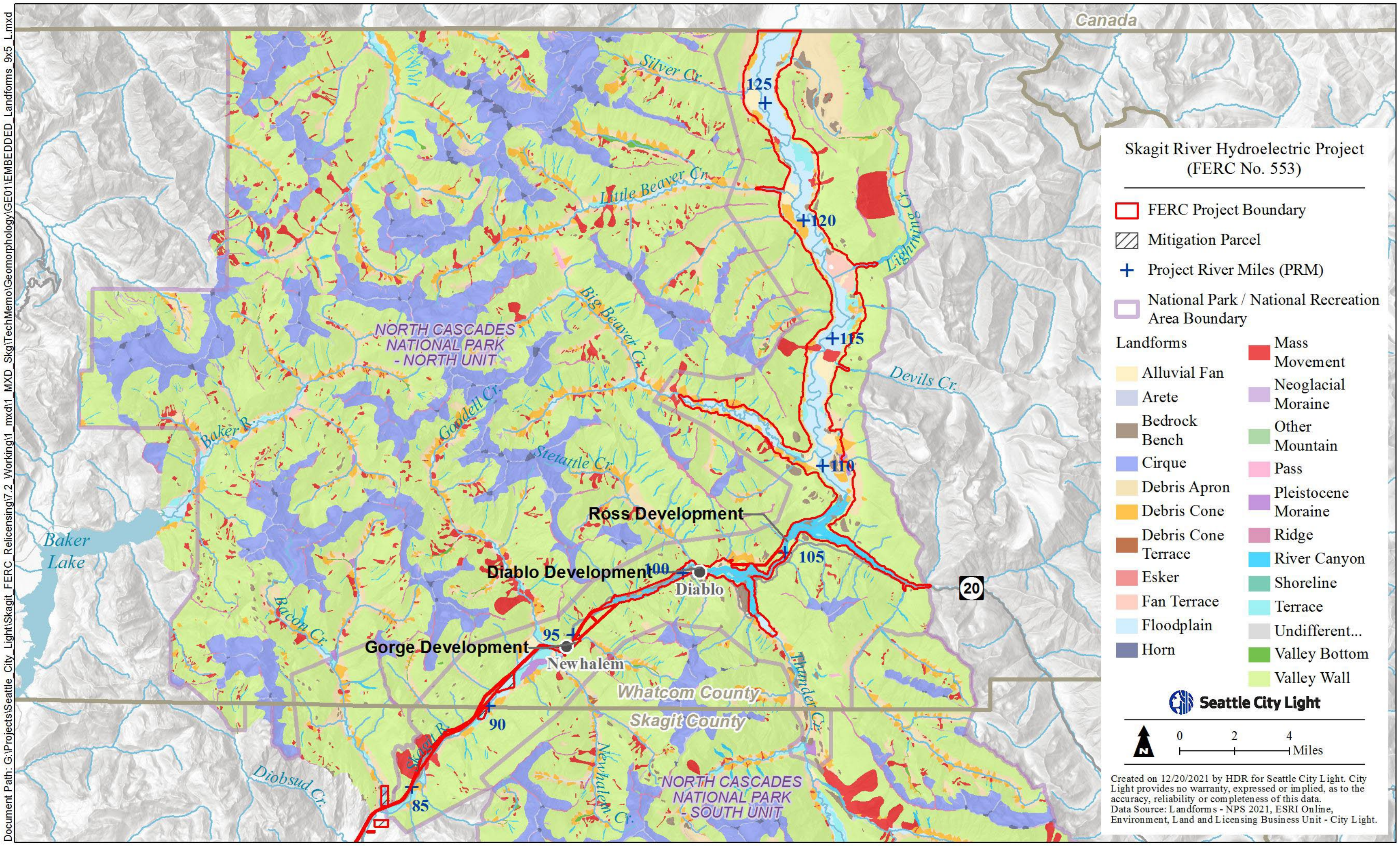


Figure 5.1-2. Landforms of the Project vicinity in the North Cascades National Park (NPS 2021).

The dominant landforms along Ross Lake are debris aprons with smaller lengths of river canyon, valley wall and debris cones (Table 5.1-2). Diablo and Gorge lake shorelines, in contrast, intersect primarily with river canyon landforms which tend to be bedrock-lined canyons and relatively stable.

Table 5.1-2. Landforms along reservoir shorelines.

Landform	Ross Lake		Diablo Lake		Gorge Lake	
	Length (ft)	Percent of total length	Length (ft)	Percent of total length	Length (ft)	Percent of total length
Alluvial fan	8,353	2%	2,512	2%	0	0%
Bedrock bench	16,480	5%	5,874	5%	1,486	3%
Debris apron	143,269	41%	11,308	11%	1,245	2%
Debris cone	38,539	11%	7,239	7%	5,902	10%
Fan terrace	1,434	0%	0	0%	0	0%
Floodplain	139	0%	12,358	12%	441	1%
Mass movement - debris avalanche	2,210	1%	0	0%	979	2%
Mass movement - debris torrent	0	0%	26	0%	0	0%
Mass movement - fall/topple	1,415	0%	673	1%	497	1%
Pleistocene moraine	3,121	1%	0	0%	0	0%
River canyon	79,979	23%	60,627	56%	44,036	75%
Terrace	12,815	4%	0	0%	3,177	5%
Undifferentiated	341	0%	0	0%	790	1%
Valley wall	41,917	12%	6,694	6%	486	1%

5.1.2 Vegetation

Project reservoirs lie within the Western Hemlock Zone and Pacific Silver Fir Zone of the Northern Cascades Physiographic Province (Franklin and Dyrness 1988). Forests are primarily mesic to wet and dominated by western hemlock (*Tsuga heterophylla*), Douglas-fir (*Pseudotsuga menziesii*), and western redcedar (*Thuja plicata*). In the rain shadow of the Pickett Range near Ross and Diablo lakes, the drier sites support lodgepole pine (*Pinus contorta* var. *latifolia*) and Ponderosa pine (*P. ponderosa*). Deciduous tree species occur as scattered individuals in mixed stands, as pure stands in early seral situations, and in wetland and riparian habitats. Deciduous shrub species occur in forest edges and understories, small avalanche shoots, and wetland communities. Deciduous species observed along reservoir shorelines included red alder (*Alnus rubra*), black cottonwood

(*Populus trichocarpa*), maples (*Acer* spp.), cherry (*Prunus* spp.), willows (*Salix* spp.), ocean spray (*Holodiscus discolor*), saskatoon (*Amalanchier alnifolia*), berries (*Rubus* spp.), and various forbs and grasses. Drier plant communities were generally found more commonly on south and west aspects on the eastern shore of Ross Lake. Refer to the TR-01 Vegetation Mapping and TR-02 Wetland Assessment study reports for more information on vegetation (City Light 2022c and 2022d).

5.1.3 Shoreline Erosion Processes

Six erosion processes were observed during the reservoir erosion inventory (Figure 5.1-3 through Figure 5.1-8):

- **Undercut banks** – Undercut banks occur in locations where the soil or rock is consolidated enough to form steep, sometimes nearly vertical banks. Erosion occurring at the base of a bank removes material, which results in an undercut bank. The undercutting proceeds until the weight of the overlying material exceeds the material strength, the bank topples or slides, and the process repeats. Roots and vegetation can provide additional strength to material at the top of the bank which often results in overhanging vegetation, roots, and a thin surficial soil layer that is bound by roots.
- **Shallow translational slides** – Shallow translational slides occur on steep banks. The surficial soil layer (generally 3 to 5 feet thick) slides down the slope. Shallow translational slides can be initiated by removal of toe support or by saturated soils within or at the base of the slope.
- **Slumping** – Slumping is a rotational mass movement of material that often occurs in more homogeneous, fine-grained sediments. Slumping can be initiated by removal of toe support or saturated soils within or at the base of the slope.
- **Raveling** – Raveling is a loose, grain-by-grain movement of material downslope. It often occurs in unconsolidated material on steep slopes when vegetative cover is removed.
- **Rills/gullies** – Rills and gullies form when surface runoff is concentrated and has enough energy to erode and transport soil particles.
- **Trampling** – Trampling occurs in locations where people congregate, trample vegetation, travel up and down shorelines, and scuff underlying soils.

Figure 5.1-3. Undercut bank erosion observed at Project reservoirs.

Figure 5.1-4. Shallow translational slide with raveling surface erosion observed at Project reservoirs.

Figure 5.1-5. Slumping erosion covered by trees that have slid observed at Project reservoirs.

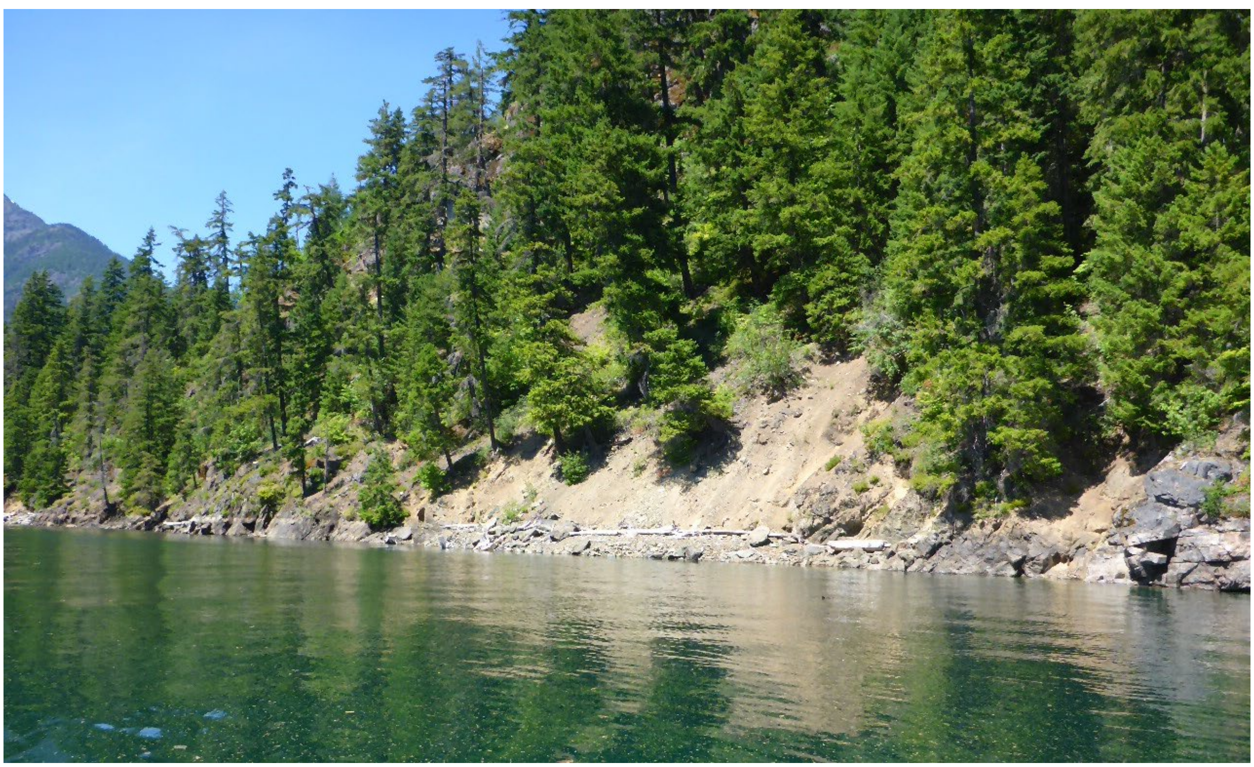


Figure 5.1-6. Raveling colluvium/till mix erosion observed at Project reservoirs.

Figure 5.1-7. Erosion and rilling from road runoff observed at Project reservoirs.

Figure 5.1-8. Trampling erosion at a camping area observed at Project reservoirs.

5.1.4 Erosive Forces Acting on Reservoir Shorelines

The primary erosive forces influencing reservoir shoreline erosion in the study area include wave action, reservoir fluctuations, frost heave/creep, saturated soils/seeps, recreation use/trampling, road runoff, and shoreline development.

5.1.4.1 Wave action

Wind waves and boat waves can cause erosion along the banks of the reservoir. Wave-related erosion in the reservoir can result in steep or undercut banks at the normal maximum water surface elevation level in areas of erodible materials. Waves also re-work material in the fluctuation zone as the reservoir level moves up and down as a result of Project operations.

The size of waves caused by motorboat wakes is related to the size, displacement, and speed of the boat with larger displacement and faster boats generally causing larger waves than smaller, slower boats. Hand-powered boats (kayaks, canoes) result in only minor wakes. Wave energy is also related to the distance from the boat to the shoreline; in narrow canyon areas boat wakes are concentrated and reflected back and forth off canyon walls resulting in higher wave energy compared to large, open areas where boats travel farther from the shoreline and wake energy can disperse through friction. Motorboat use in Ross Lake includes small motorboats rented at Ross Lake Resort; personal boats launched at ramps in the Hozomeen area; and City Light, NPS, and Border Patrol working boats and barges. The relatively large, wide lake area results in more dispersed boat wake energy on the Ross Lake shorelines. Diablo Lake is more accessible and has a higher density of boat traffic. Personal motorboats as well as City Light and NPS working boats, barges, and ferries/tour boats traverse the lake frequently, and boat travel through the canyon leading up to the Ross Powerhouse results in reflected wave energy in the canyon. Currently there is limited motorboat use in Gorge Lake due to the difficult boat launch conditions (shallow water and reservoir fluctuations make launching success unpredictable).

Wind-related wave size is driven by wind speed, direction, and fetch distance. Wind waves generally affect the shoreline toward which the wind is blowing at a given time. Wind waves are driven by storm activity as well as the general up-valley wind generated most summer afternoons by warmer conditions in Eastern Washington driving air from the cooler west side up the Skagit River Valley and through all three reservoirs. Wind waves are likely most dynamic along east- and west-facing shorelines in the wider areas of the reservoirs and along shorelines at bends in the reservoirs.

5.1.4.2 Reservoir fluctuations

Reservoir fluctuations influence shoreline erosion by moving the zone of erosive wave energy up and down across a shoreline. Water surface elevations in the three Project reservoirs vary seasonally (Ross Lake) and daily (Diablo and Gorge lakes) in response to inflow, outflow, and power needs and flood control rule curves. Lake elevation curves (2007-2019) and annual percent exceedance curves of water surface elevations for Ross Lake, Diablo Lake, and Gorge Lake from 1991 to 2018 are provided in Figure 5.1-9 through Figure 5.1-14. Exceedance values refer to the value that is exceeded for the specified percent of the time. For example, the 40 percent exceedance elevation in Ross Lake is 1,595.26 feet North American Vertical Datum of 1988 (NAVD 88) (1,589 feet CoSD), which means that the reservoir elevation was above this level 40 percent of the time for the period 1991–2018, and lower than this level 60 percent of the time.

Ross Lake is drawn down as much as 120 feet seasonally, with normal maximum water surface elevation generally maintained between July 31 and Labor Day each year. City Light typically begins drawing down Ross Lake shortly after Labor Day and maintains a drawdown through April 15, subject to flood control and other needs. Wave energy in Ross Lake follows this drawdown cycle, so waves impact the reservoir shoreline near the normal maximum water surface elevation during summer (generally between July 31 – Labor Day) and surfaces at lower elevations within the drawdown zone at other times of the year. Lengthy inundation during the growing season also restricts the establishment of stabilizing vegetation at or below normal maximum water surface elevation.

The primary function of Diablo Lake is to reregulate flows between the Ross and Gorge developments. The reservoir typically fluctuates only 4-5 feet daily, although drawdowns of 10-12 feet occur occasionally as needed for construction projects or maintenance. The primary function of Gorge Lake is to regulate downstream flows for fish protection. Gorge Lake is drawn down, via spill or generation, to provide some additional usable storage in advance of a predicted flood event. Both Diablo and Gorge lakes are maintained at or near normal maximum water surface elevation levels most of the time, so these reservoir shorelines are subject to wave energy the majority of the year.

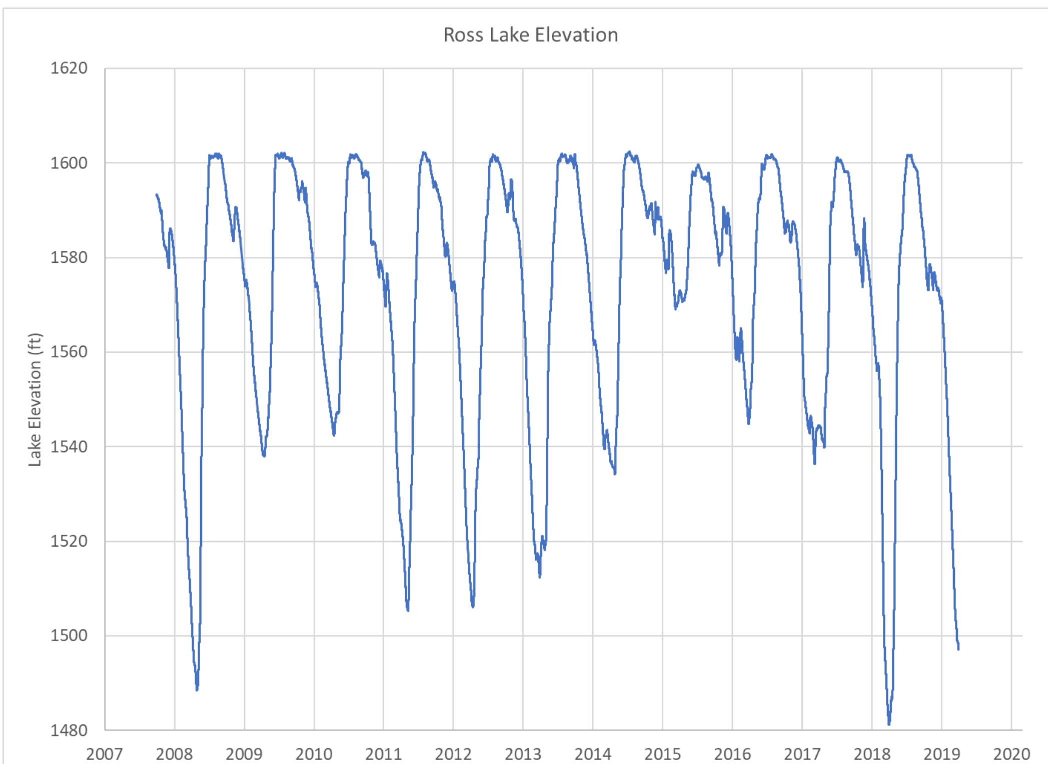


Figure 5.1-9. Ross Lake elevation, 2007-2019 (elevations in CoSD).

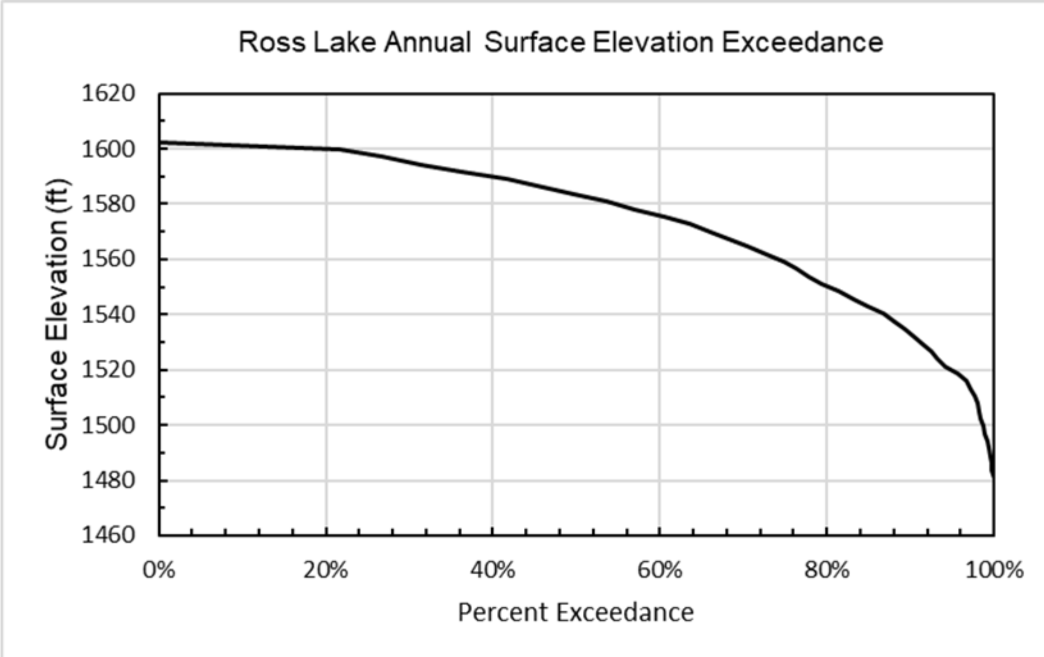


Figure 5.1-10. Annual percent exceedance curve of water surface elevations for Ross Lake, based on the period 1991-2018 (elevations in CoSD).

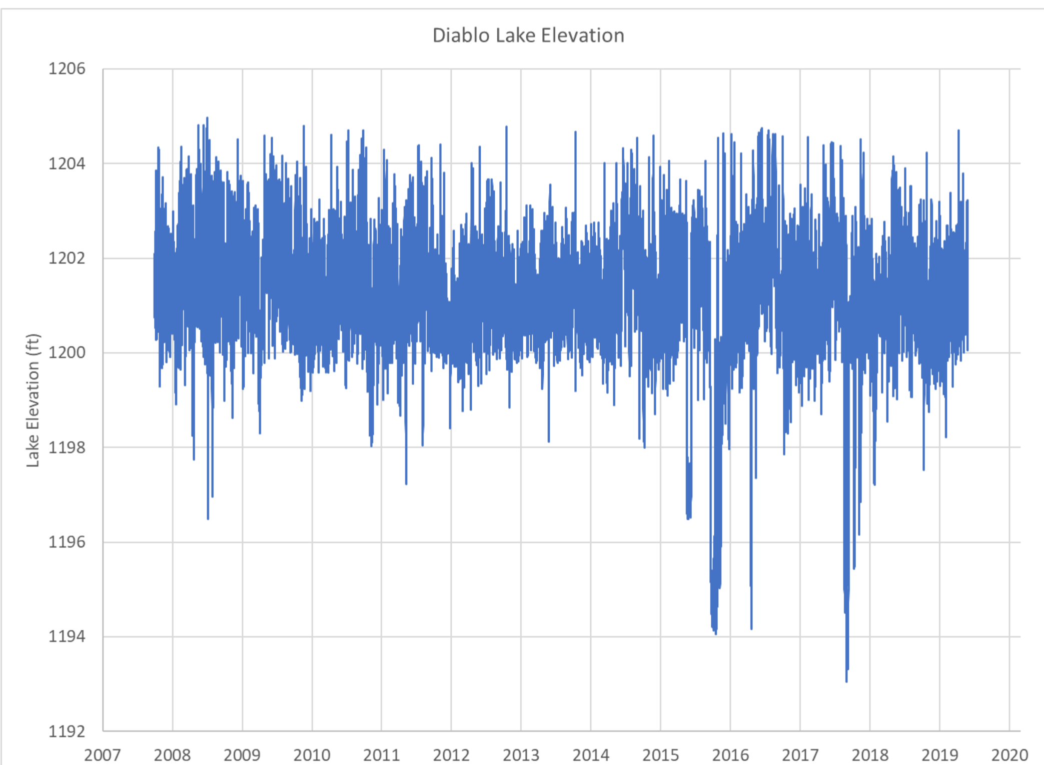


Figure 5.1-11. Diablo Lake elevation, 2007-2019 (elevations in CoSD).

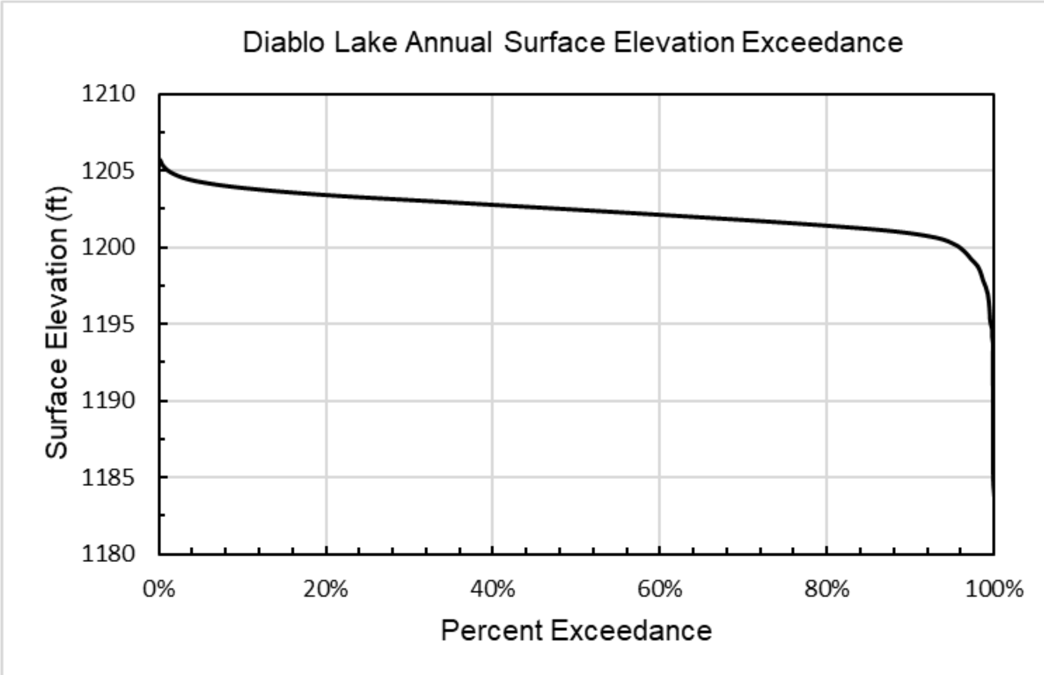


Figure 5.1-12. Annual percent exceedance curve of water surface elevations for Diablo Lake, based on the period 1991-2018 (elevations in CoSD).

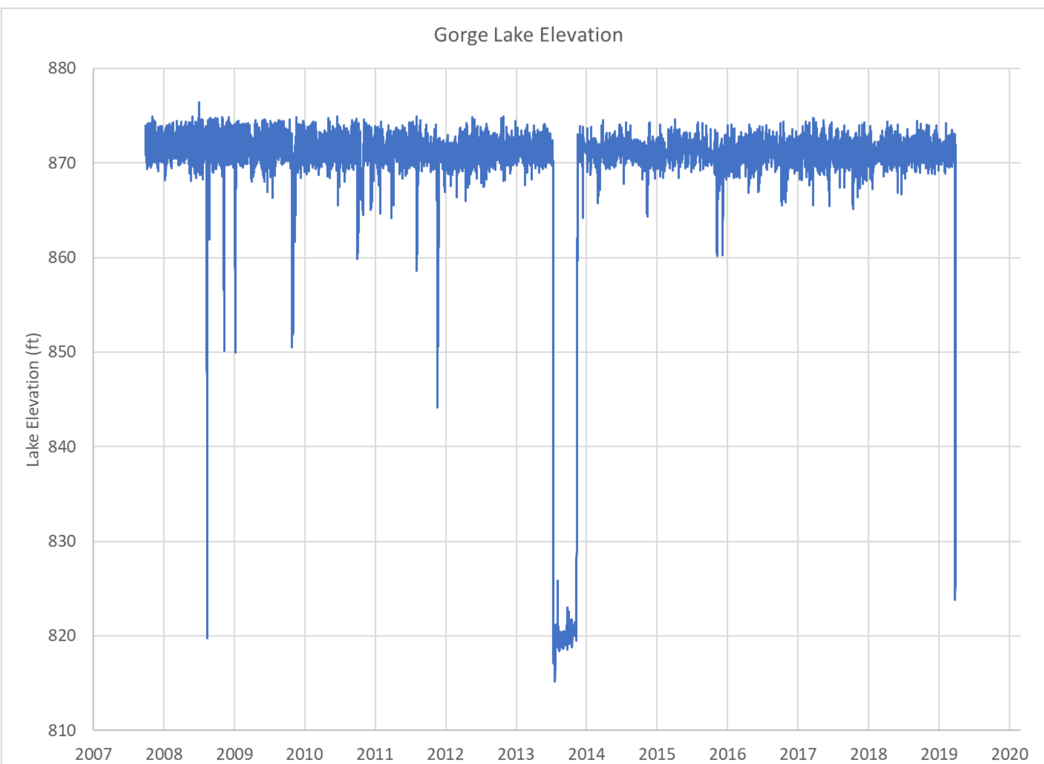


Figure 5.1-13. Gorge Lake elevation, 2007-2019 (elevations in CoSD).

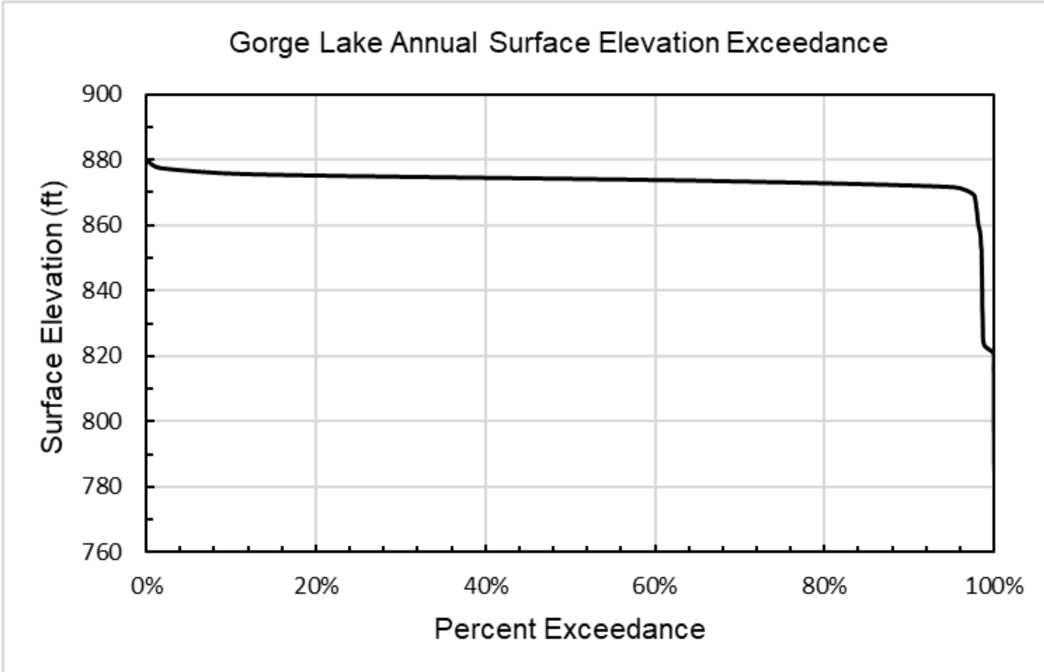


Figure 5.1-14. Annual percent exceedance curve of water surface elevations for Gorge Lake, based on the period 1991-2018 (elevations in CoSD).

5.1.4.3 Frost heave and frost creep

Frost heave occurs as the water in soil expands in response to freezing temperatures. Frost creep occurs during freeze-thaw cycles as soil freezes and expands, then moves downslope in response to gravity as it thaws. Evidence of frost heave was not observed during the field inventory, which took place during the summer, but it is likely that frost heave and frost creep occur in some of the exposed finer-grained sediments during the winter/spring months.

5.1.4.4 Saturated soils/Seeps

Seeps were observed in several locations, primarily in Ruby Arm of Ross Lake where layers of permeable outwash or till were on top of impermeable layers. Saturated soils are more prone to mass wasting (shallow slides and slumping) due to the elevated pore pressure which reduces friction between particles.

5.1.4.5 Recreational Use/Trampling

Foot traffic on reservoir banks can cause removal of stabilizing vegetation and disturbance of soil and rocks on the banks as people access the shoreline at campsites, docks, or dispersed use sites.

5.1.4.6 Road Runoff

Concentrated road runoff was observed at several locations in Diablo Lake and Ross Lake where the reservoir shoreline parallels roadways. Road runoff can cause gullying in unconsolidated deposits.

5.1.4.7 Shoreline Development

Shoreline development such as road fill, boat ramps, docks, or recreation facilities can result in over-steepened areas along the shoreline and/or vegetation removal that can cause shoreline erosion.

5.2 Previous Reservoir Shoreline Erosion Work

An inventory of shoreline conditions was completed for the current Project license (Riedel 1990). Riedel found that shorelines along the three Project reservoirs (Ross, Diablo, and Gorge lakes) are composed of a variety of materials based on the underlying geology and soils materials (Table 5.2-1). The majority of shoreline length on all three reservoirs consists of stable bedrock. Colluvium comprises another large portion of lake shoreline; colluvium can be unstable on steep slopes, but is thin, resulting in limited erosion volumes or shoreline retreat if the colluvium is underlain by bedrock. Lodgment till (till that is deposited subglacially) on shorelines in Ross and Diablo lakes is generally consolidated and more stable, but in some areas till is unconsolidated and erodible. Less stable deposits (outwash, unconsolidated areas of alluvial fan, alluvium, and landslide deposits) are subject to erosion.

Table 5.2-1. Length (ft) and percentage of shoreline composed of various materials.[1]

Material	Ross Lake	Diablo Lake	Gorge Lake
Bedrock	95,670 (33%)	38,090 (48%)	19,195 (40%)
Talus	18,440 (6%)	5,250 (7%)	8,365 (17%)
Colluvium	56,675 (20%)	8,990 (11%)	1,970 (4%)
Undifferentiated	0	985 (1%)	655 (1%)
Glacial Till	67,750 (23%)	8,840 (12%)	0
Outwash	8,675 (3%)	0	0
Alluvial Fan	28,740 (10%)	8,775 (11%)	7,710 (16%)
Alluvium	2,295 (<1%)	1,805 (2%)	1,970 (4%)
Landslide	2,625 (<1%)	0	0
Fill	5,415 (2%)	6,238 (8%)	8,040 (17%)
Total	**286,285**	**75,973**	**47,905**

1 Source: Riedel 1990.

As part of the 1990 shoreline condition inventory (Riedel 1990), information on bank material, bank slope, bluff height, sediment thickness, site aspect, and evidence of slope instability were recorded. Each eroding site was classified based on erosion type and extent using the following criteria:

- Class I – over 1,000 cubic feet of mass movement had or could occur.
- Class II – less than 1,000 cubic feet of mass movement had or could occur with bluffs over 3-5 feet.
- Class III – less than 1,000 cubic feet of mass movement had or could occur with bluffs less than 3-5 feet.

Shoreline conditions at Ross, Diablo, and Gorge lakes varied considerably at the time of the 1990 report (Table 5.2-2). Approximately 26 percent of the Ross Lake shoreline was eroding to some extent, with 2 percent of the shoreline in Class I sites, 14 percent in Class II sites, and 10 percent in Class III sites. Most of the erosion sites were located in the southern 17 miles of the reservoir where colluvium and glacial sediments occur on steep valley slopes. Bluff sites at the Class I areas ranged from 5 to over 50 feet in height. Dominant processes affecting erosion were waves (wind waves and boat waves) undercutting the base of bluffs; at some sites, freeze-thaw activity (observed by Riedel during early spring) or groundwater seepage contributed to instability.

Table 5.2-2. Number of erosion sites and length (ft) and percentage of total shoreline eroding in 1990.[1]

Erosion Class	Ross Lake	Diablo Lake	Gorge Lake
Class I	34 sites; 6,529 ft (2%)	5 sites; 1,801 ft (2%)	3 sites; 312 ft (<1%)
Class II	719 sites; 40,072 ft (14%)	17 sites; 2,310 ft (3%)	3 sites; 341 ft (<1%)
Class III	390 sites; 29,878 ft (10%)	56 sites; 3,927 ft (5%)	11 sites; 272 ft (<1%)
Total	**1,143 sites; 76,479 ft (26%)**	**78 sites; 8,038 ft (10%)**	**17 sites; 925 ft (2%)**

1 Source: Riedel 1990.

At Diablo Lake, 10 percent of the shoreline was eroding; much of the lake perimeter consists of relatively stable material (e.g., bedrock and talus). The eroding areas were glacial till and colluvium; wave action was the primary cause of erosion. The Gorge Lake shoreline is composed of very stable material; only 2 percent of the shoreline was eroding. Erosion along the Gorge Lake shoreline was primarily caused by mass wasting due to waves undercutting areas of erodible material.

5.3 2021 Field Inventory

The 2021 field inventory included the shorelines of Ross and Diablo lakes (Gorge Lake will be inventoried in 2022).

Detailed site data from the 1990 inventory were not included in the 1990 report, so comparisons were limited to data and maps presented in the 1990 report (Riedel 1990). Sites from the 1990 erosion inventory were correlated with 2021 sites as closely as possible during the field inventory to determine if sites were still eroding or had stabilized. The 1990 inventory locations were mapped on USGS quad sheets and were identified during the 2021 inventory by comparing locations digitized from the 1990 maps to 2021 GPS field positioning. If the 1990 mapped locations did not show evidence of erosion in 2021, they were marked “stable” in the field inventory/database. A correlation between the 1990 and 2021 erosion sites can be made on: (1) maps in Attachment B where both 1990 and 2021 sites are shown; and (2) the detailed 2021 inventory data (available upon request) which includes the corresponding 1990 site number.

Due to differences in how erosion sites were lumped or split in the field during both the 1990 and 2021 inventories, comparisons of eroding lengths between 1990 and 2021 inventories (rather than number of sites) are most appropriate. Note that the number of sites listed in the 1990 data table (see Table 5.2-2 above) on Ross Lake (1,143 sites) is appreciably more sites than mapped on the

1990 maps (337 sites) due to combining of sites in Ross Lake by Riedel (1990). The number of sites in Diablo and Gorge lakes match between the 1990 tables and maps.

Note also that total shoreline length in 2021 was based on a GIS analysis of the higher resolution 2018 LiDAR data at normal maximum water surface elevation and included many small bays and promontories that were not included in the methods used to determine shoreline length in 1990 (Riedel 1990 page 37). Total shoreline length measured using the 1990 methods (measured from 1:24,000 scale USGS maps) was 286,285 feet in Ross Lake and 75,973 feet in Diablo Lake. Total shoreline length measured using the 2021 methods (measured based on 2018 LiDAR) was 397,848 feet in Ross Lake and 107,282 feet in Diablo Lake.

5.3.1 Reservoir Shoreline Erosion Sites

The reservoir erosion inventory conducted in 2021 identified a total of 306 erosion sites covering 74,272 feet (19 percent) of reservoir shoreline length in Ross Lake and 43 sites (4,556 feet or 4 percent of shoreline length) in Diablo Lake (Figure 5.3-1 through Figure 5.3-5 and Attachment B of this study report; detailed data available upon request). In Ross Lake, 87 of the sites shown on the 1990 map were stabilized and 79 new sites were identified. In Diablo Lake, 49 of the 1990 sites were stabilized and 15 new sites were mapped. Stabilized sites include those where erosion control measures have been implemented and sites that have re-vegetated.

Erosion banks were classified by the primary type of erosion observed. In 2021, undercut banks were the primary type of erosion in Ross Lake (86 percent of eroding length) with raveling (12 percent) and slumps/shallow slides (3 percent) comprising the remainder of the banks. Note that the erosion mechanism on undercut banks is by wave erosion of the toe of the slope followed by failure of the overlying material, most likely block failure or slumping. The majority of the undercut banks are in relatively consolidated deposits with an overlying mantle of vegetation/roots. On Diablo Lake, erosion mechanisms included undercut banks (48 percent of eroding length) and raveling (44 percent) with slumps and shallow slides on 8 percent of the eroding length. The higher proportion of raveling on Diablo Lake is likely due to the bank composition; much of Diablo Lake is situated in a narrower canyon with debris cones and shallow colluvium that are subject to ravel.

Eroding areas were classified by bank height (Table 5.3-1), which was measured as height of bank above normal maximum water surface elevation. Bank heights ranged from 3 feet up to 150 feet at one large slide location. In both Ross and Diablo lakes, the majority of eroding shorelines were 5-15 feet high. Higher bank heights are generally indicative of higher volumes of past erosion, although in a few areas of raveling, thin layers of colluvium are raveling far up the slope and result in a high bank height without a large volume of past erosion.

Table 5.3-1. Number of erosion sites and length (ft) and percentage of total shoreline eroding in 2021 by bank height category.

Bank Height Category	Ross Lake	Diablo Lake	Gorge Lake
Over 15 feet	76 sites; 18,684 ft (5%)	13 sites; 1,164 (1%)	Survey not yet completed
5-15 feet	166 sites; 43,492 ft (11%)	30 sites; 3,392 (3%)	
Up to 5 feet	61 sites; 12,096 ft (3%)	0	
Total	**306 sites; 74,272 ft (19%)**	**43 sites; 4,556 (4%)**	

The geologic conditions underlying the shoreline greatly influence the erodibility of the bank. Areas underlain by competent bedrock are not erodible; those underlain by unconsolidated deposits are most erodible. Many of the erosion sites in both Ross and Diablo lakes had a mix of unconsolidated and difficult-to-differentiate loose till, colluvium, and outwash—in these locations a primary geologic type was chosen and second and third geologic types were also recorded. In some locations, the till was consolidated (e.g., lodgment till) and quite resistant to erosion, forming caves and vertical banks. In Ross Lake, till and colluvium dominated areas with eroding banks (96 percent of eroding length). Small amounts of talus on debris cones were also eroding, primarily along the edges of the cones. In Diablo Lake, till and colluvium dominated eroding banks (84 percent of eroding length). Road fill underlay 10 percent of the eroding banks with 4 percent talus and 2 percent stream alluvium.

On both Ross and Diablo lakes, the primary cause of erosion at sites is wave action that removes material at the toe of banks and transports it down into the lake as reservoir water surface elevations fluctuate. As noted in the 1990 report, this movement of material from the toe of the bank during reservoir fluctuations does not allow a stable shoreline to develop, particularly in areas where there is a steep slope below the eroding bluff. The seasonal reservoir fluctuations in Ross Lake are likely a contributing factor to the ongoing shoreline erosion—there was little reduction in total eroding shoreline length between the 1990 and 2021 inventory in Ross Lake (3 percent decrease) compared to Diablo Lake, which has relatively stable water surface elevations and had a 76 percent decrease in length of eroding shoreline.

In a few locations, recreational use, road runoff, shoreline development, and seepage contributed to bank erosion. It is likely that freeze-thaw activity also contributes to erosion, but since the sites were visited in the summer this mechanism was not observed directly.

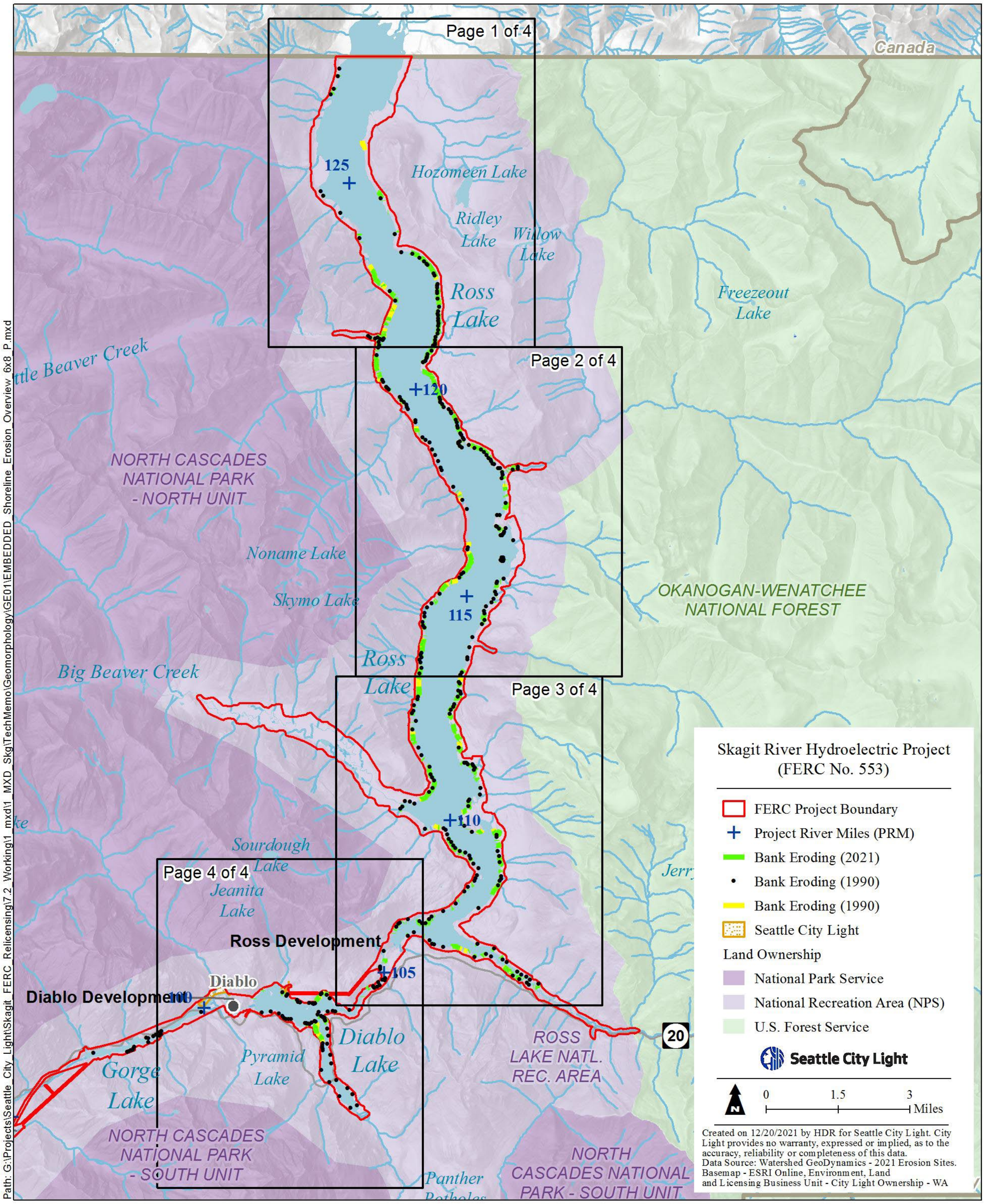


Figure 5.3-1. Reservoir shoreline erosion sites, 2021.

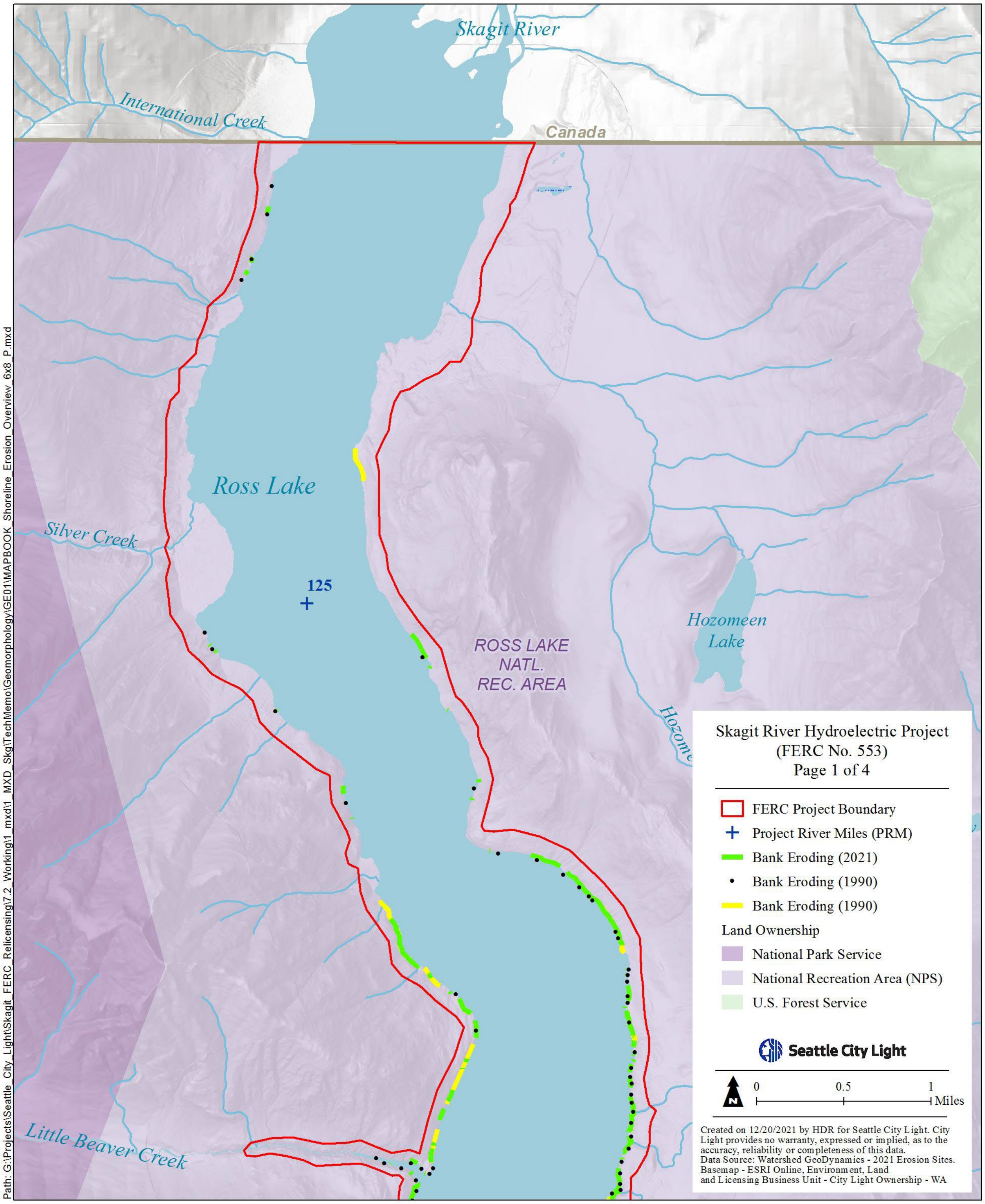


Figure 5.3-2. Reservoir shoreline erosion sites upper Ross Lake, 2021.

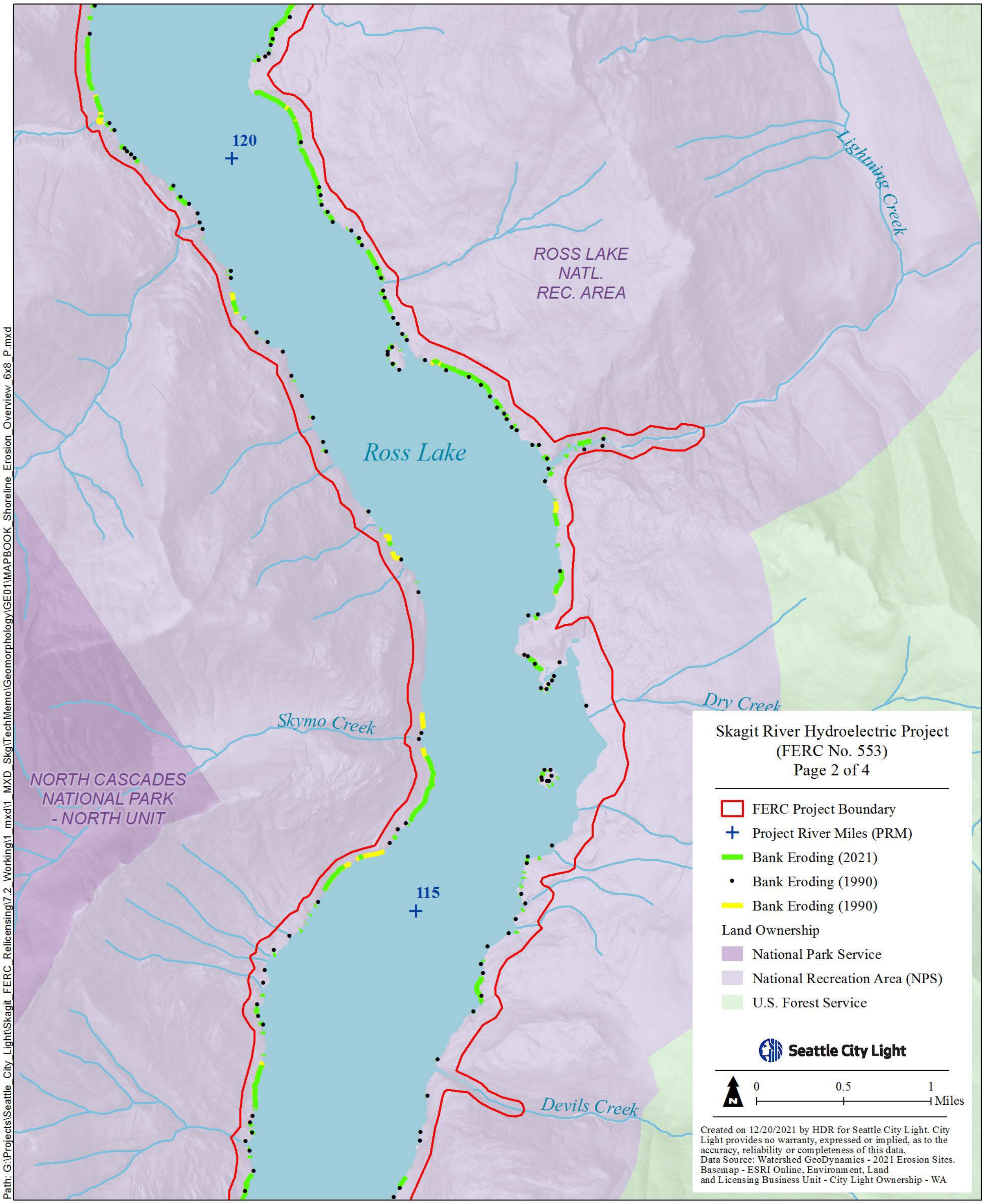


Figure 5.3-3. Reservoir shoreline erosion sites central Ross Lake, 2021.

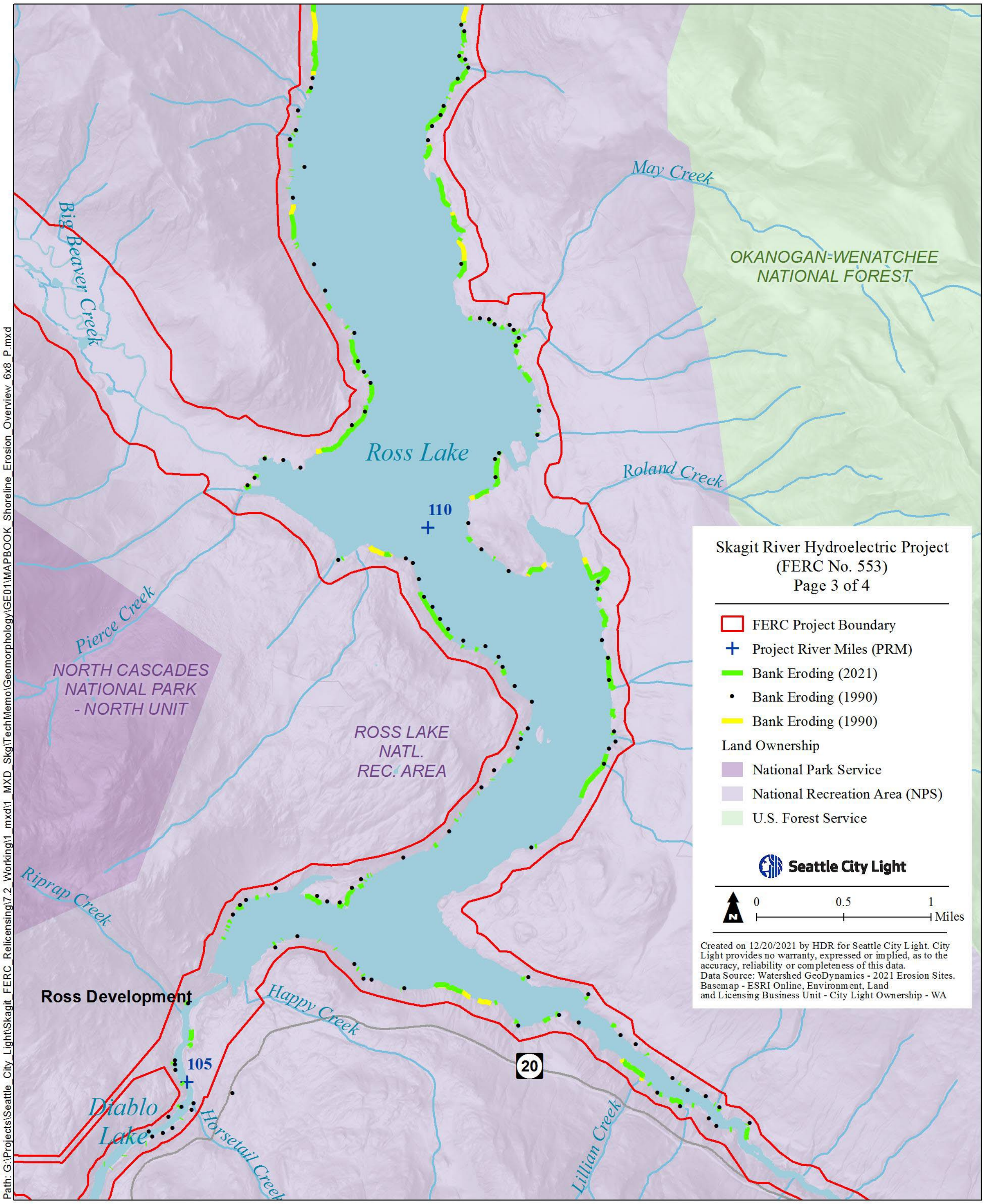


Figure 5.3-4. Reservoir shoreline erosion sites lower Ross Lake, 2021.

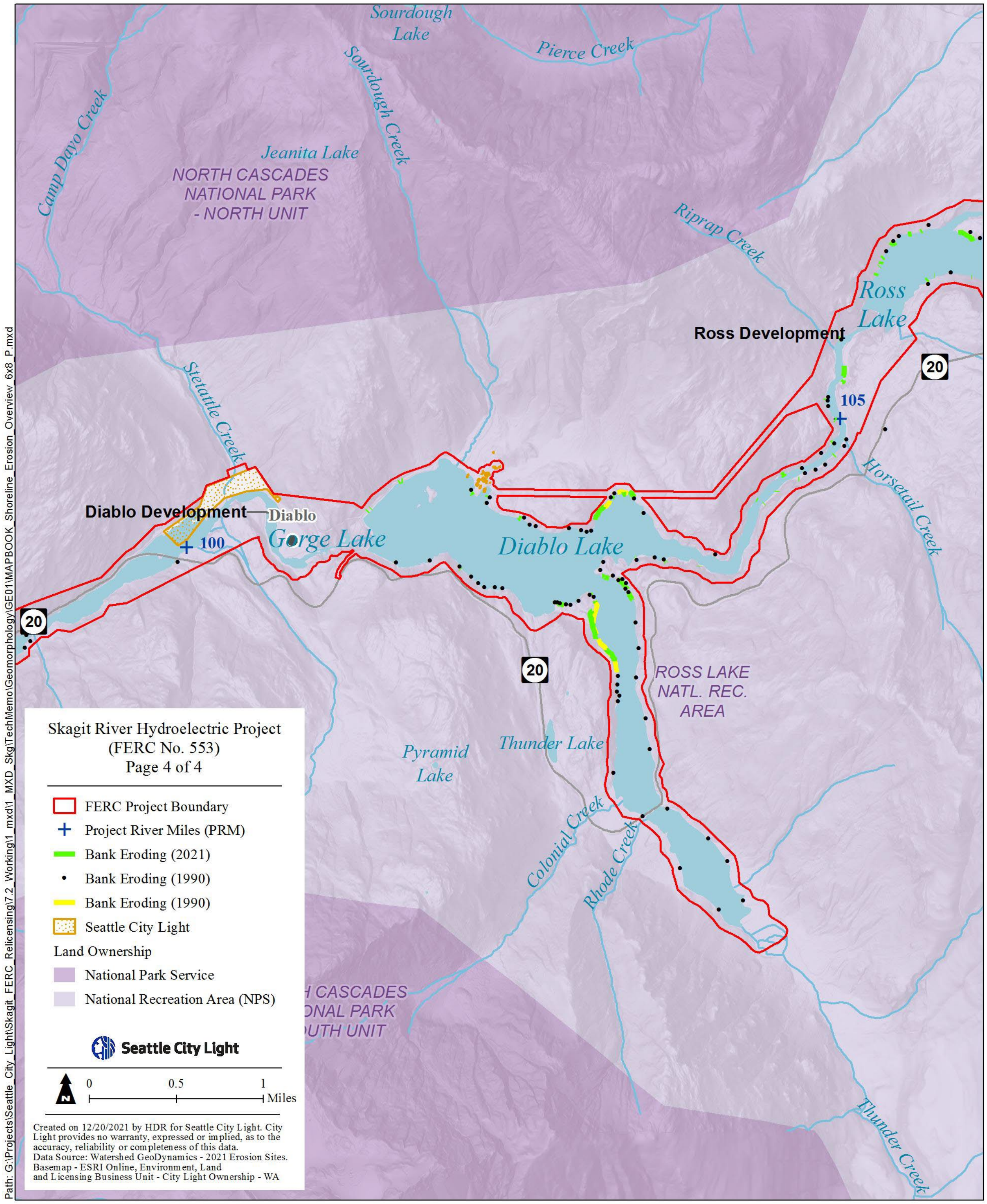


Figure 5.3-5. **Reservoir shoreline erosion sites Diablo Lake, 2021.**

5.3.2 Current Status of Sites with Existing Erosion Control Measures

Thirty-two sites where erosion control measures have been implemented were evaluated as part of the reservoir shoreline erosion inventory—29 sites on Ross Lake and three sites on Diablo Lake (Figure 5.3-6). No sites are located on Gorge Lake. Observations made at each site are included in Table 5.3-2. Erosion control measures included installation of rock walls, rock stairs to access the lake, log walls, wood cribbing, and rerouted sections of trails and log booms at boat-in campsites, along trails, and at other recreation facilities (trailheads, docks). Generally, the erosion control measures are in good condition and continue to function to minimize erosion with only minor maintenance required, such as providing fill around the base rocks at walls or dock footings. Three sites need major repairs, including McMillan Campsite (site E-40; rock wall is failing); the Desolation Trailhead (site E-150; rock wall has almost totally failed and is eroding), and the rock wall and stairs at Little Beaver Campsite (site W-124 needs base support). NPS conducts biennial erosion control and revegetation surveys in more detail and files the resulting reports with FERC. The most recent report covered the 2018-2019 period (NPS 2019); the next survey was scheduled for completion in 2021 (results are forthcoming at this time).

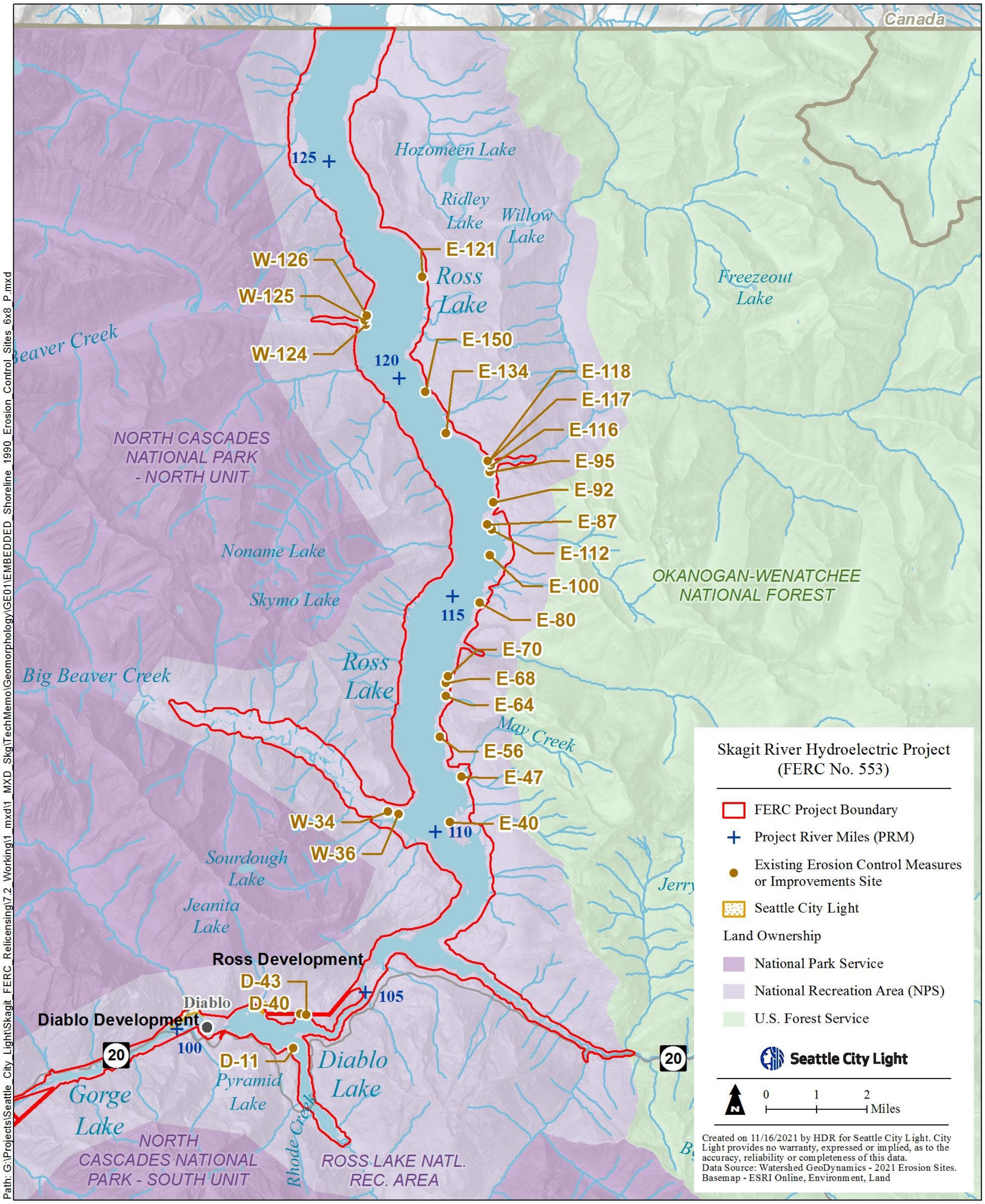


Figure 5.3-6. Existing erosion control site locations.

Table 5.3-2. Status of sites with existing erosion control measures or improvements.[1]

Reservoir	1990 Site Number	Name and Erosion Control Method	Year Constructed	Condition Assessment Summer 2021
Ross	E-40	McMillian - rock wall 33ft x 3ft	2004	Rock wall is a jumble (failing) but still providing erosion protection.
Ross	E-47	May Creek - rock wall 39ft x 4.5ft (north of dock) 4ft x 4.5, (south of dock)	2002	North side of wall needs fill around base rocks. South side good.
Ross	E-56	Rainbow Point - rock wall 170ft x 4ft	N/A	Not found. Note that there is piping of sediment from behind the Rainbow Point dock footings
Ross	E-64	East Bank Trail - reroute 120ft x 3ft (height estimated)	2003	Not visited.
Ross	E-68	East Bank Trail - rock wall 80ft x 4ft	2003	Not found.
Ross	E-70 (A-1)	East Bank Trail - cribbing 30ft x 60ft	1995	Cribbing in good condition.
Ross	E-70 (A-lA)	East Bank Trail - cribbing	1997-98	Cribbing in good condition.
Ross	E-70 (A-2)	East Bank trail - cribbing upper tier: 35ft x 6ft Lower tier: 30ft x 6ft	1996-97	Cribbing in good condition.
Ross	E-70 (A-3)	East Bank trail - cribbing 100ft x 15ft	1998	Cribbing in good condition.
Ross	E-70 (A-4)	East Bank trail - cribbing 45ft x 25ft	2001	Cribbing in good condition.
Ross	E-70 (A-5)	East Bank trail - cribbing 30ft x 3ft and 50ft x 10ft; also 40ft x 5ft mid-section	1995	Cribbing in good condition.
Ross	E-70 (A-5A)	East Bank trail - cribbing	1997	Cribbing in good condition.
Ross	E-70 (A-6)	East Bank trail - cribbing No rebuild, only reveg. 2000 sq ft	2000-2001	Cribbing in good condition.
Ross	E-80 (A)	Devils Junction - rock wall 103ft x 4.5ft	1992	Cribbing in good condition.
Ross	E-80 (B)	Devils Junction - rock wall44ft x 2 to 3ft	2004	Cribbing in good condition.
Ross	E-100	10 Mile - rock wall and logs 54ft x 3.5ft (E of NE point) 60ft x 4ft (W of N point)	2001	Walls in good shape.
Ross	E-112	Dry Creek - rock wall & logs 23ft x 3ft (SE corner of campground) 45ft x 4.5ft (S shore of campground)	1999	Rock wall in good condition but could use fill around base rocks.
Ross	E-87	Ponderosa - rock wall 141ft x 5ft	2003	Wall to south side of stairs needs fill around base rocks.

Reservoir	1990 Site Number	Name and Erosion Control Method	Year Constructed	Condition Assessment Summer 2021
Ross	E-92	Lodgepole - two rock walls 10ft x 3- 4ft	2004	Walls not found; site eroding.
Ross	E-95	Lightning Horse - rock wall 287ft x 4ft faced with 2-3ft diameter rocks	1998-99	Wall looks to be in good shape but could use fill around base rocks in a few spots.
Ross	E-116	Lightning Trail - reroute about 350ft long	unknown	Trail re-route not found; large wood anchored along shoreline.
Ross	E-117	Lightning Trail - rock wall 60ft x 2 to 3ft	2000	New section of wall is in good shape; old section of wall is failing in spots because rocks are too small.
Ross	E-118A	Lightning Camp - log wall Two 20ft x 1ft walls	2000	In good shape; accumulating wood at base of wall.
Ross	E-118B	Light Camp - rock wall 45ft x 1ft	2000	In good shape; accumulating wood at base of wall.
Ross	E-134A	Cat Island - rock wall 18ft x <2ft	2000	Wall generally in good shape, but a few rocks fallen off wall on east end. Logs cabled parallel to shoreline.
Ross	E-134B	Cat Island - rock wall 50ft x 6ft (W of dock) 68ft x 3.5ft (Further W of bedrock)	2001	Wall in good shape. Base of dock support is being undermined by waves.
Ross	E-150	Desolation Peak Trailhead rock wall	unknown	Rock wall has failed; not long enough, eroding.
Ross	E-181	Boundary bay - rock wall 155ftx 4 to 5ft	1993	Needs fill around base rocks in several locations. Raveling on north end of wall.
Ross	W-34	Big Beaver trail - rock wall 200ft x 3ft	1996	Wall generally in good shape. Needs fill around base rocks on east end.
Ross	W-36	Big Beaver - rock wall 50ft x 2ft	2002	In good shape.
Ross	W-124	Little Beaver - rock wall, steps, stairs are 25ft section	1998	Rock wall and dock anchor are being undermined by wave action. Stairs are raveling.
Ross	W-125	Little Beaver - rock wall 70ft x 5 to 6ft	NA	Rock wall not found. Log boom parallel to shore.
Ross	W-126	Little Beaver Trail - cribbing and dock removal	NA	Not removed yet. Cribbing failing.
Diablo	D-11	Thunder Point - rock wall 290ft x 2 to 3ft	2005	Needs fill around base rocks along wall. Dock anchor wall being undermined.
Diablo	D-40	Power Line - rock & log boom 93ft x 2-3ft	2005	Log boom in good shape. Did not see wall; area not eroding.
Diablo	D-43	Buster Brown - rock wall 100' x3.5'	2005	West end of wall is tumbling down because fill behind wall is eroded (piping through wall?). Wall could use fill under base rock in several places. Dock footings are in good shape.

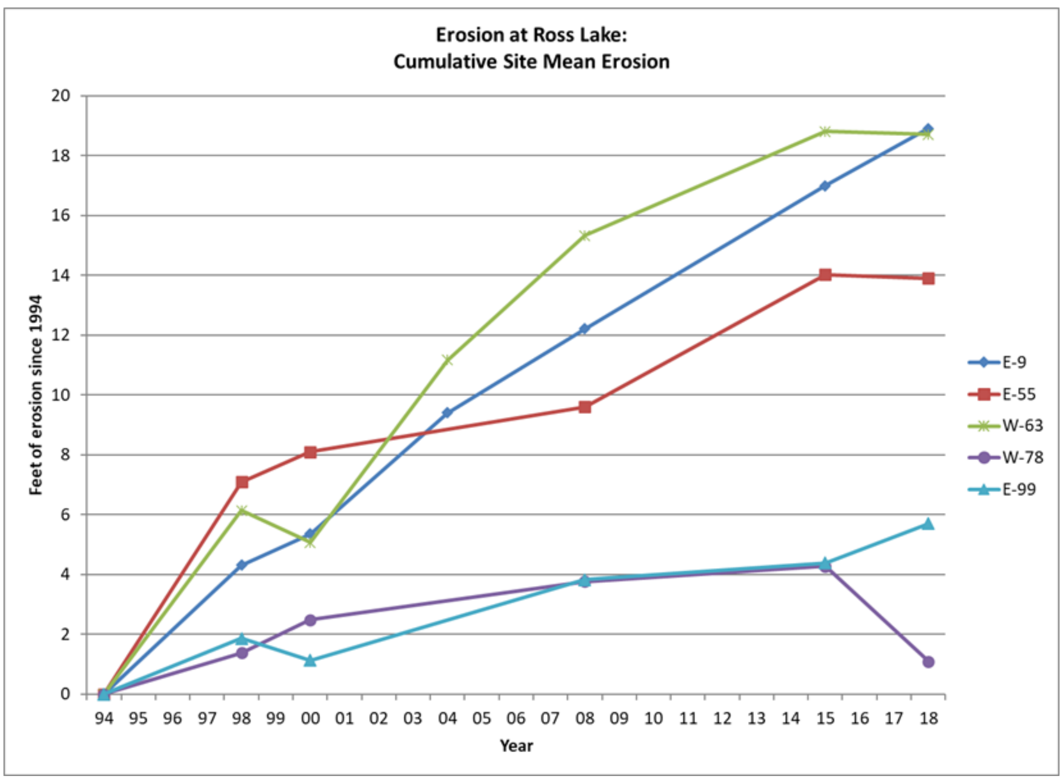
1 Site Number, Erosion Control Method, and Year Constructed based on NPS data. Crib walls at Ross E-70 and E-80 are differentiated by letters in this table but shown as single locations on Figure 5.3-6 due to map scale.

5.4 Shoreline Bank Erosion Retreat Rates

5.4.1 NPS Erosion Monitoring Transects

NPS has monitored five 1990 Class I bank erosion sites (22 total transects) in Ross Lake as part of the Erosion Control Plan (Ebasco Environmental and NPS 1990; and Figure 4.3-1 in Section 4.3 in this study report). The 1990 Class I sites were assumed to have the highest erosion rates compared to Class II or III sites. The most recent monitoring occurred in 2018. Each of the five sites monitored has a different rate of erosion because of varying bank material, aspect, and slope (NPS 2020; Figure 5.4-1). The site designations in Figure 5.4-1 refer to the 1990 erosion site numbers as shown on the map in Figure 4.3-1 and the maps in Attachment B. The E and W represent the east and west side of Ross Lake, respectively.

The greatest total amount of bank recession is at three sites with thick, unconsolidated glacial deposits (E9, E55, and W63), where erosion has a mean of 14 to 19 feet of bank retreat in 24 years. Relatively low rates of erosion were observed at the other two sites (sites E99 and W78) with a mean of less than 6 feet of erosion in 24 years. Site E99 is a rocky slope with colluvial soils, while site W78 has a shoreline composed of consolidated glacial till.



Source: NPS 2020.

Figure 5.4-1. Total mean distance of bank recession 1994–2018 at Ross Lake monitoring sites.

Of the 22 individual transects that were measured as part of the five erosion site areas, the majority had less than 10 feet of erosion over the 24-year monitoring period; the transect with the highest erosion rate had nearly 65 feet of bank retreat. This transect was located in an area of unconsolidated soil.

5.4.2 Bank Retreat Measured from Sequential Aerial Photographs

The shoreline position on the 1990 and 2018 aerial photographs was compared to determine if a measurement of bank retreat could be made using this method. No difference in shoreline location was seen along the majority of the reservoir shorelines. At 42 sites, a difference in shoreline position could be seen. The maximum distance of bank retreat at these sites ranged from 7 to 80 feet (Table 5.4-1; see maps in Attachment B for site locations). Note that at most sites only one or two locations along the mapped erosion site had this much bank retreat; much of the eroding bank had either no retreat or much less retreat than the maximum based on the aerial photograph comparison.

Table 5.4-1. Bank retreat measured from 1990-2018 aerial photographs.

2021 Site ID	Maximum bank retreat (ft)	Geology	Bank height (ft)
2009	15	Till/outwash (unconsolidated)	20-30
2011	40	Till (unconsolidated)	20-50
2012	80	Till/outwash (unconsolidated)	150
2014	12	Till/outwash (unconsolidated)	3-7
2019	15	Till (unconsolidated)	45
2029	18	Till (unconsolidated)	5-7
2031	9	Till (unconsolidated)	15-25
2034	7	Till (unconsolidated)	5-7
2045	20	Colluvium	3-5
2047	15	Till/colluvium mix	2-5
2048	8	Outwash	5-20
2064	20	Till	5-15
2069b	8	Colluvium	20
2070	10	Till (unconsolidated)	10-20
2071	23	Till (unconsolidated)	10-30
2072a	25	Till (unconsolidated)	20
2072c	15	Till (unconsolidated)	20
2072d	37	Till (unconsolidated)	25
2072e	45	Till (unconsolidated)	20
2072f	13	Till (unconsolidated)	20
2072g	45	Till (unconsolidated)	10-25
2073c	7	Till/colluvium (unconsolidated)	10-30
2074	17	Till (unconsolidated)	10-30
2082	12	Colluvium	5-7
2082g	7	Till	5-10
2082h	8	Till/colluvium (unconsolidated)	10
2083b	9	Colluvium	20
2084b	12	Till	5-7
2084c	28	Till/outwash (unconsolidated)	10-40
2085i	10	Till	5-10

2021 Site ID	Maximum bank retreat (ft)	Geology	Bank height (ft)
2087f	15	Colluvium	15
2109	18	Till (unconsolidated)	30-35
2124a	10	Fine-grained colluvium	5-25
2124b	25	Fine-grained colluvium	25-40
2124c	20	Fine-grained colluvium	5-25
2128	10	Till (consolidated)	5-10
2132	15	Till	3-12
2133	10	Talus/colluvium	15
2134	8	Till/colluvium (unconsolidated)	20-30
2145	15	Till (unconsolidated)	5-15
2146	10	Till (mix)	5
2149	17	Till (unconsolidated)	5-15

The average bank retreat rates using the aerial photograph and NPS field measurement methods were compared at the five NPS erosion monitoring sites (Table 5.4-2). There was relatively good agreement between the average rates using the two methods. This provides confidence that the bank retreat rates measured from aerial photographs can be applied to estimate total bank retreat between 1990 and 2018 at sites along the entire reservoir, and confidence that sites with no bank retreat measured from the aerial photograph analysis likely have very low erosion rates.

Table 5.4-2. Comparison of aerial photograph and NPS field measurements of bank retreat.

2021 Site ID	NPS 1990 Site ID	Geology	Average bank retreat from aerial photographs 1990-2018 (ft)	NPS field measured bank retreat 1994-2018 (ft)
2011	E9	Till (unconsolidated)	17	18
2072g	W63	Till (unconsolidated)	12	18
2084c	E55	Till/outwash (unconsolidated)	18	14
2163	E99	Colluvium	0	5
2077	W78	Till (consolidated)	0	1

5.4.3 Comparison of 1990 and 2021 shoreline site photographs

Comparison of 1990 and 2021 field photographs of reservoir erosion locations yielded only one site where a definitive comparison could be made (Figure 5.4-2) since few of the 1990 photographs were labeled with site number. Comparison of Ross Lake site E-116, just north of Lightning Creek, showed evidence of a few feet of bank retreat based on root exposure. There did not appear to be any loss of trees at this site; trees in the 1990 photograph can be seen as larger trees on the 2021 photograph.

Figure 5.4-2. Ross Lake Site E-116 in 1989 (top photo) and 2021 (bottom photo).

6.0 SUMMARY

During 2021, reservoir shoreline erosion sites along the shorelines of Ross Lake and Diablo Lake were mapped and characterized. Shoreline erosion along Gorge Lake and measurement of erosion rates in the drawdown zone of Ross Lake has not yet been completed (see Next Steps section below).

The 1990 reservoir erosion inventory identified 76,479 feet of eroding shoreline in Ross Lake and 8,038 feet of eroding shoreline in Diablo Lake. The reservoir erosion inventory conducted in 2021 identified a total of 306 erosion sites covering 74,272 feet (19 percent) of reservoir shoreline length in Ross Lake and 43 sites (4,556 feet or 4 percent of shoreline length) in Diablo Lake. In Ross Lake, 87 of the sites shown on the 1990 map were stabilized and 79 new sites were identified. In Diablo Lake, 49 of the 1990 sites were stabilized and 15 new sites were mapped.

The primary cause of erosion at sites on both reservoirs is wave action that removes material at the toe of banks and transports it down into the lake as reservoir water surface elevations fluctuate. As noted in the 1990 report, this movement of material from the toe of the bank during reservoir fluctuations, primarily in Ross Lake, does not allow a stable shoreline to develop, particularly in areas where there is a steep slope below the eroding bluff. The seasonal reservoir fluctuations in Ross Lake are likely a contributing factor to the ongoing shoreline erosion; there was little reduction in total eroding shoreline length between the 1990 and 2021 inventory in Ross Lake (3 percent decrease) compared to Diablo Lake, which has relatively stable water surface elevations and had a 76 percent decrease in length of eroding shoreline.

Bank retreat rates were measured using a comparison of 1990 and 2018 aerial photographs and the rates were compared to the field measurements made by NPS; the two methods were in relatively good agreement.

Sites where erosion control measures have been implemented were evaluated as part of the reservoir shoreline erosion inventory. Generally, the erosion control measures are in good condition and function to minimize erosion with only minor maintenance needed, such as providing fill around the base rocks at walls or dock footings. Three sites need significant repairs to reinstate functionality, including McMillan Campsite (rock wall failing), the Desolation Trailhead (where the rock wall has almost totally failed and is eroding), and the rock wall and stairs at Little Beaver Campsite (which need base support).

6.1 Next Steps

Field data in Gorge Lake will be collected in Spring 2022. Field data to measure erosion rates in the five locations in the Ross Lake drawdown zone will also take place in Spring 2022 during low pool levels. Mapping of erosion and deposition zones within the Ross Lake drawdown will take place in spring 2022 during low lake levels to meet the commitment made in the June 9, 2021 Notice. Details of the planned work are included in the GE-03 Sediment Deposition Study report (City Light 2022b). These data will be reported on in the study report to be included in the USR.

The analysis of 2021 and 2022 data will continue in 2022 and be reported in the study report to be included in the USR. The following analyses will be conducted:

- Further analysis of erosion site characteristics such as aspect with wind speed and direction and fetch distances.
- Present and discuss the Gorge Lake erosion data.
- Present and discuss the Ross Lake drawdown erosion rate measurements (at the five FERC SPD sites as well as other sites in the drawdown zone) to meet the commitments in the FERC SPD and the June 9, 2021 Notice.
- Correlate existing shoreline erosion rate data collected by the NPS at monitoring sites during the current Project license term and data collected at un-monitored sites with erosion site characteristics (e.g., underlying geology, slope, aspect, shoreline height, landform, type of erosion) to extrapolate and help estimate ongoing erosion rates at unmeasured sites.

As a follow up to this study, the reservoir erosion data are being provided to the NPS Archaeologist/Section 106 Coordinator to support cross resource coordination and protection of archaeological sites.

7.0 VARIANCES FROM FERC-APPROVED STUDY PLAN AND PROPOSED MODIFICATIONS

The schedule in the RSP stated that all reservoir shoreline erosion field data would be collected during summer 2021 (June to August). Due to lake level and scheduling constraints, field work did not occur in Gorge Lake during summer 2021. Instead, field work in Gorge Lake will occur during spring 2022 when the FERC SPD additions to the study (measure erosion at five specified locations within the Ross Lake drawdown zone) will also be collected. City Light will map erosion and deposition in the Ross Lake drawdown zone in spring 2022 in response to the June 9, 2021 Notice commitments. There are no other variances from the FERC-approved study plan.

8.0 REFERENCES

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RESERVOIR SHORELINE EROSION STUDY INTERIM REPORT

ATTACHMENT A

RESERVOIR EROSION FIELD FORM

Skagit Hydroelectric Project Reservoir Erosion Field Form

Site ID ____________________ Date/Time ____________________
Reservoir ____________________ Surveyors ____________________
Location ____________________ Former Site ID ____________________

Erosion Type
- ❑ Undercut bank
- ❑ Slumping
- ❑ Raveling
- ❑ Rills/gullies
- ❑ Trampling
- ❑ ____________

Seepage? Y / N

Shore Area Affected
- ❑ Shore above high water
- ❑ Drawdown zone
- ❑ ____________

Dimensions of eroding area (ft)
- Shoreline length ____________
- Bank height ____________
- Dist. from shore ____________
- Area (sq ft) ____________
- Disturbed slope gradient (%) ____________
- Undisturbed slope gradient (%) ____________

Geology/Soils
- ❑ Bedrock
- ❑ Talus
- ❑ Colluvium
- ❑ Till
- ❑ Outwash
- ❑ Alluvial Fan
- ❑ Alluvium
- ❑ Fill
- ❑ ____________

Piping? Y / N

Gleyed soils? Y / N

Evidence of erosion rate/activity
- Exposed roots/stump depth (ft) ____________
- Fresh tree fall (#, decay class) ____________
- Fresh soil ____________
- Stabilized (rationale) ____________

Vegetation

Type ____________________
Tree diameter (dbh): ____________________
Condition: heathy dead unhealthy beaver
Age ____________________
% Bare soil ____________________

LWD: On Bank ______ In water ________

Comments/Sketch

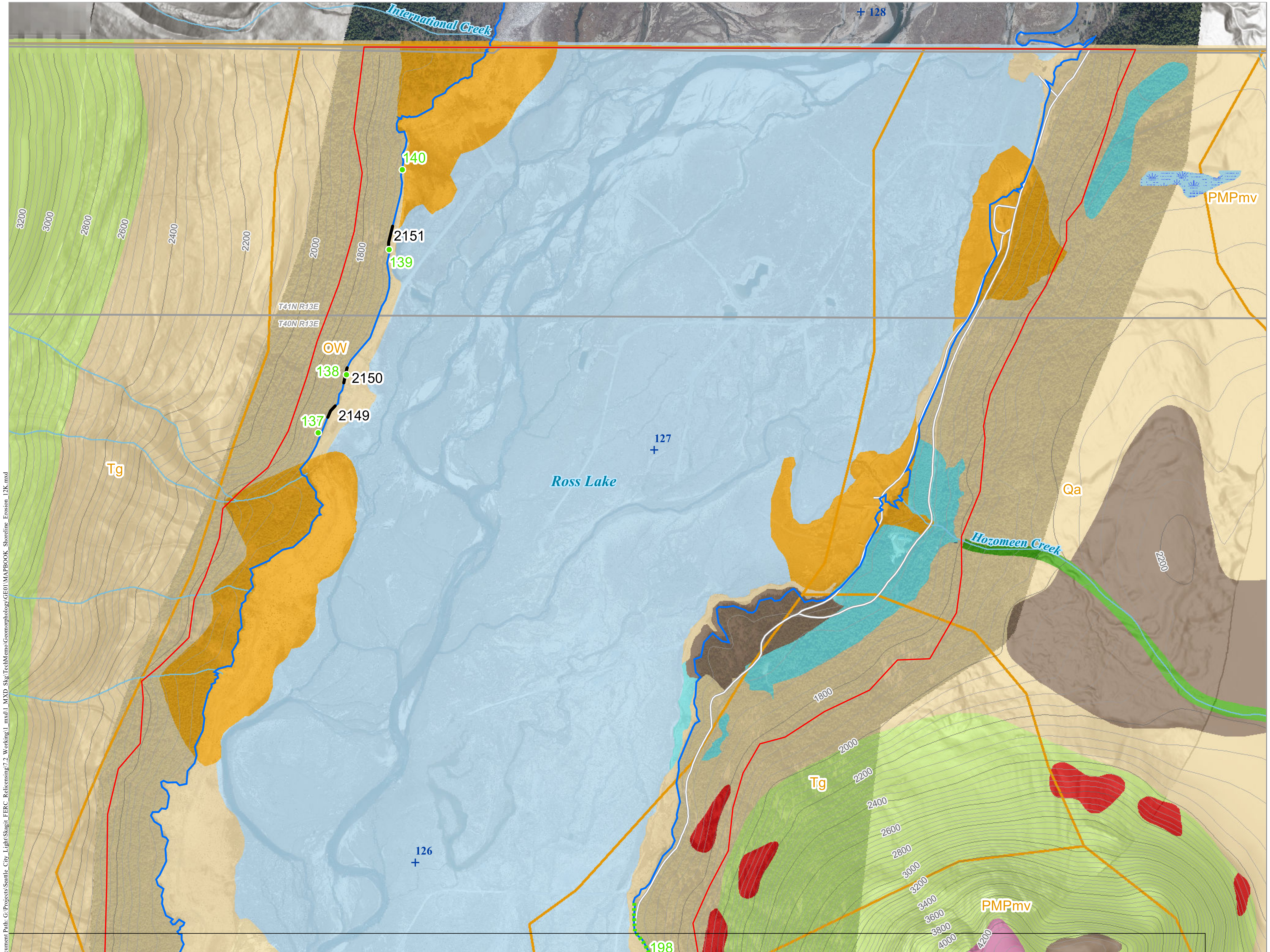
Percent Cover:	Trees	Shrub	Herb	Other
Disturbed	______	______	______	______
Undisturbed	______	______	______	______

Factors Affecting Erosion
- ❑ Reservoir fluctuations
- ❑ Wave action
- ❑ Recreation use
- ❑ Stream erosion
- ❑ Shoreline Development
- ❑ Road Runoff
- ❑ ____________

RESERVOIR SHORELINE EROSION STUDY INTERIM REPORT

ATTACHMENT B

2021 RESERVOIR SHORELINE EROSION SITES MAPBOOK



GE-01 RESERVOIR SHORELINE EROSION STUDY ROSS LAKE SITES

- FERC Project Boundary
- Project River Miles (PRM)
- Bank Eroding (2021)
- Partial Bank Length Eroding (2021)
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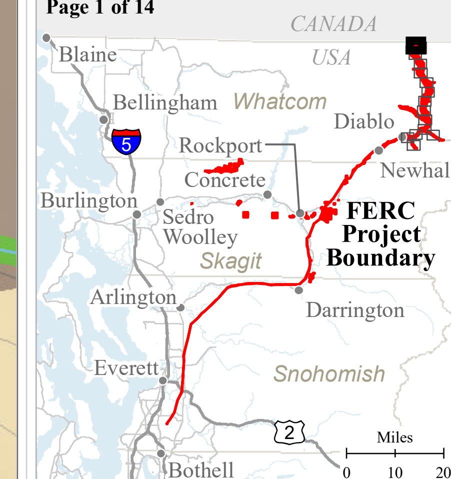
- Geologic Unit Label

Landforms

- Alluvial Fan
- Bedrock Bench
- Debris Apron
- Debris Cone
- Floodplain
- Mass Movement
- Ridge
- Terrace
- Valley Bottom
- Valley Wall

N

0 500 1,000 Feet



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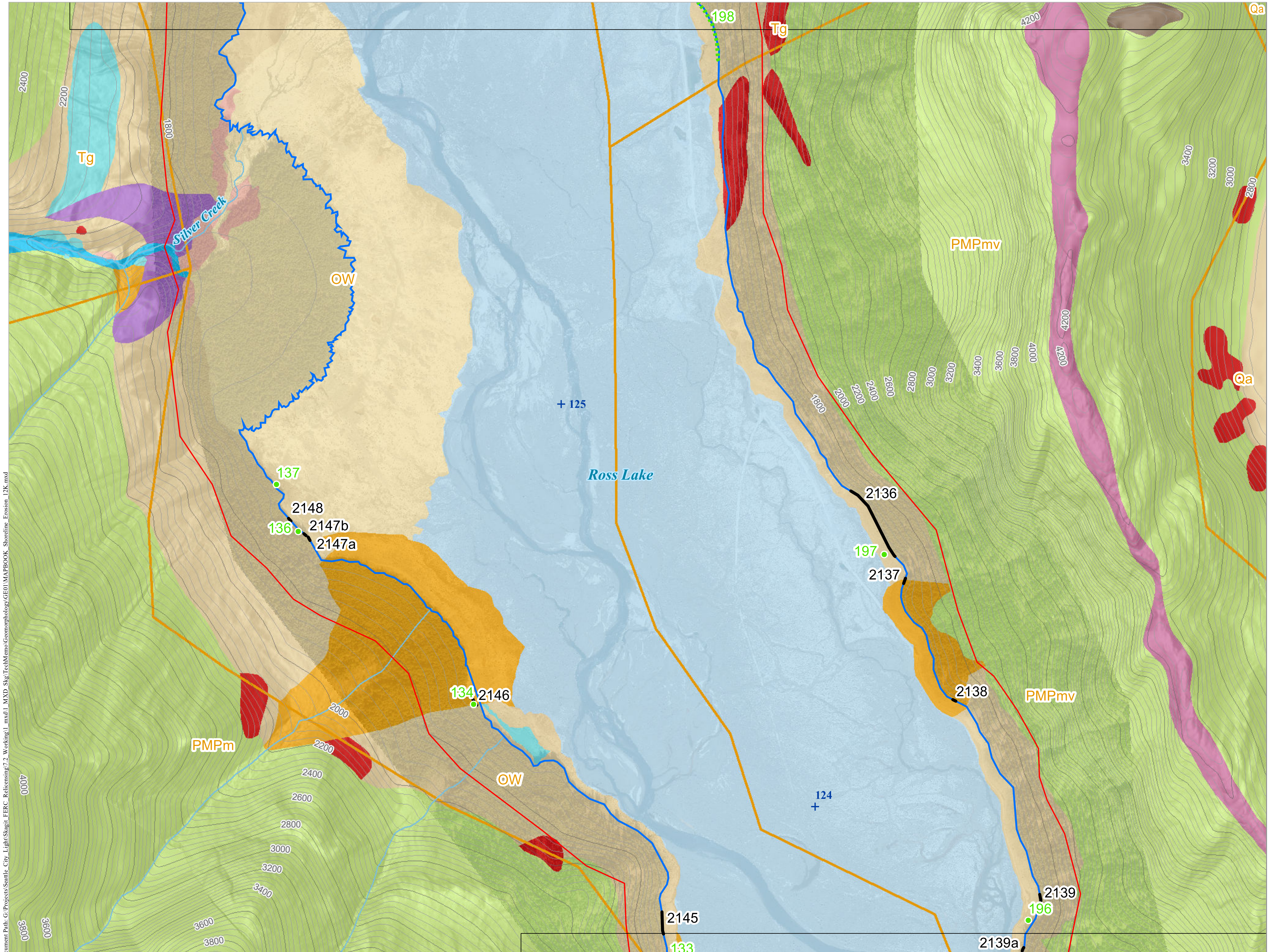

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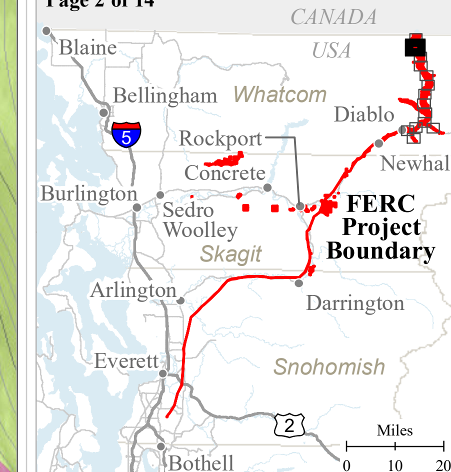
Ridge
River Canyon
Terrace
Valley Wall

N
0 500 1,000 Feet



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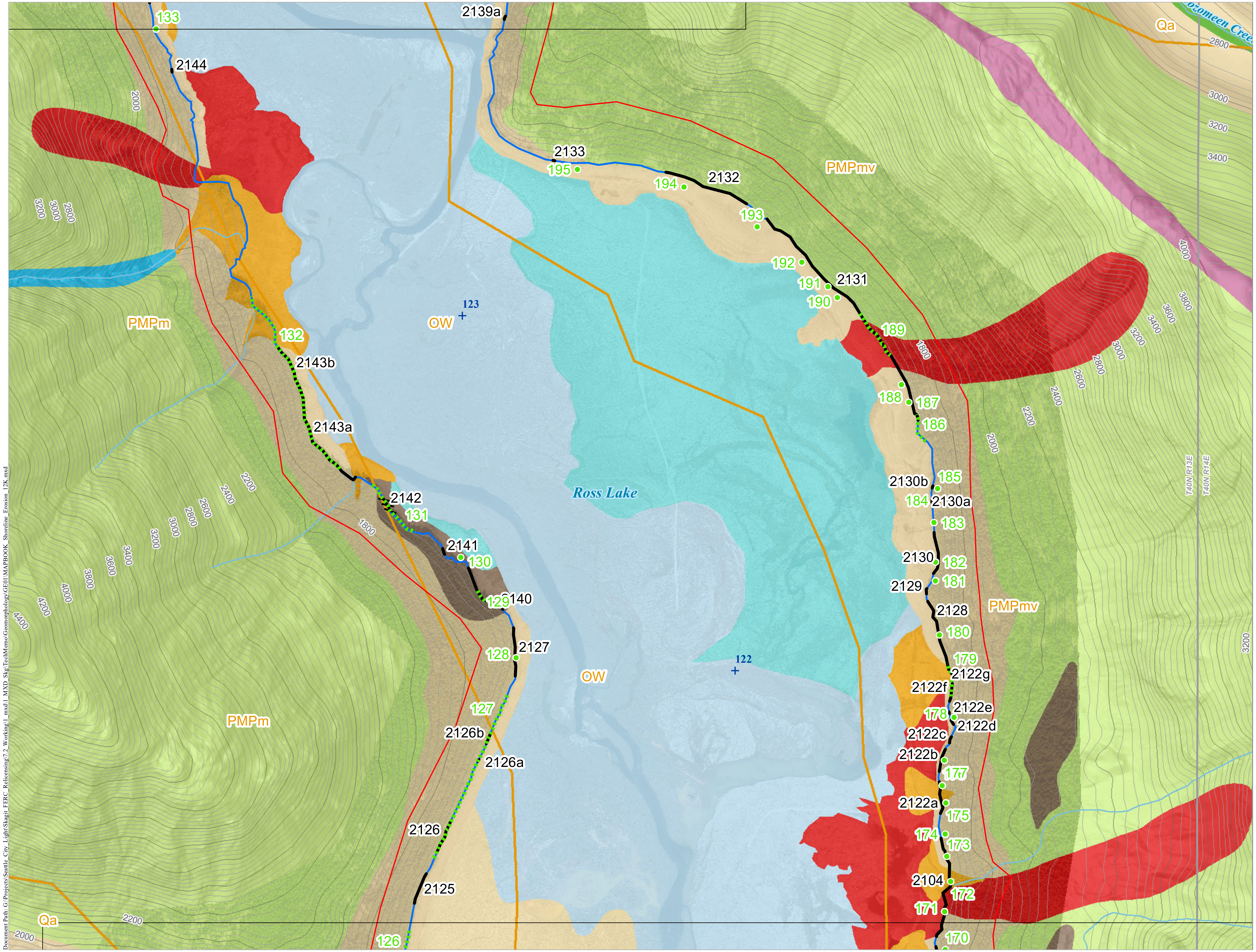

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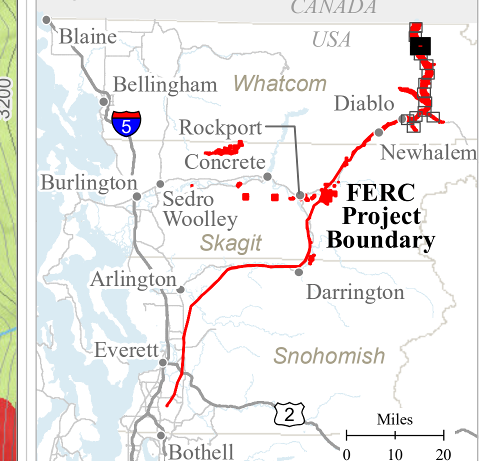
N

0 500 1,000 Feet



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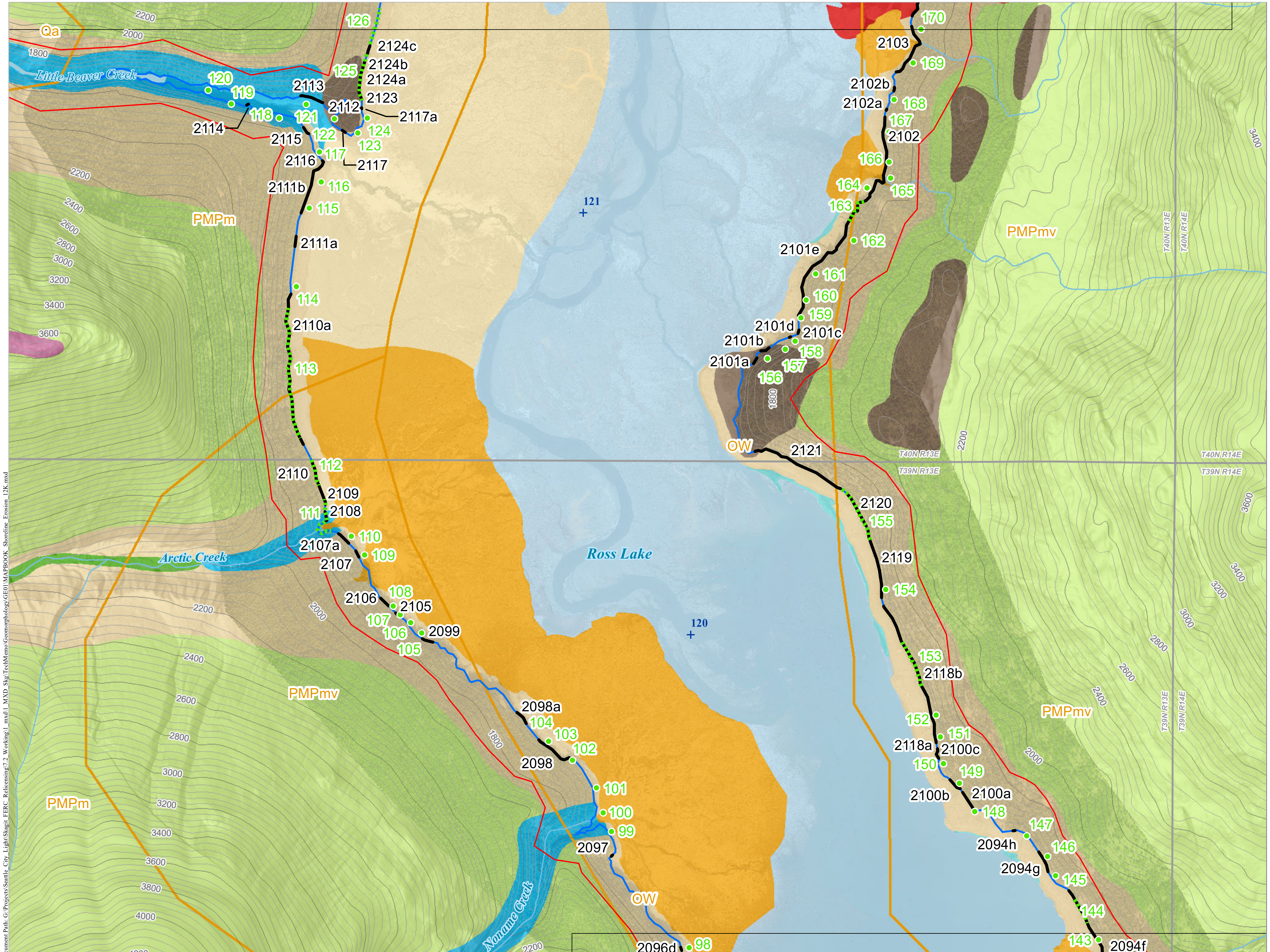
GE-01 RESERVOIR SHORELINE EROSION STUDY ROSS LAKE SITES



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0 500 1,000 Feet

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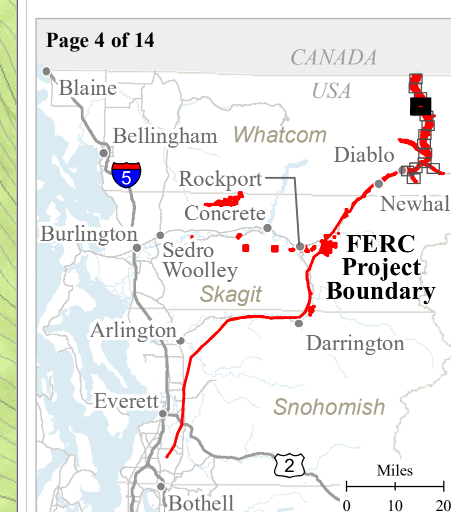

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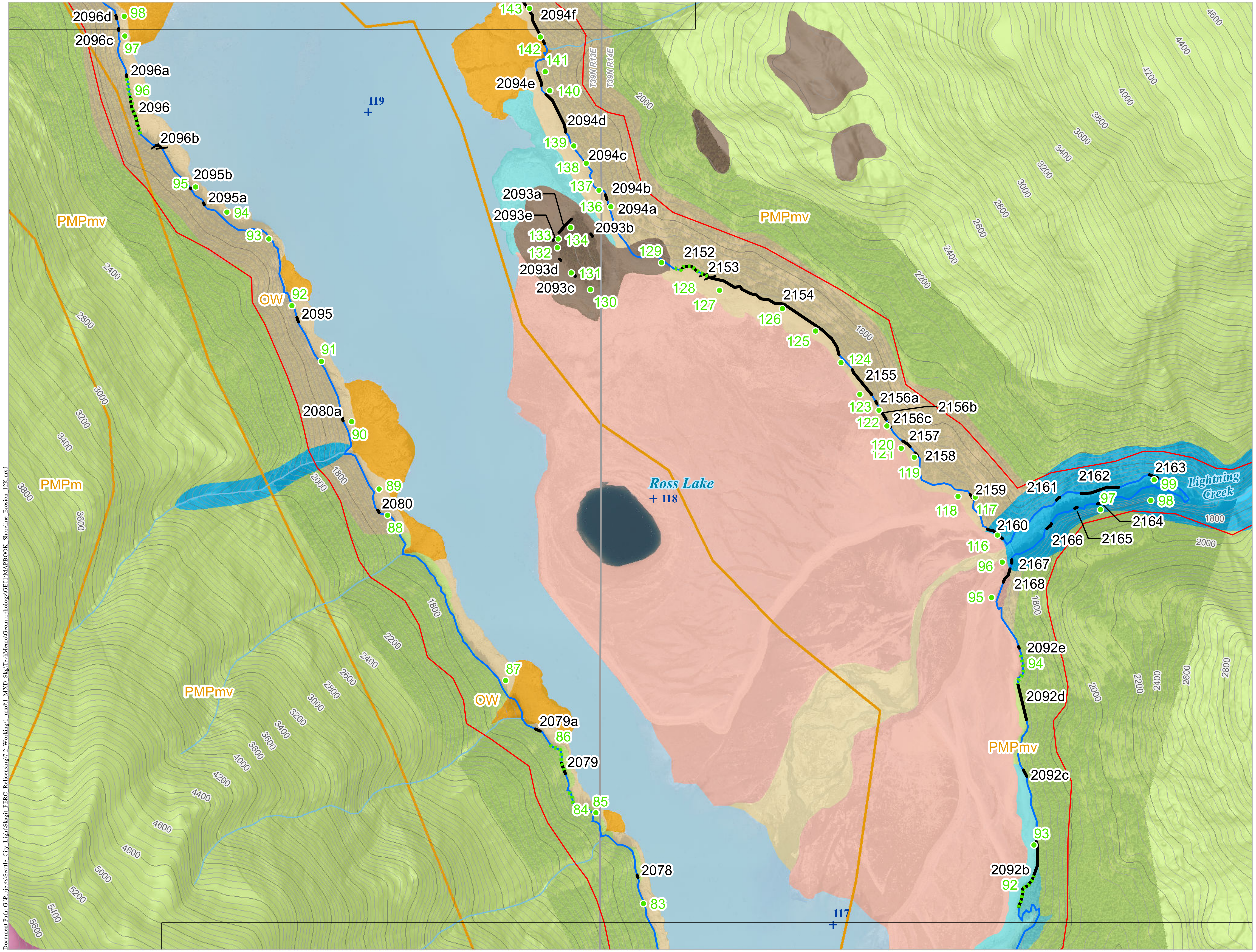
GE-01 RESERVOIR SHORELINE EROSION STUDY
ROSS LAKE SITES



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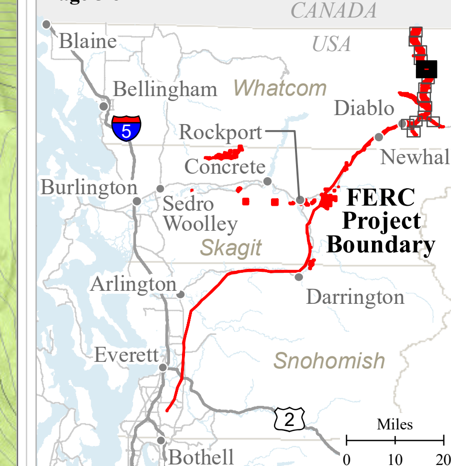

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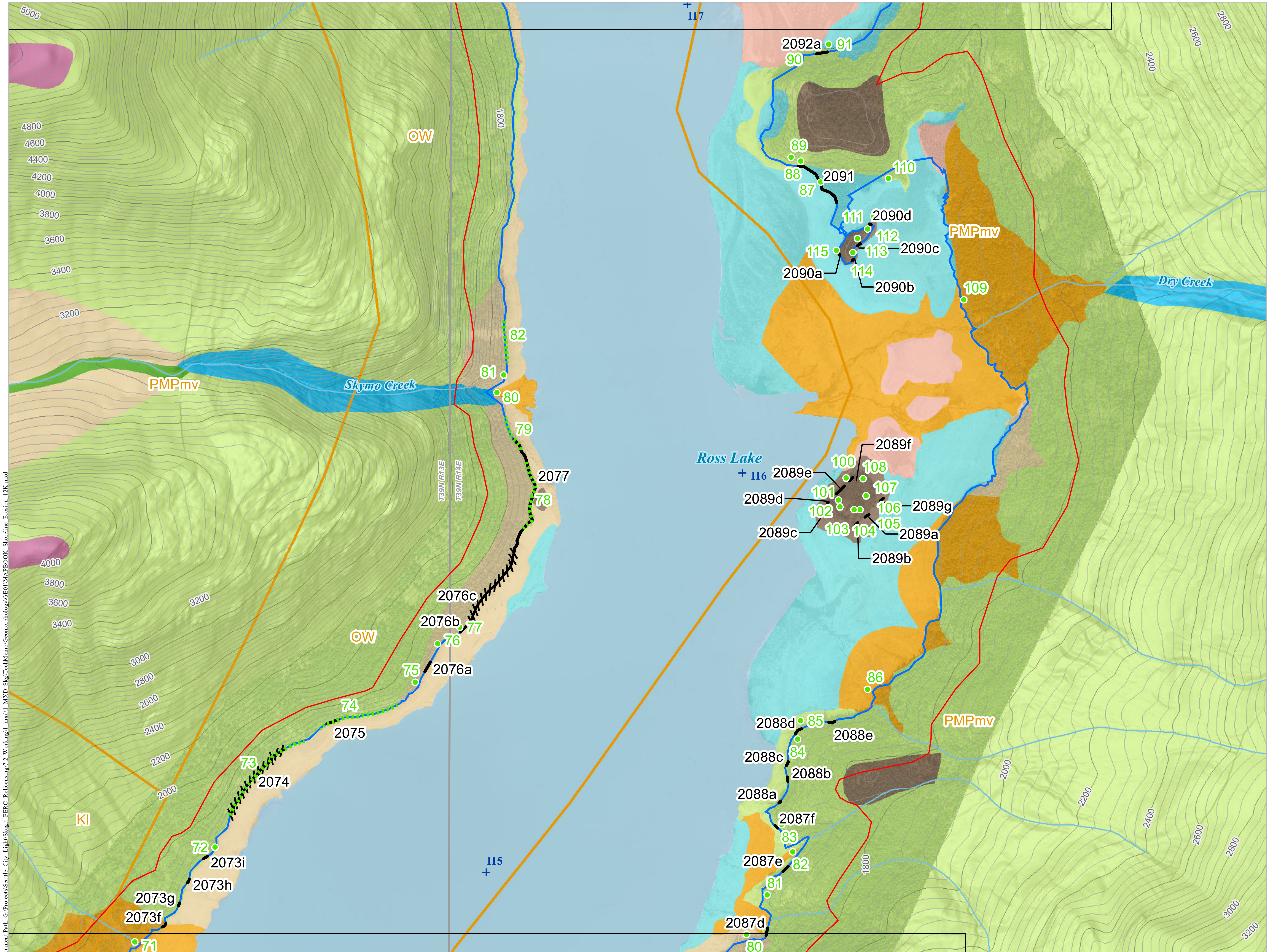

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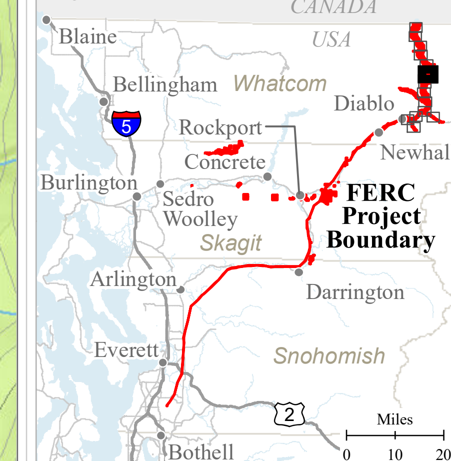
0 500 1,000 Feet



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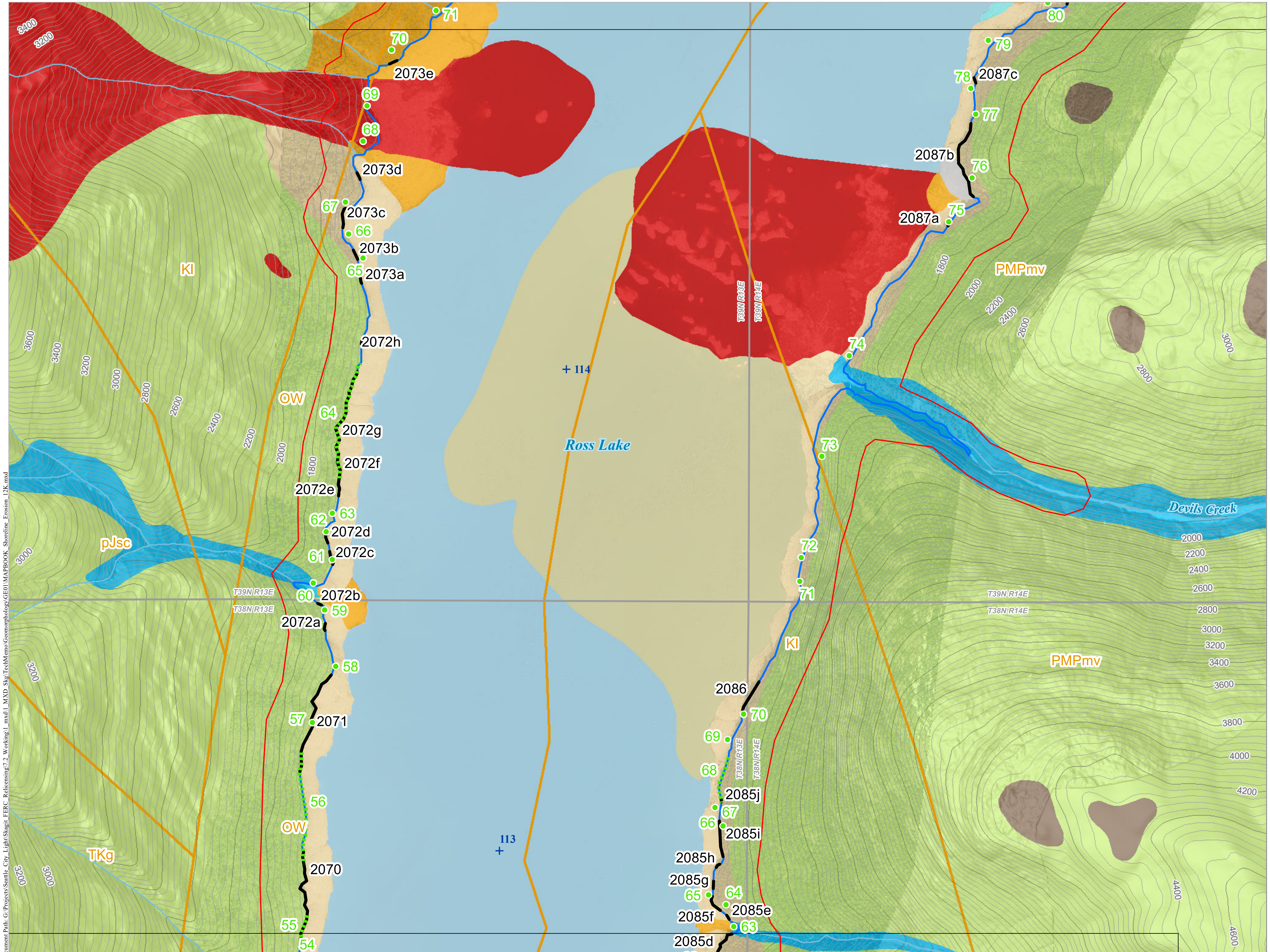

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Mass Movement
River Canyon
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Undifferentiated
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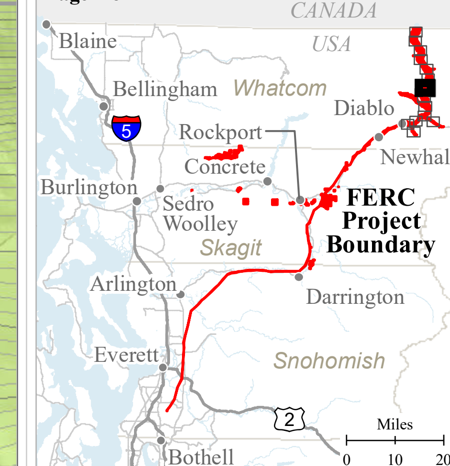
N

0 500 1,000 Feet



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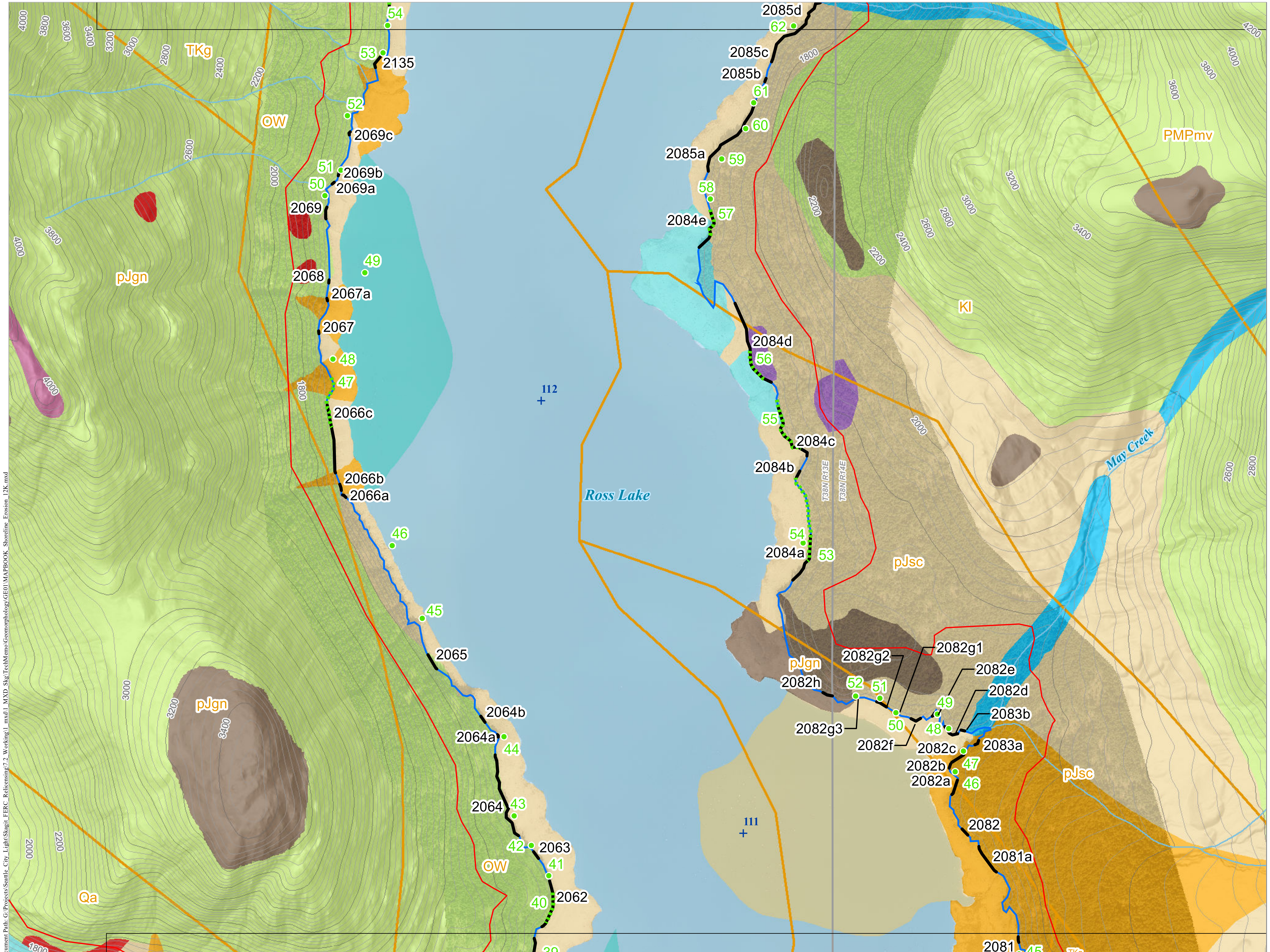

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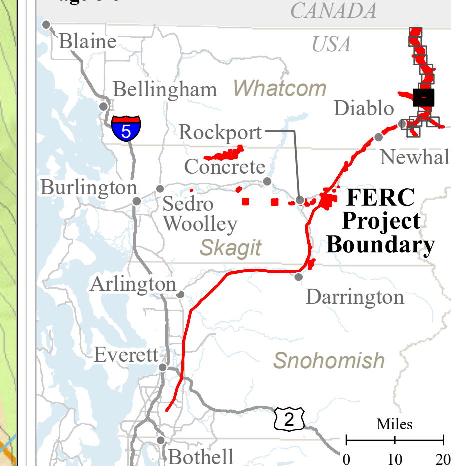

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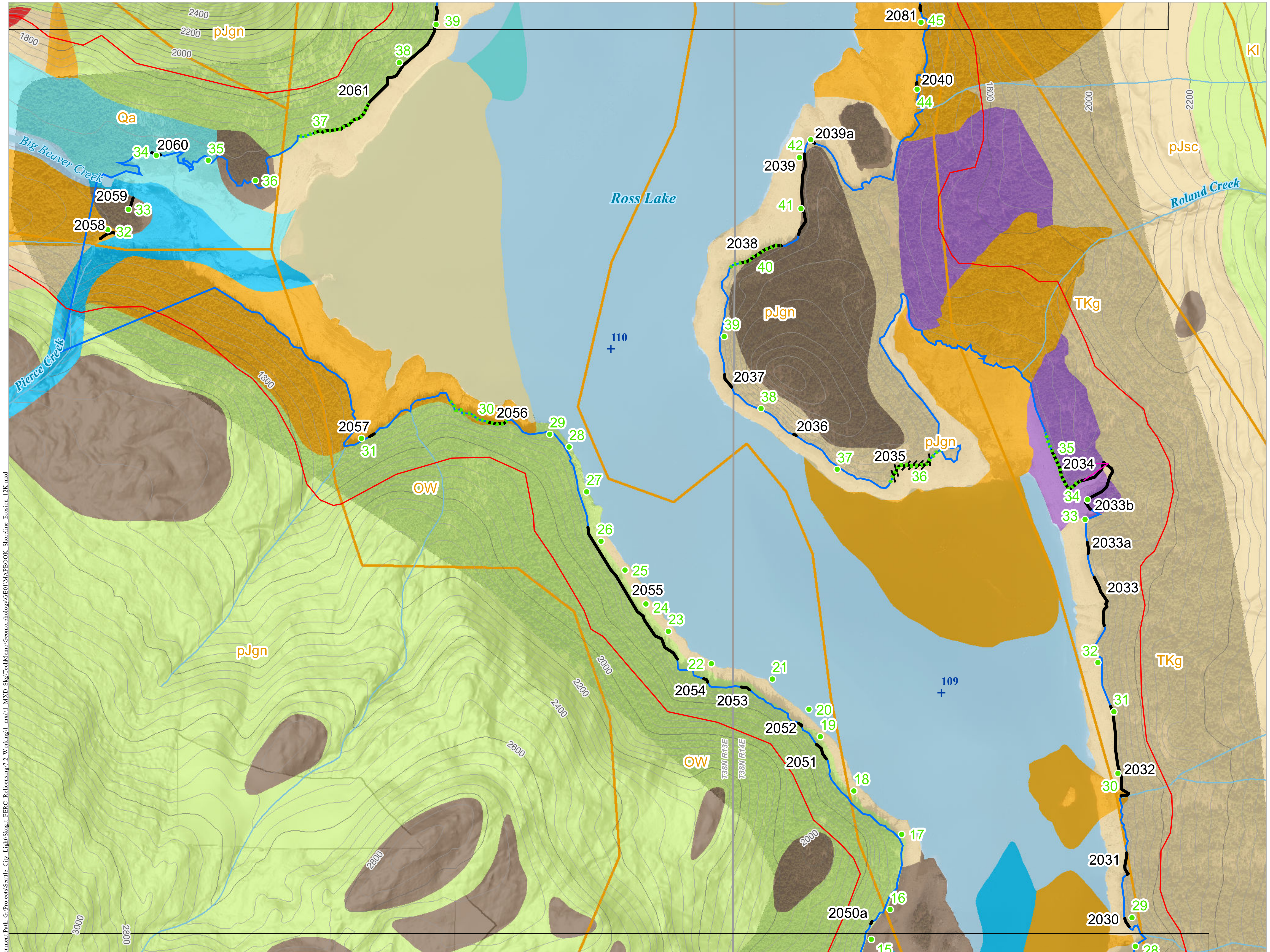

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- Valley Wall

0 500 1,000 Feet

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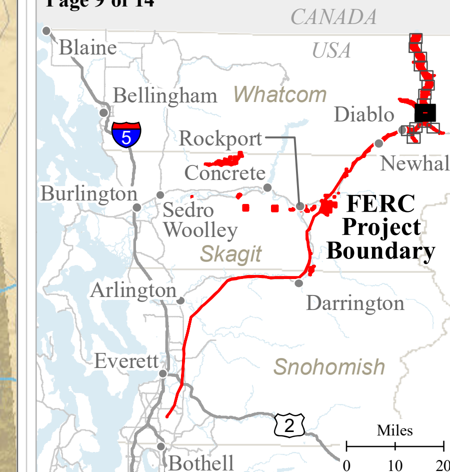

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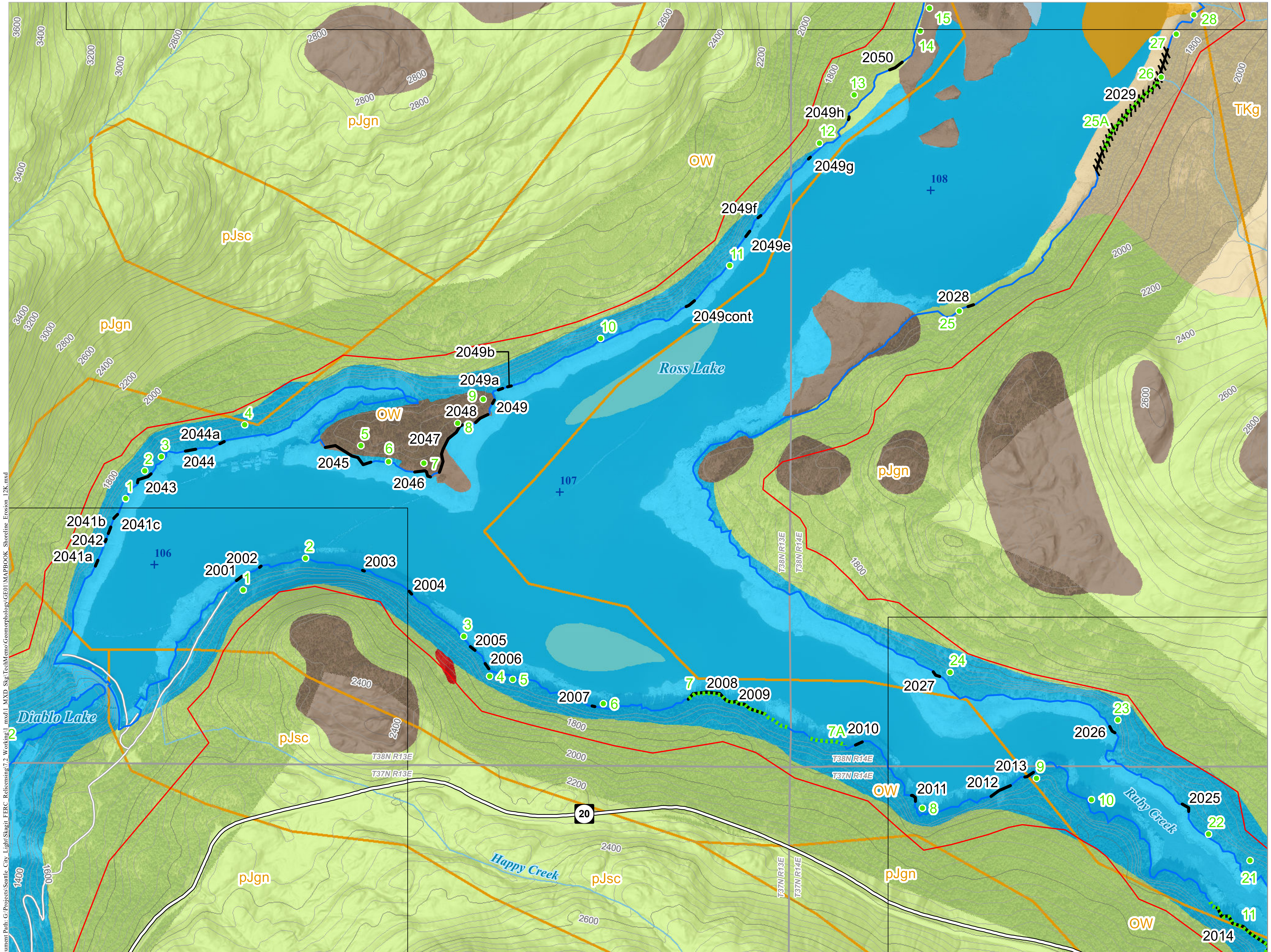

GE-01 RESERVOIR SHORELINE EROSION STUDY
ROSS LAKE SITES

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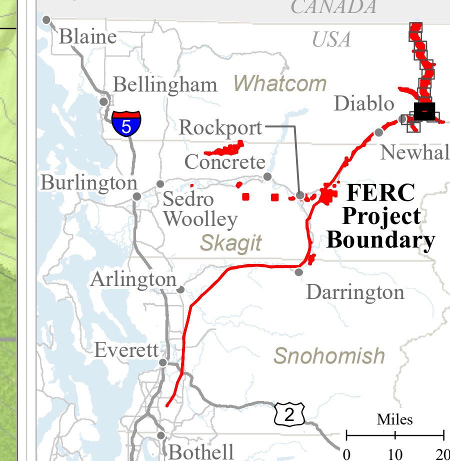
- Partial Bank Length Eroding (2021)
- Bank Eroding (1990)
- Bank Eroding (1990)
- Normal Max Water Surface Elevation Area
- Geologic Unit Label

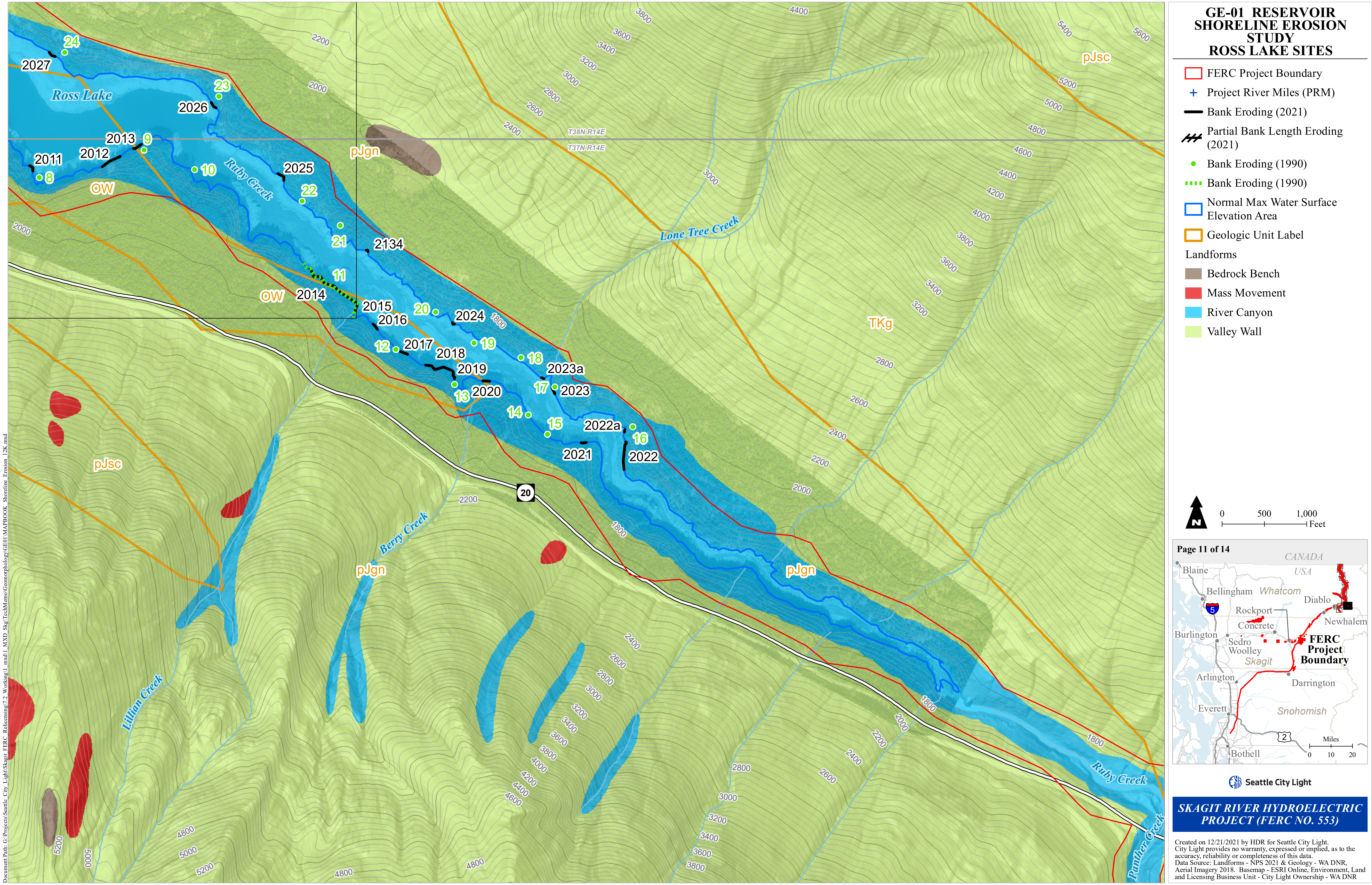
Landforms
- Bedrock Bench
- Debris Apron
- Debris Cone
- Floodplain
- Mass Movement
- River Canyon
- Terrace
- Valley Wall

0 500 1,000 Feet



Seattle City Light

SKAGIT RIVER HYDROELECTRIC PROJECT (FERC NO. 553)



GE-01 RESERVOIR SHORELINE EROSION STUDY
ROSS LAKE SITES
FERC Project Boundary
Project River Miles (PRM)
Bank Eroding (2021)
Partial Bank Length Eroding (2021)
Bank Eroding (1990)
Bank Eroding (1990)
Normal Max Water Surface Elevation Area
Geologic Unit Label
Landforms
Bedrock Bench
Mass Movement
River Canyon
Valley Wall
0
500
1,000
Feet
Page 11 of 14
CANADA
USA
Blaine
Bellingham
Whatcom
Diablo
Rockport
Concrete
Newhalem
Burlington
Sedro Woolley
Skagit
FERC Project Boundary
Arlington
Darrington
Everett
Snohomish
Bothell
Miles
0
10
20
Seattle City Light
SKAGIT RIVER HYDROELECTRIC PROJECT (FERC NO. 553)
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Data Source: Landforms - NPS 2021 & Geology - WA DNR, Aerial Imagery 2018. Basemap - ESRI Online, Environment, Land and Licensing Business Unit - City Light Ownership - WA DNR
Ross Lake
Ruby Creek
Lone Tree Creek
Berry Creek
Lillian Creek
Panther Creek
pJgn
pJsc
OW
TKg
T38N R14E
T37N R14E
20
2027
2026
2025
2024
2023
2023a
2022
2022a
2021
2020
2019
2018
2017
2016
2015
2014
2013
2012
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2134
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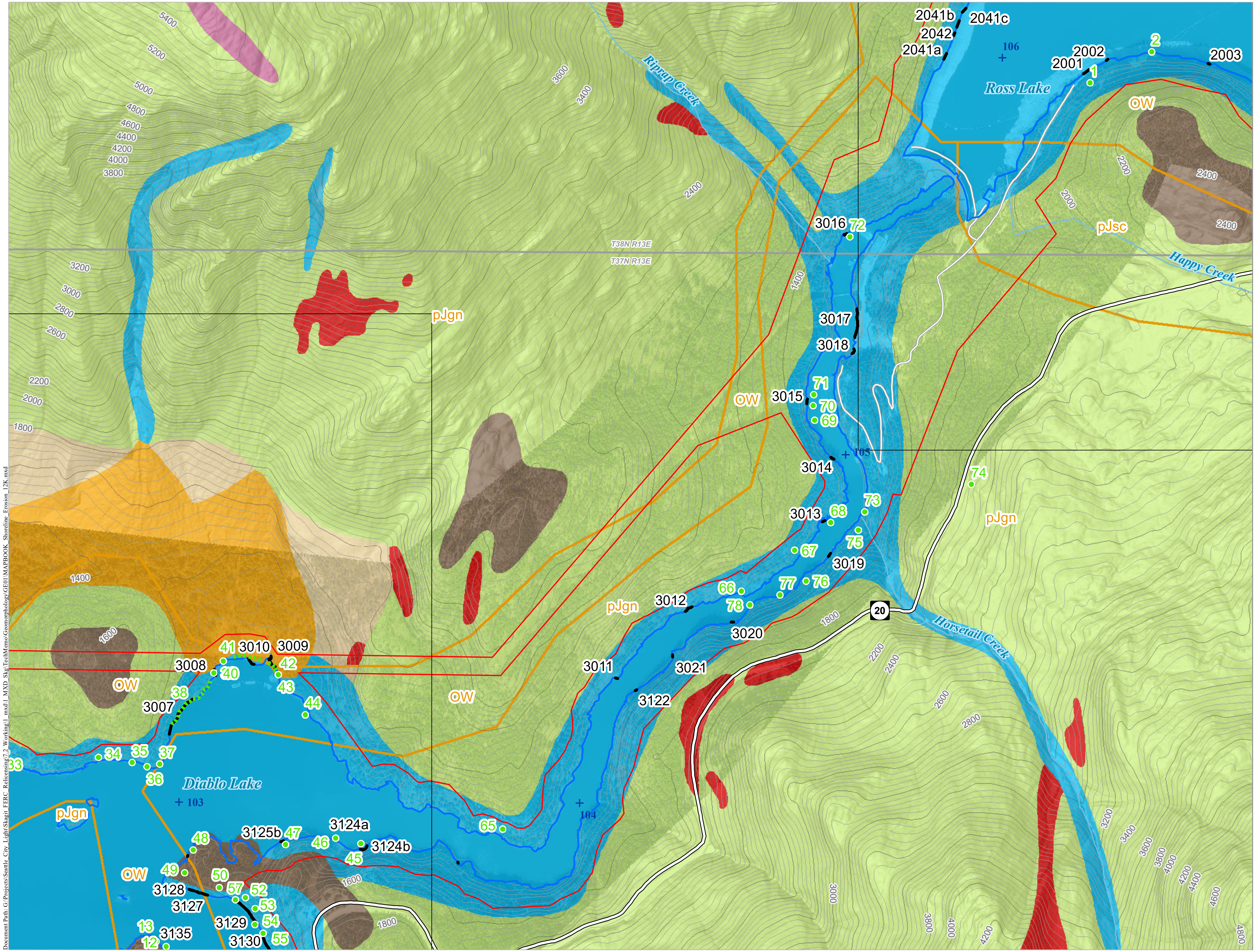


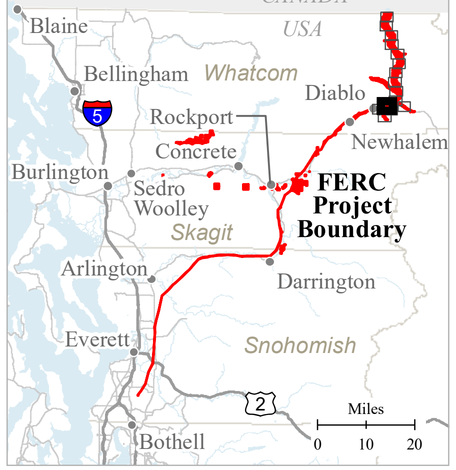
GE-01 RESERVOIR SHORELINE EROSION STUDY DIABLO LAKE SITES

- FERC Project Boundary
- Project River Miles (PRM)
- Bank Eroding (2021)
- Partial Bank Length Eroding (2021)
- Bank Eroding (1990)
- Bank Eroding (1990)
- Normal Max Water Surface Elevation Area
- Geologic Unit Label

Landforms

- Bedrock Bench
- Debris Apron
- Debris Cone
- Mass Movement
- Ridge
- River Canyon
- Valley Wall

0 500 1,000 Feet



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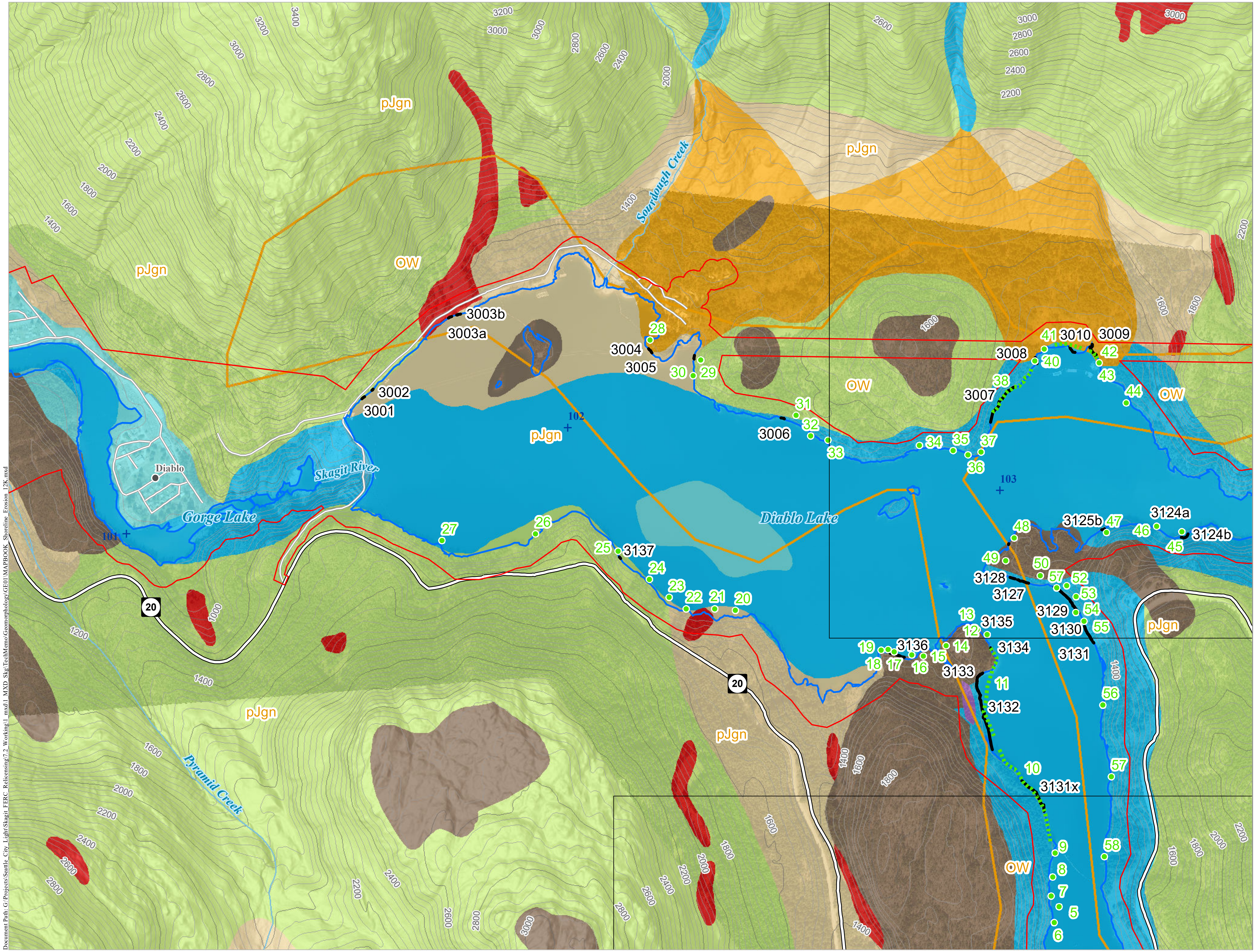


GE-01 RESERVOIR SHORELINE EROSION STUDY DIABLO LAKE SITES

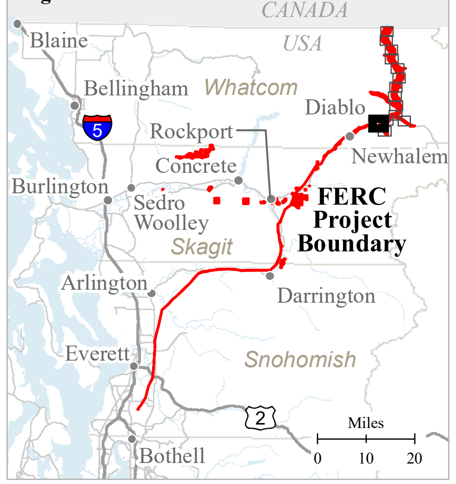
- FERC Project Boundary
- Project River Miles (PRM)
- Bank Eroding (2021)
- Partial Bank Length Eroding (2021)
- Bank Eroding (1990)
- Bank Eroding (1990)
- Normal Max Water Surface Elevation Area
- Geologic Unit Label

Landforms

- Bedrock Bench
- Debris Apron
- Debris Cone
- Mass Movement
- Pleistocene Moraine
- River Canyon
- Terrace
- Valley Wall

N

0 500 1,000 Feet



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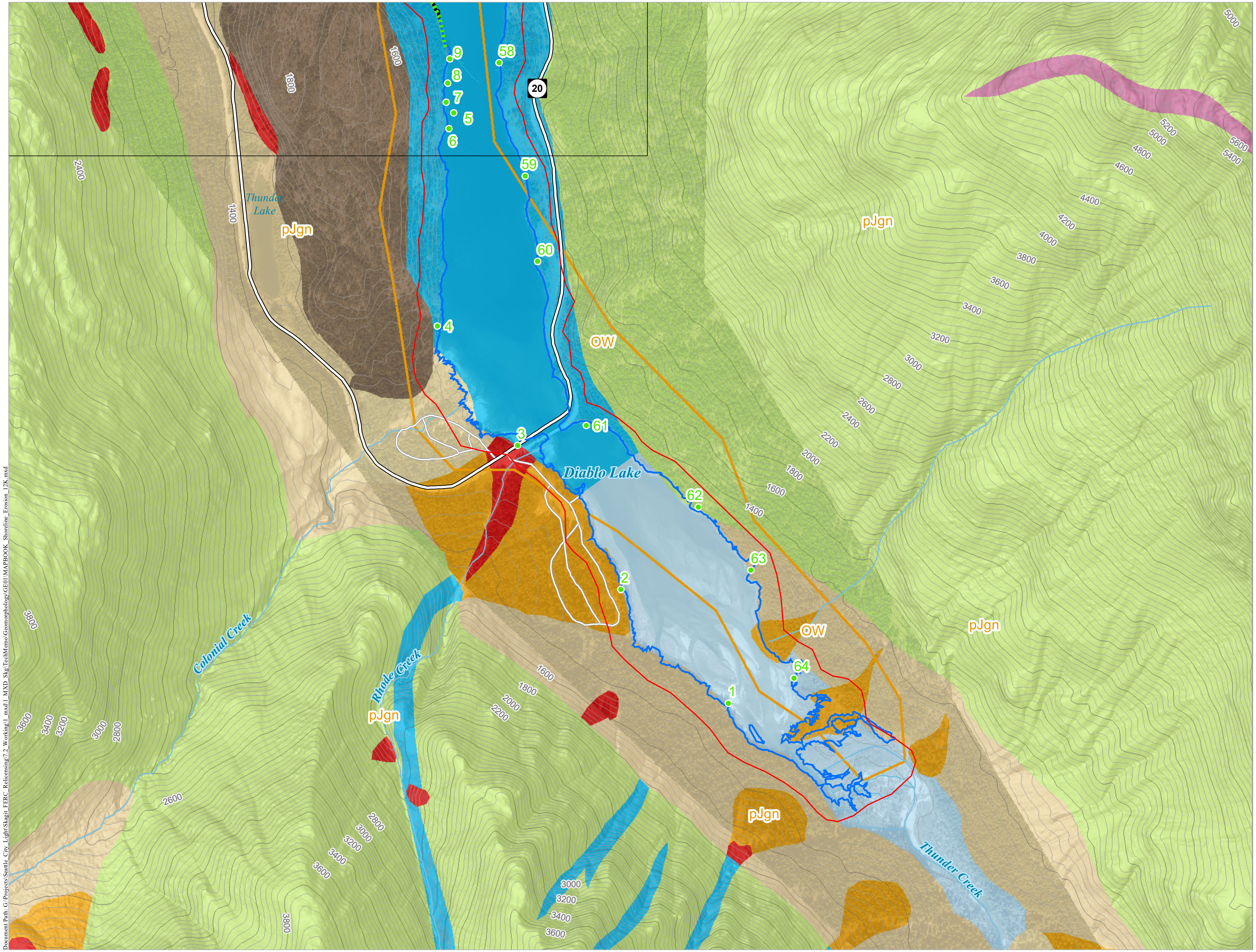
GE-01 RESERVOIR SHORELINE EROSION STUDY DIABLO LAKE SITES



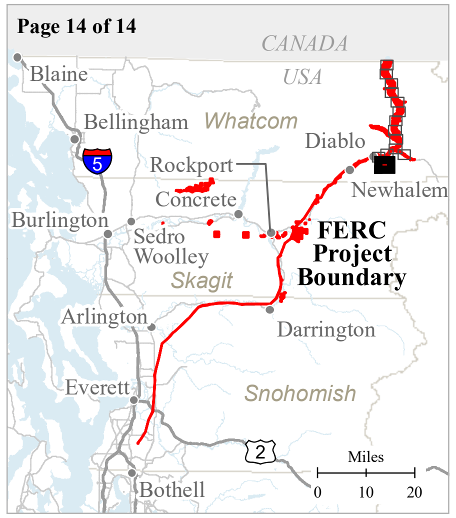
- FERC Project Boundary
- Project River Miles (PRM)
- Bank Eroding (2021)
- Partial Bank Length Eroding (2021)
- Bank Eroding (1990)
- Bank Eroding (1990)
- Normal Max Water Surface Elevation Area
- Geologic Unit Label

Landforms

- Alluvial Fan
- Bedrock Bench
- Debris Apron
- Debris Cone
- Floodplain
- Mass Movement
- Ridge
- River Canyon
- Valley Wall

N

0 500 1,000 Feet



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